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2 of 4

APPENDIX A

BASELINE HUMAN HEALTH RISK ASSESSMENT

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EXECUTIVE SUMMARY

This risk assessment evaluates the potential human health risks in selected areas of the Hanford Site's Central Plateau from exposure to contaminants formerly used at the Site that are still present in subsurface soil and groundwater. The specific areas addressed are contaminants and radionuclides in the 200-ZP-1 Groundwater Operable Unit (OU) under the northern portion of the 200 West Area of the Hanford Site and at five representative soil sites located in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs. The soil sites evaluated in this assessment include 216-A-8, 216-Z-1A, 216-Z-8, 216-Z-9, and 216-Z-10. These soil sites were identified in the *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (DOE/RL-2006-51) as representative or unique of the 17 individual waste sites in these three OUs. This risk assessment will be used to evaluate the need for remedial action in soil in these OUs and to evaluate the protectiveness of certain remedies for soil and groundwater based on current and potential future uses of the land. All the evaluated waste sites are located in the 200 West Area, with the exception of 216-A-8, which is located in the 200 East Area.

Previous investigations identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West and 200 East Areas from past spills, leaks, and work practices associated with the processing of uranium and plutonium to make nuclear weapons. This risk assessment evaluated whether potential health risks are present if people encounter these contaminants in their environment.

The risk assessment evaluates risks under current conditions (industrial land use, assuming the existing institutional controls with adult workers as the population potentially exposed) and future conditions (unrestricted land use if institutional controls fail in the future). Under current conditions, existing institutional controls prevent use of groundwater until such time as concentrations are below maximum contaminant levels (MCLs). The unrestricted land-use scenario assumes that land-use controls will remain in place for 150 years; after that time there is assumed to be a failure of institutional controls so potential exposures to a residential farming population (adults and children) and a working population (well drillers) are hypothetically possible. Including an unrestricted land-use scenario, this risk assessment fulfills National Contingency Plan requirements (40 *Code of Federal Regulations* [CFR] 300) for risk evaluation

under a "no action" scenario, fulfills Federal U.S. Environmental Protection Agency (EPA) requirements to address current and future conditions (*Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual* [EPA 540/1-89/002]), assesses food chain exposures consistent with EPA guidance (EPA 540/1-89/002) and the *Hanford Site Risk Assessment Methodology* (DOE/RL-91-45), and provides information to risk managers regarding the protectiveness of various remedies during the feasibility study (FS) process. However, cleanup concentration goals and decisions will be based on industrial land-use exposures as consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

The first step in a human health risk assessment is an evaluation of the data in order to select contaminants of potential concern (COPCs) for human health. For groundwater, the *Remedial Investigation Report for the 200-ZP-1 Groundwater Operable Unit* (DOE/RL-2006-24) made a preliminary selection of likely contaminants of concern (COCs) after a rigorous and thorough assessment of potential sources, quality of data, and a statistical evaluation of the detected constituents in groundwater. Note that in risk assessment, contaminants are referred to as "COPCs" until health risk calculations are complete. Contaminants that exceed target health goals at the end of the risk assessment process are referred to as "COCs." In the 200-ZP-1 OU remedial investigation (RI) report, the term "COCs" was used to identify contaminants that required further examination; therefore, the RI term is retained when referring to RI findings.

The risk assessment refined the RI list using only the last 5 years of data (2000 through 2005) to represent current conditions. This data set was further evaluated using the target action levels from the RI and additional health-based information. Of the RI list of 15 possible COCs, the groundwater data evaluation selected the following 12 COPCs to carry through the risk assessment process:

- Carbon tetrachloride
- Chloroform
- Trivalent chromium
- Hexavalent chromium
- Methylene chloride
- Nitrate
- Tritium
- Tetrachloroethylene (PCE)
- Trichloroethylene (TCE)
- Uranium
- Iodine-129
- Technetium-99.

For soil, the risk assessment primarily used the available soil data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for the representative and unique soil sites, supplemented by additional historical data reports. In addition to soil data, three air samples collected from within the 216-Z-9 Trench were selected for inclusion in the risk assessment as the most representative data of what vapor concentrations might possibly intrude into basements.

Maximum detected concentrations in soil from each of the waste sites were compared to EPA Region 6 human health screening levels for residential soil and EPA generic residential screening levels for radionuclides to select COPCs in soil. (Note that EPA Region 10 does not calculate their own screening levels but instead mandates the use of Region 6 screening levels on EPA projects in Region 10.) Selected COPCs are provided in Table ES-1.

No contaminants were detected in soil at the 216-Z-10 injection/reverse well, and analytical reporting limits were below EPA screening criteria; therefore, the site was not evaluated further. There may be a limited area of contamination present in the immediate vicinity of the well (within 4.6 m [15 ft]) that was not sampled; however, concentrations of radionuclides in the immediate vicinity of the well are unlikely to present a health concern.

Concentrations of carbon tetrachloride and chloroform in air, collected from within the covered 216-Z-9 Trench, are at concentrations below health concerns for workers; however, if these concentrations were in a residential home basement in the future, the indoor air pathway would be a health concern. Volatile organic compounds (VOCs) are still being collected from the subsurface at the 216-Z-1A tile field, as well as 216-Z-9 Trench, even though VOCs are not COPCs in soil at the 216-Z-1A tile field. Thus, carbon tetrachloride and chloroform are COPCs for indoor air for a future residential farmer at both 216-Z-9 Trench and 216-Z-1A tile field.

EXPOSURE ASSESSMENT

The risk assessment evaluated risks under current conditions (industrial land use, assuming the existing institutional controls with current construction workers as the population potentially exposed) and future conditions (unrestricted land use post-2150, if institutional controls fail in the future). The unrestricted land-use scenario assumes that after the year 2150, potential exposures to a future residential farming population (adults and children) and a working population (future well drillers and future regular workers) are hypothetically possible.

Soil risks were evaluated at four different waste sites, and groundwater risks were evaluated for three concentrations for each COPC (the 25th, 50th, and 90th percentile concentration of the plume). Thus, soil risks are waste site-specific, and groundwater risks are evaluated for low, medium, and high COPC concentrations independent of location. Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site.

RISK ASSESSMENT RESULTS

Risks (for cancer) and hazards (for non-cancer effects) are calculated for a reasonable maximum exposure scenario for each pathway, which is a calculation that over-estimates risks for the majority of the population in order to ensure that public health is protected. Cancer risk estimates represent the potential for cancer effects by estimating the probability of developing cancer over a lifetime due to site exposures (e.g., a risk of 1×10^{-6} indicates a one in 1 million chance of developing cancer due to exposures at the site). Non-cancer hazards assume there is a level of contaminant intake that is not associated with an adverse health effect even in sensitive individuals. The EPA's target cancer risk goal is 1×10^{-6} to 1×10^{-4}, with action usually required if risks exceed 1×10^{-4}; target health goals for non-cancer contaminants are a hazard index (HI) of ≤ 1.

Under current industrial land use and institutional controls, there are no exposures to contaminants and radionuclides in groundwater and soil. Volatile or radiological emissions from the subsurface are insignificant for workers. Institutional controls prevent the use of impacted groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of non-impacted soil. However, if construction workers disturbed soil down to 4.6 m (15 ft) at the 216-Z-1A tile field,

216-Z-8 french drain, or 216-A-8 Crib, they could come into contact with COPCs. Under that unlikely scenario (i.e., existing institutional control programs at Hanford are designed to prevent unprotected digging in impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A tile field and 216-A-8 Crib, indicating that remedial action would be necessary. Risks from digging in soil at 216-Z-8 were less than 1×10^{-6}. Risks from subsurface soil exposures at the 216-Z-1A tile field were driven by plutonium-239, followed by plutonium-240, then americium-241. Risks from subsurface soil at 216-A-8 Crib are driven by cesium-137. There are no nonradionuclides in soil that are a health concern for construction workers. Construction workers were not evaluated for exposure to subsurface soil at the 216-Z-9 Trench due to the depth to impacted soil and because the area is covered with a concrete cover; however, if construction workers were to disturb soil beneath the bottom of the trench, construction worker risks would likely exceed 1×10^{-4}. Table ES-2 summarizes the cancer risks from exposure to COPCs in soil. Non-cancer hazards due to chemicals in soil never exceeded an HI of 1.

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and in growth of daughter products. For the three Z Plant sites (216-Z-1A tile field, 216-Z-8 french drain, and 216-Z-9 Trench) where risks are driven by plutonium-239, plutonium-240, and americium-241 (true for all soil scenarios), cumulative risks at future time horizons are not significantly different than current risks because the half-lives of the plutonium isotopes are so long (or, in the case of the well driller and residential farmer), risks at 150 years are not very different than risks at 500 and 1,000 years, although at the 216-A-8 Crib where cesium-137 is the risk driver for all soil scenarios, risks are significantly lower at future time horizons due to the relatively short half-life (approximately 30 years) of cesium-137.

In the event that knowledge of the site is lost and institutional controls fail, a future unrestricted land-use scenario was evaluated where people could come into contact with groundwater and subsurface soil brought to the surface as drill cuttings from drilling a groundwater well. This scenario is assumed to occur 150 years in the future. Therefore, radiological concentrations in soil were modeled assuming 150 years of decay (although, as noted above, this assumption does not make a difference for the Z Plant sites). Two of the three radionuclides selected as COPCs in groundwater (technetium-99 and iodine-129) have very long half-lives and future concentrations would not be different than current concentrations. However, the third radionuclide COPC,

tritium, will likely be at concentrations that are below a health concern within 150 years. Future soil risks for a driller and a residential farmer are summarized in Table ES-2. Future groundwater risks and hazards for future in regular workers and future residential farmers are summarized in Table ES-3.

In summary, risks from exposure to soils at the 216-Z-8 french drain are below levels that are a health concern. Risks from soil exposures at the 216-Z-1A tile field and 216-A-8 Crib are similar and exceed 1×10^{-4} for construction workers and residential farmers. Radionuclide risks from soil exposures at 216-Z-9 Trench were the highest for the four waste sites evaluated, with risks of 2×10^{-5} for well drillers and 1×10^{-1} for residential farmers. Plutonium-239 and americium-241, followed by plutonium-240, were the risk drivers in soil for the Z Plant sites, and cesium-137 was the risk driver in soil at the 216-A-8 Crib.

Risks from exposure to groundwater exceeded 1×10^{-4} at the 90th and 50th percentiles, due primarily to carbon tetrachloride, followed by technetium-99, for both residential and industrial drinking water exposures. Carbon tetrachloride's non-cancer hazards were also non-cancer risk drivers and exceeded target health goals at the 90th and 50th percentiles. Although reductions in future concentrations were not quantified for carbon tetrachloride, the contaminant's concentrations will be decreasing relatively rapidly over time in comparison to technetium-99 with a half-life of 213,000 years. Therefore, while carbon tetrachloride concentrations represent the highest current risks, in the future, technetium-99 will likely become the risk driver.

Residential farmer risks were highest for ingestion of produce, followed by ingestion of soil, ingestion of groundwater, consumption of dairy products, and consumption of beef.

UNCERTAINTIES

Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks. Some key areas of uncertainty evaluated in the risk assessment are discussed below:

- In regard to produce ingestion, risks and hazards are significantly above target health goals due to ingesting homegrown produce grown in impacted soil and watered with impacted groundwater. Calculated risks and hazards from ingestion of homegrown produce are dependent upon the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling and likely over-estimate the amount of COPC that could be in the plant. Ingestion rates were selected to represent a rural farming population that would be expected to receive a significant portion of their produce from their own garden.
- A Native American population was not quantitatively evaluated. With some exceptions, Native American exposures are similar in type to the residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain), but exposures may be different in kind (e.g., more time spent outdoors and greater consumption of native plants and animals) than the typical default exposures that EPA has developed for a residential population. Combined exposures to soil and groundwater for Native Americans result in an increase of about an order of magnitude (10 times) the exposure of the residential farmer. Because cancer risks and non-cancer hazards for the residential farmer are already well above target health goals under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (i.e., have an HI above 1 and cancer risks above 1×10^{-4}), increased exposures for a Native American population would not result in a change in action as the risks already exceed the action threshold and require action to be taken. A sweat lodge using groundwater is a pathway applicable to Native Americans but is not evaluated for a residential farmer. A sweat lodge could be a significant exposure pathway of contaminants in groundwater, with risks and hazards equal to or exceeding the drinking water pathway.
- For construction worker exposure-to-soil calculations at all three of the soil sites, characterization of the top 4.6 m (15 ft) was limited with few samples representing that depth horizon because the shallower soil has not been impacted. Therefore, use of exposure concentrations from the deepest soil depth that construction workers would likely encounter has potentially resulted in risks that are biased as high because the majority of a construction worker's exposure would be to the shallower, uncontaminated soil.

- For residential farmer soil concentrations, concentrations are dependent upon the size of garden over which drill cuttings would be spread. The risk calculations assumed a 100-m^2 (1, 076 ft2) garden, based on an area that could likely supply approximately 25% of vegetables and fruit for a family of four. Larger size gardens or other types of spreading areas would result in a decrease in concentrations.

RISK-BASED CONCENTRATIONS

Although risks were calculated under both a current and future industrial land-use scenario, as well as for a future unrestricted land-use scenario, cleanup goals and decisions will generally be based on industrial land-use exposures as consistent with the current industrial nature of the site. Therefore, the risk-based concentrations (RBCs) were calculated based only on industrial land use and were only calculated for the risk drivers (americium-241, plutonium-239, plutonium-240, and cesium-137 in soil, and carbon tetrachloride in groundwater). These levels may be used in the FS process to evaluate remedial options. For groundwater, RBCs are based on future regular workers drinking the water and for soil are based on the current construction worker. The RBCs are summarized in Table ES-4.

The RBCs for each of the risk drivers were calculated to be protective of the maximum acceptable cancer risk level of 1×10^{-4}. For the radionuclides in soil, RBCs were also calculated protective of 100 mrem/yr level. However, combined exposures to each of the risk drivers at the RBCs could result in an exceedance of the target health goals. The RBCs were not adjusted downward to account for cumulative exposures because risk drivers may not all be present at the same location, nor may the high concentrations of the risk drivers be co-located with each other. Therefore, risk managers will consider potential cumulative exposures to the COPCs when applying RBCs at specific locations in the evaluation of the protectiveness of various remedies during the FS process; a downward adjustment to account for cumulative exposures may or may not be necessary.

Table ES-1. Selected Contaminants of Potential Concern in Soil.

Contaminant	216-Z-1A	216-Z-8	216-Z-9	216-A-8
Americium-241	√	√	√	
Cadmium			√	
Carbon-14				√
Carbon tetrachloride			√	
Cesium-137				√
Europium-152			√	
Manganese			√	
Neptunium-237			√	√
Nickel-63			√	
Plutonium -238		√	√	
Plutonium-239/240	√	√	√	√
Protactinium-231			√	
Radium-226			√	
Radium-228			√	√
Strontium-90			√	
Technetium-99			√	√
Thallium				√
Thorium-228			√	√
Thorium-230			√	

Table ES-2. Summary of Risks from Soil. (2 sheets)

Radionuclide or Contaminant	Current Construction Worker	Future Well Driller	Future Residential Farmer	
	Soil	Soil	Soil	Produce[a]
216-Z-1A Tile Field				
Am-241	3E-03	3E-06	1E-03	3E-04
Np-237[b]	--	--	6E-06	6E-07
Pu-239	3E-02	5E-07	1E-03	7E-03
Pu-240	6E-03	1E-07	2E-04	2E-03
Total[c]	**4E-02**	**3E-06**	**2E-03**	**9E-03**
216-Z-8 French Drain				
Am-241	1E-07	2E-09	2E-08	2E-07
Pu-238	1E-08	4E-12	7E-09	5E-08
Pu-239	7E-07	7E-10	2E-06	9E-06
Pu-240	1E-07	2E-10	3E-07	2E-06
Total[c]	**9E-07**	**2E-09**	**3E-06**	**1E-05**

Table ES-2. Summary of Risks from Soil. (2 sheets)

Radionuclide or Contaminant	Current Construction Worker	Future Well Driller	Future Residential Farmer	
	Soil	Soil	Soil	Produce[a]
216-Z-9 Trench				
Ac-227[b]	Construction worker not evaluated at 216-Z-9	--	1E-05	6E-07
Am-241		7E-06	4E-03	8E-04
Eu-152		1E-10	1E-07	3E-11
Ni-63		4E-012	7E-09	2E-06
Np-237		7E-08	2E-04	1E-05
Pa-231[b]		--	2E-06	1E-06
Pb-210[b]		--	6E-07	3E-05
Pu-238		8E-10	2E-06	1E-05
Pu-239		7E-06	2E-02	9E-02
Pu-240		2E-06	3E-03	2E-02
Ra-226		8E-08	2E-04	2E-05
Ra-228		5E-16	3E-13	2E-13
Sr-90		5E-12	5E-09	3E-07
Tc-99		6E-21	1E-18	1E-14
Th-228		1E-15	9E-13	3E-15
Th-230		3E-11	5E-08	2E-07
U-235[b]		--	8E-07	1E-08
Radionuclide total[c]		**2E-05**	**2E-02**	**1E-01**
Cadmium		1E-12	1E-09	--
Carbon tetrachloride		2E-06	5E-05	1E-03
Chemical total[c]		**2E-06**	**6E-05**	**1E-03**
216-A-8 Crib				
C-14	--	--	6E-16	6E-16
Cs-137	5E-02	7E-06	2E-02	4E-04
Np-237	7E-08	1E-09	3E-06	3E-07
Pu-239	1E-07	1E-11	3E-08	2E-07
Pu-240	2E-08	3E-12	6E-09	4E-08
Ra-228	1E-07	8E-15	6E-12	3E-12
Tc-99	--	--	4E-24	3E-20
Th-228	1E-07	2E-14	2E-11	5E-14
Total[c]	**5E-02**	**7E-06**	**2E-02**	**4E-04**
Total (500 years)[c]	**7E-07**	**4E-11**	**2E-06**	**2E-07**
Total (1,000 years[c])	**2.E-07**	**3E-13**	**1E-06**	**9E-08**

[a] Produce grown in impacted soil is the only food chain evaluated for soil.
[b] This radionuclide was not on the original COPC list, but is included here because it is a daughter product with risk greater than 1E-7.
[c] Totals are calculated using unrounded values.
-- = indicates incomplete pathway or not applicable (e.g., not a COPC for this receptor)
COPC = contaminant of potential concern

Table ES-3. Summary of Hazards and Risks from Groundwater Post-2150, Unrestricted Land Use.

Exposure Pathway	Receptor Population	Receptor Age	Contaminant Group	High	Medium	Low
Total[a] Non-Cancer Hazards						
Tap water	Industrial worker	Adult	Nonradionuclides	42	7	0.2
	Residential farmer	Child/adult	Nonradionuclides	316	55	1
Irrigation	Residential farmer	Adult	Nonradionuclides	2	0.28	0.006
Meat (beef)	Residential farmer	Child/adult	Nonradionuclides	0.34	0.02	0.01
Ingestion of produce	Residential farmer	Child/adult	Nonradionuclides	362	63	1
Dairy products (dairy)	Residential farmer	Child/adult	Nonradionuclides	0.09	0.02	0.0006
Total Cancer Risks						
Tap water	Industrial worker	Adult	Radionuclides	4E-05	4E-06	1E-06
			Nonradionuclides	3E-03	5E-04	7E-06
	Residential farmer	Child/adult	Radionuclides	1E-04	1E-05	4E-06
			Nonradionuclides	2E-02	3E-03	5E-05
Irrigation	Residential farmer	Adult	Radionuclides	2E-07	2E-08	3E-09
			Nonradionuclides	8E-05	1E-05	2E-07
Meat (beef)	Residential farmer	Child/adult	Radionuclides	3E-05	3E-06	8E-07
			Nonradionuclides	2E-06	3E-07	5E-09
Ingestion of produce	Residential farmer	Child/adult	Radionuclides	3E-03	4E-04	1E-04
			Nonradionuclides	1E-02	2E-03	3E-05
Dairy products (dairy)	Residential farmer	Child/adult	Radionuclides	2E-04	2E-05	6E-06
			Nonradionuclides	4E-06	6E-07	1E-08

NOTE: "High," "medium," and "low" columns are the hazards and risks from exposure to concentrations of the contaminants of potential concern at the 90th percentile, 50th percentile, and 25th percentile, respectively, for all of the 200-ZP-1 Operable Unit groundwater data from 2000 through 2005.

[a] Totals are calculated using unrounded values

Table ES-4. Risk-Based Concentrations for Groundwater and Soil.

Risk Driver	RBC Based on a Target Annual Risk of 1 x 10^{-4} (µg/L or pCi/g)	RBC[a] Based on Target Dose of 100 mrem/yr (pCi/g)
Regular Worker Exposure to Groundwater		
Carbon tetrachloride	62	NA
Construction Worker Exposure to Soil		
Am-241	45,000	2,510
Pu-239	50,000	2,650
Pu-240	50,000	2,650
Cs-137	1,600	1,220

[a] The RBC is based on a combined dose via the dust inhalation, radon inhalation, soil ingestion, and external exposure pathways.
NA = not applicable
RBC = risk-based concentration

TABLE OF CONTENTS

A1.0 INTRODUCTION A-1

A2.0 DATA EVALUATION AND SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN A-9

A2.1 SELECTION OF DATA APPLICABLE TO HUMAN HEALTH A-9

A2.1.1 Soil A-9

A2.1.2 Soil Gas A-10

A2.1.3 Groundwater A-10

A2.1.4 Data Usability and Data Quality A-11

A2.2 CONTAMINANT SELECTION PROCESS FOR CONTAMINANTS IN SOIL A-14

A2.3 RESULTS OF SCREENING FOR SOIL A-15

A2.3.1 216-Z-1A Tile Field A-15

A2.3.2 216-Z-8 French Drain A-16

A2.3.3 216-Z-9 Trench A-16

A2.3.4 216-Z-10 Injection/Reverse Well A-18

A2.3.5 216-A-8 Crib A-18

A2.4 RESULTS OF SCREENING FOR SOIL GAS A-19

A2.5 RESULTS OF SCREENING FOR GROUNDWATER A-20

A2.6 SUMMARY OF CONTAMINANTS OF POTENTIAL CONCERN A-21

A3.0 EXPOSURE ASSESSMENT A-63

A3.1 CONCEPTUAL SITE MODEL A-63

A3.1.1 Affected Media and Land Use A-63

A3.1.2 Selected Populations A-64

A3.1.3 Identification of Exposure Pathways A-66

A3.2 EXPOSURE POINT CONCENTRATIONS A-69

A3.2.1 Exposure Point Concentrations for Soil A-69

A3.2.2 Exposure Point Concentrations for Groundwater A-74

A3.2.3 Calculation of Tissue Concentrations from Groundwater and Soil Exposure Point Concentrations A-75

A3.3 CALCULATION OF CONTAMINANT DOSE A-78

A3.3.1 Current Industrial Land-Use Scenario A-79

A3.3.2 Post-2150 Unrestricted Land-Use Scenario A-80

A4.0 TOXICITY CRITERIA A-113

A4.1 CANCER EFFECTS A-113

A4.2 NON-CANCER EFFECTS A-114

A4.3 ORAL TOXICITY CRITERIA A-115

A4.4 INHALATION TOXICITY CRITERIA A-115

A4.5 DERMAL TOXICITY CRITERIA A-116

A5.0 RISK CHARACTERIZATION A-123

A5.1 METHODOLOGY FOR EVALUATING NONCARCINOGENIC HAZARDS A-123

A5.2 METHODOLOGY FOR EVALUATING CARCINOGENIC RISKS A-123

A5.3 SUMMARY OF RISK RESULTS A-124

A5.3.1 Current Industrial Land Use: Risks from Soil Exposures for Construction Workers A-125

A5.3.2 Post-2150 Unrestricted Land Use: Worker Exposures A-126

A5.3.3 Post-2150 Unrestricted Land Use: Residential Farmer Exposures A-128

A5.3.4 Future Groundwater Risks for Residential Farmer A-134

A5.3.5 Cumulative Risks from Multiple Media Exposures A-135

A5.4 SUMMARY OF DOSE RESULTS A-135

A5.5 RISK CHARACTERIZATION SUMMARY AND CONCLUSIONS A-136

A6.0 UNCERTAINTIES IN RISK ASSESSMENT A-157

A6.1 UNCERTAINTIES RELATED TO DATA EVALUATION AND THE SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN A-157

A6.1.1 Soil Data and Contaminant of Potential Concern Selection A-157

A6.1.2 Groundwater Data and Contaminant of Potential Concern Selection A-161

A6.2 UNCERTAINTIES RELATED TO EXPOSURE A-161

A6.2.1 Tribal Subsistence Exposures A-162

A6.2.2 Other Exposure Pathways and Populations Not Quantified A-163

A6.2.3 Exposure Point Concentrations A-164
A6.2.4 Uncertainties in Food Chain Ingestion Rates A-165
A6.2.5 Uncertainties in Other Exposure Factors A-167
A6.3 UNCERTAINTIES IN ASSESSMENT OF TOXICITY A-168
A6.4 UNCERTAINTIES IN RISK CHARACTERIZATION A-170
A6.4.1 Uncertainties Associated with Large Estimates of Risk A-171
A6.4.2 Uncertainties in Radiation Risk Assessment A-171
A6.5 SUMMARY OF UNCERTAINTY A-172
A7.0 POTENTIAL RISK-BASED CONCENTRATIONS A-181
A7.1 CALCULATION METHODS A-181
A7.1.1 Soil A-181
A7.1.2 Groundwater A-184
A7.2 APPLICATION OF CLEANUP LEVELS A-185
A8.0 SUMMARY AND CONCLUSIONS A-189
A8.1 DATA EVALUATION A-189
A8.2 EXPOSURE ASSESSMENT A-191
A8.3 TOXICITY ASSESSMENT A-192
A8.4 RISK CHARACTERIZATION A-192
A8.5 UNCERTAINTIES IN RISK ASSESSMENT A-195
A8.6 RISK-BASED CONCENTRATIONS A-196
A9.0 REFERENCES A-197

FIGURES

Figure A1-1. Site Vicinity and Location Map. A-4
Figure A1-2. Locations of 216-Z-1A Tile Field and 216-Z-9 Trench in the 200 West Area. A-5
Figure A1-3. Locations of 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well in the 200 West Area. A-6
Figure A1-4. Location of 216-A-8 Crib in the 200 East Area. A-7
Figure A2-1. 216-Z-1A Tile Field Sample Locations for Soil. A-22
Figure A2-2. 216-Z-8 French Drain Sample Location for Soil. A-23
Figure A2-3. 216-Z-9 Trench Sample Locations for Soil. A-24
Figure A2-4. 216-A-8 Crib Sample Location for Soil. A-25
Figure A2-5. Section Views of the 216-Z-9 Trench. A-26
Figure A3-1. Schematic Human Health Conceptual Site Model Current Industrial Land Use. A-85
Figure A3-2. Schematic Human Health Conceptual Site Model Future Unrestricted Land Use. A-86
Figure A3-3. Ingrowth of Americium-241 at 216-Z-1A Vadose Zone. A-87
Figure A3-4. Ingrowth of Americium-241 at 216-Z-9 Vadose Zone. A-87
Figure A3-5. Ingrowth of Americium-241 at 216-Z-1A Shallow Soils (Construction Worker Soil Contact Zone). A-88
Figure A5-1. Decreases in Cancer Risks Over Time – Future Residential Farmer at the 216-Z-9 Trench. A-139
Figure A5-2. Decreases in Cancer Risks Over Time – Future Residential Farmer at the 216-A-8 Crib. A-140
Figure A5-3. Cancer Risks from Tritium in Groundwater Over Time. A-141
Figure A6-1. Carbon Tetrachloride Groundwater Concentration Frequencies. A-173
Figure A6-2. Technetium-99 Groundwater Concentration Frequencies. A-173
Figure A6-3. Change in Plutonium-239 Concentration with Garden Size. A-174

TABLES

Table A2-1. Summary of Soil Data Locations Included in the Risk Assessment, 216-Z-1A Tile Field. A-27
Table A2-2. Summary of the Number of Samples by Contaminant Group A-28
Table A2-3. Summary of Soil Data Locations Included in the Risk Assessment for the 216-Z-9 Trench A-29
Table A2-4. Summary of Groundwater Data Locations Included in the Risk Assessment for the 200-ZP-1 Operable Unit. A-29
Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection Agency's Data Usability Guide. (3 sheets) A-30
Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values.[a] (2 sheets) A-32
Table A2-7. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-1A Tile Field. (2 sheets) A-35
Table A2-8. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-8 French Drain. A-39
Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-9 Trench. (4 sheets) A-41
Table A2-10. Frequency and Magnitude of Exceedance for Contaminants in Soil With Detected Concentrations Greater Than the Screening Values and Less Than Background at the 216-Z-9 Trench. A-49
Table A2-11. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets) A-51
Table A2-12. Frequency and Magnitude of Exceedance for Contaminants in Soil with Detected Concentrations Greater Than the Screening Values and Less Than Background at the 216-A-8 Crib. A-55
Table A2-13. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Trench Air at the 216-Z-9 Trench. A-57
Table A2-14. Draft Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Groundwater (Based on Target Action Levels) at the 200-ZP-1 Operable Unit. A-59
Table A2-15. Contaminants Selected as Contaminants of Potential Concern in Soil. A-61
Table A3-1. Summary of Exposure Point Concentrations for Soil Current Construction Worker A-89
Table A3-2. Summary of Exposure Point Concentrations for Soil Representative of Current Vadose Zone Concentrations (Cwaste). (2 sheets) A-90
Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors. (2 sheets) A-92
Table A3-4. Summary of Exposure Point Concentrations for Groundwater for 200-ZP-1 Operable Unit Source Area A-93
Table A3-5. Summary of Food Chain Pathway Exposure Point Concentrations (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants (Nonradionuclides Only). (2 sheets) A-94
Table A3-6. Summary of Homegrown Produce Exposure Point Concentrations Soil to Plant Pathway (RESRAD Methodology) 150 Years from Now.[a] A-96

Table A3-7. Plant Tissue Modeling Calculations Future Residential Farmer, 200-ZP-1 Groundwater and Residential Soil (Nonradionuclides). A-97
Table A3-8. Summary of Transfer Coefficients Used in Tissue Modeling Calculations. A-98
Table A3-9. Beef Tissue and Dairy Products Modeling Calculations, Residential Farmer, 200-ZP-1 Operable Unit Groundwater. A-99
Table A3-10. Construction Worker Exposures to Soil – Exposure Assumptions and Intake Equations. A-100
Table A3-11. Summary of Volatilization Factor and Particulate Emission Factor Inputs and Equations. (2 sheets) A-101
Table A3-12. Residential Farmer Exposures to Soil – Exposure Assumptions and Intake Equations. (2 sheets) A-103
Table A3-13. Intake Assumptions Children (2 to 6 Years) and Adults – Residential Exposures Ingestion, Dermal, and Inhalation Exposure to Tap Water. (2 sheets) A-105
Table A3-14. Absorbed Dose per Event Dermal Exposure to Tap Water and Irrigation Water. A-107
Table A3-15. Intake Assumptions Adults - Residential Farmer Dermal and Inhalation Exposure to Groundwater During Irrigation. A-108
Table A3-16. Intake Assumptions Child and Adults – Residential Farmer Food Chain Pathways. A-109
Table A3-17. Well Driller Exposures to Well Cuttings – Exposure Assumptions and Intake Equations. A-110
Table A3-18. Intake Assumptions Adults – Industrial Exposures. Ingestion and Inhalation Exposure to Tap Water. A-111
Table A4-1. Carcinogenic Toxicity Criteria for the Nonradionuclide Contaminants of Potential Concern. A-117
Table A4-2. Radionuclide Toxicity Criteria for Contaminants of Potential Concern.[a] A-118
Table A4-3. Noncarcinogenic Chronic and Subchronic Toxicity Criteria for Contaminants of Potential Concern. (3 sheets) A-119
Table A5-1. Summary of Risks for the Current Construction Worker from Soil. A-142
Table A5-2. Summary of Risks for the Future Well Driller from Soil. A-143
Table A5-3. Future Well Driller – Summary of Non-Cancer Hazards from Soil at the 216-Z-9 Trench. A-144
Table A5-4. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker. A-144
Table A5-5. Summary of Non-Cancer Hazards for Contaminants of Potential Concern (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker. A-145
Table A5-6. Summary of Risks for the Future Residential Farmer from Soil. (2 sheets) A-145
Table A5-7. Future Residential Farmer – Summary of Non-Cancer Hazards from Soil Exposures. A-147

Table A5-8. Summary of Cancer Risks for Contaminants of Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Residential Farmer A-148
Table A5-9. Summary of Non-Cancer Hazards for Contaminants of Potential Concern (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Residential Farmer A-149
Table A5-10. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Food Chain Pathways – Future Residential Farmer. A-150
Table A5-11. Summary of Non-Cancer Hazards for the Nonradionuclide Contaminants of Concern Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Food Chain Pathways – Future Residential Farmer A-151
Table A5-12. Summary of Dose (mrem/yr) for Current Construction Worker from Soil. A-152
Table A5-13. Summary of Dose (mrem/yr) for Future Well Driller from Soil. A-153
Table A5-14. Summary of Dose (mrem/yr) for the Future Residential Farmer from Soil. A-154
Table A5-15. Cumulative Risks for the Residential Farmer from Soil and Groundwater. A-155
Table A6-1. Contaminants Analyzed in Soil but Never Detected with Method Detection Limits Exceeding Screening Values A-175
Table A6-2. 200-ZP-1 Contaminants in Groundwater Detected Above EPA Region 6 Tap Water Screening Levels. A-177
Table A6-3. Comparison of Residential Farmer Exposure Factors with Tribal Subsistence Exposure Factors. A-179
Table A6-4. Groundwater Percentile Concentrations and Summary Statistics. A-180
Table A6-5. Summary of Available Ingestion Rates for Homegrown Produce. A-180
Table A7-1. Summary of Soil Risk-Based Concentrations for Current Construction Worker Exposures. A-186
Table A7-2. Dose Conversion Factors and Risk Coefficients for Different Exposure Pathways. A-186

ATTACHMENTS

A-1 ProUCL Outputs for Contaminants of Potential Concern in Soil
A-2 C_{waste} Details and Exposure Point Concentration Calculations for Well Driller and Residential Farmer
A-3 RESRAD Input Summary
A-4 Default Exposure Factors
A-5 Toxicity Profiles for Each Contaminant of Potential Concern
A-6 Groundwater and Soil Risk Calculations
A-7 Soil RESRAD Risk Summary Tables
A-8 Risk-Based Concentrations for Groundwater and Soil RESRAD Summaries

LIST OF TERMS

ARAR	applicable or relevant and appropriate requirement
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
CalEPA	California Environmental Protection Agency
CAS	Chemical Abstract Services
CERCLA	*Comprehensive Environmental Responses, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
DNAPL	dense nonaqueous phase liquid
DOE	U.S. Department of Energy
DOD	U.S. Department of Defense
DQO	data quality objective
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
EFH	*Exposure Factors Handbook*
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FS	feasibility study
HEAST	*Health Effects Assessment Summary Tables* (EPA 540/R-97-036)
HHRA	human health risk assessment
HHSL	human health screening level
HI	hazard index
HQ	hazard quotient
HSRAM	*Hanford Site Risk Assessment Methodology*
IRIS	Integrated Risk Information System
K_d	distribution coefficient
LOAEL	lowest-observed-adverse-effect level
MCL	maximum contaminant level
MDL	method detection limit
MRL	method reporting limit
MTCA	*Model Toxics Control Act*
NA	not applicable
NAS	National Academy of Sciences
NCEA	National Center for Environmental Assistance
NCP	National Contingency Plan
NE	not evaluated
NOAEL	no-observed-adverse-effect level
NRC	U.S. Nuclear Regulatory Commission
OEHHA	California Office of Environmental Health Hazard Assessment
ORNL	Oak Ridge National Laboratory

OU	operable unit
PCE	tetrachloroethylene
PEF	particulate emission factor
PEL	permissible exposure limit
PPRTV	provisional peer-reviewed toxicity value
PRG	preliminary remediation goal
ProUCL	EPA's Software for Calculating the Upper Confidence Limit, Version 3.00.02
RAIS	Risk Assessment Information System
RBC	risk-based concentration
RESRAD	RESidual RADioactivity (dose model)
RfC	reference concentration
RfD	reference dose
RfDi	reference dose for inhalation
RI	remedial investigation
RME	reasonable maximum exposure
SF	slope factor
SF_i	inhalation slope factor
SIF	summary intake factor
SSL	soil screening level
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TAL	target action level
TCE	trichloroethylene
UCL	upper confidence limit
UF	uncertainty factor
URF	unit risk factor
USDA	U.S. Department of Agriculture
VF	volatilization factor
VF_w	volatilization factor for water
VOC	volatile organic compound
WAC	*Washington Administrative Code*
WISHA	*Washington State Industrial Safety and Health Act*

APPENDIX A

BASELINE HUMAN HEALTH RISK ASSESSMENT

A1.0 INTRODUCTION

This risk assessment evaluates potential human health risks in selected areas of the Hanford Site's Central Plateau from exposure to contaminants formerly used at the Site that are still present in subsurface soil and groundwater. Specifically, this risk assessment addresses contaminants in the 200-ZP-1 Groundwater Operable Unit (OU) under the northern portion of the 200 West Area of the Hanford Site and at five representative soil sites located in the 200-PW-1, 200-PW-3, and 200-PW-6 OUs (hereinafter referred to as the 200-PW-1/3/6 OUs). The soil sites evaluated in this assessment are 216-A-8 Crib, 216-Z-1A tile field, 216-Z-8 french drain, 216-Z-9 Trench, and 216-Z-10 injection/reverse well. These soil sites were selected in the *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (DOE/RL-2006-51) as representative or unique of the 17 individual waste sites in these three OUs. This risk assessment will be used to evaluate the need for remedial action in soil and groundwater in these OUs and/or to evaluate the protectiveness of certain remedies based on current and potential future uses of the land as part of the Central Plateau Closure Project. Figure A1-1 shows the 200 West and 200 East Areas of the Hanford Site, and Figures A1-2 through A1-4 show the locations of the individual waste sites. All the waste sites are located in the 200 West Area, with the exception of 216-A-8, which is located in the 200 East Area.

Previous investigations have identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West Area from past spills, leaks, and work practices associated with the processing of uranium to make nuclear weapons and related activities (e.g., reprocessing of nuclear fuels and storing spent fuels). Industrial activities at Hanford have been ongoing since the 1940s and, while the nuclear processing activities are no longer occurring, much of the 200 West Area is still being used for industrial purposes (e.g., various storage and waste management activities). This appendix evaluates whether potential health risks are present if people encounter these solvent- and radionuclide-impacted materials in their environment. The risk assessment evaluates risks under current conditions (industrial land use, assuming the existing institutional controls with adult workers as the population potentially exposed) and future conditions (unrestricted land use if institutional controls fail in the future). The unrestricted land-use scenario assumes that land-use controls will remain in place for 150 years; after that time, potential exposures to a residential farming population (adults and children) and a working population are evaluated. The intent of including an unrestricted land-use scenario is to fulfill National Contingency Plan (NCP) (40 *Code of Federal Regulations* [CFR] 300) requirements for a risk evaluation under a "no action" scenario, to fulfill U.S. Environmental Protection Agency (EPA) requirements to address current and future conditions (*Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Part A* [EPA 540/1-89/002]), assesses food chain exposures consistent with EPA guidance (EPA 540/1-89/002) and the *Hanford Site Risk Assessment Methodology* (HSRAM) (DOE/RL-91-45), and to provide information to risk managers regarding the protectiveness of various remedies during the feasibility study (FS) process. However, cleanup

concentration goals and decisions will generally be based on industrial land-use exposures, as consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

A risk assessment evaluates the likelihood of adverse effects occurring in human populations potentially exposed to contaminants released in the environment. Risk assessments are not intended to predict the actual risk for an individual; rather, they provide upper-bound and central tendency estimates of risk with an adequate margin of safety, according to EPA guidelines, for the protection of the majority of all receptors that may potentially come into contact with contaminants at the site.

According to EPA, U.S. Department of Energy (DOE), and Hanford-specific risk guidance, human health risk assessments (HHRAs) are composed of four basic steps:

1. The sampling data are initially screened to select the applicable data set for humans and, within that data set, to select contaminants that could be a health concern.
2. Contaminant sources, pathways, receptors, exposure duration and frequency, and routes of exposure are evaluated to quantitatively assess the amount of exposure to the contaminants of potential concern (COPCs).
3. A toxicity assessment is performed, which summarizes the carcinogenic and noncarcinogenic effects associated with the COPCs and provides toxicity values that are used to estimate the dose-response relationship.
4. Risk characterization is performed that integrates the quantitative and qualitative results of the data evaluation, exposure, and toxicity assessment sections.

For use in the feasibility evaluations, a fifth step was conducted, where risk-based cleanup levels were calculated for various exposure scenarios.

The accuracy of the information presented in this section depends, in part, on the quality and representativeness of the available sample, exposure, and toxicological data. Where information is incomplete, conservative assumptions were made so risk to human health was not under-estimated. A discussion of uncertainties in the HHRA is presented in Section A6.0 in the main text of this FS. This appendix was prepared in accordance with current EPA, Hanford-specific, and DOE guidelines for risk assessment (*Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Part A, Interim Final* [EPA 540/1-89/002]; *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors, Interim Final* [OSWER Directive 9285.6-03]; *Exposure Factors Handbook* (EPF), Volumes I–III [EPA/600/P-95-002Fa]; *EPA Region 10, Interim Final Guidance: Developing Risk-Based Cleanup Levels at Resource Conservation and Recovery Act Sites in Region 10* [EPA 910/R-98-001]; *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* [OSWER Directive 9285.6-10]; *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* [OSWER Directive 9355.4-24]; *Final Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* [EPA 540/R/99/05]; and DOE/RL-91-45). Risk assessment methodology primarily follows EPA guidelines (EPA 540/1-89/002; OSWER Directive 9285.7-01B; OSWER Directive 9285.6-03; EPA/600/P-95-002Fa; EPA/540-R-00-006; OSWER Directive 9285.6-10; OSWER Directive 9355.4-24), with consideration of DOE (DOE/RL-91-45; *Exposure Scenarios*

and Unit Factors for the Hanford Tank Waste Performance Assessment [Rittman 2004]) and Washington State's "Model Toxic Control Act (MTCA) – Cleanup," (*Washington Administrative Code* [WAC] 173-340). In the absence of appropriate regulatory guidance (e.g., for site-specific conditions), the evaluation followed the available science.

This appendix is organized as follows.

- Section A1.0: Contains an introduction.
- Section A2.0: Selects the data for the risk assessment and the COPCs for workers and residential populations.
- Section A3.0: Describes the exposure assessment, including the conceptual site model (CSM), the rationale for the selection/exclusion of exposure pathways, and the methodology and inputs that are used to calculate contaminant dose.
- Section A4.0: Presents the toxicity criteria that are used in the risk and hazard calculations.
- Section A5.0: Presents the results of the risk calculations for carcinogenic (cancer) risks and noncarcinogenic (non-cancer) hazards.
- Section A6.0: Discusses the major uncertainties in the risk assessment.
- Section A7.0: Presents the results of the calculation of risk-based concentrations (RBCs) for industrial land use.
- Section A8.0: Summarizes the risk assessment and presents the conclusions.
- Section A9.0: Provides the references used in preparing this document.

Figure A1-1. Site Vicinity and Location Map.

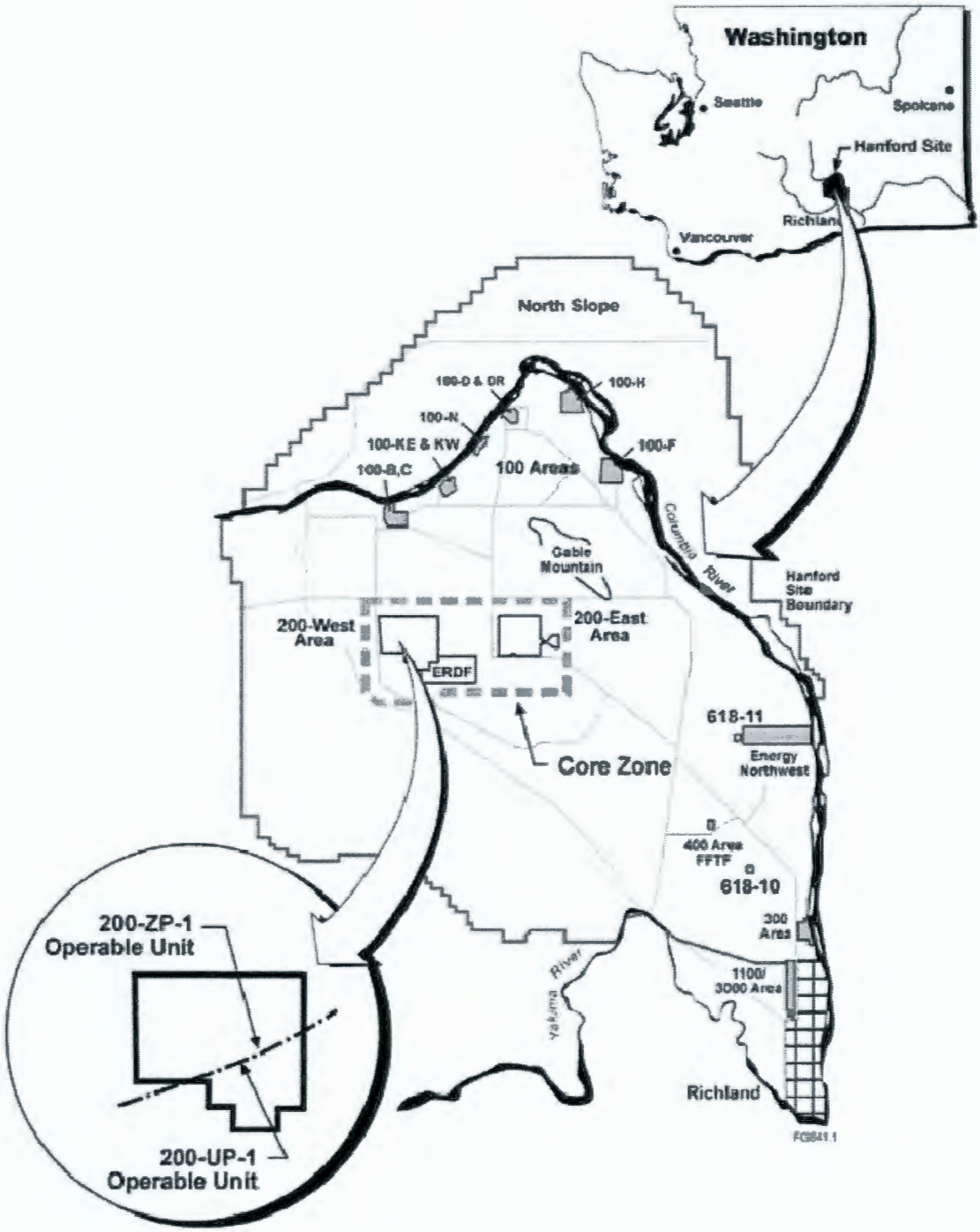


Figure A1-2. Locations of 216-Z-1A Tile Field and 216-Z-9 Trench in the 200 West Area.

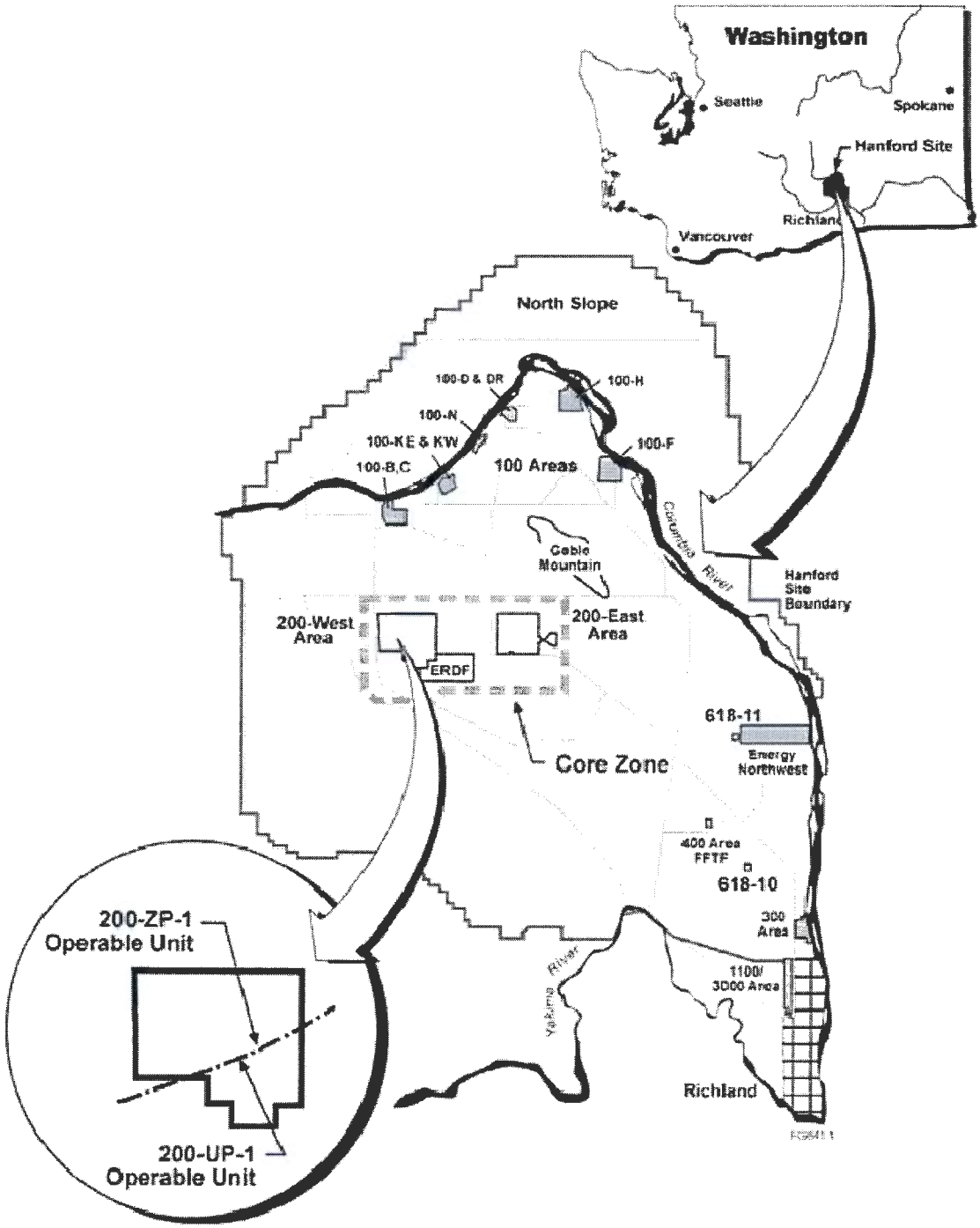


Figure A1-3. Locations of 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well in the 200 West Area.

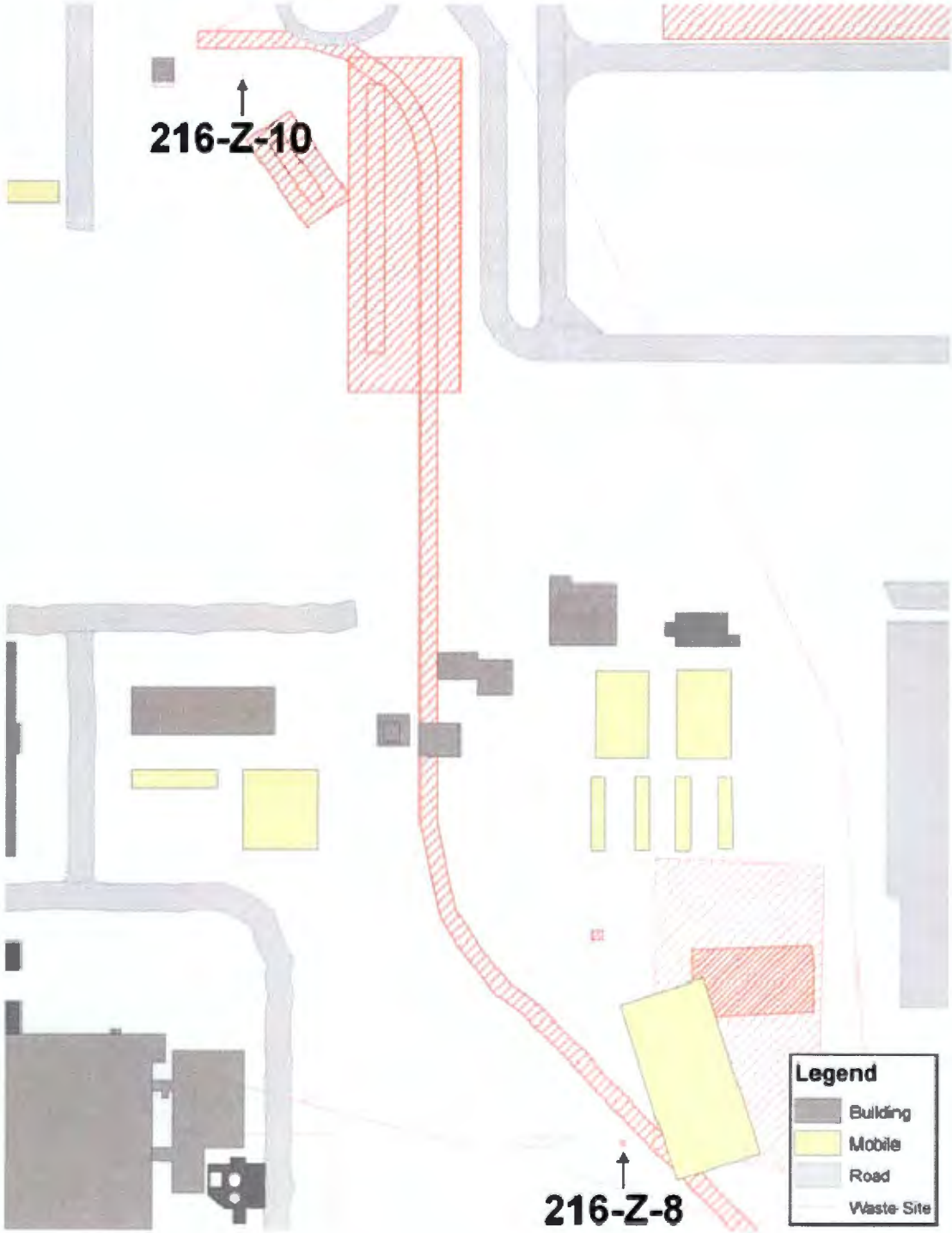
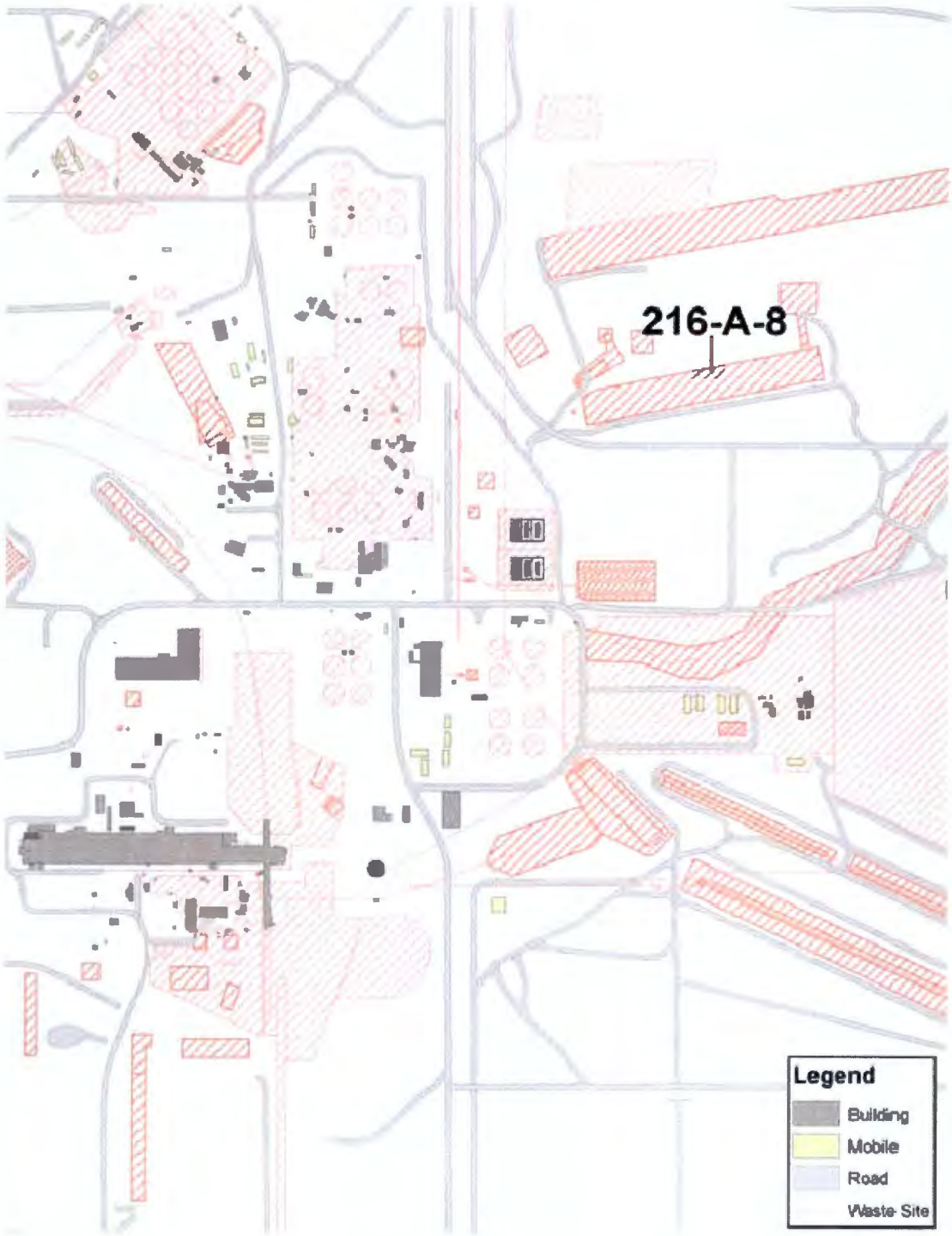


Figure A1-4. Location of 216-A-8 Crib in the 200 East Area.



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A2.0 DATA EVALUATION AND SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

The primary objective of the data collection and evaluation process in the HHRA is to develop a data set of sufficient quality and quantity to adequately evaluate the potential constituent impacts to human receptors. The initial step has two parts: (1) the available sampling data and site information are reviewed to select data applicable to human health, and (2) constituent concentrations within the data set are evaluated to identify constituents and affected environmental media (i.e., soil) that are potential human health concerns requiring a more detailed assessment.

A2.1 SELECTION OF DATA APPLICABLE TO HUMAN HEALTH

Not all of the data available at a particular site are usually selected for inclusion in the risk assessment because not all are relevant to human health exposures. For example, the quality of the data may be insufficient for the needs of the risk assessment, or the soil data may be from a depth interval for which there would be no human exposures. This section presents the data selected for inclusion or exclusion, along with any rationale for exclusion for each of the soil sites, followed by a discussion of soil gas data from the 216-Z-9 Trench, and lastly, the groundwater data.

A2.1.1 Soil

This risk assessment used the available data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for all of the representative sites, except the 216-Z-8 french drain and 216-Z-10 injection/reverse well, where the sources of the data were earlier documents. The data sources are as follows:

- At the 216-Z-1A tile field, the data used for screening are from the cone penetrometer rig locations in and around the 216-Z-1A tile field (Table 3-9 of the 200-PW-1/3/6 RI report [DOE/RL-2006-51]), Appendix C of the RI report [circa 1992-1993 sampling], and Appendix D of the RI report [circa 1979 sampling]). Data are available from depth ranges of 1.5 to 46.6 m (5 to 153 ft) below ground surface (bgs). Sample locations used in the risk analysis are tabulated in Table A2-1. Figure A2-1 shows the sample locations at the 216-Z-1A tile field.
- At the 216-Z-8 french drain, the data used for screening are from Table 3 of *The 216-Z-8 French Drain Characterization Study* (Marratt et al. 1984), which shows samples collected circa 1979, with sample depths from approximately 5 to 11 m (16 to 35 ft) bgs. Only one sample location, 299-W15-202, is available and was used in the risk analysis. Figure A2-2 shows the location of the single boring, and Table A2-2 shows the numbers of samples by constituent group available for the risk assessment.
- At the 216-Z-9 Trench, the data used for screening are from Appendix B of the 200-PW-1/3/6 RI report (DOE/RL-2006-51) (circa 2003-2006 sampling), in addition to historical data from 1961, 1963, and 1973 (*Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench* [ARH-2915]). Sample depths ranged from 6.6 to 40 m (22 to 133 ft) bgs. Sample locations used in the risk analysis are tabulated in Table A2-3 and

are shown spatially in Figure A2-3. Table A2-2 shows the numbers of samples by constituent group available for the risk assessment.

- At the 216-Z-10 injection/reverse well, the source of the data used to evaluate the site was *Underground Waste Disposal at Hanford Works* (HW-9671). Three borings were sampled within 4.6 m (15 ft) of the drain from ground surface down to 45.7 m (150 ft) bgs. No contaminants were detected.
- At the 216-A-8 Crib, the data used for screening are from Appendix B of the 200-PW-1/3/6 RI report (DOE/RL-2006-51) (circa 2005 sampling). Data were available from a single location, C4545, with sample depths ranging from approximately 5.8 to 80 m (19 to 264.5 ft) bgs. Figure A2-4 shows the location of the boring. Table A2-2 shows the numbers of samples by constituent group available for the risk assessment.

A2.1.2 Soil Gas

Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater beneath the 200-PW-1 OU (particularly in the vicinity of the 216-Z-9 Trench and 216-Z-1A tile field), soil gas sampling has occurred over a number of years. Soil gas data from the vicinity of 216-Z-9 collected in 2006 were reviewed to evaluate its suitability for inclusion in the risk assessment. Soil gas was collected from three sample locations and analyzed for volatile organic compounds (VOCs) (locations P66, P67 and P68 [see Figure A2-3]), approximately 3 m (10 ft) south of the 216-Z-9 Trench. The depth of the screened interval during sample collection was 19.8 to 21.3 m (65 to 70 ft) bgs. These sample locations are in the dense nonaqueous phase liquid (DNAPL) pool that was identified at this location (DOE/RL-2006-51). Therefore, these soil gas samples likely represent worst-case conditions for subsurface vapors, and high concentrations of some VOCs were measured at these locations. Low concentrations of soil gas are generally seen at most of the waste sites, with the exception of the 216-Z-9 Trench and 216-Z-1A tile field (DOE/RL-2006-51).

In addition to the soil gas data from the vapor probe locations, three air samples were also collected in 2006 from within the 216-Z-9 Trench (top, middle, and bottom [see Figure A2-5]) The top and bottom samples were within 0.3 m (1 ft) of the roof slab and the floor, respectively; both were within the trench's air space. The middle sample was collected within the middle of the air space, approximately 3.2 m (10.5 ft) from the trench roof.

The greatest human health concern with respect to soil gas is the possibility for subsurface vapors to move into basements of buildings and adversely impact indoor air. The EPA's *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (EPA 530-F-02-052) preferentially recommends the collection of indoor air samples, where possible, rather than modeling from soil gas or groundwater concentrations, due to the uncertainties and limitations of modeling. Therefore, the three air samples collected from within the 216-Z-9 Trench were selected for inclusion in the risk assessment as the most representative data regarding what concentrations could be inside a basement.

A2.1.3 Groundwater

Data used for the RI evaluation consisted of groundwater monitoring well data from samples collected from 116 wells between the years from 1988 through 2005. Table 1-2 of the *Remedial Investigation Report for the 200-ZP-1 Groundwater Operable Unit* (hereinafter referred to as the

200-ZP-1 RI report) (DOE/RL-2006-24) presents the wells used in the evaluation. Data excluded were samples collected prior to 1988, rejected data by laboratory validators, data with "null' results, and nonradioactive data reported as "zero" without reporting limits or detection limits (DOE/RL-2006-24).

This risk assessment evaluation for site 200-ZP-1 OU used a subset of the 200-ZP-1 RI report (DOE/RL-2006-24) data set. Specifically, the last 5 years of data were selected as representative of current conditions (samples collected between the years 2000 through 2005), and data prior to 2000 were excluded; the HHRA includes only the data from the past 5 years. In addition, of the 116 wells evaluated in the 200-ZP-1 RI report, 107 wells were selected for the risk assessment because their screening intervals were the most applicable for the depth that a groundwater-supply well might be screened. These 107 wells include the wells with the highest concentrations found for groundwater. The selected wells are listed in Table A2-4, and Table A2-2 shows the numbers of samples available per constituent or constituent group.

A2.1.4 Data Usability and Data Quality

Optimizing data usability reduces uncertainty in the environmental data used in a risk assessment. The data usability and quality issues discussed hereafter are based on *Final Guidance for Data Usability in Risk Assessment, Parts A and B* (OSWER Directive 9285.7-09A), which provides practical guidance on how to obtain an appropriate level of quality in all environmental analytical data. All data have been collected following DOE and EPA requirements, and the data are generally of sufficient quality for use in risk assessment. Where multiple analyses of a sample exist (i.e., field duplicates), the highest detected concentration is selected as the single-most valid analytical result for the sample collected; if all the of the results for a specific constituent were reported as "nondetected," then the lowest nondetect concentration (i.e., from the sample with the lowest [most-sensitive] sample-specific detection limit) was selected as the single-most valid analytical result for that sample.

A.2.1.4.1 Data Usability. The following four data application questions from EPA's data usability guidance (OSWER Directive 9285.7-09A) provide a very useful perspective for risk assessment:

1. <u>What contamination is present, and at what levels?</u> The quantity and location of samples were chosen based on an understanding of the sources of contamination and the potential migratory pathways of constituents. Details for each site are included in Table A2-5. However, one issue is common to the four Z Plant sites (216-Z-1A tile field, 216-Z-9 Trench, 216-Z-8 Crib, and 216-Z-10 Crib) and is discussed here; there are no analytical data for plutonium-241, which was produced as part of the plutonium-production processes, because of the difficulties with analyzing for this isotope of plutonium. Plutonium-241 is the parent compound of americium-241 for which there are analytical data. Plutonium-241 has a relatively short half-life of 14.5 years. The production of plutonium (including plutonium-241) started around 1944 at the Hanford Site. The final waste disposals to the major 200-PW-1/3/6 facilities varied and, therefore, some sites are further along the americium-241 ingrowth curve than others. Therefore, there is uncertainty at the Z Plant sites whether the maximum concentrations of americium-241 have been adequately captured in the existing data. In Section A3.2.1.1, an estimation of potential increases in americium-241 concentrations is performed based on the known

concentrations at specific dates and the specific disposal dates at each site. This issue is also further discussed in the uncertainty section of this appendix (Section A6.1.1).

2. Are site concentrations different from background? Concentrations of constituents that occur onsite in the absence of site activities are defined as background concentrations and include inorganic species and radionuclides. Comparison of site data to background concentrations allows for the determination of the degree of contamination caused by site-related activity. For this analysis, site-specific background concentrations are available for radionuclides and metals in soil and groundwater developed specifically for the Hanford Site (*Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes* [DOE/RL-92-24]; *Hanford Site Background: Part 2, Soil Background for Radionuclides* [DOE/RL-96-12]; *Hanford Site Background: Part 3, Groundwater Background* [DOE/RL-96-61]). Background soil concentrations are listed in the soil screening tables (Tables A2-7 through A2-11), and Table A2-14 presents background levels for groundwater. Section A2.3 discusses the detected constituents not selected as COPCs in the risk assessment (because they are present at background levels).

3. Are all exposure pathways and areas identified and examined? Sufficient site knowledge exists to understand potential current and future exposure pathways. Exposure pathways are identified and discussed in detail in Section A3.1 of this appendix. Exposure pathways also are presented pictorially and schematically on CSM figures in Section A3.0.

4. Are all exposure areas fully characterized? Sufficient data exist to characterize exposures to constituents in soil and groundwater and to adequately perform the risk assessment. In some cases, data are limited, but health-protective assumptions will be made so health risks will not be under-estimated. Details for each soil waste site are presented in Table A2-5.

A.2.1.4.2 Data Quality. All data have been collected following DOE and EPA requirements; however, some of the older historical radionuclide data (from 1948 and 1973) were not collected using modern techniques. Because the older data measured radionuclides with very long half-lives and significant concentrations of radionuclides were detected in the 1973 data, these data are considered of sufficient quality for the risk assessment, as are the more recently collected data. Therefore, the focus of this section is to address any method reporting limit (MRL) issues that are specifically applicable to human health. The MRLs are the laboratory quantitation limits (also referred to as reporting limits) that are adjusted to reflect sample-specific factors such as dilution, use of a smaller sample aliquot for analysis, or for matrix interference. The method detection limit (MDL) is defined as the minimum concentration of an analyte that can be routinely identified using a specific method. The reporting limit is the minimum level at which an analyte can be accurately and reproducibly quantified. The MRLs are used in risk assessment data evaluations because they "take into account sample characteristics, sample preparation, and analytical adjustments" (EPA 540/1-89/002), and they are considered to be the most relevant quantitation limits for evaluating nondetected constituents.

Due to the extensive analysis process that was conducted in the 200-ZP-1 RI report (DOE/RL-2006-24) to validate and verify the groundwater analytical data, assess potential sources, and establish RI contaminants of concern (COCs)[1], further analysis of MRLs for the groundwater data is not necessary. The groundwater data set established by the RI has appropriately identified the constituents that would be a concern from the human health perspective.

For soil, MRLs were reviewed. The MRLs below screening values are ideal, providing the risk assessor with a higher degree of certainty in identifying COPCs and appropriately estimating media exposure concentrations for the risk calculations. With MRLs above screening levels, potential bias can be introduced into the evaluation of media concentrations under certain circumstances, as described below.

An MRL evaluation is conducted because risk assessment typically assigns nondetected constituents with a proxy concentration of half the MRL in the risk calculations for the COPCs. Therefore, for those constituents with both a low detection frequency and a high percentage of the nondetected values, with MRLs above a health-based level, there is a greater degree of uncertainty as to whether their concentrations are a health concern. If a constituent has both a low frequency of detection and a large portion of the data set with MRLs above health-based levels, then exposure concentrations could be either over- or under-estimated. Very high MRLs may bias an exposure concentration downward because the constituents are actually present above half the MRL; or, if the constituent is actually not present at all or is present at a concentration less than half the MRL, then the exposure concentration using half the MRL could result in over-estimating concentration. While there is no specific guidance on this issue, if more than 50% of the data for a constituent are in this uncertain category (i.e., low frequency of detection and high MRLs), this uncertainty should be taken into account when interpreting risk results, especially if risks are near a decision point (either slightly above or below a target health goal used to establish the need for a some type of action at the site).

Table A2-6 presents the results of the MRL analysis for each waste for all of the constituents that were detected at least once. As shown in Table A2-6, there are compounds at both the 216-Z-9 Trench and 216-A-8 Crib where 50% or greater of the data set are in this uncertain category. The 216-Z-8 french drain and 216-Z-10 injection/reverse well sites are not presented in Table A2-6 because they had no nondetected compounds (216-Z-8 french drain) or had no detected compounds (216-Z-10 injection/reverse well). The uncertainties surrounding the inadequate MRLs for these compounds and the potential effect on the selection of COPCs and the risk assessment results is discussed further in Section A6.1.1.

Constituents that were never detected, but with MRLs exceeding a screening level, were not carried through the risk assessment but were instead identified as an area of uncertainty. The impacts of these never-detected constituents on the conclusions of the risk assessment are discussed qualitatively in the uncertainty section (see Section A6.1.1).

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[1] Note that in risk assessment, contaminants are referred to as COPCs until health risk calculations are complete. Contaminants that exceed target health goals at the end of the risk assessment process are referred to as COCs. In the 200-ZP-1 RI report (DOE/RL-2006-24), the term "COCs" was used to identify contaminants that required further examination; therefore, the RI term is retained when referring to RI findings.

A2.2 CONTAMINANT SELECTION PROCESS FOR CONTAMINANTS IN SOIL

Typically, not all contaminants present at a site pose health risks or contribute significantly to overall site risks. EPA guidelines (EPA 540/1-89/002) recommend focusing on a group of COPCs based on inherent toxicity, site concentration, and the behavior of the constituents in the environment. To identify these COPCs, health-protective risk-based screening values are compared to site concentrations of constituents in soil. As noted above, because of the extensive analysis in the groundwater RI, an initial set of COPCs for groundwater have already been identified (referred to as "COCs" in the RI), and Section A2.4 describes the RI COPC selection process and the further selection activities conducted in this appendix.

The steps of the screening process for identifying soil COPCs in this risk assessment are as follows.

1. Essential nutrients: Calcium, magnesium, potassium, and sodium are considered essential nutrients and, under normal circumstances, are not associated with toxicity to humans. Therefore, these constituents are not considered for inclusion as COPCs. Although an essential nutrient, iron does have a screening level and, therefore, iron is included on the screening tables.

2. Comparison of maximum detected contaminant concentrations to health-protective screening levels: Specifically, EPA's Region 6 human health screening levels (HHSLs) for residential soil were used as the risk-based screening values for nonradionuclides[2] (OSWER Directive 9355.4-24) and EPA's generic residential screening levels for radionuclides (EPA/540-R-00-006) were selected for the radiological evaluation. If contaminant concentrations were above screening values, they were considered for selection as COPCs. Contaminants with concentrations below screening values were not selected because they are unlikely to present a health concern. EPA Region 10 guidance for screening was followed in that non-cancer HHSLs were divided by 10 to account for additivity, but the screening levels for carcinogens were not divided by 10 (EPA 910/R-98-001). If the maximum concentration exceeded its screening level, then further evaluation was conducted as described in steps #3, #4, and #5 below.

3. Comparison of maximum detected contaminant concentrations to background: The maximum concentrations of inorganics and radionuclides were compared to the Hanford-specific background values shown in the screening tables (Tables A2-7 through A2-11). Inorganics and radionuclides were eliminated from selection as COPCs based on these background levels if their maximum concentrations did not exceed background. Because of the heterogeneous nature of soil, isolated concentrations of inorganic and radiological analytes above established background levels may simply represent random members of the background population. Such values are expected to occur in a small percentage (approximately 5%) of samples. Therefore, if the maximum concentration exceeded background but was within two times the background level and exceedances above background were <5%, the constituent was eliminated as a COPC because it was likely present at background levels.

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[2] Where there was no Region 6 HHSL available, EPA Region 9 preliminary remediation goals were used (*U.S. EPA Region 9 Preliminary Remediation Goal [PRG] Table and Supplemental Information* [EPA Region 9, 2004]) were used.

4. Evaluation of the frequency of detection: EPA generally allows constituents detected in <5% of the data to be eliminated from risk assessment even if a health-based screening level is exceeded (EPA 540/1-89/002). Therefore, at least 20 samples are needed in order to evaluate a constituent's frequency of detection. The goal of risk assessment is to identify the constituents contributing 99% of the risk, and those representing <1% of the total risk are addressed in the uncertainty section of the risk assessment.
5. Evaluation of evidence for eliminating a COPC not significantly contributing to overall site risks: EPA guidance (EPA 540/1-89/002) allows further reduction in the number of constituents carried through the risk assessment as long as the rationale is clearly documented and the constituents contributing 99% of the risk have been identified. Therefore, in addition to frequency of detection, a comparison of 95% upper confidence limit (UCL) with health-based values (as opposed to screening values that are below health-based levels), the frequency of exceedance of concentrations above the screening level, the magnitude of exceedance over the screening value, and the target populations relative to the screening value were also evaluated. Estimates of risk are calculated using 95% UCL of the mean concentration for each constituent/radionuclide because the risk calculations are based on an estimate of average exposure concentration over time, not the maximum concentration. Therefore, a constituent can be eliminated as a COPC if the 95% UCL does not exceed a screening or health-based level. Likewise, if a constituent's magnitude of exceedance is not large relative to other site constituents, its contribution to cumulative site risks is likely low, and it can potentially be eliminated from the risk evaluations. All contaminants excluded as COPCs based on the rationale presented above in steps #4 and #5 are further discussed in the uncertainty section of this appendix (Section A6.1.1) after the risk assessment calculations are complete, where their concentrations are re-assessed in light of the results of the risk assessment and the identified risk drivers.

A2.3 RESULTS OF SCREENING FOR SOIL

This section describes the results of the screening processes for soil, including the rationale for selecting COPCs or eliminating constituents that are not significant contributors to health risks. Tables A2-7 through A2-11 present the details of screening for each of the soil sites, and Table A2-15 summarizes the COPCs for all the soil sites.

A2.3.1 216-Z-1A Tile Field

Table A2-7 summarizes the screening processes of soil at this site. In the 216-Z-1A tile field area, 24 contaminants were detected in soil, and 3 radionuclides (americium-241 and plutonium-239/240) had maximum concentrations greater than their respective screening values and were selected as COPCs. Iron, manganese, and vanadium had maximum concentrations greater than their respective screening values, but their maximum concentrations did not exceed background levels by two times; thus, concentrations of these constituents are likely present due to their natural occurrence (i.e., background levels) and were not selected as COPCs.

Compounds without health-based screening levels have an "NE" (not evaluated) in the screening value column in Table A2-7 and, if applicable, an "NA" (not applicable) in the final rationale column. In this case, it is not known whether the compound represents a health risk and is an uncertainty in the risk assessment process.

The data quality objectives (DQOs) for the 200-PW-1/3/6 OUs (DOE/RL-2006-51) required that all of the COPCs for the 216-Z-9 Trench also be listed as COPCs for the 216-Z-1A tile field. The COPCs for 216-Z-9 Trench are presented in Section A2.3.3. However, only 24 constituents were detected in soil at the 216-Z-1A tile field, with only 3 above screening levels, compared to the 216-Z-9 Trench with 108 detected constituents and 31 with concentrations above screening levels. The additional constituents selected as COPCs at the 216-Z-9 Trench were either not detected (all VOCs, except methylene chloride) or were below either screening levels or background, or both; therefore, these additional contaminants are not included as COPCs at the 216-Z-1A tile field. In particular, the data set for the 216-Z-1A tile field included 23 soil samples analyzed for VOCs, 17 samples for metals, and over 400 samples for radionuclides (Table A2-2); thus, it is unlikely that additional constituents present at the 216-Z-9 Trench were mis-identified at the 216-Z--A-1A tile field. A possible exception is VOCs at depth. A soil gas extraction system is in operation at the 216-Z-1A tile field and VOCs are being collected. The VOCs were sampled in soil down to a depth of 26 m (85 ft); therefore, VOCs still present in soil at the 216-Z-1A tile field appear to be located deeper than 26 m (85 ft). Consequently, VOCs are considered COPCs in soil gas beneath the 216-Z-1A tile field, as well as the 216-Z-9 Trench (see Sections A2.4 and A2.6).

A2.3.2 216-Z-8 French Drain

At the 216-Z-8 french drain site, there were only three detected contaminants, and all had maximum concentrations greater than their respective screening values and were selected as COPCs. Table A2-8 summarizes the COPC selection for this site and the three constituents selected (americium-241, plutonium-238, and plutonium-239/240).

A2.3.3 216-Z-9 Trench

Table A2-9 summarizes the screening process of soil at the 216-Z-9 Trench site. A total of 107 constituents and radionuclides were detected, and of these detected contaminants, 30 had maximum concentrations greater than their respective screening values. These 30 contaminants were further evaluated according to the steps outlined in Section A2.2. Of these 30 contaminants, 13 were eliminated as COPCs because they are not present at levels that would be a health concern. Six constituents (aluminum, arsenic, iron, cesium-137, potassium-40, and vanadium) were not selected as COPCs because concentrations are likely due to background levels. One contaminant, europium-154, was only detected once in 30 samples (see Table A2-9) and was eliminated as a COPC based on infrequent detection (<5%) and a short half-life of 8.5 years. As shown in Table A2-10, the remaining seven contaminants (antimony, chloroform, europium-155, lead, tetrachloroethylene [PCE], uranium, and uranium-233/234) were not selected as COPCs because the calculated 95% UCLs were below or near health-based values. These health-based values are the residential screening level adjusted to a target goal of one and a cancer risk level of 1×10^{-5}, which is an acceptable risk level for this site and protective of residents or construction workers. Further, if exposure point concentrations (EPCs) were calculated for the well driller and residential farmer, they would be lower than the 95% UCL because of the dilution involved with the mixing of clean and contaminated soil, as described in Section A3.2. Additional support for eliminating five of the seven contaminants is that their frequency of exceedance was <5%. As shown in Table A2-10, the remaining two contaminants had exceedances above health screening levels at frequencies >5% (uranium and uranium-234); however, the magnitude of exceedance was only two in both cases. In addition, the extremely

large exceedances identified for americium-241 and the plutonium isotopes (Table A2-10) indicate that the risks from the seven contaminants that were not selected would be insignificant relative to overall risk totals and would not affect risk assessment conclusions. The impact of excluding these seven contaminants on the findings of the risk assessment is discussed in Section A6.1.1.

The 17 contaminants (counting plutonium-239 and plutonium-240 as individual compounds, even though analytical results cannot separate the isotopes) selected as COPCs for soil are listed below:

- Americium-241
- Cadmium
- Carbon tetrachloride
- Europium-152
- Manganese
- Neptunium-237
- Nickel-63
- Plutonium-238
- Plutonium-239/240
- Protactinium-231
- Radium-226
- Radium-228
- Strontium-90
- Technetium-99
- Thorium-228
- Thorium-230.

As described for the 216-Z-1A tile field, compounds without health-based screening levels represent an area of uncertainty in the risk assessment process. At the 216-Z-9 Trench, the following constituents are without health-based screening levels:

Inorganics	Semi-Volatile Organic Compounds (SVOCs)	VOCs
Bismuth	2,6-di-tert-Butyl-p-benzoquinone	2-ethyl-l-hexanol
Phosphorous	Decamethylcyclopentasiloxane	2-hexone
Phosphate	Octadecanoic acid	2-methyl-2-propanol
Sulfide	Tributyl phosphate	2-petanone
		2-propanol
		Butanoic acid, methyl ester
		Butyl aldehyde
		Decane
		Hexanal
		Methyl proprianate
		Nitromethane
		n-Valeraldehyde
		Tribromoethylene

For the SVOCs and VOCs, almost all of these contaminants were detected only once at concentrations in the low parts-per-billion range. Therefore, the lack of health-based screening levels for these contaminants is unlikely to significantly affect the outcome of the risk assessment. For inorganics, these compounds are likely naturally present in soil or are due to the agricultural activities throughout the area. Phosphate is the only inorganic with a background level, and the maximum concentration was five times the background level; however, phosphate was only detected in 2 out of 24 samples and is unlikely to represent a significant additional

source of health risk in comparison to the compounds selected as COPCs for quantitative evaluation. However, the lack of screening criteria for all of the above constituents indicates that they cannot be quantitatively evaluated in the risk assessment and, thus, remain an area of uncertainty.

A2.3.4 216-Z-10 Injection/Reverse Well

Historically, plutonium was discharged into well 216-Z-10 (formerly well 231-W-150). During 1947, three soil borings were drilled within a 4.6–m (15-ft) radius of well 231-W-150, and no plutonium was detected (HW-9671). HW-9671 did not report the MRL used; therefore, the MRL from *Calculation Constants Used by Regional Survey* (HW-23769) of 0.15 pCi/g is used as a surrogate value. The soil borings were drilled to approximately 53.3 m (175 ft) bgs, and 210 soil samples were collected (including field duplicates) and analyzed in the laboratory using an alpha counter (HW-9671). More recently, passive neutron logging (a non-analytical method which is not suitable for inclusion in a risk assessment) to detect alpha contamination was conducted at this site, and the results confirm the 1948 report's (HW-9671) findings that plutonium has not moved 4.6 m (15 ft) laterally toward the soil borings (*299-W15-59 [A7360] Log Data Report* [DOE-EM/GJ918-2005], *299-W15-60 [A7361] Log Data Report* [DOE-EM/GJ919-2005], *299-W15-61 [A7362] Log Data Report* [DOE-EM/GJ920-2005]). Low levels of contamination may still be present in the immediate vicinity of the well (i.e., <4.6 m [<15 ft]), and the uncertainties surrounding excluding this site from the risk assessment based on no detected contaminants are further discussed in Section A6.1.1. Other radionuclides (cesium-137, cobalt-60, and europium-154) were detected using the non-analytical method of spectral-gamma logging; their concentrations are unlikely to represent a health risk, as discussed further in the uncertainty section (Section A6.1).

In conclusion, the information gathered from the 216-Z-10 injection/reverse well does not indicate that plutonium isotopes are present at levels that are a health concern (the MDL of 0.15 pCi/g does not exceed the screening level of 2.9 pCi/g). Although the maximum concentrations may not have been captured in the sampling, the potentially impacted area is very small (i.e., contaminants have not moved laterally 4.6 m [15 ft] from the well). Therefore, no COPCs were selected for this site, and further evaluation of health risks is only discussed in the uncertainty section of this appendix.

A2.3.5 216-A-8 Crib

Table A2-11 summarizes the screening processes for soil at the 216-A-8 Crib, where 46 constituents were detected. Thirteen constituents had maximum concentrations greater than their respective residential screening values, and eight were selected as COPCs. Arsenic, potassium-40, and radium-226 had maximum concentrations below natural background levels; therefore, they were not selected as COPCs. Tritium and uranium were eliminated as COPCs because they are not present at levels that would be a health concern. As shown in Table A2-12, the calculated 95% UCLs for these constituents are below or near the screening value. Because the screening value is based on a hazard of 0.1 or a risk of 1×10^{-6}, the risks from these constituents would not exceed target health goals. Additional support for eliminating these two constituents is a low magnitude of exceedance over the screening value. Section A6.1.1 addresses the impacts to the risk assessment regarding the exclusion of these constituents. The following COPCs were identified for soil at this site:

- Carbon-14 (does not exceed an HHSL protective of workers and will not be evaluated as a COPC for worker populations)
- Cesium-137
- Neptunium-237
- Plutonium-239/240
- Radium-228
- Technetium-99 (does not exceed an HHSL protective of workers and will not be evaluated as a COPC for worker populations)
- Thallium (does not exceed an HHSL protective of workers and will not be evaluated as a COPC for worker populations)
- Thorium-228.

At the 216-A-8 Crib, the following constituents are without health-based screening levels and represent an area of uncertainty in the risk assessment:

Inorganics	SVOCs	VOCs
Bismuth	Decane	2-ethyl-l-hexanol
Phosphorous	Nondecane	
Nitrite	Tributyl phosphate	
Phosphate		

The discussions regarding the constituents without health screening levels for the 216-Z-1A tile field and 216-Z-9 Trench apply also to the 216-A-8 Crib (i.e., inorganics naturally present and few detections at very low concentrations for the SVOCs and VOCs). There were three detections of phosphate out of 10 samples, and the maximum concentration did exceed background levels by a factor of 3.

A2.4 RESULTS OF SCREENING FOR SOIL GAS

The air samples collected from within the 216-Z-9 Trench were compared to both residential screening levels (EPA Region 6 HHSLs) in air ([*Integrated Risk Information System [IRIS] Online Database* [EPA 2007]) and worker permissible exposure limits (PELs) established through the *Washington State Industrial Safety and Health Act* (WISHA) ("Airborne Contaminants" [WAC 296-841-20025]). As noted in Section A2.2, HHSLs are health-protective levels established for the general public. In contrast, PELs are air concentrations established as safe for healthy adult workers to breathe 8 hours/day, 5 days/week over a working lifetime.

The screening levels and a summary of the air concentration data are presented in Table A2-13. Carbon tetrachloride and chloroform both exceeded EPA Region 6 HHSLs by many orders of magnitude and are selected as COPCs in indoor air for a future residential population (see Section A3.1.1). Because the trench air concentrations did not exceed PELs and were collected from an area with the highest carbon tetrachloride concentrations still present in soil, these air concentrations are likely worst-case scenarios (i.e., equivalent to a basement with limited ventilation, there are two 4-in. vent pipes that pierce the concrete cover at 216-Z-9) (see

Figure A2-5) (DOE/RL-2006-24). Therefore, neither indoor nor outdoor air concentrations of VOCs are considered health hazards for a working population. Outdoor air concentrations would be lower than any concentrations collected from within the trench.

A2.5 RESULTS OF SCREENING FOR GROUNDWATER

The RI for groundwater had identified 55 compounds of possible concern in groundwater in *Data Quality Objectives Summary Report Supporting the 200-ZP-1 Operable Unit Remedial Investigation/Feasibility Study Process* (CP-16151) and *Remedial Investigation Work Plan for 200-ZP-1 Groundwater Operable Unit, Hanford* (DOE/RL-2003-55). The DQO summary report and 200-ZP-1 RI/FS (CP-16151) went through a rigorous process of identifying potential sources of contaminants and establishing what constituents could possibly be present in groundwater due to site activities. The RI then further evaluated these contaminants by comparing maximum concentrations to health-based screening levels. The selected screening levels were either risk-based drinking water cleanup levels from the Washington State Department of Ecology's (Ecology's) MTCA Method B cleanup levels or were maximum contaminant levels (MCLs) from state and Federal drinking water regulations. Details of these screening levels and how they were selected (screening levels are referred to as target action levels [TALs] in the RI) are presented in Table 1-5 of the 200-ZP-1 RI report (DOE/RL-2006-24). Details of the RI screening process follow.

In the 200-ZP-1 RI report, the COCs selected after an initial screening of maximum concentrations against TALs were grouped into two groups: Group A and Group B. Group A included the analytes of groundwater plumes (presented in Table 1-9 of the 200-ZP-1 RI report [DOE/RL-2006-24]), and Group B included analytes not part of a known plume. Group A, or the potential major risk drivers, had a least one result greater than two times the TAL. The other analytes of Group B were separated into two subgroups: (1) analytes with fewer than 10% of detects above a TAL and the 95% UCL (calculated by "bootstrapping") of results were above the TAL, and (2) analytes with >10% of detects above the TAL with 95% UCL also above the TAL. The results of this process identified 15 contaminants that were likely to be COCs in groundwater:

- Antimony
- Chromium (total)
- Hexavalent chromium
- Iron
- Technetium-99
- Trichloroethylene (TCE)
- Uranium (constituent toxicity only)
- Methylene chloride
- Carbon tetrachloride
- Chloroform
- Iodine-129
- Nitrate
- PCE
- Tritium
- 1,2-dichloroethane.

As noted in Section A2.1.3, the RI used data from 1988 through 2005 to select the 15 contaminants listed above. When only the last 5 years of groundwater monitoring data are compared to the RI's TALs to estimate current concentrations, three of the above contaminants do not represent a health concern and do not require evaluation in the risk assessment:

- 1,2-dichloroethane: Maximum contaminant concentration did not exceed the TAL in the last 5 years of data.

- Antimony: Maximum concentration in the last 5 years does not exceed background levels.
- Iron: The TAL is a secondary MCL, and very little of the data over the last 5 years exceeded the TAL (<5%). Secondary MCLs are not health-based, and the maximum concentration of iron in the last 5 years of data did not exceed the EPA Region 6 HHSL for tap water. Thus, this contaminant is not present at levels that are a health concern.

Uranium is retained as a COPC based on its chemical toxicity, not on its radioactive toxicity. The radioactive isotopes of uranium have either not been detected in recent groundwater monitoring rounds or have been detected at chemical well below health-based levels (DOE/RL-2003-55); thus, only chemical toxicity is a concern for uranium. Uranium is unique in that its chemical toxicity occurs at or below levels that are a concern for radioactive toxicity.

Table A2-14 presents a summary of the last 5 years of data for the 15 contaminants identified in the RI as COCs. The following 12 COPCs are selected for quantitative evaluation in the risk assessment:

- Carbon tetrachloride
- Chloroform
- Chromium (total)
- Hexavalent chromium
- Iodine-129
- PCE
- TCE
- Tritium
- Nitrate
- Technetium-99
- Uranium
- Methylene chloride.

A2.6 SUMMARY OF CONTAMINANTS OF POTENTIAL CONCERN

Table A2-15 summarizes the contaminants selected as COPCs in soil by site. A total of 21 contaminants were selected as soil COPCs for quantitative analysis. Plutonium-239 and plutonium-240 were the only contaminants selected at every site. The COPCs selected for the sites around the former Z Plant (those sites labeled "Z" in the middle) are all similar. Site 216-A-8, located in the 200 East Area rather than the 200 West Area, shows a different pattern of COPCs (e.g., cesium-137).

Of the 15 constituents selected as COCs in the 200-ZP-1 RI report, 12 COPCs were selected for inclusion in the risk assessment for quantitative analysis (DOE-/RL-2006-24).

Carbon tetrachloride and chloroform were selected as COPCs in soil gas beneath the 216-Z-9 Trench and 216-Z-1A tile field and are a potential concern in indoor air in hypothetical future residential homes.

Figure A2-1. 216-Z-1A Tile Field Sample Locations for Soil.

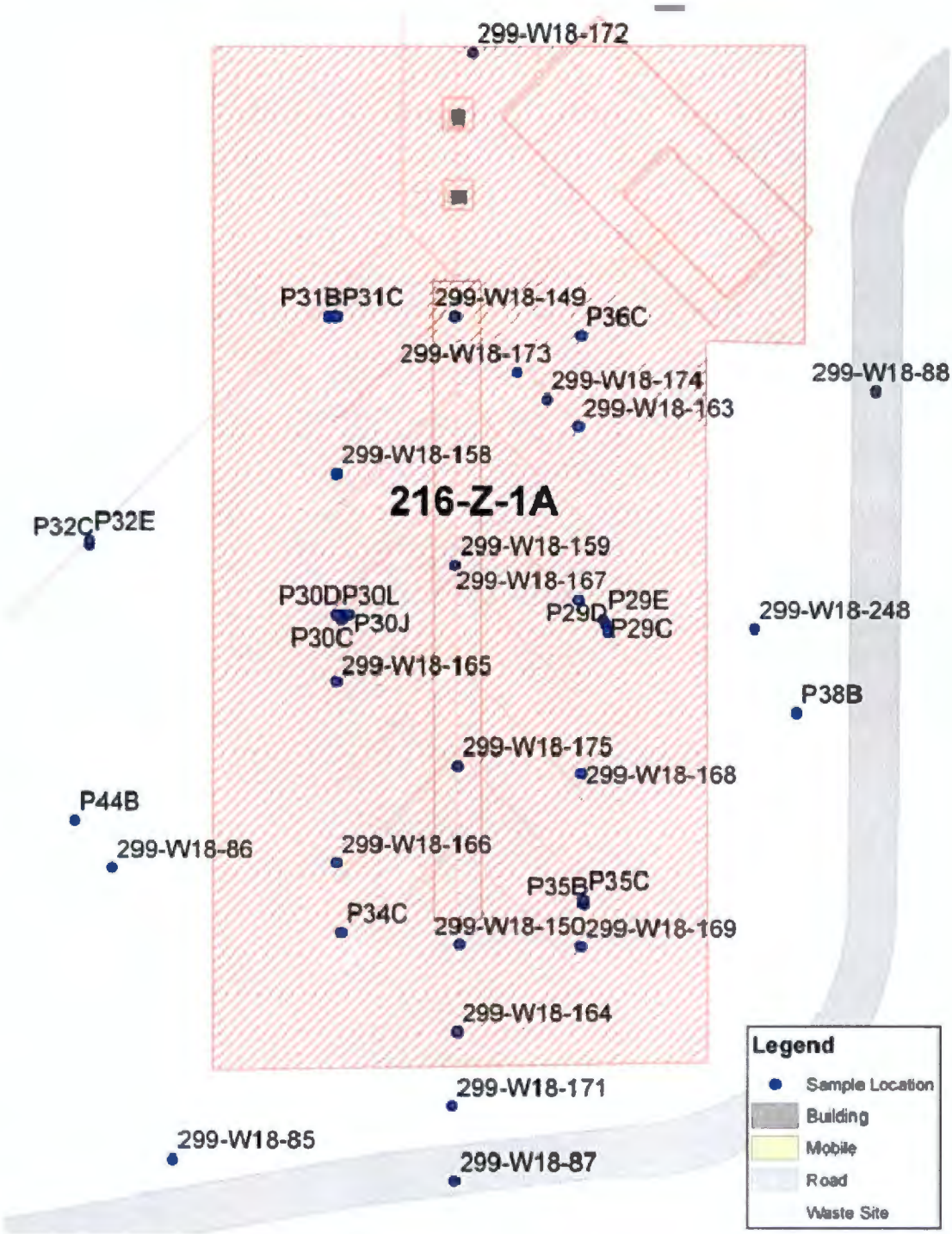


Figure A2-2. 216-Z-8 French Drain Sample Location for Soil.

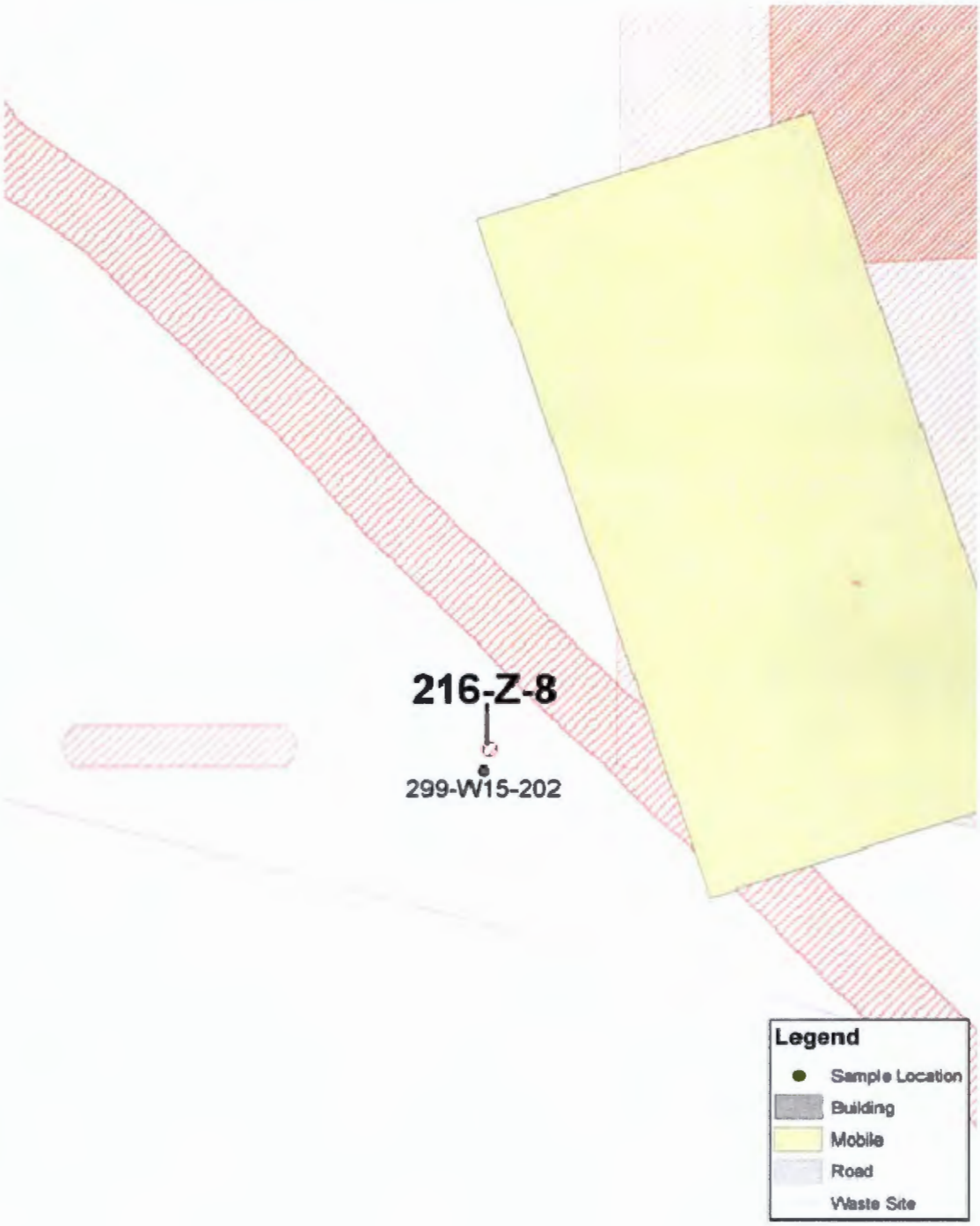


Figure A2-3. 216-Z-9 Trench Sample Locations for Soil.

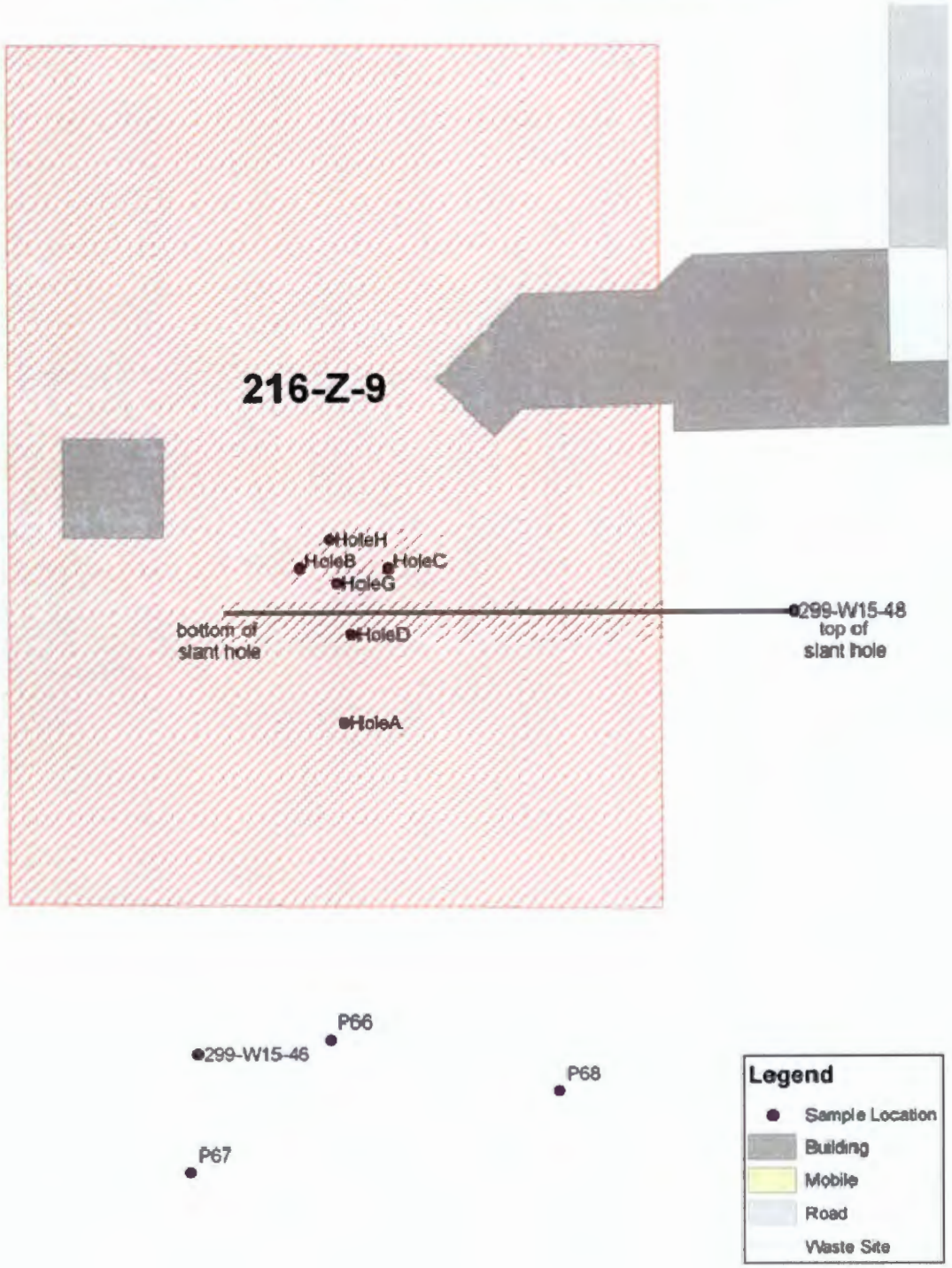


Figure A2-4. 216-A-8 Crib Sample Location for Soil.

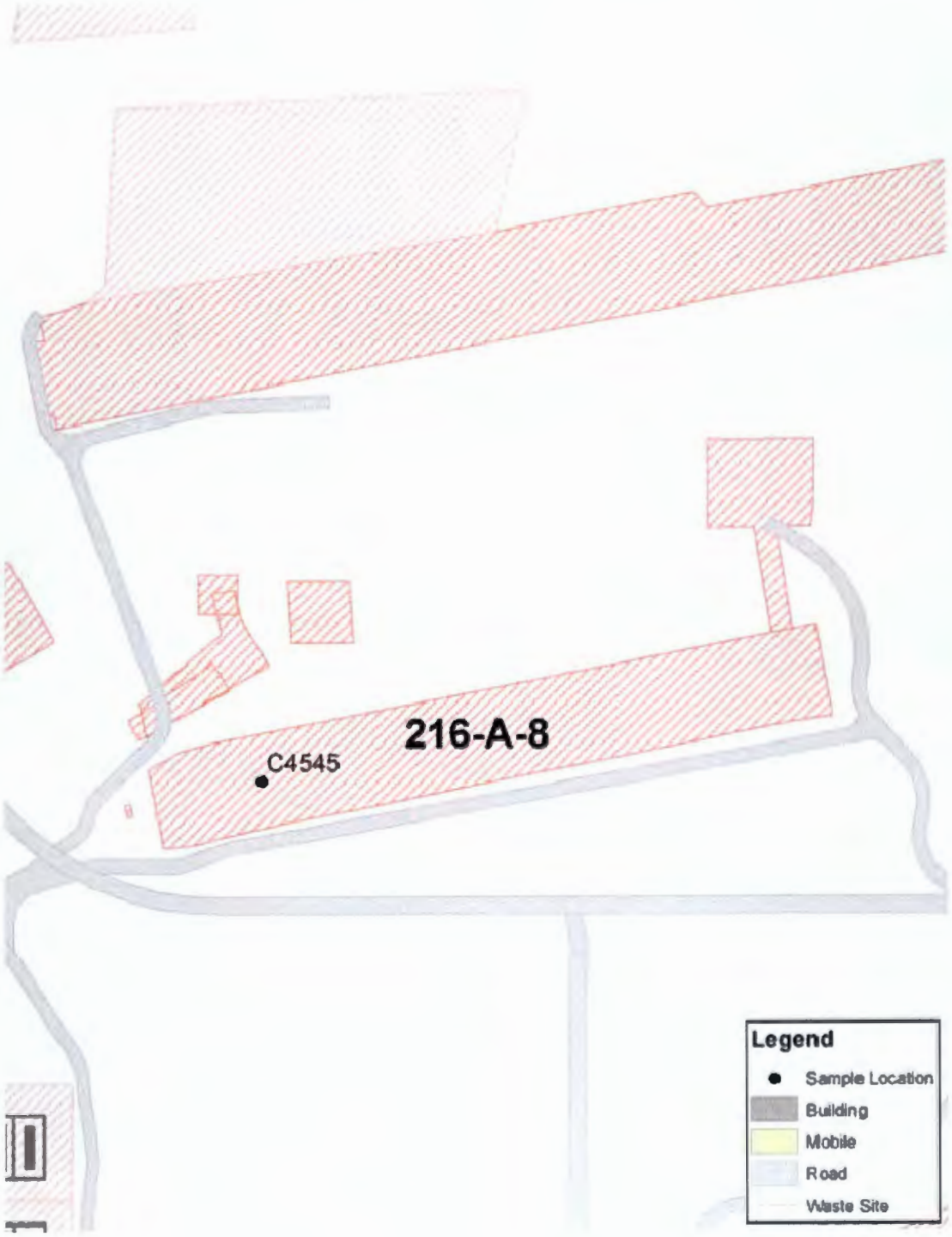
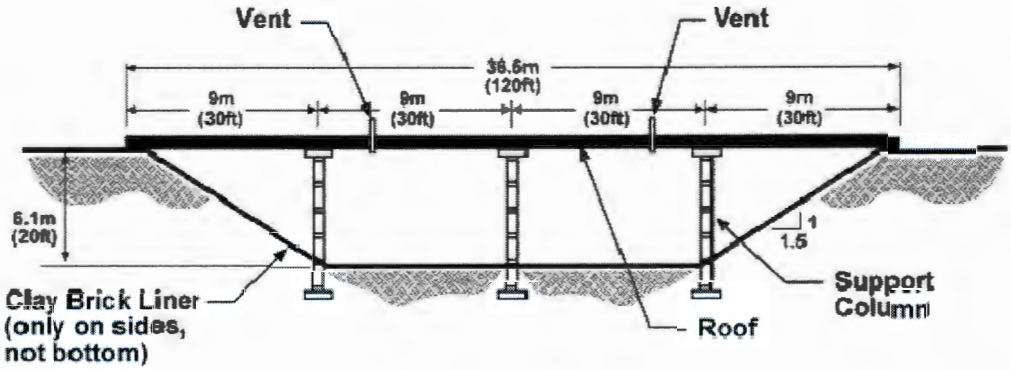
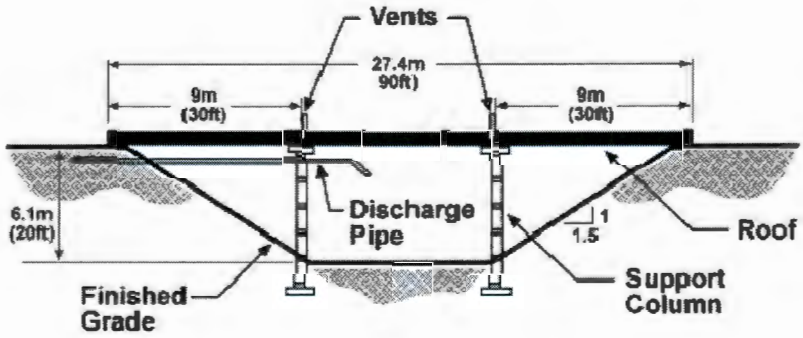


Figure A2-5. Section Views of the 216-Z-9 Trench.





FG303.3

Table A2-1. Summary of Soil Data Locations Included in the Risk Assessment, 216-Z-1A Tile Field.

299-W18-149	P29C
299-W18-150	P29D
299-W18-158	P29E
299-W18-159	P30C
299-W18-163	P30D
299-W18-164	P30J
299-W18-165	P30L
299-W18-166	P31B
299-W18-167	P31C
299-W18-168	P32C
299-W18-169	P32E
299-W18-171	P34C
299-W18-172	P35B
299-W18-173	P35C
299-W18-174	P36C
299-W18-175	P38B
299-W18-248	P44B
299-W18-85	P32E
299-W18-86	P34C
299-W18-87	
299-W18-88	

Table A2-2. Summary of the Number of Samples by Contaminant Group.

Contaminant Group	Number of Samples
216-Z-1A Tile Field Soil	
Total inorganics (metals)	17
Radionuclides	458
VOCs	23
Other	17
216-Z-8 French Drain Soil	
Radionuclides	8
216-Z-9 Trench Soil	
Total inorganics (metals)	24
Radionuclides	165
SVOCs	23
VOCs	42
Other	24
216-A-8 Crib Soil	
Total inorganics (metals)	10
Polychlorinated biphenyls	10
Radionuclides	20
SVOCs	10
VOCs	10
Other	10
200-ZP-1 Groundwater	
Total inorganics (metals)	1,005
Radionuclides	1,094
SVOCs	38
VOCs	700
Other	1,083

NOTE: Number of samples may include multiple depths at the same location.
SVOC = semi-volatile organic compound
VOC = volatile organic compound

Table A2-3. Summary of Soil Data Locations Included in the Risk Assessment for the 216-Z-9 Trench.

299-W15-46 (from depths 14.5 to 69.8 [47.5 to 229 ft] bgs)
299-W15-48 (slant hole depths from 20 to 43 m [67 to 140 ft])
HoleA
HoleB
HoleC
HoleD
HoleG
HoleH

bgs = below ground surface

Table A2-4. Summary of Groundwater Data Locations Included in the Risk Assessment for the 200-ZP-1 Operable Unit.

299-W10-1	299-W11-7	299-W15-40	299-W7-4
299-W10-17	299-W12-1	299-W15-41	299-W7-5
299-W10-19	299-W13-1	299-W15-42	299-W7-6
299-W10-20	299-W14-13	299-W15-43	299-W7-7
299-W10-21	299-W14-14	299-W15-44	299-W7-8
299-W10-22	299-W14-15	299-W15-45	299-W7-9
299-W10-23	299-W14-16	299-W15-46	299-W8-1
299-W10-24	299-W14-17	299-W15-47	699-19-88
299-W10-26	299-W14-18	299-W15-49	699-26-89
299-W10-27	299-W14-19	299-W15-50	699-34-88
299-W10-28	299-W14-5	299-W15-7	699-36-93
299-W10-4	299-W14-6	299-W15-763	699-39-79
299-W10-5	299-W15-1	299-W15-765	699-43-89
299-W10-8	299-W15-11	299-W17-1	699-44-64
299-W11-10	299-W15-15	299-W18-1	699-45-69A
299-W11-12	299-W15-16	299-W18-16	699-47-60
299-W11-13	299-W15-17	299-W18-23	699-48-71
299-W11-14	299-W15-2	299-W18-24	699-48-77A
299-W11-18	299-W15-30	299-W18-27	699-48-77D
299-W11-24	299-W15-31A	299-W18-4	699-49-100C
299-W11-3	299-W15-32	299-W6-10	699-49-79
299-W11-37	299-W15-33	299-W6-11	699-50-85
299-W11-39	299-W15-34	299-W6-12	699-51-75
299-W11-40	299-W15-35	299-W6-7	699-55-60A
299-W11-41	299-W15-36	299-W7-1	699-55-76
299-W11-42	299-W15-38	299-W7-11	699-55-89
299-W11-6	299-W15-39	299-W7-12	

Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection Agency's Data Usability Guide. (3 sheets)

	What contamination is present, and at what levels?	**Are all exposure areas fully characterized?**
216-Z-1A Tile Field	The 216-Z-1A tile field operated from 1949 to 1969, during which time 6,200,000 L (1.37 million gal) of effluent waste containing uranium, americium, plutonium, and carbon tetrachloride were released. Although only radionuclides were detected in the data used in this risk assessment, based on the potential sources, samples were appropriately analyzed for inorganics, VOCs, and radionuclides (DOE/RL-2006-51).	Soil is well characterized, with samples of over 400 radionuclides from 38 sample locations throughout the 1,812-m^2 (19,500-ft^2) area at depths ranging from 1.5 to 46 m bgs (5 to 150 ft). A smaller subset of samples was analyzed for VOCs and metals (23 and 17, respectively); however, the lack of detections of VOCs and/or metals above background indicates that radionuclides have been appropriately identified as the COPCs at this location. One caveat to this statement is that VOCs were sampled down to 26 m (85 ft) bgs and may be present in deeper strata. Evidence for this is that the soil vapor extraction system at the site is still pulling vapor out of the subsurface. Samples where taken to evaluate impacts to the subsurface at locations where maximum waste discharge to tile field crib was expected to have occurred, as well as to evaluate lateral extent of contamination (DOE/RL-2006-51).
216-Z-8 French Drain	According to waste disposal history, the 216-Z-8 french drain received low levels of plutonium-contaminated wastes from a plutonium finishing facility (234-5Z Building). An estimated 9,590 L (2,530 gal) of liquid waste containing an estimated 48.2 g of plutonium overflowed from the 216-2-8 settling tank to the 216-Z-8 french drain. Samples were appropriately analyzed for plutonium and americium in soils beneath the end of the french drain (*The 216-2-8 French Drain Study* [RHO-RE-EV-46P]).	Because of the small volume of waste discharge and the nature of the waste plume, the 216-Z-8 french drain soil is characterized with eight samples from one location. Samples were also taken from depths up to 10.7 m (35.1 ft), even though plutonium activity was expected to be found at low concentrations at deeper depths (RHO-RE-EV-46P).

Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection Agency's Data Usability Guide. (3 sheets)

	What contamination is present, and at what levels?	Are all exposure areas fully characterized?
216-Z-9 Trench	The 216-Z-9 Trench, which operated from 1955 to 1962, received 4,090,000 L (1.1 million gal) of effluent waste containing 50 to 150 kg of plutonium, cadmium, nitrates, americium-241, and carbon tetrachloride. Approximately 58 kg of plutonium were removed from the 216-Z-9 Trench as part of the trench floor mining activities completed from 1976 to 1978. An estimated 48 kg of plutonium remains in the trench (DOE/RL-2006-51). Historical contaminant investigations detected radioactive contamination in soil at a maximum depth of 37 m (122 ft) and detected carbon tetrachloride at concentrations up to 380 mg/kg. Therefore, analysis has appropriately focused on inorganics, SVOCs/VOCs, and radionuclides (DOE-/RL-2006-51).	For the 216-Z-9 Trench area, 24 samples were collected from two boreholes from beneath the trench down to the water table at well 299-W15-46 (at depths ranging from 14.5 to 69.8 m [47.5 to 229 ft] bgs) and well 299-W15-48 located underneath the trench (at depths ranging from 20 to 43 m [67 to 140 ft] bgs). During the mining of plutonium, the upper 0.3 m (1 ft) of soil was removed from the trench floor, and the 216-Z-9 Trench's 6-m (20-ft)-deep excavation remains void of any soil; therefore, no samples were taken between the 0 to 6-m (0 to 19.6-ft) range. Both borehole locations are where maximum radionuclide and contaminant accumulation is expected to occur; characterization before the plutonium mining indicated that the region of the lowest floor elevation was in the southern half of the trench where most of the surface plutonium accumulated. Because of the long half-life of plutonium-239 and americium-241, six locations sampled in 1973 were also used in characterization (DOE/RL-2006-51). Therefore, sample locations were biased high, and the likely relevant radionuclides and nonradionuclides (VOCs and metals) were appropriately selected for analysis (DOE/RL-2006-51).
216-A-8 Crib	The 216-A-Crib operated from 1955 to 1991, at which time 1,150,000,000 L (303.8 million gal) of waste containing 57.6 kg uranium; 9.1 Ci plutonium; 3.91 Ci cesium-137; 0.0388 Ci ruthenium-106; 10 Ci tritium; 128,582 kg TBP; 55,107 kg naphthalene; 1,364 kg butanol; and 0.1588 kg ammonia were released onto the site. The main source being vapor condensate from operation of several ventilation systems associated with the A, AX, AY, and AZ Tank Farms. Analysis of this site has focused appropriately on inorganics, SVOCs/VOCs, and radionuclides (DOE/RL-2006-51).	Historical contaminant investigations found that the higher concentrations of radionuclides and contaminants were found in the western end of the 216-A-8 Crib at 7.6 to 9 m (25 to 30 ft); therefore, one sample location (C4545) was used to characterize the area. Ten samples from this location C4545 were collected at depths ranging from 3.2 to 80.62 m bgs (19 to 264.5 ft). Historical data also suggest that contaminants reached at least 41 m (135 ft) deep, so the soil depths taken are appropriate for exposure characterization and sample results are likely biased high based on the location of C4545 (DOE/RL-2006-51).

Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection Agency's Data Usability Guide. (3 sheets)

	What contamination is present, and at what levels?	Are all exposure areas fully characterized?
216-Z-10 Injection/Reverse Well	Historically, plutonium was discharged into 216-Z-10 (former well 231-W-150). In 1947, sampling analysis found no detection of plutonium at a 4.5-m (15-ft) radius from the well (HW-9671). More recently, plutonium and other radionuclides were analyzed by non-analytical methods, where plutonium was still not detected and cesium-37, cobalt--137, cobalt60, and europium-154 were detected at low concentrations within a 4.5-m (15-ft) radius of the well.	Although no plutonium detections were found, exposures were appropriately characterized with over 70 samples taken from three wells drilled down to 46 m (150 ft). Because of the relatively small amount of waste liquids discharged into the 216-Z-10 injection well, contamination exposures are most likely confined (HW-9671).

bgs = below ground surface
COPC = contaminant of potential concern
SVOC = semi-volatile organic compound
TBP = tributyl phosphate
VOC = volatile organic compound

Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values.[a] (2 sheets)

Contaminant	Range of Detection Limits (pCi/g or mg/kg)	Risk Assessment Screening Value (see Section A2.2)	Nondetects per Total Number of Samples	Number of Nondetects Exceeding Screening Value	% of Data Set with Nondetects Exceeding Screening Values
216-Z-1A Tile Field					
Am-241	-0.0752 to 20,900	3.7	175/458	26	6
Pu-239/240	-250 to 188,000	2.9	295/423	146	35
216-Z-9 Trench					
Antimony	0.25 to 9.32	3	12/24	2	8
Arsenic	1.2 to 10.3	0.39	5/24	5	21
Trichloroethylene (TCE)	0.00026 to 0.19	0.043	40/42	7	17
Am-241	0.009 to 300,000	3.7	5/165	3	2
Cs-137	-0.045 to 766	0.044	21/30	13	43
Eu-152	-0.182 to 701	0.021	27/30	18	60
Eu-154	-0.027 to 1,020	0.019	29/30	16	53
Eu-155	-0.048 to 788	0.9	25/30	13	43
Np-237	-0.003 to 504	0.14	18/23	5	22
Ni-63	308 to 1,540	29.6	3/4	3	75
Pu-238	-218 to 19,200	2.9	17/24	7	29

Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values.[a] (2 sheets)

Contaminant	Range of Detection Limits (pCi/g or mg/kg)	Risk Assessment Screening Value (see Section A2.2)	Nondetects per Total Number of Samples	Number of Nondetects Exceeding Screening Value	% of Data Set with Nondetects Exceeding Screening Values
K-40	20 to 300	0.14	5/17	5	29
Ra-226	0.584 to 43	0.013	9/18	9	50
Ra-228	0.29 to 66	0.025	10/18	10	56
Sr-90	7.86	0.0492	1/3	1	33
Tc-99	-4.77 to 15.8	0.0704	11/16	9	56
Th-228	-58.1 to 166	0.014	17/31	13	42
Th-230	-231 to 102	3.9	10/14	4	29
Th-232	-57.8 to 66	3.4	20/34	7	21
U-233/234	-17.8 to 50.3	5	10/23	6	26
U-235	-24.4 to 79.8	0.21	30/38	18	47
U-238	-17.8 to 2,100	0.98	27/40	21	53
216-A-8 Crib					
Cs-137	-0.001 to 0.15	0.044	8/18	4	22
Eu-155	-0.338 to 860	0.9	16/18	3	17
Np-237	0 to 0.27	0.14	2/4	1	25
K-40	1.7 to 6,200	0.14	2/10	2	20
Ra-226	0.31 to 760	0.013	4/11	4	36
Ra-228	0.387 to 870	0.025	4/11	4	36
Tc-99	-0.006 to 1.3	0.0704	7/10	5	50
Th-228	0 to 650	0.014	5/14	4	29
Th-232	-1.67 to 870	3.4	5/14	1	7
U-235	-0.002 to 1,400	0.21	16/20	9	45
U-238	0 to 20,000	0.98	11/20	10	50

[a] The 216-Z-8 french drain site did not have any nondetected contaminants.

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Table A2-7. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-1A Tile Field. (2 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale Contaminant Deletion or Selection[d]
Metals																
7440-39-3	Barium	44		160		mg/kg	299-W18-174	17/17	--	160	132	1,564		HHSL	NO	BSL
7440-41-7	Beryllium	0.3		0.7		mg/kg	299-W18-174	13/17	na	0.7	1.51	15.4		HHSL	NO	BSL
7440-70-2	Calcium	5,900		230,000		mg/kg	299-W18-248	17/17	--	230,000	17,200	NE		NA	NO	NUT
7440-47-3	Chromium	4.8		19		mg/kg	299-W18-174	17/17	--	19	18.5	211	c	HHSL	NO	BSL
7440-48-4	Cobalt	3.8		10		mg/kg	299-W18-174	17/17	--	10	15.7	903	c	HHSL	NO	BSL
7440-50-8	Copper	8.6		24		mg/kg	299-W18-248/299-W18-174	17/17	--	24	22	291		HHSL	NO	BSL
7439-89-6	Iron	6,800		25,000		mg/kg	299-W18-248	17/17	--	25,000	32,600	5,475		HHSL	NO	BCK
7439-92-1	Lead[e]	1.5		11		mg/kg	299-W18-174	17/17	--	11	10.2	400		HHSL	NO	BSL
7439-95-4	Magnesium	3,300		8,900		mg/kg	299-W18-248	17/17	--	8,900	7,060	NE		NA	NO	NUT
7439-96-5	Manganese	200		760		mg/kg	299-W18-248	17/17	--	760	512	324		HHSL	NO	BCK
7440-02-0	Nickel	5.5		16		mg/kg	299-W18-174/299-W18-248	12/17	na	16	19.1	156		HHSL	NO	BSL
7440-09-7	Potassium	740		2,700		mg/kg	299-W18-248	17/17	--	2,700	2,150	NE		NA	NO	NUT
7440-23-5	Sodium	190		1,600		mg/kg	299-W18-174	17/17	--	1,600	690	NE		NA	NO	NUT
7440-62-2	Vanadium	16		59		mg/kg	299-W18-248	16/17	na	59	85.1	39		HHSL	NO	BCK
7440-66-6	Zinc	13		52		mg/kg	299-W18-248/299-W18-174	17/17	--	52	67.8	2,346		HHSL	NO	BSL
Volatile Compounds																
75-09-2	Methylene chloride	0.005	B	0.008	B	mg/kg	P29C--C4917--P29C-60	4/23	0.0025 to 0.011	0.008	0	8.9	c	HHSL	NO	BSL
Radionuclides																
14596-10-2	Am-241	-0.0436		259,0000		pCi/g	299-W18-149	283/458	-0.0752 to 20,900	2,590,000	NE	3.7		SSL	YES	ASL
PU-239/240	Pu-239/240	0.0135		38,200,000		pCi/g	299-W18-149	128/423	-250 to 188,000	38,200,000	0.0248	2.9		SSL	YES	ASL
Other																
16887-00-6	Chloride	0.6		9.4		mg/kg	299-W18-248	17/17	--	9.4	100	NE		NA	NO	BCK
16984-48-8	Fluoride	0.3		16		mg/kg	299-W18-174	13/17	na	16	2.81	367		HHSL	NO	BSL
14797-55-8	Nitrate	1		250		mg/kg	299-W18-174	17/17	--	250	52	12,167		CALC	NO	BSL
14797-65-0	Nitrite	0.4		1.6		mg/kg	299-W18-248	4/17	na	1.6	NE	760		CALC	NO	BSL
14265-44-2	Phosphate	1		1		mg/kg	299-W18-174	1/17	na	1	0.785	NE		NA	NA	NA
14808-79-8	Sulfate	2		26		mg/kg	299-W18-248	17/17	--	26	237	NE		NA	NO	BCK

Table A2-7. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-1A Tile Field. (2 sheets)

NOTE: Contaminants bolded exceeded their screening value. Highlighted contaminants were selected as COPCs.

a Minimum/maximum detected concentration. Includes analytical data from 4.92 to 153.5 ft bgs.

b Background was assumed to be zero for volatile organic compounds. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12 and DOE/RL-96-24, respectively.

c For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA Region 6, 2006) and were adjusted to be protective of a non-cancer hazard of 0.1 and a cancer risk of 10-6. For radionuclides, screening values are the lowest value of ingestion of homegrown produce, direct ingestion, inhalation of fugitive dusts, or external radiation exposures from Table A.1. Generic (no accounting for decay) SSLs from EPA's *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-R-00-006).

d Rationale codes: Selection reason: ASL = above screening level

Deletion reason: BSL = below screening level

BCK = near or below background levels (magnitude of exceedance over background less than two times)

NUT = essential nutrient

NA = not applicable

e Lead is evaluated differently from other chemicals because the screening value is not equivalent to a hazard quotient of 1 and lead health risks are not additive with other chemical effects; therefore, the full screening value was used.

-- = contaminant has 100% detection frequency
B = analyte is found in both the associated method blank and in the sample, indicating probable blank contamination
c = cancer
CALC = screening level calculated based on hazard quotient of 0.1 and child (6 yrs and 15 kg)
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
HHSL = EPA Region 6 *Human Health Medium-Specific Screening Levels for Residential Soil*
EPA = U.S. Environmental Protection Agency
NA = not applicable
na = not available
NE = not established
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)

Table A2-8. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-8 French Drain.

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Radionuclides																
14596-10-2	Am-241	0.0901		457		pCi/g	299-W15-202-20.008	8/8	--	457	NE	3.7		SSL	YES	ASL
PU-239/240	Pu-238	0.0143		77.5		pCi/g	299-W15-202-24.928	8/8	--	77.5	0.0248	2.9		SSL	YES	ASL
13981-16-3	Pu-239/240	0.92		4,620		pCi/g	299-W15-202-24.928	8/8	--	4,620	0.00378	2.9		SSL	YES	ASL

NOTE: Contaminants bolded exceeded their screening value. Highlighted contaminants were selected as COPCs.

a Minimum/maximum detected concentration. Analytical data included from 16 to 35 ft bgs.

b Radionuclide background values were taken from DOE/RL-96-12.

c Screening values are the lowest value of ingestion of homegrown produce, direct ingestion, inhalation of fugitive dusts, or external radiation exposures from Table A.1. Generic (no accounting for decay) SSLs from EPA's *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-R-00-006).

d Rationale codes: Selection reason: ASL = above screening level
Deletion reason: BSL = below screening level

-- = contaminant has 100% detection frequency
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
NE = not established
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-0006)

Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-9 Trench. (4 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration([a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Metals																
7429-90-5	Aluminum	4,970		13,100		mg/kg	299-W15-46/B17N63	21/21	-	13,100	11,800	7,619		HHSL	NO	BCK
7440-36-0	Antimony	0.5		4.63		mg/kg	299-W15-46/B17TM6	12/24	0.25 to 9.32	4.63	NE	3		HHSL	NO	MAG
7440-38-2	Arsenic	1.62		11		mg/kg	299-W15-46/B17N46	19/24	1.2 to 10.3	11	6.47	0.39	c	HHSL	NO	BCK
7440-39-3	Barium	36		112		mg/kg	299-W15-46/B17N65	24/24	-	112	132	1,564		HHSL	NO	BSL
7440-41-7	Beryllium	0.13		0.68		mg/kg	299-W15-48/B1HL26	22/24	0.27 to 1.43	0.68	1.51	15		HHSL	NO	BSL
7440-69-9	Bismuth	53.6		156		mg/kg	299-W15-48/B1HL26	8/24	0.24 to 10.4	156	NE	NE		NA	NA	NA
7440-43-9	Cadmium	0.145		118		mg/kg	299-W15-48/B1HK57	18/24	0.07 to 0.14	118	NE	3.9		HHSL	YES	ASL
7440-70-2	Calcium	2,240		209,000		mg/kg	299-W15-48/B1HK67	21/21	-	209,000	17,200	NE		NA	NO	NUT
7440-47-3	Chromium	6.65		162		mg/kg	299-W15-46/B17N63	24/24	-	162	18.5	211	c	HHSL	NO	BSL
7440-48-4	Cobalt	5.19		20.6		mg/kg	299-W15-46/B17N60	21/21	-	20.6	15.7	903	c	HHSL	NO	BSL
7440-50-8	Copper	7		26.3		mg/kg	299-W15-46/B17N65	24/24	-	26.3	22	291		HHSL	NO	BSL
18540-29-9	Hexavalent chromium	0.22		0.75		mg/kg	299-W15-46/B17TM6-B	3/20	0.15 to 0.4	0.75	18.5	30	c	HHSL	NO	BSL
7439-89-6	Iron	9,230		49,400		mg/kg	299-W15-46/B17N60	21/21	-	49,400	32,600	5,475		HHSL	NO	BCK
7439-92-1	Lead[e]	2.39		620		mg/kg	299-W15-46/B191Y7	20/24	0.063	620	10.2	400		HHSL	NO	MAG
7439-93-2	Lithium	5.06		16.1		mg/kg	299-W15-48/B1HK57	24/24	-	16.1	33.5	156		HHSL	NO	BSL
7439-95-4	Magnesium	3,120		7,900		mg/kg	299-W15-48/B1HK67	21/21	-	7,900	7,060	NE		NA	NO	NUT
7439-96-5	Manganese	157		2,240		mg/kg	299-W15-46/B17N70	24/24	-	2,240	512	324		HHSL	YES	ASL
7439-97-6	Mercury	0.0405		1.02		mg/kg	299-W15-46/B17N67	22/24	0.01 to 0.987	1.02	2.3	NE		NA	NA	NA
7440-02-0	Nickel	5.67		72.9		mg/kg	299-W15-46/B17N63	24/24	-	72.9	19.1	156		HHSL	NO	BSL
7723-14-0	Phosphorus	426		1,470		mg/kg	299-W15-46/B17N60	24/24	-	1,470	NE	NE		NA	NA	NA
7440-09-7	Potassium	89.8		1,990		mg/kg	299-W15-48/B1HK57	21/21	-	1,990	2,150	NE		NA	NO	NUT
7782-49-2	Selenium	0.28		3.76		mg/kg	299-W15-46/B17N63	10/24	0.18 to 10.5	3.76	NE	39		HHSL	NO	BSL
7440-22-4	Silver	0.565		2.88		mg/kg	299-W15-46/B17N67	9/24	0.06 to 1.11	2.88	0.73	39		HHSL	NO	BSL
7440-23-5	Sodium	144		2,660		mg/kg	299-W15-46/B17N63	20/21	1,950	2,660	690	NE		NA	NO	NUT
7440-24-6	Strontium	11.7		264		mg/kg	299-W15-48/B1HK67	24/24	-	264	NE	4,693		HHSL	NO	BSL
7440-61-1	Uranium	0.382		3.14		mg/kg	299-W15-46/B191Y7	8/11	0.158 to 0.995	3.14	NE	1.6		PRG	NO	MAG
7440-62-2	Vanadium	22.2		137		mg/kg	299-W15-46/B17N60	21/21	-	137	85.1	39		HHSL	NO	BCK
7440-66-6	Zinc	31.9		84		mg/kg	299-W15-48/B1HK77	24/24	-	84	67.8	2,346		HHSL	NO	BSL
Semi-Volatile Compounds																
719-22-2	2,6-di-tert-Butyl-p-benzoquinone	0.0045		0.0062		mg/kg	299-W15-46/B17N64	2/2	-	0.0062	0	NE		NA	NA	NA
117-81-7	Bis(2-ethylhexyl) phthalate	0.034		0.5		mg/kg	299-W15-48/B1HK32	4/20	0.035 to 0.63	0.5	0	35	c	HHSL	NO	BSL
110-82-7	Cyclohexane	2		2		mg/kg	299-W15-48/B1HK77	1/1	-	2	0	14	sat	HHSL	NO	BSL
541-02-6	Decamethylcyclopentasiloxane	0.22		0.22		mg/kg	299-W15-48/B1HK27	1/1	-	0.22	0	NE		NA	NA	NA
84-66-2	Diethylphthalate	0.22		0.71		mg/kg	299-W15-48/B1HK62	5/20	0.035 to 0.38	0.71	0	4,888		HHSL	NO	BSL
84-74-2	Di-n-butylphthalate	0.038		1.3		mg/kg	299-W15-48/B1HK57	8/20	0.035 to 0.38	1.3	0	611		HHSL	NO	BSL
57-11-4	Octadecanoic acid	0.22		0.22		mg/kg	299-W15-48/B1HK27	1/1	-	0.22	0	NE		NA	NA	NA
127-63-9	Phenyl sulfone	0.24		0.24		mg/kg	299-W15-46/B17NL5	1/1	-	0.24	0	18		HHSL	NO	BSL
126-73-8	Tributyl phosphate	0.049		3,000		mg/kg	299-W15-48/B1HK32	10/23	0.035 to 0.96	3,000	0	NE		NA	NA	NA

Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-9 Trench. (4 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Volatile Compounds																
79-34-5	1,1,2,2-Tetrachloroethane	0.0038		0.024		mg/kg	299-W15-48/B1HK49	3/32	0.00031 to 0.19	0.024	0	0.38	c	HHSL	NO	BSL
75-35-4	1,1-Dichloroethene	0.0011		0.0011		mg/kg	299-W15-46/B191Y4	1/42	0.00064 to 0.19	0.0011	0	28		HHSL	NO	BSL
71-36-3	1-Butanol	**0.075**		5.7		**mg/kg**	**299-W15-48/B1HK34**	**1/1**	**-**	5.7	**0**	611		**HHSL**	NO	BSL
78-93-3	1-Butanol	0.075		1.7		mg/kg	299-W15-48/B1HK54	25/42	0.0091 to 9.3	1.7	0	611		HHSL	NO	BSL
78-93-3	2-Butanone	0.0021		1.7		mg/kg	299-W15-48/B1HK54	25/42	0.0008 to 0.16	1.7	0	3,209		HHSL	NO	BSL
104-76-7	2-Ethyl-1-hexanol	0.0085		0.024		mg/kg	299-W15-46/B18XW3	2/2	-	0.024	0	NE		NA	NA	NA
591-78-6	2-Hexanone	0.0013		0.0076		mg/kg	299-W15-46/B17N64-A	6/36	0.0011 to 0.37	0.0076	0	NE		NA	NA	NA
75-65-0	2-Methyl-2-Propanol	0.0043		0.0043		mg/kg	299-W15-46/B17N61	1/1	-	0.0043	0	NE		NA	NA	NA
107-87-9	2-Pentanone	0.006		0.0066		mg/kg	299-W15-46/B17N64	2/2	-	0.0066	0	NE		NA	NA	NA
108-10-1	2-Pentanone, 4-Methyl	0.0012		0.0012		mg/kg	299-W15-46/B17N64	1/42	0.00062 to 0.37	0.0012	0	580		HHSL	NO	BSL
67-63-0	2-Propanol	0.01		0.01		mg/kg	299-W15-46/B191Y4	1/1	-	0.01	0	NE		NA	NA	NA
79-20-9	Acetic acid, methyl ester	0.2		12		mg/kg	299-W15-48/B1HK54	2/2	-	12	0	2,212		HHSL	NO	BSL
67-64-1	Acetone	0.0061		2.9		mg/kg	299-W15-48/B1HK64	30/42	0.0019 to 0.18	2.9	0	1,415		HHSL	NO	BSL
75-05-8	Acetonitrile	0.0066		1.3		mg/kg	299-W15-48/B1HK29	7/32	0.0026 to 0.75	1.3	0	62		HHSL	NO	BSL
71-43-2	Benzene	0.00072		0.0037		mg/kg	299-W15-48/B1HK30	6/42	0.00024 to 0.19	0.0037	0	0.66	c	HHSL	NO	BSL
3789-85-3	Benzoic acid	0.0063		0.0063		mg/kg	299-W15-46/B191Y4	1/1	-	0.0063	0	10,000		HSSL	NO	BSL
74-83-9	Bromomethane	0.031		0.031		mg/kg	299-W15-46/B18XT1	1/32	0.00043 to 0.37	0.031	0	0.39		HHSL	NO	BSL
623-42-7	Butanoic Acid Methyl Ester	0.082		0.082		mg/kg	299-W15-48/B1HK54	1/1	-	0.082	0	NE		NA	NA	NA
123-72-8	Butylaldehyde	0.018		0.018		mg/kg	299-W15-46/B18XW3	1/1	-	0.018	0	NE		NA	NA	NA
75-15-0	Carbon disulfide	0.011		0.011		mg/kg	299-W15-46/B191Y4	1/33	0.00027 to 0.19	0.011	0	72	sat	HHSL	NO	BSL
56-23-5	**Carbon tetrachloride**	**0.00083**		**380**		**mg/kg**	**299-W15-46/B17TM6**	**20/42**	**0.00016 to 0.24**	**380**	**0**	**0.24**	**c**	**HHSL**	**YES**	**ASL**
108-90-7	Chlorobenzene	0.00098		0.00098		mg/kg	299-W15-46/B191Y4	1/42	0.00013 - 0.19	0.00098	0	27		HHSL	NO	BSL
67-66-3	**Chloroform**	**0.00096**		**4.9**		**mg/kg**	**299-W15-46/B17TM6**	**16/42**	**0.00024 to 0.19**	**4.9**	**0**	**0.25**	**c**	**HHSL**	**NO**	**FREQ**
74-87-3	Chloromethane	0.11		0.11		mg/kg	299-W15-46/B18XT1	1/42	0.00025 to 0.62	0.11	0	1	c	HHSL	NO	BSL
124-18-5	Decane	0.75		0.88		mg/kg	299-W15-48/B1HK59	2/2	-	0.88	0	NE		NA	NA	NA
100-41-4	Ethylbenzene	0.0008		0.0008		mg/kg	299-W15-48/B1HK35	1/42	0.00017 to 0.19	0.0008	0	23	sat	HHSL	NO	BSL
67-72-1	Hexachloroethane	0.0052		20		mg/kg	299-W15-48/B1HK29	9/28	0.035 to 0.53	20	0	35	c	HHSL	NO	BSL
66-25-1	Hexanal	0.013		0.013		mg/kg	299-W15-46/B17N64-A	1/1	-	0.013	0	NE		NA	NA	NA
110-54-3	Hexane	0.002		0.0034		mg/kg	299-W15-48/B1HK30	2/32	0.00032 to 0.19	0.0034	0	11	sat	HHSL	NO	BSL
554-12-1	Methyl propionate	0.084		0.084		mg/kg	299-W15-48/B1HK59	1/1	-	0.084	0	NE		NA	NA	NA
75-09-2	Methylene chloride	0.0056		0.14		mg/kg	299-W15-48/B1HK49	7/42	0.0011 to 0.25	0.14	0	8.9	c	HHSL	NO	BSL
75-52-5	Nitromethane	0.0055		0.0055		mg/kg	299-W15-46/B18XW3	1/1	-	0.0055	0	NE		NA	NA	NA
110-62-3	n-Valeraldehyde	0.0089		0.0089		mg/kg	299-W15-46/B17N64-A	1/1	-	0.0089	0	NE		NA	NA	NA
100-42-5	Styrene	0.00048		0.0034		mg/kg	299-W15-46/B17N70	3/33	0.00026 to 0.19	0.0034	0	173	sat	HHSL	NO	BSL
127-18-4	**Tetrachloroethylene**	**0.00094**		**17**		**mg/kg**	**299-W15-46/B17TM6**	**12/42**	**0.00041 to 0.19**	**17**	**0**	**0.55**	**c**	**HHSL**	**NO**	**FREQ**
109-99-9	Tetrahydrofuran	0.0096		0.49		mg/kg	299-W15-48/B1HK54	9/9	-	0.49	0	64	c	HHSL	NO	BSL
108-88-3	Toluene	0.00065		0.0038		mg/kg	299-W15-48/B1HK65	7/42	0.00047 to 0.19	0.0038	0	52	sat	HHSL	NO	BSL

Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-9 Trench. (4 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
598-16-3	Tribromoethylene	0.0057		0.0057		mg/kg	299-W15-46/B17N64-A	1/1	-	0.0057	0	NE		NA	NA	NA
79-01-6	Trichloroethylene	0.0011		0.0013		mg/kg	299-W15-48/B1HK35	2/42	0.00026 to 0.19	0.0013	0	0.043	c	HHSL	NO	BSL
75-69-4	Trichloromonofluoromethane	0.003		0.003		mg/kg	299-W15-48/B1HK55	1/1	-	0.003	0	39		HHSL	NO	BSL
1330-20-7	Xylenes (total)	0.003		0.003		mg/kg	299-W15-48/B1HK35	1/42	0.0004 to 0.31	0.003	0	21	sat	HHSL	NO	BSL
Radionuclides																
14596-10-2	**Am-241**	**0.038**		**43,478,261**		**pCi/g**	**HoleC/4-13 (1973 Smith data)**	**160/165**	**0.009 to 300,000**	**43,478,261**	**NE**	**3.7**		**SSL**	**YES**	**ASL**
10045-97-3	**Cs-137**	**0.047**		**1.04**		**pCi/g**	**299-W15-46/B17N57**	**9/30**	**-0.045 to 766**	**1.04**	**1.05**	**0.044**		**SSL**	**NO**	**BCK**
14683-23-9	**Eu-152**	**0.843**		**20.7**		**pCi/g**	**299-W15-46/B18XR8**	**3/30**	**-0.182 to 701**	**20.7**	**NE**	**0.021**		**SSL**	**YES**	**ASL**
15585-10-1	**Eu-154**	**44**		**44**		**pCi/g**	**299-W15-46/B18XR8**	**1/30**	**-0.027 to 1020**	**44**	**0.0334**	**0.019**		**SSL**	**NO**	**FREQ**
14391-16-3	**Eu-155**	**0.057**		**20.6**		**pCi/g**	**299-W15-46/B18XR8**	**5/30**	**-0.048 to 788**	**20.6**	**0.0539**	**0.9**		**SSL**	**NO**	**FREQ**
13994-20-2	**Np-237**	**0.005**		**28.9**		**pCi/g**	**299-W15-46/B18XR8**	**5/23**	**-0.003 to 504**	**28.9**	**NE**	**0.14**		**SSL**	**YES**	**ASL**
13981-37-8	**Ni-63**	**2,360**		**2,360**		**pCi/g**	**299-W15-46/B191Y7**	**1/4**	**308 to 1,540**	**2,360**	**NE**	**29.6**		**SSL**	**YES**	**ASL**
13981-16-3	**Pu-238**	**0.41**		**3,680**		**pCi/g**	**299-W15-48/B1HK32**	**7/24**	**-218 to 19,200**	**3,680**	**0.00378**	**2.9**		**SSL**	**YES**	**ASL**
PU-239/240	**Pu-239/240**	**0.03**		**404,347,826**		**pCi/g**	**Hole C 4-13 (1979 Smith data)**	**146/149**	**0.002 to 0.006**	**404,347,826**	**0.0248**	**2.9**		**SSL**	**YES**	**ASL**
13966-00-2	**K-40**	**2.22**		**29.4**		**pCi/g**	**299-W15-48/B1HK42**	**12/17**	**20 to 300**	**29.4**	**16.6**	**0.14**		**SSL**	**NO**	**BCK**
14331-85-2	**Pa-231**	**12.9**		**12.9**		**pCi/g**	**299-W15-46/B17TM6-A**	**1/4**	**0 to 7.4**	**12.9**	**NE**	**0.623**		**SSL**	**YES**	**ASL**
13982-63-3	**Ra-226**	**0.48**		**2.16**		**pCi/g**	**299-W15-48/B1HK67**	**9/18**	**0.584 to 43**	**2.16**	**0.815**	**0.013**		**SSL**	**YES**	**ASL**
15262-20-1	**Ra-228**	**0.31**		**2.79**		**pCi/g**	**299-W15-46/B17N57**	**8/18**	**0.29 to 66**	**2.79**	**NE**	**0.025**		**SSL**	**YES**	**ASL**
10098-97-2	**Sr-90**	**0.741**		**13.4**		**pCi/g**	**299-W15-46/B17TM6**	**2/3**	**7.86**	**13.4**	**0.178**	**0.0492**		**SSL**	**YES**	**ASL**
14133-76-7	**Tc-99**	**14.3**		**272**		**pCi/g**	**299-W15-48/B1HK32**	**5/16**	**-4.77 to 15.8**	**272**	**NE**	**0.0704**		**SSL**	**YES**	**ASL**
14274-82-9	**Th-228**	**0.542**		**2.2**		**pCi/g**	**299-W15-48/B1HL26**	**14/31**	**-58.1 to 166**	**2.2**	**NE**	**0.014**		**SSL**	**YES**	**ASL**
14269-63-7	**Th-230**	**1.57**		**72**		**pCi/g**	**299-W15-46/B191Y7**	**4/14**	**-231 to 102**	**72**	**NE**	**3.9**		**SSL**	**YES**	**ASL**
TH-232	Th-232	0.322		2.79		pCi/g	299-W15-46/B17N57	14/34	-57.8 to 66	2.79	1.32	3.4		SSL	NO	BSL
13966-29-5	**U-233/234**	**0.08**		**11.8**		**pCi/g**	**299-W15-46/B17N46**	**13/23**	-17.8 to 50.3	**11.8**	**1.1**	**5**		**SSL**	**NO**	**MAG**
15117-96-1	U-235	0.0147		0.13		pCi/g	299-W15-46/B17N63	8/38	-24.4 to 79.8	0.13	0.109	0.21		SSL	NO	BSL
U-238	U-238	0.094		0.67		pCi/g	299-W15-46/B17N63	13/40	-17.8 to 2,100	0.67	1.06	0.98		SSL	NO	BSL
Other																
7664-41-7	Ammonia	3.4		7.05		mg/kg	299-W15-46/B17N52	2/9	2.8 to 11.3	7.05	9.23	NE		NA	NO	BCK
16887-00-6	Chloride	3.3		93.7		mg/kg	299-W15-48/B1HK32	24/24	-	93.7	100	NE		NA	NO	BCK
16984-48-8	Fluoride	1.7		51.4		mg/kg	299-W15-48/B1HK42	18/24	1.15 to 24.9	51.4	2.81	367		HHSL	NO	BSL
14797-55-8	Nitrate	28.9		6,990		mg/kg	299-W15-48/B1HK52	23/24	0.487	6,990	52	12,167		CALC	NO	BSL
14797-65-0	Nitrite	1.05		12.1		mg/kg	299-W15-46/B17N46	5/24	0.141 to 224	12.1	NE	760		CALC	NO	BSL
14265-44-2	Phosphate	2.5		3.9		mg/kg	299-W15-48/B1HL26	2/24	0.2 to 249	3.9	0.785	NE		NA	NA	NA
14808-79-8	Sulfate	8.1		456		mg/kg	299-W15-46/B17TM6	21/24	1.2 to 287	456	237	NE		NA	NO	BCK
18496-25-8	Sulfide	69.3		69.3		mg/kg	299-W15-46/B17N69	1/9	10.6 to 54.8	69.3	NE	NE		NA	NA	NA

Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-9 Trench. (4 sheets)

CAS No.	Chemical	Minimum Concentration(1)	Minimum Qualifier	Maximum Concentration(1)	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value(2)	Screening Value(3)	Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection(4)

NOTE: Chemicals bolded exceeded their screening toxicity value. Highlighted chemicals were selected as COPCs.

a Minimum/maximum detected concentration. Analytical data included from 14.3 to 40 m (47 to 133 ft).

b Background is assumed to be zero for VOCs and SVOCs. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12 and DOE/RL-96-24, respectively.

c For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA Region 6, 2006) and were adjusted to be protective of a non-cancer hazard of 0.1 and a cancer risk of 1E-6. For radionuclides, screening values are the lowest value.

d Rationale codes: Selection reason: ASL = above screening level

Deletion reason: BSL = below screening level

BCK = near or below background levels (magnitude of exceedance over background less than two times)

NUT = essential nutrient

FREQ = low frequency of samples exceeding the screening value (<5%)

MAG = low magnitude of exceedance over the screening value (less than two times)

e Lead is evaluated differently from other chemicals because the screening value is not equivalent to a hazard quotient of 1 and lead health risks are not additive with other chemical effects; therefore, the full screening value was used.

-- = contaminant has 100% detection frequency
c = cancer
CALC = screening level calculated based on a hazard quotient of 0.1 and child (6 yrs and 15 kg)
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
HHSL = EPA Region 6 *Human Health Medium-Specific Screening Levels for Residential Soil*
NA = not applicable
na = not available
NE = not established
PRG = EPA Region 9 preliminary remediation goal for residential soil (EPA Region 9, 2004)
sat = saturated
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)
SVOC = semi-volatile organic compound
VOC = volatile organic compound

Table A2-10. Frequency and Magnitude of Exceedance for Contaminants in Soil With Detected Concentrations Greater Than the Screening Values and Less Than Background at the 216-Z-9 Trench.

Chemical/ Radionuclide	Maximum Concentration	95% UCL	Screening Value	Health Based Value	Units	Total Number of Samples	Number of Detected Results Exceeding the Screening Value	Percent Frequency of Exceedance	Magnitude of Exceedance (Times the Screening Value)
Chemical/Radionuclide Not Selected as COPCs									
Antimony	4.63	1.7	3	31	mg/kg	24	1	4%	2
Chloroform	4.9	1.3	0.25	2.5	mg/kg	42	2	5%	20
Eu-155	20.6	10.3	0.9	9	pCi/g	30	1	3%	23
Lead	620	286	400	400	mg/kg	24	1	4%	2
Tetrachloroethylene	17	4.4	0.55	5.5	mg/kg	42	1	2%	31
Uranium	3.14	1.5	1.6	16	mg/kg	11	3	27%	2
U-233/234	11.8	5.3	5	50	pCi/g	23	1	4%	2
Chemical/Radionuclide Selected as COPCs									
Americium-241	0.588	--	3.7	--	pCi/g	1	1	95%	196
Americium-241	43,478,261	--	3.7	--	pCi/g	165	156	95%	11,750,881
Cadmium	118	--	3.9	--	mg/kg	24	10	42%	30
Carbon tetrachloride	380	--	0.24	--	mg/kg	42	12	29%	1,583
Eu-152	20.7	--	0.021	--	pCi/g	30	3	10%	986
Manganese	2,240	--	324	--	mg/kg	24	7	29%	7
Np-237	28.9	--	0.14	--	pCi/g	23	4	17%	206
Ni-63	2,360	--	29.6	--	pCi/g	4	1	25%	80
Pu-238	3,680	--	2.9	--	pCi/g	24	5	21%	1,269
Pu-239/240	404,347,826	--	2.9	--	pCi/g	149	143	96%	139,430,285
Pa-231	12.9	--	0.632	--	pCi/g	4	1	25%	20
Ra-226	2.16	--	0.013	--	pCi/g	18	9	50%	166
Ra-228	2.79	--	0.025	--	pCi/g	18	8	44%	112
Sr-90	13.4	--	0.0492	--	pCi/g	3	2	67%	272
Tc-99	272	--	0.0704	--	pCi/g	16	5	31%	3,864
Th-228	2.2	--	0.014	--	pCi/g	31	14	45%	157
Th-230	72	--	3.9	--	pCi/g	14	2	14%	18

-- = not presented for these contaminants, as they are selected as COPCs
COPC = contaminant of potential concern
UCL = upper confidence limit

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Table A2-11. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Metals																
7440-36-0	Antimony	1.7		1.9		mg/kg	C4545-B1D7C8/C4545-B1D9Y4	3/3	--	1.9	NE	3.1		HHSL	NO	BSL
7440-38-2	Arsenic	0.65		2.45		mg/kg	C4545-B1D994	10/10	--	2.45	6.47	0.39	c	HHSL	NO	BCK
7440-39-3	Barium	25.5		88.6		mg/kg	C4545-B1D7C8	10/10	--	88.6	132	1,564		HHSL	NO	BSL
7440-69-9	Bismuth	94.3		102		mg/kg	C4545-B1D9Y4	3/10	1.08 to 1.1	102	NE	NE		NA	NA	NA
7440-43-9	Cadmium	0.118		0.24		mg/kg	C4545-B1D992	5/10	0.104 to 0.14	0.24	NE	3.9		HHSL	NO	BSL
7440-47-3	Chromium	3.3		41.8		mg/kg	C4545-B1D993	10/10	--	41.8	18.5	211	c	HHSL	NO	BSL
7440-50-8	Copper	5.01		14.7		mg/kg	C4545-B1D7C8	10/10	--	14.7	22	291		HHSL	NO	BSL
18540-29-9	Hexavalent chromium	0.27		0.278		mg/kg	C4545-B1D7C7	2/10	0.2 to 0.25	0.278	18.5	30.1	c	HHSL	NO	BSL
7439-92-1	Lead[e]	1.39		5.34		mg/kg	C4545-B1D7C7	10/10	--	5.34	10.2	400		HHSL	NO	BSL
7439-97-6	Mercury	0.119		0.3		mg/kg	C4545-B1D9Y4	2/10	0.007 to 0.106	0.3	0.33	2.3		HHSL	NO	BSL
7440-02-0	Nickel	3.89		30.6		mg/kg	C4545-B1D7D0	10/10	--	30.6	19.1	156		HHSL	NO	BSL
7723-14-0	Phosphorus	451		1430		mg/kg	C4545-B1D9Y4	10/10	--	1430	NE	NE		NA	NA	NA
7782-49-2	Selenium	0.583		1.8		mg/kg	C4545-B1D9Y4	5/10	0.408 to 0.42	1.8	NE	39		HHSL	NO	BSL
7440-22-4	Silver	0.135		0.135		mg/kg	C4545-B1D7C9	1/10	0.102 to 0.27	0.135	0.73	39		HHSL	NO	BSL
7440-28-0	Thallium	0.84	B	2.5		mg/kg	C4545-B1D9Y4	3/3	--	2.5	NE	0.55		HHSL	YES	ASL
7440-61-1	Uranium	0.18		2.16		mg/kg	C4545-B1D9Y4	10/10	--	2.16	NE	1.6		PRG	NO	MAG
PCBs																
11097-69-1	Aroclor-1254	0.039		0.039		mg/kg	C4545-B1D994	1/10	0.0048 to 0.013	0.039	0	0.22	c	HHSL	NO	BSL
Semi-Volatile Compounds																
124-18-5	Decane	0.5	J	0.5	J	mg/kg	C4545-B1D992	1/7	0.18 to 0.34	0.5	0	NE		NA	NA	NA
84-74-2	Di-n-butylphthalate	0.18	J	0.73	J	mg/kg	C4545-B1D7C7	5/10	0.028 to 0.16	0.73	0	611		HHSL	NO	BSL
629-92-5	Nonadecane	1.6	J	1.6	J	mg/kg	C4545-B1D992	1/1	--	1.6	0	NE		NA	NA	NA
126-73-8	Tributyl phosphate	0.59	J	0.59	J	mg/kg	C4545-B1D7C7	1/10	0.072 to 0.35	0.59	0	NE		NA	NA	NA
Volatile Compounds																
104-76-7	2-Ethyl-1-hexanol	0.76	J	0.76	J	mg/kg	C4545-B1D7C7	1/1	-	0.76	0	NE		NA	NA	NA
67-64-1	Acetone	0.0033	J	0.019	J	mg/kg	C4545-B1D9Y4	3/10	0.0017 to 0.0021	0.019	0	1,415		HHSL	NO	BSL
75-05-8	Acetonitrile	0.012	J	0.012	J	mg/kg	C4545-B1DB24	1/10	0.0034 to 0.026	0.012	0	62.3		HHSL	NO	BSL
141-78-6	Ethyl acetate	0.013		0.023		mg/kg	C4545-B1DB24	2/2	--	0.023	0	1,874		HHSL	NO	BSL
Radionuclides																
14762-75-5	C-14	4.34		89.7		pCi/g	C4545-B1D7C7	3/10	-1.11 to 0.004	89.7	NE	0.128		SSL	YES	ASL
10045-97-3	Cs-137	0.432		877,000		pCi/g	C4545-B1D9Y4	10/18	-0.001 to 0.15	877,000	1.05	0.044		SSL	YES	ASL
14391-16-3	Eu-155	0.045		0.055		pCi/g	C4545-B1D7C9	2/18	-0.338 to 860	0.055	0.0539	0.9		SSL	NO	BSL
13994-20-2	Np-237	0.015		3.53		pCi/g	C4545-B1D9Y4	2/4	0 to 0.27	3.53	NE	0.14		SSL	YES	ASL
PU-239/240	Pu-239/240	0.011		55.7		pCi/g	C4545-B1D9Y4	4/10	-0.002 to 0.043	55.7	0.0248	2.9		SSL	YES	ASL
13966-00-2	K-40	7.9		17.4		pCi/g	C4545-B1D994	8/10	1.7 to 6,200	17.4	16.6	0.14		SSL	NO	BCK

Table A2-11. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]	Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
13982-63-3	Ra-226	0.224		0.617		pCi/g	C4545-B1D994	7/11	0.31 to 760	0.617	0.815	0.013	SSL	NO	BCK
15262-20-1	Ra-228	0.479		1.1		pCi/g	C4545-B1D9Y5	7/11	0.387 to 870	1.1	NE	0.025	SSL	YES	ASL
14133-76-7	Tc-99	0.992		79.6		pCi/g	C4545-B1D9Y4	3/10	-0.006 to 1.3	79.6	NE	0.0704	SSL	YES	ASL
14274-82-9	Th-228	0.298		0.884		pCi/g	C4545-B1D992	9/14	0 to 650	0.884	NE	0.014	SSL	YES	ASL
14269-63-7	Th-230	0.378		0.378		pCi/g	C4545-B1D7D0	1/4	-5 to 0.417	0.378	NE	3.9	SSL	NO	BSL
TH-232	Th-232	0.447		1.1		pCi/g	C4545-B1D9Y5	9/14	-1.67 to 870	1.1	1.32	3.4	SSL	NO	BSL
10028-17-8	Tritium	3.24		8.5		pCi/g	C4545-B1D994	6/10	0.89 to 3.78	8.5	NE	4.5	SSL	NO	MAG
U-233/234	U-233/234	0.069		0.36		pCi/g	C4545-B1D7C8	9/10	2.34	0.36	1.1	4.96	SSL	NO	BSL
15117-96-1	U-235	0.012		0.02		pCi/g	C4545-B1D994	4/20	-0.002 to 1,400	0.02	0.109	0.21	SSL	NO	BSL
U-238	U-238	0.098		0.469		pCi/g	C4545-B1D9Y5	9/20	0 to 20,000	0.469	1.06	0.98	SSL	NO	BSL
Other															
16887-00-6	Chloride	0.76	B	5.28	B	mg/kg	C4545-B1D7C7	4/10	2.55\to 2.6	5.28	100	NE	NA	NO	BCK
14797-55-8	Nitrate	1.55		31.4		mg/kg	C4545-B1D9Y4	4/10	2.82 to 2.88	31.4	52	12,167	CALC	NO	BSL
14797-65-0	Nitrite	0.312	B	0.312	B	mg/kg	C4545-B1D9Y5	1/10	0.2 to 3.12	0.312	NE	760	CALC	NO	BSL
14265-44-2	Phosphate	1.5	B	2.6	B	mg/kg	C4545-B1D9Y4	3/10	8.13 to 8.28	2.6	0.785	NE	NA	NA	NA
14808-79-8	Sulfate	3.4	B	107		mg/kg	C4545-B1D7C7	5/10	4.9 to 5	107	237	NE	NA	NO	BCK

NOTE: Chemicals bolded exceeded their screening value. Highlighted chemicals were selected as COPCs.

a Minimum/maximum detected concentration. Includes analytical data from 19 to 264.5 ft bgs.

b Background is assumed to be zero for SVOCs, PCBs, and VOCs. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12 and DOE/RL-96-24, respectively.

c For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA Region 6, 2006) and were adjusted to be protective of a non-cancer hazard of 0.1 and a cancer risk of 1E-6. For radionuclides, screening values are the lowest value of ingestion of homegrown produce, direct ingestion, inhalation of fugitive dusts, or external radiation exposures from Table A.1. Generic (no accounting for decay) SSLs from EPA's *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-R-00-006).

d Rationale codes:

Selection reason:	ASL =	above screening levels
	ABCK =	above background (magnitude of exceedance more than two times)
	TXT =	see text for qualitative discussion of these chemicals
Deletion reason:	BSL =	below screening level
	BCK =	near or below background levels (magnitude of exceedance over background less than two times)
	MAG =	low magnitude of exceedance over the screening value (less than two times)

e Lead is evaluated differently from other chemicals because the screening value is not equivalent to a hazard quotient of 1 and lead health risks are not additive with other chemical effects; therefore, the full screening value was used.

-- = compound has 100% detection frequency
B = analyte is found in both the associated method blank and in the sample, indicating probable blank contamination
c = cancer
CALC = screening level calculated based on a hazard quotient of 0.1 and child (6 yrs and 15 kg)
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
HHSL = EPA Region 6, *Human Health Medium-Specific Screening Levels for Residential Soil*
J = estimated concentration for compounds quantified to be less than required quantitation limit but greater than zero
NA = not applicable
NE = not established
PCB = polychlorinated biphenyl
PRG = EPA Region 9 preliminary remediation goal for residential soil (EPA Region 9, 2004)
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)
SVOC = semi-volatile organic compound
VOC = volatile organic compound

Table A2-12. Frequency and Magnitude of Exceedance for Contaminants in Soil with Detected Concentrations Greater Than the Screening Values and Less Than Background at the 216-A-8 Crib.

Radionuclide	Maximum Concentration	95% UCL	Screening Value	Health-Based Value	Units	Total Number of Samples	Number of Detected Results Exceeding the Screening Value	Percent Frequency of Exceedance	Magnitude of Exceedance (Times the Screening Value)
Chemical/Radionuclide Not Selected as COPCs									
Tritium	8.5	4.7	4.5	NA	pCi/g	10	2	20%	2
Uranium	2.16	1.1	1.6	16.0	mg/kg	10	1	10%	1
Chemical/Radionuclide Selected as COPCs									
C-14	89.7	--	0.128	--	pCi/g	10	3	30%	701
Cs-137	877,000	--	0.044	--	pCi/g	18	10	56%	19,931,818
Np-237	3.53	--	0.14	--	pCi/g	4	1	25%	25
Pu-239/240	55.7	--	2.9	--	pCi/g	10	1	10%	19
Ra-228	1.1	--	0.025	--	pCi/g	11	7	64%	44
Tc-99	79.6	--	0.0704	--	pCi/g	10	3	30%	1,131
Thallium	2.5	--	0.55	--	mg/kg	3	3	100%	5
Th-228	0.884	--	0.014	--	pCi/g	14	9	64%	63

-- = not presented for these contaminants as they are selected as COPCs
COPC = contaminant of potential concern
NA = not applicable
UCL = upper confidence limit

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Table A2-13. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Trench Air at the 216-Z-9 Trench.

CAS No.	Chemical	Minimum Detected Concentration	Minimum Qualifier	Maximum Detected Concentration	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Screening Value[a]	ARAR Value	ARAR Source	Chemical Selected as COPC?
Trench Air Data														
106-98-9	1-Butene	0.048		0.048		mg/m^3	Middle of trench (B1MLF8)	1/1	--	0.048	NE	NA	NA	NO
56-23-5	Carbon tetrachloride	0.1		9.4		mg/m^3	Bottom and middle of trench	5/5	--	9.4	0.00013	12.6	WISHA PEL	YES
67-66-3	Chloroform	0.04		0.04		mg/m^3	Top, middle, and bottom of trench	3/5	0.04 to 0.04	0.04	0.0000084	9.8	WISHA PEL	YES
67-56-1	Methanol	0.018		0.018		mg/m^3	Middle of trench (B1MLF8, B1M560)	2/2	--	0.018	NE	262	WISHA PEL	NO
106-97-8	n-Butane	0.078		0.078		mg/m^3	Middle of trench (B1MLF8, B1M560)	1/2	0.02	0.078	NE	1901	WISHA PEL	NO
74-98-6	n-Propane	0.022		0.04		mg/m^3	Middle of trench (B1MLF8, B1M560)	1/2	0.018	0.04	NE	1803	WISHA PEL	NO
115-07-1	Propylene	0.022		0.022		mg/m^3	Middle of trench (B1MLF8)	1/1	--	0.022	NE	Simple asphyxiant[b]	WISHA PEL	NO

NOTE: Chemicals bolded exceeded their screening toxicity value.

[a] Screening values are the EPA Region 6 human health screening level for ambient air (EPA Region 6, 2006).

[b] An asphyxiant is a substance that can cause unconsciousness or death by suffocation (asphyxiation). Asphyxiants that have no other health effects are sometimes referred to as simple asphyxiants. More specifically, simply asphyxiants are physiologically inert gases that can act principally by dilution of the atmospheric oxygen below partial pressure necessary to maintain oxygen saturation in the blood sufficient for normal tissue respiration.

-- = compound has 100% detection frequency
ARAR = applicable or relevant and appropriate requirement
CAS = Chemical Abstract Services
EPA = U.S. Environmental Protection Agency
NA = not available
NE = not established
PEL = permissible exposure limit
WISHA = *Washington Industrial Safety and Health Act* (WAC 296-841-20025)

Table A2-14. Draft Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Groundwater (Based on Target Action Levels) at the 200-ZP-1 Operable Unit.

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Metals																
7440-36-0	Antimony	2.4	B	56.5	B	µg/L	299-W15-15	51/1002	1.1 to 67.71	56.5	55.1	10		TAL	BCK	NO
7440-47-3	**Chromium (total)**	**0.406**		**769**		**µg/L**	**299-W14-13**	**821/1005**	**0.73 to 7.5**	**769**	**2.4**	**100**		**TAL**	**YES**	**ASL**
18540-29-9	**Hexavalent chromium**	**3**		**730**		**µg/L**	**299-W14-13**	**27/29**	**3 to 3**	**730**	**NE**	**48**		**TAL**	**YES**	**ASL**
7439-89-6	Iron	7	B	2,080		µg/L	299-W15-40	575/1000	6.8 to 56.6	2,080	570	300		TAL	NO	FREQ
7440-61-1	**Total uranium**	**0.0724**		**454**		**µg/L**	**299-W11-37**	**294/301**	**0.1 to 1.02**	**454**	**9.85**	**30**		**TAL**	**YES**	**ASL**
Radionuclides																
15046-84-1	**I-129**	**0.765**		**50.8**		**pCi/L**	**299-W14-13**	**34/487**	**-1.22 to 35.7**	**50.8**	**0.9**	**1**		**TAL**	**YES**	**ASL**
14133-76-7	**Tc-99**	**3.4**		**27,400**		**pCi/L**	**299-W11-39**	**850/933**	**-6.05 to 15.4**	**27,400**	**0.83**	**900**		**TAL**	**YES**	**ASL**
10028-17-8	**Tritium**	**3.59**		**2,940,000**		**pCi/L**	**299-W14-13**	**850/1094**	**-221 to 369**	**2,940,000**	**119**	**20,000**		**TAL**	**YES**	**ASL**
Volatile Organic Compounds																
75-35-4	1,1-Dichloroethene	0.11	J	0.11	J	µg/L	699-48-77D'299-W15-765	2/61	0.04 to 20	0.11	0	NE		NA	NA	NA
56-23-5	**Carbon tetrachloride**	**0.15**	**J**	**5,200**	**D**	**µg/L**	**299-W15-31A**	**553/693**	**0.09 to 1**	**5,200**	**0**	**3**	**c**	**TAL**	**YES**	**ASL**
67-66-3	**Chloroform**	**0.077**	**J**	**420**		**µg/L**	**299-W15-46**	**528/700**	**0.07 to 250**	**420**	**0**	**7**	**c**	**TAL**	**YES**	**ASL**
75-09-2	**Methylene chloride**	**0.23**	**JB**	**740.52**	**B**	**µg/L**	**299-W15-33**	**151/700**	**0.12 to 100**	**740.52**	**0**	**5**	**c**	**TAL**	**YES**	**ASL**
127-18-4	Tetrachloroethylene	0.12	JN	5	N	µg/L	299-W15-1	199/700	0.08 to 250	5	0	5	c	TAL	NO	BSL
79-01-6	**Trichloroethylene**	**0.17**	**J**	**36**	**N**	**µg/L**	**299-W15-50**	**406/700**	**0.09 to 250**	**36**	**0**	**5**	**c**	**TAL**	**YES**	**ASL**
Other																
NO2-N	Nitrogen in nitrite	7.4		11,000	D	µg/L	299-W11-24	63/1083	2 to 74	1,1000	--	1,000		TAL	NO	FREQ

a Minimum/maximum detected concentration.

b Background is assumed to be zero for radionuclides. Background values were taken from *Hanford Site Background: Part 3, Groundwater Background* (DOE/RL-96-61).

c Screening values are TALs from DOE/RL-2006-24, Table 1-5

d Rationale codes: Selection reason: ASL = above screening level
Deletion reason: BSL = below screening level
BCK = near or below background levels (magnitude of exceedance over background less than two times)
FREQ = low frequency of samples exceeding the screening value (<5%)

-- = contaminant has 100% detection frequency
B = analyte concentration in sample may not be distinguishable from results reported in method blank
c = cancer
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
D = contaminant identified in an analysis at a secondary dilution factor
J = estimated value
N = the analysis indicates the presence of an analyte for which there is presumptive evidence to make a tentative identification
NA = not applicable
NE = not established
TAL = target action level

Table A2-15. Contaminants Selected as Contaminants of Potential Concern in Soil.

Contaminant	216-Z-1A	216-Z-8	216-Z-9	216-A-8	216-Z-10
Am-241	√	√	√		No COPCs selected
Cadmium			√		
C-14				√	
Carbon tetrachloride			√		
Cs-137				√	
Eu-152			√		
Manganese			√		
Np-237			√	√	
Ni-63			√		
Pu-238		√	√		
Pu-239	√	√	√	√	
Pu-240	√	√	√	√	
Pa-231			√		
Ra-226			√		
Ra-228			√	√	
Sr-90			√		
Tc-99			√	√	
Thallium				√	
Th-228			√	√	
Th-230			√		

COPC = contaminant of potential concern

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A3.0 EXPOSURE ASSESSMENT

This section evaluates the sources, pathways, receptors, exposure duration and frequency, and routes of exposure to assess total human exposure to the substances of concern in groundwater and the four evaluated soil sites at Hanford. The goal of this section is to calculate a dose of contaminant that each receptor might contact for each COPC and exposure pathway combination. Three elements are required to calculate a dose: (1) a CSM must be developed that identifies complete pathways for the exposure of receptor populations to COPCs, (2) estimates of media concentrations at the exposure point (the point of contact between the COPC and receptor) must be developed, and (3) factors must be selected that quantify the amount of exposure. The combination of media concentrations and exposure factors results in the dose[3] estimates for each contaminant.

A3.1 CONCEPTUAL SITE MODEL

A CSM portrays the sources of contaminants at a site, their release and transfer through environmental media (e.g., soil and air), and the points and means by which human populations might contact the contaminants. This section provides a brief description of which environmental media have been impacted by contaminant releases, a description of the site's land uses, and characterization of the exposed populations under both current and future conditions, as is required by EPA guidance (EPA 540/1-89/002). Note that the detailed information regarding contaminant sources, releases to the environment, and contaminant fate and transport information required to fully characterize the sites were developed and presented as part of the DQO (CP-16151) and RI (DOE/RL-2006-24) documents for the 200-ZP-1 OU and the 200-PW-1/3/6 OU sites (DOE/RL-2006-51). In addition, Table A2-5 provided specific information on sources and characterization information. This section provides a general discussion of contaminated media and focuses on human exposure to the media; it is not intended to provide a complete picture of characterization.

The goal of the CSM is to provide an understanding of where the site-related contaminants are present and where they may be present in the future so the populations that could encounter the contaminants can be identified. The pathways of exposure for these populations can then be selected for a quantitative evaluation of health risks. The subsections that follow describe the CSM and identify exposure pathways.

A3.1.1 Affected Media and Land Use

Based on site investigative work, subsurface soil and groundwater have been identified as containing site-related contaminants.

As discussed in the RIs for soil (DOE/RL-2006-51) and groundwater (DOE/RL-2006-24) and numerous additional documents, the processing of ores to produce plutonium and nuclear fuel reprocessing in the 200-PW-1/3/6 OUs led to contaminants being discharged to subsurface soils

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[3] Note that, because radionuclides are measured as radiological activity per gram and nonradiological contaminants are measured as a weight per weight (e.g., milligrams of contaminant per kilogram of media), the "dose" of radionuclide is not equivalent to a "dose" of a regular contaminant. Where there are differences in terms and calculations between radiological contaminants and regular contaminants, these are noted in the text.

where they leached to groundwater. There are no longer any active nuclear-processing operations that could contribute to contamination; however, there are sites with subsurface soil contamination that could be serving as an ongoing source of contamination to groundwater throughout the area covered by the 200-PW-1/3/6 sites (a total of 17 past-practice waste sites and unplanned release sites). An extensive vapor extraction system is in place in the 200-PW-1 OU, particularly in the vicinity of the 216-Z-9 Trench and 216-Z-1A tile field, to provide ongoing removal of the chlorinated solvents still present in soil.

Groundwater flow is generally from west to east across the Central Plateau and toward the Columbia River. Currently, contaminants in the 200-ZP-1 groundwater plume have not reached the nearest surface water body (i.e., the Columbia River); therefore, surface water is currently not impacted by any of the waste sites evaluated in this report. Conservative modeling indicates that the groundwater plumes may reach the Columbia River in 75 years or more if no actions are taken. Due to the uncertainties in estimating groundwater concentrations at the river boundary 75 years or more in the future, these potential future pathways are not quantified in the risk assessment but are included as an uncertainty in potentially affected media. Groundwater ranges from approximately 58 to 80 m (190 to 262 ft) bgs. Groundwater in the vicinity of the site is not being used for any purpose, and the current use of groundwater is restricted by institutional controls managed by DOE. There is no downgradient use of groundwater from this aquifer; however, there is cross-gradient groundwater use (also on the Hanford Site), and there is a hydraulic barrier in place to ensure that the cross-gradient groundwater remains unimpacted. All public water systems currently supplying water to the Hanford Site are sampled annually to ensure that there are no contaminant or radiological impacts (*Hanford Site Environmental Report for Calendar Year 2005* [PNNL-15892]).

Current land use at the site is industrial and public access to the site is restricted (PNNL-15892). The large overall size of the Hanford Site (1,524 km^2 [586 mi^2]) also provides a buffer around the Central Plateau area that contributes to access control. As noted earlier, the Central Plateau contains the 200-PW-1/3/6 OU waste sites and overlies the groundwater plumes that are evaluated in this report. The 200 West Area of the Central Plateau is approximately 8 km (5 mi) from both the nearest boundary of the Site to the west and the nearest section of the Columbia River to the north (Figure A1-1).

Land use at the 200 West Area is anticipated to remain industrial for the foreseeable future. This area is part of the Central Plateau core zone, which is designated as an industrial exclusion zone that will be used for ongoing waste disposal operations and infrastructure services (DOE/RL-2006-51).

A3.1.2 Selected Populations

Based on the site's current and potential future land use, the following populations are selected for further discussion:

- Current and future worker exposures (adults)
- Future residential farmers (adults and children)
- Future Native American populations (adults and children).

Under the current industrial land-use conditions, two worker populations (regular worker [i.e., no active soil disturbance] and construction worker) could theoretically come into contact with contaminants in impacted soil and groundwater in the 200 West Area. Because soil impacts at

the four selected sites are to subsurface soil, contact with impacted soil by current regular workers is not occurring. In addition, the existing institutional controls programs at the Hanford Site preclude unprotected worker contact (e.g., by current construction workers) with any of the impacted soils at the 200-PW-1/3/6 OUs and would also prevent contact with groundwater (PNNL-15892). Therefore, there currently is no significant exposure to impacted soil and groundwater by workers at the selected waste sites (see also discussion in Section A3.1.3).

While land use is anticipated to remain industrial for the foreseeable future, because the radionuclides present in soil and groundwater have very long half-lives, a residential farming population is also selected for evaluation, assuming exposure to contaminants in groundwater and soil if institutional controls fail at some point in the future, and also assuming additional exposures via the food chain (i.e., plants, meat, and dairy products). The future point selected for residential exposures to begin is the year 2150. At this time, it is assumed that someone could drill a well and bring drill cuttings to the surface where they would be available for direct exposure by future residential farmers. Under this post-2150 scenario, the groundwater from this well could be used by residents or at a business. Thus, a working population could be exposed to soil during drilling (future well drillers), and a separate working population would be exposed to groundwater via drinking it at their place of work (future regular workers).

Native Americans currently live near the Hanford Site and could potentially be exposed to contaminants in groundwater and subsurface soil in the 200 West Area under a future failure of institutional controls scenario, similar to a residential farming population. Native Americans also have treaty fishing rights on portions of the Columbia River and have reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on open unclaimed land (PNNL-15892). With some exceptions, Native American exposures are similar in type to the residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain), but exposures may be different in kind (e.g., more time spent outdoors and greater consumption of native plants and animals) than the typical default exposures that the EPA has developed for a residential population (OSWER Directive 9285.6-03; EPA/600/P-95-002Fa; *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper 2004]).

For this assessment, the residential farming population has been selected to represent the future highly exposed population under the institutional controls failure scenario. Because soil contamination is at depth and groundwater is very deep, technology (i.e., drilling a well) would have to be employed to access the impacted materials. Native plants and animals would be expected to be minimally exposed, as contamination would be centered around a residence and groundwater would be used to grow crops and water domestic livestock. Evaluating risks for a residential farming population fulfills the NCP requirements for a risk evaluation under a "no action" scenario, fulfills Federal EPA requirements to address current and future conditions (EPA 540/1-89/002), assesses food chain exposures consistent with EPA (EPA 540/1-89/002) and Hanford Site risk assessment guidance (DOE/RL-91-45), and provides information to risk managers regarding the protectiveness of various remedies during the FS process. Potential under-estimation of future Native American exposures using EPA residential parameters is discussed further in the uncertainty section of this appendix (Section A6.2.1).

A3.1.3 Identification of Exposure Pathways

Several possible pathways of exposure may exist at this site. An exposure pathway is the mechanism by which a receptor (human) is exposed to contaminants from a source. The following four elements constitute a complete exposure pathway:

- A source and mechanism of contaminant release
- A retention or transport medium (e.g., soil)
- A point of potential human contact with the affected medium
- A means of entry into the body (e.g., ingestion) at the contact point.

Only complete pathways containing all four elements result in exposures. However, in some circumstances, an exposure pathway may be considered complete (i.e., meets all four of the elements) but insignificant. An exposure pathway is considered complete but insignificant if one or more of the following three conditions are met (EPA 540/1-89/002):

- The exposure resulting from the pathway is much less than the exposure resulting from another pathway involving the same medium.
- The potential magnitude of exposure from the pathway is low or of limited toxicological importance.
- The probability of the exposure occurring is very low, and the risks associated with the occurrence are not high.

Only complete and significant pathways of exposure are quantitatively evaluated in this risk assessment. Complete but insignificant pathways of exposure generally do not require quantitative evaluation but are discussed qualitatively. The CSMs (see Figures A3-1 and A3-2) depict the complete pathways for this site for industrial land use and future unrestricted land use and indicate which have been selected for quantitative evaluation.

Under current industrial land-use and institutional control conditions, only a construction worker has the potential to come into contact with impacted soil (and, as described above, actual exposures to an unprotected worker are extremely unlikely). There are no complete and significant pathways for current regular workers. Under a failure of institutional controls scenario (post-2150), soil and groundwater exposures are possible for a residential farmer, soil exposures are possible for a well driller, and groundwater exposures are possible to a future regular worker population drinking groundwater at their place of business. These current and future exposure pathways are discussed in more detail below.

A.3.1.3.1 Contact with Soil by Workers. For risk assessment purposes, human exposures to soil can occur to "surface" and/or "subsurface" soil, depending on the particular population exposed. For workers, EPA has three general categories: (1) outdoor workers not involved in active soil disturbance (e.g., groundskeepers), (2) indoor workers, and (3) construction workers who would have intensive soil contact through active digging (OSWER Directive 9355.4-24). In this risk assessment, regular workers include both outdoor and indoor workers. Outdoor workers would be exposed primarily only to surface soil over the long exposure durations (25 to 70 years) assumed in the risk assessment equations. Construction workers involved in active soil disturbance (e.g., putting in an underground utility line or constructing a building) could be exposed to soils at depth for much shorter durations. Surface soil is defined by EPA as the top 2 cm (0.78 in.) (*Soil Screening Guidance: Technical Background Document* [EPA/540/R-95/128]), although depths of 0 to 0.61 m (0 to 2 ft) and 0 to 0.91 m (0 to 3 ft) are

frequently used as the "surface soil" horizon as a protective measure (*Final Guidance for Conduct of Deterministic Human Health Risk Assessments* [ODEQ 2000]; *Draft Risk Assessment Procedures Manual* [ADEC 2005]). The depth horizon for direct contact with subsurface soil in risk assessment is limited to depths up to 4.6 m (15 ft) bgs because there would be very few instances of construction projects with deeper soil disturbance requirements (OSWER Directive 9355.4-24; WAC 173-340).

Under the existing land-use controls, outdoor or indoor regular worker exposures would only occur via the vapor intrusion pathway. At all four of the quantitatively evaluated soil sites, impacts to soil do not begin until more that 1 m (3 ft) bgs and, in some cases, contamination is also below 4.6 m (15 ft) the depth interval for construction workers. Specific depth intervals of soil contamination as established by the 200-PW-1/3/6 RI report (DOE/RL-2006-51) and *The 216-2-8 French Drain Study* (RHO-RE-EV-46P) are as follows:

- 216-Z-1A tile field: 1.8 to 30.5 m (6 to 100 ft)
- 216-Z-8 french drain: 5 to 11 m (16 to 35 ft)
- 216-Z-9 Trench: 6.4 to 36.6 m (21 to 120 ft)
- 216-A-8 Crib: 3.2 to 20 m (10.5 to 70 ft).

Note that these depths are not identical to the intervals where samples were collected, as described in Section A2.1.1.

Based on the above, the direct soil contact pathways (i.e., ingestion, inhalation of particles, dermal contact, and external radiation) are incomplete for current regular workers (either outdoor or indoor). As presented in Section A2.4, worst-case air concentrations collected from inside the 216-Z-9 Trench are below a concentration of health significance for workers. Therefore, while the vapor pathway from subsurface soil contamination may be complete (i.e., molecules of a contaminant may be reaching a worker), the concentrations are too low to be a health concern and the insignificant vapor inhalation pathway from subsurface contaminants does not need to be quantified. Because of the depth of the impacted soil, the clean soil provides sufficient shielding to also effectively eliminate the external radiation pathway for the regular worker. The minimum of 1.8 m (6 ft) of clean soil cover at all the waste sites provides sufficient shielding for all but the very highest energy photon emitters (>1 Mev) (DOE/RL-91-45). In addition, aboveground radiation levels are continuously monitored at many locations throughout the Hanford Site, and no exceedances above health-based levels are seen (PNNL-15892). Most of the airborne radionuclides that were measured in 2005 were at background levels for the Hanford Site (PNNL-15892).

A current construction worker is evaluated at all sites except the 216-Z-9 Trench, where in addition to the depth to contamination, the area is also covered by a concrete cap over the trench (see Figure A2-5). For the other three sites, a construction worker could potentially come into contact with the shallowest of the impacted materials. Post-2150, well drillers could have exposure to concentrations throughout the entire impacted depth interval, as a well would be drilled to the water table. The deeper contamination limit for each of the waste sites generally represents the point where contamination is below health-based screening levels and where well gamma logs indicate little-to-no radiological activity. Current construction workers and future well drillers would have potentially significant exposures to all the direct-contact soil pathways (i.e., ingestion, inhalation, dermal contact, and external radiation), as depicted in Figures A3-1 and A3-2 for construction workers and well drillers, respectively. The direct soil pathways for

future regular workers are identified as potentially complete but insignificant in Figure A3-2, under the assumption that the drill cuttings would be spread around a home and not a place of business. Thus, any drill cutting materials tracked into the workplace would likely be diluted to the point where concentrations would be too low to be a health concern. If drill cuttings happened to end up around a business rather than a home, significant exposures to regular workers might be possible and are discussed in the uncertainty section of this appendix (Section A6.2).

While both current construction workers and future well drillers would be expected to get soil on their skin where contaminants could be absorbed into the body, the dermal pathway for soil is not both complete and significant for all contaminants. EPA guidance (EPA 540/R/99/05) recommends evaluating dermal soil exposures only for SVOCs and the two metals that have sufficient absorption information (e.g., arsenic and cadmium). The HSRAM (DOE/RL-91-45) does not recommend quantitative evaluation of dermal exposures for radionuclides in soil because the dermal pathway is insignificant in comparison to the soil ingestion pathway. Sample calculations in Rittman (2004) found that the dermal pathway for radionuclides was, at most, 3% of the ingestion dose. Of the contaminants recommended by EPA for dermal soil exposures, only one COPC at one site (cadmium at the 216-Z-9 Trench) requires dermal evaluation. No SVOCs were selected as COPCs at any waste site. Therefore, the dermal pathway is complete, but insignificant, for current construction workers (Figure A3-1) and is complete and significant only for future well drillers exposed to cadmium in soils at the 216-Z-9 Trench (Figure A3-2).

A.3.1.3.2 Contact with Soil by a Residential Farming Population. In order for residents to come into contact with contamination in soil, the impacted materials at depth at the 200-PW-1/3/6 OU waste sites must be brought to the surface. This scenario would only occur if all knowledge of the site is lost, as well as any markers or indicators that could be placed on the site; thus, this is not considered to be possible in this assessment until at least the year 2150. At this time, it is assumed that the likeliest way for subsurface material to be brought to the surface would be through drilling a well and spreading the drill cuttings in the area of a residential home and vegetable garden. Then, through daily activities, residents could potentially be exposed to surface soil through ingestion, dermal contact (only cadmium at the 216-Z-9 Trench), inhalation of fugitive dust and vapors, and external radiation.

The assumption of contamination brought to the surface as well cuttings is consistent with other Hanford documents, particularly the Rittman (2004). This scenario has been referred to as an "intruder scenario" in tank waste performance assessment documents (Rittman 2004; *Status of Hanford Site Risk Assessment Integration, FY 2005* [DOE/RL-2005-37]).

A.3.1.3.3 Inhalation of Vapors in Indoor Air by a Residential Farming Population Post-2150. Exposures to VOCs in subsurface soil might be possible for a future residential farming population through inhalation of vapors emanating from the subsurface into the ambient air. Section A2.4 identified vapor concentrations in the 216-Z-9 Trench as a possible health concern for a residential population if a home were built above the impacted soil at this site, or possibly near the 216-Z-1A tile field (i.e., the waste areas with chlorinated solvents). The concentrations of VOCs that are a possible health concern via this pathway based on the 2006 data are declining over time due to their removal via the active soil vapor extraction (SVE) system, and due to their natural decrease in environmental media because of volatization and breakdown in the environment. Thus, it is not known whether the indoor air pathway would still be a concern 150 years in the future if institutional controls were to fail. In addition, indoor

vapor concentrations are affected by the size of the building, ventilation, and type of building construction, and there are many uncertainties in predicting what those parameters might be at a distant future date. Therefore, while this pathway is shown as potentially complete and significant in Figure A3-2, possible risks will only be semi-quantitatively discussed in the risk characterization section of this appendix (Section A5.0).

According to EPA guidance (EPA 530-F-02-052), because the depth to groundwater is >30.5 m (>100 ft), the movement of vapors from groundwater into indoor air would not be a health concern. Consequently, the vapor migration pathway is only potentially complete for volatile contaminants in groundwater if the groundwater table is shallower than 30.5 m (100 ft).

A.3.1.3.4 Contact with Groundwater Post-2150 (Residential Farmer and Worker). If a well is drilled under an institutional controls failure scenario, then the water could be used for drinking and for irrigation of crops and livestock. A future residential farming population drinking the water would be exposed via ingestion, inhalation of VOCs, and dermal contact during domestic use of the water (e.g., showering and cleaning). In addition, there could also be dermal and inhalation exposures during irrigation (these irrigation exposures are likely only to be to the adult population). The external radiation pathway is generally only significant for photon emitters in soil (DOE/RL-91-45, EPA 540/1-89/002); therefore, the external radiation pathway is considered insignificant for exposures to groundwater via domestic use or irrigation.

If a well were drilled, the water could also be supplied to a local business. Therefore, post-2150, a working population is evaluated assuming that they drink the water and inhale any released vapors during their business activities. Under this scenario, no showering is assumed to occur in the workplace; therefore, dermal contact with the water is not significant.

A.3.1.3.5 Residential Farmer Food Chain Exposures. In order to estimate an upper-bound risk value for the residential farming population, the risk assessment assumes that the farming family will be consuming a portion of their diet from vegetables and fruit grown in soil mixed with drill cuttings, eating cattle watered by groundwater, and drinking dairy products from the cattle. Quantification of food chain risks from eating beef and drinking dairy products assume that the cattle are not pastured on impacted soil but do eat fodder that has been watered with the groundwater.

A3.2 EXPOSURE POINT CONCENTRATIONS

To calculate a cancer risk or a non-cancer hazard, an estimate must be made of the contaminant or radiological concentration to which an individual may be exposed. According to EPA guidance (OSWER Directive 9285.7-081, OSWER Directive 9285.6-10), the concentration term at the exposure point (the EPC) should be an estimate of the average concentration to which an individual would be exposed over a significant part of a lifetime. Different approaches were used to estimate the EPCs for soil and groundwater, and modeling was required to estimate EPCs in foods. The following subsections discuss the calculation of the EPCs for soil, groundwater, and living tissue (i.e., plants, cattle, and dairy products).

A3.2.1 Exposure Point Concentrations for Soil

Because of the uncertainty associated with estimating the true average concentration at a site, the EPA generally recommends the use of the 95% UCL of the arithmetic mean as the appropriate estimate of the average site concentration for an reasonable maximum exposure (RME) scenario

(OSWER Directive 9285.6-03, OSWER Directive 9285.6-10). At the 95% UCL, the probability of under-estimating the true mean is <5%. The 95% UCL can address the uncertainties surrounding a distribution average due to limited sampling data.

The formula used to calculate a 95% UCL depends on the distribution of the data (i.e., the "shape" of the curve) (OSWER Directive 9285.7-081). A statistical test is performed for each COPC data set to determine the best distribution assumption for the data set. The 95% UCL is then calculated using EPA's ProUCL software (EPA/600/R04/079). The EPA recommends using half of the MRL as a surrogate concentration if the contaminant is selected as a COPC for nondetected samples (EPA 540/1-89/002). This methodology described for calculating the 95% UCL was employed for estimation of the RME EPCs whenever there were sufficient data. For data sets with fewer than seven samples, statistical analysis is generally not meaningful and the maximum concentration was used as the RME EPC. Attachment A-1 to this appendix contains the ProUCL outputs for the COPCs.

Plutonium-239 and plutonium-240 were analyzed together in the laboratory and one 95% UCL was calculated for these radionuclides. In order to calculate individual radionuclide EPCs for plutonium-239 and plutonium-240, a ratio of 4.4:1 (plutonium-239:plutonium-240) was assumed. The basis for this ratio is as follows:

- In weapons-grade plutonium, 94.2% of the weight of plutonium-239/240 mixture is plutonium-239 and 5.8% of the weight is plutonium-240. Therefore, 1 g of weapons-grade plutonium-239/240 contains 0.942 g of plutonium-239 and 0.058 g of plutonium-240.
- The specific activity of plutonium-239 is 61.5 mCi/g and the specific activity of plutonium-240 is 227 mCi/g.
- Therefore, the activity of plutonium-239 in 1 g of weapons-grade plutonium-239/240 is 61.5 mCi/g x 0.942 g = 57.9 mCi.
- The activity of plutonium-240 in 1 g of weapons-grade plutonium-239/240 is 227 mCi/g x 0.058 g = 13.2 mCi.

Therefore, the relative activity of plutonium-239 to plutonium-240 in a weapons-grade mixture of plutonium-239/240 = 4.4:1 (4.4 times as much plutonium-239 as plutonium-240 in units of activity).

Recall that the COPCs for each population and exposure area are not the same (see Sections A2.3 and A3.1.3.1); consequently, the COPCs, samples, and evaluated populations differ between the different populations and exposure area combinations. The data used to calculate the EPCs for the different receptor populations are summarized below.

A.3.2.1.1 Estimation of Americium-241 Concentrations at 216-Z-1A Tile Field and 216-Z-9 Trench. As noted in Section A2.1.4.1, there are no available soil data for plutonium-241, which is the parent compound for americium-241. Plutonium-241 has a relatively short half-life of 14.5 years. The production of plutonium (including plutontium-241) started in 1944 at the Hanford Site. The final waste disposals to the major 200-PW-1/3/6 facilities varied and, therefore, some sites are further along the americium-241 ingrowth curve than others. Because the americium-241 data at the 216-Z-1A tile field and 216-Z-9 Trench are relatively old (1979 and 1963 through 1973, respectively), americium-241 concentrations in the available data sets likely do not represent the maximum ingrowth

concentrations of this radionuclide at these two sites (uncertainties surrounding maximum americium concentrations at the 216-Z-8 french drain are discussed in Section A6.1.1; americium-241 is not a COPC at the 216-A-8 Crib). Therefore, maximum concentrations of americium-241 were estimated using the disposal date information from the waste sites, the date of the available americium-241 data, and the RESidual RADioactivity dose model (RESRAD), which can estimate radiological concentrations in the future taking into consideration radionuclide decay and ingrowth.

Maximum americium-241 concentrations were estimated as follows:

- Liquid waste disposal at the 216-Z-1A Crib occurred from 1964 to 1969 and at 216-Z-9 Trench from 1955 to 1962. The "0" year in RESRAD was, therefore, estimated to be 1967 for the 216-Z-1A tile field and 1960 for the 216-Z-9 Trench.
- Site-specific information on the vadose zone and the contaminant distribution for each site was entered into RESRAD (see Section 3.0).
- The known americium-241 concentration for each site was the 95% UCL of the available historical data. This was 1979 for the 216-Z-1A tile field (year 12 in RESRAD) and 1973 for the 216-Z-9 Trench (year 13 in RESRAD).
- Plutonium-241 concentrations at year 0 were entered into RESRAD until the americium-241 concentrations at the applicable year matched the existing data.

The resulting americium-241 ingrowth curves were graphed for each site and are presented in Figures A3-3 and A3-4 for vadose zone soils at the 216-Z-1A tile field and 216-Z-9 Trench, respectively. Figure A3-5 is a graph of the americium-241 and plutonium-241 concentrations in the shallow soils at the 216-Z-1A tile field. Vadose zone concentrations are used to estimate EPCs for the future driller and residential farmer; shallow soil concentrations are used to estimate an EPC for the current construction worker. At both sites, it appears that the maximum americium-241 concentration would occur around 60+ years from year 0. Therefore, current americium-241 concentrations are likely 20 to 25 years from their maximum values. Because current concentrations are aged to represent 150 years in the future for drillers and residential farmers (the earliest vadose zone exposures [see Section A3.1]), use of the maximum americium-241 concentration as the current concentration slightly over-estimates americium-241 concentrations in the year 2150. For the 216-Z-1A tile field, current (year 2005) concentrations are 93% of their maximum concentration (occurring approximately 73 years from time 0, or year 2040 if time 0 is 1967). For the 216-Z-9 Trench, current year concentrations are 96% of their maximum concentration, which occurs around 63 years from time 0, or year 2023 if time 0 is 1960. Because this analysis is meant to be a reasonable approximation of a maximum americium concentration, an exhaustive analysis has not been performed over exactly what year should be year 0, and the possible differing amounts of plutonium-241 that might have been disposed each year of operation. The maximum concentrations estimated as described above were used as reasonably health-protective, given the lack of plutonium-241 data and the uncertainties in the estimation process. This slight potential over-estimation does not have a significant effect on estimates of health risk (see also Section 6.1.1.1).

At the 216-Z-9 Trench where there is current (2005 to 2006), as well as historical, data for americium-241, the current americium-241 data were not adjusted, as it is sufficiently close to its maximum concentration. The maximum predicted values for the 216-Z-1A tile field and the

maximum predicted values from 1973 combined with the 2005-2006 data at the 216-Z-9 Trench were used to estimate soil concentrations and subsequent health risks in the following subsections.

A.3.2.1.2 Construction Worker. Construction worker exposure from contact with soil was evaluated for each waste site with COPCs, except the 216-Z-9 Trench. As shown in Figure A2-5, at the 216-Z-9 Trench, contaminated soil does not begin until below the bottom of the 216-Z-9 Trench (more than 6.1 m [20 ft] bgs), and the trench area is currently capped with a concrete cover. Therefore, no construction worker exposures are expected at the 216-Z-9 Trench.

For the construction worker, exposure is typically to a depth of 4.6 m (15 ft) bgs. However, all of the data was used for 216-Z-8 french drain because only eight samples are available and the contamination is spread in a relatively small area over the 5- to 11-m [16- to 35-ft]-bgs depth interval of contamination present at this site. In some cases, the ProUCL output recommends use of the maximum concentration rather than a 95% UCL where the data sets are small, as was the case with 216-Z-8 french drain (Table A3-1). At the 216-A-8 Crib (3.2 to 20 m [10.5 to 70 ft] bgs), the maximum concentration was used because the maximum concentration was found at the shallowest sample where a construction worker would be most likely to come into contact with the material, providing an upper-bound estimate of EPCs at the 216-A-8 Crib. A 95% UCL was calculated for the 216-Z-1A tile field because there were sufficient samples (17 samples) collected at depths shallower than 5 m (16.4 ft). A summary of construction worker EPCs are provided in Table A3-1.

A.3.2.1.3 Future Well Driller. For the well driller, it was assumed that a driller would be directly exposed to drill cuttings brought out of the ground during well construction 150 years in the future. It was assumed that a well could be drilled anywhere within each of the waste areas; therefore, the entire data set for each area down to the water table was used in the 95% UCL calculation to represent a high-end estimate of the average contaminant concentration that could be in the drill cuttings (Cwaste). The 95% UCLs calculated for current Cwaste concentrations for each site are presented in Table A3-2. The future well driller would not be exposed to contaminants in soil until 150 years in the future; thus, current Cwaste concentrations for radionuclides were entered into RESRAD) dose model, where concentrations 150 years in the future were calculated taking into consideration radionuclide decay and ingrowth. This "aging" of soil concentrations is potentially not significant for the driller because of the long half-lives of the principal radionuclides. However, because the driller EPCs are the basis of the future residential farmer EPCs (Section A3.2.1.3), and once out of the ground, different environmental processes can affect COPC concentration (e.g., erosion and surface run-off), assuming that the COPCs in subsurface soil are not brought to the surface for 150 years prior to weathering affects residential farmer EPCs at future time horizons. These future Cwaste concentrations were the basis for estimating EPCs for the future driller (Ccut) using the methodology from Rittman (2004).

At the 216-Z-9 Trench, there is a preponderance of data in the shallowest layer (ARH-2915), and the data also represent the highest concentrations. Therefore, in order to reasonably estimate drill-cutting concentrations, the following additional steps were used in the Cwaste EPC calculations at the 216-Z-9 Trench:

- Because the sampling was biased towards the shallower depth in holes A, B, C, D, G, and H, whereas in locations 299-W15-46 and 299-W15-48 samples were collected in relatively even depth intervals at deeper depths, less "weight" must be given to each individual data points collected from the "holes" (see Figure A2-3).
- In order to reduce the effect of data points collected from the holes, the average of data collected in each "hole" must first be taken into account and then use this average value as a single data point in calculating the 95% UCL.
- No averaging is needed for locations 299-W15-46 and 299-W15-48 because the depths are evenly spread out.
- Accordingly, the number of data points entered into the 95% UCL calculation is reduced, but the sample size is still adequate. The biased high concentrations from the holes are reduced in their importance.
- Because more weight is not given to the data collected from deeper depths (>36.6 m [<120 ft]) where the concentrations are much lower even though there is a larger volume of cuttings from deeper depths, 95% UCLs are still likely over-estimates of the concentrations in Cwaste.

Future soil concentrations for radionuclides are summarized in Table A3-3 and were calculated as follows:

- It was assumed that the average density in the soil was the same as the density in the waste (a reasonable assumption for contamination mixed into soil via leaching).
- It was assumed that the concentration of contaminant in the impacted soil (future Cwaste) would be diluted by the depth interval between the ground surface and the water table that was unimpacted.

Therefore, the future Cwaste concentration was multiplied by the ratio of the thickness of the waste to the depth of the well to estimate a concentration in the cuttings (Ccut). Details are presented in Attachment A-2 of this appendix. The thickness of the impacted soil is much less than the depth of the well at all waste sites (see Section A3.1.3.1); consequently, driller EPCs (Ccut) are significantly lower than the Cwaste concentrations as can be seen by the differences in concentrations between Cwaste and Ccut shown in Table A3-3.

A.3.2.1.4 Future Residential Farmer. For the residential farmer, it was assumed that the drill cuttings soil (Cwaste) exhumed during well construction would be spread over a certain area of a residential yard that would include a vegetable garden. The Ccut 95% UCL concentrations (Table A3-3) were thus modified to reflect dilution and mixing of cuttings in the area of a home and garden, including the volume of soil excavated during drilling, the area over which the cuttings are spread, and assumed tilling depth (i.e., mixing with unimpacted soil before planting a garden). These assumptions for size of garden and mixing depths are taken from Rittman (2004) and are as follows:

- A 26.7–cm (10.5-in.)-diameter well is drilled (small-scale irrigation well, larger than a well used only for drinking water 16.5 cm [6.5 in.] and smaller than a commercial irrigation well 40.6 cm [16 in.]).
- Drill cuttings will be spread over a 100-m^2 (1,076-ft^2) area.

- The depth of contaminated soil is 15 cm (6 in.) default shallowest tilling depth.

Consequently, the residential farmer EPCs in Table A3-3 are lower than those for the driller because they are spread over a garden area mixed with unimpacted soil. The selection of the size of the area to spread drill cuttings has a direct impact on the concentration of contaminant in the soil. The selection of 100 m^2 (1,076 ft^2) from Rittman (2004) was considered the smallest reasonable area that could still produce a significant portion of a family's food and was selected after taking into consideration information on garden sizes from various sources such as the Washington Department of Agriculture and the Washington State University Cooperative Extension (Rittman 2004). There is an obvious trade-off between selecting too large a garden (diluting concentrations below a RME) and too small a garden (insufficient size to produce a significant portion of a family's food).

Attachment A-2 of this appendix provides the equations and details of how residential farmer EPCs were calculated. The soil EPCs for the residential farmer scenario are provided in Table A3-3.

A3.2.2 Exposure Point Concentrations for Groundwater

Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest concentrations do not occur at the same location). In addition, a large amount of groundwater data has been collected at the site and includes samples collected at the water table, as well as samples collected from deeper in the aquifer, from over 100 wells. (The available groundwater data and the data selected for inclusion in the risk assessment are discussed in Section A2.1.3) Using a well-by-well approach to estimate EPCs would generate a large amount of data of concentrations and health risks per well (i.e., risks at the concentrations found in well X, X1, X2, etc.), many of which would be similar. Because the purpose of the risk assessment is to provide risk managers with the information necessary to make remedial decisions, contaminants in groundwater were evaluated for a range of concentrations for each COPC, with the high-end of the range sufficient to cover the RME to groundwater, rather than on a well-by-well basis.

The range of concentrations selected for EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing groundwater data set (i.e., from the last 5 years). These EPCs were used to evaluate "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. Table A3-4 summarizes the range of groundwater EPCs for each COPC used in the risk calculations. This methodology does not provide risks at a specific location but instead results in information on the range of possible risks for each COPC at the current concentrations. In addition, the cumulative risks from the 90th percentile evaluation represent a bounding exposure condition, or RME, because not all COPCs are at the 90th percentile concentration at the same location. Implications for the risk assessment results on using different groundwater concentrations (e.g., the more typical risk assessment methodology of the 95% UCL of the mean or possible increase in risks if water were drunk at the location of a maximum concentration) are discussed further in the uncertainty section of this appendix (Section A6.2).

Risks were not calculated for future groundwater concentrations under baseline conditions. Future risks from groundwater are assumed to be at least as "risky" as current conditions. This approach is standard for nonradiological contaminants where concentrations are assumed to be either staying the same (many inorganics) or reducing over time (mostly organic compounds). For the three radionuclides that are COPCs in groundwater, decay curves are provided to support

the assumption that risks will not be worse in the future due to changes in contaminant composition or concentration. The potential lowering of future groundwater concentrations is further discussed in Section A5.3.4.

A3.2.3 Calculation of Tissue Concentrations from Groundwater and Soil Exposure Point Concentrations

The methodology recommended on Oak Ridge National Laboratory's (ORNL's) Risk Assessment Information System (RAIS) website (http://rais.ornl.gov) was applied to estimate concentrations in homegrown produce and farm raised beef and dairy products for all COPCs in groundwater and for nonradionuclides in soil. The ORNL online database is part of the Toxicology and Risk Analysis section in the Life Sciences Division at ORNL. ORNL is a DOE multi-program laboratory, and its risk information database is routinely used on a wide variety of public and private sector risk assessment projects. The equations presented in RAIS use site-specific soil and groundwater concentrations and bio-uptake factors to estimate concentrations in plants, beef, and dairy products, as described below. For the radionuclides in soil, RESRAD Version 6.3 was used to determine risks from eating produce grown in soil impacted with radionuclides. RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials (*User's Manual for RESRAD Version 6* [ANL/EAD-4]). Because only soil concentrations can be used in the RESAD model, the radionuclides in groundwater were calculated based on the ORNL methodology. Tables A3-5 and A3-6 summarize the EPCs for the food chain pathways calculated using RAIS and RESRAD, respectively.

A.3.2.3.1 Plant Tissue Exposure Point Concentrations. Homegrown produce could potentially accumulate concentrations of the COPCs because it is assumed that crops are irrigated with contaminated groundwater and are grown in contaminated post-intrusion soils. Table A3-7 summarizes the equations and input parameters used to estimate plant tissue concentrations from groundwater EPCs and the nonradionuclide soil EPCs. The end result of the calculations is an estimate of the concentrations in plant tissues consumed by humans. This methodology was used to estimate plant tissue EPCs for the radionuclide and nonradionuclide COPCs in groundwater for each of the percentiles and for the nonradionuclide EPCs calculated for residential soil. Of the four representative soil waste sites evaluated, only the 216-Z-9 Trench area and the 216-A-8 Crib area had nonradionuclide COPCs. As noted above, plant concentrations for the radionuclides in soil were estimated using the RESRAD model.

As shown in Table A3-7, the calculation of radionuclide and contaminant concentrations in living terrestrial plants from irrigation with contaminated water uses three main routes: (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) aerial deposition of irrigation water on foliage. Also shown in Table A3-7, the calculation of contaminant concentrations in living terrestrial plants growing in contaminated soil uses two main routes: (1) root uptake, and (2) resuspension to leaves (note that very similar formulas and defaults are used in the RESRAD code to estimate radionuclide uptake into plants from soil). Each of these is considered separately in the plant tissue concentration calculations. The uptake routes are then combined to obtain the total concentration in edible portions of plants. In general, the RAIS and RESRAD default values were used for the plant parameters. The default values were developed for use in DOE's preliminary remediation goals (PRGs) and represent health-protective estimates of the amount of contaminant that would end up in plant tissue. Only the transfer factors for

estimating the root uptake portion of the equations differ from the default values presented in the RAIS. The transfer factors are discussed below.

The model for root uptake of a contaminant into terrestrial plants assumes that the concentration in the edible portion is proportional to the concentration in the soil at the time of harvest. The soil-to-plant transfer factor is used to quantify this pathway. The soil-to-plant transfer factors presented in Rittman (2004) were used in the plant modeling equations. The following discussions detail the derivation of the transfer factors for the radionuclides (except tritium), tritium, and the nonradionuclides, respectively. Table A3-8 summarizes the transfer factors that were used in the plant tissue calculations.

Soil-to-Plant Transfer Factors for Radionuclides (Except Tritium). For radionuclides, transfer factors are available for leafy vegetables, root vegetables, and fruits. A weighted average, based on the ratio of human consumptions for each of these types of plants, was calculated to derive a single transfer factor that could be applied to consumption of all types of fruits and vegetables. (Note that transfer factors are also available for grains; however, grains are not typically irrigated or grown in gardens. Therefore, grains are not included in the total vegetable consumption equations.) As presented in Rittman (2004), based on the U.S. Department of Agriculture's (USDA's) consumption rates, an individual's typical fruit and vegetable diet consists of 16 kg, 55 kg, and 38 kg per year of leafy vegetables, root vegetables, and fruits, respectively. This corresponds to 9%, 46%, and 45% for leafy vegetables, root vegetables, and fruits, respectively. These percentages were applied to the transfer factors presented in Rittman (2004) for the radionuclides to derive a weighted average transfer factor. The equations presented in RAIS require transfer factors in wet weight. Therefore, these transfer factors were converted to wet weight by applying the dry-to-wet ratio of 0.2, also described in Rittman (2004).

Soil-to-Plant Transfer Factor for Tritium. Uptake of tritium by organisms is evaluated differently than other radionuclides. Tritium (which is ubiquitous, mobile, and is equivalent to stable hydrogen isotopes in the environment) requires special consideration in radiological analysis to more accurately assess its potential hazard. In general, it is assumed that tritium is transferred in environmental media through its association with water as tritiated water (ANL/EAD-4). Transfer factors for tritium are not typically used because the animal concentration is calculated using an equilibrium model based on the mass fraction of hydrogen in water and mass fraction of hydrogen in plant tissue. However, because the tissue and pathway analysis models are inherently complex, to avoid additional complexity, the basic strategy employed for the other radionuclides was applied in the evaluation of tritium in the environment.

Tritium, with an atomic mass number of 3 and a decay half-life of 12.26 years, is a naturally occurring isotope of hydrogen produced by the interaction of cosmic-ray protons and neutrons with nitrogen and oxygen atoms. Because tritium (H-3) has essentially the same contaminant behavior as stable isotopes of hydrogen (i.e., H-1 and H-2), it will occur in organisms throughout ecosystems in concentrations that depend on the ratio of tritium to stable hydrogen in the environment. Tritium released to the environment is usually converted to the oxide form quite rapidly and is dispersed like ordinary water. In general, the circulation of tritium would be expected to closely follow that of water (ANL/EAD-4).

The special models used for tritium are a result of tritium existing in the form of water. Because tritium behavior in the environment closely resembles that of water, a simple and conservative way to model tritium in plant tissues is to assume that the soil-to-plant transfer factor is equal to one. In other words, the tritium concentration in the soil is equal to the tritium concentration in the plant. Therefore, for the plant tissue EPC calculation for tritium, a transfer factor of 1 was used in the equations presented in Table A3-7.

Soil-to-Plant Transfer Factors for Nonradionuclides. The soil-to-plant transfer factors for contaminants were obtained from Rittman (2004). Concentration ratios for organic contaminants are derived from the octanol-water constants. The formula used to calculate the soil-to-plant (wet) factors is from "Uncertainty and Variability in Human Exposures to Soil Contaminants Through Home-Grown Food: a Monte Carlo Assessment" (McKone 1994), as cited in Rittman (2004), and is shown below.

$$FPLANTS = 7.7\ (KOW) - 0.58.$$

The concentration ratios for the inorganic contaminants were also obtained from Rittman (2004). As described above for the transfer factors for the radionuclides, the transfer factors for the nonradionuclides were converted to wet weight by applying the dry-to-wet ratio of 0.2 for generic crops.

A.3.2.3.2 Beef Tissue and Dairy Product Exposure Point Concentrations. Beef and dairy cattle could potentially accumulate concentrations of the COPCs if the livestock were watered with contaminated groundwater and if the fodder was irrigated with contaminated groundwater. Unlike the plant tissue calculations described above, groundwater is the only source of COPCs to cattle because the soil from drill cuttings is assumed to be dispersed in a relatively small area of a residential garden and is not expected to be dispersed throughout an entire grazing pasture. Therefore, the soil-to-cattle food chain pathways are considered incomplete. This section summarizes the methodology used to model beef tissue and dairy products concentrations from cattle that are raised by the residential farmer.

Beef consumption should be considered a surrogate for other livestock (e.g., sheep and goats) that may be eaten. Beef is used because beef consumption is usually greater than for other livestock and because equations that model the contaminant uptake in animals are primarily developed for cattle. The dairy product EPCs will be used to estimate the intake of dairy products and other related dairy products. Dairy product consumption includes drinking milk, as well as eating dairy products made from the milk. The equations and equation inputs are presented in Table A3-9 for beef and dairy product EPC calculations. The end result of these calculations is an estimate of the concentration in beef muscle tissue (generally only muscle tissue is consumed by humans) and cows' dairy products.

As shown in Table A3-9, the equations used to estimate beef tissue and dairy product concentrations in cattle are very similar. In general, the ORNL RAIS default values were used for the beef parameters. The default values were developed for use in DOE PRGs and represent health-protective estimates of the amount of contaminant that would end up in beef tissue and dairy products. The transfer factors for estimating the uptake into tissue and the concentration in fodder were obtained from Rittman (2004). Table A3-8 summarizes the transfer factors used in the calculations of the beef and dairy product tissue EPCs.

As discussed above for plant tissue EPCs, tritium is evaluated differently than the other radionuclides. Because tritium's behavior in the environment closely resembles that of water, a simple and conservative way to model tritium in the meat and dairy pathways is to assume that the tritium concentration in the meat and dairy products is equal to the tritium concentration in animal forage or animal drinking water, which is equivalent to the tritium concentration in the irrigation water. Therefore, the meat and dairy products EPCs calculations were calculated as follows:

$$H\text{-}3_{m,d}\ (pCi/g) = H\text{-}3_{w}\,(pCi/L) \times 1\ (L/kg) \times 10^{-3}\ (kg/g)$$

where: $H\text{-}3_{m,d}$ = tritium concentration in meat and dairy products
$H\text{-}3_{w}$ = tritium concentration in irrigation water.

Table A3-5 summarizes the EPCs for beef and dairy products.

A3.3 CALCULATION OF CONTAMINANT DOSE

This section defines the magnitude, frequency, and duration of exposure for the populations and pathways selected for quantitative evaluation. Doses were calculated only under RME conditions, as defined by EPA. The RME incorporates several conservative assumptions in estimating the contaminant intake rates and characteristics of the receptor population. The RM is, thus, an estimate of the highest exposure that reasonably can be expected to occur at the site; it may over-estimate the actual risk for most of the population. As stated in EPA's *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* [OSWER Directive 9355.0-30]), "...the goal of RME is to combine upper-bound and mid-range exposure factors so that the result represents an exposure scenario that is both protective and reasonable; not the worst possible case." The RME is typically defined as a combination of upper-bound and average values that reflect exposures somewhere between the 90th and 98th percentile of the range of possible exposures that reasonably can be expected to occur at the site for a given population.

While different methods are used to calculate the dose from radionuclides and nonradionuclides, as described by EPA (EPA 540/1-89/002; EPA 1999), exposure assessment for both nonradionuclide contaminants and radionuclides follow the same basic steps. However, in addition to the exposure pathways considered for contaminants, external radiation is an important exposure pathway for radionuclides in surface soils. The dermal absorption pathway is typically not a significant exposure pathway for radionuclides and was not considered in this risk assessment (as discussed in Section A3.1.3.1). For radionuclide exposures in soil, EPCs and site-specific information were entered into RESRAD Version 6.3 to determine risks. The RESRAD model can only be used to estimate radionuclide risks based on site-specific soil concentrations. Attachment A-3 to this appendix contains a summary of the site-specific and default values used in RESRAD to quantify radionuclide exposures in soil. The following discussions and cited tables are specific to the calculation of dose for the nonradionuclide COPCs in soil and both the radionuclide and nonradionuclide COPCs in groundwater. However, the majority of the exposure assumptions discussed in these subsections for the exposure populations were also used as site-specific inputs into the RESRAD model, as described in Attachment A-3 of this appendix.

The formulas and exposure factors that were used together with the EPCs to quantify doses for the complete pathways are presented in Tables A3-11 through 3-18; the tables also indicate the sources of the factors. In general, EPA default exposure factors (OSWER Directive 9355.4-24) were assumed for construction worker exposures; EPA/600/P-95-002Fa and OSWER Directive 9285.6-03 default exposure factors were used for residential and industrial exposures. No default exposure factors are available to quantify exposures to the well driller. Default exposure factors are discussed in Attachment A-4 of this appendix. Where site-specific factors rather than accepted defaults are proposed, the rationale for their selection is provided in the following discussions for each land-use scenario. Note that for the radionuclides in soil, RESRAD was used to calculate doses for construction workers, driller, and residential farmers. For some residential parameters, RESRAD exposure estimates are less conservative than EPA defaults, but the defaults in RESRAD were not changed in order to be consistent with past risk assessments at the Hanford Site. Differences between RESRAD and EPA defaults for the residential farmer and potential impacts on the risk results are discussed in Section A6.2.5, and RESRAD input parameters are included in Attachment A-3 of this appendix.

A3.3.1 Current Industrial Land-Use Scenario

Current construction workers were evaluated for exposures to soil during active earth-moving activities through the ingestion, inhalation of vapors, fugitive dust pathways, and external radiation. In general, EPA default exposure factors (OSWER Directive 9355.4-24) were assumed for construction worker exposures. Table A3-10 summarizes the exposure assumptions used to calculate construction worker exposures. The following subsections discuss the site-specific factors used in the exposure assessment.

A.3.3.1.1 Exposure Duration and Frequency. The EPA default value for construction workers (OSWER Directive 9355.4-24) assumes exposure duration of one year, during which workers are at a job site in a contaminated area for 250 days (exposure frequency). However, construction activities are not expected to occur throughout an entire year because of the size of these sites. Therefore, an exposure frequency of 30 days/yr was selected as a more appropriate site-specific exposure frequency for construction activities.

A.3.3.1.2 Particulate Emission Factor. The particulate emission factor (PEF) relates the concentration of contaminants in soil with the concentration of dust particles in the air, or "fugitive dust" (EPA/540/R-95/128). A site-specific PEF was calculated for the site using the equation from EPA's soil screening-level guidance (OSWER Directive 9355.4-24). The emissions part of the equation is based on the "unlimited reservoir" model from *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination* (EPA/600/8-85/002) developed to estimate particulate emissions owing to wind erosion (as cited in EPA/540/R-95/128. The dispersion part of the equation includes a dispersion coefficient (Q/C_{wind}). The variable, Q/C_{wind}, is dependent on the climatic zone and meteorology conditions at a site. Therefore, site-specific dispersion factors can be calculated that reflect the site location and climate, as well as the site size. Table A3-11 summarizes the inputs for the PEF equation. The PEF calculated for the Hanford Site is 2.72×10^9 m^3/kg.

A3.3.2 Post-2150 Unrestricted Land-Use Scenario

In the post-2150 unrestricted land-use scenario, a future residential farming population was evaluated assuming exposure to contaminants in soil and groundwater if institutional controls fail at some point in the future. In addition, the post-2150 scenario also evaluated worker risks for two populations: future drillers exposed to drill cuttings from the subsurface, and future regular workers drinking groundwater from the 200-ZP-1 OU at their place of employment. The following subsections discuss the exposure factors used to quantify exposures for each of these populations.

A.3.3.2.1 Residential Farmer. Future residential farming populations were evaluated for exposures to soil and groundwater (as described in Section A3.1.3) for the post-intrusion scenario. This section describes the exposure assumptions that were used to quantify the various residential pathways. With the exception of the transfer factors from soil to air, exposure factors for exposures to irrigation water and food chain exposures, default exposure assumptions were used to evaluate residential exposures and default exposure parameters (see Attachment A-4). Exposure factors and formulas for the residential farmer are presented in Table A3-12 (soil), Table A3-13 (tap water), Table A3-14 (dermal absorption of compounds in water), Table A3-15 (irrigation water exposures), and Table A3-16 (food chain exposures). Non-default exposures are discussed below.

Site-Specific Exposures to Surface Soil

Particulate Emission Factor. The PEF described above for construction workers was also used to evaluate residential exposures to COPCs in fugitive dust. Table A3-11 summarizes the inputs for the PEF equation. The PEF calculated for the Hanford Site is 2.72×10^9 m^3/kg.

Volatilization Factor for Soil. The soil-to-air volatilization factor (VF) is used to define the relationship between the concentration of the volatile contaminant in soil and the flux of the volatilized contaminant to air. The VF only applies to volatile contaminants in soil, while the PEF (described above) only applies to nonvolatile contaminants. OSWER Directive 9355.4-24 provides a method for deriving contaminant-specific VFs that are appropriate for evaluating exposures for outdoor inhalation of volatiles by residential populations. The equation used to derive the VFs for the residential scenario is Equation B-11 of the supplemental guidance and is shown in Table A3-11. The VF equation combines contaminant-specific properties with dispersion assumptions. As described above for the PEF, the dispersion part of the equation also includes a dispersion coefficient (Q/C_{vol}). The variable, Q/C_{vol}, is dependent upon the climatic zone and meteorology conditions at a site. Therefore, site-specific dispersion factors can be calculated that reflect the site location and climate, as well as the site size. The site-specific Q/C_{vol} is calculated to be the same as the Q/C_{wind} described above.

Exposures to Groundwater During Irrigation

Future residential farmers are assumed to use the groundwater as an irrigation source for their crops and livestock. Therefore, adult residential farmers were evaluated for dermal and inhalation exposures to COPCs in groundwater during irrigation activities. Default exposure factors are not available to quantify exposures through this pathway. The exposure factors used to quantify exposures through this pathway are discussed below and are presented in Table A3-15.

Exposure Frequency. An exposure frequency of 90 days/yr was assumed for this pathway. This value was obtained from the ORNL RAIS website (http://rais.ornl.gov) and assumes that irrigation will occur for the three driest months of the year (i.e., July through September).

Exposure Time. An exposure time of 2 hours/day was assumed for this pathway. It was assumed that residential farmers would be in direct contact with irrigation water for a total of 2 hours/day for the entire 3-month irrigation period.

Skin Surface Area. For this pathway, an exposed skin surface area of 1,933 cm^2 (299.6 $in.^2$) was selected. The mean surface area of forearms and hands (average for men and women) from Table 6-4 of EPA/600/8-89/043 was used to calculate this value. This value corresponds to exposure to forearms and hands during irrigation.

Event Frequency for Irrigation. An event frequency of 1 event/day was assumed for this pathway. This value was obtained from the ORNL RAIS website (http://rais.ornl.gov) and assumes that irrigation will occur once every day for the entire 3-month irrigation period.

Inhalation Rate for Irrigation. An inhalation rate of 1.5 m^3/hr was assumed for irrigation activities. According to the EPA's EFH (EPA/600/P-95-002Fa), an inhalation rate for adults engaged in light outdoor activities is 1 m^3/hr, 1.5 m^3/hr for those engaged in moderate outdoor activities, and a rate 2.5 m^3/hr for those engaged in heavy activities outdoors. The inhalation rate of 1.5 m^3/hr for moderate activities was considered appropriate for evaluating inhalation exposures during irrigation. While the definitions of heavy activities are somewhat subjective, *Lognormal Distribution in Environmental Applications* (EPA/600/R-97/006) states that representative "moderate" activities include slow running, yard work, heavy indoor cleanup, and climbing stairs.

Volatilization Factor for Water for Irrigation. The inhalation pathway during irrigation of groundwater is considered to be complete and significant only for volatile contaminants. The volatilization factor for water (VF_w) is used to estimate the concentration in air of a volatile contaminant off-gassing from water. Of the three radionuclide COPCs in groundwater, only tritium is considered volatile from groundwater. Therefore, the VF_w for tritium from Rittman (2004) was used to quantify inhalation exposures from tritium during irrigation.

Five of the nine nonradionuclide COPCs are considered volatile. To estimate a concentration in air during irrigation from the volatile COPCs in water, it was assumed that a surface irrigation system was used. An upper-bound VF_w was calculated using the methodology developed by EPA to estimate a VF from water in flooded trenches (from EPA Region 8, *Derivation of a Volatilization Factor to Estimate Upper Bound Exposure Point Concentration for Workers in Trenches Flooded with Groundwater Off-Gassing Volatile Organic Contaminants* [EPA 8EPR-PS]). The EPA method examines the mass of a contaminant that could be transferred from water to air using the following equation. For the irrigation scenario, the following assumptions were used:

$$VF_w\left(\frac{L}{m^3}\right) = \frac{(k_{lg})}{(k)\left(\frac{\mu}{L}\right)(H)} \bullet \left(\frac{1000L}{m^3}\right)$$

where:

k_{lg} = a conservative estimate of the overall mass transfer coefficient from the liquid phase to the gas phase of 3.0E–6 m (EPA 8EPR-PS)
L = an average irrigation system length of up to 30 m (EPA 8EPR-PS)
H = an average breathing zone height of 2 m
μ = site-specific average wind speed of 7.6 mph (3.4 m/sec) over a year's time
μL = air changes per day of 0.11/sec, assuming the wind flow is in the direction of the irrigation system (3.4 m/sec ÷ 30 m) (EPA 8EPR-PS)
k = an air mixing rate between irrigation system and ambient air of 75%.

The resulting VF_w for the irrigation scenario of 0.02 L/m^3 was used in the risk calculations.

Future Residential Farmer Exposures through Ingestion of Garden Produce, Beef, and Dairy Products. Residential farmers are assumed to consume homegrown fruits and vegetables from gardens that are cultivated in post-intrusion contaminated soils and irrigated with groundwater and to consume beef and dairy products from cattle that drink site groundwater and graze on pastures irrigated with groundwater. Table A3-16 presents the exposure factors used to quantify the ingestion of fruits and vegetables, ingestion of beef, and ingestion of dairy pathways. Discussions regarding the selection of the ingestion rates for these pathways are provided hereafter. Some of the uncertainties in the different factors that could be selected to assess food chain exposures and how different assumptions might impact risk results are discussed in Section A6.2.4.

Fruit and Vegetable Ingestion Rate. Chapter 13 of EPA's EFH (EPA/600/8-89/043) reports intake rates for individuals who consume their own homegrown produce. As shown in Table 13-12 of EPA/600/8-89/043, the mean total homegrown fruit intake for households who farm in the west is 1.85 g/kg of body weight per day (g/kg-day). Similarly, as shown in Table 13-17 of EPA/600/8-89/043, the mean total homegrown vegetable intake for households who farm in the west is 2.73 g/kg-day. Summing these intake rates together results in a total mean homegrown fruit and vegetable intake rate for households who farm in the west of 4.56 g/kg-day. This ingestion rate is assumed to constant over a lifetime and was used to evaluate child and adult combined exposures.

Beef Ingestion Rate. Chapter 13 of the EFH (EPA/600/8-89/043) reports intake rates for individuals who consume their own home-raised beef cattle. As shown in Table 13-22 of EPA/600/8-89/043, the mean total beef intake for households who farm in the west is 2.41 g/kg-day. This ingestion rate is assumed to constant over a lifetime and was used to evaluate child and adult combined exposures.

Dairy Ingestion Rate. Chapter 13 of the EFH (EPA/600/8-89/043) reports intake rates for individuals who consume their own home-raised dairy cattle. As shown in Table 13-32 of EPA/600/8-89/043, the mean total dairy intake for households in the west is 10 g/kg-day. This ingestion rate is assumed to constant over a lifetime and was used to evaluate child and adult combined exposures.

A.3.3.2.2 Future Well Driller. Future well drillers are assumed to be exposed to contaminants in soil during the course of drilling a drinking water well. Table A3-17 presents the exposure factors used to quantify the soil exposure pathways. The EPA OSWER Directive 9355.4-24 default exposure factors for outdoor industrial worker and the exposures specific to drillers

identified in Rittman (2004) were used to evaluate this pathway. Discussions regarding the selection of the site-specific exposure factors for this pathway are provided below.

Exposure Duration. It is assumed that a well driller's exposure will be of a short duration and will be limited to the amount of time it would take to install a well. An exposure duration of 5 days was used to evaluate this scenario (Rittman 2004). This exposure duration is considered a reasonable estimate for the amount of time that it would take to install a well.

Particulate Emission Factor. The PEF described above for construction workers and residential farmers was also used to evaluate well driller exposures to COPCs in fugitive dust. Table A3-11 summarizes the inputs for the PEF equation. The PEF calculated for the Hanford Site is 2.72×10^9 m^3/kg.

Volatilization Factor for Soil. As described above for residential farmer exposures to volatile contaminants in outdoor air, the soil-to-air VF is used to define the relationship between the concentration of the volatile contaminant in soil and the flux of the volatilized contaminant to air. While the VF described above is appropriate for evaluating residential exposures to vapors in outdoor air, OSWER Directive 9355.4-24 also provides a method for deriving contaminant-specific VFs that are appropriate for evaluating exposures for subchronic outdoor inhalation of volatiles by construction workers that was applied to well drillers. The equation used to derive the VFs for the construction worker scenario is Equation 5-14 of the supplemental guidance and is shown in Table A3-11. The VF equation combines contaminant-specific properties with dispersion assumptions. The default subchronic dispersion factor for volatiles factor, Q/C_{sa}, was derived using EPA's SCREEN3 dispersion model for a hypothetical site under a wide range of meteorological conditions. Unlike the Q/C value for the PEF above, the Q/C_{sa} can only be modified to reflect different site sizes; it cannot be modified for climatic zone. The default Q/C_{sa} was used that assumes a 0.2–ha (0.5-ac) site. The time interval, T, is the total time over which construction or in this case well drilling occurs in seconds. For the well driller scenario, a time interval of 4.32×10^5 sec (1 year x 5 days/yr x 24 hours/day x 60 min/hr x 60 sec/min) was used, which is equal to the assumed exposure duration of 5 days for the well driller. The time interval of 24 hours accounts for the duration of contaminant volatilization, which is assumed to be constant and not the duration of drilling activities.

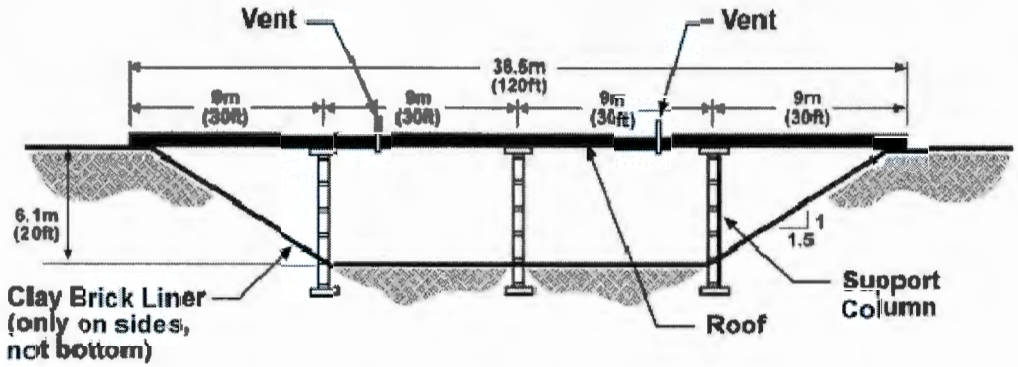
A.3.3.2.3 Industrial Worker Drinking Water Exposures. For this scenario, it was assumed that an onsite worker could drink the water from wells drilled on the site. Adult workers were evaluated for exposures to groundwater through the ingestion and inhalation of vapors pathways. The dermal pathway was not quantified for this population because workers are not expected to bathe in the water (as is assumed for a residential exposure scenario), and other dermal exposures to groundwater (i.e., washing hands) would be expected to be of limited duration. Thus, the dermal pathway for industrial workers is considered insignificant. In general, OSWER Directive 9285.6-03 default values for industrial exposures to tap water were used. These factors are presented in Table A3-18 and are discussed in Attachment A-4. The following site-specific exposure parameters were used in the evaluation of industrial exposures to groundwater.

Inhalation Rate for Irrigation. An inhalation rate of 1.5 m^3/hr was assumed for industrial workers. According to the EFH (EPA/600/8-89/043), an inhalation rate for adults engaged in light outdoor activities is 1 m^3/hr, 1.5 m^3/hr for those engaged in moderate outdoor activities, and 2.5 m^3/hr for those engaged in heavy activities outdoors. The inhalation rate of 1.5 m^3/hr

for moderate activities was considered appropriate for evaluating inhalation exposures during irrigation. While the definitions of heavy activities are somewhat subjective, EPA/600/8-89/043 states that representative "moderate" activities include slow running, yard work, heavy indoor cleanup, and climbing stairs.

Exposure Time for Inhalation Exposures. An exposure time of 3 hours/day was assumed for inhalation exposures to groundwater used as an industrial tap water source. It was assumed that throughout the course of a day, inhalation exposures would occur only intermittently (e.g., during bathroom breaks and during drinking from water fountains). The assumption of 3 hours/day is considered a conservative estimation of inhalation exposures to groundwater.

Figure A3-1. Schematic Human Health Conceptual Site Model Current Industrial Land Use.



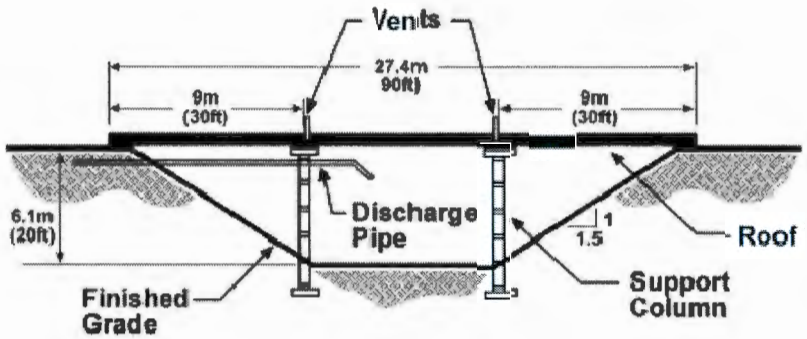


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Figure A3-2. Schematic Human Health Conceptual Site Model Future Unrestricted Land Use.

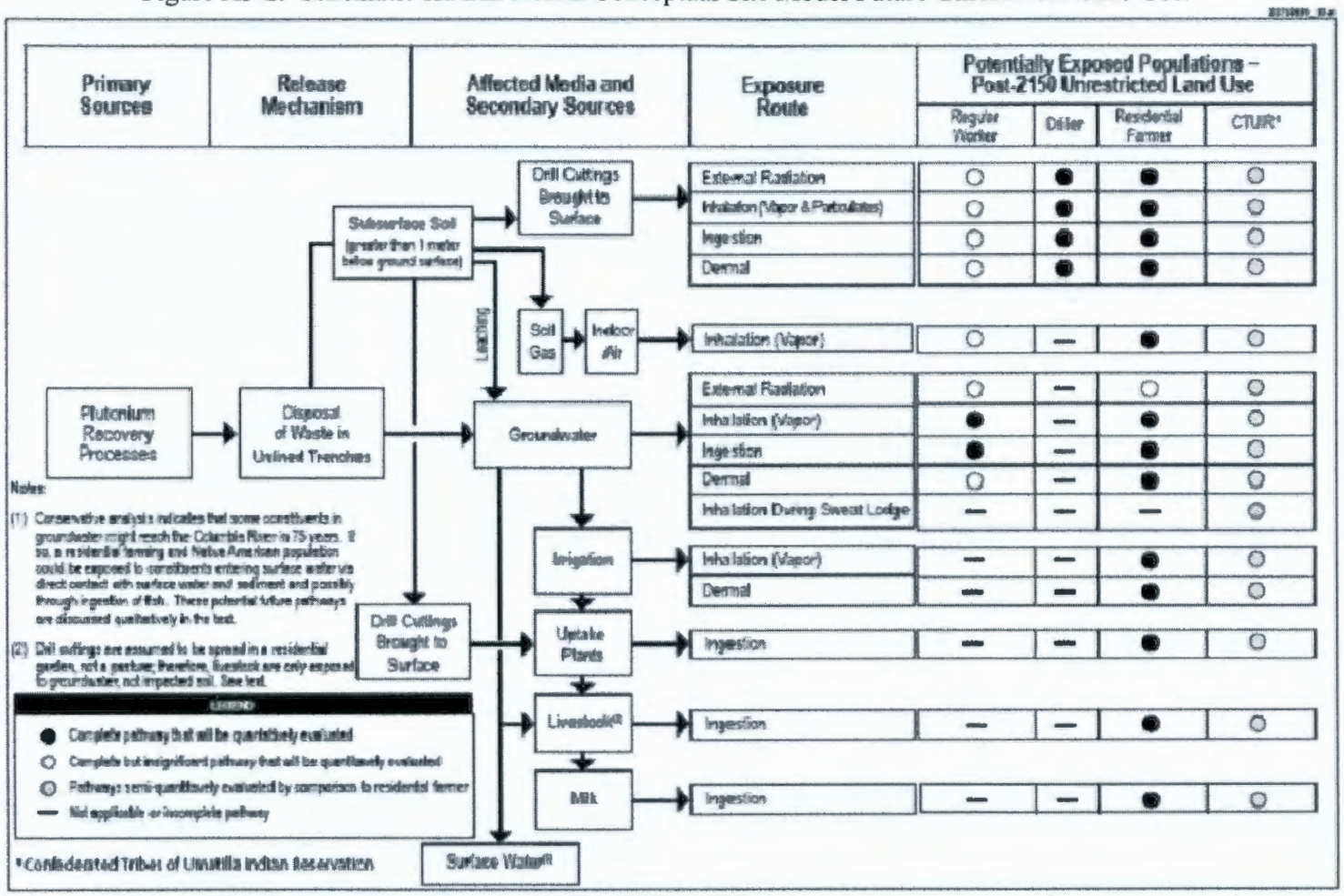

Figure A3-3. Ingrowth of Americium-241 at 216-Z-1A Vadose Zone.

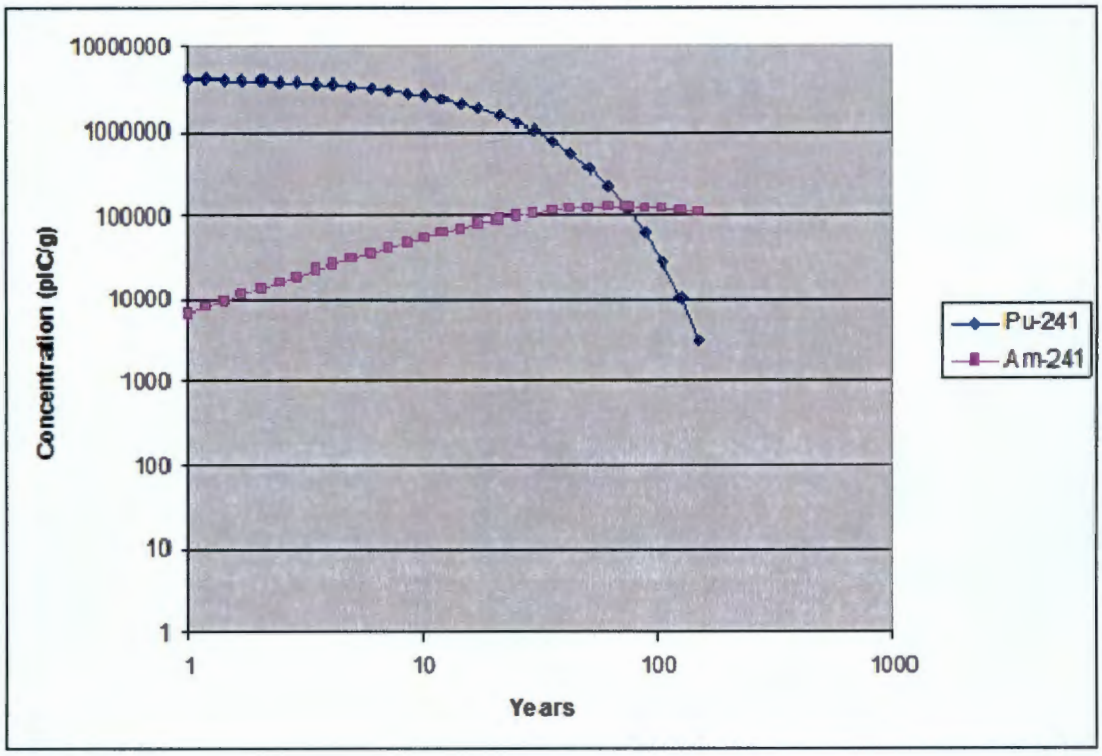

Figure A3-4. Ingrowth of Americium-241 at 216-Z-9 Vadose Zone.

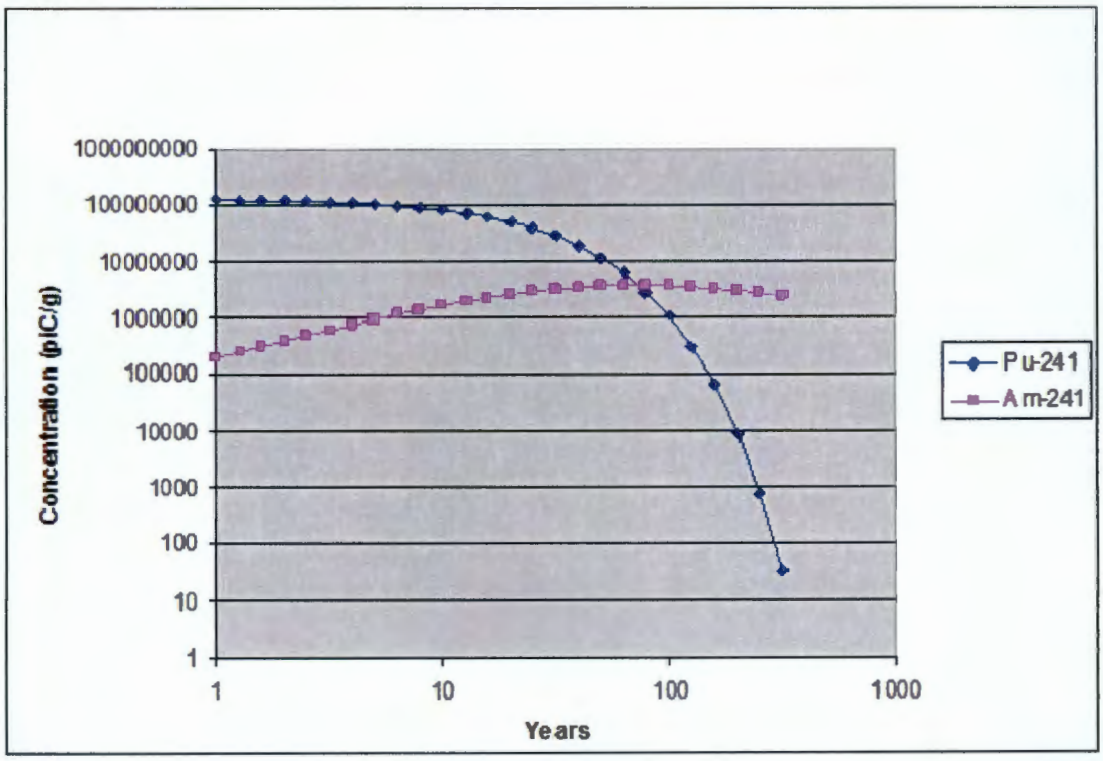

Figure A3-5. Ingrowth of Americium-241 at 216-Z-1A Shallow Soils (Construction Worker Soil Contact Zone).

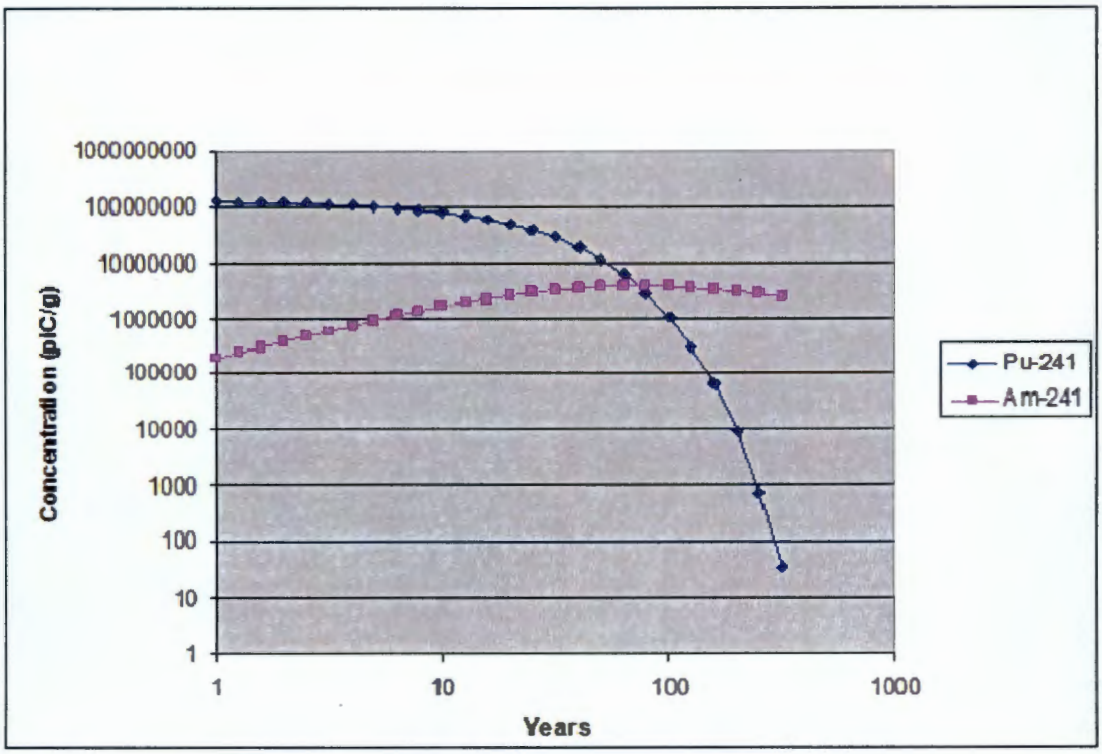

Table A3-1. Summary of Exposure Point Concentrations for Soil Current Construction Worker.

COPC	EPC	Units	EPC Rationale	Number of Samples
216-Z-1A Tile Field				
Am-241[a]	2,028,358	pCi/g	95% Chebyshev (Mean, Sd) UCL	17
Pu-239/240	15,509,199	pCi/g	95% Chebyshev (Mean, Sd) UCL	17
Pu-239	12,637,125	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
Pu-240	2,872,074	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
216-Z-8 French Drain				
Am-241	457	pCi/g	Maximum, adjusted gamma exceeds maximum	8
Pu-238	77.5	pCi/g	Maximum, adjusted gamma exceeds maximum	8
Pu-239/240	4,620	pCi/g	Maximum, adjusted gamma exceeds maximum	8
Pu-239	3,764.44	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
Pu-240	855.56	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
216-A-8 Crib				
Cs-137	877,000	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	Shallowest
Np-237	3.53	pCi/g	Maximum at depth (19 to 21.5) ft bgs	Maximum concentration selected
Pu-239/240	55.7	pCi/g	Maximum at depth (19 to 21.5) ft bgs	
Pu-239	45.39	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	
Pu-240	10.31	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	
Ra-228	1.1	pCi/g	Maximum at depth (22.5 to 25 ft bgs)	
Th-228	0.699	pCi/g	Maximum at depth 6.8 to 7.6 m (22.5 to 25 ft bgs)	

[a] Americium-241 concentrations estimated based on methodology in Section A3.2.1.1. The statistical analysis was done on the historical data set.

bgs = below ground surface
COPC = contaminant of potential concern
EPC = exposure point concentration
UCL = upper confidence limit

Table A3-2. Summary of Exposure Point Concentrations for Soil Representative of Current Vadose Zone Concentrations (Cwaste). (2 sheets)

Site Name	Contaminant Name	Cwaste (pCi/g or mg/kg)	Distribution	Rationale from ProUCL	Number of Samples
216-Z-1A tile field	Am-241[b]	122,528	Non-parametric	95% Chebyshev (Mean, Sd) UCL	458
	Pu-239/240	698,678	Non-parametric	95% Chebyshev (Mean, Sd) UCL	423
216-Z-8 french drain	Am-241	457	Gamma	Maximum, adjusted gamma exceeds max	8
	Pu-238	77.5	Gamma	Maximum, adjusted gamma exceeds max	8
	Pu-239/240	4,620	Gamma	Maximum, adjusted gamma exceeds max	8
216-Z-9 Trench	Am-241	300,556	Gamma	Adjusted gamma UCL	41
	Cadmium	22.4	Gamma	Adjusted gamma UCL	24
	Carbon tetrachloride	99.4	Non-parametric	99% Chebyshev (Mean, Sd) UCL	42
	Eu-152	74.6	Non-parametric	95% Chebyshev (Mean, Sd) UCL	30
	Manganese	738.3	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24
	Np-237	87.2	Non-parametric	95% Chebyshev (Mean, Sd) UCL	23
	Ni-63	2,360	NA	Maximum concentration[a]	4
	Pu-238	2,885	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24
	Pu-239/240	8,903,844	Non-parametric	99% Chebyshev (Mean, Sd) UCL	25
	Pa-231	12.9	NA	Maximum concentration[a]	4
	Ra-226	17.2	Non-parametric	99% Chebyshev (Mean, Sd) UCL	18
	Ra-228	12.3	Lognormal	95% Chebyshev (Mean, Sd) UCL	18
	Sr-90	13.4	NA	Maximum concentration[a]	3
	Tc-99	99.8	Non-parametric	97.5% Chebyshev (Mean, Sd) UCL	16
	Th228	17.7	Non-parametric	95% Chebyshev (Mean, Sd) UCL	31
	Th-230	19.2	Normal	Student's-t UCL	14

Table A3-2. Summary of Exposure Point Concentrations for Soil Representative of Current Vadose Zone Concentrations (Cwaste). (2 sheets)

Site Name	Contaminant Name	Cwaste (pCi/g or mg/kg)	Distribution	Rationale from ProUCL	Number of Samples
216-A-8 Crib	C-14	67.03	Non-parametric	95% Chebyshev (Mean, Sd) UCL	10
	Cs-137	261,460	Non-parametric	95% Chebyshev (Mean, Sd) UCL	18
	Np-237	3.53	NA	Maximum concentration[a]	4
	Pu-239/240	29.85	Non-parametric	95% Chebyshev (Mean, Sd) UCL	10
	Ra-228	433.02	Non-parametric	99% Chebyshev (Mean, Sd) UCL	11
	Tc-99	42.81	Non-parametric	95% Chebyshev (Mean, Sd) UCL	10
	Thallium	2.5	NA	Maximum concentration[a]	3
	Th-228	124.75	Non-parametric	95% Chebyshev (Mean, Sd) UCL	14

[a] Too few samples available to produce a meaningful 95% UCL using ProUCL.
[b] Americium-241 concentrations estimated based on methodology in Section A3.2.1.1. The statistical analysis was done on the historical data set.
NA = not applicable
ProUCL = U.S. Environmental Protection Agency's software for calculating the UCL (Version 3.00.02)
UCL = upper confidence limit

Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors. (2 sheets)

COPC	Cwaste 150 Years in the Future	Well Driller EPC Ccut 150 Years in the Future	Residential Farmer EPC Cgarden 150 Years in the Future	Units
216-Z-1A Tile Field				
Am-241	89,640	29,037	10,609	pCi/g
Pu-239	566,400	183,471	67,035	pCi/g
Pu-240	127,300	41,236	15,066	pCi/g
216-Z-8 French Drain				
Am-241	253.5	17.6	6.2	pCi/g
Pu-238	23.61	1.64	0.58	pCi/g
Pu-239	3735	260	91.28	pCi/g
Pu-240	839.5	58.41	20.52	pCi/g
216-Z-9 Trench				
Am-241	221,000	80,156	28,152	pCi/g
Cadmium	--	8.12	2.85	mg/kg
Carbon tetrachloride	--	36.07	12.67	mg/kg
Eu-152	0.03052	0.01107	0.003888	pCi/g
Manganese	--	267.78	94.05	mg/kg
Np-237	114.7	41.6	14.61	pCi/g
Ni-63	798	289.39	101.64	pCi/g
Pu-238	882	319.72	112.29	pCi/g
Pu-239	7,264,000	2,634,617	925,331	pCi/g
Pu-240	1,574,000	570,882	200,505	pCi/g
Pa-231	12.5	4.54	1.59	pCi/g
Ra-226	17.0	6.17	2.17	pCi/g
Ra-228	1.93E-07	6.98E-08	2.45E-08	pCi/g
Sr-90	0.4	0.13	0.05	pCi/g
Tc-99	3.67E-06	1.33E-06	4.68E-07	pCi/g
Th-228	2.76E-07	1.00E-07	3.52E-08	pCi/g
Th-230	19.2	6.95	2.44	pCi/g
216-A-8 Crib				
C-14	2.63E-35	5.02E-36	2.02E-36	pCi/g
Cs-137	8,167	1,557.87	625.32	pCi/g
Np-237	3.5	0.67	0.27	pCi/g
Pu-239	24.2	4.62	1.85	pCi/g

Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors. (2 sheets)

COPC	Cwaste 150 Years in the Future	Well Driller EPC Ccut 150 Years in the Future	Residential Farmer EPC Cgarden 150 Years in the Future	Units
Pu-240	5.44	1.04	0.42	pCi/g
Ra-228	5.88E-06	1.12E-06	4.51E-07	pCi/g
Tc-99	1.83E-11	3.50E-12	1.40E-12	pCi/g
Thallium	--	0.48	0.19	mg/kg
Th-228	8.83E-06	1.68E-06	6.76E-07	pCi/g

COPC = contaminant of potential concern
EPC = exposure point concentration

Table A3-4. Summary of Exposure Point Concentrations for Groundwater for 200-ZP-1 Operable Unit Source Area.

COPC	Percentiles			Units
	25th	50th	90th	
Carbon tetrachloride	6.53	505.00	2,900.00	µg/L
Chloroform	0.58	6.40	24.00	µg/L
Chromium (total)	3.6	10.3	130	µg/L
Chromium (VI)	7.00	10.90	203.40	µg/L
Methylene chloride	0.12	0.185	2.734	µg/L
Nitrate (analyzed as nitrogen)	14,000	21,900	81,050	µg/L
PCE	0.18	0.36	2.5	µg/L
TCE	0.155	1.7	10.9	µg/L
Uranium	0.74	1.17	5.06	µg/L
I-129	ND	0.030	1.170	pCi/L
Technetium-	54.1	173	1436	pCi/L
Tritium	513.75	3,605	36,200	pCi/L

COPC = contaminant of potential concern
ND = not detected
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A3-5. Summary of Food Chain Pathway Exposure Point Concentrations (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants (Nonradionuclides Only). (2 sheets)

COPC	Units	200-ZP-1 Groundwater Area			Soil Waste Sites	
		25th [a]	50th [a]	90th [a]	216-Z-9 Trench	216-A-8 Crib
Homegrown Produce						
Cadmium	mg/kg	d	d	d	0.83	d
Carbon tetrachloride	mg/kg	0.126395	9.782275	5.62E+01	5.52	d
Chloroform	mg/kg	0.018989	0.209536	7.86E-01	d	d
Chromium (total)	mg/kg	0.046597	0.133319	1.68E+00	d	d
Chromium (VI)	mg/kg	0.090605	0.141086	2.63E+00	d	d
Manganese	mg/kg	d	d	d	29.59	d
Methylene chloride	mg/kg	0.007772	0.011982	1.77E-01	d	d
Nitrate	mg/kg	b	b	b	d	d
PCE	mg/kg	0.002857	0.005715	3.97E-02	d	d
TCE	mg/kg	0.00369	0.040466	2.59E-01	d	d
Thallium	mg/kg	d	d	d	d	0.05
Uranium	mg/kg	0.009623	0.015215	6.58E-02	d	d
I-129	pCi/g	ND	0.000393	1.53E-02	d	d
Tc-99	pCi/g	7.363375	23.54647	1.95E+02	e	e
Tritium	pCi/g	13	95	9.50E+02	d	d
Meat						
Carbon tetrachloride	mg/kg	3.1E-05	0.002398	1.38E-02	Cattle are assumed to be directly exposed only to groundwater.	
Chloroform	mg/kg	5.92E-07	6.54E-06	2.45E-05		
Chromium (total)	mg/kg	0.006653	0.019036	2.40E-01		
Chromium (VI)	mg/kg	1.29E-02	0.020145	3.76E-01		
Methylene chloride	mg/kg	4.35E-08	6.71E-08	9.92E-07		
Nitrate	mg/kg	b	b	b		
PCE	mg/kg	2.71E-06	5.42E-06	3.77E-05		
TCE	mg/kg	3.4E-07	3.73E-06	2.39E-05		
Uranium	mg/kg	4.57E-05	7.23E-05	3.13E-04		
I-129	pCi/g	ND	0.000252	9.82E-03		
Tc-99	pCi/g	0.091243	0.291775	2.42E+00		
Tritium	pCi/g	0.5	3.6	3.60E+01		
Dairy Products						
Carbon tetrachloride	mg/kg	1.46E-05	0.001131	6.49E-03	Cattle are assumed to be directly exposed only to groundwater.	
Chloroform	mg/kg	2.76E-07	3.04E-06	1.14E-05		
Chromium (total)	mg/kg	1.12E-05	3.2E-05	4.04E-04		
Chromium (VI)	mg/kg	2.18E-05	3.39E-05	6.32E-04		

Table A3-5. Summary of Food Chain Pathway Exposure Point Concentrations (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants (Nonradionuclides Only). (2 sheets)

COPC	Units	200-ZP-1 Groundwater Area			Soil Waste Sites	
		25th [a]	50th [a]	90th [a]	216-Z-9 Trench	216-A-8 Crib
Methylene chloride	mg/kg	1.99E-08	3.07E-08	4.54E-07	Cattle are assumed to be directly exposed only to groundwater.	
Nitrate	mg/kg	[b]	[b]	[b]		
PCE	mg/kg	1.28E-06	2.57E-06	1.78E-05		
TCE	mg/kg	1.59E-07	1.75E-06	1.12E-05		
Uranium	mg/kg	9.23E-05	0.000146	6.31E-04		
I-129	pCi/g	ND	0.000114	4.45E-03		
Tc-99	pCi/g	0.183536	0.58691	4.87E+00		
Tritium	pCi/g	0.5	3.6	3.60E+01		

[a] Tissue concentrations were calculated using each of the groundwater percentile exposure point concentrations as presented above.

[b] Nitrate does not bioaccumulate. The food chain pathways are incomplete for nitrate.

[c] The uptake of tritium in the food chain is evaluated differently than the other contaminants. Tritium is discussed separately in Section A3.2.3 of this appendix.

[d] Contaminant not selected as a COPC in this source area.

[e] Technetium-99 in soil was evaluated for the food chain pathways through use of the RESidual RADioactivity (RESRAD) dose model.

COPC = contaminant of potential concern
ND = not detected
ORNL = Oak Ridge National Laboratory
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A3-6. Summary of Homegrown Produce Exposure Point Concentrations Soil to Plant Pathway (RESRAD Methodology) 150 Years from Now.[a]

Radionuclide	Homegrown Produce EPC[b] (pCi/g)	Radionuclide	Homegrown Produce EPC[b] (pCi/g)
216-Z-1A Tile Field		***216-Z-9 Trench***	
Am-241	4	Ac-227[c]	0.001
Np-237[c]	0.002		
Pu-239	23	Am-241	9
Pu-240	5	Eu-152	0.000003
		Ni-63	2
216-Z-8 French Drain		Np-237	0.1
Am-241	0.002	Pa-231	0.005
Pu-238	0.0002	Pb-210[c]	0.007
Pu-239	0.03	Pu-238	0.04
Pu-240	0.007	Pu-239	311
216-A-8 Crib		Pu-240	67
C-14	6E-37	Ra-226	0.03
Cs-137	8	Ra-228	0.0000000004
Np-237	0.002	Sr-90	0.005
Pu-239	0.0006	Tc-99	0.0000008
Pu-240	0.0001	Th-228	0.00000000001
Ra-228	0.00000001	Th-230	0.0008
Tc-99	0.000000000002		
Th-228	0.0000000002		

[a] Concentrations assume that a well is drilled 150 years in the future; thus, there is no erosion or leaching of contaminants prior to the year 2150.

[b] The EPC is the sum of leafy and non-leafy plant concentrations estimated by the RESidual RADioactivity (RESRAD) dose model.

[c] This radionuclide is not a COPC; however, it is included as a daughter product in order to calculate risks.

COPC = contaminant of potential concern

EPC = exposure point concentration

Table A3-7. Plant Tissue Modeling Calculations Future Residential Farmer, 200-ZP-1 Groundwater and Residential Soil (Nonradionuclides).

Calculation of Plant Concentration from Groundwater Used for Irrigation:

$$C = (Cw \times Irr\ rup \times CF^*) + (Cw \times Irr\ res \times CF^*) + (Cw \times Irr\ dep \times CF^*) \quad \text{Equation 1}$$

$$Irr\ rup = \frac{Ir \times F \times Bv\ wet \times (1-\exp(-Lb \times tb))}{P \times Lb} \quad \text{Equation 2}$$

$$Irr\ res = \frac{Ir \times F \times MLF \times (1-\exp(-Lb \times tb))}{P \times Lb} \quad \text{Equation 3}$$

$$Irr\ dep = \frac{Ir \times F \times If \times T \times (1-\exp(-LE \times tv))}{Yv \times LE} \quad \text{Equation 4}$$

Calculation of Plant Concentration Grown in Post-2150 Residential Soil:

$$C = (Cs \times Rupv) + (Cs \times Res) \quad \text{Equation 5}$$

Variable	Variable Definition	Units	Value	Source
Bv wet	Soil to plant transfer factor wet weight	kg/kg	Contaminant-specific	Table A3-8
CF	Conversion factor	kg/g	0.001[a]	Not applicable
C	Contaminant concentration in plant	mg/kg or pCi/g	Calculated value	Equations 1 and 5
Cw	Contaminant concentration in water	mg/L or pCi/L	Contaminant-specific	Table A3-5
Cs	Contaminant concentration in residential soil	mg/kg	Contaminant-specific	Table A3-4
F	Irrigation period	unit-less	0.25	Default value, ORNL RAIS
If	Interception fraction	unit-less	0.42	Default value, ORNL RAIS
Irr rup	Root uptake from irrigation multiplier	L/kg	Calculated value	Equation 2
Irr res	Resuspension from irrigation multiplier	L/kg	Calculated value	Equation 3
Irr dep	Aerial deposition from irrigation multiplier	L/kg	Calculated value	Equation 4
Rupv	Wet root uptake for vegetables multiplier	unit-less	Bv wet	Default value, ORNL RAIS
Res	Resuspension multiplier	unit-less	MLF	Default value, ORNL RAIS
Ir	Irrigation rate	L/m^2-day	3.62	Default value, ORNL RAIS
MLF	Plant mass loading factor	unit-less	0.26	Default value, ORNL RAIS
P	Area density for root zone	kg/m^2	240	Default value, ORNL RAIS
T	Translocation factor	unit-less	1	Default value, ORNL RAIS
tb	Long-term deposition and buildup	day	10950	Default value, ORNL RAIS
Tr	Half-life	day	Chemical-specific[a]	Rittman (2004)
tv	Aboveground exposure time	day	60	Default value, ORNL RAIS
tw	Weathering half-life	day	14	Default value, ORNL RAIS
Yv	Plant yield (wet)	kg/m^2	2	Default value, ORNL RAIS
Lb	Effective rate for removal	1/day	Li + Lhl	Default value, ORNL RAIS
LE	Decay for removal on produce	1/day	Li + (0.693/tw)	Default value, ORNL RAIS
Lhl	Soil leaching rate	1/day	0.000027	Default value, ORNL RAIS
Li	Decay	1/day	0.693/Tr*	Default value, ORNL RAIS

[a] Radionuclides only.
ORNL = Oak Ridge National Laboratory
RAIS = Risk Assessment Information System

Table A3-8. Summary of Transfer Coefficients Used in Tissue Modeling Calculations.

	Fruits and Vegetables (bv wet) kg/kg		Beef and Dairy Cattle Fodder (bv wet) kg/kg		Beef (Fb) day/kg		Dairy Products (Fm) day/kg	
I-129	0.00454	a	0.01	c	0.04	d	0.012	d
Tc-99	3.44584	a	39.6	c	1.00E-04	d	1.40E-04	d
Tritium	1	h	--	g	--	g	--	g
Cadmium	0.18	b	--	b	--	d	--	d
Carbon tetrachloride	0.18	b	0.18	b	1.69E-05	d	5.34E-06	d
Chloroform	0.554	b	0.554	b	2.33E-06	d	7.37E-07	d
Chromium	0.0002	b	0.0002	b	9.00E-03	d	1.00E-05	d
Chromium (VI)	0.0002	b	0.0002	b	9.00E-03	d	1.00E-05	d
Manganese	0.055	b	--	f	--	f	--	f
Methylene chloride	1.45	b	1.45	b	4.45E-07	d	1.40E-07	d
Nitrate	--	e	--	e	--	e	--	e
PCE	0.0822	b	0.0822	b	6.28E-05	d	1.98E-05	d
TCE	0.304	b	0.304	b	6.58E-06	d	2.08E-06	d
Thallium	0.00012	b	--	f	--	f	--	f
Uranium	0.001888	b	0.001888	b	3.00E-04	d	4.00E-04	d

[a] The transfer coefficients used to estimate concentrations in fruits and vegetables for radionuclides are based on the weighted average of Bv (dry weight) values presented in *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment* (Rittman 2004) for leafy vegetables, root vegetables, and fruits relative to the consumption rates for the residential farmer. The transfer coefficients were adjusted from dry weight to wet weight by applying the dry to wet ratio of 0.2 presented in Rittman (2004).

[b] The transfer coefficients used to estimate concentrations in fruits and vegetables, and cattle fodder for contaminants, were obtained from Rittman (2004). The transfer coefficients for the organic contaminants are based on the organic carbon-water partition coefficient. The transfer coefficients were adjusted from dry weight to wet weight by applying the dry to wet ration of 0.2 presented in Rittman (2004).

[c] The transfer coefficients used to estimate concentrations in cattle fodder for radionuclides are based on the values presented in Rittman (2004) for leafy vegetables. The transfer coefficients were adjusted from dry weight to wet weight by applying the dry to wet ratio of 0.22 presented in Rittman (2004) for fodder.

[d] The transfer coefficients used to estimate concentrations in beef tissue and dairy products were obtained from Rittman (2004).

[e] Contaminant does not bioaccumulate and the food chain pathways are incomplete for this contaminant.

[f] Value obtained from Oak Ridge National Laboratory's Risk Assessment Information System (RAIS) (http://rais.ornl.gov).

[g] Tritium in the food chain is evaluated differently than the other radionuclides. See Section A3.2.3 of this appendix for discussion on tritium.

COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A3-9. Beef Tissue and Dairy Products Modeling Calculations, Residential Farmer, 200-ZP-1 Operable Unit Groundwater.

$$Cb = Fb \times [(Cp \times Qp \times fp \times fs) + (Cw \times CF \times Qw)] \quad \text{Equation 1}$$

$$Cm = Fm \times [(Cp \times Qp \times fp \times fs) + (Cw \times CF \times Qw)] \quad \text{Equation 2}$$

Variable	Variable Definition	Units	Value	Source
Cb	Contaminant concentration in beef	mg/kg	Calculated value	Equation 1
Cm	Contaminant concentration in dairy products	mg/kg	Calculated value	Equation 2
Cp	Contaminant concentration in fodder	mg/kg	Calculated value	Table A3-5 or A3-6
CF	Conversion factor	kg/g	0.001[a]	Not applicable
Cw	Contaminant concentration in water	mg/L	Site-specific	Analytical data
fp	Fraction of year animal is onsite	unit-less	1	Default value, ORNL RAIS
fs	Fraction of animal's food from site	unit-less	1	Default value, ORNL RAIS
Fb	Beef transfer coefficient	day/kg	Contaminant-specific	Table A3-8
Fm	Dairy products transfer coefficient	day/kg	Contaminant-specific	Table A3-8
Qp	Quantity of pasture ingested	kg/day	11.77	Default value, ORNL RAIS
Qw	Quantity of water ingested	L/day	53	Default value, ORNL RAIS

[a] Radionuclides only.
ORNL = Oak Ridge National Laboratory
RAIS = Risk Assessment Information System

Table A3-10. Construction Worker Exposures to Soil – Exposure Assumptions and Intake Equations.

Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):

Ingestion = CS x IR x EF x ED x CF / ATnc x BW

Inhalation = CS x InhR x EF x ED x (1/PEF or VF) / ATnc x BW

Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):

Ingestion = CS x IR x EF x ED x CF / ATca x BW

Dermal absorption = CS x SA x AF x ABS x EF x ED x CF / ATca x BW

Inhalation = CS x InhR x EF x ED x (1/PEF or VF) / ATca x BW

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion = CS x IR x EF x ED x CF2

Inhalation = CS x InhR x EF x ED x (1/PEF) x CF3

Intake Parameter		Value	Unit	Source
ABS	Absorption factor	Contaminant-specific	unit-less	*ProUCL Version 3.0 User Guide*, (EPA/600/R04/079)
AF	Soil to skin adherence factor	0.3	mg/cm^2	Default value, OSWER Directive 9355.4-24
ATca	Averaging time (carcinogen)	25,550	days	Default value, OSWER Directive 9355.4-24
ATnc	Averaging time (noncarcinogen)	ED x 365 days/year	days	Default value, OSWER Directive 9355.4-24
BW	Body weight	70	kg	Default value, OSWER Directive 9355.4-24
CF	Conversion factor	1.00E-06	kg/mg	Not applicable
CF2	Conversion factor 2	1.00E-03	g/mg	Not applicable
CF3	Conversion factor 3	1.00E+03	g/kg	Not applicable
CS	Contaminant concentration in soil	Contaminant-specific	mg/kg or pCi/g	Analytical data
ED	Exposure duration	1	years	Default value, OSWER Directive 9355.4-24
EF	Exposure frequency:			
	216-Z-1A tile field	30	days/year	Site-specific, OSWER Directive 9355.4-24
	216-Z-8 french drain	30	days/year	Site-specific, OSWER Directive 9355.4-24
	216-A-8 Crib	30	days/year	Site-specific, OSWER Directive 9355.4-24
InhR	Inhalation rate	20	m^3/day	Default value, OSWER Directive 9355.4-24
IR	Ingestion rate	330	mg/day	Default value OSWER Directive 9355.4-24
PEF	Particulate emission factor	2.72E+09	m^3/kg	Site-specific, OSWER Directive 9355.4-24
SA	Surface area	3300	cm^2	Default value, OSWER Directive 9355.4-24
VF	Volatilization factor	Contaminant-specific	m^3/kg	OSWER Directive 9355.4-24

COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
OSWER = EPA Office of Solid Waste and Emergency Response

Table A3-11. Summary of Volatilization Factor and Particulate Emission Factor Inputs and Equations. (2 sheets)

$$D_A = \{[(q_a^{10/3} \times D_i \times H') + (q_w^{10/3} \times D_w)]/n^2\} / \{p_b k_{oc} f_{oc} + q_w + q_a H'\}$$

Parameter	Definition (Units)	Value	Source
q_a	Air-filled soil porosity (L_{air}/L_{soil})	0.28	Default value, OSWER Directive 9355.4-24
D_i	Diffusivity in air (cm^2/s)	Contaminant-specific	Table 37, page 137 of EPA/540/R-95/128
H'	Henry's Law constant (unit-less)	Contaminant-specific	Table 36, page 134 of EPA/540/R-95/128
q_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15	Default value, OSWER Directive 9355.4-24
D_w	Diffusivity in water (cm^2/s)	Contaminant-specific	Table 37, page 137 of EPA/540/R-95/128
n	Total soil porosity (L_{pore}/L_{soil})	0.43	$1-(p_b/p_s)$
p_b	Dry soil bulk density (g/cm^3)	1.5	Default value, OSWER Directive 9355.4-24
p_s	Soil particle density (g/cm^3)	2.65	Default value, OSWER Directive 9355.4-24
k_{oc}	Soil organic carbon-water partition coefficient (cm^3/g)	Contaminant-specific	Table 39, page 143 of EPA/540/R-95/128. The larger of the calculated K_{oc} or measured K_{oc} was used.
f_{oc}	Organic carbon content (g/g)	0.006	Default value, OSWER Directive 9355.4-24

$$VF = Q/C \times (1/F_D)^* \times [(3.14 \times D_A \times T)^{1/2} / (2 \times p_b \times D_A)] \times 10^{-4}$$

(Note: The F_D factor is only used with the Q/C_{sa} dispersion coefficient.)

Parameter	Definition (Units)	Value	Source
Q/C_{vol} [Q/C_{sa}]	Dispersion coefficient for volatiles (subchronic dispersion coefficient) (g/m^2-s per kg/m^3)	71.23 [14.31]	Site-specific. Used Boise, Idaho defaults from OSWER Directive 9355.4-24. (EPA's subchronic dispersion coefficient default from Exhibit D-3.)
F_D	Dispersion correction factor (unit-less); the F_D factor is only used with the Q/C_{sa} dispersion coefficient	0.19	Default value, OSWER Directive 9355.4-24
T (well driller)	Exposure interval (s)	4.32E+05	Site-specific; total time over which well drilling occurs (OSWER Directive 9355.4-24)
T (residential farmer)	Exposure interval (s)	9.50E+08	Default value, OSWER Directive 9355.4-24
p_b	Dry soil bulk density (g/cm^3)	1.5	Default value, OSWER Directive 9355.4-24
VF	Volatilization factor (m^3/kg)	Contaminant-specific	Calculated value

Table A3-11. Summary of Volatilization Factor and Particulate Emission Factor Inputs and Equations. (2 sheets)

$$PEF = [Q/C \times 3600] / [0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)]$$

Parameter	Definition (Units)	Value	Source
Q/C	Dispersion coefficient (g/m^2-s per kg/m^3)	71.23	Site-specific. Used Boise, Idaho defaults from OSWER Directive 9355.4-24.
V	Fraction of vegetative cover (unit-less)	0.5	Default value, OSWER Directive 9355.4-24
U_m	Mean annual wind speed (m/s)	3.4	Site-specific (Rittman 2004)
U_t	Equivalent threshold value of wind speed at 7 m (m/s)	11.32	Default value, OSWER Directive 9355.4-24
F(x)	Function dependent on U_m/U_t	0.194	Default value, OSWER Directive 9355.4-24
PEF	Particulate emission factor (m^3/kg)	2.72E+09	Calculated value

EPA = U.S. Environmental Protection Agency
OSWER = EPA Office of Solid Waste and Emergency Response

Table A3-12. Residential Farmer Exposures to Soil – Exposure Assumptions and Intake Equations. (2 sheets)

Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):

Ingestion child =	CS x IRc x EF x EDc x CF / ATnc-c x BWc
Dermal absorption child =	CS x SAc x AFc x AB x EF x EDc x CF / ATnc-c x BWc
Inhalation child =	InhRc x EF x EDc x (1/PEF or VF) / ATnc-c x BWc
Ingestion adult =	CS x IRs x EF x EDa x CF / ATnc-a x BWa
Dermal absorption adult =	CS x SAa x AFa x AB x EF x EDa x CF / ATnc-a x BWa
Inhalation adult =	InhRa x EF x EDa x (1/PEF or VF) / ATnc-a x BWa

Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):

Ingestion child/adult =	(CS x EF x CF / ATca) x (IRc x EDc/ BWc + IRa x EDa/ Bwa)
Dermal absorption child/adult =	(CS x EF x AB / ATca) x (SAc x AFc x EDc / BWc + SAa x AFa x EDa / BWa)
Inhalation child/adult =	(CS x EF x (1/PEF of VF) / ATca) x (InhRc xEDc / BWc + InhRa xEDa / Bwa)

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	(CS x EF x CF2) x (IRc x EDc + IRa x EDa)
Inhalation child/adult =	(CS x EF x (1/PEF) x CF3) x (InhRc xEDc + InhRa xEDa)

Intake Parameter			Value	Unit	Source
AB	Absorption factor		Contaminant-specific	unit-less	EPA 540/R/99/05
AF	Adherence factor, soil:				
	AFa:	Adult	0.07	mg/cm^2-day	Default value, OSWER Directive 9355.4-24
	Afc:	Child	0.2	mg/cm^2-day	Default value, OSWER Directive 9355.4-24
AT	Averaging time:				
	Noncarcinogenic		(ED x 365 days)		
	Atnc-a:	Adult	8,760	days	Default value, OSWER Directive 9355.4-24
	Atnc-c:	Child	2,190	days	Default value, OSWER Directive 9355.4-24
	Carcinogenic				
	Atca:	Lifetime (adult/child)	25,550	days	Default value, OSWER Directive 9355.4-24
BW	Body weight:				
	Bwa:	Adult	70	kg	Default value, OSWER Directive 9355.4-24
	BWc:	Child	15	kg	Default value, OSWER Directive 9355.4-24
CF	Conversion factor		1E-06	kg/mg	Not applicable
CF2	Conversion factor 2		1E-03	g/mg	Not applicable
CF3	Conversion factor 3		1E+03	g/kg	Not applicable
CS	Contaminant concentration in soil		Contaminant-specific	mg/kg or pCi/g	Analytical data
EF	Exposure frequency (adult/child)		350	days/yr	Default value, OSWER Directive 9355.4-24

Table A3-12. Residential Farmer Exposures to Soil – Exposure Assumptions and Intake Equations. (2 sheets)

Intake Parameter			Value	Unit	Source
ED	Exposure duration:				
	EDa:	Adult	24	years	Default value, OSWER Directive 9355.4-24
	EDc:	Child	6	years	Default value, OSWER Directive 9355.4-24
InhR	Inhalation rate (adult/child):				
	InhRa:	Adult	20	m^3/day	Default value, OSWER Directive 9285.6-03
	InhRc:	Child	10	m^3/day	Default value, OSWER Directive 9285.6-03
IR	Ingestion rate, soil:				
	IRa:	Adult	100	mg/day	Default value, OSWER Directive 9355.4-24
	IRc:	Child	200	mg/day	Default value, OSWER Directive 9355.4-24
PEF	Particulate emission factor		2.72E+09	m^3/kg	Site-specific, OSWER Directive 9355.4-24
SA	Skin surface area:				
	SAa:	Adult	5,700	cm^2	Default value, OSWER Directive 9355.4-24
	SAc:	Child	2,800	cm^2	Default value, OSWER Directive 9355.4-24
VF	Volatilization factor		Contaminant-specific	m^3/kg	OSWER Directive 9355.4-24

COPC = contaminant of potential concern
OSWER = U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response

Table A3-13. Intake Assumptions Children (2 to 6 Years) and Adults – Residential Exposures Ingestion, Dermal, and Inhalation Exposure to Tap Water. (2 sheets)

Water Intake Factors - Nonradioactive COCs, Non-Cancer (mg/kg BW-day):

Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)

Ingestion child =	Cwx IRc x EF x EDc x CF/ ATc x BWc
Dermal absorption child =	DAev-c x SAc x EVw x EF x EDc x / ATc x BWc
Inhalation child =	Cw x InhRc x EF x EDc x VFw x CF / ATc x BWc
Ingestion adult =	Cw x IRa x EF x EDa x CF/ ATa x BWa
Dermal absorption adult =	DAev-a x SAa x EVw x EF x EDa x / ATa x BWa
Inhalation adult =	Cw x InhRa x EF x EDa x VFw x CFw / ATa x BWa

Water Intake Factors - Nonradioactive COCs/COPCs, Cancer (mg/kg BW-day):

Ingestion child/adult =	(Cw x EF x CF / ATca) x (IRc x EDc/ BWc + IRa x EDa/ Bwa)
Dermal absorption child/adult =	(DAev-a x EF x EVw / ATca) x (SAc x EDc / BWc + SAa x EDa / BWa)
Inhalation child/adult =	(Cw x EF x VFw x CFw / ATca) x (InhRc xEDc / BWc + InhRa xEDa / Bwa)

Water Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	Cw x IRa x EF x ED
Inhalation child/adult =	Cw x InhRa x EF x ED x VFrad

Intake Parameter		Value	Unit	Source
CW	Contaminant concentration in water	Contaminant-specific	µg/L or pCi/L	Analytical data
CF	Conversion factor	1.00E-03	mg/µg	Not applicable
EF	Residential exposure frequency	350	days/yr	Default value, EPA 540/1-89/002
ED	Residential exposure duration	30	years	Default value, EPA 540/1-89/002
EDa	Residential exposure duration - adult	24	years	Default value, EPA 540/1-89/002
EDc	Residential exposure duration -child	6	years	Default value, EPA 540/1-89/002
IRa	Ingestion rate-adult	2	L/day	Default value, EPA 540/1-89/002
IRc	Ingestion rate-child	1	L/day	Default value, EPA 540/1-89/002
SAa	Skin surface area -adult	18,000	cm^2	Default value, EPA 540/R/99/05
SAc	Skin surface area - child	6,600	cm^2	Default value, EPA 540/R/99/05
EVw	Event frequency-water contact	1	events/day	Default value, EPA 540/R/99/05
DAev	Absorbed dose per event	Contaminant-specific	mg/cm^2-event	Calculated value (see Table A3-14)
InhRa	Inhalation rate - adult	20	m^3/day	Default value, EPA/600/P-95-002Fa
InhRc	Inhalation rate - child	10	m^3/day	Default value, EPA/600/P-95-002Fa
VFw	Volatilization factor for water	0.5	L/m^3	Default value, EPA/600/P-95-002Fa
VFrad	Volatilization factor for radionuclides	Radionuclide-specific	m^3/L	EPA 402-R-99-001
BWa	Body weight - adult	70	kg	Default value, EPA 540/1-89/002
BWc	Body weight - child	15	kg	Default value, EPA 540/1-89/002

Table A-13. Intake Assumptions Children (2 to 6 Years) and Adults – Residential Exposures Ingestion, Dermal, and Inhalation Exposure to Tap Water. (2 sheets)

Intake Parameter		Value	Unit	Source
ATa	Averaging time - adult (noncarcinogen)	8,760	days	Default value, EPA 540/1-89/002 (EDa x 365)
ATc	Averaging time - child (noncarcinogen)	2,190	days	Default value, EPA 540/1-89/002 (EDc x 365)
ATca	Averaging time (carcinogen)	25,550	days	Default value, EPA 540/1-89/002 (70 years x 365)

COC = contaminant of concern
COPC = contaminant of potential concern
OSWER = U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response

Table A3-14. Absorbed Dose per Event Dermal Exposure to Tap Water and Irrigation Water.

DA_{event}:

Organic Contaminants:

If $t_{event} \leq t^*$, then $DA_{event} = 2\ FA \times PC \times Cw \times \sqrt{\frac{(6 \times tau_{event}) \times t_{event}}{Pi}}$ Equation 1

If $t_{event} > t^*$, then $DA_{event} = FA \times PC \times Cw \times \left(\frac{t_{event}}{1+B} + (2 \times Tau_{event}) \times \frac{[1 + (3 \times B) + (3 \times B^2)]}{(1 \times B)^2} \right)$ Equation 2

Inorganic Contaminants:

$DA_{event} = PC \times t_{event} \times Cw$ Equation 3

Intake Parameter		Value	Source
DA_{event}	Absorbed dose per event (mg/cm^2-event)	Calculated value	Equation 1, 2, or 3
FA	Fraction absorbed (dimension-less)	Contaminant-specific	Exhibit B-3 of EPA 540/R/99/05
PC	Permeability constant (cm/hr)	Contaminant-specific	Exhibit B-3 of EPA 540/R/99/05
Cw	Contaminant concentration in water (mg/cm^3)	Site-specific	Analytical data
t_{event}	Event duration (hr/event):		
	Duration for adult showering event	0.17	EPA/600/P-95-002Fa
	Duration for child bathing event	0.33	EPA/600/P-95-002Fa
	Duration for adult irrigation event	2	Professional judgment
t*	Time to reach steady-state (hr) = 2.4 x tau_{event}	Contaminant-specific	Exhibit B-3 of EPA Region 9 preliminary remediation goal
tau_{event}	Lag time per event (hr/event)	Contaminant-specific	Exhibit B-3 of EPA 540/R/99/05
B	Dimension-less ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimension-less)	Contaminant-specific	Exhibit B-3 of EPA 540/R/99/05

Table A3-15. Intake Assumptions Adults - Residential Farmer Dermal and Inhalation Exposure to Groundwater During Irrigation.

Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)

Dermal Absorption adult = DAev-a x SAa x EVw x EF x ED x / ATnc x BWa

Inhalation adult = Cw x InhRa x EF x ED x ET x VFw x CFw / ATnc x BWa

Water Intake Factors - Nonradioactive COPCs, Cancer (mg/kg BW-day)

Dermal Absorption adult = DAev-a x SAa x EVw x EF x ED x / ATca x BWa

Inhalation adult = Cw x InhRa x EF x ED x ET x VFw x CFw / ATca x BWa

Water Intake Factors - Radioactive COPCs (pCi)

Inhalation adult = Cw x InhRa x EF x ED x ET x VFrad

Intake Parameter		Value	Unit	Source
CW	Contaminant concentration in water	Contaminant-specific	µg/L or pCi/L	Analytical data
CF	Conversion factor	1.00E-03	mg/µg	Not applicable
EF	Irrigation exposure frequency	90	days/yr	ORNL RAIS
ED	Residential farmer exposure duration	30	years	Default value, EPA 540/1-89/002
ET	Irrigation exposure time	2	hours/day	Professional judgment
SAa	Skin surface area - adult	1,933	cm^2	Site-specific, forearms and hands, EPA 540/R/99/05
EVw	Event frequency - water contact	1	events/day	ORNL RAIS
DAev	Absorbed dose per event	Contaminant-specific	mg/cm^2-event	Calculated value (see Table A3-14)
InhRa	Inhalation rate - adult	1.5	m^3/hr	EPA/600/P-95-002Fa
VFw	Volatilization factor for water	2.00E-02	L/m^3	EPA Region 8 (EPA 8EPR-PS)
VFrad	Volatilization factor for radionuclides	Radionuclide-specific	m^3/L	EPA Region 8 (EPA 8EPR-PS)
BWa	Body weight - adult	70	kg	Default value, EPA 540/1-89/002
ATnc	Averaging time (noncarcinogen)	10,950	days	Default value, EPA 540/1-89/002 (ED x 365)
ATca	Averaging time (carcinogen)	25,550	days	Default value, EPA 540/1-89/002 (70 years x 365)

COPC = contaminant of potential concern
ORNL = Oak Ridge National Laboratory
RAIS = Risk Assessment Information System

Table A3-16. Intake Assumptions Child and Adults – Residential Farmer Food Chain Pathways.

Tissue Intake Factors - Nonradioactive COCs, Non-Cancer (mg/kg BW-day):

Ingestion child/adult = Cti x IRti x EF x ED x CF / ATnc

Tissue Intake Factors - Nonradioactive COCs, Cancer (mg/kg BW-day):

Ingestion child/adult = Cti x IRti x EF x ED x CF / ATca

Tissue Intake Factors - Radioactive COCs (pCi):

Ingestion adult = Cti x IRti x EF x ED

Intake Parameter		Value	Unit	Source
Cti	Contaminant concentration in tissue	Contaminant-specific	mg/kg or pCi/g	Modeled value, see Tables A3-5 and A3-6
CF	Conversion factor	1.00E-03	kg/g	Not applicable
IRpa	Ingestion rate of tissue:			
	Plant ingestion rate	4.56	g/kg-day	Table 13-12 in EPA/600/P-95-002Fa
	Beef ingestion rate	2.41	g/kg-day	Table 13-22 in EPA/600/P-95-002Fa
	Dairy ingestion rate	10	g/kg-day	Table 13-32 in EPA/600/P-95-002Fa
	Plant ingestion rate	4.56	g/kg-day	Table 13-12 in EPA/600/P-95-002Fa
	Beef ingestion rate	2.41	g/kg-day	Table 13-22 in EPA/600/P-95-002Fa
	Dairy ingestion rate	10	g/kg-day	Table 13/32 in EPA/600/P-95-002Fa
EF	Residential farmer exposure frequency	350	days/yr	ORNL RAIS
ED	Residential farmer exposure duration	30	years	Default value, EPA 540/1-89/002
ATnc	Averaging time (noncarcinogen)	10,950	days	Default value, EPA 540/1-89/002 (ED x 365)
ATca	Averaging time (carcinogen)	25,550	days	Default value, EPA 1989540/1-89/002 (70 years x 365)

COC = contaminant of concern
ORNL = Oak Ridge National Laboratory
RAIS = Risk Assessment Information System

Table A3-17. Well Driller Exposures to Well Cuttings – Exposure Assumptions and Intake Equations.

Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):

Ingestion =	CS x IR x ED x CF / ATnc x BW
Dermal absorption =	CS x SA x AF x ABS x ED x CF / ATnc x BW
Inhalation =	InhR x ED x (1/PEF or VF) / ATnc x BW

Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):

Ingestion =	CS x IR x ED x CF / ATca x BW
Dermal absorption =	CS x SA x AF x ABS x ED x CF / ATca x BW
Inhalation =	InhR x ED x (1/PEF or VF) / ATca x BW

Soil Intake Factors - Radioactive COPCs, Cancer (pCi):

Ingestion =	CS x IR x ED x CF2
Inhalation =	CS x InhR x ED x (1/PEF or VF) x CF3

Intake Parameter		Value	Unit	Source
ABS	Absorption factor	Contaminant-specific	unit-less	EPA 540/R/99/05
AF	Soil to skin adherence factor	0.2	mg/cm^2	Default value, OSWER Directive 9355.4-24
ATca	Averaging time (carcinogen)	25,550	days	Default value, OSWER Directive 9355.4-24
ATnc	Averaging time (noncarcinogen)	ED x 365 days/yr	days	Default value, OSWER Directive 9355.4-24
BW	Body weight	70	kg	Default value, OSWER Directive 9355.4-24
CF	Conversion factor	1.00E-06	kg/mg	Not applicable
CF2	Conversion factor 2	1.00E-03	g/mg	Not applicable
CF3	Conversion factor 3	1.00E+03	g/kg	Not applicable
CS	Contaminant concentration in soil	Contaminant-specific	mg/kg	Analytical data
ED	Exposure duration	5	days	Site-specific
InhR	Inhalation rate	20	m^3/day	Default value, OSWER Directive 9355.4-24
IR	Ingestion rate	100	mg/day	Default value, OSWER Directive 9355.4-24
PEF	Particulate emission factor	2.72E+09	m^3/kg	Site-specific, OSWER Directive 9355.4-24
SA	Surface area	3,300	cm^2	Default value, OSWER Directive 9355.4-24
VF	Volatilization factor	Contaminant-specific	m^3/kg	OSWER Directive 9355.4-24

COPC = contaminant of potential concern
OSWER = U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response

Table A3-18. Intake Assumptions Adults – Industrial Exposures. Ingestion and Inhalation Exposure to Tap Water.

Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)

Ingestion adult = Cw x IRa x EF x EDa x CF/ ATnc x BWa

Inhalation adult = Cw x InhRa x EF x ED x ET x VFw x CFw / ATnc x BWa

Water Intake Factors - Nonradioactive COPCs, Cancer (mg/kg BW-day)

Ingestion adult = Cw x IRa x EF x ED x CF/ ATca x BWa

Inhalation adult = Cw x InhRa x EF x ED x ET x VFw x CFw / ATca x BWa

Water Intake Factors - Radioactive COPCs (pCi)

Ingestion adult = Cw x IRa x EF x ED

Inhalation adult = Cw x InhRa x EF x ET x ED x VFrad

Intake Parameter		Value	Unit	Source
CW	Contaminant concentration in water	Contaminant-specific	µg/L or pCi/L	Analytical data
CF	Conversion factor	1.00E-03	mg/µg	Not applicable
EF	Industrial exposure frequency	250	days/yr	Default value, OSWER Directive 9285.6-03
ED	Industrial exposure duration	25	years	Default value, OSWER Directive 9285.6-03
ET	Exposure time	3	hour/day	Site-specific
IRa	Ingestion rate - adult	1	L/day	Default value, OSWER Directive 9285.6-03
InhRa	Inhalation rate - adult	1.5	m^3/hr	Default value, EPA/600/P-95-002Fa
VFw	Volatilization factor for water	0.5	L/m^3	Default value, EPA/600/P-95-002Fa
VFrad	Volatilization factor for radionuclides	Radionuclide-specific	m^3/L	EPA 402-R-99-001
BWa	Bodyweight - adult	70	kg	Default value, EPA 540/1-89/002
ATna	Averaging time (noncarcinogen)	9,125	days	Default value, EPA 540/1-89/002 (EDa x 365)
ATca	Averaging time (carcinogen)	25,550	days	Default value, EPA 540/1-89/002 (70 years x 365)

COC = contaminant of concern
OSWER = U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response

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A4.0 TOXICITY CRITERIA

The purpose of the toxicity assessment is to weigh the available and relevant evidence regarding the potential for contaminants to cause adverse health effects in exposed individuals and to provide a quantitative estimate of the relationship between the magnitude of exposure and the likelihood of adverse effects (EPA 540/1-89/002). A fundamental principle of toxicology is that the dose determines the severity of the effect. Accordingly, the toxicity criteria describe the quantitative relationship between the dose of a contaminant and the type and incidence of the toxic effect. This relationship is referred to as the dose-response. The types of toxicity criteria are described in the following subsections. Tables A4-1 and A4-2 present the carcinogenic toxicity criteria for the nonradionuclides and the radionuclides, respectively, for the COPCs in this assessment. Table A4-3 lists the noncarcinogenic toxicity criteria used for the COPCs in this assessment. Attachment A-5 of this appendix contains discussions of the specific criteria and associated health effects for each COPC.

A dose-response evaluation is the process of quantitatively evaluating toxicity information and characterizing the relationship between the dose of the contaminant and the incidence of adverse health effects in the exposed population. From this quantitative dose-response relationship, toxicity criteria are derived that can be used to estimate the potential for adverse health effects as a function of exposure to the contaminant. Toxicity values are combined with the summary intake factors (SIFs) listed in Tables A3-10, A3-12, and A3-13 through A3-18 and provide estimates of carcinogenic risks or indicate the potential for non-cancer health effects for various exposure scenarios. Exposure to contaminants can result in cancer or non-cancer effects, which are characterized separately. Essential dose-response criteria are the EPA slope factor (SF) values for assessing cancer risks and the EPA-verified reference dose (RfD) values for evaluating non-cancer effects. The following hierarchy was used to select toxicity criteria:

1. Integrated Risk Information System (IRIS) database
2. EPA Interim Toxicity Criteria published by the National Center for Environmental Assistance (NCEA)
3. *Health Effects Assessment Summary Tables* (HEAST) (EPA 540/R-97-036)
4. Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profiles.

A4.1 CANCER EFFECTS

The cancer SF (expressed as $[mg/kg\text{-}day]^{-1}$) expresses excess cancer risk as a function of dose. The dose-response model is based on high- to low-dose extrapolation and assumes that there is no lower threshold for the initiation of toxic effects. Specifically, cancer effects observed at high doses in laboratory animals or from occupational or epidemiological studies are extrapolated using mathematical models to low doses common to environmental exposures. These models are essentially linear at low doses, so no dose is without some risk of cancer. The cancer SFs for each of the nonradionuclide COPCs are presented in Table A4-1.

The SFs for radionuclides are incremental cancer risks resulting from exposure to radionuclides via inhalation, ingestion, and external exposure pathways. The SFs represent the probability of cancer incidence as a result of unit exposure to a given radionuclide averaged over a lifetime. The cancer SFs for the radionuclide COPCs are presented in Table A4-2. These values are from

the HEAST (EPA 540/R-97-036) update on April 16, 2001, which is based on Federal Guidance Report No. 13 (EPA 402-R-99-001). Federal Guidance Report No. 13 incorporates state-of-the-art models and methods that take into account age- and gender-dependence of radionuclide intake, metabolism, dosimetry, radiogenic cancer risk, and competing risks.

The EPA has classified all radionuclides as known human carcinogens based on epidemiological studies of radiogenic cancers in humans (EPA 402-R-99-001). Cancer SFs for radionuclides are central tendency estimates of the age-averaged increased lifetime cancer risk. This is in contrast to the methodology for nonradionuclide SFs, where upper-bound estimates of cancer potency are often used.

A4.2 NON-CANCER EFFECTS

Chronic RfDs are defined as an estimate of a daily exposure level for the human population, including sensitive subpopulations, that are likely to be without appreciable risk of non-cancer effects during a lifetime of exposure (EPA 402-R-99-001). Chronic RfDs are specifically developed to be protective for long-term exposure to a contaminant and are generally used to evaluate the potential non-cancer effects associated with exposure periods of 7 years to a lifetime. The RfDs are expressed as mg/kg-day and are calculated using lifetime average body weight and intake assumptions. The non-cancer toxicity criteria for nonradionuclide COPCs are presented in Table A4-3.

The RfD values are derived from experimental data on the no-observed-adverse-effect level (NOAEL) or the lowest-observed-adverse-effect level (LOAEL) in animals or humans. The NOAEL is the highest tested contaminant dose given to animals or humans that has not been associated with any adverse health effects. The LOAEL is the lowest contaminant dose at which health effects have been reported. The RfDs are calculated by the EPA by dividing the NOAEL or LOAEL by a total uncertainty factor, which represents a combination of individual factors for various sources of uncertainty associated with the database for a particular contaminant or with the extrapolation of animal data to humans. The IRIS database also assigns a level of confidence in the RfD. The level of confidence is rated as high, medium, or low, based on confidence in the study and confidence in the database.

Chronic RfDs, as discussed above, are used in the evaluation of onsite worker exposures because the long-term exposure (7 years to a lifetime) to relatively low-contaminant concentrations are of greatest concern for that population. However, for the construction worker scenario evaluated in this assessment, EPA guidance (EPA 530-F-02-052) recommends evaluating construction exposures over a one-year duration. A one-year timeframe is defined by EPA 540/1-89/002 as a subchronic exposure (i.e., lasting between 2 weeks and 7 years). Chronic RfDs are designed to be protective over a lifetime and reflect the safe dose level for chronic, rather than subchronic, exposures. Therefore, according to EPA (see Section 5.3.1 of EPA/630/P-02/002F), construction worker non-cancer hazards should be evaluated using subchronic RfDs (cancer risks are not affected because all cancer risks are evaluated based on lifetime exposure). EPA's HEAST (EPA 540/R-97-036) is the only published EPA source of subchronic criteria; however, subchronic criteria have been calculated by EPA since 1997 for specific contaminants. The ATSDR has minimum risk levels for intermediate exposures (defined as >14 to 364 days). However, these minimum risk levels do not necessarily use the same information as EPA RfDs and do not always correspond to EPA values. Therefore, these risk levels are difficult to use

with EPA toxicity criteria as they often do not represent an "apples-to-apples" comparison with EPA criteria.

In EPA's methodology used to derive chronic RfDs, uncertainty factors (UFs) are applied to the NOAEL or LOAEL of the critical research study. These UFs are used to address the uncertainties/variabilities that are present in the data set for each individual contaminant (see Section 4.4.5 of EPA/630/P-02/002F). The uncertainty factors (up to 5) are assigned values of either 10 or 3, these values are multiplied together, and then the critical study NOAEL or LOAEL is divided by the total UF (see Section 4.4.5 of EPA/630/P-02/002F). In general, EPA has estimated subchronic criteria from chronic criteria by removing the UF of 10 to account for the use of a subchronic study to estimate chronic exposure; therefore, the vast majority of the subchronic criteria presented in HEAST are an order of magnitude larger than their corresponding chronic values.

In this assessment, subchronic criteria would apply to both well driller and construction worker exposures; however, only radionuclides were evaluated for the construction worker. Therefore, subchronic criteria were used to evaluate nonradionuclide contaminants for well drillers. The subchronic criteria were obtained from the following sources:

- HEAST: Subchronic criteria from HEAST were used if the chronic RfD has not been updated since 1997 (i.e., the subchronic criteria are based on the same critical study as the chronic criteria).
- IRIS: Where the chronic criteria have been updated since 1997 and are in IRIS database, the IRIS file was reviewed. If a UF was used to decrease a chronic value to account for subchronic to chronic exposure, that UF was removed to obtain a subchronic criteria. In addition, if the NOAEL or LOAEL was adjusted from a 5-day exposure to a 7-day exposure, that adjustment was removed to reflect the worker population of concern (see Sections 4.4.2 and 4.4.3 in EPA/630/P-02/002F).
- NCEA (EPA's toxicity research arm): Where the source of the chronic criteria is the NCEA (this information is listed on the EPA Region 9 PRG list), the backup documentation that NCEA used to derive the chronic criteria was reviewed to evaluate whether sufficient information was provided to make an adjustment to the chronic value as described above under bullet number two.

Where information is insufficient to derive a subchronic value, the chronic RfD was used to evaluate hazards for well drillers. Table A4-3 summarizes the chronic RfDs, the subchronic RfDs, and the methods used to derive the subchronic criteria for each nonradionuclide COPC.

A4.3 ORAL TOXICITY CRITERIA

The RfDs for oral/ingestion exposures are expressed as mg/kg-day and are calculated using lifetime average body weight and intake assumptions.

A4.4 INHALATION TOXICITY CRITERIA

The criteria for inhalation are reference concentrations (RfCs) expressed in milligrams of contaminant per cubic meter of air (mg/m^3) for noncarcinogens and unit risk factors (URFs) expressed in cubic meters of air per microgram of contaminant ($m^3/\mu g$) for carcinogenic exposures. The RfCs and URFs are developed in the same way as RfDs and SFs except that they

include, as part of their development, a default inhalation rate assumption of 20 m^3 of air inhaled per day. Because the default inhalation rate is not applicable to all the receptors in this risk assessment, RfCs and URFs were converted into reference doses for inhalation (RfD_i) and inhalation slope factors (SF_i) according to the protocols presented by EPA (EPA 540/1-89/002; OSWER Directive 9285.7-53). The conversions are as follows:

$$RfD_i \text{ (mg/kg-day)} = RfC \text{ (mg/m}^3\text{)} \times 20 \text{ (m}^3\text{/day)} \times 1 / 70 \text{ (kg)}$$

$$SF_i \text{ (kg-day/mg)} = URF \text{ (m}^3\text{/}\mu\text{g)} \times 1 / 20 \text{ (m}^3\text{/day)} \times 70 \text{ (kg)} \times 10^3 \text{ (}\mu\text{g/mg)}.$$

Route-to-route extrapolation from the oral route to the inhalation route was not performed because of the toxicological uncertainties involved in assuming that contaminants are as toxic and have the same toxic endpoint by ingestion as by inhalation. Therefore, contaminants that do not have inhalation toxicity criteria were not evaluated by the inhalation route. The impacts of not evaluating all COPCs by the inhalation route are discussed in the uncertainty section.

A4.5 DERMAL TOXICITY CRITERIA

Most oral RfDs and SFs are expressed as an administered dose (i.e., the amount of substance taken into the body by swallowing). In contrast, exposure estimates for the dermal route of exposure are expressed as an absorbed dose (i.e., the amount of contaminant that is actually absorbed through the skin). Because dermal toxicity criteria are not readily available, oral toxicity values are used in conjunction with an absorption correction factor to adjust for the difference in administered to absorbed dose. The EPA recommends absorption correction factors for a limited amount of inorganic contaminants in Exhibit 4-1 of EPA 540/R/99/05. For those contaminants that do not appear on the table, the recommendation is to assume 100% absorption (EPA 540/R/99/05) (i.e., the dermal toxicity criteria would not differ from the oral toxicity criteria).

In this instance, cadmium and manganese have recommended absorption correction factors. Because EPA 540/R/99/05 does not recommend evaluating manganese via the dermal pathway in soil (the contaminant is not a COPC in water), only dermal exposure to cadmium was evaluated in soil. An absorption correction factor of 2.5% was used to derive the dermal RfD for cadmium. The specifics are discussed in the toxicity profiles for each contaminant in Attachment A-5 to this appendix.

Table A4-1. Carcinogenic Toxicity Criteria for the Nonradionuclide Contaminants of Potential Concern.

Contaminant	Oral Cancer: Slope Factor $(mg/kg\text{-}day)^{-1}$	Inhalation Cancer: Slope Factor $(mg/kg\text{-}day)^{-1}$	Tumor Type	EPA Cancer Classification[a]	Reference
1,2-Dibromo-3-chloropropane	0.8	21	—	Not classified	PPRTV
Cadmium	—	6.3	Lung (human)	B1	IRIS
Carbon tetrachloride	0.13	0.053	Liver (mice)	B2	IRIS
Chloroform	—	0.081	Liver (mice)	B2	IRIS
Chromium (III) (total)	—	—	—	D	IRIS
Chromium (VI) (hexavalent)	—	290	Lung (human)	A	IRIS
Manganese	—	—	—	D	IRIS
Methylene chloride	0.0075	0.0016	Liver (mice)	B2	IRIS
Nitrate	—	—	—	D	IRIS
PCE	0.54	0.021	Liver (mice and rats)	Not classified	CalEPA
Thallium	—	—	—	D	IRIS
TCE	0.013	0.0007	Liver, kidney, lymph, cervical, prostate	B1	CalEPA
Uranium	—	—	—	Not classified	IRIS

[a] EPA's weight-of-evidence classification system:
Group A = human carcinogen (sufficient evidence in humans)
Group B1 = probable human carcinogen (limited human data available)
Group B2 = probable human carcinogen (sufficient evidence in animals, inadequate or no evidence in humans)
Group C = possible human carcinogen (limited evidence in animals)
Group D = not classifiable as to human carcinogenicity

CalEPA = California Environmental Protection Agency
EPA = U.S. Environmental Protection Agency
IRIS = Integrated Risk Information System - Online Database (EPA 2007)
PCE = tetrachloroethylene
PPRTV = provisional peer-reviewed toxicity value
TCE = trichloroethylene

Table A4-2. Radionuclide Toxicity Criteria for Contaminants of Potential Concern.[a]

Radionuclide	Ingestion (Risk/pCi)			Inhalation (Risk/pCi)	External (Risk/yr per pCi/g)
	Soil	Food	Water		
Am-241	2.17E-10	1.34E-10	[b]	2.81E-08	2.76E-08
C-14	2.79E-12	2.00E-12	[b]	7.07E-12	7.83E-12
Cs-137	4.33E-11	3.7E-11	[b]	1.19E-11	5.32E-10
Eu-152	1.62E-11	8.70E-12	[b]	9.10E-11	5.30E-06
I-129	[b]	3.2E-10 (c)	1.50E-10	6.10E-11	6.10E-09
Np-237	1.46E-10	8.29E-11	[b]	1.77E-08	5.36E-08
Ni-63	1.79E-12	9.51E-13	[b]	1.64E-12	[b]
Pu-238	2.72E-10	1.69E-10	[b]	3.36E-08	7.22E-11
Pu-239	2.76E-10	1.74E-10	[b]	3.33E-08	2.00E-10
Pu-240	2.77E-10	1.74E-10	[b]	3.33E-08	6.98E-11
Pa-231	3.74E-10	2.26E-10	[b]	4.55E-08	1.39E-07
Ra-226	7.29E-10	5.14E-10	[b]	1.15E-08	2.29E-08
Ra-228	2.28E-09	1.43E-09	[b]	5.18E-09	(b)
Sr-90	9.18E-11	6.88E-11	[b]	1.05E-10	4.82E-10
Tc-99	7.66E-12	4.00E-12	2.80E-12	1.41E-11	8.14E-11
Th-228	2.89E-10	1.48E-10	[b]	1.32E-07	5.59E-09
Th-230	2.02E-10	1.19E-10	[b]	2.85E-08	8.19E-10
Tritium	[b]	1.40E-13	5.10E-14	5.6E-14 (d)	[b]

[a] EPA classifies all radionuclides as Group A, known human carcinogens. Values are from EPA's *Health Effects Assessment Summary Tables* (EPA 540/R-97-036), update April 16, 2001, which is based on Federal Guidance Report No. 13 (EPA 402-R-99-001).

[b] Radionuclide not evaluated by this pathway.

[c] This value is protective of ingestion of iodine-129 in dairy products. For non-dairy products, the criterion is one-half this value, or 1.6E-6 x 10.

[d] This value is protective of inhalation exposures of tritium vapors.

EPA = U.S. Environmental Protection Agency

Table A4-3. Noncarcinogenic Chronic and Subchronic Toxicity Criteria for Contaminants of Potential Concern. (3 sheets)

Contaminant	Chronic RfD (mg/kg-day)	Toxic Endpoint	Critical Study	Chronic RfD UF[a]	RfD Source	Adjustment from Chronic to Subchronic	Subchronic RfD (mg/kg-day)
Inhalation Exposures							
1,2-Dibromo-3-chloropropane	5.7E-05	Testicular effects	Subchronic rabbit	1,000	IRIS	Adjusted hours of dosing to 8 hours, removed UF of 10 for subchronic to chronic.	9.0E-04
Cadmium	None[b]	--	--	--	--	--	--
Carbon tetrachloride	None[b]	--	--	--	--	--	--
Chloroform	1.30E-02	Liver, kidney, and central nervous system toxicity	Subchronic mouse	100	NCEA	NC	NC
Chromium (III) (total)	None[b]	--	--	--	--	--	--
Chromium (VI) (hexavalent)	2.90E-05	Respiratory toxicity	Subchronic rat	300	IRIS	NC	NC
Manganese	1.4E-05	Impairment of neurobehavioral function	Human chronic occupational study	1,000	IRIS	No adjustment made because primary study is human.	1.4E-05
Methylene chloride	8.6E-01	Hepatotoxicity	2-year chronic rat	100	HEAST	NC	NC
Nitrate	None[b]	--	--	--	--	--	--
PCE	1.1E-01	--	--	--	NCEA	NC	NC
Thallium	None[b]	--	--	--	--	--	--
TCE	1.10E-02	Central nervous system, liver, and endocrine toxicity	Subchronic human occupational	1,000	EPA 2001	NC	NC
Uranium	None[b]	--	--	--	--	--	--

Table A4-3. Noncarcinogenic Chronic and Subchronic Toxicity Criteria for Contaminants of Potential Concern. (3 sheets)

Contaminant	Chronic RfD (mg/kg-day)	Toxic Endpoint	Critical Study	Chronic RfD UF[a]	RfD Source	Adjustment from Chronic to Subchronic	Subchronic RfD (mg/kg-day)
Oral Exposures							
1,2-Dibromo-3-chloropropane	2.0E-04	--	--	--	NCEA	NCEA backup is not available so the chronic RfD is used.	2.0E-04
Cadmium	1.0E-03	Proteinuria	Human chronic	10	IRIS	No adjustment made because primary study is human.	1.0E-03
Carbon tetrachloride	7.0E-04	Liver lesions	Subchronic rat	1,000	IRIS	Used unadjusted NOAEL; removed UF of 10 for subchronic to chronic.[c]	1.0E-02
Chloroform	1.0E-02	Liver, kidney, and central nervous system toxicity	Chronic dog study	100	IRIS	NC	NC
Chromium (III) (total)	1.5E+00	None observed	Chronic oral rat study	1,000	IRIS	NC	NC
Chromium (VI) (hexavalent)	3.0E-03	None reported	One-year rat drinking water study	1,000	IRIS	NC	NC
Manganese	7.0E-02	Central nervous system	Human chronic	1	IRIS	No adjustment made because primary study is human.	7.0E-02
Methylene chloride	6.0E-02	Liver toxicity	Chronic rat	100	IRIS	NC	NC
Nitrate	1.6E+00	Methemoglobinemia in infants	Human epidemiological studies	1	IRIS	NC	NC
PCE	1.0E-02	Hepatotoxicity	6-week mouse gavage study	1,000	IRIS	NC	NC
Thallium[d]	6.6E-05	None reported	Rat oral subchronic study	3,000	IRIS	Remove UF of 10 for subchronic to chronic.	0.0007
TCE	3.0E-04	Central nervous system, liver, and endocrine toxicity	Subchronic mouse	3,000	EPA 2001	NC	NC

Table A4-3. Noncarcinogenic Chronic and Subchronic Toxicity Criteria for Contaminants of Potential Concern. (3 sheets)

Contaminant	Chronic RfD (mg/kg-day)	Toxic Endpoint	Critical Study	Chronic RfD UF[a]	RfD Source	Adjustment from Chronic to Subchronic	Subchronic RfD (mg/kg-day)
Uranium	3.0E-03	Weight loss, nephrotoxicity	30-day rat bioassay	1,000	IRIS	NC	NC

[a] EPA indicates that there are generally five areas of uncertainty where an application of a UF may be warranted:
1. Variation between species (applied when extrapolating from animal to human).
2. Variation within species (applied to account for differences in human response and sensitive subpopulations).
3. Use of a subchronic study to evaluate chronic exposure.
4. Use of a LOAEL, rather than a NOAEL.
5. Deficiencies in the database.

[b] There is no non-cancer toxicity criteria for this contaminant for this pathway.

[c] EPA adjusted the 5-day/week exposure of the NOAEL to a 7-day NOAEL to account for continuous exposure (chronic), rather than subchronic, exposures.

[d] The oral RfD for thallium was derived from the RfD for thallium sulfate, which was adjusted based on the molecular weight of thallium in the thallium salt, as described in *U.S. EPA Region 9 Preliminary Remediation Goal (PRG) Table and Supplemental Information* (EPA Region 9, 2004).

COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
IRIS = EPA Integrated Risk Information System (on-line database) (EPA 2007)
LOAEL = lowest-observed-adverse-effect level
NC = not calculated (subchronic criteria were not derived for these contaminants because these contaminants were not selected as COPCs for the subchronic pathways)
NCEA = EPA's National Center for Environmental Assessment
NOAEL = no-observed-adverse-effect level\
PCE = tetrachloroethylene
RfD = reference dose
TCE = trichloroethylene
UF = uncertainty factor

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A5.0 RISK CHARACTERIZATION

Risk characterization is the summarizing step of a risk assessment. In risk characterization, the toxicity values (RfDs and SFs) are applied, in conjunction with the concentrations of COPCs and summary intake assumptions, to estimate carcinogenic (cancer) risks and noncarcinogenic (non-cancer) health hazards. This section describes the methods that are used to estimate risks and hazards, the health threshold levels that are used to evaluate the results of the risk calculations for the site, and the results of the risk calculations.

A5.1 METHODOLOGY FOR EVALUATING NONCARCINOGENIC HAZARDS

The potential for adverse health effects other than carcinogenic effects (i.e., noncarcinogenic effects) is characterized by dividing estimated contaminant intakes by contaminant-specific RfDs. The resulting ratio is the hazard quotient (HQ), which is derived as follows:

$$HQ = \frac{\text{Chemical Intake (mg/kg - day)}}{\text{RfD (mg/kg - day)}}$$

The EPA's risk assessment guidelines (EPA 540/1-89/002) consider the additive effects associated with simultaneous exposure to several contaminants by specifying that all HQs initially must be summed across exposure pathways and contaminants to estimate the total hazard index (HI). This summation conservatively assumes that the toxic effects of all contaminants would be additive or, in other words, that all contaminants cause the same toxic effect and act by the same mechanism.

If the total HI is ≤ 1, multiple-pathway exposures to COPCs at the site are considered unlikely to result in an adverse effect. If the total HI is >1, further evaluation of exposure assumptions and toxicity (including consideration of specific affected target organs and the mechanisms of toxic actions of COPCs) is conducted to ascertain whether the cumulative exposure would, in fact, be likely to harm exposed individuals.

A5.2 METHODOLOGY FOR EVALUATING CARCINOGENIC RISKS

The potential for carcinogenic effects is evaluated by estimating the probability of developing cancer over a lifetime based on exposure assumptions and constituent-specific toxicity criteria. The increased likelihood of developing cancer from exposure to a particular contaminant is defined as the excess cancer risk. Excess cancer risk is the risk in excess of a background cancer risk of one chance in three (0.3, or 3E–1) for every American female and one chance in two (0.5, or 5×10^{-1}) for every American male of eventually developing cancer (*Cancer Facts and Figures – 2001* [ACS 2001]). Cancer risk estimates are the product of exposure assumptions (i.e., intake) and the contaminant or radiological-specific SF. Excess lifetime cancer risks were estimated by multiplying the estimated contaminant intake or radiological dose by the cancer SF, as follows:

$$\text{Cancer risk (nonradionuclides)} = \text{contaminant intake (mg/kg-day)} \times \text{SF (mg/kg-day)}^{-1}$$
$$\text{Cancer risk (radionuclides)} = \text{radiological dose (piC)} \times \text{SF (risk/piC)}$$

The linear equation is valid only for risks below 1 in 100 (1×10^{-2}). For risks above 1×10^{2}, the following "one-hit" equation is used (EPA 540/1-89/002). The one-hit model is based on the concept that a cancer can be induced after a single susceptible target or receptor has been exposed to a single effective dose unit of a carcinogen (*Proposed Guidelines for Carcinogen Risk Assessment* [EPA/600/P-92/003C]):

$$\text{Cancer risk} = 1-\{e^{-(\text{contaminant intake or radiological dose x SF})}\}$$

The risk from exposure to multiple carcinogens is assumed to be additive but is bounded by 1, corresponding to a 100% risk or certainty of developing cancer. Because risk is generally understood as an estimate of cancer probability, and since probabilities are limited to the range between 0 and 1, another purpose of the non-linear calculation above is to avoid calculating risks that exceed 1 and, therefore, lose meaning (EPA 540/1-89/002). The total cancer risk is estimated by adding together the estimated risk for each COPC and for each exposure pathway.

Because of differences in the methodology used to estimate their SFs, radiological and nonradiological cancer risks are tabulated and summed separately on the summary cancer risk tables. For most contaminant (nonradiological) carcinogens, laboratory experiments and animal data are the basis for estimates of risk. In the case of radionuclides, however, the data come primarily from epidemiological studies of exposure to humans. Another important difference is that the SFs used for contaminant carcinogens generally represent an upper-bound or 95% UCL of risk, while radionuclide SFs are based on the most likely estimates values. (Note: Also see the discussions regarding cancer estimates for radionuclides in Sections A4.0 and A6.3.) For soil, separation of radionuclides and nonradionuclide carcinogens only affects 216-Z-9 risks for the post-2150 scenario because that is the only site with nonradiological carcinogens as COPCs in soil. For groundwater, there are a number of nonradiological carcinogens in addition to the three radionuclides that are COPCs in groundwater.

The EPA's target cancer risk range is 1×10^{-6} to 1×10^{-4}, and EPA considers risk levels as high as 1×10^{-4} (the upper end of EPA's target risk range) to be acceptable under some circumstances (OSWER Directive 9355.0-30).

A5.3 SUMMARY OF RISK RESULTS

All final risk and hazard estimates up to 9 were presented to one significant figure only, as recommended by EPA 540/1-89/002. Therefore, an HQ or HI of 1 could range between 0.95 and 1.4, and a risk of 2×10^{-5} could range between 1.5×10^{-5} and 2.4×10^{-5}. Hazards >9 were shown with all positive integers (i.e., an HI of 312 was not rounded to 300). The risk and hazard results, presented to one significant figure, are summarized on Tables A5-1 through A5-11. Details of the calculations, with risks and hazards presented to at least two significant figures, are included in Attachment A-6 of this appendix for all nonradionuclides in soil and the nonradionuclides and radionuclides in groundwater. For the radionuclide contaminants in soil, summaries of the RESRAD computer model outputs are included in Attachment A-7.

The RESRAD model calculates risks from radionuclides in soil taking into consideration radioactive decay and ingrowth (i.e., increasing concentrations of daughter products), leaching, erosion, and mixing (ANL/EAD-4). The change in radionuclide concentrations over time due to radioactive decay and ingrowth can be a significant factor in assessing health risks and RESRAD modeling for the soil sites evaluated in this assessment was used to calculate future risks for the following time horizons:

- 17 years from now (2024)
- 28 years from now (2035)
- 150 years from now
- 500 years from now
- 1,000 years from now (maximum required time horizon in "Standards for Protection Against Radiation," 10 CFR 20, Subpart E).

Because two of the three risk driver radionuclides at the three Z Plant sites (216-Z-1A tile field, 216-Z-8 french drain, 216-Z-9 Trench) are plutonium isotopes with extremely long half-lives in soil (24,000+ years for plutonium-239, and 6,500+ years for plutonium-240), the future risk calculations for these sites are not significantly different than current risks, nor are there daughter products that become significant (from a health risk perspective) in the 1,000-year timeframe. The other risk driver radionuclide, americium-241, has a shorter half-life (432 years) than the plutonium isotopes, and a significantly toxic daughter product (neptunium-237) with a long half-life. Risks from americium-241 (including daughter products) do decrease significantly over the 1,000-year period[4]; however, cumulative risks do not change significantly within 1,000 years. Figure A5-1 illustrates the decline in risk over 1,000 years for the future residential farmer at the 216-Z-9 Trench, which shows cumulative risks decreasing very little over 1,000 years. This risk-reduction pattern would be similar for all receptors at all the Z Plant sites. Therefore, future time-horizon risks and additional daughter products not selected as initial COPCs are not included in the risk summary tables presented in this section (unless the daughter product had a risk exceeding 1×10^{-6}). Current and future risk results, including daughter product risks, are included in the tables in Attachment A-7.

For the 216-A-8 Crib, where cesium-137 is the risk-driving radionuclide, risks from future time horizons are presented in the summary tables in this section. Cesium-137 has a half-life of approximately 30 years, and risks at 216-A-8 Crib decrease significantly within the 1,000 years evaluated in this assessment. Figure A5-2 shows the decrease in cancer risks for the future residential farmer for 216-A-8 Crib. The decrease pattern is similar for the well driller and construction worker. Daughter products never contribute significantly to overall risks at any of the time periods evaluated for 216-A-8 Crib, so daughter risks are included in Attachment A-7, but individual radionuclides for future time horizons are not presented in the risk summary tables in this section.

A5.3.1 Current Industrial Land Use: Risks from Soil Exposures for Construction Workers

Risks to construction workers were evaluated for all soil sites, except the 216-Z-9 Trench. At the 216-Z-9 Trench, contamination does not begin until 6.4 m (21 ft) bgs, and the site is covered with a concrete cap. Risks were calculated for ingestion, inhalation, and external radiation exposure routes. In addition, risks from exposure to inhaled radon were also evaluated. Radon risks were extremely low at all three sites (orders of magnitude below the *de minimis* cancer risk

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[4] Part of the reason for the decline of americium-241 is not due to decay but due to leaching from the site. The relatively high leaching is due to the low default distribution coefficient (Kd) value that RESRAD assigns the compound, which likely over-estimates its leach rate from a future garden.

level of 1×10^{-6}). Only radionuclides were selected as COPCs for construction workers at these sites. Cancer risks are presented for construction workers in Table A5-1, and the results are as follows:

- 216-Z-1A tile field: Risks from exposure to all three COPCs exceed 1×10^{-4} (EPA's upper-bound risk range), with a total risk of 4×10^{-2}. Plutonium-239 has the highest risk (3×10^{-2}, 77% of the total risks), and the ingestion pathway is the pathway contributing the most to overall risk. External radiation risks from plutonium-239 and plutonium-240 were less than 1×10^{-4}, but the external radiation risk for americium-241 exceeded 1×10^{-4}.
- 216-Z-8 french drain: Risks were below 1×10^{-6} for all COPCs and exposure pathways evaluated.
- 216-A-8 Crib: Only cesium-137 exceeded target health goals at this site, primarily due to external radiation, with cumulative risks of 5×10^{-2}, and over 99% of the risks due to cesium-137. No other contaminants exceeded 1×10^{-6}. Somewhere between 150 and 500 years in the future, cesium-137 decays to the point where risks fall below 1×10^{-6} (cumulative risks at 500 years are 7×10^{-7}).

It should be noted that although construction worker risks were not calculated at the 216-Z-9 Trench, if a construction worker were to dig in the soils immediately beneath the bottom of the trench, risks would likely be higher than those at the 216-Z-1A tile field and would exceed 1×10^{-4}.

A5.3.2 Post-2150 Unrestricted Land Use: Worker Exposures

Under a future situation where all knowledge of the site is lost and there is a failure of institutional controls, two worker populations were evaluated: (1) a well driller exposed to contaminants in soil via drill cuttings while engaged in installing a water supply well, and (2) a regular worker in the area who would drink groundwater from the well while at their place of employment. For the radionuclide COPCs, the risks presented on the summary tables are for 150 years in the future, as it is anticipated that institutional controls would be unlikely to fail before that time. However, as noted above for construction workers, on all sites but the 216-A-8, Crib, the long half-lives of the principal radionuclides preclude risks changing significantly over 1,000 years.

A.5.3.2.1 Well Drillers. A future water supply well could be constructed at any of the four waste sites; thus, potential risks to drillers were evaluated at all four sites. The exposure routes evaluated are the same as those for the construction worker (and for all the populations exposed to soil) and were inhalation (including radon), ingestion, and external radiation. Two sites (216-Z-9 Trench and 216-A-8 Crib) have at least one nonradionuclide COPC in addition to radionuclides. Risks for well drillers are presented in Table A5-2, and non-cancer hazards for the 216-Z-9 Trench are presented in Table A5-3. Well driller risks were much less than those for construction workers and did not exceed 1×10^{-4} at any site, but did exceed 1×10^{-6} at all sites except 216-Z-8. The results are as follows:

- 216-Z-1A tile field: Cumulative risks were 2×10^{-6}, due to americium-241 (80% of total risks), followed by plutonium-239 (18% of total). Risks are driven by the external radiation pathway for americium-241.

- 216-Z-8 french drain: Risks were below 1 x 10^{-6} for all COPCs and exposure pathways evaluated.
- 216-Z-9 Trench: Cumulative risks were 2 x 10^{-5} for the radionuclides, with plutonium-239 (46% of total), americium-241 (43% of total risks), and plutonium-240 having risks in excess of 1 x 10^{-6}. Carbon tetrachloride had the highest risks of the two nonradionuclide carcinogens, with a risk of 2 x 10^{-6}. Ingestion of plutonium-239 and external radiation due to americium-241 are the pathways contributing to overall risks. All non-cancer hazards (Table A5-3) were well below a target HI of 1.
- 216-A-8 Crib: Risks were 7 x 10^{-6} due almost entirely to cesium-137 via the external radiation pathway.

A.5.3.2.2 Regular Workers Drinking Groundwater Exposures. Future regular workers post-2150 were evaluated for exposures to drinking water through the ingestion and inhalation pathways. Three radionuclides and nine nonradionuclides were selected as COPCs and quantitatively evaluated for this scenario. As discussed in Section A3.2, groundwater exposures were evaluated under low-, medium-, and high-exposure concentrations using the 25th, 50th, and 90th percentile groundwater concentrations, respectively. Tables A5-4 and A5-5 summarize the cancer risks and hazards, respectively, for the industrial worker drinking water pathway for the low-, medium-, and high-exposure scenarios. These tables present the combined risks and hazards from the ingestion and inhalation pathways. For detailed presentation of the risks and hazards for each of the pathways, refer to the summary tables in Attachment A-6 of this appendix. The following summarizes the risk and hazard results for the industrial drinking water scenario:

- Cancer risks from radionuclides: As shown in Table A5-4 under the high-exposure scenario (i.e., using the 90th percentile groundwater concentration), cancer risks for the radionuclides are 4 x 10^{-5}, within EPA's acceptable risk range of 1 x 10^{-6} to 1 x 10^{-4}. Technetnium-99 contributes the most to the total cancer risk with a risk of 2 x 10^{-5}, followed by tritium and iodine-129 with cancer risks of 1 x 10^{-5} and 1 x 10^{-6}, respectively. Under the medium-exposure scenario (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower, at 4 x 10^{-6}. Under the low-exposure scenario (25th percentile), total cancer risks were even lower and were equal to the *de minimis* cancer risk level of 1 x 10^{-6}.
- Cancer risks from nonradionuclides: As shown in Table A5-4, total nonradionuclide cancer risks exceed 1 x 10^{-4} under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios, at 3 x 10^{-3} and 5 x 10^{-4}, respectively. Total cancer risks under the low-exposure (25th percentile) scenario are 7 x 10-6. Carbon tetrachloride contributes the majority of the total cancer risk, followed by chloroform, with cancer risks nearly two orders of magnitude lower than that of carbon tetrachloride. Carbon tetrachloride is responsible for 99% of the total nonradionuclide cancer risks under both the high- and medium-exposure scenario but for only 88% of the total cancer risks under the low-exposure scenario. Approximately 50% of the cancer risks for carbon tetrachloride result from ingestion exposures, while the other 50% of the cancer risk for carbon tetrachloride results from inhalation exposures.

- Non-cancer hazards: As shown in Table A5-5, total non-cancer hazards exceeded 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios at 42 and 7, respectively. Total non-cancer hazard under the low-exposure (25th percentile) scenario is 0.2. Carbon tetrachloride contributes the majority of the non-cancer hazard and is the only single COPC with an HI >1. Carbon tetrachloride is responsible for over 95% of the total non-cancer hazard under both the high- and medium-exposure scenario but for only 44% of the total cancer risks under the low-exposure scenario.

A5.3.3 Post-2150 Unrestricted Land Use: Residential Farmer Exposures

In an institutional control failure scenario, a residential farmer could be exposed to contaminants in soil if soil at depth was brought to the surface. As described in earlier sections, the scenario selected to evaluated this possibility is through drilling a well and subsequent exposure to drill cuttings spread over a vegetable garden next to a residential home. In addition to the soil exposures, water from the groundwater well would be used for domestic supply, irrigation, and watering of livestock.

A.5.3.3.1 Soil Exposures. Residential farmer exposures to soil would occur via ingestion, inhalation, dermal absorption (only cadmium at the 216-Z-9 Trench), and external radiation for the radionuclides. As with well drillers, under the failure of institutional controls scenario a future water supply well and residence could be constructed at any of the four waste sites; thus, potential risks to residential farmers exposed to drill cuttings were evaluated at all four waste sites. Risks for residential farmer soil exposures are presented in Table A5-6, and non-cancer hazards for the 216-Z-9 Trench are presented in Table A5-7. Residential farmers' risks from direct soil exposures were higher than for well drillers and were comparable to that of construction workers. Although the concentrations to which residents would be exposed were lower than the concentrations for construction workers and drillers due to the dilution that would occur by spreading and tilling the drill cuttings, the resident's exposures occur over a longer period of time and include children's exposures. The results are as follows:

- 216-Z-1A tile field: Risks from exposure to all COPCs are above 1×10^{-4}, with a total risk of 2×10^{-3}. As with all the Z Plant sites, risks are driven by americium-241 and plutonium-239. For this site, risks are driven by the ingestion pathway for plutonium-239 and external radiation pathway for americium-241.
- 216-Z-8 french drain: Cumulative risks are 3×10^{-6}; only plutonium-239 has risks greater than 1×10^{-6}.
- 216-Z-9 Trench: Cumulative risks are 2×10^{-2} for the radionuclides, with plutonium-239 (63% of total risks), americium-241 (20% of total), plutonium-240 (16% of total), neptunium-237, radium-226, and radon (including entire radon decay chain) all having risks in excess of 1×10^{-4}. Carbon tetrachloride had the highest risks of the three nonradionuclide carcinogens, with a risk of 5×10^{-5}. The ingestion and external radiation pathways are contributing the most to over-all risks; however inhalation risks were also greater than 1×10^{-4}. All non-cancer hazards from direct contact (i.e., not food chain) were well below a target HI of 1 (Table A5-7).

- 216-A-8 Crib: Only cesium-137 exposures exceeded 1×10^{-4}, with risks of 2×10^{-2} due to external radiation. No other radionuclides exceed 1×10^{-6}, with the exception of neptunium-237 with a risk of 3×10^{-6}. Somewhere between 150 and 500 years in the future, cesium-137 decays to the point where risks fall below 1×10^{-4} (cumulative risks at 500 years are 2×10^{-6}). Health hazards due to thallium were well below target health goals with an HI of 0.2 for child exposures and an HI of 0.02 for residential adults.

A.5.3.3.2 Groundwater Exposures. Future child and adult residents were evaluated for exposures to groundwater used as a tap water (i.e., domestic supply) and groundwater used as an irrigation source. Child and adult residents were evaluated for exposures to groundwater through the ingestion, dermal, and inhalation of vapors pathways. In addition to exposures to groundwater from drinking and other domestic uses, future residential farmers are assumed to use the groundwater as an irrigation source for their crops and livestock. Therefore, adult residential farmers were evaluated for dermal (nonradionuclides) and inhalation exposures to COPCs in groundwater during irrigation activities.

Tables A5-8 and A5-9 summarize the cancer risks and non-cancer hazards, respectively, for the residential farmer exposures to groundwater for the low-, medium-, and high-exposure scenarios. These tables present the combined risks and hazards from the ingestion, dermal, and inhalation pathways under each exposure scenario. For detailed presentation of the risks and hazards for each of the individual pathways, refer to the summary tables in Attachment A-6 of this appendix.

Exposures to Groundwater as Tap Water. The following summarizes the results for the tap water exposure scenario evaluated for the residential farmer:

- Cancer risks from radionuclides: As shown in Table A5-8, under the high-exposure scenario, cancer risks from tap water for the radionuclides are 1×10^{-4}, equal to EPA's maximum acceptable risk. Technetium-99 contributes the most to the total cancer risk with a risk of 8×10^{-5}, followed by tritium and iodine-129 with cancer risks of 4×10^{-5} and 4×10^{-6}, respectively. Under the medium-exposure scenario (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower, at 1×10^{-5}. Under the low-exposure scenario (25th percentile), total cancer risks were even lower (4×10^{-6}).
- Cancer risks from nonradionuclides: As shown in Table A5-8, total nonradionuclide cancer risks from tap water exposures exceed 1×10^{-4} under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios, at 2×10^{-2} and 3×10^{-3}, respectively. Total cancer risks under the low (25th percentile) exposure scenario is 5×10^{-5}. Carbon tetrachloride contributes the majority of the total cancer risk, followed by chloroform, with cancer risks nearly two orders of magnitude lower than for carbon tetrachloride. Carbon tetrachloride is responsible for 99% of the total nonradionuclide cancer risks under both the high- and medium-exposure scenario but only for 87% of the total cancer risks under the low-exposure scenario. As detailed in Attachment A-6 of this appendix, total cancer risks from the nonradionuclides in tap water are primarily driven by the inhalation pathway, which contributes 64% to the total cancer risk, followed by the ingestion pathway (32%) and the dermal pathway (4%).
- Non-cancer hazards: As shown in Table A5-9, total child and adult non-cancer hazards exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios. Child and adult hazards under the high-exposure scenario are

316 and 135, respectively; child and adult hazards under the medium-exposure scenario are 55 and 23, respectively; and child and adult hazards under the low-exposure scenario are 1 (equal to the target health goal) and 0.6 (below the target health goal), respectively. Carbon tetrachloride is by far the greatest contributor to total non-cancer hazard in tap water exposures and contributes over 96% to the total hazard in the high- and medium-exposure scenarios. Carbon tetrachloride is the only COPC that results in an HI >1 in both the high- and medium-exposure scenarios. In the high-exposure scenario, hexavalent chromium (5 and 2, for child and adult), nitrate (3 and 1, for child and adult), and TCE (3 and 1, for child and adult) also result in HIs >1. No individual contaminants have HIs >1 in the low-exposure scenario.

Exposures During Irrigation Using Groundwater. As shown in Tables A5-8 and A5-9, risks and hazards from exposures to groundwater through irrigation are much lower (by at least two orders of magnitude) than the risks and hazards calculated from exposures to groundwater used as tap water. Therefore, the contribution from irrigation exposures to cumulative groundwater exposures for the adult residential farmer are insignificant relative to the tap water exposure pathway, cumulative cancer risks from the combined exposures are unchanged from the tap water cancer risks at one significant figure, and the hazards only slightly increased over the tap water hazards for the high- and medium-exposure scenarios. No cancer risks during irrigation activities exceed 1×10^{-4}, although carbon tetrachloride risks exceed 1×10^{-6} at the 50th and 90th percentile concentrations. The non-cancer hazards are all <1, with the exception of carbon tetrachloride exposures at the 90th percentile where the HI is 2. Because of the uncertainties surrounding the amount of exposure that would actually occur during irrigation (e.g., dependent on what type of irrigation system is used), based on the weather, and based on the amount of land irrigated), this pathway can be considered semi-quantitative and useful as an estimate of groundwater exposures through another pathway than drinking the water.

A.5.3.3.3 Food Chain Exposures. Residential farmers are assumed to consume homegrown fruits and vegetables from gardens that are cultivated in post-intrusion contaminated soils and irrigated with groundwater; and to consume beef and dairy products from cattle that drink site groundwater and graze on pastures irrigated with groundwater. For beef and dairy products, the source of site contaminants is groundwater; for plants, the source of contaminants is obtained from both soil (grown in impacted soil from drill cuttings) and groundwater (irrigation). The risk and hazard results for food chain pathways for the COPCs in soil are presented in Tables A5-6 and A5-7 (soil summary tables), and for the COPCs in groundwater, risks and hazards are shown in Tables A5-10 and A5-11. The following subsections summarize the risk and hazard results for the food chain pathways.

Homegrown Produce.

- Cancer risk from radionuclides: The total radionuclide cancer risk from ingestion of homegrown produce irrigated with groundwater exceeds 1×10^{-4} under both the high and medium groundwater concentrations (Table A5-10) and also for produce grown in soil for all soil sites except for the 216-Z-8 french drain (Table A5-6). The highest produce consumption risks are from produce grown in 216-Z-9 soil where risks are 1×10^{-1}; however, risks due to ingestion of produce grown in impacted soil also exceeded 1×10^{-4} at 216-Z-1A and 216-A-8. For produce irrigated with impacted groundwater, technetium-99 is the greatest contributor to total radionuclide cancer risk in the plant ingestion pathway and is the only radionuclide that had an individual cancer risk greater

than or equal to 1 x 10^{-4} under each of the high-, medium-, and low-exposure scenarios. Note that current tritium concentrations would result in produce ingestion risks greater than 1 x 10^{-4} under the high-exposure scenario (as shown in Table 5A-10), but as shown in Section 5.3.2.5, tritium concentrations would be below levels of health concern in 150 years because tritium's half-life is only 12 years, and existing institutional controls are assumed to prevent use of groundwater until at least that time. Risks from produce ingestion due to the contribution from soil at 216-Z-1A and 216-Z-9 are due primarily to americium-241, plutonium-239, and plutonium-240. Risks are highest for plutonium-239, followed by plutonium-240, and then americium-241 at the Z Plant sites, and target risks are exceeded at the 216-A-8 Crib primarily due to cesium-137 at 216-A-8.

- Cancer risk from nonradionuclides: As shown in Table A5-10 for groundwater, the total nonradionuclide cancer risk from ingestion of homegrown produce also exceeds 1 x 10^{-4} under both the high- and medium-exposure scenarios. Total cancer risks under the high-exposure scenario are 1 x 10^{-2}, and total cancer risks under the medium-exposure scenario are 2 x 10^{-3}. Total cancer risks under the low-exposure scenario are 3 x 10^{-5}. Carbon tetrachloride contributes the majority of the total cancer risk, followed by PCE and TCE, with cancer risks nearly three orders of magnitude lower than risks from carbon tetrachloride. As shown in Table A5-6, the only soil site with nonradionuclide carcinogens is the 216-Z-9 Trench, where cancer risks due to ingestion of produce containing carbon tetrachloride were 1 x 10^{-3}. However, this contaminant is unlikely to be a risk in soil 150 years from now because its concentration would be considerably lower in the future and even if present, its half-life in surface soil is relatively short (unlike irrigating the plants with groundwater, which would be providing a continuous source of COPCs, again depending on the type of irrigation system used).
- Non-cancer hazards: As shown in Table A5-11, total combined child and adult non-cancer hazards exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios. Total non-cancer hazards under the high-exposure scenario are 362, total hazards under the medium-exposure scenario are 63, and total hazards under the low-exposure scenario are 1 (equal to the target health goal). Carbon tetrachloride is overwhelmingly the greatest contributor to total non-cancer hazard in the ingestion of homegrown produce exposure scenario and contributes over 95% to the total hazard in the high- and medium-exposure scenarios. Carbon tetrachloride is the only COPC that results in a hazard >1 in both the high- and medium-exposure scenarios. Non-cancer hazards for carbon tetrachloride are 354 and 62 under the high- and medium-exposure scenarios, respectively. In the high-exposure scenario, hexavalent chromium and TCE also have non-cancer hazards that exceed 1 (each has a hazard of 4). No other contaminants have individual hazards >1 under any exposure scenario.

  As shown in Table A5-7 for the two sites with non-cancer contaminants selected as COPCs in soil (216-Z-9 Trench and 216-A-8 Crib), hazards exceeded 1 for all three of the COPCs at 216-Z-9 but were primarily due to carbon tetrachloride. However, carbon tetrachloride at 216-Z-9 is unlikely to be a hazard if impacted soil is brought to the surface in 150 years because once exposed to the air, the half-life of carbon tetrachloride in soil is relatively short (i.e., 6 to 12 months) (*Toxicological Profile for Carbon Tetrachloride* [ATSDR 2005]); therefore, carbon tetrachloride concentrations in soil, and

consequently plants, will not remain at the levels currently seen in subsurface soil if they are at the surface for 30 years (the exposure duration for the residential farmer). Hazards due to ingesting thallium at the 216-A-8 tile field (the only nonradionuclide COPC at this site) also exceeded one with an HQ of 3.

Ingestion of Beef.

- Cancer risk from radionuclides: As shown in Table A5-10, the total radionuclide cancer risk from ingestion of beef is below 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total cancer risks under the high-exposure scenario are 3×10^{-5}, under the medium-exposure scenario are 3×10^{-6}, and under the low-exposure scenario are 8×10^{-7}. Technetium-99 is the greatest contributor to total radionuclide cancer risk in the beef ingestion pathway. Technetium-99 is responsible for approximately 60%, 68%, and 83% of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. Tritium is the next greatest contributor to total cancer risks, contributing approximately 32%, 30%, and 17% of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. The contribution from iodine-129 is insignificant relative to the cancer risks from technetium-99 and tritium.
- Cancer risk from nonradionuclides: As shown in Table A5-10, the total nonradionuclide cancer risk from ingestion of beef is also below 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total cancer risks under the high-exposure scenario are 2×10^{-6}, under the medium-exposure scenario are 3×10^{-7}, and under the low-exposure scenario are 5×10^{-9}. Carbon tetrachloride contributes the majority of the total cancer risk and is the only single nonradionuclide COPC with a cancer risk greater than the *de minimis* cancer risk level of 1×10^{-6}, with a cancer risk of 2×10^{-6} in the high-exposure scenario. Carbon tetrachloride is responsible for 99% of the total nonradionuclide cancer risks under the high- and medium- exposure scenarios and for 73% the total nonradionuclide cancer risks under the low-exposure scenario.
- Non-cancer hazards from nonradionuclides: As shown in Table A5-11, total combined child and adult non-cancer hazards for the beef ingestion pathway are below the target health goal of 1 under each of the high-, medium-, and low-exposure scenarios. Total non-cancer hazards under the high-exposure scenario are 0.3, under the medium-exposure scenario are 0.02, and under the low-exposure scenario are 0.01. Hexavalent chromium is the greatest contributor to total non-cancer hazard in the ingestion of beef pathway and contributes 86%, 66%, and 99% to the total hazard in the high-, medium-, and low-exposure scenarios, respectively.

Ingestion of Dairy Products from Dairy Cattle.

- Cancer risk from radionuclides: As shown in Table A5-10, the total radionuclide cancer risk from ingestion of dairy products exceeds 1×10^{-4} under the high-exposure scenario, with total cancer risks of 2×10^{-4}. Total cancer risks under the medium-exposure scenario are approximately one order of magnitude lower at 2×10^{-5}, and total cancer risks under the low-exposure scenario are 6×10^{-6}. Technetium-99 is the greatest contributor to total radionuclide cancer risk in the dairy product ingestion pathway, with cancer risks under the high-, medium-, and low-exposure scenarios of 1×10^{-4}, 2×10^{-5}, and 5×10^{-6}, respectively. Technetium-99 is responsible for approximately 75%, 80%,

and 90% of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. Tritium is the next greatest contributor to total cancer risks using current concentrations, although as noted for plants, tritium concentrations are unlikely to be a risk in 150 years. The contribution from iodine-129 is insignificant relative to the cancer risks from technetium-99 and tritium.

- Cancer risk from nonradionuclides: The total nonradionuclide cancer risk from ingestion of dairy products is below 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total cancer risks under the high-exposure scenario are 4×10^{-6}, under the medium-exposure scenario are 6×10^{-7}, and under the low-exposure scenario are 1×10^{-8}. Carbon tetrachloride contributes the majority of the total cancer risk and is the only single nonradionuclide COPC with a cancer risk greater than the *de minimis* cancer risk level of 1×10^{-6}, with a cancer risk of 3×10^{-6} under the high-exposure scenario. Carbon tetrachloride is responsible for 99% of the total nonradionuclide cancer risks under the high- and medium-exposure scenarios and for 73% the total nonradionuclide cancer risks under the low-exposure scenario.
- Non-cancer hazards from nonradionuclides: As shown in Table A5-11, total combined child and adult non-cancer hazards for the dairy ingestion pathway are well below the target health goal of 1 under each of the high-, medium-, and low-exposure scenarios. Total non-cancer hazards under the high-exposure scenario are 0.09, under the medium-exposure scenario are 0.02, and under the low-exposure scenario are 0.0006. Carbon tetrachloride is the greatest contributor to total non-cancer hazard in the ingestion of dairy products pathway under the high- and medium-exposure scenarios, contributing 95% and 96% of the total hazards of each scenario, respectively.

Total Residential Farmer Exposures Through the Food Chain Pathways. It is possible for residential farmers to have combined exposures to groundwater through ingestion of all three food chain pathways: homegrown produce, beef, and dairy products. Risks and hazards from ingestion beef and dairy products are much lower (by at least three orders of magnitude) than the risks and hazards calculated from ingestion of homegrown produce. Therefore, the contribution from the ingestion of beef and dairy products pathways to cumulative food chain exposures for the residential farmer are insignificant relative to the ingestion of homegrown produce exposure pathway. Consequently, the cumulative cancer risks and hazards from the combined exposures are unchanged from the homegrown produce cancer risks to one significant figure.

A.5.3.3.4 Vapor Intrusion Exposures. Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater beneath the 200-PW-1 OU (particularly in the vicinity of the 216-Z-9 Trench and 216-Z-1A tile field), soil gas sampling has occurred over a number of years. Generally, low concentrations of soil gas are seen at most of the 200-PW waste sites, with the exception of the 216-Z-9 Trench and 216-Z-1A tile field (DOE/RL-2006-51). The greatest human health concern with respect to soil gas is the possibility for subsurface vapors to move into basements of buildings and adversely impact indoor air. EPA's vapor intrusion guidance document (EPA 530-F-02-052) preferentially recommends collection of indoor air samples, where possible, rather than modeling from soil gas or groundwater concentrations, due to the uncertainties and limitations of modeling. Therefore, the three air samples collected from within the 216-Z-9 Trench area were selected for inclusion in the risk assessment as the most representative data of what concentrations could be inside a basement. Section A2.4 identified carbon tetrachloride and chloroform vapor concentrations in

the 216-Z-9 Trench as a possible health concern for a residential population if a home were ever built above the impacted soil at this site or possibly near the 216-Z-1A tile field (the waste areas with chlorinated solvents). This section presents a semi-quantitative evaluation of the potential residential risks from vapor intrusion exposures.

The air samples collected from within the 216-Z-9 Trench were compared to residential screening levels (EPA Region 6 HHSLs) in air (EPA 2007), calculated to be protective of a 1×10^{-6} cancer risk level. Carbon tetrachloride and chloroform both exceeded EPA Region 6 HHSLs by many orders of magnitude and were selected as COPCs in indoor air for a future residential population (see Section A2.4). If the concentrations of carbon tetrachloride and chloroform identified in the trench air are assumed to be the same concentrations as one would find in the basement of a residential home, then these concentrations would correspond to a cancer risk of 7×10^{-1} and 5×10^{-2} for carbon tetrachloride and chloroform, respectively, which is significantly greater than the maximum acceptable cancer risk level of 1×10^{-4}.

The concentrations of VOCs that are a possible health concern via this pathway (based on 2006 data) are declining over time due to their removal via the active SVE system, and also due to their natural decrease in environmental media because of volatization and breakdown in the environment. Thus, it is not known whether the indoor air pathway would still be a concern 150 years in the future if institutional controls were to fail. In addition, indoor vapor concentrations are affected by the size of building, ventilation, and type of building construction, and there are many uncertainties in predicting what those parameters might be at a distant future date. Therefore, while this pathway is shown as potentially complete and significant, as shown in Figure A3-2, these risks are only considered to be semi-quantitative because of the simplification of the evaluation process. Regardless of the semi-quantitative nature of this evaluation, vapor concentrations in the 216-Z-9 Trench will have to decrease by at least three orders of magnitude over the next 150 years before the vapor intrusion pathway is not a concern.

A5.3.4 Future Groundwater Risks for Residential Farmer

Risks for radionuclides were not calculated for future groundwater based on future concentrations (150 years from now), as was done for soil. For the VOCs in groundwater, particularly the risk-driving carbon tetrachloride, concentrations would be lower but the methods required to model degradation are complex and require many assumptions. Therefore, it can be concluded that carbon tetrachloride risks are over-estimated for the residential farmer, and it may be that the 25th percentile concentration risks are more indicative of future groundwater risks under an institutional controls failure scenario.

For the three radionuclides that are COPCs in groundwater, concentration decay curves are provided in Figure A5-1 based on the half-lives of the radionuclides. These decay curves are based on the 90th percentile groundwater concentrations. Because the half-lives of iodine-129 and technetium-99 are so long (16 million and 213,000 years, respectively), no change in groundwater concentrations are expected over a 1,000-year period for these radionuclides. Therefore, the cancer risks described in the previous sections for iodine-129 and technetium-99 based on current groundwater concentrations also represent the cancer risks expected up to 1,000 years in the future.

Tritium has a half-life of only 12.26 years; therefore, the concentration of tritium in the environment decreases rapidly relative to the other radionuclide COPCs. Thus, the cancer risks described in the previous sections for tritium, based on current groundwater concentrations,

significantly over-estimate the cancer risks from tritium 150 years into the future. Because the risk calculation equations are linear, cancer risks from tritium decrease proportionally with decreasing groundwater concentrations. Figure A5-3 depicts the decrease in cancer risk based on the 90th percentile groundwater concentrations of tritium expected over the next 150 years. As shown in Figure A5-3, tritium cancer risks from each exposure scenario decrease below the *de minimis* cancer risk level of 1×10^{-6} before 150 years is reached. Therefore, tritium exposures in groundwater are not expected to result in unacceptable cancer risks after 150 years of decay. Based on the slope of the decay curve, cancer risks at 150 years can be predicted. The following summarizes what cancer risks would be in 150 years for each groundwater pathway based on the 90th percentile groundwater concentration of tritium:

- Regular worker drinking water: 3×10^{-9}
- Residential farmer drinking water: 1×10^{-8}
- Residential farmer irrigation exposures: 5×10^{-11}
- Residential farmer plant ingestion: 1×10^{-7}.

A5.3.5 Cumulative Risks from Multiple Media Exposures

A residential farmer could potentially build a house at the 216-Z-9 Trench site (or another waste site) and could be exposed to contaminants in soil, groundwater, and the food chain at the same time. Table A5-15 presents an example of potential cumulative risks if a future residential farmer lived at the 216-Z-9 Trench site and was exposed to all pathways. Under this scenario, cumulative risks are 2×10^{-1} for the residential farmer. The ingestion of nonradionuclides in tap water and produce irrigated with groundwater and the ingestion of produce grown in radionuclide-contaminated soil were the pathways with the highest risks. Cumulative hazards are not shown but would also increase over the HI values shown in Tables A5-7, A5-9, and A5-11 for the residential farmer. If construction workers were exposed to the soils beneath the bottom of the trench, risks would likely exceed 1×10^{-4}.

A5.4 SUMMARY OF DOSE RESULTS

The focus of this risk assessment is the calculation of cancer risk estimates according to the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). However, health risks for radionuclides are commonly also presented in terms of their radiological dose. Radiation dose levels for carcinogens in soil are presented in Tables A5-12 through A5-14. Acceptable dose levels in accordance with the U.S. Nuclear Regulatory Commission are generally 25 mrem/yr, with exemptions of up to 100 mrem/yr allowed in some cases (*Memorandum re: Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* [EPA 1997]; 10 CFR 20, Subpart E). The EPA generally only allows dose levels as high as 15 mrem/yr before an action under CERCLA is required (*Memorandum re: Distribution of OSWER Radiation Risk Assessment Q&A's, Final Guidance* [EPA 1999]). Dose levels for all sites except the 216-Z-8 Crib are many times greater than 100 mrem/yr for construction workers and residential farmers. For well drillers, dose levels exceed 100 mrem/yr only at the 216-Z-9 Trench. Although radiation dose levels are not presented for the radionuclides in groundwater, dose levels for those exposures would also exceed 100 mrem/yr, primarily due to exposure to technetium-99 in the food chain pathways.

A5.5 RISK CHARACTERIZATION SUMMARY AND CONCLUSIONS

Risks were evaluated for a construction worker digging in subsurface soil under current conditions and under future conditions. Risks were evaluated for a well digger exposure to soil as drill cuttings, a regular worker drinking groundwater at their place of employment, and a residential farming population exposed to soil, groundwater, homegrown produce, and beef and dairy cattle impacted with site COPCs. Soil risks were evaluated at four different waste sites, and groundwater risks were evaluated for three concentrations for each COPC, the 25th, 50th, and 90th percentile concentration of the plume. Thus, soil risks are waste-site-specific, and groundwater risks are evaluated for low, medium, and high concentrations independent of location. Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site.

Under current industrial land use and institutional controls, there are no exposures to contaminants and radionuclides in groundwater and soil. Volatile or radiological emissions from the subsurface are insignificant. Institutional controls prevent the use of impacted groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of unimpacted soil. However, if construction workers disturbed soil at depths at the 216-Z-1A tile field, 216-Z-8 french drain, or 216-A-8 Crib, they could come into contact with COPCs. Under that unlikely scenario (i.e., existing institutional control programs at Hanford are designed to prevent unprotected digging in impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A tile field and 216-A-8 Crib, indicating that remedial action would be necessary. Risks from digging in soil at 216-Z-8 were less than 1×10^{-6}. Risks from subsurface soil exposures at the 216-Z-1A tile field were driven by plutonium-239, followed by plutonium-240, and then americium-241. Risks from subsurface soil at 216-A-8 Crib are driven by cesium-137. None of the nonradionuclides in soil are a health concern for construction workers. Construction workers were not evaluated for exposure to subsurface soil at the 216-Z-9 Trench due to the depth to impacted soil and because the area is covered with a concrete cap.

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and ingrowth of daughter products. For the three Z Plant sites (216-Z-1A tile field, 216-Z-8 french drain, and 216-Z-9 Trench), where risks are driven by plutonium-239, plutonium-240, and americium-241 (true for all soil scenarios), risks at future time horizons are not significantly different than current risks because the half-lives of these contaminants are long (or, in the case of the well driller and residential farmer, risks at 150 years are not very different than risks at 500 and 1,000 years). At the 216-A-8 Crib where cesium-137 is the risk driver for all soil scenarios, risks are significantly lower at future time horizons due to the relatively short half-life of cesium-137 (approximately 30 years).

In the event that knowledge of the site is lost and institutional controls fail, a future unrestricted land-use scenario was evaluated where people could come into contact with groundwater and subsurface soil brought to the surface as drill cuttings from drilling a groundwater well. This scenario is assumed to occur 150 years in the future. Therefore, radiological concentrations in soil were modeled assuming 150 years of decay (although, as noted above, this assumption does not make a difference for the Z Plant sites). Two of the three radionuclides selected as COPCs in groundwater, technetium-99 and iodine-129, have very long half-lives and future concentrations would not be different than current concentrations. However, the third radionuclide COPC,

tritium, will be at concentrations that are below a health concern within 150 years. Specifics of the post-2150 unrestricted land-use scenario are listed below:

- Risks to future well driller were much less than those for construction workers and did not exceed 1×10^{-4} at any site. Well driller risks were the highest at the 216-Z-9 Trench (risk = 2×10^{-5}).
- Future workers drinking groundwater at their place of employment exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations. Carbon tetrachloride was also the only contaminant with a non-cancer hazard above the target goal of 1.
- Future residents exposed to drill cuttings in their home yard had risks similar to those for construction workers; risks were greater than 1×10^{-3} for all soil sites, except the 216-Z-8 french drain where risks were 3×10^{-6}.
- Future residents drinking groundwater exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations. Radionuclide risks were the highest for technetium-99 (8×10^{-5}), assuming that tritium concentrations decay to low levels in 150 years. Non-cancer hazards are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In addition, hexavalent chromium, nitrate, and TCE all have non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentration. However, carbon tetrachloride's HI is two orders of magnitude higher than any other contaminant's HI.
- Future residents exposed to contaminants through their food chain would have risks greater than 1×10^{-1}, primarily due to growing produce in contaminated soils, although eating produce irrigated with impacted groundwater resulted in risks in the 1×10^{-2} range. Of contaminants and radionuclides in groundwater, carbon tetrachloride had the highest produce ingestion risks (1×10^{-2}), followed by technetium-99 (3×10^{-3}). Risks from the dairy products pathway exceed 1×10^{-4}, whereas risks from eating beef was below 1×10^{-4}.
- Carbon tetrachloride is the risk driver currently for all groundwater pathways (two orders of magnitude higher than most other things), with the exception of the dairy products and meat pathways, where risks from technetium-99 are the highest. In the future (post-150 years), technetium-99 is likely to be the risk-driving contaminant in groundwater.

In summary, risks from exposure to soils at the 216-Z-8 french drain are below levels that are a health concern. Risks from soil exposures at the 216-Z-1A tile field and 216-A-8 Crib are similar and exceed 1×10^{-4} for construction workers and residential farmers. Risks from soil exposures at the 216-Z-9 Trench were the highest for the four waste sites evaluated, with risks exceeding 1×10^{-2} for residential farmers. Risks for future well drillers at all four soil sites were below 1×10^{-4}. Plutonium-239 and americium-241, followed by plutonium-240, were the risk drivers in soil for the Z Plant sites, and; cesium-137 was the risk driver in soil at the 216-A-8 Crib.

Risks from exposure to groundwater exceeded 1×10^{-4} at the 90th and 50th percentiles due primarily to carbon tetrachloride, followed by technetium-99, for both residential and industrial drinking water exposures. Carbon tetrachloride's non-cancer hazards were also non-cancer risk drivers and exceeded target health goals at the 90th and 50th percentiles. Although reductions in

future concentrations were not quantified for carbon tetrachloride, the contaminant's concentrations will be decreasing relatively rapidly over time in comparison to technetium-99 with a half-life of 213,000 years. Therefore, while carbon tetrachloride concentrations represent the highest current risks, in the future, technetium-99 will likely become the risk driver.

Residential farmer risks were highest for ingestion of produce, followed by ingestion of soil, ingestion of groundwater, consumption of dairy products, and then consumption of beef.

Figure A5-1. Decreases in Cancer Risks Over Time – Future Residential Farmer at the 216-Z-9 Trench.

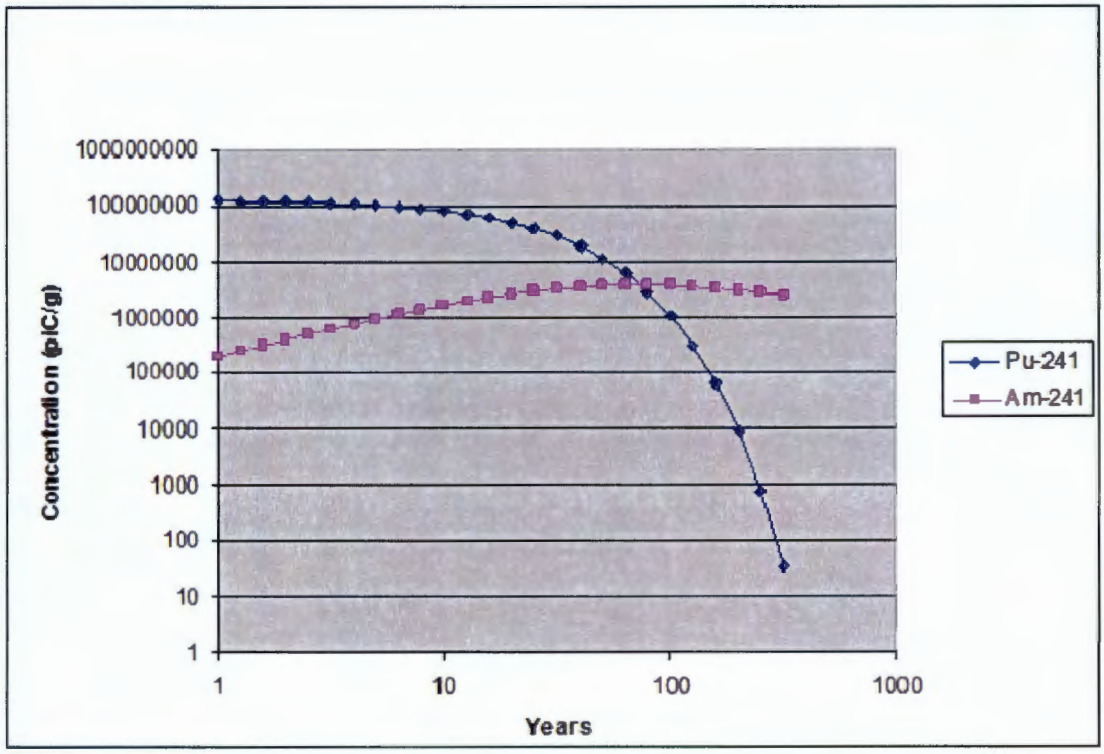

Figure A5-2. Decreases in Cancer Risks Over Time – Future Residential Farmer at the 216-A-8 Crib.

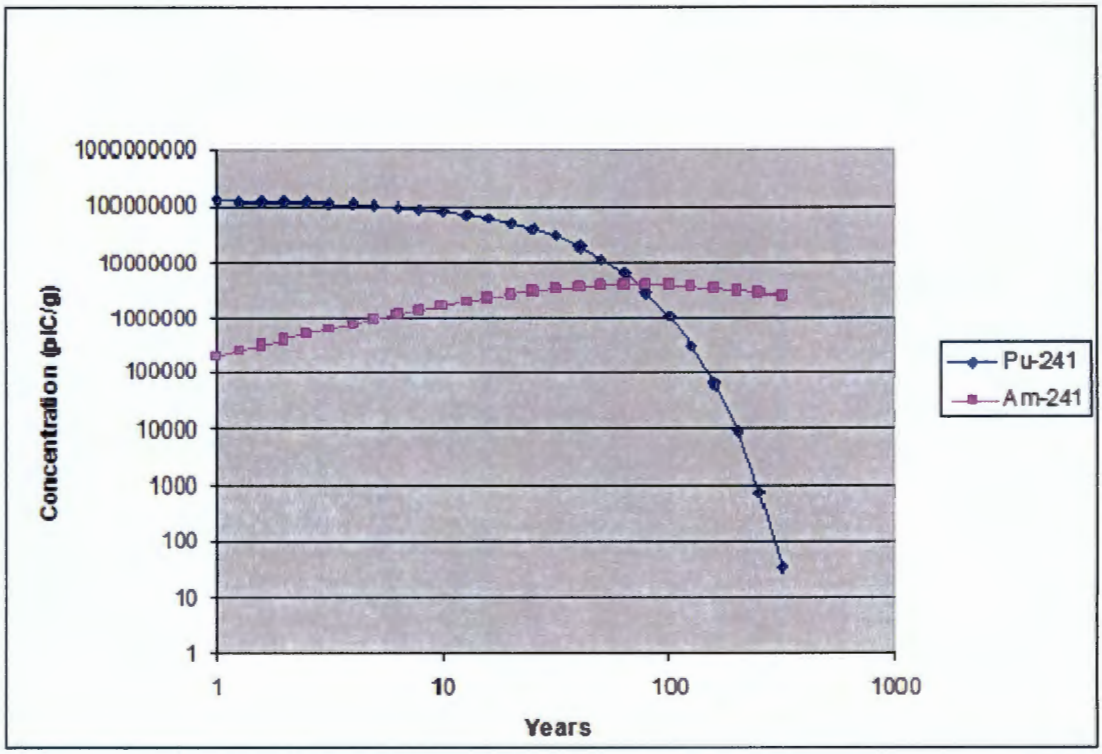

Figure A5-3. Cancer Risks from Tritium in Groundwater Over Time.

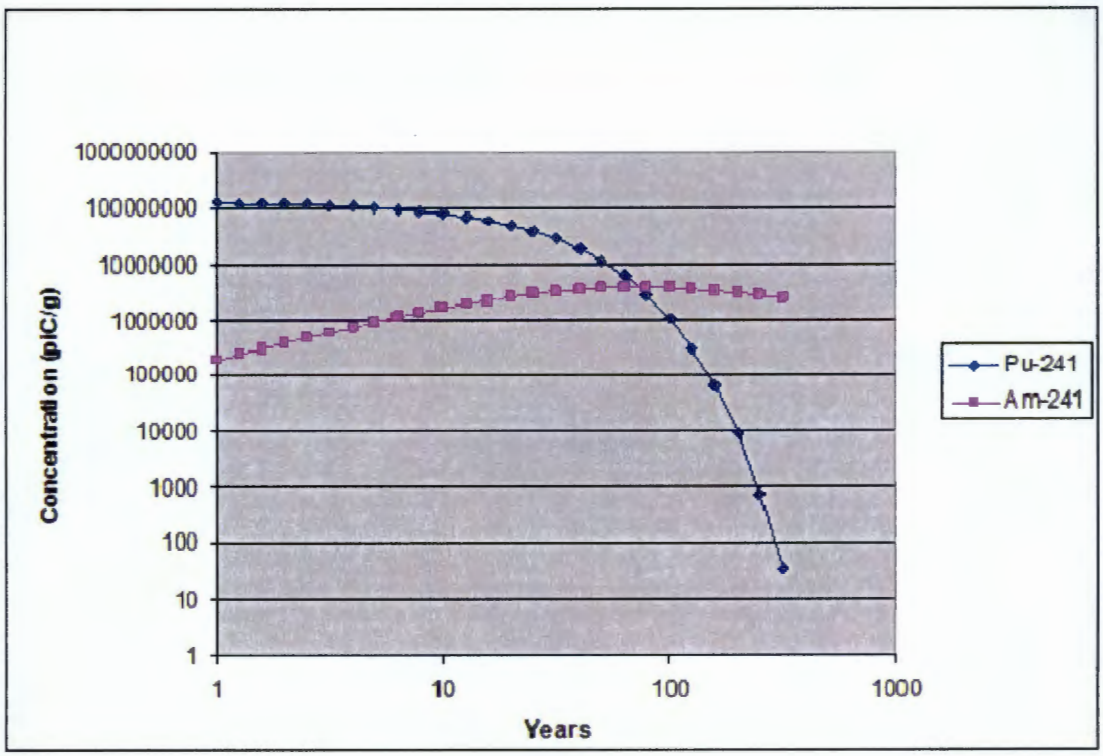

Table A5-1. Summary of Risks for the Current Construction Worker from Soil.

Radionuclide (Parent and Decay)	Total[a]	Inhalation	Ingestion	External Radiation	Radon
216-Z-1A Tile Field					
Am-241	4E-03	5E-04	3E-03	1E-03	--
Pu-239	3E-02	5E-03	2E-02	6E-05	--
Pu-240	6E-03	1E-03	5E-03	5E-06	--
Total - now	**4E-02**	**6E-03**	**3E-02**	**IE-03**	**2E-23**
216-Z-8 French Drain					
Am-241	1E-07	5E-08	1E-09	7E-08	--
Pu-238	1E-08	1E-08	3E-10	4E-11	--
Pu-239	7E-07	6E-07	2E-08	4E-09	--
Pu-240	1E-07	1E-07	3E-09	4E-10	--
Total - now	**9E-07**	**8E-07**	**2E-08**	**8E-08**	**9E-26**
216-A-8 Crib					
Cs-137	5E-02	6E-07	3E-04	5E-02	--
Np-237	7E-08	6E-10	3E-09	7E-08	--
Pu-239	1E-07	2E-08	8E-08	2E-10	--
Pu-240	2E-08	4E-09	2E-08	2E-11	--
Ra-228	1E-07	3E-10	1E-08	1E-07	--
Th-228	1E-07	7E-10	3E-09	1E-07	--
Total - now	**5E-02**	**6E-07**	**3E-04**	**5E-02**	**1E-08**
Total - 17 years	**4E-02**	**4E-07**	**2E-04**	**4E-02**	**3E-09**
Total - 28 years	**3E-02**	**3E-07**	**2E-04**	**3E-02**	**8E-10**
Total - 150 years	**2E-03**	**4E-08**	**1E-05**	**2E-03**	**3E-16**
Total - 500 years	**7E-07**	**2E-08**	**1E-07**	**6E-07**	**2E-20**
Total - 1,000 years	**2E-07**	**2E-08**	**9E-08**	**7E-08**	**9E-20**

[a] Totals are calculated using unrounded values.

Table A5-2. Summary of Risks for the Future Well Driller from Soil.

Radionuclide (Parent and Decay) or Contaminant	Total[a]	Inhalation	Ingestion	External Radiation	Radon
216-Z-1A Tile Field					
Am-241	3E-06	9E-10	5E-08	2E-06	--
Pu-239	5E-07	9E-09	4E-07	9E-08	--
Pu-240	1E-07	2E-09	1E-07	1E-08	--
Total - 150 years	**3E-06**	**1E-08**	**6E-07**	**3E-06**	**6E-24**
216-Z-8 French Drain					
Am-241	2E-09	5E-13	3E-11	2E-09	--
Pu-238	4E-12	8E-14	4E-12	5E-13	--
Pu-239	7E-10	1E-11	6E-10	1E-10	--
Pu-240	2E-10	3E-12	1E-10	2E-11	--
Total - 150 years	**2E-09**	**2E-11**	**8E-10**	**2E-09**	**3E-24**
216-Z-9 Trench					
Am-241	7E-06	2E-09	1E-07	7E-06	--
Eu-152	1E-10	2E-18	1E-15	1E-10	--
Ni-63	4E-12	2E-15	4E-12	--	
Np-237	7E-08	1E-12	5E-11	7E-08	--
Pu-238	8E-10	2E-11	7E-10	9E-11	--
Pu-239	7E-06	1E-07	6E-06	1E-06	--
Pu-240	2E-06	3E-08	1E-06	2E-07	--
Ra-226	8E-08	2E-13	4E-11	8E-08	--
Ra-228	5E-16	3E-21	1E-18	5E-16	--
Sr-90	5E-12	5E-17	1E-13	5E-12	--
Tc-99	6E-21	7E-25	1E-21	5E-21	--
Th-228	1E-15	1E-20	5E-19	1E-15	--
Th-230	3E-11	2E-13	1E-11	2E-11	--
Radionuclide total- 150 years	**2E-05**	**2E-07**	**7E-06**	**8E-06**	**3E-11**
Cadmium	1E-12	1E-12	--	--	--
Carbon tetrachloride	2E-06	2E-06	1E-09	--	--
Contaminant total – 150 years	**2E-06**	**2E-06**	**1E-09**	**--**	**--**
216-A-8 Crib					
Cs-137	7E-06	2E-13	8E-10	7E-06	--
Np-237	1E-09	2E-14	8E-13	1E-09	--
Pu-239	1E-11	2E-13	1E-11	2E-12	--
Pu-240	3E-12	5E-14	2E-12	3E-13	--
Ra-228	8E-15	4E-20	2E-17	8E-15	--
Th-228	2E-14	2E-19	9E-18	2E-14	--
Total - 150 years	**7E-06**	**5E-13**	**8E-10**	**7E-06**	**7E-16**
Total - 500 years	**4E-11**	**7E-14**	**3E-12**	**4E-11**	**1E-24**
Total - 1,000 years	**3E-13**	**2E-14**	**8E-14**	**2E-13**	**1E-24**

[a] Totals are calculated using unrounded values.

Table A5-3. Future Well Driller – Summary of Non-Cancer Hazards from Soil at the 216-Z-9 Trench.

Contaminant	Total[a]	Ingestion	Dermal	Inhalation
	HI	HI	HI	HI
Cadmium	0.002	0.0002	0.00004	--
Cadmium	0.00007	0.00007	--	--
Manganese	0.0001	0.00007	--	--
Total	**0.0004**	**0.0003**	**0.00004**	**0.00003**

[a] Totals are calculated using unrounded values.
HI = hazard index

Table A5-4. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker.

	Tap Water[a]		
	90th	50th	25th
Radionuclide COPCs			
I-129	1E-06	3E-08	[b]
Tc-99	2E-05	3E-06	9E-07
Tritium	1E-05	1E-06	2E-07
Total	**4E-05**	**4E-06**	**1E-06**
Nonradionuclide COPCs			
Carbon tetrachloride	3E-03	5E-04	6E-06
Chloroform	2E-05	4E-06	4E-07
Methylene chloride	1E-07	7E-09	5E-09
PCE	5E-06	7E-07	4E-07
TCE	6E-07	9E-08	9E-09
Total	**3E-03**	**5E-04**	**7E-06**

[a] Totals are calculated using unrounded values.
[b] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-5. Summary of Non-Cancer Hazards for Contaminants of Potential Concern (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker.

COPC	Tap Water[a]		
	90th	50th	25th
Carbon tetrachloride	41	7	0.1
Chloroform	0.07	0.02	0.002
Chromium (III)	0.0008	0.00007	0.00002
Chromium (VI) (groundwater)	0.7	0.04	0.02
Methylene chloride	0.0005	0.00004	0.00002
Nitrate	0.5	0.1	0.09
PCE	0.003	0.0004	0.0002
TCE	0.4	0.06	0.005
Uranium	0.02	0.004	0.002
Total	**42**	**7**	**0.2**

[a] Totals are calculated using unrounded values.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-6. Summary of Risks for the Future Residential Farmer from Soil. (2 sheets)

Radionuclide or Contaminant	Direct-Exposure Pathways					Food Chain Pathway
	Total[a]	Inhalation	Ingestion	External Radiation	Radon	Produce[b]
216-Z-1A Tile Field						
Am-241	1E-03	4E-07	4E-05	1E-03	--	3E-04
Np-237	6E-06	5E-11	4E-09	6E-06	--	6E-07
Pu-239	1E-03	1E-05	9E-04	2E-04	--	7E-03
Pu-240	2E-04	3E-06	2E-04	2E-05	--	2E-03
Total - 150 years	**2E-03**	**1E-05**	**1E-03**	**1E-03**	**1E-17**	**9E-03**
216-Z-8 French Drain						
Am-241	2E-08	3E-10	2E-08	1E-12	--	2E-07
Pu-238	7E-09	9E-11	7E-09	2E-10	--	5E-08
Pu-239	2E-06	2E-08	1E-06	2E-07	--	9E-06
Pu-240	3E-07	4E-09	3E-07	2E-08	--	2E-06
Total – 150 years	**3E-06**	**2E-08**	**2E-06**	**3E-07**	**1E-13**	**1E-05**
216-Z-9 Trench						
Ac-227	1E-05	4E-10	3E-08	1E-05	--	6E-07
Am-241	4E-03	1E-06	1E-04	4E-03	--	8E-04
Eu-152	1E-07	1E-15	1E-12	1E-07	--	3E-11
Ni-63	7E-09	2E-12	7E-09	0E+00	--	2E-06

Table A5-6. Summary of Risks for the Future Residential Farmer from Soil. (2 sheets)

Radionuclide or Contaminant	Direct-Exposure Pathways					Food Chain Pathway
	Total[a]	Inhalation	Ingestion	External Radiation	Radon	Produce[b]
Np-237	2E-04	1E-09	1E-07	2E-04	--	1E-05
Pa-231	2E-06	2E-10	2E-08	2E-06	--	1E-06
Pb-210	6E-07	2E-10	5E-07	1E-07	--	3E-05
Pu-238	2E-06	2E-08	1E-06	1E-07	--	1E-05
Pu-239	2E-02	2E-04	1E-02	3E-03	--	9E-02
Pu-240	3E-03	4E-05	3E-03	2E-04	--	2E-02
Ra-226	2E-04	1E-10	6E-08	2E-04	--	2E-05
Ra-228	3E-13	1E-18	8E-16	3E-13	--	2E-13
Sr-90	5E-09	3E-14	1E-10	5E-09	--	3E-07
Tc-99	1E-18	1E-22	3E-19	1E-18	--	1E-14
Th-228	9E-13	5E-18	4E-16	9E-13	--	3E-15
Th-230	5E-08	3E-10	2E-08	3E-08	--	2E-07
U-235	8E-07	8E-12	8E-10	8E-07	--	1E-08
Radionuclide total - 150 years	**2E-02**	**2E-04**	**1E-02**	**8E-03**	**9E-04**	**1E-01**
Cadmium	1E-09	1E-09	--	--	--	--
Carbon tetrachloride	5E-05	5E-05	3E-06	--	--	1E-03
Contaminant total	**6E-05**	**5E-05**	**3E-06**	**--**	**--**	**1E-03**
216-A-8 Crib						
Cs-137	2E-02	2E-10	1E-06	2E-02	--	4E-04
Np-237	3E-06	2E-11	2E-09	3E-06	--	3E-07
Pu-239	3E-08	3E-10	3E-08	5E-09	--	2E-07
Pu-240	6E-09	7E-11	6E-09	5E-10	--	4E-08
Ra-228	6E-12	1E-17	1E-14	6E-12	--	3E-12
Tc-99	4E-24	3E-28	8E-25	3E-24	--	3E-20
Th-228	2E-11	8E-17	6E-15	2E-11	--	5E-14
Total – 150 years	**2E-02**	**6E-10**	**1E-06**	**2E-02**	**1E-13**	**4E-04**
Total – 500 years	**2E-06**	**3E-10**	**2E-08**	**2E-07**	**4E-21**	**2E-07**
Total - 1,000 years	**1E-06**	**2E-10**	**1E-08**	**5E-09**	**6E-21**	**9E-08**

[a] Totals are calculated using unrounded values.
[b] Plants grown in impacted soil is the only food chain evaluated for soil. For beef cattle and dairy cattle, their exposures are due to drinking impacted water and foraging on plants irrigated with impacted water. Impacted soil is assumed to be limited to the garden area of the home.
-- = indicates incomplete pathway or not applicable (i.e., radon column)

Table A5-7. Future Residential Farmer – Summary of Non-Cancer Hazards from Soil Exposures.

Contaminant	Total[a]		Ingestion		Dermal		Inhalation		Plant
	Child HI	Child/Adult HI	Child HI	Child/Adult HI	Child HI	Child/Adult HI	Child HI	Child/Adult HI	Child/Adult HI
216-Z-9 Trench									
Cadmium	0.04	0.005	0.04	0.004	0.004	0.0006	--	--	4
Carbon tetrachloride	0.2	0.02	0.2	0.02	--	--	--	--	35
Manganese	--	0.003	0.02	0.002	--	--	0.002	0.0009	2
Total	**0.3**	**0.03**	**0.3**	**0.03**	**0.004**	**0.0006**	**0.002**	**0.0009**	**41**
216-A-8 Crib									
Thallium	0.04	0.004	0.04	0.004	--	--	--	--	3
Total	**0.04**	**0.004**	**0.04**	**0.004**	**--**	**--**	**--**	**--**	**3**

[a] Totals are calculated using unrounded values.
HI = hazard index

Table A5-8. Summary of Cancer Risks for Contaminants of Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Residential Farmer.

	Tap Water			Irrigation		
	90th	50th	25th	90th	50th	25th
Radionuclide COPCs						
I-129	4E-06	9E-08	[b]	[a]	[a]	[b]
Tc-99	8E-05	1E-05	3E-06	[a]	[a]	[a]
Tritium	4E-05	4E-06	6E-07	2E-07	2E-08	3E-09
Total[c]	**1E-04**	**1E-05**	**4E-06**	**2E-07**	**2E-08**	**3E-09**
Nonradionuclide COPCs						
Carbon tetrachloride	2E-02	3E-03	4E-05	7E-05	1E-05	2E-07
Chloroform	1E-04	4E-05	3E-06	2E-07	5E-07	4E-08
Methylene chloride	6E-07	4E-08	3E-08	9E-10	6E-11	4E-11
PCE	3E-05	4E-06	2E-06	5E-07	7E-08	4E-08
TCE	3E-06	4E-07	4E-08	2E-08	3E-09	2E-10
Total[c]	**2E-02**	**3E-03**	**5E-05**	**8E-05**	**1E-05**	**2E-07**

[a] Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.
[b] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.
[c] Totals are calculated using unrounded values.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-9. Summary of Non-Cancer Hazards for Contaminants of Potential Concern (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Future Residential Farmer.

COPC	Tap Water						Irrigation		
	90th		50th		25th		90th	50th	25th
	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult
Carbon tetrachloride	304	130	53	23	0.7	0.3	2	0.3	0.004
Chloroform	0.8	0.3	0.2	0.09	0.02	0.008	0.0007	0.001	0.0001
Chromium (III)	0.007	0.003	0.0005	0.0002	0.0002	0.00007	0.00009	0.000007	0.000003
Chromium (VI) (groundwater)	5	2	0.3	0.1	0.2	0.1	0.07	0.004	0.003
Methylene chloride	0.004	0.002	0.0003	0.0001	0.0002	0.0001	0.000004	0.0000002	0.0000002
Nitrate	3	1	0.9	0.4	0.6	0.2	[a]	[a]	[a]
PCE	0.03	0.01	0.004	0.002	0.002	0.001	0.0002	0.00003	0.00002
TCE	3	1	0.5	0.2	0.04	0.02	0.009	0.002	0.0001
Uranium	0.1	0.05	0.03	0.011	0.02	0.007	0.00005	0.00001	0.000007
Total[b]	**316**	**135**	**55**	**23**	**1**	**0.6**	**2**	**0.28**	**0.006**

[a] No toxicity criteria available to quantify exposures by this pathway.
[b] Totals are calculated using unrounded values.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-10. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Food Chain Pathways – Future Residential Farmer.

	Homegrown Produce			**Beef**			**Dairy Products**		
	90th	**50th**	**25th**	**90th**	**50th**	**25th**	**90th**	**50th**	**25th**
Radionuclide COPCs									
I-129	8E-06	2E-07	[a]	3E-06	7E-08	[a]	1E-05	3E-07	[a]
Tc-99	3E-03	3E-04	1E-04	2E-05	2E-06	6E-07	1E-04	2E-05	5E-06
Tritium	5E-04	5E-05	7E-06	9E-06	9E-07	1E-07	4E-05	4E-06	5E-07
Total[b]	**3E-03**	**4E-04**	**1E-04**	**3E-05**	**3E-06**	**8E-07**	**2E-04**	**2E-05**	**6E-06**
Nonradionuclide COPCs									
Carbon tetrachloride	1E-02	2E-03	3E-05	2E-06	3E-07	4E-09	3E-06	6E-07	8E-09
Methylene chloride	3E-06	2E-07	1E-07	7E-12	5E-13	3E-13	1E-11	9E-13	6E-13
PCE	4E-05	6E-06	3E-06	2E-08	3E-09	1E-09	4E-08	6E-09	3E-09
TCE	6E-06	1E-06	9E-08	3E-10	5E-11	4E-12	6E-10	9E-11	9E-12
Total[b]	**1E-02**	**2E-03**	**3E-05**	**2E-06**	**3E-07**	**5E-09**	**4E-06**	**6E-07**	**1E-08**

[a] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.
[b] Totals are calculated using unrounded values.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-11. Summary of Non-Cancer Hazards for the Nonradionuclide Contaminants of Concern Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations, Post-2150 Unrestricted Land Use – Food Chain Pathways – Future Residential Farmer.

COPC	Homegrown Produce			Beef			Dairy Products		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Carbon tetrachloride	354	62	0.8	0.05	0.008	0.0001	0.09	0.02	0.0002
Chloroform	0.4	0.09	0.008	0.000006	0.000002	0.0000001	0.00001	0.000003	0.0000003
Chromium (III)	0.005	0.0004	0.0001	0.0004	0.00003	0.00001	0.000003	0.0000002	0.00000007
Chromium (VI)	4	0.2	0.1	0.3	0.02	0.01	0.0020	0.0001	0.00007
Methylene chloride	0.01	0.0009	0.0006	0.00000004	0.000000003	0.000000002	0.00000007	0.000000005	0.000000003
PCE	0.02	0.003	0.001	0.000009	0.000001	0.0000006	0.00002	0.000002	0.000001
TCE	4	0.6	0.05	0.0002	0.00003	0.000003	0.0004	0.00006	0.000005
Uranium	0.1	0.02	0.01	0.0002	0.00006	0.00004	0.002	0.0005	0.0003
Total[a]	**362**	**63**	**1**	**0.3**	**0.02**	**0.01**	**0.09**	**0.02**	**0.0006**

[a] Totals are calculated using unrounded values.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table A5-12. Summary of Dose (mrem/yr) for Current Construction Worker from Soil.

Radionuclide	Total	Inhalation	Ingestion	External Radiation
216-Z-1A Tile Field				
Am-241	79,791	5,598	72,000	2,193
Pu-239	490,896	35,200	455,600	96
Pu-240	109,462	7,851	101,600	11
Total - now	**680,149**	**48,649**	**629,200**	**2,300**
216-Z-8 French Drain				
Am-241	1	1	<1	<1
Pu-238	<1	<1	<1	<1
Pu-239	5	5	<1	<1
Pu-240	1	1	<1	<1
Total - now	**7**	**7**	**<1**	**<1**
216-A-8 Crib				
Cs-137	71,819	<1	429	71,390
Np-237	<1	<1	<1	<1
Pu-239	2	<1	2	<1
Pu-240	<1	<1	<1	<1
Ra-228	<1	<1	<1	<1
Th-228	<1	<1	<1	<1
Total - now	**71,821**	**<1**	**431**	**71,390**
Total - 17 years	**48,492**	**<1**	**292**	**48,200**
Total - 28 years	**37,607**	**<1**	**227**	**37,380**
Total - 150 years	**2,247**	**<1**	**16**	**2,231**
Total - 500 years	**3**	**<1**	**2**	**1**
Total - 1,000 years	**2**	**<1**	**2**	**<1**

Table A5-13. Summary of Dose (mrem/yr) for Future Well Driller from Soil.

Radionuclide	Total	Inhalation	Ingestion	External Radiation
216-Z-1A Tile Field				
Am-241	5	<1	1	4
Pu-239	9	<1	9	<1
Pu-240	2	<1	2	<1
Total - 150 years	**16**	**<1**	**12**	**4**
216-Z-8 French Drain				
Am-241	<1	<1	<1	<1
Pu-238	<1	<1	<1	<1
Pu-239	<1	<1	<1	<1
Pu-240	<1	<1	<1	<1
Total - 150 years	**<1**	**<1**	**<1**	**<1**
216-Z-9 Trench				
Am-241	14	<1	3	11
Eu-152	<1	<1	<1	<1
Ni-63	<1	<1	<1	<1
Np-237	<1	<1	<1	<1
Pa-231	<1	<1	<1	<1
Pu-238	<1	<1	<1	<1
Pu-239	126	1	123	2
Pu-240	28	<1	27	<1
Ra-226	<1	<1	<1	<1
Ra-228	<1	<1	<1	<1
Sr-90	<1	<1	<1	<1
Tc-99	<1	<1	<1	<1
Th-228	<1	<1	<1	<1
Th-230	<1	<1	<1	<1
Total - 150 years	**168**	**2**	**153**	**13**
216-A-8 Crib				
C-14	<1	<1	<1	<1
Cs-137	10	<1	<1	10
Np-237	<1	<1	<1	<1
Pu-239	<1	<1	<1	<1
Pu-240	<1	<1	<1	<1
Ra-228	<1	<1	<1	<1
Tc-99	<1	<1	<1	<1
Th-228	<1	<1	<1	<1
Total - 150 years	**10**	**<1**	**<1**	**10**
Total - 500 years	**<1**	**<1**	**<1**	**<1**
Total - 1,000 years	**<1**	**<1**	**<1**	**<1**

0076368
3 of 4

Table A5-14. Summary of Dose (mrem/yr) for the Future Residential Farmer from Soil.

Radionuclide	Direct Contact with Soil				Produce Ingestion
	Total	Inhalation	Ingestion	External Radiation	
216-Z-1A Tile Field					
Am-241	1,044	1	101	221	721
Pu-239	5,283	3	649	10	4,621
Pu-240	1,187	1	146	1	1,039
Total - 150 years	**7,514**	**5**	**896**	**232**	**6,381**
216-Z-8 French Drain					
Am-241	1	<1	<1	<1	<1
Pu-238	<1	<1	<1	<1	<1
Pu-239	7	<1	1	<1	6
Pu-240	2	<1	<1	<1	1
Total - 150 years	**9**	**<1**	**1**	**<1**	**8**
216-Z-9 Trench					
Am-241	2,770	1	268	588	1,913
Eu-152	<1	<1	<1	<1	<1
Ni-63	<1	<1	<1	<1	<1
Np-237	33	<1	<1	8	25
Pa-231	3	<1	<1	<1	3
Pu-238	8	<1	1	<1	7
Pu-239	72,930	43	8,963	134	63,790
Pu-240	15,787	9	1,942	16	13,820
Ra-226	12	<1	<1	10	2
Ra-228	<1	<1	<1	<1	<1
Sr-90	<1	<1	<1	<1	<1
Tc-99	<1	<1	<1	<1	<1
Th-228	<1	<1	<1	<1	<1
Th-230	<1	<1	<1	<1	<1
Total - 150 years	**91,543**	**53**	**11,174**	**756**	**79,560**
216-A-8 Crib					
C-14	<1	<1	<1	<1	<1
Cs-137	965	<1	<1	941	24
Np-237	1	<1	<1	<1	<1
Pu-239	<1	<1	<1	<1	<1
Pu-240	<1	<1	<1	<1	<1
Ra-228	<1	<1	<1	<1	<1
Tc-99	<1	<1	<1	<1	<1
Th-228	<1	<1	<1	<1	<1
Total - 150 years	**966**	**<1**	**<1**	**941**	**25**
Total - 500 years	**<1**	**<1**	**<1**	**<1**	**<1**
Total - 1,000 years	**<1**	**<1**	**<1**	**<1**	**<1**

Table A5-15. Cumulative Risks for the Residential Farmer from Soil and Groundwater.

Exposure Pathway	Receptor Age[a]	Contaminant Group	Risk
Total Cancer Risks for Soil at 216-Z-9 Trench[b]			
Inhalation	Child/adult	Radionuclides	2E-04
		Nonradionuclides	5E-05
Ingestion	Child/adult	Radionuclides	1E-02
		Nonradionuclides	3E-06
External radiation	Child/adult	Radionuclides	8E-03
Radon	Child/adult	Radionuclides	9E-04
Ingestion of produce	Child/adult	Radionuclides	1E-01
		Cumulative cancer risks for soil =	**1E-01**
Total Cancer Risks for Groundwater (High)[b]			
Tap water	Child/adult	Radionuclides	1E-04
		Nonradionuclides	2E-02
Irrigation	Adult	Radionuclides	2E-07
		Nonradionuclides	8E-05
Meat (beef)	Child/adult	Radionuclides	3E-05
		Nonradionuclides	2E-06
Ingestion of produce	Child/adult	Radionuclides	3E-03
		Nonradionuclides	1E-02
Dairy products	Child/adult	Radionuclides	2E-04
		Nonradionuclides	4E-06
		Cumulative cancer risks for groundwater =	**3E-02**
		Cumulative risks to residential farmer at 216-Z-9 Trench =	**2E-01**

[a] The child/adult receptor age corresponds to a lifetime of exposure.
[b] The 216-Z-9 Trench and groundwater high were chosen as examples in order to provide cumulative risks.

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A6.0 UNCERTAINTIES IN RISK ASSESSMENT

The purpose of this risk assessment is to identify potential risks and hazards from exposure to contaminants and radionuclides in areas or from activities within the overall study area. Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks.

In this assessment, uncertainties relate to the selection of COPCs and the development of media concentrations to which people may be exposed, the assumptions about exposure and toxicity, and the characterization of health risks. Uncertainty in the development of media concentrations results from the inability to sample every square inch of potentially impacted media at a site. Instead, a limited number of samples must be obtained to represent the contaminant characteristics of a larger area. The sampling strategies for contaminants in this assessment were, in general, designed to prevent under-estimation of media concentrations, thus avoiding an under-estimation of the risks to public health.

There are uncertainties regarding the quantification of health risks in terms of several assumptions about exposure and toxicity, including site-specific and general uncertainties. Based on the anticipation of uncertainty when quantifying exposure and toxicity, the health risks and hazards presented in this risk assessment are more likely to over-estimate risk.

Uncertainty in the risk assessment produces the potential for two kinds of errors. A Type I error is the identification of a specific contaminant, area, or activity as a health concern when, in fact, it is not a concern (i.e., false-positive conclusion). A Type II error is the elimination of a contaminant, area, or activity from further consideration when, in fact, there should be a concern (i.e., false-negative conclusion). In the risk assessment, uncertainties were handled conservatively (i.e., health-protective choices were preferentially made). This strategy is more likely to produce false-positive errors than false-negative errors.

The following sections provide additional detail regarding uncertainties in the estimations of health risks.

A6.1 UNCERTAINTIES RELATED TO DATA EVALUATION AND THE SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

The data evaluation process addresses whether contaminants may be present in various environmental media at levels of health concern, whether site concentrations differ from background, and whether sufficient samples have been collected to fully characterize each exposure pathway.

A6.1.1 Soil Data and Contaminant of Potential Concern Selection

Soil data were adequate in extent at 216-Z-1A tile field (hundreds of samples from 36 locations over an area of 1,812 m^2 [19,500 ft^2]) and, to a lesser extent, also at the 216-Z-9 Trench (30 samples at nine locations over an area of 1,000 m^2 [10,800 ft^2]) to select COPCs and identify the range of potential concentrations of contaminants. For the two sites where data were more limited (216-Z-8 and 216-A-8 Cribs), sample locations were selected in the area expected to have the highest concentrations. At 216-Z-1A tile field and 216-Z-9 Trench, sample locations were also biased to identify the maximum concentrations. Thus, concentrations of the COPCs

were likely biased high, and health risks have not been under-estimated. Because of the large amount of information on Hanford's history and past practices, the available samples were analyzed for contaminants based on the known sources of constituents at the various waste sites; thus, contaminant classes have not been left out of the COPC selection process.

For the two limited data sets, the release at the 216-Z-8 french drain was very small and impacts appear to be confined to a limited area (DOE/RL-2006-51). The risk calculations used the maximum concentrations at the 216-Z-8 french drain to estimate health risk and these concentrations were in the 6- to 8-m (20- to 26–ft) range. Because maximum concentrations were used and samples were collected in the area of greatest contamination, the limited data at the 216-Z-8 Crib are unlikely to have under-estimated health risks. Therefore, the risk assessment conclusions regarding the low levels of risk at this location (less than 1×10^{-6} for all pathways except ingestion of vegetables, which was 5×10^{-5}, still below 1×10^{-4}) are likely over-estimates, rather than under-estimates, of risk.

For the second site with a limited data set, the 216-A-8 Crib, the area of contamination is potentially much larger than at the 216-Z-8 french drain (1,580 m^2 [17,000 ft^2] versus 2.3 m^2 [25 ft^2]), thus, the single boring provides less certainty on what actual exposure concentrations for this location might be. While the boring location was selected because that area had historically contained the highest concentrations, the range of concentrations beneath this area has likely not been identified. Therefore, use of the shallowest maximum concentration in the construction worker calculations has potentially over-estimated risk unless the concentrations at the single sample location (C4545) are similar throughout the area. Risk estimates for the well driller and the residential farmer at this location used data from the multiple depth samples, 3 to 18 samples depending on the compound. The data are valid if a well is drilled at the location of the C4545 boring, but it is not known whether the rest of the soil beneath this site is as impacted.

At two sites, 216-Z-9 Trench and 216-A-8 Crib, some compounds had maximum concentrations in excess of screening values but were not selected as COPCs because <5% of the data exceeding screening levels and/or the magnitude of exceedance over a screening level did not exceed a factor of 2 (see Tables A2-10 and A2-12). The two primary technical issues regarding screening are whether the toxic additivity of contaminants is adequately addressed and whether the screening level is sufficiently protective. Additivity is addressed through use of the maximum concentration for screening and by using a screening level below the target health goal (i.e., dividing non-cancer screening levels by 10 and using cancer screening levels based on a cancer risk of 1×10^{-6} when the upper target risk goal is 1×10^{-4}). Because risks and hazards for soil were calculated using the 95% UCL (and not the maximum concentration) for the evaluated populations at these sites (except construction workers at the 216-A-8 Crib) and concentrations equal to the screening level represent an acceptable risk, it is highly unlikely that contaminants not selected as COPCs represent an additive risk. In addition, for soil exposures at the 216-Z-9 Trench and 216-A-8 Crib, cancer risks are already extremely large for residential farmers, above 1 x 10-; therefore, adding incremental additional contaminants (i.e., chloroform or europium-155) would not make a significant difference in the conclusions or identification of risk drivers at the site. These results indicate that contaminants that were screened out would not have added significantly to risk/hazard totals, and health risks have not been under-estimated by screening procedures.

A.6.1.1.1 Plutonium-241 Decay to Americium-241. Americium-241 is a risk driver at both the 216-Z-1A tile field and 216-Z-9 Trench. At the 216-Z-8 french drain, its maximum risks for a residential farmer were 2 x 10^{-8}, several orders of magnitude below a level that is a health concern. The measured concentrations of americium-241 are the result of ingrowth from decay of plutonium-241 released from the plutonium-production process at the Z Plant sites. Because laboratory analysis for plutonium-241 is difficult, plutonium-241 has not been analyzed at any of the Z Plant sites; therefore, the americium-241 concentrations measured at the sites may not be at their maximum concentration, depending on how much plutonium-241 is present and how much has decayed. In Section A.3.2.1.1, maximum americium-241 concentrations were estimated using RESRAD. The resulting plutonium-241 decrease and americium-241 increases were graphed, and estimated maximum americium-241 concentrations from the graphs were used in the risk equations for the 216-Z-1A tile field and 216-Z-9 Trench. Different concentration estimates are possible if a different year "0" were to be selected, either closer to or further away from the date of the known concentrations. If there is a larger length of time between time 0 and the known concentration, then the known concentration is closer to maximum and vice versa. For example, if there were 20 years between time 0 and the known concentration of americium-241 at the 216-Z-1A tile field instead of the 12 years assumed in Section A3.2.1.1, then the maximum concentration is only around 40% of the known concentration instead of double the known concentration. Therefore, maximum americium-241 concentrations would only be under-estimated if there was actually less time between time 0 and the known concentration. Liquid waste disposal at the 216-Z-1A tile field occurred from 1964 to 1969 and at the 216-Z-9 Trench from 1955 to 1962. The "0" year in RESRAD was estimated to be 1967 for the 216-Z-1A tile field and 1960 for the 216-Z-9 Trench. The 0 years for both sites were, thus, close to the end of the disposal period and, thus, changing year 0 to the end of the disposal period (shortening the time between year 0 and the known concentration date) would not result in a significant increase in americium-241 concentrations. The known americium-241 concentration was 1979 for 216-Z-1A tile field (year 12 in RESRAD) and 1973 for the 216-Z-9 Trench (year 13 in RESRAD).

Americium-241 concentration estimates were not performed for the 216-Z-8 french drain. Even substantial increases in americium-241 would not affect the risk assessment conclusions for the 216-Z-8 french drain because risks are so far below target health goals. At the 216-Z-1A tile field and 216-Z-9 Trench, americium-241 risks already exceed the target cancer risk goal of 1 x 10^{-4}; therefore, an increase in americium-241 risks would not affect the conclusions of the risk assessment.

A.6.1.1.2 216-Z-10 Injection/Reverse Well. The 216-Z-10 injection/reverse well site had data from an old report, indicating that plutonium had not been detected in over 100 samples drilled within a 4.6–m (15-ft) radius of where the waste had been injected. More recently, passive neutron logging to detect alpha contamination was conducted at this site using non-analytical methods (non-analytic data are not suitable for inclusion in a risk assessment), and the results confirm the GE report (HW-9671) findings that plutonium has not moved 4.6 m (15 ft) laterally toward the soil borings (DOE-EM/GJ918-2005, DOE-EM/GJ919-2005, DOE-EM/GJ920-2005). Other radionuclides were detected using the non-analytical method of spectral-gamma logging (DOE-EM/GJ918-2005, DOE-EM/GJ919-2005, DOE-EM/GJ920-2005). These include the following:

- Cesium-137 was found at 1 pCi/g at ground surface at one well and near MRL of 0.2 pCi/g at 10, 14.3, 24.4, and 50.9 m (33, 47, 80, and 167 ft) bgs (shallow values may be from leaks around the casing or from other nearby waste sites).
- Cobalt-60 was found in only one well at <0.2 pCi/g from 39.9 to 40.8 m (131 to 134 ft) bgs.
- Europium-154 was detected in two wells: a maximum of 0.25 pCi/g from 29.3 to 29.9 m (96 to 98 ft) bgs in one well, and near the 0.6 pCi/g MDL at 28.2 and 34.9 m (92.5 and 114.5 ft) bgs in the second well.

These three radionuclides are unlikely to represent a health risk at 216-Z-10, even if analysis confirmed the above concentrations because these concentrations are all relatively low and would be lower today because of the short half-lives of these radionuclides (30.17 years for cesium-137, 5.27 years for cobalt-60, and 8.8 years for europium-154) and because there are no more toxic constituents in their decay chains. Because plutonium was not detected within 4.6 m (15 ft) of the well and the above radionuclides do not appear to be resent at levels that are a health concern (although the data are only screening level), there are unlikely to be significant radionuclide hazards present at 216-Z-10-Z-10 injection/rejection well, even though there may be a limited area of contamination above screening levels in the immediate vicinity of the well (i.e., <4.6 m [<15 ft]). It was also noted that any lateral spreading of plutonium at 216-Z-10 injection/rejection well would likely be less than the lateral spreading seen at 216-Z-8 french drain, where contaminants are limited to a small area and concentrations did not result in significant health risks. Therefore, while there is uncertainty regarding the maximum plutonium concentrations at the 216-Z-10 injection/rejection well, the site was appropriately screened out of the risk assessment.

A.6.1.1.3 Method Reporting Limits. Section A2.1.4.2 indicates that, in some cases, laboratory MRLs exceeded screening values. For detected contaminants in soil, the majority of contaminants in Table A2-6 were either selected as COPCs and, thus, included in the exposure and risk calculations or were detected concentrations were at background levels. Therefore, while there is uncertainty regarding the actual exposure concentration of the majority of contaminants in Table A2-6 (because half of the MRL was used as a surrogate concentration in the EPC calculations), this uncertainty is unlikely to affect the conclusions of the risk assessment. For the contaminants where the nondetects exceeding a screening value were a small percentage of the total number of samples, the uncertainty regarding the concentration is very low. For the contaminants where a significant portion of the data used to calculate the EPCs were nondetected values exceeding screening levels, the uncertainty is greater regarding the actual concentration. Constituents that fall into this latter category at the 216-Z-9 Trench include europium-152, nickel-63, radium-226, radium-228, and technetium-99.

The contaminants listed in Table A6-1 were never detected and, thus, were not carried through the risk assessment, but all had at least some MRLs above health-based screening levels. Thus, there is some uncertainty regarding whether they are actually present at concentrations above a screening level. While it is likely that the risk-driver contaminants have been appropriately identified due to their high concentrations and association with known source, and risks already exceed target health goals, these nondetected constituents remain an area of uncertainty in the risk assessment.

A6.1.2 Groundwater Data and Contaminant of Potential Concern Selection

With the exception of hexavalent chromium, the groundwater data set for the COPCs is very robust, with over 1,000 samples available from more than 40 wells that have been routinely sampled over many years. Therefore, the groundwater data set is adequate for risk assessment. For hexavalent chromium, there were analytical issues (which are discussed in the 200-ZP-1 RI report [DOE/RL-2006-24) that resulted in only 145 valid results available for the risk assessment compared to 1,035 samples for total chromium. This amount of information is likely still sufficient for the purposes of risk assessment. It should be noted that although hexavalent chromium and total chromium have been evaluated separately, a significant portion of the chromium present in groundwater is potentially in the hexavalent state. Unlike hexavalent chromium in surface materials (where it typically rapidly reduces to trivalent chromium), chromium in groundwater can be stable in the hexavalent form under certain aquifer conditions (EPA 910/R-98-001; *Laboratory Receive Latest Data on Chromium in Regional Aquifer* [LANL 2006], *Human Health Fact Sheet for Chromium* [ANL 2005]). As shown on the groundwater percentile table (Table A3-5), the concentrations of hexavalent chromium and total chromium are very similar (see also the groundwater EPC discussion in Section A6.2.3 and Table A6-4). The similarity of the concentrations provides some indication that the majority of the chromium in groundwater at the 200-ZP-1 OU is likely in hexavalent form. Evaluating total chromium as hexavalent chromium does not change the results of the risk analysis because the concentrations appear to be almost the same, with hexavalent chromium concentrations slightly higher. If total chromium is mostly in the hexavalent form, it could possibly change the extent of the plume. Hexavalent chromium in drinking water exceeded an HI of 1 (HI = 5 for children) only at the 90th percentile concentration, a very minor contaminant when compared to a child HI of 304 for carbon tetrachloride at the 90th percentile concentration (Table A5-9).

With regards to the selection of COPCs, the HHRA typically selects COPCs in water by comparing maximum concentrations to screening values based on EPA tap water levels, not MCLs or the other levels used in the groundwater RI to select RI COCs. As shown in Table A6-2, if the maximum concentrations in groundwater were compared to EPA Region 6 HHSLs for tap water and some evaluation of frequency and magnitude of exceedance is used, only two additional contaminants might be selected as COPCs: fluoride and vanadium. Neither of these contaminants is very toxic or present in sufficient concentrations to outweigh the risks and hazards in groundwater due to carbon tetrachloride or technetium-99. Therefore, adding these contaminants to the risk assessment would not affect the total risks or the conclusions of the report.

A6.2 UNCERTAINTIES RELATED TO EXPOSURE

For estimating the RME, 95% UCL values (or upper-bound estimates of national averages) are generally used for exposure assumptions, and exposed populations and exposure scenarios are also selected to represent upper-bound exposures. The intent of the RME, as discussed by the EPA Deputy Administrator and the Risk Assessment Council (*Guidance on Risk Characterization for Risk Managers and Risk Assessors* [Habicht 1992]) is to present risks as a range from central tendency to high-end risk (i.e., above the 90th percentile of the population distribution). This descriptor is intended to estimate the risks that are expected to occur in small but definable "high-end" segments of the subject population (Habicht 1992). The EPA distinguishes between those scenarios that are possible but highly improbable and those that are

conservative but more likely to occur within a population, with the latter being favored in risk assessment. The RME calculations, thus, over-estimate risk for most of a hypothetical population, even though all assumptions may not be at their maximum. The following subsections evaluate the populations not selected for evaluation, the exposure concentrations, and exposure assumptions to qualitatively evaluate where exposures (and, thus, risks) might be over- or under-estimated.

A6.2.1 Tribal Subsistence Exposures

As discussed in Section A3.1.1, Native Americans currently live near the Hanford Site and could potentially be exposed to contaminants in groundwater and subsurface soil in the 200 West Area under a future failure of institutional controls scenario, similar to a residential farming population. A residential farming population was selected to represent the RME "bounding" scenario because this population has more widely used exposure factors that have been used over many years at many CERCLA sites. However, based on the ongoing work evaluating the differences between a Tribal scenario and a residential farmer, Native Americans likely have increased exposure to many environmental media although, with few exceptions, Native American exposure pathways are the same as the residential farmer's (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain). Table A6-3 compares the exposure factors for a residential farmer and those established for the Confederated Tribes of the Umatilla Indian Reservation by Harris and Harper (2004) for the exposure pathways that are the same (i.e., direct soil and water contact pathways). Because the risk assessment equations are linear for non-cancer hazards and for cancer risks up to 1×10^{-2}, an increase in exposure could result in an increase in risk of the same amount. Thus, as shown in Table A6-3, combined exposures to soil and groundwater for Native Americans result in an increase of about an order of magnitude (10 times) of the exposure of the residential farmer. Because the multi-media cumulative cancer risks for the residential farmer already approach the maximum risk possible (i.e., approaching 100%), increased exposures for a Native American population would not necessarily result in an increase in risks. Non-cancer hazards can increase, so rather than having HIs in the 100's due to carbon tetrachloride exposures to groundwater, or in the 80's for ingestion of soil, a Native American population would have hazards in the 1,000's at the 90th percentile groundwater exposures and around 800 for exposure to soil.

Another area where Tribal subsistence scenarios and residential scenarios can differ is in the amount of food gathered or grown locally. Under the assumptions in this risk assessment, drill cuttings are spread over a 100-m^2 (1,076-ft^2) garden area, sufficient to produce a significant portion of a residential farmer's diet, but not sufficient in size to supply all a family's dietary needs. Therefore, in this case, the homegrown produce ingestion rates (produce ingestion was a risk-driving pathway) would be similar between the two populations. If the size of the garden is increased, then concentrations in soil and produce decrease; therefore, growing more produce does not necessarily increase risks. However, irrigating a garden with groundwater is not limited by area. Produce ingestion risks, assuming that the only source of contaminants into plants was irrigation water, were also significant (greater than 1×10^{-4} for carcinogens and HIs well above 1 due to carbon tetrachloride exposures, at the 90th and 50th groundwater concentrations). Therefore, if more food is produced from a larger garden irrigated with groundwater, risks and hazards would increase. This would be true for both a residential farming population as well as a Native American population. However, risks and hazards already exceed target health goals by

a significant amount, so an increase in the amount of homegrown produce ingested would not change the conclusions of the risk assessment.

Similar to produce irrigated with groundwater, if a Native American produced more of their own protein than a residential farmer, they might ingest more of their own beef. Beef ingestion had the lowest risks and hazards for the residential farmer exposure pathways with risks of 3×10^{-5} or less and no non-cancer hazards >1. Ingestion of dairy products for children is not expected to be any different for Native Americans than the child ingestion rates established by EPA (Harris and Harper 2004); therefore, risks and hazards due to dairy products ingestion are unlikely to be higher for a Tribal versus a residential farmer population.

There are several exposure pathways applicable to a Native American population that are not evaluated for the residential farmer: ingestion of wild plants and wild game, and exposures to water and water vapor in a sweat lodge. Under the assumptions in this assessment, wild plants and wild game would not be significantly affected by contaminants because contaminants are confined to a residential garden and water from groundwater. While contaminants in soil might be spread by windblown dust and, if an irrigation ditch system is used, there could be minimal exposure to groundwater, in general a developed farm would not be conducive to wild plant and wild game growth and habitat. Therefore, these exposure pathways are not applicable to Hanford's Central Plateau waste sites. However, a sweat lodge using groundwater would be possible and, using the sweat lodge exposure parameters developed by Harris and Harper (2004), a sweat lodge could be a significant source of contaminants in groundwater, with risks and hazards equal to or exceeding the drinking water pathway. Based on work done for a Tribal scenario at the Midnite Uranium Mine Site in northern Washington State, the inhalation of contaminants in sweat lodge vapor could result in risks an order of magnitude above the risks from drinking the water (*EPA Region 10 Midnite Mine Superfund Site Spokane Indian Reservation Washington, Record of Decision* [EPA Region 10, 2006]). The risk value shown in Table A6-4 is estimated based on the Midnite Uranium Mine Site work. As noted above for ingestion of produce, risks and hazards already exceed target health goals by a significant amount, so an increase in the amount exposure and risk due to addition of the sweat lodge pathway would not change the conclusions of the risk assessment.

A6.2.2 Other Exposure Pathways and Populations Not Quantified

Soil exposures were only evaluated for a construction worker under current conditions and for a well driller and residential farmer in the future. Drill cuttings spread at a place of business instead of a residential garden could result in regular outdoor worker exposures. However, these exposures would be much lower than those for a residential farmer and would not include the food chain pathways; therefore, risks and hazards have not been under-estimated. In addition, recreational/trespass exposures to drill cuttings and/or irrigation water (if water is present in irrigation ditches) are possible but would be unlikely to be significant due to the short-term and intermittent nature of such exposures.

As noted in Section A3.1, groundwater plumes from the 200-ZP-1 OU have not reached the nearest surface water body (i.e., the Columbia River) but may reach the river in 75 years or more if actions are not taken. Due to the uncertainties in estimating groundwater concentrations at the river boundary 75 years or more in the future, these potential future pathways were not quantified in the risk assessment but represent an area of future uncertainty. Depending on the concentrations reaching the river, there could be a human health concern via contact with

contaminants in sediment or surface water during recreational activities, or through ingestion of impacted fish.

A6.2.3 Exposure Point Concentrations

The EPCs for **groundwater** were the 25th, 50th, and 90th percentile concentrations, selected in order to evaluate "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. This methodology does not provide risks at a specific location but results in information on the range of possible risks for each COPC at the current concentrations. Typical risk assessment methodology is to calculate a 95% UCL on the mean as the EPC (OSWER Directive 9285.6-10) using data from within the exposure area or, in the case of groundwater, the data from one well location. To provide additional information on possible ranges of concentrations in groundwater EPCs for the COPCs, Table A6-4 shows the percentile concentrations used in the risk calculations, as well as the maximum concentrations, average concentrations, and 95% UCL concentrations using all of the data. For the risk-driving contaminants in groundwater, carbon tetrachloride and technetium-99, the 90th percentile values are above the 95% UCL values because the data set is robust. Generally the larger the data set, the closer the 95% UCL is to the mean concentration. For example, carbon tetrachloride's 95% UCL is 1,491 μg/L and the mean is 1,009 μg/L; in contrast, the 90th percentile is 2,900 μg/L. Therefore, 90th percentile values are reasonable upper-bounds of concentrations for the purposes of the risk assessment. However, if a well was drilled at the location of the maximum concentration, risks would be significantly under-estimated for the COPCs where the maximum concentration is considerably larger than the 90th percentile value (true for 8 of the 12 COPCs where the maximum concentration is more than an order of magnitude larger than the 90th percentile). Because only 10% of the data exceed the 90th percentile values, these very high concentrations are few and represent a very limited areal extent. Figures A6-1 and A6-2 present histograms of the carbon tetrachloride and technetium-99 groundwater concentrations. From these two figures, it can be noted that a large majority of the concentrations are lower, rather than higher, values.

For the **construction worker exposures to soil** calculations at all three of the soil sites, characterization of the top 4.6 m (15 ft) was limited with few, if any, samples representing that depth horizon. For the COPCs at the 216-Z-8 french drain and 216-A-8 Crib sites, the EPCs were the maximum concentration because either the 95% UCL exceeded the maximum concentration (216-Z-8 french drain) or there were too few samples in the depth interval of concern to calculate a 95% UCL (216-A-8 Crib). Therefore, use of these EPCs likely has resulted in risks that are biased as high because the majority of a construction worker's exposure would be to uncontaminated shallower soil.

For **residential farmer soil** concentrations, concentrations are dependent on the size of the garden over which drill cuttings would be spread. The risk calculations assumed a 100-m^2 (1,076-ft^2) garden from the analysis performed for the tank waste performance assessment (Rittman 2004). The value of 100 m^2 (1,076 ft^2) is based on an area that could likely supply at 25% of vegetables and fruit for a family of four. Larger size gardens or other types of spreading areas would result in a decrease in concentrations. Figure A6-3 presents the plutonium-239 concentrations at the 216-Z-1A and 216-Z-9 sites for a residential farmer, assuming garden sizes of 100 m^2, 500 m^2, 1,000 m^2, 1,500 m^2, and 2,000 m^2 (1,076 ft^2, 5,382 ft^2, 10,764 ft^2, 16,146 ft^2, and 21,528 ft^2). At 1,500 m^2 (16,146 ft^2), concentrations are reduced over an order of magnitude

(the relationship of concentration to garden size is linear). Because the concentrations of plutonium-239 are so high at both of these wastes sites, concentration reductions by an order of magnitude would still result in risks well above 1×10^{-4} for the soil pathways.

A6.2.4 Uncertainties in Food Chain Ingestion Rates

The evaluation of the food chain pathways has resulted in risks and hazards significantly above the target health goals, primarily due to ingestion of homegrown produce, and this pathway has resulted risks and hazards that are equal to or greater than direct ingestion of groundwater used as a drinking water source. There are two main factors that drive the calculated risks and hazards from ingestion of homegrown produce: (1) the concentration in the plant tissue, and (2) the plant ingestion rate. The uncertainties associated with these factors and their impacts on the conclusions of the risk assessment are discussed below.

The modeling used to calculate plant tissue concentrations for COPCs in groundwater is based on a conservative approach developed by ORNL in the RAIS (http://rais.ornl.gov). For the soil-to-plant pathway, risks were estimated using RESRAD based on site soil concentrations. Both models are designed to be health protective in an attempt to over-estimate, rather than under-estimate, the potential concentrations of contaminants in plant tissues irrigated with contaminated groundwater or grown in contaminated soil. The plant tissue calculations depend largely on the transfer factor used to estimate the uptake of contaminants by the plant from the soil. The transfer factors used in the plant tissue EPC calculations for groundwater were generally obtained from Rittman (2004), and for most contaminants, these factors are consistent with the default transfer factors used by ORNL and are similar to those in RESRAD (although Rittman [2004] used site-specific data for Hanford where the data were available). Transfer factors are based on the assumed behavior of the contaminant in the environment, as well as the assumed affinity of the contaminant to reside in plant tissues. For some contaminants, the transfer factors are greater than unity, which indicates that the concentration in plant tissue is higher than the concentration in soil and that the plant has a tendency to bio-accumulate the contaminant in the plant tissues. Transfer factors could vary depending on the type of plant being cultivated and specific soil conditions. However, to simplify the process for modeling plant tissue concentrations and because the specific future conditions in which produce might be grow 150 years from now are not known, the health-protective default transfer factors that can be applied to most types of plant grown in most any type of soil conditions were used in this assessment. In lieu of site-specific bio-transfer data, use of these transfer factors provides a method for quantifying exposures through this pathway. It is likely that the amount of COPC estimated to be in plant tissue is over-estimated by this modeling process. In addition, this modeling process does not take into account high concentrations in soil or groundwater that could result in direct toxicity to the plant, either through stunting growth and or yield or resulting in plant death.

The second area of uncertainty associated with the plant ingestion pathway is the ingestion rate used in the risk calculations. The ingestion rate used in the risk calculations is based on the mean (average) total homegrown fruit intake for households who farm in the west of 1.85 g/kg-day and the mean (average) total homegrown vegetable intake for households who farm in the west of 2.73 g/kg-day, as shown in Tables 13-12 and 13-17 of EPA/600/P-95-002Fa. EPA/600/P-95-002Fa recommends using mean intake rates rather than an upper percentile value (as is commonly used for many RME exposure values) for these particular ingestion rates

because of the uncertainties in the higher percentile estimates. Seasonally adjusted intake rates from EPA/600/P-95-002Fa could be more representative of long-term exposures and were lower than those for households who farm in the west of 2.73 g/kg-day (see Table A6-5 sources are Tables 13-12 and 13-17 in EPA/600/P-95-002Fa); however, because food-preparation methods could result in eating homegrown food all year round, and because of uncertainties in intake rates between people who live in the west (but may not be farmers) and specifically those who engage in farming activities, the unadjusted intake rates for households who farm were deemed the best RME values for a future farming population. These values were also not adjusted for cooking or preparation loss, again because of uncertainties regarding actual food preparation methods, but cooking and certain types of food preparation (e.g., peeling) can reduce concentrations of contaminants in food.

Summing fruit and vegetable rates for households who farm together results in a total mean homegrown fruit and vegetable intake rate for households who farm in the west of 4.56 g/kg-day (equivalent to 319 g/day for a 70 kg person, or approximately 0.75 lb of fruits and vegetables eaten every day for 30 years) (Table A6-5). This is equivalent to producing around 60% of a person's total fruit and vegetable intake using USDA average consumption rates (521 g/day, as cited in Rittman [2004]) or 49% of a person's total fruit and vegetable intake using EPA's mean capita consumption rates (*Analysis of Total Food Intake and Composition of Individual's Diet Based on USDA's 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII)* [EPA/600/R-05/062F]). If total fruit and vegetable consumption rates for high consumers are compared to the ingestion rates used in this risk assessment, the ingestion rates used in this assessment are 16% of total consumption rates (EPA/600/R-05/062F). While the ingestion rates used in this assessment may be an over-estimate of the amount of vegetables and fruit (grains are excluded) that could be produced from a 100-m^2 (1,076-ft^2) garden for a family of four or more people (Rittman [2004] assumed that a 100-m^2 [1,076-ft^2] garden could produce 25% of total fruit and vegetables for a family of four) (see Table A6-6), this value was used as an upper-bound because of the issues around using irrigation water for a larger size garden than the drill cuttings could reasonably be spread over (without lowering concentrations in soil significantly). A recent evaluation at another DOE site identified 200 m^2 (2,153 ft^2) as adequate to provide half the entire yearly intake of vegetables (ORNL-TM/13401, as cited in Rittman [2004]).

The produce intake rates used in this assessment are more than double those presented in the HSRAM (DOE/RL-91-45) (see Table A6-6). The values in the risk assessment methodology were obtained from OSWER Directive 9285.6-03). OSWER Directive 9285.6-03 estimates that an average fruit and vegetable consumption is 340 g/day (less than the USDA estimate and much less than the current EPA estimates presented in EPA/600/R-05/062F), and that 30% to 40% of that value represented an RME consumption for homegrown fruits and vegetables. This information has been updated in EPA/600/P-95-002Fa, which was the source of the values used in this assessment.

In conclusion, the homegrown produce intake rates used here likely over-estimate the amount of produce that could be grown in a 100-m^2 (1,076-ft^2) garden but may be representative of a larger garden area irrigated with impacted groundwater. If intake rates were lowered one-third, risks would lower slightly but would still be well above 1×10^{-4} for all risk drivers for this pathway (e.g., technetium-99 produce ingestion risks from plants irrigated with groundwater would change from 3×10^{-3} to 9×10^{-4}).

Another reason to use higher ingestion rates is to provide an over-estimation that accounts for other food chain exposures not evaluated in this assessment. For example, if poultry were watered with groundwater or had contact with impacted soil, ingestion of poultry and ingestion of eggs could also contribute to exposures to the COPCs under a residential farming scenario.

A6.2.5 Uncertainties in Other Exposure Factors

Intake rates of **soil for construction workers** assumed a soil ingestion of 330 mg/day. This value for construction workers is the 95th percentile ingestion rate from a mass-balance study conducted with 10 adults who were followed over a 4-week period (280 subject-days). The average and median amounts of soil ingested in the study were 10 mg/day and 1 mg/day, respectively (*Soil Ingestion in Adults – Results of a Second Pilot Study* [Stanek et al. 1997]). Because of the small population and the large variability in the data, the 95th percentile value is highly uncertain.

Soil exposures for the radionuclides used the default exposure assumptions in RESRAD for the residential farmer risks. The RESRAD default assumptions differ from EPA residential defaults as follows:

- There is no increase in **soil ingestion rate** for young children. RESRAD assumes a total ingestion rate of 36.5 g/yr (equivalent to 100 mg/day, the default adult outdoor ingestion rate used in the nonradionuclide residential farmer equations, for 365 days/yr). Of the total, RESRAD assumes only 10% would come from the impacted garden area of 100 m^2 (1,076 ft^2). This means that the RESRAD soil risks are significantly lower than the EPA defaults.
- RESRAD assumes that only 75% of a person's **time will be spent onsite**; EPA residential defaults assume that 96% of a person's time will be spent at home.
- RESRAD assumes an annual **inhalation rate** of 8,400 m^3/yr, corrected to account for time spent offsite, time indoors (50%), and an indoor dust reduction factor (0.4), to 3,780 m^3/yr (45% reduction of annual inhalation rate due to site exposures), equivalent to a daily onsite inhalation rate for 350 days/yr of 10.8 m^3/day, approximately one-half the EPA residential default of 20 m^3/day. However, the dust inhalation pathway for radionuclides at this site is not significant in comparison to ingestion and external radiation, with inhalation risks several orders of magnitude below ingestion and external radiation.

If RESRAD parameters were to be changed to match EPA defaults, radionuclide risks due to ingestion would significantly increase, but such increases would not affect the conclusions of the risk assessment. Direct-contact soil pathways already had risks greater than 1×10^{-2} for the radionuclides for all soil sites, except the 216-Z-8 french drain (risks below 1×10^{-6}); therefore, risk assessment conclusions (i.e., exceedances well above 1×10^{-4}) would not change.

If the EPA time on site defaults were changed to match those in RESRAD, the nonradionuclide risks would fall. This decrease would not change the over-all risks at the 216-Z-9 Trench (the only soil site with nonradionuclide carcinogens), which are driven by the radionuclides for the direct-contact pathways; however, because the nonradionuclide cancer risks at the 216-Z-9 Trench were primarily due to ingestion of produce (risks = 1×10^{-3}), lowering soil ingestion risks at least 25% to account for time spent offsite would not affect the overall nonradionuclide cancer risks at the site (direct-contact soil pathway risks were only 6×10^{-5}) (see Table A5-6). It is

reasonable to assume that most people typically do not spend 96% of their time at home, and other risk assessments at Hanford have assumed a 60/20/20 factor (i.e., 60% inside, 20% outside, and 20% offsite). Assuming less time outdoors and onsite lowers risk estimates.

A6.3 UNCERTAINTIES IN ASSESSMENT OF TOXICITY

Toxicity values have been developed by EPA from the available toxicological data. These values frequently involve high-to-low-dose extrapolations and are often derived from animal rather than human data. In addition, few studies may be available for a particular contaminant. As the unknowns increase, the uncertainty of the value increases. Uncertainty is addressed by reducing RfDs using uncertainty factors and by deriving SFs using a conservative model. The greater the uncertainty, the greater the uncertainty factors and tendency to over-estimate the toxicity to ensure health-protective analyses.

Traditionally, EPA has developed toxicity criteria for carcinogens by assuming that all carcinogens are non-threshold contaminants. However, EPA has recently published revised cancer guidelines (*Guidelines for Carcinogen Risk Assessment* [EPA/630/P-03/001F]) where they have modified their former position of assuming non-threshold action for all carcinogens. This new guidance emphasizes establishing the specific toxicokinetic mode of action that leads to development of cancer. Toxicity criteria for carcinogens in the United States will in future be developed assuming no threshold only for contaminants that exhibit genotoxic modes of action, or where the mode of action is not known. However, currently available EPA toxicity criteria for carcinogens were all derived assuming a no-threshold model.

In most of the world, non-threshold toxicity criteria are developed only for those carcinogens, which appear to cause cancer through a genotoxic mechanism (Health Canada, Netherlands). Specifically, for genotoxic contaminants, the cancer dose-response model is based on high- to low-dose extrapolation and assumes that there is no lower threshold for the initiation of toxic effects. Cancer effects observed at high doses in laboratory animals or from occupational or epidemiological studies are extrapolated, using mathematical models, to low doses common to environmental exposures. These models are essentially linear at low doses so no dose is without some risk of cancer.

The linear low-dose model and genotoxicity are likely an appropriate model for the radionuclides, as radiation can alter DNA; therefore, all radionuclides have been classified as known human carcinogens (EPA 402-R-99-001). On the other hand, scientific evidence does not rule out the possibility that the risk per unit dose is effectively zero at environmental exposure levels or that there may be a net beneficial effect of low-dose radiation (i.e., hormesis). Radiation-induced genetic effects have not been observed in human populations, and extrapolation from animal data reveals risks per unit exposure that are smaller than, or comparable to, the risk of cancer (EPA 540/1-89/002). The equations to estimate risk from radiation exposure assume that at low levels of exposure, the probability of incurring cancer increases linearly with dose and without a threshold (EPA 402-R-99-001).

All of the epidemiological studies used in the development of radiation risk models involve high radiation doses delivered over relatively short periods of time. Evidence indicates that the response per unit dose at low doses and dose rates from low linear-energy transfer radiation (primarily gamma rays) may be over-estimated if extrapolations are made from high doses acutely delivered. The degree of over-estimation is often expressed in terms of a dose, and

a dose-rate effectiveness factor is used to adjust risks observed from high doses and dose rates for the purpose of estimating risks from exposures at environmental levels. The EPA models for radiation risk include a dose and dose-rate effectiveness factor of 2, applicable to most low linear-energy transfer radiation exposure. For high linear-energy transfer radiation (e.g., alpha particles), the differences in relative biological effect are accounted for in weighting factors applied in the calculation of dose and risk.

The SFs used in this risk assessment for the radionuclides are morbidity SFs. For a given radionuclide and exposure mode, they represent an estimate of the average total risk of experiencing a radiogenic cancer, whether or not the cancer is fatal. They are derived using age-specific models and are age-averaged. These SFs are appropriate for use in estimating exposure over a lifetime because they are derived by taking into account the different sensitivities to radiation as a function of age. The SFs in this assessment were used to assess the risk due to chronic lifetime exposure of an average individual to a constant environmental concentration. The risk estimates in this report are intended to be prospective assessments of estimated cancer risks from long-term exposure to radionuclides in the environment. The use of the SFs listed for retrospective analyses of radiation exposures to populations should be limited to estimation of total or average risks in large populations. Because the SFs were averaged from large study populations, they may not be predictive for specific individuals or small groups.

The cancer SF values for TCE used in this assessment were those established by the California EPA (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) and are generally being recommended for use in risk assessment. The SFs derived by OEHHA are an inhalation slope factor (SF_i) of 0.0007 $(mg/kg\text{-}day)^{-1}$ (as presented in *Technical Support Document for Describing Available Cancer Potency Factors* [OEHHA 2002]) and an oral SF of 0.013 $(mg/kg\text{-}day)^{-1}$ (as presented in *Public Health Goal for Trichloroethylene in Drinking Water* [OEHHA 1999]).

The OEHHA values are considerably lower than EPA's selection of 0.4 $(mg/kg\text{-}day)^{-1}$ for both oral and inhalation exposures from EPA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization* (EPA 2001). This document is an external review draft to which EPA is soliciting comments and the findings are subject to change; however, the findings have sparked controversy in the regulatory and scientific community and have been the subject of a National Academy of Sciences (NAS) review. Until EPA addresses the NAS findings and revises their TCE risk assessment, most jurisdictions in the United States are recommending use of the California values; however, Ecology is currently recommending use of the 0.4 $(mg/kg\text{-}day)^{-1}$ value.

The U.S. Department of Defense (DOD) has published a critique of EPA's proposed SF range for TCE (*Critique of the U.S. Environmental Protection Agency's Draft Trichloroethylene Health Risk Assessment (EPA/600/P-01/002A)* [AFIERA 2001]). In particular, they note that the upper end of the proposed recommended range, 0.4 $(mg/kg\text{-}day)^{-1}$, is based on a residential drinking water study where the confidence interval around the calculated relative risk included one. The relative risk is defined as the cancer incidence rate in the exposed population relative to an unexposed population. If the relative risk is one, then cancer incidence rates are equal for the exposed and unexposed populations and the study cannot conclude that there is an increased association between cancer and site exposures relative to an unexposed population. Generally, if the confidence interval around the relative risk includes one, then cancer incidence rates for the two populations (exposed and unexposed) are not significantly different. Therefore, the DOD

review concluded that there was insufficient evidence to conclude that TCE exposures in drinking water were associated with an increase in non-Hodgkins lymphoma; thus, no SF should be calculated based on that study. Only one study had non-Hodgkins lymphoma associated with TCE exposure.

Because of the uncertainty surrounding EPA's new proposed SF and because of the criticisms that the health assessment document has received, this risk assessment has selected the California values as more appropriate at this time. If the EPA provisional value were used to estimate TCE risks in groundwater, risks at the 90th percentile go from barely exceeding *de minimis* levels (3×10^{-6}) to 4×10^{-4}, greater than the upper-bound target risk goal. TCE is currently identified as a slight potential hazard in groundwater at the 90th percentile concentration with a child HI of 3. There is some uncertainty regarding whether exposure to 90th percentile TCE concentrations in groundwater represents a potential cancer risk in excess of target health goals. If the OEHHA SFs are revised upwards and/or the higher EPA SFs are validated, cancer risks due to TCE might be under-estimated. However, risks due to domestic use of groundwater at 90th percentile concentrations are driven by carbon tetrachloride with risks of 2×10^{-2}. Increasing TCE risks even to 4×10^{-4} does not make a difference in the overall cumulative cancer risks from groundwater.

A6.4 UNCERTAINTIES IN RISK CHARACTERIZATION

Radiation is naturally present in the environment, and the radionuclide risks estimated in this assessment have not been corrected to account for natural background. The impacts of remediation background are typically described in terms of radiation dose (millirem, or mrem). For the United States as a whole, the average radiation dose from background sources is approximately 300 mrem/yr. Approximately 200 mrem/yr is from radon inhalation. Radon emanates from the uranium decay series naturally present in soil and rock. (Note that the radon risk levels at all the waste sites evaluated in this assessment were insignificant with dose concentrations well below 1 mrem/yr [see Attachment A-7]). The remaining 100 mrem is from internal sources, primarily radioactive potassium-40 (present on the Hanford Site), cosmic rays, and direct exposure from radioactive sources in soils and rocks. The background total varies with altitude (cosmic radiation increases with altitude) and geology (determines radon and gamma sources at the ground surface). A general estimate of the range of variability in background radiation dose in the United States is from 100 to 1,000 mrem/yr. For comparison, the upper end of the CERCLA risk range, which represents the level below which CERCLA decisions are typically made, generally corresponds to dose rates that are less than 15 mrem/yr. The DOE uses a dose level of 100 mrem/yr as their acceptable target dose goal (NRC decommissioning requirements under 10 CFR 20, Subpart E). Because the radiation doses at this site are so high for the risk drivers (thousands or even tens of thousands of mrem/yr), the contribution of background to overall dose for cesium-137, americium-241, plutonium-239, and plutonium-240 is insignificant at all sites (except the 216-Z-8 french drain), and dose levels at that site are below 15 mrem/yr for the construction worker and well driller and were only 49 mrem/yr for the residential farmer due to ingestion of homegrown produce.

Studies have not been able to relate variations in health effects to variation in background radiation doses. Based on international studies, the National Research Council reports that in areas of high natural background radiation an increased frequency of chromosome aberrations has been noted. However, no increase in the frequency of cancer has been documented in

populations residing in areas of high natural background radiation (*Health Effects of Exposure to Low Levels of Ionizing Radiation, Committee on the Biological Effects of Ionizing Radiation (BEIR V)* [BRER-K-97-01-A]).

A6.4.1 Uncertainties Associated with Large Estimates of Risk

The CERCLA risk estimates are designed to support decisions relative to the CERCLA risk range, but risks approaching 1 are subject to additional uncertainties and technical limitations. Because relatively low intakes are most likely from environmental exposures at Superfund sites, it can generally be assumed that the dose-response relationship will be linear in the low-dose portion of the multi-stage model dose-response curve. In this case, the SF is a constant and risk can be directly related to intake. This linear relationship is valid only at relatively low-risk levels (i.e., below estimated risks of 0.01). For estimated risks above this level, alternative calculations are used. Since risk is generally understood as an estimate of cancer probability, and since probabilities are limited to the range between 0 and 1, one of the purposes of these alternative calculations is to avoid calculating risks which exceed 1 and, therefore, lose meaning (EPA 540/1-89/002).

In addition to the assumption of dose-response linearity, risks based on high doses should be considered with caution because the SFs are based on radiation risk models developed for application to low doses or dose rates. The assumption is made that doses are sufficiently low that the survival function is not significantly altered by the number of radiogenic cancer deaths at any age (EPA 402-R-99-001). Risks calculated based on large cumulative doses should therefore be considered with caution.

A third consideration regarding large dose estimates is the effect of multiple contaminants. Standard risk assessment practice is to add the estimated risks from contaminants. These risk summation techniques assume that intakes of individual substances are small, that there are no synergistic or antagonistic interactions among contaminants, and that all contaminants have the same effect (i.e., cancer). This is an approximation that is useful when the total estimated cancer risk is <0.1. However, because SFs are often 95th percentile estimates of potency, and because upper 95th percentiles of probability distributions are not strictly additive, the total cancer risk estimate may become more of an artificial over-estimate as risks from a number of different carcinogens are summed. If the individual contaminant risks are themselves large, or if the number of contaminants is large, or if the assumptions applied are otherwise incorrect, simple risk summation may result in large estimates of cumulative cancer risk that lose some usefulness (EPA 540/1-89/002).

A6.4.2 Uncertainties in Radiation Risk Assessment

The uncertainties associated with the SFs are likely to be larger than those due to analytical uncertainties. EPA's Federal Guidance Report No. 13 does not provide specific quantitative uncertainty estimates of the cancer SFs (EPA 540/1-89/002). *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection* (NCRP Report No. 126) examined the question of uncertainties in SFs for the relatively simple case of external radiation exposure to low linear energy transfer (primarily gamma) radiation (NCRP Report No. 126). The conclusion was that the 90% confidence interval was approximately three times higher or lower than the central risk estimate. Since estimates of risk from ingestion of food necessarily involve the added

complexity of modeling of physiological processes to determine dose and risk, the uncertainties in this context are likely to be even greater.

The BEIR V report (BRER-K-97-01-A) addressed the issue of uncertainty in risk estimates for low doses from low linear energy transfer radiation. The report considered the assumptions inherent in modeling such risks and concluded that at low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates includes zero.

A6.5 SUMMARY OF UNCERTAINTY

Every aspect of the risk assessment contains multiple sources of uncertainty. Simplifying assumptions are often made so health risks can be estimated quantitatively. Because the exact amount of uncertainty cannot be quantified, the risk assessment is intended to over-estimate rather than under-estimate probable risk. The results of this assessment, therefore, are likely to be protective of health despite the inherent uncertainties in the process.

Figure A6-1. Carbon Tetrachloride Groundwater Concentration Frequencies.

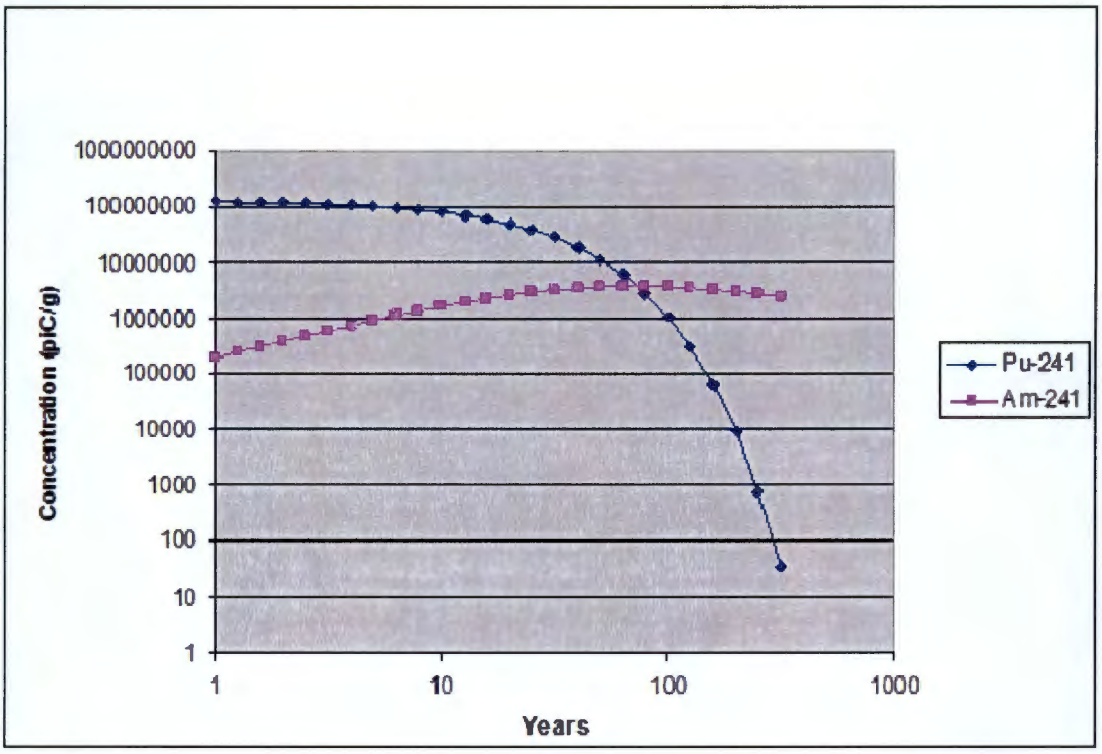

Figure A6-2. Technetium-99 Groundwater Concentration Frequencies.

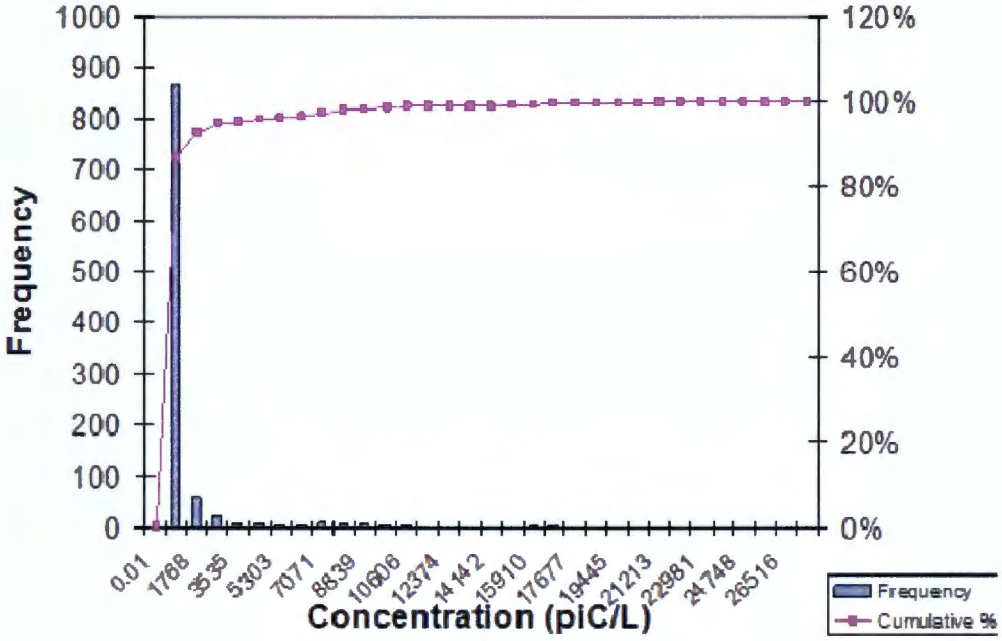

Figure A6-3. Change in Plutonium-239 Concentration with Garden Size.

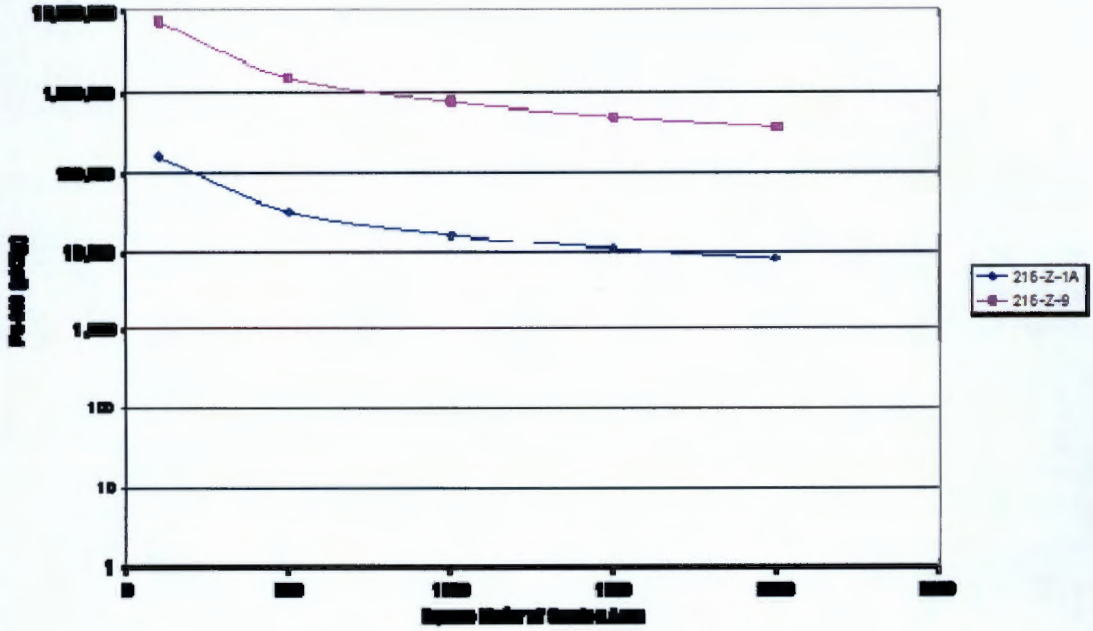

Table A6-1. Contaminants Analyzed in Soil but Never Detected with Method Detection Limits Exceeding Screening Values.

Contaminant	Range of Detection Limits	Risk Assessment Screening Value (see Section 2.2)	Total Number of Samples (All Nondetect)	Number of Samples Exceeding Screening Value	Frequency of Exceedance (%)
216-Z-9 Trench					
1,2,4-Trichlorobenzene	0.035 to 160	14	23	1	4
1,4-Dichlorobenzene	0.035 to 160	3.2	23	1	4
2,4-Dinitrotoluene	0.035 to 160	12	23	1	4
2-Chlorophenol	0.035 to 160	6.4	23	1	4
4-Nitrophenol	0.31 to 160	49	23	1	4
Benzo(a)anthracene	0.035 to 0.38	0.15	20	6	30
Benzo(a)pyrene	0.035 to 0.38	0.015	20	20	100
Benzo(b)fluoranthene	0.035 to 0.38	0.15	20	6	30
Bis(2-chloroethyl) ether	0.035 to 0.38	0.21	20	11	55
Dibenz[a,h]anthracene	0.035 to 0.39	0.015	20	20	100
Hexachlorobenzene	0.035 to 0.38	0.3	20	3	15
Indeno(1,2,3-cd)pyrene	0.035 to 0.39	0.15	20	6	30
n-Nitrosodi-n-dipropylamine	0.035 to 160	0.069	23	13	57
Pentachlorophenol	0.26 to 160	3	23	1	4
Vinyl chloride	0.00032 to 0.56	0.043	42	12	29
216-A-8 Crib					
Am-241	-0.054 to 1,300	3.66	20	2	10
Sb-125	-0.418 to 1,800	0.0617	12	10	83
Benzo(a)anthracene	0.036 to 0.19	0.15	10	4	40
Benzo(a)pyrene	0.032 to 0.14	0.015	10	10	100
Benzo(b)fluoranthene	0.037 to 0.17	0.15	10	4	40
Cs-134	0.026 to 340	0.0157	12	12	100
Co-60	-0.005 to 170	0.009	18	10	56
Dibenz[a,h]anthracene	0.035 to 0.25	0.015	10	10	100
Eu-152	-0.011 to 1,500	0.0211	18	12	67
Eu-154	-0.03 to 520	0.0191	18	10	56
Indeno(1,2,3-cd)pyrene	0.017 to 0.19	0.15	10	4	40
I-129	-2.39 to 1.13	0.219	10	1	10
n-Nitrosodi-n-dipropylamine	0.039 to 0.26	0.069	10	7	70

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Table A6-2. 200-ZP-1 Contaminants in Groundwater Detected Above EPA Region 6 Tap Water Screening Levels.

CAS No.	Chemical	Units	Maximum Detected Value	Screening Value (HHSL)	Detection Frequency	No of Samples Exceeding Screening Value	No. Tested	Percent Exceedance (Based on HHSL)	Magnitude of Exceedence Ratio (Based on HHSL)	Background Value	No of Samples Exceeding Background Value	Percent Exceedance (Based on Background)	Magnitude of Exceedence Ratio (Based on Background)	COPC Inclusion/ Exclusion Rationale
7440-36-0	Antimony	ug/L	56.5	1.46	51/1,002	51	1,002	5%	38.7	55.1	1	0.1	1	3
7440-38-2	Arsenic	ug/L	14	0.045	126/145	126	145	87%	312.4	7.85	3	2.1	2	3
7440-43-9	Cadmium	ug/L	7.3	1.825	19/1,010	14	1,010	1%	4.0	0.916	15	1.5	8	1
7440-47-3	Chromium	ug/L	769	10.95	821/1,005	474	1,005	47.2%	70.2	2.4	767	76.3	320	RI COC
18540-29-9	Hexavalent chromium	ug/L	730	10.95	27/29	13	29	45%	66.7	--	--	--	--	RI COC
7439-92-1	Lead	ug/L	23.7	15	14/297	1	297	0.3%	1.6	0.92	11	3.7	26	1
7439-96-5	Manganese	ug/L	2030	170.3	721/999	24	999	2%	11.9	38.5	53	5.3	53	1
7439-97-6	Mercury	ug/L	0.24	0.06	7/322	6	322	2%	3.8	0.003	7	2.2	80	1
7440-02-0	Nickel	ug/L	328	73	264/1,000	22	1,000	2%	4.5	1.56	260	26	210	1
7440-22-4	Silver	ug/L	85	18.25	58/1,002	2	1,002	0.2%	4.7	5.28	18	1.8	16	1
7440-62-2	**Vanadium**	**ug/L**	**101**	**18**	**989/999**	**869**	**999**	**87%**	**5.6**	**1.67**	**989**	**99**	**60**	**--**
7440-28-0	Thallium	ug/L	57.7	0.26	10/52	10	52	19	221.9	9.85	9	17.3	6	4
7440-61-1	Total uranium	ug/L	454	11	294/301	18	301	6	41.3	11.5	22	7.3	39.5	RI COC
107-06-2	1,2-Dichloroethane	ug/L	1	0.123	8/578	6	578	1%	8.1	0	0	0	0	1
56-23-5	Carbon tetrachloride	ug/L	5,200	0.171	553/693	550	693	79%	30,356.2	0	0	0	0	RI COC
67-66-3	Chloroform	ug/L	420	0.167	528/700	519	700	74%	2,514.2	0	0	0	0	RI COC
75-09-2	Methylene chloride	ug/L	740.5	4.276	151/700	45	700	6%	173.2	0	0	0	0	RI COC
127-18-4	Tetrachloroethylene	ug/L	5	0.105	199/700	199	700	28%	47.8	0	0	0	0	RI COC
79-01-6	Trichloroethylene	ug/L	36	0.028	406/700	406	700	58%	1,285.0	0	0	0	0	RI COC
16984-48-8	**Fluoride**	**ug/L**	**10,500**	**219**	**1,080/1,083**	**1,053**	**1,083**	**97%**	**47.9**	**1,047**	**270**	**24.9**	**10**	**--**
NO3-N	Nitrogen in nitrate	ug/L	1,720,000	5,800	1,188/1,190	1,037	1,190	0.9	296.6	--	--	--	--	RI COC
NO2-N	Nitrogen in nitrite	ug/L	11,000	3,700	63/1,083	5	1,083	0.005	3.0	--	--	--	--	1

NOTES: Bolded chemicals were not selected as COPCs and may represent an under-estimation of health risks.

COPC rationale for exclusions:

1. Low frequency of samples exceeding the screening value (<5%).
2. Low magnitude of exceedance over the screening value (less than two times).
3. Near or below background levels (magnitude of exceedance over background less than two times).

COPC = contaminant of potential concern
HHSL = human health screening level
COC = contaminant of concern (chemical selected as a COC during the remedial investigation and selected as a COPC for this risk assessment)

Table A6-3. Comparison of Residential Farmer Exposure Factors with Tribal Subsistence Exposure Factors.

Exposure Pathway	**Residential Farmer (Soil at 216-Z-9; 90th Percentile Groundwater)**		**Tribal Exposures (Intake Rates from Harris and Harper 2004)**	
	Intake Rate	**Risk**	**Intake Rate**	**Risk[b]**
Drinking groundwater	2 L/day, 30 years	2E-02	4 L/day, 70 years	8E-02
Soil exposure				
Incidental ingestion	200 mg/day (child – 6 yrs); 100 mg/day (adult – 24 yrs)	2E-02	400 mg/day (child and adult – 70 years)	2E-01
Inhalation	20 m^3/day, 30 years	2E-04	30 m^3/day, 70 years	7E-04
External radiation	30 yrs	1E-02	70 yrs	2E-02
Produce ingestion	16% to 49% homegrown[a], 30 years	1E-01	Not stated, up to 100%, 70 years	3E-01
Sweat lodge *(inhalation of vapor)*	Not evaluated for residential farmer		Estimated	4E-01
Total cancer risks	**2E-01**		**9E-01**	

NOTE: Harper and Harris 2004 reference is made to *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*.

[a] Produce (fruits and vegetables) ingestion rates used in the risk assessment calculation are 16% of total per capita consumption rates for high-end consumers (95th percentile) and are 49% of total per capita average consumption rates from *Analysis of Total Food Intake and Composition of Individual's Diet Based on USDA's 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII)* (EPA/600/R-05/062F).

[b] These values should be considered screening-level and may not capture every difference between a residential farming and a Tribal risk scenario.

Table A6-4. Groundwater Percentile Concentrations and Summary Statistics.

COPC	Units	Percentile Concentrations					Summary Statistics		
		5th	25th	50th	90th	95th	Max.	Mean	95% UCL
Groundwater									
Carbon tetrachloride	µg/L	0.08	6.53	505	2,900	3,300	5,200	1,009	1,491
Chloroform	µg/L	0.04	0.58	6.40	24.00	28.00	420	10	19
Chromium (total)	µg/L	1.7	3.6	10.3	130	235.2	769	50	74
Hexavalent chromium (chromium [VI])	µg/L	2.1	7.00	10.90	203.40	311.00	730	74.9	176
Methylene chloride	µg/L	0.06	0.12	0.185	2.734	25	740.52	8	20
Nitrate	µg/L	326	14,000	21,900	81,050	156,000	1,720,000	44,750	63,187
PCE	µg/L	0.05	0.18	0.36	2.5	12.375	60	2.5	4
TCE	µg/L	0.07	0.155	1.7	10.9	15	60	4.7	7
Uranium	µg/L	0.14	0.74	1.17	5.06	12.7	433	11	31.9
I-129	pCi/L	-0.05	-0.004	0.030	1.170	11.298	36.7	1.3	2.4
Tc-99	pCi/L	3.38	54.1	173	1,436	3,934	27,400	786	1145
Tritium	pCi/L	4.3375	513.75	3,605	36,200	98,750	2,170,000	51,030	87,345

COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene
UCL = upper confidence limit

Table A6-5. Summary of Available Ingestion Rates for Homegrown Produce.

	Units	Fruits	Vegetables	Total Produce
EPA Recommended Intakes for Homegrown Produce (EPA/600/P-95-002Fa))				
Households who garden in the west (mean)	g/kg-day	2.76	1.9	4.7
Households who farm in the west (mean)	g/kg-day	1.85	2.73	4.6
Seasonally adjusted intake for households in the west (P75)	g/kg-day	1.81	1.46	3.3
Hanford tank waste performance assessment (Rittman 2004)	g/kg-day	--	--	1.86
HSRAM (DOE/RL-91-45)	g/kg-day	0.6	1.14	1.7

NOTES:
Exposure Factors Handbook, Volumes 1-III (EPA/600/P-95/002Fa).
Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment (Rittman 2004).
EPA = U.S. Environmental Protection Agency
HSRAM = *Hanford Site Risk Assessment Methodology* (DOE/RL-91-45)

A7.0 POTENTIAL RISK-BASED CONCENTRATIONS

For this evaluation, risks were calculated under both a current and future industrial land-use scenario, as well as for a future unrestricted land-use scenario. However, cleanup concentration goals and decisions will generally be based on industrial land-use exposures, as consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future; therefore, the RBCs presented in this section have been calculated based only on industrial land use. These levels may be used in the FS process to evaluate remedial options. For groundwater, RBCs are based on future regular workers drinking the water, and for soil RBCs are based on the current construction worker.

If contaminants at a site are found to exceed target health goals, then the calculation of site-specific RBCs may be warranted to provide information to risk managers. The RBCs do not need to be calculated for every COPC at the site. In general, RBCs are calculated in two cases:

- The contaminant exceeds target health goals (as presented in Section A5.0).
- The contaminant does not exceed a target health goal but contributes a significant percentage to total site risks (i.e., is a concern not necessarily alone, but contributes substantially to the site's cumulative risks.

Under the current industrial land-use scenario, the soil risks presented in Table A5-1 for current construction workers indicate that four radionuclides (americium-241, plutonium-239, plutonium-240, and cesium-137) exceed both the *de minimis* target risk level of 1×10^{-6} and the upper-bound 1×10^{-4} target cancer risk level. No other constituents exceed 1×10^{-6}; therefore, current construction worker RBCs are calculated only for these four radionuclides. For groundwater used post-2150 for industrial exposures (only industrial exposures are considered for cleanup levels [see Section A1.0]), Table A5-4 indicates that five constituents exceed 1×10^{-6} (technetium-99, tritium, carbon tetrachloride, chloroform, and PCE). Only carbon tetrachloride exceeds 1×10^{-4} and is also the only contaminant with a non-cancer HI >1 (see Table A5-5). Therefore, the future regular worker RBCs are calculated only for carbon tetrachloride for those five constituents.

A7.1 CALCULATION METHODS

The RBCs are generally calculated by defining a target health goal and then solving the basic risk assessment equations for concentration, rather than for risk or for hazard. The calculations use the site-specific information developed in the HHRA. The target health goals for human receptors are 1×10^{-4} for carcinogens and an HI of 1 for noncarcinogens. If a 1×10^{-6} target risk level is of interest, then the RBCs presented here should be divided by 100 because these calculations are linear. Although similar, the approaches used to calculate RBCs for soil and groundwater are slightly different. The following subsections discuss the calculation methods for the RBCs for soil and groundwater separately.

A7.1.1 Soil

The RBC values shown in Table A7-1 are based on a target risk of 1×10^{-4} or a target dose of 100 mrem/yr. The 100 mrem/yr target dose level is allowed by the NRC if there are existing institutional controls and exposures have been controlled to the extent practicable (10 CFR 20, Subpart E); thus, it is appropriate for the Hanford Site industrial land-use scenario. In some

specific cases where long-term protectiveness is being evaluated, an acute dose of 500 mrem may also be considered in accordance with 10 CFR 20, Subpart E. Because the equations for dose calculation are linear, an RBC corresponding to a 500 mrem dose (for a 30-day construction worker exposure) could be obtained by multiplying the 100 mrem RBCs in Table A7-1 by five.

In contrast to the NRC, EPA's OSWER Directive No. 9200.4-18 (*Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*) states that, at CERCLA sites, PRGs should be based on the CERCLA target risk range of 1×10^{-6} to 1×10^{-4} and not on dose. An EPA memorandum (EPA 1999) further states that "...cleanup levels at CERCLA sites should be established as they would for any chemical that poses an unacceptable risk and the risks should be characterized in standard Agency risk language consistent with CERCLA guidance." Therefore, RBC values based on a target risk level of 1×10^{-4} were also calculated and are presented in Table A7-1.

The RBCs for dose and risk were obtained from the RESRAD dose model and site-specific input parameters, as detailed in Attachment A-6 of this appendix. The RBCs were calculated using the same site-specific inputs and exposure assumptions for construction workers (see Attachment A-3, Tables 2 and 5 of this appendix) as were used in the RESRAD model during the calculation of radionuclide risks for construction workers. Concentrations of soil were input into the RESRAD model until the target cancer incidence risk level of 1×10^{-4} for the COPC was achieved, or the target dose of 100 mrem was achieved. The process to calculate the risk-based RBCs for the radionuclides in soil considered combined exposures through the soil ingestion, dust inhalation, radon inhalation, and external radiation pathways, such that the RBC is protective of a 1×10^{-4} cancer risk level across all pathways combined. For the dose-based RBCs, the soil concentrations are also protective of all these pathways for the construction worker scenario. Because the site size affects the RESRAD output results (although the size only significantly affects results if the size is much smaller than the sizes assumed here [see Section A7.2]), it is necessary to calculate RBCs for radionuclides in soil that are specific to the site. Therefore, site-specific RBCs were calculated for the risk drivers at both the 216-Z-1A and 216-A-8 sites. The RBCs were calculated for the following radionuclides as they are the primary risk drivers for these sites.

- 216-Z-1A: americium-241, plutonium-239, and plutonium-240
- 216-A-8: cesium-137.

Details of the RBC calculations for the radionuclides in soil based on a 1×10^{-4} cancer risk and a 100 mrem/yr dose at these sites are provided in Attachment A-8, Tables 5 and 6, respectively, in this appendix. The RBCs for each contaminant are presented in Table A7-1.

Differences in dose-based and risk-based RBCs are further discussed below.

Dose Versus Risk. Selecting a dose-based or a risk-based RBC leads to very different soil concentrations as shown in Table A7-1. The differences depend on the individual radionuclide dose and risk conversion factors and the assumptions of exposure duration. There are two major reasons for the differences in the dose and risk RBC values shown in Table A7-1:

- Nominal dose-to risk conversion versus radionuclide-specific conversion factors: The connection between dose and risk can be made using the "nominal" dose-to-risk conversion factor of 0.05 risk/Sv (5.0×10^{-7} risk/mrem) stated in *Recommendations of the*

International Commission on Radiological Protection (ICRP Publication 60). Using this conversion factor, a dose of 100 mrem/yr corresponds to a one-year cancer risk of 5×10^{-5}, less than the target health goal of 1×10^{-4} assumed in the soil RBC calculations. Conversely, assuming a 30-year exposure, the lifetime risk corresponding to 100 mrem/yr is 1.5×10^{-3}, more than 10 times the 1×10^{-4} risk criterion. However, the dose-to-risk conversion factor can vary significantly from the "nominal" value of 0.05 risk/Sv for some radionuclides. For the radionuclides evaluated here, cesium-137 has a dose-to-risk conversion factor very close to nominal, while americium-241 and the plutonium isotopes do not. Therefore, the 100 mrem/yr RBC and the 1×10^{-4} cancer risk RBC are similar for cesium-137 but are very different for americium-241 and the plutonium isotopes (see Table A7-1).

- Differences in the use of organ and tissue weighting factors between the dose factors and the cancer risk factors: The effective dose equivalent (EDE) factors in Federal Guidance Report No. 11 (*Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion* [EPA-520/1-88-020]) are a *weighted* sum of the organ and tissue doses; the risk factors in Federal Guidance Report No. 13 (EPA 402-R-99-001) are a *simple* sum of the organ and tissue risks. The distinction between the weighted sum and the simple sum is not very important for cesium-137 because the organ-specific dose factors are all about the same. For americium and the plutonium isotopes, the organ-specific ingestion dose factors vary significantly from 7.49×10^{-12} Sv/Bq for the thyroid to 1.76×10^{-5} Sv/Bq for bone surface (EPA-520/1-88-020), while the (weighted) EDE factor is 9.56×10^{-7} Sv/Bq. Therefore, weighted sum and simple sum differences are much larger. This causes the ratio of risk to EDE to vary significantly from the nominal value of ICRP Publication 60.

The relationship between dose and risk can be quantified for individual radionuclides by taking the ratio of the radionuclide-specific dose and risk factors. In this analysis, dose conversion factors were taken from Federal Guidance Report No. 11 (EPA-520/1-88-020) for ingestion and inhalation and from Federal Guidance Report No. 12 (*External Exposure to Radionuclides in Air, Water, and Soil* [EPA 402-R-93-081]) for external exposure. Risk factors were taken from Federal Guidance Report No. 13 (EPA 402-R-99-001) for cancer morbidity (see Table A7-2). Table A7-3 shows the risks that correspond to a dose of 100 mrem/yr from individual exposure pathways. The top portion of the table shows the risks from a one-year dose of 100 mrem. The lower portion of the table shows the risks from a chronic dose of 100 mrem for 30 years from individual pathways.

The risks in Table A7-3 show an interesting relationship between one-year exposure and chronic exposures. For a one-year exposure, the only risk to exceed 1×10^{-4} was the cesium-137 inhalation pathway. Therefore, the 100-mrem criterion is more protective than 1×10^{-4} risk in all cases, except for the cesium-137 inhalation pathway. The 100-mrem criterion, therefore, provides greater protection for a one-year exposure, such as the construction scenario. For 30-year exposures, the situation is very different. In this case, all of the exposure pathway risks exceed 1×10^{-4} except for the americium-241 ingestion pathway. Therefore, the 1×10^{-4} risk criterion is generally more protective for chronic exposure scenarios where the exposure is for long term.

Turning to cleanup criteria, it is clear that dose- and risk-based criteria can result in very different cleanup standards for some radionuclides. For the case of the plutonium-239 ingestion

pathway, the 1×10^{-4} risk criterion is comparable to the 100 mrem/yr criterion for a 30-year exposure duration. In contrast, for the cesium-137 ingestion pathway, the 1×10^{-4} risk criterion is at least 10 times more protective than the 100 mrem/yr dose criterion for a 30-year exposure duration. For americium-241 and the plutonium isotopes, a 100 mrem/yr dose corresponds to risk less than 1×10^{-4} for one-year exposure duration; therefore, the soil RBCs based on the 100 mrem/yr dose are smaller than those based on a target risk of 1×10^{-4}.

Therefore, for the construction scenario (one year or less exposure), the difference between the risk and dose criteria appears greater than if the exposure was for long term.

Because the 100 mrem RBCs are lower (i.e., more protective) than the cancer risk RBCs, the 100 mrem RBC values are recommended for use in the FS evaluations of protectiveness and remedial options.

A7.1.2 Groundwater

The RBCs calculated for groundwater considered both exposure routes evaluated for the future regular worker (i.e., ingestion and inhalation). In order to calculate RBCs protective of both exposure routes, the RBCs were initially calculated separately for each route and then combined (see Attachment A-8 of this appendix for detailed calculations). Because carbon tetrachloride's non-cancer hazards exceeded a target health goal, a non-cancer RBC was also calculated to ensure that the lowest level is selected (for some contaminants, non-cancer hazards result in a lower RBC at a 1×10^{-4} target risk level). For carbon tetrachloride, non-cancer risks drive the RBC (i.e., an RBC based on non-cancer hazards is lower than a cancer RBC at the 1×10^{-4} risk level). The formulas are as follows:

$$\text{RBCnc} = \frac{\text{HQ} \times \text{RfD}}{\text{SIF}}$$

$$\text{RBCca} = \frac{\text{TCR}}{\text{SF} \times \text{SIF}}$$

where:

RBCnc	=	non-cancer RBC
RBCca	=	cancer RBC
HQ	=	hazard quotient (1)
TCR	=	target cancer risk (1×10^{-4})
RfD	=	reference dose
SF	=	slope factor
SIF	=	summary intake factor (dose calculations shown in Section A3.0 without the concentration term).

The above equations are used to calculate RBCs for each pathway. The combined RBCs are then calculated using the following general equation:

$$\text{Combined RBC} = \frac{\text{ingRBC} \times \text{inhRBC}}{(\text{ingRBC} + \text{inhRBC})}$$

where:

ingRBC	=	ingestion RBC
inhRBC	=	inhalation RBC.

Table A7-3 summarizes the RBCs for each of the COPCs that contribute to exceedance of target health goals for the industrial drinking water exposure scenario.

The results of these equations for carbon tetrachloride are an RBC based on a cancer risk level of 1×10^{-4} of 220 µg/L and an RBC based on HI of 1 of 62 µg/L. Because the non-cancer toxicity results in a lower RBC than the cancer RBC, the RBC for carbon tetrachloride is 62 µg/L.

A7.2 APPLICATION OF CLEANUP LEVELS

The RBCs for each of the risk drivers were calculated to be protective of the maximum acceptable cancer risk level of 1×10^{-4}. However, combined exposures to each of the risk drivers at the RBCs could result in an exceedance of the target health goals. For example, if concentrations of the two radionuclide risk drivers in groundwater are present in the same well at the RBC concentrations, the drinking water exposure would result in a cumulative cancer risk of 2×10^{-4}. However, RBC adjustments downward to account for cumulative exposures are best applied at specific locations, evaluating the specific constituent concentrations at each location. Applications to specific areas of the site are needed because risk drivers may not all be present at the same location, nor may the high concentrations of the risk drivers be co-located with each other. Therefore, although risk managers should consider potential cumulative exposures to the COPCs when applying the RBCs in the evaluation of the protectiveness of various remedies during the FS process, a downward adjustment to account for cumulative exposures may not be necessary.

A sensitivity analysis was performed in RESRAD on the soil data for the 216-Z-1A tile field and 216-A-8 Crib to determine if changes to the site area size and contaminant thickness would affect risks for the summed pathways, including external radiation, inhalation, and ingestion under current conditions. It was noted that external radiation risks and the median calculated risks that were done in this risk assessment were not affected by increasing or decreasing site area or contaminant thickness by five times. The contaminant thickness was increased and decreased by five times, and there were no significant differences between these risks and the median calculated risks that were performed in this risk assessment. Also, the site area size was increased and decreased by five times, and there were no significant differences between risks from the larger site and the median calculated risks that were performed in this risk assessment. However, risks that were calculated using a site area that was five times lower were between two and three times lower than the median calculated risks that were performed in the risk assessment. For example, the inhalation and ingestion risks for americium-241 decreased from 7×10^{-5} to 3×10^{-5}, the inhalation and ingestion risks for plutonium-239 decreased from 1×10^{-4} to 5×10^{-5}, and the inhalation and ingestion risks for cesium-137 decreased from 6×10^{-7} to 2×10^{-7}. In conclusion, the sensitivity analysis indicates that different site area sizes may affect risks, particularly if the site area is small. Therefore, site size should be considered when using the calculated the RBCs included in this risk assessment.

Table A7-1. Summary of Soil Risk-Based Concentrations for Current Construction Worker Exposures.

Risk Driver	RBC Based on a Target Annual Risk of 1E-4 (pCi/g)	RBC[a] Based on Target Dose of 100 mrem/yr (pCi/g)
Am-241	45,000	2,510
Pu-239	50,000	2,650
Pu-240	50,000	2,650
Cs-137	1,600	1,220

[a] RBC is based on a combined dose via the dust inhalation, radon inhalation, soil ingestion, and external exposure pathways.
RBC = risk-based concentration

Table A7-2. Dose Conversion Factors and Risk Coefficients for Different Exposure Pathways.

Radionuclide	Dose Conversion Factors[a]			Risk Coefficients[b]		
	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	External (mrem/yr per pCi/g)	Soil ingestion (risk/pCi)	Inhalation (risk/pCi)	External (risk/yr per pCi/g)
Cs-137+D	5E-5	3.19E-5	3.41	3.74E-11	1.12E-10	2.55E-6
Pu-239	3.54E-3	4.29E-1	2.95E-4	1.74E-10	5.51E-8	2E-10
Pu-240	3.54E-3	4.29E-1	1.47E-4	1.74E-10	5.55E-8	6.98E-11
Am-241	3.64E-3	4.44E-1	4.37E-2	1.34E-10	3.77E-8	2.76E-8

[a] Committed effective dose equivalent conversion factors for ingestion and inhalation are from Federal Guidance Report No. 11 (EPA-520/1-88-020). Effective dose equivalent conversion factors for external exposure are from Federal Guidance Report No. 12 (EPA 402-R-93-081).
[b] Morbidity risk coefficients are from Federal Guidance Report No. 13 (EPA 402-R-99-001). Morbidity risk coefficients are from Federal Guidance Report No. 13 (EPA 402-R-99-001).

Table A7-3. Risks at a 100 mrem/yr Dose Limit for 1-Year and 30-Year Exposure Durations from Individual Pathways.

Radionuclide	Risk from 100 mrem/yr Dose Limit for 1-Year Exposure Duration		
	Ingestion	Inhalation	External
Cs-137+D	7.48E-05	3.51E-04	7.48E-05
Pu-239	4.92E-06	1.28E-05	6.78E-05
Pu-240	4.92E-06	1.29E-05	4.75E-05
Am-241	3.68E-06	8.49E-06	6.32E-05
	Risk from 100 mrem/yr Dose Limit for 30-Year Exposure Duration		
	Ingestion	Inhalation	External
Cs-137+D	1.64E-03	7.68E-03	1.64E-03
Pu-239	1.47E-04	3.84E-04	2.03E-03
Pu-240	1.47E-04	3.87E-04	1.42E-03
Am-241	1.08E-04	2.49E-04	1.85E-03

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A8.0 SUMMARY AND CONCLUSIONS

This section provides a summary of the HHRA that has been conducted for this site. This risk assessment evaluated potential human health risks from exposure to contaminants formerly used at the site that are still present in subsurface soil and groundwater. Specifically, this risk assessment addressed contaminants in the 200-ZP-1 Groundwater OU and at five representative or unique soil sites in the 200-PW-1/3/6 OUs: 216-A-8 Crib, 216-Z-1A tile field, 216-Z-8 french drain, 216-Z-9 Trench, and 216-Z-10 injection/reverse well. This risk assessment will be used to evaluate the need for remedial action in soil in these OUs and/or to evaluate the protectiveness of certain remedies for soil and groundwater based on current and potential future land use as part of the Central Plateau Closure Project.

Previous investigations have identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West and 200 East Areas of the Hanford Site from past spills, leaks, and work practices associated with the processing of uranium and plutonium to make nuclear weapon materials. This risk assessment evaluated whether potential health risks are present if people encounter these impacted soils in their environment. The risk assessment evaluated risks under current conditions (industrial land use, assuming the existing institutional controls with current construction workers as the population potentially exposed) and future conditions (unrestricted land use post-2150, if institutional controls fail in the future). The unrestricted land-use scenario assumes that after the year 2150, potential exposures to a future residential farming population (adults and children) and a working population (future well drillers and future regular workers) are hypothetically possible. Although an unrestricted land-use scenario has been evaluated as part of this assessment, cleanup concentration goals and decisions will be based on industrial land-use exposures as consistent with the current industrial nature of the site. The land use of the site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

The results and conclusions of risk assessment are summarized in the following subsections.

A8.1 DATA EVALUATION

The first step in a HHRA is an evaluation of the data in order to select COPCs for human health. For groundwater, the 200-ZP-1 RI report (DOE/RL-2006-24) made a preliminary selection of likely COPCs after a rigorous and thorough assessment of potential sources, quality of data, and a statistical evaluation of the detected contaminants in groundwater. The risk assessment refined the RI list using only the last 5 years of data (2000 through 2005) to represent current conditions, the TALs for groundwater from the RI, and additional health-based information. Of the RI list of 15 possible COPCs, the groundwater data evaluation selected 12 to carry through the risk assessment process:

- Carbon tetrachloride
- Chloroform
- Trivalent chromium
- Hexavalent chromium
- Methylene chloride
- Nitrate
- PCE
- TCE
- Uranium (contaminant toxicity only)
- Iodine-129
- Technetium-99
- Tritium.

For soil, the risk assessment primarily used the available soil data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for the representative soil sites, supplemented by additional historical data reports. In addition to soil data, soil gas data collected in the vicinity of 216-Z-9 and air samples collected from within the 216-Z-9 Trench were also reviewed to evaluate their suitability for inclusion in the risk assessment. The three air samples collected from within the 216-Z-9 Trench were selected for inclusion in the risk assessment as the most representative data of what concentrations might be possible in vapor intruding into basements.

Typically, not all contaminants present at a site pose health risks or contribute significantly to overall site risks. The EPA guidelines (EPA 540/1-89/002) recommend focusing on a group of COPCs based on inherent toxicity, site concentration, and the behavior of the contaminants in the environment. To identify these COPCs, health-protective, risk-based screening values are compared to site concentrations of detected contaminants to select COPCs for soil and soil gas.

Maximum detected concentrations in soil from each of the waste sites were compared to EPA Region 6 HHSLs for residential soil and EPA generic residential screening levels for radionuclides (EPA/540-R-00-006) to select COPCs in soil. The selected COPCs are as follows:

Contaminant	216-Z-1A	216-Z-8	216-Z-9	216-A-8
Am-241			√	
Cadmium			√	
Cadmium				
C-14				
Carbon tetrachloride				
Cs-137				
Manganese			√	
Manganese			√	
Ni-63			√	
Pu-238		√	√	
Pu-239	√	√	√	√
Pu-240	√	√	√	√
Pa-231			√	
Ra-226			√	
Ra-228			√	√
Sr90			√	
Tc99			√	√
Thallium				√
Th-228			√	√
Th-230			√	

No contaminants were identified as COPCs in soil at 216-Z-10.

The air samples collected from within the 216-Z-9 Trench were compared to both residential screening levels (EPA Region 6 HHSLs) in air (EPA 2007) and worker PELs established through WISHA (WAC 296-841-20025). Carbon tetrachloride and chloroform both exceeded the EPA Region 6 HHSLs by many orders of magnitude and were selected as COPCs in indoor air for a future residential population (COPCs are present in soil gas at both 216-Z-9 and 216-Z-1A; no VOCs were detected in soil at 216-Z-1A down to 26 m [85 ft] bgs, but deep soil gas may be present because the operating SVE system at the site is still capturing VOCs). Air levels inside the trench did not exceed PELs and, thus, are not a concern for a working population.

A8.2 EXPOSURE ASSESSMENT

Once COPCs are selected, the second step in risk assessment is an evaluation of the exposure pathways by which people could encounter contaminants. The exposure assessment identifies the populations potentially exposed to contaminants at the site, the means by which exposure occurs, and the amount of contaminant received from each exposure medium (i.e., the dose). Only complete exposure pathways are quantitatively evaluated. Complete pathways consist of four elements: (1) a source and mechanism of contaminant release, (2) a retention or transport medium (e.g., groundwater), (3) a point of potential human contact with the affected medium, and (4) a means of entry into the body at the contact point. Figures A3-1 and A3-2 present the CSMs, which depict the complete pathways for this site under the current industrial land-use and the future unrestricted land-use scenarios, respectively.

The risk assessment evaluated risks from exposures to contaminants in groundwater and soil for two broad categories: restricted land use and unrestricted land use. The following briefly summarizes the pathways selected for quantitative evaluation:

- Restricted (current industrial) land use: A current construction worker population was evaluated, assuming exposures to contaminants in subsurface soil at three of the four waste sites where COPCs were selected. Construction workers were not evaluated at the 216-Z-9 Trench because of the depth of impacted material (6.4 m [21 ft] bgs) and because 216-Z-9 Trench is covered with a concrete cap, making any digging activity more difficult. Typically in risk assessment, construction workers are not assumed to dig deeper than 4.6 m (15 ft) bgs. However, where impacted materials began very close to, or slightly deeper than the 4.6-m (15-ft) level and there was no barrier to prevent digging, contact with impacted materials for current construction workers was considered possible (note that contact with buried materials by construction workers assumed for the purposes of the risk evaluation is very unlikely to actually occur for an unprotected worker due to the existing institutional controls program at the Hanford Site). Construction workers were evaluated for exposures to subsurface soil through the ingestion, inhalation (of fugitive dust and vapors), dermal contact, and external radiation exposure routes.

  Current regular worker populations (outdoor and indoor workers not engaged in active soil disturbance) will not be exposed to subsurface soil because impacted material is too deep (below the 1-m [3.3-ft]-bgs limit considered as surface soil in most risk assessments), nor will they be exposed to groundwater because, under existing institutional controls, the water cannot be used for drinking.

- Post-2150 unrestricted land use: While land use is anticipated to remain industrial for the foreseeable future, because the radionuclides present in soil and groundwater have very long half-lives, a future residential farming population was also selected for evaluation, assuming exposure to contaminants in groundwater and soil if institutional controls fail at some point in the future, and also assuming additional exposures via the food chain (i.e., fruits and vegetables, meat, and dairy products). The future point selected for residential exposures to begin is the year 2150. At this time, it is assumed that someone could drill a well and bring drill cuttings to the surface where they would be available for direct exposure by future residential farmers. Child and adult future residential farming populations were evaluated for (1) direct contact with impacted soil brought to the surface as drill cuttings, (2) exposures to groundwater as drinking water, (3) ingestion of homegrown produce cultivated in contaminated soil and irrigated with groundwater, and (4) ingestion of beef and dairy products from cattle watered with groundwater and grazing in pastures irrigated with groundwater. Adult residential farmers were also evaluated for exposures to groundwater through irrigation of gardens and livestock. Exposures to VOCs in subsurface through inhalation of vapors emanating from the subsurface into the ambient air based on the 2006 data were evaluated semi-quantitatively.

  Under this post-2150 scenario, the groundwater from a well could be used by residents or at a business. Thus, a future regular working population could be exposed to soil during drilling (future well drillers), and a separate working population was evaluated assuming exposure to groundwater via drinking it at their place of work (future regular workers).

For the quantification of exposures to COPCs in soil, either 95% UCL or maximum concentrations were used as reasonable maximum EPCs. Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest concentrations do not occur at the same location). Therefore, a range of concentrations was selected for EPCs to evaluate "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. These EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing groundwater data set.

A8.3 TOXICITY ASSESSMENT

The third step in risk assessment is an evaluation of the toxicity of the COPCs by an assessment of the relationship between the dose of a contaminant and the occurrence of toxic effects. Contaminant toxicity criteria, which are based on this relationship, consider both cancer effects and effects other than cancer (non-cancer effects). The toxicity criteria are required in order to quantify the potential health risks due to the COPCs. Only cancer effects are of concern for the radionuclides (except for uranium); however, a number of the nonradionuclide COPCs are considered toxic for their potential to induce cancer and because of their non-cancer toxic effects.

A8.4 RISK CHARACTERIZATION

The last step in HHRA is a characterization of the health risks. The exposure factors, media concentrations, and toxicity criteria are combined to calculate health risks. Health risks are calculated differently for contaminants that cause cancer and for contaminants that cause

non-cancer effects. The calculation of cancer risk assumes that no level of the contaminant is without some risk, whereas for contaminants with non-cancer effects, a "threshold" dose exists. Risks (for cancer) and hazards (for non-cancer effects) are calculated for a RME scenario for each pathway, a calculation that over-estimates risks for the majority of the population in order to ensure that public health is protected. Cancer risk estimates represent the potential for cancer effects by estimating the probability of developing cancer over a lifetime due to site exposures. Non-cancer hazards assume that there is a level of contaminant intake that is not associated with an adverse health effect even in sensitive individuals.

While different methods are used to calculate the dose from radionuclides and nonradionuclides, as described in EPA 540/1-89/002, exposure assessment for both nonradionuclide contaminants and radionuclides follow the same basic steps. However, in addition to the exposure pathways considered for contaminants, external radiation is an important exposure pathway for radionuclides in surface soils. The dermal absorption pathway is typically not a significant exposure pathway for radionuclides and was not considered in this risk assessment, as discussed in Section A3.1.3.1. For radionuclide exposures in soil, EPCs and site-specific information were entered into RESRAD Version 6.3 to determine risks. RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials (ANL/EAD-4). The RESRAD model requires site-specific soil concentrations and other site-specific data to estimate radionuclide risk.

Soil risks were evaluated at four different waste sites, and groundwater risks were evaluated for three concentrations for each COPC based on concentration ranges throughout the groundwater plumes. Thus, soil risks are waste site-specific, and groundwater risks are specific to concentration ranges, but are independent of location. Because a groundwater well could be drilled at any location, and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site.

Under current industrial land use and institutional controls, there are no exposures to contaminants and radionuclides in groundwater or soil. Volatile or radiological emissions from the subsurface are insignificant for a working population. Institutional controls prevent the use of impacted groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of unimpacted soil. However, if construction workers disturbed soil at depth at the 216-Z-1A tile field, 216-Z-8 french drain, or 216-A-8 Crib, they could come into contact with COPCs. Under that unlikely scenario (existing institutional control programs at Hanford are designed to prevent digging in impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A tile field and 216-A-8, Crib indicating that remedial action would be necessary (risks from digging in soil at 216-Z-8 were less than 1×10^{-6}). Risks from subsurface soil exposures at the 216-Z-1A tile field were driven by plutonium-239, followed by plutonium-240, and then americium-241. Risks from subsurface soil at 216-A-8 are driven by cesium-137. No nonradionuclides in soil are a health concern for construction workers.

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and ingrowth of daughter products. For the three Z Plant sites (216-Z-1A tile field, 216-Z-8, and french drain, 216-Z-9 Trench), where risks are driven by plutonium-239, plutonium-240, and americium-241 (true for all soil scenarios), cumulative risks at future time horizons are not significantly different than current risks because the half-lives of the plutonium contaminants are long (or, in the case of the future well driller and future residential farmer, risks

at 150 years are not very different than risks at 500 and 1,000 years). However, americium-241 risks do decline significantly over 1,000 years. At the 216-A-8 Crib where cesium-137 is the risk driver for all soil scenarios, risks are significantly lower at future time horizons due to the relatively short half-life of cesium-137 (approximately 30 years). Although construction worker exposures were not quantified at the 216-Z-9 Trench due to the depth to impacted soil and the concrete cover over the site, if exposure to the soils beneath the bottom of the trench were ever to occur, risks would likely exceed 1×10^{-4}.

Because future residential farmer, well driller, or regular worker groundwater exposures are assumed not to occur until at least the year 2150, radiological concentrations in soil for these populations were modeled assuming 150 years of decay (although, as noted above, this assumptions does not make a difference for the Z Plant sites). Two of the three radionuclides selected as COPCs in groundwater, technetium-99 and iodine-129, have very long half-lives (213,000 years and 16 million years, respectively) and future concentrations would not be different than current concentrations. However, the third radionuclide COPC, tritium, will be at concentrations that are below a health concern within 150 years. Specifics of the post-2150 unrestricted land-use scenario are as follows:

- Future well driller risks were much less than those for construction workers and did not exceed 1×10^{-4}. Driller risks were the highest at the 216-Z-9 Trench (2×10^{-5}).
- Future workers drinking groundwater at their place of employment exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations. Four additional COPCs (technetium-99, tritium, PCE, and chloroform) exceed a 1×10^{-6} risk level at the 90th percentile. Carbon tetrachloride was also the only contaminant with a non-cancer hazard above the target goal of 1.
- Future residents exposed to drill cuttings in their home yard had risks similar to those for construction workers. Risks from direct soil exposure were above 1×10^{-4} for all soil sites, except 216-Z-8 where risks were 3×10^{-6}.
- Future residents drinking groundwater exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations. Radionuclide risks were highest for technetium-99 (8×10^{-5}). Tritium concentrations will decay to levels less than 1×10^{-6} risk in 150 years. Non-cancer hazards are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In addition, hexavalent chromium, nitrate, and TCE all have non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentration. Carbon tetrachloride's HI is two orders of magnitude higher than any other contaminant's HI.
- Future residents exposed to contaminants through their food chain would have risks greater than 1×10^{-4} (all sites except the 216-Z-8 french drain) and as high as 1×10^{-1} (216-Z-9 Trench) primarily due to growing produce in contaminated soils (plutonium-239 and plutonium-240 are risk drivers), although eating produce irrigated with impacted groundwater resulted in risks in the 1×10^{-2} range. For produce irrigated with groundwater, carbon tetrachloride had the highest produce ingestion risks (1×10^{-2}), followed by technetium-99 (3×10^{-3}). Risks from the dairy products pathway exceed 1×10^{-4}, and the risks from eating beef are below 1×10^{-4}.

- Carbon tetrachloride is the risk driver currently for all groundwater pathways (two orders of magnitude higher than most other contaminants), with the exception of the dairy products and meat pathways, where risks from technetium-99 are the highest. In the future (post-150 years), technetium-99 is likely to be the risk-driving contaminant in groundwater due to the natural degradation of carbon tetrachloride at much faster rates than are expected for technetium-99.

In summary, risks from exposure to soils at the 216-Z-8 french drain are below levels that are a health concern. Risks from soil exposures at the 216-Z-1A tile field and 216-A-8 Crib are similar and exceed 1×10^{-4} for construction workers and residential farmers. Risks from soil exposures at the 216-Z-9 Trench were the highest for the four waste sites evaluated, with risks exceeding 1×10^{-1} for residential farmers. Risks for future well drillers at all four soil sites were below 1×10^{-4}. Plutonium-239 and americium-241, followed by plutonium-240, were the risk drivers in soil for the Z Plant sites. Cesium-137 was the risk driver in soil at the 216-A-8 Crib.

Risks from exposure to groundwater exceeded 1×10^{-4} at the 90th and 50th percentiles, due primarily to carbon tetrachloride, followed by technetium-99 for both residential and industrial drinking water exposures. Carbon tetrachloride's non-cancer hazards were also non-cancer risk drivers and exceeded target health goals at the 90th and 50th percentiles. Although reductions in future concentrations were not quantified for carbon tetrachloride, the contaminant's concentrations will be decreasing relatively rapidly over time in comparison to technetium-99 (with a half-life of 213,000 years). Therefore, while carbon tetrachloride concentrations represent the highest current risks, in the future technetium-99 will likely become the risk driver.

Residential farmer risks were highest for ingestion of produce, followed by ingestion of soil, ingestion of groundwater, consumption of dairy products, and consumption of beef.

A8.5 UNCERTAINTIES IN RISK ASSESSMENT

Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks.

In this assessment, uncertainties relate to the selection of COPCs and the development of media concentrations to which people may be exposed, the assumptions about exposure and toxicity, and the characterization of health risks. Uncertainty in the development of media concentrations results from the inability to sample every square inch of potentially impacted media at a site. Instead, a limited number of samples must be obtained to represent the contaminant characteristics of a larger area. The sampling strategies for contaminants in this assessment were, in general, designed to prevent under-estimation of media concentrations, thus avoiding under-estimation of the risks to public health.

There are uncertainties regarding the quantification of health risks in terms of several assumptions about exposure and toxicity, including site-specific and general uncertainties, particularly for the food chain pathways. Based on the anticipation of uncertainty when quantifying exposure and toxicity, the health risks and hazards presented in this risk assessment are more likely to over-estimate risk.

Section A6.0 provides a detailed assessment of the uncertainties inherent in the risk assessment process, as well as the uncertainties that are specific to this risk assessment.

A8.6 RISK-BASED CONCENTRATIONS

Although risks were calculated under both a current and future industrial land-use scenario, as well as for a future unrestricted land-use scenario, cleanup goals and decisions will generally be based on industrial land-use exposures as consistent with the current industrial nature of the site. Therefore, the RBCs were calculated based only on industrial land use. These levels may be used in the FS process to evaluate remedial options. For groundwater, RBCs are based on future regular workers drinking the water and for soil are based on the current construction worker.

The RBCs for current construction workers were calculated for four radionuclides (americium-241, plutonium-239, plutonium-240, and cesium-137) because these constituents exceed the upper-bound 1×10^{-4} target cancer risk level. For groundwater used post-2150 under an industrial land-use scenario, for future regular worker exposures to drinking water only carbon tetrachloride exceeds 1×10^{-4} and is also the only contaminant with a non-cancer HI >1. Therefore, a future regular worker RBC was calculated only for carbon tetrachloride.

The RBCs for each of the risk drivers were calculated to be protective of the maximum acceptable cancer risk level of 1×10^{-4}, or an HI of 1, whichever was lower. The RBCs for the radionuclides in soil were also estimated based on target dose levels of 100 mrem/yr. Because the RBCs based on 100 mrem/yr were lower than those based on 1×10^{-4}, the dose-based RBCs are selected as the appropriate health-protective values for the construction worker. Combined exposures to each of the risk drivers at the RBCs could result in an exceedance of target health goals. For example, if concentrations of the two radionuclide risk drivers in soil are present at the same location as the RBC concentrations, the soil exposure would result in a cumulative cancer risk of 2×10^{-4}. Nevertheless, RBCs were not adjusted downward to account for cumulative exposures because risk drivers may not all be present at the same location, nor may the high concentrations of the risk drivers be co-located with each other. Therefore, risk managers will address cumulative exposures to the COPCs when applying RBCs at specific locations in the evaluation of the protectiveness of various remedies during the FS process, a downward adjustment to account for cumulative exposures will be made, if necessary.

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APPENDIX A

ATTACHMENT 1

PROUCL OUTPUTS FOR CONTAMINANTS OF POTENTIAL CONCERN IN SOIL

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ATTACHMENT 1
TABLE OF CONTENTS

216-Z-1A Tile Field

Table 1.1 ProUCL Output Summary for 216-Z-1A Tile Field – Resident and Driller Concentration in Waste
Table 1.2 ProUCL Output Summary for 216-Z-1A Tile Field - Construction Soil

216-Z-8 French Drain

Table 1.3 ProUCL Output Summary for 216-Z-8 French Drain Soil

216-Z-9 Trench

Table 1.4 ProUCL Output Summary for 216-Z-9 Trench - Resident and Driller Concentration in Waste

216-A-8 Crib

Table 1.5 ProUCL Output Summary for 216-A-8 Crib - Resident and Driller Concentration in Waste

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216-Z-1A Tile Field

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Table 1-1. ProUCL Output Summary for 216-Z-1A Tile Field - Resident and Driller Concentration in Waste.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241 (ingrowth)	122527.6	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	458	-0.0872	5180000	61113.03	41.3	301527.7	4.933935	12.63184	9.09E+10
Pu-239-240	698677.7	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	423	-125	38200000	235363.4	6.45	2186095	9.28817	14.64864	4.78E+12

Data File

Variable: Am-241 ingrowth

Raw Statistics	
Number of Valid Samples	458
Number of Unique Samples	393
Minimum	-0.0872
Maximum	5180000
Mean	61113.03
Median	41.3
Standard Deviation	301527.7
Variance	9.09E+10
Coefficient of Variation	4.933935
Skewness	12.63184

Normal Distribution Test	
Lilliefors Test Statisitic	0.419693
Lilliefors 5% Critical Value	0.0414
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	84335.21

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs	
CLT UCL	84288.14
Adj-CLT UCL (Adjusted for skewness)	93174.19
Mod-t UCL (Adjusted for skewness)	85721.25
Jackknife UCL	84335.21
Standard Bootstrap UCL	84431.08
Bootstrap-t UCL	104477.9
Hall's Bootstrap UCL	184676.7
Percentile Bootstrap UCL	87392.24
BCA Bootstrap UCL	96583.27
95% Chebyshev (Mean, Sd) UCL	**122527.6**
97.5% Chebyshev (Mean, Sd) UCL	149101.7
99% Chebyshev (Mean, Sd) UCL	201301.4

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\Z_1A\Copy of SoiltoLoadZ-1A_NBR_02.20.06- hak.xls Variable: Pu-239-240

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	423	Lilliefors Test Statisitic	0.457108
Number of Unique Samples	351	Lilliefors 5% Critical Value	0.043079
Minimum	-125	Data not normal at 5% significance level	
Maximum	38200000		
		95% UCL (Assuming Normal Distribution)	
Mean	235363.4	Student's-t UCL	410582.1
Median	6.45		
Standard Deviation	2186095		
Variance	4.78E+12		
Coefficient of Variation	9.28817		
Skewness	14.64864		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	410197.5
	Adj-CLT UCL (Adjusted for skewness)	491089.7
	Mod-t UCL (Adjusted for skewness)	423199.7
	Jackknife UCL	410582.1
	Standard Bootstrap UCL	410576.2
	Bootstrap-t UCL	941103
RECOMMENDATION	Hall's Bootstrap UCL	1016959
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	435919.5
	BCA Bootstrap UCL	530598.1
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	698677.7
	97.5% Chebyshev (Mean, Sd) UCL	899154.1
	99% Chebyshev (Mean, Sd) UCL	1292951

Table 1.2. ProUCL Output Summary for 216-Z-1A Tile Field - Construction Soil.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241(ingrowth)	2028358	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	0	5180000	596009.2	14500	1354866	2.27323	2.916279	1.84E+12
Pu-239-240	15509199	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	-0.185	38200000	4838800	305000	10093187	2.085886	2.762745	1.02E+14

NOTE: Includes data from 0 to 15 feet

Data File

Variable: Am-241 0to15

Raw Statistics

Number of Valid Samples	17
Number of Unique Samples	17
Minimum	0
Maximum	5180000
Mean	596009.2
Median	14500
Standard Deviation	1354866
Variance	1.84E+12
Coefficient of Variation	2.27323
Skewness	2.916279

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.517712
Shapiro-Wilk 5% Critical Value	0.892

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	1169712

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	1136513
Adj-CLT UCL (Adjusted for skewness)	1384859
Mod-t UCL (Adjusted for skewness)	1208449
Jackknife UCL	1169712
Standard Bootstrap UCL	1115963
Bootstrap-t UCL	2711884
Hall's Bootstrap UCL	3256298
Percentile Bootstrap UCL	1197557
BCA Bootstrap UCL	1374380
95% Chebyshev (Mean, Sd) UCL	2028358
97.5% Chebyshev (Mean, Sd) UCL	2648136
99% Chebyshev (Mean, Sd) UCL	3865571

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File	Z:\Hanford\Soil Data\Z_1A\Copy of SoiltoLoadZ-1A_NBR_02.20.06-hak.xls	Variable:	Pu-239-240

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	17	Shapiro-Wilk Test Statisitic	0.557117
Number of Unique Samples	17	Shapiro-Wilk 5% Critical Value	0.892
Minimum	-0.185	Data not normal at 5% significance level	
Maximum	38200000		
Mean	4838800	95% UCL (Assuming Normal Distribution)	
Median	305000	Student's-t UCL	9112648
Standard Deviation	10093187		
Variance	1.02E+14		
Coefficient of Variation	2.085886		
Skewness	2.762745		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	8865331
	Adj-CLT UCL (Adjusted for skewness)	10618003
	Mod-t UCL (Adjusted for skewness)	9386030
	Jackknife UCL	9112648
	Standard Bootstrap UCL	8892804
	Bootstrap-t UCL	18764160
RECOMMENDATION	Hall's Bootstrap UCL	25118717
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	9089027
	BCA Bootstrap UCL	10787012
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	15509199
	97.5% Chebyshev (Mean, Sd) UCL	20126289
	99% Chebyshev (Mean, Sd) UCL	29195668

216-Z-8 French Drain

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Table 1.3. ProUCL Output Summary for 216-Z-8 French Drain Soil.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am241	457	pCi/g	Gamma	Maximum, Adjusted Gamma Exceeds Max	8	0.0901	457	110.5145	4.9955	189.3509	1.713358	1.4757375	35853.755
Pu238	77.5	pCi/g	Gamma	Maximum, Adjusted Gamma Exceeds Max	8	0.0143	77.5	10.80115	0.491	27.02562	2.502106	2.7980155	730.38421
Pu239/240	4620	pCi/g	Gamma	Maximum, Adjusted Gamma Exceeds Max	8	0.92	4620	1183.251	45.1	2060.368	1.741276	1.4303542	4245114.6

NOTE: Includes data from 17 to 35 ft bgs

Data File	Z:\Hanford\Z-8\Copy of Z-8_SlData.xls

Variable: Am241

Raw Statistics

Number of Valid Samples	8
Number of Unique Samples	8
Minimum	0.0901
Maximum	457
Mean	110.5145
Median	4.9955
Standard Deviation	189.3509
Variance	35853.75
Coefficient of Variation	1.713358
Skewness	1.475738

Gamma Statistics

k hat	0.209537
k star (bias corrected)	0.214294
Theta hat	527.4235
Theta star	515.7152
nu hat	3.352585
nu star	3.428699
Approx.Chi Square Value (.05)	0.509773
Adjusted Level of Significance	0.01946
Adjusted Chi Square Value	0.299402

Log-transformed Statistics

Minimum of log data	-2.40684
Maximum of log data	6.124683
Mean of log data	1.218547
Standard Deviation of log data	3.748667
Variance of log data	14.0525

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.645095
Shapiro-Wilk 5% Critical Value	0.818

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	237.3483

Gamma Distribution Test

A-D Test Statistic	0.701619
A-D 5% Critical Value	0.832197
K-S Test Statistic	0.294748
K-S 5% Critical Value	0.322703

Data follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	743.3133
Adjusted Gamma UCL	1265.592

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.820202
Shapiro-Wilk 5% Critical Value	0.818

Data are lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	4.49E+10
95% Chebyshev (MVUE) UCL	1230.399
97.5% Chebyshev (MVUE) UCL	1658.203
99% Chebyshev (MVUE) UCL	2498.541

95% Non-parametric UCLs

CLT UCL	220.6303
Adj-CLT UCL (Adjusted for skewness)	257.9525
Mod-t UCL (Adjusted for skewness)	243.1698

	Jackknife UCL	237.3483
	Standard Bootstrap UCL	213.3997
	Bootstrap-t UCL	1336.548
RECOMMENDATION	Hall's Bootstrap UCL	1876.583
Data follow gamma distribution (0.05)	Percentile Bootstrap UCL	224.7306
	BCA Bootstrap UCL	242.6668
Use Adjusted Gamma UCL	95% Chebyshev (Mean, Sd) UCL	402.3238
	97.5% Chebyshev (Mean, Sd) UCL	528.5899
	99% Chebyshev (Mean, Sd) UCL	776.6153

Recommended UCL exceeds the maximum observation

Data File	Z:\Hanford\Z-8\Copy of Z-8_SlData.xls

Variable: Pu238

Raw Statistics

Number of Valid Samples	8
Number of Unique Samples	8
Minimum	0.0143
Maximum	77.5
Mean	10.80115
Median	0.491
Standard Deviation	27.02562
Variance	730.3842
Coefficient of Variation	2.502106
Skewness	2.798016

Gamma Statistics

k hat	0.240264
k star (bias corrected)	0.233498
Theta hat	44.9553
Theta star	46.25791
nu hat	3.844227
nu star	3.735975
Approx.Chi Square Value (.05)	0.619988
Adjusted Level of Significance	0.01946
Adjusted Chi Square Value	0.372265

Log-transformed Statistics

Minimum of log data	-4.2475
Maximum of log data	4.350278
Mean of log data	-0.59559
Standard Deviation of log data	2.857899
Variance of log data	8.167585

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.471093
Shapiro-Wilk 5% Critical Value	0.818

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	28.90385

Gamma Distribution Test

A-D Test Statistic	0.65109
A-D 5% Critical Value	0.82033
K-S Test Statistic	0.255249
K-S 5% Critical Value	0.320749

Data follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	65.08649
Adjusted Gamma UCL	108.3981

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.963939
Shapiro-Wilk 5% Critical Value	0.818

Data are lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	453060
95% Chebyshev (MVUE) UCL	41.18952
97.5% Chebyshev (MVUE) UCL	55.22036
99% Chebyshev (MVUE) UCL	82.78123

95% Non-parametric UCLs

CLT UCL	26.51773
Adj-CLT UCL (Adjusted for skewness)	36.61761
Mod-t UCL (Adjusted for skewness)	30.47922

	Jackknife UCL	28.90385
	Standard Bootstrap UCL	25.04163
	Bootstrap-t UCL	499.2393
RECOMMENDATION	Hall's Bootstrap UCL	269.2376
Data follow gamma distribution (0.05)	Percentile Bootstrap UCL	29.41486
	BCA Bootstrap UCL	39.56836
Use Adjusted Gamma UCL	95% Chebyshev (Mean, Sd) UCL	52.45043
	97.5% Chebyshev (Mean, Sd) UCL	70.47211
	99% Chebyshev (Mean, Sd) UCL	105.8722

Recommended UCL exceeds the maximum observation

Data File	Z:\Hanford\Z-8\Copy of Z-8_SIData.xls	Variable:	Pu239

Raw Statistics	
Number of Valid Samples	8
Number of Unique Samples	8
Minimum	0.92
Maximum	4620
Mean	1183.251
Median	45.1
Standard Deviation	2060.368
Variance	4245115
Coefficient of Variation	1.741276
Skewness	1.430354

Gamma Statistics	
k hat	0.213146
k star (bias corrected)	0.21655
Theta hat	5551.355
Theta star	5464.106
nu hat	3.410342
nu star	3.464797
Approx.Chi Square Value (.05)	0.522252
Adjusted Level of Significance	0.01946
Adjusted Chi Square Value	0.307486

Log-transformed Statistics	
Minimum of log data	-0.08338
Maximum of log data	8.43815
Mean of log data	3.657681
Standard Deviation of log data	3.595035
Variance of log data	12.92428

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.60902
Shapiro-Wilk 5% Critical Value	0.818
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	2563.357

Gamma Distribution Test	
A-D Test Statistic	0.714831
A-D 5% Critical Value	0.830803
K-S Test Statistic	0.286701
K-S 5% Critical Value	0.322474
Data follow gamma distribution at 5% significance level	

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	7850.098
Adjusted Gamma UCL	13333.07

Lognormal Distribution Test	
Shapiro-Wilk Test Statisitic	0.847747
Shapiro-Wilk 5% Critical Value	0.818
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	8.02E+10
95% Chebyshev (MVUE) UCL	10667.69
97.5% Chebyshev (MVUE) UCL	14368.31
99% Chebyshev (MVUE) UCL	21637.47

95% Non-parametric UCLs	
CLT UCL	2381.445
Adj-CLT UCL (Adjusted for skewness)	2775.066
Mod-t UCL (Adjusted for skewness)	2624.754

	Jackknife UCL	2563.357
	Standard Bootstrap UCL	2314.488
	Bootstrap-t UCL	20653.06
RECOMMENDATION	Hall's Bootstrap UCL	28524.89
Data follow gamma distribution (0.05)	Percentile Bootstrap UCL	2306.136
	BCA Bootstrap UCL	2835.618
Use Adjusted Gamma UCL	95% Chebyshev (Mean, Sd) UCL	4358.491
	97.5% Chebyshev (Mean, Sd) UCL	5732.42
	99% Chebyshev (Mean, Sd) UCL	8431.237

Recommended UCL exceeds the maximum observation

216-Z-9 Trench

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Table 1.4. ProUCL Output Summary for 216-Z-9 Trench - Resident and Driller Concentration in Waste

From File Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls

ProUCL

Variable Name	EPC	Units	Distribution	Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241	300556	pCi/g	Gamma	Adjusted Gamma UCL	41	0.0045	3713432	141568	40000	576536.8	4.072508	6.2428041	3.32E+11
Cd	22.39928	mg/kg	Gamma	Adjusted Gamma UCL	24	0.035	118	10.36946	2.545	24.89633	2.400929	3.8985018	619.8272
Carbon tet	99.44115	mg/kg	Non-parametric	99% Chebyshev (Mean, Sd) UCL	42	8.00E-05	380	9.512263	0.03225	58.57418	6.157755	6.4764679	3430.935
Eu-152	74.62122	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	30	-0.091	350.5	19.4715	0.3075	69.29903	3.558998	4.3398745	4802.356
Mn	738.3181	mg/kg	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24	157	2240	374	296	409.4582	1.094808	4.4540946	167656
Np-237	87.18264	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	23	-0.0015	252	29.22737	0.0685	63.76466	2.181676	2.6792333	4065.931
Pu-238	2884.77	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24	-109	9600	879.4467	3.05	2253.789	2.562735	3.1484161	5079563
Pu-239/240	8903844	pCi/g	Lognormal	99% Chebyshev (Mean, Sd) UCL	25	0.001	20296010	834963.9	2260	4054765	4.856216	4.9984798	1.64E+13
Ra-226	17.2231	pCi/g	Non-parametric	99% Chebyshev (Mean, Sd) UCL	18	0.292	21.5	2.971333	0.739	6.076974	2.045201	2.7301023	36.92961
Ra-228	12.33369	pCi/g	Lognormal	95% Chebyshev (MVUE) UCL	18	0.145	33	5.308389	1.435	9.671092	1.821851	2.4620907	93.53002
Tc-99	99.82143	pCi/g	Non-parametric	97.5% Chebyshev (Mean, Sd) UCL	16	-2.385	272	25.53288	0.8675	68.17185	2.669964	3.5824985	4647.401
Th-228	17.7264	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	31	-29.05	83	4.312452	1.025	17.13407	3.973162	3.2844905	293.5764
Th-230	19.2267	pCi/g	Normal	Student's-t UCL	14	-115.5	72	-1.23929	2.135	43.24088	-34.8918	-1.10746	1869.773

Data File	Z:\Hanford\Soil 95 UCLs\EPCS_Z-9(Historical Data) rev2.xls	Variable:	AM-241 (in-growth)

Raw Statistics	
Number of Valid Samples	41
Number of Unique Samples	41
Minimum	0.0045
Maximum	3713432
Mean	141568
Median	40000
Standard Deviation	576536.8
Variance	3.32E+11
Coefficient of Variation	4.072508
Skewness	6.242804

Gamma Statistics	
k hat	0.179947
k star (bias corrected)	0.183041
Theta hat	786718.7
Theta star	773423.6
nu hat	14.75569
nu star	15.00933
Approx.Chi Square Value (.05)	7.266851
Adjusted Level of Significance	0.044146
Adjusted Chi Square Value	7.069697

Log-transformed Statistics	
Minimum of log data	-5.40368
Maximum of log data	15.12747
Mean of log data	7.703691
Standard Deviation of log data	5.238751
Variance of log data	27.44451

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.239062
Shapiro-Wilk 5% Critical Value	0.941
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	293181.8

Gamma Distribution Test	
A-D Test Statistic	1.117117
A-D 5% Critical Value	0.915467
K-S Test Statistic	0.145628
K-S 5% Critical Value	0.153484
Data follow approximate gamma distibution at 5% significance level	

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	292401.9
Adjusted Gamma UCL	**300556.2**

Lognormal Distribution Test	
Shapiro-Wilk Test Statisitic	0.836863
Shapiro-Wilk 5% Critical Value	0.941
Data not lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	2.70E+12
95% Chebyshev (MVUE) UCL	5.99E+08
97.5% Chebyshev (MVUE) UCL	8.09E+08
99% Chebyshev (MVUE) UCL	1.22E+09

95% Non-parametric UCLs	
CLT UCL	289670.5
Adj-CLT UCL (Adjusted for skewness)	383470.6
Mod-t UCL (Adjusted for skewness)	307812.7

	Jackknife UCL	293181.8
	Standard Bootstrap UCL	298645.2
	Bootstrap-t UCL	1152617
RECOMMENDATION	Hall's Bootstrap UCL	798834.7
Assuming gamma distribution (0.05)	Percentile Bootstrap UCL	321802.9
	BCA Bootstrap UCL	414510.8
	95% Chebyshev (Mean, Sd) UCL	534042.9
Use Adjusted Gamma UCL	97.5% Chebyshev (Mean, Sd) UCL	703867.1
	99% Chebyshev (Mean, Sd) UCL	1037454

Data File Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls Variable: Cd

Raw Statistics	
Number of Valid Samples	24
Number of Unique Samples	22
Minimum	0.035
Maximum	118
Mean	10.36946
Median	2.545
Standard Deviation	24.89633
Variance	619.8272
Coefficient of Variation	2.400929
Skewness	3.898502

Gamma Statistics	
k hat	0.332195
k star (bias corrected)	0.318449
Theta hat	31.21493
Theta star	32.5624
nu hat	15.94538
nu star	15.28554
Approx.Chi Square Value (.05)	7.459383
Adjusted Level of Significance	0.0392
Adjusted Chi Square Value	7.076246

Log-transformed Statistics	
Minimum of log data	-3.35241
Maximum of log data	4.770685
Mean of log data	0.29734
Standard Deviation of log data	2.451743
Variance of log data	6.011044

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.446464
Shapiro-Wilk 5% Critical Value	0.916
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	19.07925

Gamma Distribution Test	
A-D Test Statistic	0.797431
A-D 5% Critical Value	0.843994
K-S Test Statistic	0.167838
K-S 5% Critical Value	0.192367
Data follow gamma distribution at 5% significance level	

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	21.24878
Adjusted Gamma UCL	22.39928

Lognormal Distribution Test	
Shapiro-Wilk Test Statisitic	0.918468
Shapiro-Wilk 5% Critical Value	0.916
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	316.7228
95% Chebyshev (MVUE) UCL	70.59346
97.5% Chebyshev (MVUE) UCL	93.15594
99% Chebyshev (MVUE) UCL	137.4756

95% Non-parametric UCLs	
CLT UCL	18.72851
Adj-CLT UCL (Adjusted for skewness)	23.04969
Mod-t UCL (Adjusted for skewness)	19.75327

	Jackknife UCL	19.07925
	Standard Bootstrap UCL	18.61767
	Bootstrap-t UCL	38.36575
RECOMMENDATION	Hall's Bootstrap UCL	43.84014
Data follow gamma distribution (0.05)	Percentile Bootstrap UCL	19.44425
	BCA Bootstrap UCL	23.95873
	95% Chebyshev (Mean, Sd) UCL	32.52113
Use Adjusted Gamma UCL	97.5% Chebyshev (Mean, Sd) UCL	42.10618
	99% Chebyshev (Mean, Sd) UCL	60.93414

Data File Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls

Variable: Carbon tet

Raw Statistics

Number of Valid Samples	42
Number of Unique Samples	35
Minimum	8.00E-05
Maximum	380
Mean	9.512263
Median	0.03225
Standard Deviation	58.57418
Variance	3430.935
Coefficient of Variation	6.157755
Skewness	6.476468

Gamma Statistics

k hat	0.132292
k star (bias corrected)	0.138716
Theta hat	71.9035
Theta star	68.57382
nu hat	11.11253
nu star	11.65212
Approx.Chi Square Value (.05)	4.99781
Adjusted Level of Significance	0.044286
Adjusted Chi Square Value	4.842618

Log-transformed Statistics

Minimum of log data	-9.43348
Maximum of log data	5.940171
Mean of log data	-3.66212
Standard Deviation of log data	3.57811
Variance of log data	12.80287

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.166203
Shapiro-Wilk 5% Critical Value	0.942

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	24.72244

Gamma Distribution Test

A-D Test Statistic	5.389183
A-D 5% Critical Value	0.945324
K-S Test Statistic	0.279075
K-S 5% Critical Value	0.153539

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	22.17731
Adjusted Gamma UCL	22.88803

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.909448
Shapiro-Wilk 5% Critical Value	0.942

Data not lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	451.381
95% Chebyshev (MVUE) UCL	30.60308
97.5% Chebyshev (MVUE) UCL	40.93227
99% Chebyshev (MVUE) UCL	61.22196

95% Non-parametric UCLs

CLT UCL	24.37877
Adj-CLT UCL (Adjusted for skewness)	34.02984
Mod-t UCL (Adjusted for skewness)	26.22781

	Jackknife UCL	24.72244
	Standard Bootstrap UCL	24.31989
	Bootstrap-t UCL	760.0957
RECOMMENDATION	Hall's Bootstrap UCL	593.5827
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	27.51828
	BCA Bootstrap UCL	45.46445
Use Hall's Bootstrap UCL	95% Chebyshev (Mean, Sd) UCL	48.90883
	97.5% Chebyshev (Mean, Sd) UCL	65.95576
Recommended UCL exceeds the maximum observation	99% Chebyshev (Mean, Sd) UCL	99.44115

In case Hall's Bootstrap method yields
an erratic, unreasonably large UCL value,
use 99% Chebyshev (Mean, Sd) UCL

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Eu-152

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	30	Shapiro-Wilk Test Statisitic	0.319683
Number of Unique Samples	30	Shapiro-Wilk 5% Critical Value	0.927
Minimum	-0.091	Data not normal at 5% significance level	
Maximum	350.5		
Mean	19.4715	95% UCL (Assuming Normal Distribution)	
Median	0.3075	Student's-t UCL	40.96922
Standard Deviation	69.29903		
Variance	4802.356		
Coefficient of Variation	3.558998		
Skewness	4.339875		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	40.28254
	Adj-CLT UCL (Adjusted for skewness)	50.99437
	Mod-t UCL (Adjusted for skewness)	42.64004
	Jackknife UCL	40.96922
	Standard Bootstrap UCL	40.08738
	Bootstrap-t UCL	233.3827
RECOMMENDATION	Hall's Bootstrap UCL	187.3592
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	42.104
	BCA Bootstrap UCL	54.61752
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	74.62122
	97.5% Chebyshev (Mean, Sd) UCL	98.48455
	99% Chebyshev (Mean, Sd) UCL	145.3594

Data File Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls Variable: Mn

Raw Statistics	
Number of Valid Samples	24
Number of Unique Samples	24
Minimum	157
Maximum	2240
Mean	374
Median	296
Standard Deviation	409.4582
Variance	167656
Coefficient of Variation	1.094808
Skewness	4.454095

Gamma Statistics	
k hat	2.514166
k star (bias corrected)	2.227673
Theta hat	148.7571
Theta star	167.8882
nu hat	120.68
nu star	106.9283
Approx.Chi Square Value (.05)	84.05927
Adjusted Level of Significance	0.0392
Adjusted Chi Square Value	82.63385

Log-transformed Statistics	
Minimum of log data	5.056246
Maximum of log data	7.714231
Mean of log data	5.712394
Standard Deviation of log data	0.538309
Variance of log data	0.289777

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.420188
Shapiro-Wilk 5% Critical Value	0.916

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	517.2459

Gamma Distribution Test

A-D Test Statistic	2.21363
A-D 5% Critical Value	0.753029
K-S Test Statistic	0.235072
K-S 5% Critical Value	0.179686

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	475.7499
Adjusted Gamma UCL	483.9565

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.804186
Shapiro-Wilk 5% Critical Value	0.916

Data not lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	438.027
95% Chebyshev (MVUE) UCL	521.4815
97.5% Chebyshev (MVUE) UCL	596.8055
99% Chebyshev (MVUE) UCL	744.7649

95% Non-parametric UCLs

CLT UCL	511.4774
Adj-CLT UCL (Adjusted for skewness)	592.674
Mod-t UCL (Adjusted for skewness)	529.9109

	Jackknife UCL	517.2459
	Standard Bootstrap UCL	511.8557
	Bootstrap-t UCL	858.7087
RECOMMENDATION	Hall's Bootstrap UCL	1035.487
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	527.25
	BCA Bootstrap UCL	630.0417
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	738.3181
	97.5% Chebyshev (Mean, Sd) UCL	895.9588
	99% Chebyshev (Mean, Sd) UCL	1205.613

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Np-237

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	23	Shapiro-Wilk Test Statisitic	0.538227
Number of Unique Samples	19	Shapiro-Wilk 5% Critical Value	0.914
Minimum	-0.0015	Data not normal at 5% significance level	
Maximum	252		
Mean	29.22737	95% UCL (Assuming Normal Distribution)	
Median	0.0685	Student's-t UCL	52.05826
Standard Deviation	63.76466		
Variance	4065.931		
Coefficient of Variation	2.181676		
Skewness	2.679233		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	51.0971
	Adj-CLT UCL (Adjusted for skewness)	59.03385
	Mod-t UCL (Adjusted for skewness)	53.29623
	Jackknife UCL	52.05826
	Standard Bootstrap UCL	50.70344
	Bootstrap-t UCL	80.43056
RECOMMENDATION	Hall's Bootstrap UCL	64.30795
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	52.17687
	BCA Bootstrap UCL	61.25676
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	87.18264
	97.5% Chebyshev (Mean, Sd) UCL	112.2599
	99% Chebyshev (Mean, Sd) UCL	161.5194

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Pu-238

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	24	Shapiro-Wilk Test Statisitic	0.46714
Number of Unique Samples	24	Shapiro-Wilk 5% Critical Value	0.916
		Data not normal at 5% significance level	
Minimum	-109		
Maximum	9600		
		95% UCL (Assuming Normal Distribution)	
Mean	879.4467	Student's-t UCL	1667.918
Median	3.05		
Standard Deviation	2253.789		
Variance	5079563		
Coefficient of Variation	2.562735		
Skewness	3.148416		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	1636.166
	Adj-CLT UCL (Adjusted for skewness)	1952.084
	Mod-t UCL (Adjusted for skewness)	1717.195
	Jackknife UCL	1667.918
	Standard Bootstrap UCL	1612.989
	Bootstrap-t UCL	2751.75
RECOMMENDATION	Hall's Bootstrap UCL	1994.805
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	1699.563
	BCA Bootstrap UCL	2004.143
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	2884.77
	97.5% Chebyshev (Mean, Sd) UCL	3752.475
	99% Chebyshev (Mean, Sd) UCL	5456.913

Data File	Z:\Hanford\Soil 95 UCLs\rev1\EPCS_Z-9(Historical Data) rev1.xls	Variable:	PU-239/240

Raw Statistics	
Number of Valid Samples	25
Number of Unique Samples	25
Minimum	0.001
Maximum	20296010
Mean	834963.9
Median	2260
Standard Deviation	4054765
Variance	1.64E+13
Coefficient of Variation	4.856216
Skewness	4.99848

Gamma Statistics	
k hat	0.097805
k star (bias corrected)	0.112735
Theta hat	8537045
Theta star	7406438
nu hat	4.89024
nu star	5.636744
Approx.Chi Square Value (.05)	1.456671
Adjusted Level of Significance	0.0395
Adjusted Chi Square Value	1.317999

Log-transformed Statistics	
Minimum of log data	-6.90776
Maximum of log data	16.82593
Mean of log data	5.308572
Standard Deviation of log data	6.42297
Variance of log data	41.25454

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.213266
Shapiro-Wilk 5% Critical Value	0.918
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	2222409

Gamma Distribution Test	
A-D Test Statistic	1.725285
A-D 5% Critical Value	0.951531
K-S Test Statistic	0.231697
K-S 5% Critical Value	0.197775
Data do not follow gamma distribution at 5% significance level	

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	3230982
Adjusted Gamma UCL	3570926

Lognormal Distribution Test	
Shapiro-Wilk Test Statisitic	0.936057
Shapiro-Wilk 5% Critical Value	0.918
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	9.20E+17
95% Chebyshev (MVUE) UCL	9.07E+08
97.5% Chebyshev (MVUE) UCL	1.23E+09
99% Chebyshev (MVUE) UCL	1.85E+09

95% Non-parametric UCLs	
CLT UCL	2168863
Adj-CLT UCL (Adjusted for skewness)	3035114
Mod-t UCL (Adjusted for	2357526

	skewness)	
	Jackknife UCL	2222409
	Standard Bootstrap UCL	2131796
	Bootstrap-t UCL	1.35E+08
RECOMMENDATION	Hall's Bootstrap UCL	88219103
Data are lognormal (0.05)	Percentile Bootstrap UCL	2447377
	BCA Bootstrap UCL	3278958
Use Hall's Bootstrap UCL	95% Chebyshev (Mean, Sd) UCL	4369826
	97.5% Chebyshev (Mean, Sd) UCL	5899364
	99% Chebyshev (Mean, Sd) UCL	8903844

Recommended UCL exceeds the maximum observation

In case Hall's Bootstrap method yields
an erratic, unreasonably large UCL value,
use 99% Chebyshev (Mean, Sd) UCL

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Ra-226

Raw Statistics	
Number of Valid Samples	18
Number of Unique Samples	18
Minimum	0.292
Maximum	21.5
Mean	2.971333
Median	0.739
Standard Deviation	6.076974
Variance	36.92961
Coefficient of Variation	2.045201
Skewness	2.730102

Gamma Statistics	
k hat	0.614836
k star (bias corrected)	0.5494
Theta hat	4.832729
Theta star	5.408324
nu hat	22.13408
nu star	19.7784
Approx.Chi Square Value (.05)	10.68646
Adjusted Level of Significance	0.03574
Adjusted Chi Square Value	10.04818

Log-transformed Statistics	
Minimum of log data	-1.231
Maximum of log data	3.068053
Mean of log data	0.087666
Standard Deviation of log data	1.187334
Variance of log data	1.409762

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.460257
Shapiro-Wilk 5% Critical Value	0.897

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	5.46307

Gamma Distribution Test

A-D Test Statistic	2.662123
A-D 5% Critical Value	0.789942
K-S Test Statistic	0.309545
K-S 5% Critical Value	0.213414

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	5.499315
Adjusted Gamma UCL	5.848645

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.806317
Shapiro-Wilk 5% Critical Value	0.897

Data not lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	5.153073
95% Chebyshev (MVUE) UCL	4.964818
97.5% Chebyshev (MVUE) UCL	6.213557
99% Chebyshev (MVUE) UCL	8.666464

95% Non-parametric UCLs

CLT UCL	5.32735
Adj-CLT UCL (Adjusted for skewness)	6.312209
Mod-t UCL (Adjusted for skewness)	5.616688

	Jackknife UCL	5.46307
	Standard Bootstrap UCL	5.214231
	Bootstrap-t UCL	26.12459
RECOMMENDATION	Hall's Bootstrap UCL	19.27188
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	5.331056
	BCA Bootstrap UCL	6.380611
Use 99% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	9.21483
	97.5% Chebyshev (Mean, Sd) UCL	11.9164
	99% Chebyshev (Mean, Sd) UCL	17.2231

Data File Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls Variable: Ra-228

Raw Statistics	
Number of Valid Samples	18
Number of Unique Samples	18
Minimum	0.145
Maximum	33
Mean	5.308389
Median	1.435
Standard Deviation	9.671092
Variance	93.53002
Coefficient of Variation	1.821851
Skewness	2.462091

Gamma Statistics	
k hat	0.57601
k star (bias corrected)	0.517046
Theta hat	9.215787
Theta star	10.26677
nu hat	20.73637
nu star	18.61364
Approx.Chi Square Value (.05)	9.834382
Adjusted Level of Significance	0.03574
Adjusted Chi Square Value	9.225294

Log-transformed Statistics	
Minimum of log data	-1.93102
Maximum of log data	3.496508
Mean of log data	0.590087
Standard Deviation of log data	1.430468
Variance of log data	2.046237

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.547261
Shapiro-Wilk 5% Critical Value	0.897

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	9.273819

Gamma Distribution Test

A-D Test Statistic	1.352362
A-D 5% Critical Value	0.793386
K-S Test Statistic	0.235761
K-S 5% Critical Value	0.213984

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	10.04725
Adjusted Gamma UCL	10.7106

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.951045
Shapiro-Wilk 5% Critical Value	0.897

Data are lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	16.0022
95% Chebyshev (MVUE) UCL	12.33369
97.5% Chebyshev (MVUE) UCL	15.707
99% Chebyshev (MVUE) UCL	22.33321

95% Non-parametric UCLs

CLT UCL	9.05783
Adj-CLT UCL (Adjusted for skewness)	10.4713
Mod-t UCL (Adjusted for skewness)	9.494292

	Jackknife UCL	9.273819
	Standard Bootstrap UCL	8.971703
	Bootstrap-t UCL	19.98466
RECOMMENDATION	Hall's Bootstrap UCL	23.08774
Data are lognormal (0.05)	Percentile Bootstrap UCL	9.187
	BCA Bootstrap UCL	10.88483
Use 95% Chebyshev (MVUE) UCL	95% Chebyshev (Mean, Sd) UCL	15.24449
	97.5% Chebyshev (Mean, Sd) UCL	19.54385
	99% Chebyshev (Mean, Sd) UCL	27.98911

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Tc-99

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	16	Shapiro-Wilk Test Statisitic	0.436921
Number of Unique Samples	16	Shapiro-Wilk 5% Critical Value	0.887
Minimum	-2.385	Data not normal at 5% significance level	
Maximum	272		
		95% UCL (Assuming Normal Distribution)	
Mean	25.53288	Student's-t UCL	55.41004
Median	0.8675		
Standard Deviation	68.17185		
Variance	4647.401		
Coefficient of Variation	2.669964		
Skewness	3.582498		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	53.56605
	Adj-CLT UCL (Adjusted for skewness)	69.87596
	Mod-t UCL (Adjusted for skewness)	57.95406
	Jackknife UCL	55.41004
	Standard Bootstrap UCL	52.24682
	Bootstrap-t UCL	222.7488
RECOMMENDATION	Hall's Bootstrap UCL	164.8865
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	56.87741
	BCA Bootstrap UCL	74.06884
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	99.82143
	97.5% Chebyshev (Mean, Sd) UCL	131.9661
	99% Chebyshev (Mean, Sd) UCL	195.1082

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Th-228

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	31	Shapiro-Wilk Test Statisitic	0.564074
Number of Unique Samples	30	Shapiro-Wilk 5% Critical Value	0.929
Minimum	-29.05	Data not normal at 5% significance level	
Maximum	83		
Mean	4.312452	95% UCL (Assuming Normal Distribution)	
Median	1.025	Student's-t UCL	9.53555
Standard Deviation	17.13407		
Variance	293.5764		
Coefficient of Variation	3.973162		
Skewness	3.284491		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	9.374275
	Adj-CLT UCL (Adjusted for skewness)	11.31403
	Mod-t UCL (Adjusted for skewness)	9.838113
	Jackknife UCL	9.53555
	Standard Bootstrap UCL	9.283271
	Bootstrap-t UCL	13.80307
RECOMMENDATION	Hall's Bootstrap UCL	36.46488
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	9.722871
	BCA Bootstrap UCL	11.30942
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	17.7264
	97.5% Chebyshev (Mean, Sd) UCL	23.53062
	99% Chebyshev (Mean, Sd) UCL	34.9319

Data File	Z:\Hanford\Z-9\Copy of Z-9_SoilData_All_rev03.30.07 hak.xls	Variable:	Th-230

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	14	Shapiro-Wilk Test Statisitic	0.88449
Number of Unique Samples	14	Shapiro-Wilk 5% Critical Value	0.874
Minimum	-115.5	Data are normal at 5% significance level	
Maximum	72		
Mean	-1.23929	95% UCL (Assuming Normal Distribution)	
Median	2.135	Student's-t UCL	19.2267
Standard Deviation	43.24088		
Variance	1869.773		
Coefficient of Variation	-34.8918		
Skewness	-1.10746		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	17.76965
	Adj-CLT UCL (Adjusted for skewness)	14.11475
	Mod-t UCL (Adjusted for skewness)	18.65661
	Jackknife UCL	19.2267
	Standard Bootstrap UCL	16.85922
	Bootstrap-t UCL	16.09397
RECOMMENDATION	Hall's Bootstrap UCL	16.10144
Data are normal (0.05)	Percentile Bootstrap UCL	15.96357
	BCA Bootstrap UCL	13.83571
Use Student's-t UCL	95% Chebyshev (Mean, Sd) UCL	49.13481
	97.5% Chebyshev (Mean, Sd) UCL	70.93172
	99% Chebyshev (Mean, Sd) UCL	113.7475

216-A-8 Crib

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Table 1.5. ProUCL Output Summary for 216-A-8 Crib - Resident and Driller Concentration in Waste.

From File Z:\Hanford\A_8\EPC data for A-8.xls

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
C14	67.03	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.555	89.7	17.44635	-0.00775	35.97456	2.062011	1.7852805	1294.169
Cs137	261460.45	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	18	-0.0005	877000	49206.55	0.485	206592.8	4.198481	4.2424493	4.27E+10
Pu239-240	29.85	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.001	55.7	5.5798	0.01125	17.61044	3.156107	3.1622765	310.1278
Ra228	433.02	pCi/g	Non-parametric	Use 99% Chebyshev (Mean, Sd) UCL	11	0.1935	435	40.07032	0.688	130.9837	3.268845	3.3165958	17156.72
Tc99	42.81	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.003	79.6	8.25645	0.06525	25.07114	3.036552	3.1605953	628.5619
Th228	124.75	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	14	0	325	23.73296	0.6925	86.711	3.65361	3.7415995	7518.798

Data File Z:\Hanford\A_8\EPC data for A-8.xls

Variable: C14

Raw Statistics

Number of Valid Samples	10
Number of Unique Samples	10
Minimum	-0.555
Maximum	89.7
Mean	17.44635
Median	-0.00775
Standard Deviation	35.97456
Variance	1294.169
Coefficient of Variation	2.062011
Skewness	1.78528

Gamma Statistics Not Available

Lognormal Statistics Not Available

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.544351
Shapiro-Wilk 5% Critical Value	0.842

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	38.30012

95% Non-parametric UCLs

CLT UCL	36.15846
Adj-CLT UCL (Adjusted for skewness)	43.02096
Mod-t UCL (Adjusted for skewness)	39.37054
Jackknife UCL	38.30012
Standard Bootstrap UCL	35.15268
Bootstrap-t UCL	449.5298
Hall's Bootstrap UCL	650.5096
Percentile Bootstrap UCL	35.081
BCA Bootstrap UCL	43.58905
95% Chebyshev (Mean, Sd) UCL	67.03386
97.5% Chebyshev (Mean, Sd) UCL	88.49041
99% Chebyshev (Mean, Sd) UCL	130.6377

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Cs137

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	18	Shapiro-Wilk Test Statisitic	0.255819
Number of Unique Samples	18	Shapiro-Wilk 5% Critical Value	0.897
		Data not normal at 5% significance level	
Minimum	-0.0005		
Maximum	877000		
		95% UCL (Assuming Normal Distribution)	
Mean	49206.55	Student's-t UCL	133915.6
Median	0.485		
Standard Deviation	206592.8		
Variance	4.27E+10		
Coefficient of Variation	4.198481		
Skewness	4.242449		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	129301.7
	Adj-CLT UCL (Adjusted for skewness)	181330
	Mod-t UCL (Adjusted for skewness)	142031
	Jackknife UCL	133915.6
	Standard Bootstrap UCL	127840.5
	Bootstrap-t UCL	14431865
RECOMMENDATION	Hall's Bootstrap UCL	11454120
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	146519.3
	BCA Bootstrap UCL	195537.9
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	261460.5
	97.5% Chebyshev (Mean, Sd) UCL	353302.9
	99% Chebyshev (Mean, Sd) UCL	533709.6

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Pu239-240

Raw Statistics	
Number of Valid Samples	10
Number of Unique Samples	10
Minimum	-0.001
Maximum	55.7
Mean	5.5798
Median	0.01125
Standard Deviation	17.61044
Variance	310.1278
Coefficient of Variation	3.156107
Skewness	3.162277

Gamma Statistics Not Available

Lognormal Statistics Not Available

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.366363
Shapiro-Wilk 5% Critical Value	0.842
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	15.78824

95% Non-parametric UCLs	
CLT UCL	14.73984
Adj-CLT UCL (Adjusted for skewness)	20.69031
Mod-t UCL (Adjusted for skewness)	16.71639
Jackknife UCL	15.78824
Standard Bootstrap UCL	14.21224
Bootstrap-t UCL	15363.43
Hall's Bootstrap UCL	5607.084
Percentile Bootstrap UCL	16.7169
BCA Bootstrap UCL	22.2865
95% Chebyshev (Mean, Sd) UCL	29.85412
97.5% Chebyshev (Mean, Sd) UCL	40.35764
99% Chebyshev (Mean, Sd) UCL	60.98977

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Ra228

Raw Statistics	
Number of Valid Samples	11
Number of Unique Samples	11
Minimum	0.1935
Maximum	435
Mean	40.07032
Median	0.688
Standard Deviation	130.9837
Variance	17156.72
Coefficient of Variation	3.268845
Skewness	3.316596

Gamma Statistics	
k hat	0.195489
k star (bias corrected)	0.20278
Theta hat	204.9744
Theta star	197.6047
nu hat	4.300767
nu star	4.461164
Approx.Chi Square Value (.05)	0.911559
Adjusted Level of Significance	0.02783
Adjusted Chi Square Value	0.683331

Log-transformed Statistics	
Minimum of log data	-1.64248
Maximum of log data	6.075346
Mean of log data	-0.08725
Standard Deviation of log data	2.127732
Variance of log data	4.527242

Normal Distribution Test

Shapiro-Wilk Test Statisitic	0.347063
Shapiro-Wilk 5% Critical Value	0.85

Data not normal at 5% significance level

95% UCL (Assuming Normal Distribution)

Student's-t UCL	111.65

Gamma Distribution Test

A-D Test Statistic	3.020341
A-D 5% Critical Value	0.861665
K-S Test Statistic	0.517976
K-S 5% Critical Value	0.282133

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	196.1038
Adjusted Gamma UCL	261.6012

Lognormal Distribution Test

Shapiro-Wilk Test Statisitic	0.605603
Shapiro-Wilk 5% Critical Value	0.85

Data not lognormal at 5% significance level

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	350.4608
95% Chebyshev (MVUE) UCL	21.7282
97.5% Chebyshev (MVUE) UCL	28.73452
99% Chebyshev (MVUE) UCL	42.49708

95% Non-parametric UCLs

CLT UCL	105.0306
Adj-CLT UCL (Adjusted for skewness)	147.2292
Mod-t UCL (Adjusted for skewness)	118.2321
Jackknife UCL	111.65

	Standard Bootstrap UCL	102.7759
	Bootstrap-t UCL	22544.5
RECOMMENDATION	Hall's Bootstrap UCL	7871.242
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	119.0388
	BCA Bootstrap UCL	158.576
	95% Chebyshev (Mean, Sd) UCL	212.2166
Use 99% Chebyshev (Mean, Sd) UCL	97.5% Chebyshev (Mean, Sd) UCL	286.7044
	99% Chebyshev (Mean, Sd) UCL	433.0213

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Tc99

Raw Statistics	
Number of Valid Samples	10
Number of Unique Samples	10
Minimum	-0.003
Maximum	79.6
Mean	8.25645
Median	0.06525
Standard Deviation	25.07114
Variance	628.5619
Coefficient of Variation	3.036552
Skewness	3.160595

Gamma Statistics Not Available

Lognormal Statistics Not Available

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.379108
Shapiro-Wilk 5% Critical Value	0.842
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	22.78972

95% Non-parametric UCLs	
CLT UCL	21.29716
Adj-CLT UCL (Adjusted for skewness)	29.76404
Mod-t UCL (Adjusted for skewness)	24.11038
Jackknife UCL	22.78972
Standard Bootstrap UCL	20.42788
Bootstrap-t UCL	621.1088
Hall's Bootstrap UCL	442.3178
Percentile Bootstrap UCL	24.08435
BCA Bootstrap UCL	32.0215
95% Chebyshev (Mean, Sd) UCL	42.81463
97.5% Chebyshev (Mean, Sd) UCL	57.76798
99% Chebyshev (Mean, Sd) UCL	87.14094

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Th228

Raw Statistics	
Number of Valid Samples	14
Number of Unique Samples	14
Minimum	0
Maximum	325
Mean	23.73296
Median	0.6925
Standard Deviation	86.711
Variance	7518.798
Coefficient of Variation	3.65361
Skewness	3.741599

Gamma Statistics Not Available

Lognormal Statistics Not Available

Normal Distribution Test	
Shapiro-Wilk Test Statisitic	0.299589
Shapiro-Wilk 5% Critical Value	0.874
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	64.77344

95% Non-parametric UCLs	
CLT UCL	61.85161
Adj-CLT UCL (Adjusted for skewness)	86.6135
Mod-t UCL (Adjusted for skewness)	68.63579
Jackknife UCL	64.77344
Standard Bootstrap UCL	60.46024
Bootstrap-t UCL	9924.31
Hall's Bootstrap UCL	4736.945
Percentile Bootstrap UCL	70.08564
BCA Bootstrap UCL	93.31571
95% Chebyshev (Mean, Sd) UCL	124.7482
97.5% Chebyshev (Mean, Sd) UCL	168.4576
99% Chebyshev (Mean, Sd) UCL	254.3162

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

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APPENDIX A

ATTACHMENT 2

CWASTE DETAILS AND EXPOSURE POINT CONCENTRATION CALCULATIONS FOR WELL DRILLER AND RESIDENTIAL FARMER

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Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Soil Site Characteristics

Site Name	Vcut (m3)	Ratio Lwaste&Lwell	Lwaste -Thickness of waste (m)	Lwell-Depth of Well (m)	Depth to Groundwater (m)
216-Z-1A Tile Field	5.480579867	0.3	28.04	87	71
216-Z-8 French Drain	5.268303886	0.1	5.79	83	68
216-Z-9 Trench	5.268303886	0.4	30.18	83	68
216-A-8 Crib	6.020918727	0.2	18.14	95	80

Vcut = pi x r2 x h x (Dinitial/Dfinal)

Dfinal = density of soil cuttings on surface (1.5 kg/L)

Dinitial = density of undisturbed soil (1.7 kg/L)

h = Lwell - depth of the well from surface to groundwater, plus 15.24 m (50 ft)

pi = 3.14159

r = radius of 26.67 cm (10.5 inch) well — *pg 7 of tank report*

Vcut = volume of cuttings — *Rittman, P.D. (2004)*

Pi	radius of well^2	change in density	Vcut (m3)
3.14159	0.017782223	1.133333333	5.480579867
3.14159	0.017782223	1.133333333	5.268303886
3.14159	0.017782223	1.133333333	5.268303886
3.14159	0.017782223	1.133333333	6.020918727

Ccut = Cwaste (Lwaste/Lwell)
Ccut = concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)
Cwaste = concentration of radionuclide/chemical in the disposal site;
maximum or calculated 95 UCL of the analytical data (pCi/g or mg/kg)
Lwaste = thickness of the waste (m)
Lwell = depth of the well from surface to groundwater (m)

Cgarden = Ccut (Vcut/Vgarden)
Cgarden = concentration of a radionuclide/chemical in garden soil (pCi/g or mg/kg)
Ccut = concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)
Vcut = volume of cuttings (m3)
Vgarden = volume of garden soil (15 m3)

Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Site Name	Chemical Name	Cwaste - Now (pCi/g or mg/kg)	From RESRAD Cwaste - 150 years (pCi/g or mg/kg)	Well Driller EPC - Ccut in 150 years (pCi/g or mg/kg)	Residential Farmer EPC - Cgarden in 150 years (pCi/g or mg/kg)
216-Z-1A Tile Field	Americium-241	122528	89640	29037	10609
	Neptunium-237	--	5.10	1.65	0.60
	Plutonium-239/240	698678	--	--	--
	Plutonium-239(a)	569293	566400	183471	67035
	Plutonium-240(a)	129385	127300	41236	15066
	Uranium-235	--	0.083	0.027	0.010
	Uranium-236	--	0.56	0.18	0.066
216-Z-8 French Drain	Americium-241	457	253.5	17.64	6.20
	Neptunium-237	--	0.017	0.0012	0.00040
	Plutonium-238	77.5	23.61	1.64	0.58
	Plutonium-239/240	4620	--	--	--
	Plutonium-239(a)	3764	3735	259.89	91.28
	Plutonium-240(a)	856	839.5	58.41	20.52
	Uranium-234	--	0.018	0.0012	0.00043
216-Z-9 Trench	1,2-Dibromo-3-chloropropane	0.588	--	0.21	0.07
	Actinium-227	--	12.32	4.47	1.57
	Americium-241	300556	221000	80156	28152
	Cadmium	22.4	--	8.12	2.85
	Carbon tetrachloride	99.4	--	36.07	12.67
	Europium-152	74.6	0.03052	0.01107	0.003888
	Manganese	738.3	--	267.78	94.05
	Neptunium-237	87.2	114.7	41.60	14.61
	Nickel-63	2360	798	289.39	101.64
	Lead-210	--	16.84	6.11	2.15
	Plutonium-238	2885	882	319.72	112.29
	Plutonium-239/240	8903844	--	--	--
	Plutonium-239(a)	7254984	7264000	2634617	925331
	Plutonium-240(a)	1648860	1574000	570882	200505
	Protactinium-231	12.9	12.5	4.54	1.59
	Radium-226	17.2	17.0	6.17	2.17

Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Site Name	Chemical Name	Cwaste - Now (pCi/g or mg/kg)	From RESRAD Cwaste - 150 years (pCi/g or mg/kg)	Well Driller EPC - Ccut in 150 years (pCi/g or mg/kg)	Residential Farmer EPC - Cgarden in 150 years (pCi/g or mg/kg)
216-Z-9 Trench cont'd	Radium-228	12.3	1.93E-07	6.98E-08	2.45E-08
	Strontium-90	13.4	0.36	0.13	0.046
	Technetium-99	99.8	3.67E-06	1.33E-06	4.68E-07
	Thorium-228	17.7	2.76E-07	1.00E-07	3.52E-08
	Thorium-230	19.23	19.17	6.95	2.44
	Uranium-233	--	0.066	0.024	0.0084
	Uranium-234	--	0.71	0.26	0.090
	Uranium-235	--	1.1	0.38	0.14
	Uranium-236	--	6.95	2.52	0.89
216-A-8 Crib	Carbon-14	67.03	2.63E-35	5.02E-36	2.02E-36
	Cesium-137	261460	8167	1557.87	625.32
	Neptunium-237	3.53	3.50	0.67	0.27
	Plutonium-239/240	29.85	--	--	--
	Plutonium-239(a)	24.33	24.2	4.62	1.85
	Plutonium-240(a)	5.53	5.44	1.04	0.42
	Radium-228	433.02	5.88E-06	1.12E-06	4.51E-07
	Technetium-99	42.81	1.83E-11	3.50E-12	1.40E-12
	Thallium	2.5	--	0.48	0.19
	Thorium-228	124.75	8.83E-06	1.68E-06	6.76E-07

(a) Ratio of 4.4:1 (Pu 239: Pu 240)

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APPENDIX A

ATTACHMENT 3

RESRAD INPUT SUMMARY

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ATTACHMENT 3
TABLE OF CONTENTS

Table 3.1 RESRAD Key Input Parameters and Values for Resident Farmer Direct Contact Pathways

Table 3.2 RESRAD Key Input Parameters and Values for Construction Worker Direct Contact Pathways

Table 3.3 RESRAD Key Input Parameters and Values for Well Driller Direct Contact Pathways

Table 3.4 RESRAD Key Input Parameters and Values for Residential Farmer External Radiation

Table 3.5 RESRAD Key Input Parameters and Values for Construction Worker – External Radiation

Table 3.6 RESRAD Key Input Parameters and Values for Well Driller External Radiation

Table 3.7 Site-Specific RESRAD Input Parameters for the Soil Sites

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Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	100	Site-specific; size of a garden (p. 25, Rittman 2004)
Thickness of contaminated zone	meters	0.15	Site-specific; tilling depth (p. 25, Rittman 2004)
Length parallel to aquifer flow	meters	9.1	site-specific information used for all sites (30 ft; or 9.1m)
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value = 1.5*
Cover Erosion Rate	meters/yr	greyed out	*default value =0.001*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0	Set to zero
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)
Irrigation mode (overhead or ditch?)		overhead	*default value*

Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	1000000	*default value*
Accuracy for water/soil computations		0.001	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	1.5	*default value*
Saturated zone total porosity		0.33	Ringold value
Saturated zone effective porosity		0.18	Ringold value
Saturated zone field capacity		0.21	Ringold value
Saturated zone hydraulic conductivity	meters/yr	7300	Ringold value = 7300 m/yr
Saturated zone hydraulic gradient		0.002	Ringold value
Saturated zone b parameter		4.05	RESRAD value for sand from Appendix E
Water table drop rate	meters/yr	0.2	Ringold value
Well pump intake depth	m below water table	10	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	30,000	10-20 gal/min or approx. 20,000 - 40,000 cubic meters/yr
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	**3**		number of zones set manually
Unsaturated Zone #1	Hanford Sands		
Thickness	meters	33.5	110 ft; 33.5 m
Density	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.3	Hanford Sands value; WHC-EP-0883, Appendix A
Effective Porosity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Field Capacity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2

Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Unsaturated Zone #2	CCU (silt values; ignored caliche for model)		
Thickness	meters	3.1	10 ft; 3.1 m
Density	grams/cm^3	2.0	CCU (silt) value; WHC-EP-0883, Appendix A
Total Porosity		0.37	CCU (silt) value; WHC-EP-0883, Appendix A
Effective Porosity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Field Capacity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	2740	CCU value = 8.69E-03 cm/sec; 2740 m/yr; WHC-EP-0883, Appendix A
b parameter		5.3	RESRAD value for silty loam from Appendix E; Table E.2
Unsaturated Zone #3	Ringold		
Thickness	meters	32.3	106 ft; 32.3 m
Density	grams/cm^3	1.85	Ringold = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.22	Ringold value; WHC-EP-0883, Appendix A
Effective Porosity		0.13	Ringold value; WHC-EP-0883, Appendix A
Field Capacity		0.13	Ringold value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	7300	Ringold = 7300 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2
OCCUPANCY			
Inhalation Rate	m3/yr	8400	*default value*
Mass Loading for Inhalation	g/m3	3.70E-07	Site-specific based on a PEF of 2.72E+09
Exposure duration	years	30	*default value*
Indoor Dust Filtration Factor		0.4	*default value*
External gamma shielding factor		greyed out	Not pertinent to soil ingestion, inhalation of particulates, or inhalation of radon routes of exposure
Indoor Time Fraction		0.5	*default value*
Outdoor time fraction		0.25	*default value*
Shape of contaminated zone		circular	*default*

Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
INGESTION - Dietary			
Fruits, vegetables and grain	kg/yr	106	*Site-specific value; includes ingestion of fruits and vegetables only*
Leafy vegetable	kg/yr	10.5	*Site-specific value; assuming 9% of fruit/vegetables intake is leafy*
Milk	L/yr	92	*This pathway was not used*
Meat and poultry	kg/yr	63	*This pathway was not used*
Soil Ingestion	g/yr	36.5	*default value*
Contamination fraction - Household water		1	*This pathway was not used*
Contamination fraction - Livestock water		1	*This pathway was not used*
Contamination fraction - Irrigation water		1	*This pathway was not used*
Contamination fraction - Plant food		1	*Evaluation of plant food only*
Contamination fraction - Meat		0	*This pathway was not used*
Contamination fraction - Milk		0	*This pathway was not used*
INGESTION - Non-Dietary			
Livestock fodder intake from meat	kg/day	68	*This pathway was not used*
Fodder intake from milk	kg/day	55	*This pathway was not used*
Livestock water intake for meat	L/day	50	*This pathway was not used*
Livestock water intake for milk	L/day	160	*This pathway was not used*
Livestock water intake of soil		0.5	*This pathway was not used*
Household water fraction from groundwater		1	*This pathway was not used*
Livestock water fraction from from groundwater		1	*This pathway was not used*
Irrigation fraction from groundwater		1	*This pathway was not used*
Mass loading for foliar deposition	g/m3	0.0001	*This pathway was not used*
Depth of soil mixing layer	m	0.15	*This pathway was not used*
Depth of roots	m	0.9	*This pathway was not used*

Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
PLANT FACTORS			
Wet weight crop yield for Non-Leafy	kg/m2	0.7	*default value*
Wet weight crop yield for Leafy	kg/m2	1.5	*default value*
Wet weight crop yield for Fodder	kg/m2	1.1	*default value*
Growning season for Non-Leafy	years	0.17	*default value*
Growing season for Leafy	years	0.25	*default value*
Growing season for Fodder	years	0.08	*default value*
Translocation Factor for Non-Leafy		0.1	*default value*
Translocation Factor for Leafy		1	*default value*
Translocation Factor for Fodder		1	*default value*
Dry Foliar Interception Fraction for Non-Leafy		0.25	*default value*
Dry Foliar Interception Fraction for Leafy		0.25	*default value*
Dry Foliar Interception Fraction for Fodder		0.25	*default value*
Wet Foliar Interception Fraction for Non-Leafy		0.25	*default value*
Wet Foliar Interception Fraction for Leafy		0.25	*default value*
Wet Foliar Interception Fraction for Fodder		0.25	*default value*
Weathering Removal Constant for Vegetation		20	*default value*
Radon Data			
Cover Total Porosity		0.4	*default value*
Cover Volumetric Water Content		0.05	*default value*
Cover Radon Diffusion Coefficient	m2/sec	0.000002	*default value*
Bldg Foundation Thickness	meters	0.15	*default value*
Bldg Foundation Density	g/cm3	2.4	*default value*
Bldg Foundation Total Porosity		0.1	*default value*
Bldg Foundation Volumetric Water Content		0.03	*default value*
Bldg Foundation Radon Diffusion Coefficient	m2/sec	0.0000003	*default value*
Contaminated Radon Diffusion Coefficient	m2/sec	0.000002	*default value*
Radon Vertical Dimension of Mixing	meters	2	*default value*
Building Air Exchange Rate	1/hr	0.5	*default value*
Height of Bldg. (room)	meters	2.5	*default value*
Building Indoor Area Factor		0	*default value*

Table 3.1. RESRAD Key Input Parameters and Values for Residential Farmer. (6 sheets)

RESRAD v 6.3; Pathways = plant, meat, milk, and soil ingestion, inhalation of particulates, and inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Foundation Depth Below Ground Surface	meters	-1	*default value*
Ra-222 emanation coefficient		0.25	*default value*
Ra-220 emanation coefficient		0.15	*default value*
Storage Times			
Fruits, non-leafy vegetables, and grain	days	14	*default value*
Leafy vegetables	days	1	*default value*
Milk	days	1	*default value*
Meat and poultry	days	20	*default value*
Fish	days	7	*default value*
Crustacea and mollusks	days	7	*default value*
Well water	days	1	*default value*
Surface water	days	1	*default value*
Livestock fodder	days	45	*default value*
C-14			**For Site A-8 only**
Concentration in local water	g/cm3	0.00002	*default value*
Concentration in contaminated soil	g/g	0.03	*default value*
Fraction of vegetation in carbon absorbed from soil		0.02	*default value*
Fraction of vegetation in carbon absorbed from air		0.98	*default value*
Thickness of evasion layer of C-14 in soil	meters	0.3	*default value*
C-14 evasion flux rate from soil	1/sec	0.0000007	*default value*
C-12 evasion flux rate from soil	1/sec	1.00E-10	*default value*
Grain fraction in livestock feed (balance is hay/fodder)			*default value*
Beef cattle		0.8	*default value*
Milk cow		0.2	*default value*
DCF correction factor for gaseous forms of C-14		123.4	*default value*

Table 3.2. RESRAD Key Input Parameters and Values for Construction Worker. (5 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
SOIL CONCENTRATIONS			
Basic Radiation Dose Limit	mrem/yr	25	*default value*
Number of nuclides		varies	Depends on the site
Nuclide (#1)		varies	Depends on the site
Nuclide (#1) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
Nuclide (#2)		varies	Depends on the site
Nuclide (#2) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #2):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*

Table 3.2. RESRAD Key Input Parameters and Values for Construction Worker. (5 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	1811.61 / 2.323 / 1579.35	Site-specific for Z-1A / Z-8 / A-8
Thickness of contaminated zone	meters	28.04 / 5.79 / 18.14	Site-specific for Z-1A / Z-8 / A-8
Length parallel to aquifer flow	meters	9.1	site-specific information used for all sites (30 ft; or 9.1m)
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value = 1.5*
Cover Erosion Rate	meters/yr	greyed out	*default value =*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0.001	*default value*
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)

Table 3.2. RESRAD Key Input Parameters and Values for Construction Worker. (5 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Irrigation mode (overhead or ditch?)		overhead	*default value*
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	1000000	*default value*
Accuracy for water/soil computations		0.001	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	1.5	*default value*
Saturated zone total porosity		0.33	Ringold value
Saturated zone effective porosity		0.18	Ringold value
Saturated zone field capacity		0.21	Ringold value
Saturated zone hydraulic conductivity	meters/yr	7300	Ringold value = 7300 m/yr
Saturated zone hydraulic gradient		0.002	Ringold value
Saturated zone b parameter		4.05	RESRAD value for sand from Appendix E
Water table drop rate	meters/yr	0.2	Ringold value
Well pump intake depth	m below water table	10	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	30,000	10-20 gal/min or approx. 20,000 - 40,000 cubic meters/yr
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	**3**		number of zones set manually
Unsaturated Zone #1	Hanford Sands		
Thickness	meters	33.5	110 ft; 33.5 m
Density	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.3	Hanford Sands value; WHC-EP-0883, Appendix A
Effective Porosity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Field Capacity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2

Table 3.2. RESRAD Key Input Parameters and Values for Construction Worker. (5 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Unsaturated Zone #2	CCU (silt values; ignored caliche for model)		
Thickness	meters	3.1	10 ft; 3.1 m
Density	grams/cm^3	2.0	CCU (silt) value; WHC-EP-0883, Appendix A
Total Porosity		0.37	CCU (silt) value; WHC-EP-0883, Appendix A
Effective Porosity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Field Capacity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	2740	CCU value = 8.69E-03 cm/sec; 2740 m/yr; WHC-EP-0883, Appendix A
b parameter		5.3	RESRAD value for silty loam from Appendix E; table E.2
Unsaturated Zone #3	Ringold		
Thickness	meters	32.3	106 ft; 32.3 m
Density	grams/cm^3	1.85	Ringold = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.22	Ringold value; WHC-EP-0883, Appendix A
Effective Porosity		0.13	Ringold value; WHC-EP-0883, Appendix A
Field Capacity		0.13	Ringold value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	7300	Ringold = 7300 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2
OCCUPANCY			
Inhalation Rate	m3/yr	600	Assumes 20 m3/day for 30 days/yr
Mass Loading for Inhalation	g/m3	0.0001	*default value*
Exposure duration	years	1	Standard exposure duration for construction workers (EPA 2002)
Indoor Dust Filtration Factor		0	Receptors will spend all of their time outdoors
External gamma shielding factor		greyed out	Not pertinent to soil ingestion, inhalation of particulates, or inhalation of radon routes of exposure
Indoor Time Fraction		0	Receptors will spend all of their time outdoors
Outdoor time fraction		1	Receptors will spend all of their time outdoors
Shape of contaminated zone		circular	*default*

Table 3.2. RESRAD Key Input Parameters and Values for Construction Worker. (5 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
INGESTION - Dietary			
Soil Ingestion	g/yr	9.9	Assumes 0.33 g/day for construction workers (EPA 2002) for 30 days/yr
Household Water		0	Set to zero because receptor is not exposed to household water
INGESTION - NON DIETARY			
Depth of soil mixing layer	m	0.15	*default value*
Groundwater Fractional Usage (balance from surface water) - Drinking Water		0	Set to zero because receptor is not exposed to household water
Radon Data			
Cover Total Porosity		0	Set to zero because cover depth is zero
Cover Volumetric Water Content		0	Set to zero because cover depth is zero
Cover Radon Diffusion Coefficient	m2/sec	0	Set to zero because cover depth is zero
Bldg Foundation Thickness	meters	0	Set to zero because time indoors is zero
Bldg Foundation Density	g/cm3	0	Set to zero because time indoors is zero
Bldg Foundation Total Porosity		0.0001	Set to zero because time indoors is zero
Bldg Foundation Volumetric Water Content		0	Set to zero because time indoors is zero
Bldg Foundation Radon Diffusion Coefficient	m2/sec	0	Set to zero because time indoors is zero
Contaminated Radon Diffusion Coefficient	m2/sec	0.000002	*default value*
Radon Vertical Dimension of Mixing	meters	2	*default value*
Building Air Exchange Rate	1/hr	0	Set to zero because time indoors is zero
Building Room Height	meters	0.001	Set to small number because time indoors is zero
Building Indoor Area Factor		0	Set to zero because time indoors is zero
Foundation Depth Below Ground Surface	meters	-1	*default value*
Ra-222 emanation coefficient		0.25	*default value*
Ra-222 emanation coefficient		0.15	*default value*
Storage Times	**Greyed out**		

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
SOIL CONCENTRATIONS			
Basic Radiation Dose Limit	mrem/yr	25	*default value*
Number of nuclides		varies	Depends on the site
Nuclide (#1)		varies	Depends on the site
Nuclide (#1) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
Nuclide (#2)		varies	Depends on the site
Nuclide (#2) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #2):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	80	Site-specific; well tailings spread over area (p. 21, Rittman 2004)
Thickness of contaminated zone	meters	0.05	Site-specific; layer of contaminated soil surrounding driller (p. 21, Rittman 2004)
Length parallel to aquifer flow	meters	9.1	site-specific information used for all sites (30 ft; or 9.1m)
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value = 1.5*
Cover Erosion Rate	meters/yr	greyed out	*default value =*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0	Set to zero
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)
Irrigation mode (overhead or ditch?)		overhead	*default value*
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	1000000	*default value*

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Accuracy for water/soil computations		0.001	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	1.5	*default value*
Saturated zone total porosity		0.33	Ringold value
Saturated zone effective porosity		0.18	Ringold value
Saturated zone field capacity		0.21	Ringold value
Saturated zone hydraulic conductivity	meters/yr	7300	Ringold value = 7300 m/yr
Saturated zone hydraulic gradient		0.002	Ringold value
Saturated zone b parameter		4.05	RESRAD value for sand from Appendix E
Water table drop rate	meters/yr	0.2	Ringold value
Well pump intake depth	m below water table	10	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	30,000	10-20 gal/min or approx. 20,000 - 40,000 cubic meters/yr
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	**3**		number of zones set manually
Unsaturated Zone #1	Hanford Sands		
Thickness	meters	33.5	110 ft; 33.5 m
Density	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.3	Hanford Sands value; WHC-EP-0883, Appendix A
Effective Porosity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Field Capacity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Unsaturated Zone #2	CCU (silt values; ignored caliche for model)		
Thickness	meters	3.1	10 ft; 3.1 m
Density	grams/cm^3	2.0	CCU (silt) value; WHC-EP-0883, Appendix A
Total Porosity		0.37	CCU (silt) value; WHC-EP-0883, Appendix A
Effective Porosity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Field Capacity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	2740	CCU value = 8.69E-03 cm/sec; 2740 m/yr; WHC-EP-0883, Appendix A
b parameter		5.3	RESRAD value for silty loam from Appendix E; table E.2
Unsaturated Zone #3	Ringold		
Thickness	meters	32.3	106 ft; 32.3 m
Density	grams/cm^3	1.85	Ringold = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.22	Ringold value; WHC-EP-0883, Appendix A
Effective Porosity		0.13	Ringold value; WHC-EP-0883, Appendix A
Field Capacity		0.13	Ringold value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	meters/yr	7300	Ringold = 7300 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E; table E.2
OCCUPANCY			
Inhalation Rate	m3/yr	100	Assumes 20 m3/day for 5 days/yr
Mass Loading for Inhalation	g/m3	3.70E-07	Site-specific based on a PEF of 2.72E+09
Exposure duration	years	1	Standard exposure duration for construction workers (EPA 2002)
Indoor Dust Filtration Factor		0	Receptors will spend all of their time outdoors
External gamma shielding factor		greyed out	Not pertinent to soil ingestion, inhalation of particulates, or inhalation of radon routes of exposure
Indoor Time Fraction		0	Receptors will spend all of their time outdoors
Outdoor time fraction		1	Receptors will spend all of their time outdoors

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Shape of contaminated zone		circular	*default*
INGESTION - Dietary			
Soil Ingestion	g/yr	0.5	Assumes 0.1 g/day for construction workers (EPA 2002) for 5 days/yr
Household Water		0	Set to zero because receptor is not exposed to household water
INGESTION - NON DIETARY			
Depth of soil mixing layer	m	0.15	*default value*
Groundwater Fractional Usage (balance from surface water) - Drinking Water		0	Set to zero because receptor is not exposed to household water
Radon Data			
Cover Total Porosity		0	Set to zero because cover depth is zero
Cover Volumetric Water Content		0	Set to zero because cover depth is zero
Cover Radon Diffusion Coefficient	m2/sec	0	Set to zero because cover depth is zero
Bldg Foundation Thickness	meters	0	Set to zero because time indoors is zero
Bldg Foundation Density	g/cm3	0	Set to zero because time indoors is zero
Bldg Foundation Total Porosity		0.0001	Set to zero because time indoors is zero
Bldg Foundation Volumetric Water Content		0	Set to zero because time indoors is zero
Bldg Foundation Radon Diffusion Coefficient	m2/sec	0	Set to zero because time indoors is zero
Contaminated Radon Diffusion Coefficient	m2/sec	0.000002	*default value*
Radon Vertical Dimension of Mixing	meters	2	*default value*
Building Air Exchange Rate	1/hr	0	Set to zero because time indoors is zero
Building Room Height	meters	0.001	Set to small number because time indoors is zero
Building Indoor Area Factor		0	Set to zero because time indoors is zero
Foundation Depth Below Ground Surface	meters	-1	*default value*
Ra-222 emanation coefficient		0.25	*default value*
Ra-222 emanation coefficient		0.15	*default value*
Storage Times	**Greyed out**		
C-14			**For Site A-8 only**
Concentration in local water	g/cm3	0.00002	*default value*
Concentration in contaminated soil	g/g	0.03	*default value*
Fraction of vegetation in carbon absorbed from soil		0.02	*default value*

Table 3.3. RESRAD Key Input Parameters and Values for Well Driller. (6 sheets)

RESRAD v 6.3; Pathways = soil ingestion, inhalation of particulates, inhalation of radon			
	UNITS	**VALUE**	**COMMENTS**
Fraction of vegetation in carbon absorbed from air		0.98	*default value*
Thickness of evasion layer of C-14 in soil	meters	0.3	*default value*
C-14 evasion flux rate from soil	1/sec	0.0000007	*default value*
C-12 evasion flux rate from soil	1/sec	1.00E-10	*default value*
Grain fraction in livestock feed (balance is hay/fodder)			*default value*
Beef cattle		0.8	*default value*
Milk cow		0.2	*default value*
DCF correction factor for gaseous forms of C-14		123.4	*default value*

Table 3.4. RESRAD Key Input Parameters and Values for Residential Farmer. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
SOIL CONCENTRATIONS			
Basic Radiation Dose Limit	mrem/yr	25	*default value*
Number of nuclides		varies	Depends on the site
Nuclide (#1)		varies	Depends on the site
Nuclide (#1) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
Nuclide (#2)		varies	Depends on the site
Nuclide (#2) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*

Table 3.4. RESRAD Key Input Parameters and Values for Residential Farmer. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	100	Site-specific; size of a garden (p. 25, Rittman 2004)
Thickness of contaminated zone	meters	0.15	Site-specific; tilling depth (p. 25, Rittman 2004)
Length parallel to aquifer flow	meters	greyed out	*default value*
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value*
Cover Erosion Rate	meters/yr	greyed out	*default value*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0	Set to zero
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)

Table 3.4. RESRAD Key Input Parameters and Values for Residential Farmer. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Irrigation mode (overhead or ditch?)		overhead	*default value*
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	greyed out	*default value*
Accuracy for water/soil computations		greyed out	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	greyed out	*default value*
Saturated zone total porosity		greyed out	*default value*
Saturated zone effective porosity		greyed out	*default value*
Saturated zone field capacity		greyed out	*default value*
Saturated zone hydraulic conductivity	meters/yr	greyed out	*default value*
Saturated zone hydraulic gradient		greyed out	*default value*
Saturated zone b parameter		greyed out	*default value*
Water table drop rate	meters/yr	greyed out	*default value*
Well pump intake depth	m below water table	greyed out	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	greyed out	*default value*
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #1	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #2	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #3	Greyed Out		Not pertinent to external radiation route of exposure
OCCUPANCY			
Inhalation Rate	m3/yr	greyed out	Not pertinent to external radiation route of exposure
Mass Loading for Inhalation	g/m3	greyed out	Not pertinent to external radiation route of exposure
Indoor Dust Filtration rate		greyed out	Not pertinent to external radiation route of exposure
Exposure duration	years	30	*default value*
External gamma shielding factor		0.7	*default value*
Indoor Time Fraction		0.5	*default value*

Table 3.4. RESRAD Key Input Parameters and Values for Residential Farmer. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Outdoor time fraction		0.25	*default value*
Shape of contaminated zone		circular	*default*
INGESTION - Dietary	**Greyed out**		
INGESTION - NON DIETARY	**Greyed out**		
Radon	**Greyed out**		
Storage Times	**Greyed out**		
C-14			**For Site A-8 only**
Concentration in local water	g/cm3	0.00002	*default value*
Concentration in contaminated soil	g/g	0.03	*default value*
Fraction of vegetation in carbon absorbed from soil		0.02	*default value*
Fraction of vegetation in carbon absorbed from air		0.98	*default value*
Thickness of evasion layer of C-14 in soil	meters	0.3	*default value*
C-14 evasion flux rate from soil	1/sec	0.0000007	*default value*
C-12 evasion flux rate from soil	1/sec	1.00E-10	*default value*
Grain fraction in livestock feed (balance is hay/fodder)			*default value*
Beef cattle		0.8	*default value*
Milk cow		0.2	*default value*
DCF correction factor for gaseous forms of C-14		123.4	*default value*

Table 3.5. RESRAD Key Input Parameters and Values for Construction Worker. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
SOIL CONCENTRATIONS			
Basic Radiation Dose Limit	mrem/yr	25	*default value*
Number of nuclides		varies	Depends on the site
Nuclide (#1)		varies	Depends on the site
Nuclide (#1) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
Nuclide (#2)		varies	Depends on the site
Nuclide (#2) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*

Table 3.5. RESRAD Key Input Parameters and Values for Construction Worker. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	1811.61 / 2.323 / 1579.35	Site-specific for Z-1A / Z-8 / A-8
Thickness of contaminated zone	meters	28.04 / 5.79 / 18.14	Site-specific for Z-1A / Z-8 / A-8
Length parallel to aquifer flow	meters	greyed out	*default value*
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value*
Cover Erosion Rate	meters/yr	greyed out	*default value*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0.001	*default value*
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)

Table 3.5. RESRAD Key Input Parameters and Values for Construction Worker. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Irrigation mode (overhead or ditch?)		overhead	*default value*
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	greyed out	*default value*
Accuracy for water/soil computations		greyed out	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	greyed out	*default value*
Saturated zone total porosity		greyed out	*default value*
Saturated zone effective porosity		greyed out	*default value*
Saturated zone field capacity		greyed out	*default value*
Saturated zone hydraulic conductivity	meters/yr	greyed out	*default value*
Saturated zone hydraulic gradient		greyed out	*default value*
Saturated zone b parameter		greyed out	*default value*
Water table drop rate	meters/yr	greyed out	*default value*
Well pump intake depth	m below water table	greyed out	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	greyed out	*default value*
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #1	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #2	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #3	Greyed Out		Not pertinent to external radiation route of exposure
OCCUPANCY			
Inhalation Rate	m3/yr	greyed out	Not pertinent to external radiation route of exposure
Mass Loading for Inhalation	g/m3	greyed out	Not pertinent to external radiation route of exposure

Table 3.5. RESRAD Key Input Parameters and Values for Construction Worker. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Indoor Dust Filtration rate		greyed out	Not pertinent to external radiation route of exposure
Exposure duration	years	1	Standard exposure duration for construction workers
External gamma shielding factor		0	Receptors will spend all of their time outdoors
Indoor Time Fraction		0	Receptors will spend all of their time outdoors
Outdoor time fraction		0.027	Used here to decrease exposure to external radiation from constant to 8 hr/day for 30 days/yr (8 hr/24 hours * 30 days/365 days = 0.027)
Shape of contaminated zone		circular	*default*
INGESTION - Dietary	**Greyed out**		
INGESTION - NON DIETARY	**Greyed out**		
Radon	**Greyed out**		
Storage Times	**Greyed out**		

Table 3.6. RESRAD Key Input Parameters and Values for Well Driller. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
SOIL CONCENTRATIONS			
Basic Radiation Dose Limit	mrem/yr	25	*default value*
Number of nuclides		varies	Depends on the site
Nuclide (#1)		varies	Depends on the site
Nuclide (#1) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
Nuclide (#2)		varies	Depends on the site
Nuclide (#2) Concentration	pCi/g		site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----	-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----	-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies	*chemical-specific*
Options:	-----	-----	-----
Water Concentration: Time since material placement	year	0	*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)	*default value*

Table 3.6. RESRAD Key Input Parameters and Values for Well Driller. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Solubility Limit	mol/L	0	*default value*
Leach Rate	/yr	0	*default value*
Use Plant/Soil ratio?	yes/no	no	*default value*
CALCULATION TIMES			
1	years	0	site-specific
2	years	17	site-specific
3	years	28	site-specific
4	years	150	site-specific
5	years	500	site-specific
6	years	1000	site-specific
CONTAMINATED ZONE PARAMETERS			
Area of contaminated zone	square meters	80	Site-specific; well tailings spread over area (p. 21, Rittman 2004)
Thickness of contaminated zone	meters	0.05	Site-specific; layer of contaminated soil surrounding driller (p. 21, Rittman 2004)
Length parallel to aquifer flow	meters	greyed out	*default value*
COVER/HYDROL			**Contaminated Zone = Hanford Sands**
Cover Depth	meters	0	*default value*
Density of cover material	grams/cm^3	greyed out	*default value*
Cover Erosion Rate	meters/yr	greyed out	*default value*
Density of contaminated zone	grams/cm^3	1.85	Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	meters/yr	0	Set to zero
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value
Contaminated zone hydraulic conductivity	meters/yr	1577	Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	grams/cm^3	greyed out	*default value*
Evapotranspiration coefficient		0.5	*default value*
Wind Speed	meters/s	3.4	site-specific
Precipitation	meters/yr	1	*default value*
Irrigation	meters/yr	0	assume for Hanford Sands (default was 0.2)

Table 3.6. RESRAD Key Input Parameters and Values for Well Driller. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Irrigation mode (overhead or ditch?)		overhead	*default value*
Runoff coefficient		0	assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	greyed out	*default value*
Accuracy for water/soil computations		greyed out	*default value*
SATURATED ZONE			**Saturated Zone = Ringold**
Density of saturated zone	grams/cm^3	greyed out	*default value*
Saturated zone total porosity		greyed out	*default value*
Saturated zone effective porosity		greyed out	*default value*
Saturated zone field capacity		greyed out	*default value*
Saturated zone hydraulic conductivity	meters/yr	greyed out	*default value*
Saturated zone hydraulic gradient		greyed out	*default value*
Saturated zone b parameter		greyed out	*default value*
Water table drop rate	meters/yr	greyed out	*default value*
Well pump intake depth	m below water table	greyed out	*default value*
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion	*default value*
Well pumping rate	cubic meters/yr	greyed out	*default value*
UNSATURATED			**Unsaturated Zones = Hanford Sands, CCU, and Ringold**
Number of Unsaturated Zones	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #1	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #2	Greyed Out		Not pertinent to external radiation route of exposure
Unsaturated Zone #3	Greyed Out		Not pertinent to external radiation route of exposure
OCCUPANCY			
Inhalation Rate	m3/yr	greyed out	Not pertinent to external radiation route of exposure
Mass Loading for Inhalation	g/m3	greyed out	Not pertinent to external radiation route of exposure

Table 3.6. RESRAD Key Input Parameters and Values for Well Driller. (4 sheets)

RESRAD v 6.3; Pathway = external radiation			
	UNITS	**VALUE**	**COMMENTS**
Indoor Dust Filtration rate		greyed out	Not pertinent to external radiation route of exposure
Exposure duration	years	1	Standard exposure duration for construction workers
External gamma shielding factor		0	Receptors will spend all of their time outdoors
Indoor Time Fraction		0	Receptors will spend all of their time outdoors
Outdoor time fraction		0.00457	Used here to decrease exposure to external radiation from constant to 8 hr/day for 5 days/yr (8 hr/24 hours * 5 days/365 days = 0.00457)
Shape of contaminated zone		circular	*default*
INGESTION - Dietary	**Greyed out**		
INGESTION - NON DIETARY	**Greyed out**		
Radon	**Greyed out**		
Storage Times	**Greyed out**		
C-14			**For Site A-8 only**
Concentration in local water	g/cm3	0.00002	*default value*
Concentration in contaminated soil	g/g	0.03	*default value*
Fraction of vegetation in carbon absorbed from soil		0.02	*default value*
Fraction of vegetation in carbon absorbed from air		0.98	*default value*
Thickness of evasion layer of C-14 in soil	meters	0.3	*default value*
C-14 evasion flux rate from soil	1/sec	0.0000007	*default value*
C-12 evasion flux rate from soil	1/sec	1.00E-10	*default value*
Grain fraction in livestock feed (balance is hay/fodder)			*default value*
Beef cattle		0.8	*default value*
Milk cow		0.2	*default value*
DCF correction factor for gaseous forms of C-14		123.4	*default value*

Table 3.7. Site-Specific RESRAD Input Parameters for the Soil Sites.

Site Name	Original Site Area (ft)	Radioactive Contamination			Rad Waste Thickness (ft)	Depth to Groundwater (ft bgs)	Reference
		Area (ft)	ft^2 (m^2)	Depth (ft bgs)			
216-Z-1A Tile Field (1)	260 x 75 x 8	260 x 75	19500 (1811.61)	8 - 100	92 (28.04 m)	234 (71 m)	p. 1-12, 1-23, 3-20, 3-56 (DOE/RL-2006-51)
216-Z-8 French Drain (2)	5 x 5 x 16	5 x 5	25 (2.323)	16 - 35	19 (5.79 m)	223 (68 m)	p. 7, 33, 34, 35 (RHO-RE-EV-46 P)
216-Z-9 Trench (3)	120 x 90 x 20	120 x 90	10800 (1003.35)	21 - 120	99 (30.18 m)	223 (68 m)	p. 1-11, 1-22, 3-9, 3-45 (DOE/RL-2006-51)
216-Z-10 Injection Well (4)	3 wells, 175 bgs	No Pu found in area near 231-W-150 reverse well		NA	NA	250 (76.2 m)	p. 29 (Brown and Ruppert 1948)
216-A-8 Crib (5)	850 x 20 x 8.5-11.5	850 x 20	17000 (1579.35)	10.5 - 70	59.5 (18.14 m)	262 (80 m)	p. 1-15, 1-27, 3-39, 3-75 (DOE/RL-2006-51)

(1) Thickness is between 8 to 100 ft bgs which is based on the depth of distribution pipe to where concentrations are at background or below a screening value; available analytical data is from 4.92 to 153.5 ft bgs.
(2) The RI states thickness is between 16 to 35 ft bgs; available analytical data is from 17 to 35 ft bgs.
(3) The concrete cover is 120 x 90 and the base of trench is 60 x 30. In the 70s, 1 ft of soil was removed from trench bottom. Thickness is between 21 to 120 ft bgs based on bottom of trench to where concentrations are at background or below a screening value; available analytical data is from 47.5 to 133 ft bgs.
(4) Z-10 - the 3 soil borings 15 ft from the well did not find plutonium.
(5) In 1990, 2 feet of cover was added to original depth and is included in the thickness. Thickness is between 10.5 to 70 ft bgs based on bottom of crib to where concentrations are at background or below a screening value; available analytical data is from 19 to 264.5 ft bgs.

APPENDIX A

ATTACHMENT 4

DEFAULT EXPOSURE FACTORS

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The following default exposure factors were used in the risk assessment for the 200-ZP-1 Groundwater Operable Unit and the representative soil waste sites. Site-specific exposure factors are discussed in Section A3.3 of the human health risk assessment (Appendix A).

CONSTRUCTION WORKER EXPOSURE FACTORS
(Exposures to Soil)

Body Weight. An adult body weight of 70 kg was used. This is the average body weight for adult men and women combined, rounded to 70 kg (EPA 540/1-89/002).

Inhalation Rate. The recommended construction worker inhalation rate of 20 m^3/day was selected for soil exposure (OSWER Directive 9355.4-24). According to the *Exposure Factors Handbook* (EPA/600/P-95-002Fa), an inhalation rate for adults engaged in light activities is 1 m^3/hr, 1.6 m^3/hr for those engaged in moderate activities, and a rate 2.5 m^3/hr for those engaged in heavy activities outdoors. In a construction scenario, this value of 20 m^3/day equates to an inhalation rate of 2.5 m^3/hr for 8 hr/day, which is likely an over-estimate. For example, while the definitions of heavy activities are somewhat subjective, the *Exposure Factors Handbook* states that representative "heavy" activities include vigorous physical exercise (i.e., fast running) and climbing stairs carrying a load.

Soil Ingestion Rate. An reasonable maximum exposure (RME) soil ingestion rate of 330 milligrams per day (mg/day) for a construction worker was selected as recommended in the *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (OSWER Directive 9355.4-24). This value is the upper-percentile adult ingestion rate from a soil ingestion mass-balance study conducted by Stanek et al. (1997) of adults engaged in routine day-to-day activities over a 4-week period. However, this estimate, as stated by the authors, is highly uncertain due to the small size of the study.

Skin Surface Area. For construction workers, an exposed skin surface area of 3,300 cm^2 was used as recommended in EPA's *Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites* (OSWER Directive 9355.4-24). This corresponds to exposure to head, forearms, and hands.

Adherence Factor. A soil to skin adherence factor of 0.3 mg/cm^2-event was used for the construction worker soil exposure scenario (EPA 2004). This value in EPA's soil screening guidance is based on studies (Kissel et al. 1996, Kissel et al. 1998, and Holmes et al. 1999, as cited in OSWER Directive 9355.4-24) where data suggest that (1) soil properties influence adherence, (2) soil adherence varies considerable across different parts of the body, and (3) soil adherence varies with activity (OSWER Directive 9355.4-24). The adherence factor of 0.3 mg/cm^2 represents the 95th percentile for construction workers.

Averaging Time. For carcinogens, an averaging time of 70 years (equivalent to a lifetime), or 25,550 days, was used (EPA 540/1-89-002). For noncarcinogens, an averaging time equal to the exposure duration (one year, or 365 days, for construction worker) was used (EPA 540/1-89-002).

RESIDENTIAL FARMER EXPOSURE FACTORS
(Exposures to Soil, Tap Water, Irrigation Water, Homegrown Produce, and Livestock)

Adherence Factor. Although children will have a smaller total skin surface area (SA) exposed than adult receptors, they are assumed to have a much higher soil to skin adherence factor (AF). Recent data provide evidence to demonstrate that (1) soil properties influence adherence, (2) soil adherence varies considerably across different parts of the body, and (3) soil adherence varies with activity (Kissel et al. 1996, Kissel et al. 1998, and Holmes et al. 1999, as cited in OSWER Directive 9355.4-24). Because children are assumed to have additional, more sensitive body parts exposed (e.g., feet) and to engage in higher soil contact activities (e.g., playing in wet soil), OSWER Directive 9355.4-24 recommends the use of a body part-weighted AF of 0.2 for children and 0.07 for adults in residential exposure scenarios.

Averaging Time. For carcinogens, an averaging time of 70 years (equivalent to a lifetime), or 25,550 days, was used (EPA 540/1-89-002). For noncarcinogens, an averaging time is equal to the exposure duration multiplied by 365 days, or 2,190 days for children and 8,760 days for adults (EPA 540/1-89-002).

Body Weight. An adult body weight of 70 kg was assumed. This is the average body weight for adult men and women combined, rounded to 70 kg (OSWER Directive 9285.6-03). For children aged 0 to 6 years, an average body weight of 15 kg was assumed (OSWER Directive 9385.6-03).

Exposure Duration. For evaluation of the residential exposures to soil, an exposure duration of 30 years was assumed. This represents the 90th percentile for time spent at one residence (OSWER Directive 9385.6-03). Of the 30 years total exposure duration, ages 0 to 6 years accounts for the period of lowest body weight. A 24-year duration was assessed for older children and adults (OSWER Directive 9385.6-03).

Exposure Frequency. The EPA default residential exposure frequency of 350 days/yr was used (OSWER Directive 9385.6-03). This value assumes that 2 weeks of vacation per year will be spent out of the residence.

Ingestion Rate of Soil. An RME soil ingestion rate of 200 milligrams per day (mg/day) for a child and 100 mg/day for an adult as recommended in the *Supplemental Guidance for Developing Soil Screening Levels* for superfund sites (OSWER Directive 9355.4-24). A number of studies have shown that inadvertent ingestion of soil is common among children age 6 and younger (Calabrese et al. 1989, Davis et al. 1990, and Van Wijnen et al. 1990, as cited in OSWER Directive 9355.4-24). Exposure is higher during childhood and decreases with age (OSWER Directive 9355.4-24).

Ingestion Rate of Water. A groundwater ingestion rate of 1 L/day for children and 2 L/day for adults were selected as recommended by the *Exposure Factors Handbook* (EPA/600/P-95-002Fa). The 2 L/day corresponds to the 84th percentile of the intake rate distribution among adults in the Ershow and Cantor (1989) study.

Inhalation Rate. The mean inhalation rate of 10 m^3/day was selected for children (ages 6 to 8 years) exposure to groundwater (EPA/600/P-95-002Fa). The recommended inhalation rate of 20 m^3/day was selected for adult exposure to groundwater (OSWER Directive 9355.4-24). According to the *Exposure Factors Handbook* (EPA/600/P-95-002Fa), an inhalation rate for adults engaged in light activities is 1 m^3/hr, 1.6 m^3/hr for those engaged in moderate activities, and a rate 2.5 m^3/hr for those engaged in heavy activities outdoors. In a residential scenario, this value of 20 m^3/day equates to an inhalation rate of 2.5 m^3/hr for 8 hr/day, which is likely an over-estimate. For example, while the definitions of heavy activities are somewhat subjective, the *Exposure Factors Handbook* states representative "heavy" activities include vigorous physical exercise (i.e., fast running) and climbing stairs carrying a load.

Skin Surface Area. For residential exposures to tap water, surface area values for children and adults represent the median (50th percentile) values from the *Exposure Factors Handbook* (EPA/600/P-95-002Fa). Children have 6,600 cm^2 and adults have 18,000 cm^2 of exposed total skin surface area (EPA 2004). The residential scenario assumes dermal contact while bathing or showering, thus, total skin surface values are used.

For residential exposures to soil, children are assumed to have 2,800 cm^2 of exposed skin surface area (face, forearms, hands, lower legs, and feet), while adults are assumed to have 5,700 cm^2 exposed (face, forearms, hands, and lower legs [OSWER Directive 9355.4-24]). These SA values represent the median (50th percentile) values for all children and adults (EPA/600/P-95-002Fa).

Volatilization Factor for Water. The volatilization factor is 0.5 L/m^3 for volatile chemicals only. The number was derived by Andelman (1990), as cited in *Supplemental Risk Assessment Guidance for Superfund* (EPA 1991). It is assumed that the transfer efficiency weighted by water use is 50% (i.e., half of the concentration of each chemical in water will be transferred into air by all water uses).

WELL DRILLER EXPOSURE FACTORS
(Exposures to Soil)

Body Weight. An adult body weight of 70 kg was used. This is the average body weight for adult men and women combined, rounded to 70 kg (EPA 540/1-89/002).

Inhalation Rate. The recommended construction worker inhalation rate of 20 m^3/day was selected for well driller exposures to soil (OSWER Directive 9355.4-24). According to the *Exposure Factors Handbook* (EPA/600/P-95-002Fa), an inhalation rate for adults engaged in light activities is 1 m^3/hr, 1.6 m^3/hr for those engaged in moderate activities, and a rate 2.5 m^3/hr for those engaged in heavy activities outdoors. In a construction scenario, this value of 20 m^3/day equates to an inhalation rate of 2.5 m^3/hr for 8 hr/day, which is likely an over-estimate. For example, while the definitions of heavy activities are somewhat subjective, EPA/600/P-95-002Fa) states representative "heavy" activities include vigorous physical exercise (i.e., fast running) and climbing stairs carrying a load.

Soil Ingestion Rate. The EPA default occupational soil ingestion rate of 100 mg/day was used (OSWER Directive 9355.4-24) to evaluate well driller exposures to soil

Skin Surface Area. For well drillers, an exposed skin surface area of 3,300 cm^2 was used as recommended in EPA's *Supplemental Guidance for Developing Soil Screening Levels* for Superfund Sites (OSWER Directive 9355.4-24); this corresponds to exposure to head, forearms, and hands. This is the same default factor recommended for construction worker exposures.

Adherence Factor. A soil adherence factor of 0.2 was assumed for well drillers. This is EPA's default adherence factor for commercial/industrial adult worker (OSWER Directive 9355.4-24, EPA 2004). This value is based on the 50th percentile weighted adherence factors for utility workers (EPA 2004).

Averaging Time. For carcinogens, an averaging time of 70 years (equivalent to a lifetime), or 25,550 days, was used (EPA 540/1-89/002). For noncarcinogens, an averaging time equal to the exposure duration (5 days) was used (EPA 540/1-89/002).

INDUSTRIAL EXPOSURE FACTORS
(Exposures to Tap Water)

Body Weight. An adult body weight of 70 kg was used. This is the average body weight for adult men and women combined, rounded to 70 kg (EPA 540/1-89/002).

Inhalation Rate. An inhalation rate of 1.5 m^3/hr was selected to evaluate industrial worker exposures to tap water. The value corresponds to an inhalation rate for those engaged in moderate activities (EPA/600/P-95-002FA).

Ingestion Rate. The EPA default occupational tap water ingestion rate of 1 L/day was used for the industrial worker scenarios (OSWER Directive 9285.6-03).

Exposure Duration. An industrial worker was conservatively assumed to work for 25 years in the same area; this represents the 95th percentile for length of time that employees work in the same location, according to the Bureau of Labor Statistics (as cited in OSWER Directive 9285.6-03).

Exposure Frequency. The default RME occupational exposure frequency of 250 days/yr was used (OSWER Directive 9285.6-03) for civilian building workers. This is based on a 5-day workweek with 2 weeks of vacation a year.

Averaging Time. For carcinogens, an averaging time of 70 years (equivalent to a lifetime), or 25,550 days, was used (EPA 540/1-89/002). For noncarcinogens, an averaging time equal to the exposure duration (25 years or 9,125 days) was used (EPA 540/1-89/002).

Volatilization Factor for Water. The volatilization factor is 0.5 L/m^3 for volatile chemicals only. The number was derived by Andelman (1990), as cited in EPA (1991). It is assumed that the transfer efficiency weighted by water use is 50% (i.e., half of the concentration of each chemical in water will be transferred into air by all water uses).

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APPENDIX A

ATTACHMENT 5

TOXICITY PROFILES FOR EACH CONTAMINANT OF POTENTIAL CONCERN

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ATTACHMENT 5
TABLE OF CONTENTS

1,2-Dibromo-3-chloropropan
Americium-241
Cadmium
Carbon-14
Carbon tetrachloride
Cesium-137
Chloroform
Chromium (total, hexavalent)
Europium-152
Iodine-129
Manganese
Methylene chloride
Neptunium-237
Nickel-63
Nitrate
Plutonium-238, 239, 240
Protactinium-231
Radium
Strontium-90
Technetium-99
Tetrachloroethylene
Thallium
Thorium
Trichloroethylene
Tritium
Uranium

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1,2-DIBROMO-3-CHLOROPROPANE

1,2-dibromo-3-chloropropane is a manufactured chemical used in combination with other chemicals to create materials that resist burning. It has also been used in the past as a pesticide on farms. This practice was outlawed in the United States in 1979, except Hawaii (1985). 1,2-dibromo-3-chloropropane typically enters the environment via the air or as a surface water spill that quickly evaporates. 1,2-dibromo-3-chloropropane has been shown to persist in the air for several months before it is completely broken down (ATSDR 2006). Exposure to 1,2-dibromo-3-chloropropane by inhalation has been shown to reduce a male's ability to reproduce by lowering sperm counts (ATSDR 2006). Occupational inhalation exposures have been shown to cause headaches, nausea, lightheadedness, and weakness in workers. Studies involving test animals have shown exposure to this chemical can cause nose cancer from inhalation, stomach and kidney cancers from ingestion, as well as stomach and skin cancer from dermal contact (ATSDR 2006). A clear link to human toxicological effects was not made by these studies.

Toxic Effects

Testicular effects for humans are associated with inhalation of 1,2-dibromo-3-chloropropane in occupational settings. No chronic oral RfD for 1,2-dibromo-3-chloropropane in IRIS is available at this time (EPA 2007). The NOAEL RfC for inhalation is 0.94 mg/m^3 (0.1 ppm) (EPA 2007). EPA's provisional chronic oral RfD of 2 x 10^{-4} was used in calculation and obtained from Region 6 HHSLs (EPA 2006). Further studies involving rabbit populations developed a LOAEL that is an order of magnitude higher than the NOAEL (9.4 mg/m^3, or 1 ppm) (EPA 2007). No studies have been issued assessing possible respiratory tract effects of 1,2-dibromo-3-chloropropane exposure. The oral cancer slope factor for 2-dibromo-3-chloropropane is 0.8 per mg/kg-day and the inhalation cancer slope factor is 21 per mg/kg-day (EPA 2006).

Carcinogenicity

The carcinogenicity of 1,2-dibromo-3-chloropropane is not available at this time.

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ATSDR, 2006, *Toxicological Profile for 1,2-Dibromo-3-chloropropane, Update*, dated March 2006, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

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EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

AMERICIUM-241

Americium is a human-made, radioactive element. There are no naturally occurring or stable isotopes of americium. The two major isotopes of americium are americium-241 and americium-243, both of which have the same chemical behaviour in the environment. These two isotopes emit alpha particles and gamma rays to decay into neptunium isotopes, neptunium-237 and neptunium-239, which are also radioactive isotopes. The half-life of americium-241 is 432 years, while the half-life of americium-243 is 7,370 years (ATSDR 2004).

The primary concern for exposure to americium is the risk of exposure to ionizing alpha and gamma radiation. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for americium isotopes. The oral slope factor for americium-241 is 2.17×10^{-10} risk per pCi for soil ingestion, 2.81×10^{-8} risk per pCi for inhalation, and 2.76×10^{-8} risk per pCi for external effects.

Information on adverse human health effects is mainly limited to a single case report of an individual accidentally exposed to high levels of americium that resulted in a significant internal dose. In this case, adverse effects of lymphopenia, thrombocytopenia, and histological signs of bone marrow peritrabecular fibrosis, bone cell depletion, and bone marrow atrophy were noted. These data are supported by findings in laboratory animals exposed to large does of americium in which degenerative changes in bone, liver, kidneys, and thyroid have been observed following ingestion and inhalation exposure. Increases in bone cancer have been observed in animal studies. Information on the dermal absorption of americium in humans or animals is extremely limited. At very high doses of americium, there is an increased risk for gamma radiation to cause dermal and subdermal effects such as erythema, ulceration, or even tissue necrosis. All these adverse effects have been attributed to the ionizing radiation of americium. No non-ionizing radiation effects of americium were identified (ATSDR 2004). In the absence of relevant data, provisional non-cancer risk assessment values based on americium-induced effects that are not attributable to ionizing radiation have not been derived.

References

ATSDR, 2004, *Toxicological Profile for Americium*, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

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CADMIUM

Cadmium is obtained mainly as a by-product during the processing of zinc-bearing ores and also from the refining of lead and copper from sulfide ores. Cadmium is used primarily for the production of nickel-cadmium batteries, in metal plating, and for the production of pigments, plastics, synthetics, and metallic alloys. Cadmium has been shown to be toxic to human populations from occupational inhalation exposure and accidental ingestion of cadmium-contaminated food. Inhalation of cadmium dust in certain occupational settings may be associated with an increased incidence of lung cancer. Ingestion of elevated levels of cadmium has resulted in toxicity to the kidney and skeletal system and may be associated with an elevated incidence of hypertension and cardiovascular disease.

Cadmium is poorly absorbed from the lung, gastrointestinal tract, and skin. Individuals with dietary deficiencies of iron, calcium, or protein exhibit higher absorption of ingested cadmium. The issue of cadmium bioavailability is especially important at mining, milling, and smelting sites because the cadmium at these sites often exists, at least in part, as a poorly soluble sulfide and may also occur in particles of inert or insoluble material. These factors all tend to reduce the bioavailability of cadmium in soil. Cadmium in the body binds readily to certain sulfur-containing proteins, such as metallothionein. Binding to metallothionein is thought to reduce the toxicity of cadmium. Following ingestion, fecal excretion is high due to poor gastrointestinal absorption. Most cadmium that has been absorbed, however, is excreted very slowly, with fecal and urinary excretion being about equal. Urinary cadmium levels are an indicator of body burden.

Toxic Effects

Much of the understanding about cadmium toxicity in humans is based on epidemiological studies of human populations. Humans consuming cadmium-contaminated rice in Japan developed kidney and skeletal system effects. Inhalation of cadmium in occupational settings has also been associated with kidney toxicity. There is conflicting evidence as to whether or not cadmium exposure produces cardiovascular effects or hypertension in humans; factors such as cigarette smoking are confounders in determining the relationship between cadmium exposure and cardiovascular effects. Excessive cadmium ingestion exposure in combination with a low dietary intake of iron may be associated with anemia.

Populations potentially sensitive to cadmium have not been studied systematically; however, it is possible to infer potential sensitivities based on the available data. Individuals with poor nutritional status, particularly in terms of iron and calcium, may absorb more cadmium from the gastrointestinal tract. Individuals with preexisting kidney damage may experience kidney toxicity at cadmium doses lower than the dose that would be toxic for normal individuals.

The EPA recently conducted a toxicological review of cadmium and compounds in support of a proposed revision of the toxicity factors currently listed in IRIS. However, the report is currently undergoing external review and the proposed toxicity factors have not been finalized.

The current EPA recommendation consists of two oral RfDs for cadmium, one for cadmium exposure from food and one for cadmium exposure from water. Both RfDs recognize that a concentration of 200 μg/g (wet weight) in the human kidney cortex is the highest renal level not associated with significant proteinuria. A toxicokinetic model was used by the EPA to determine the level of chronic human oral exposure (NOAEL) that results in the critical concentration of cadmium in the kidney of 200 μg/g; the model assumes that 0.01% of the cadmium body burden is eliminated per day (EPA 1985). Assuming 2.5 percent absorption of cadmium from food or 5% from water, the toxicokinetic model predicts that the NOAEL for chronic cadmium exposure is 0.005 and 0.01 mg/kg-day from water and food, respectively (i.e., the doses corresponding to the 200 μg/g critical kidney concentration). An uncertainty factor of 10 to account for intrahuman variability was applied to these NOAELs to obtain an RfD of 0.0005 mg/kg-day (water) and an RfD of 0.001 mg/kg-day (food) (EPA 2007). No inhalation RfD or RfC is currently listed for cadmium. A dermal RfD of 0.001 mg/kg-day multiplied by 2.5% (0.000025 mg/kg-day) was selected for use in the calculations, as recommended by EPA (EPA 2004). The critical toxic effect proposed for both the oral RfD and inhalation RfC is renal dysfunction, as indicated by minimal proteinuria/enzymuria.

Carcinogenicity

Cadmium is widely thought to be a possible carcinogen via the inhalation route (lung cancer); however there are few studies to evaluate whether ingested cadmium is carcinogenic in humans. Studies in laboratory animals generally do not indicate that cadmium is carcinogenic by ingestion. Inhaled cadmium is carcinogenic to laboratory animals and there is also some human data linking cadmium inhalation and lung cancer; however, epidemiological studies of cadmium-exposed workers have been inconclusive in demonstrating the carcinogenicity of inhaled cadmium. The EPA has classified cadmium as a probable human carcinogen by inhalation (Group B1) based on limited evidence in humans and sufficient evidence in laboratory animals. The EPA's (2007) inhalation slope factor is 6.3 $(mg/kg\text{-}day)^{-1}$ based on human lung, trachea, and bronchus cancer deaths in workplace exposures.

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CARBON-14

A naturally occurring radioactive isotope of carbon, carbon-14 is found at low concentrations in all carbon. Carbon-14 emits beta particles as it decays and has a half-life of 5,700 years (ANL 2007).

The primary concern for exposure to carbon-14 is the risk of exposure to ionizing radiation from beta particles. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for carbon isotope 14. The oral slope factor for carbon-14 is 2.79×10^{-12} risk per pCi for soil ingestion, 7.07×10^{-12} risk per pCi for inhalation, and 7.83×10^{-12} risk per pCi for external effects.

Although the radiation energy of carbon-14 is quite low, this isotope does have the potential to induce cancer through radiation. Since carbon-14 does not emit gamma rays and the beta particle that it does emit cannot penetrate tissue deeply or travel far in air, the primary pathway of concern is ingestion. Once taken into the body, carbon may travel to any organ and has the potential to induce cancer. Carbon is an essential component of living tissue and no non-ionizing radiation effects of carbon-14 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on carbon-induced effects that are not attributable to ionizing radiation have not been derived.

References

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

CARBON TETRACHLORIDE

Carbon tetrachloride is a solvent that has been used in the past as a cleaning fluid or degreasing agent in industrial applications. Although most uses have been discontinued, the possibility still exists for carbon tetrachloride to be released to the environment, primarily through industrial processes. Degradation of carbon tetrachloride occurs slowly in the environment, which contributes to the accumulation of the chemical in the atmosphere as well as the groundwater. Carbon tetrachloride is widely dispersed and persistent in the environment but is not detected frequently in foods.

Because of carbon tetrachloride's widespread use in medical, industrial, and residential applications, there is a reasonable amount of toxicity information available. The principal toxic effects are on the liver, kidneys, and the central nervous system (ATSDR 2005). Studies in animals, combined with limited observations in humans, indicate that the principal adverse health effects associated with inhalation exposure to carbon tetrachloride are central nervous system depression, liver damage, and kidney damage. Case reports in humans and studies in animals indicate that the liver, kidney, and central nervous system are also the primary targets of toxicity following oral exposure to carbon tetrachloride.

A number of well-conducted animal studies indicate that exposure to carbon tetrachloride produces liver tumors; however, data for humans is limited (EPA 2007). Two kinds of processes appear to contribute to the carcinogenicity of carbon tetrachloride (EPA 2005). Genotoxicity, primarily covalent binding to DNA in the liver, results from the direct binding of reactive carbon tetrachloride metabolites or lipid peroxidation products in animals exposed orally or by intraperitoneal injection. There is some evidence that carbon tetrachloride may also cause cancer by a nongenotoxic mechanism involving cellular regeneration (EPA 2005). The U.S. Department of Health and Human Services has determined that carbon tetrachloride may reasonably be anticipated to be a carcinogen. International Agency for Research on Cancer (IARC) has classified carbon tetrachloride in Group 2B, possibly carcinogenic to humans. EPA has determined that carbon tetrachloride is a probable human carcinogen (EPA 2005).

EPA has derived an oral slope factor for carbon tetrachloride of 0.13 $(mg/kg\text{-}day)^{-1}$ based on studies in rats, mice and hamsters that exhibited increased incidence of liver tumors upon higher dose exposures (EPA 2007). The geometric mean of the unit risks derived from four studies was used as the basis for the oral slope factor. According to EPA (2007), all four of the studies used were all deficient in some respect, precluding the choice of any one study as most appropriate. EPA did not assign a confidence level to the derived slope factor. From these studies, EPA (2007) has also derived an inhalation slope factor for this chemical of 0.0525 $(mg/kg\text{-}day)^{-1}$. EPA is currently working to revise the carcinogenicity assessment for carbon tetrachloride (ATSDR 2005).

EPA has established an oral RfD of 0.0007 mg/kg-day. The RfD is based on liver lesions in rats from a subchronic study and EPA has assigned an uncertainty factor of 1,000 to the RfD and listed their confidence in the value as medium. There is no RfC for this chemical; therefore, non-cancer inhalation effects were not evaluated in this assessment.

References

ATSDR,2005, *Toxicological Profile for Carbon Tetrachloride*, dated August 2004, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

CESIUM-137

Cesium is a naturally occurring element that is typically found in rocks, soil, and dust at low concentrations. Natural cesium is present in the environment in only one stable form, cesium-133. The two most important radioactive isotopes of cesium are cesium-134 and cesium-137. Each atom of cesium-137 decays into the stable barium isotope-137, barium-137, by emitting beta particles and gamma radiation (ATSDR 2004). The half-life of cesium-137 is approximately 30 years.

Although inhalation exposure is possible, the most important exposure routes for radioisotopes of cesium are external exposure to the radiation released by the radioisotopes and ingestion of radioactive cesium-contaminated food sources. The primary concern for exposure to cesium is the risk of exposure to ionizing radiation from beta particles and gamma rays. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for cesium-137. The oral slope factor for cesium-137 is 4.33×10^{-11} risk per pCi for soil ingestion, 1.19×10^{-11} risk per pCi for inhalation, and 5.32×10^{-10} risk per pCi for external effects.

Typical signs and symptoms of acute toxicity to cesium-137 are similar to those of exposure to ionizing radiation in general. These symptoms include vomiting, nausea, diarrhea, skin and ocular lesions, neurological signs, chromosomal abnormalities, compromised immune function, and death. Repeated exposures may cause reduced male fertility, abnormal neurological development following exposure during critical stages of fetal development, and genotoxic effects. Long-term cancer studies on exposed individuals have not been completed to date, and no studies were available that specifically address cesium-137 cancer effects on humans. Animal studies, however, indicate an increased risk of cancer from external or internal exposure to relatively high doses of cesium-137 radiation. No non-ionizing radiation effects of cesium were identified (ATSDR 2004). In the absence of relevant data, provisional non-cancer risk assessment values based on cesium-induced effects that are not attributable to ionizing radiation have not been derived.

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ATSDR, 2004, *Toxicological Profile for Cesium.* U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

CHLOROFORM

Chloroform is primarily used to produce the refrigerant chlorodifluoromethane, which is used in home air conditioners and large grocery store freezers. Other past uses of this chemical include its use as a solvent, a medium in fire extinguishers, an intermediate in dyes and pesticides, and as an anesthetic. However, it currently has limited medical uses in dental procedures and medications (ATSDR 1997). Chloroform is also a common disinfection byproduct of chlorinated drinking water. The potential for human exposure is generally through exposure to drinking water via the oral, dermal and inhalation routes (EPA 2006, ATSDR 1997).

The effects of chloroform on human health were observed when inhaled (its use as an anesthetic) and ingested (EPA/635/R-01/001). In addition, several studies have been performed on animals that support the human data (EPA/635/R-01/001). The major effects observed when chloroform was inhaled as an anesthetic include liver, kidney, and central nervous system toxicity (ATSDR 1997, EPA/635/R-01/001). The minor effects noted when chloroform was inhaled as an anesthetic (less than 22,500 ppm), include increase respiratory rates, cardiac hypotension and arrhythmia, and nausea and vomiting (ATSDR 1997). Phoon et al. (1983) reported workers exposed to chloroform concentrations ranging from 14 to 400 ppm for 1 to 6 months developed toxic hepatitis and other effects including jaundice, nausea, and vomiting (ATSDR 1997).

Similar major and minor health effects that occur from inhalation also occur after oral exposure to chloroform but at lower concentrations (less than 2,000 ppm) (EPA/635/R-01/001). Several studies (Piersol et al. 1933, Schroeder 1965, Storms 1973) reported deep coma occurred immediately after intentional or accidental ingestion of 2,410 or 3,755 ppm (ATSDR 1997). ATSDR (1997) reported that the overall human data are insufficient to conclude carcinogenicity from oral consumption. However, several animal studies found oral consumption to be carcinogenic. Chloroform has been shown to cause increased incidence of liver and kidney tumors in several species by several exposure routes (EPA/635/R-01/001).

EPA reports an oral reference dose for chloroform of 0.01 mg/kg-day, based on a study of eight male and eight female dogs that were fed 15 or 30 mg chloroform/kg-day, 6 days/week for 7.5 years. The observed effects were fatty cysts forming on the liver. The reference dose is based on a benchmark dose approach (coincidentally the same value as that obtained using the traditional NOAEL/LOAEL methodology) yielding a BMDL10 (benchmark dose limit associated with a 10% risk) of 1.2 mg/kg-day, an uncertainty factor of 100, and a modifying factor of 1. EPA's overall confidence in the RfD is rated medium based on the sufficiency of animal data; a higher rating is not given due to the limited human data (EPA 2007).

The NCEA has derived a provisional inhalation reference concentration for chloroform of 0.05 mg/m3 (0.014 mg/kg-day) (NCEA 2002). The studies considered in the derivation of the inhalation reference concentration include studies in humans exposed to chloroform in the workplace, as well as inhalation studies of systemic and reproductive effects in animals (NCEA 2002). Effects on liver and kidney have been observed following inhalation exposures in both humans and animals, and these effects are the most sensitive and characteristic indicators of toxicity following oral exposure. For these reasons, toxicity to liver and/or kidney was identified as the most appropriate effects for derivation of inhalation reference concentrations for

chloroform. The critical studies selected for the derivation of the inhalation reference concentration were two subchronic studies in mice that measured histological and labeling index changes in liver and kidney following exposure for 6 hr/day, 5 to 7 days/week, for 90 days. The reference concentration was calculated from the NOAEL (adjusted to the human equivalent concentration) of 4.5 mg/m^3. An uncertainty factor of 100 was assigned, of which a factor of 10 was employed to account for protection of sensitive human subpopulations, a factor of 3 for potential interspecies variability, and a factor of 3 to account for uncertainties in the database. An added uncertainty factor was not used to account for use of a subchronic study since the available data indicate that effects following inhalation exposure are not strongly duration-dependent (NCEA 2002).

According to the IRIS database (EPA 2007), chloroform is classified as a probable human carcinogen (B2) based on increased incidence of tumors in rats, mice, and dogs from ingesting chloroform in food and water. However, as reported in the recent toxicological review of chloroform (EPA/635/R-01/001), under the proposed guidelines for carcinogen risk assessment (EPA 1999), chloroform is likely to be carcinogenic to humans by all routes of exposure under high-dose conditions that lead to cytotoxicity and cell regeneration; and chloroform is not likely to be carcinogenic to humans by any routes of exposure at a dose level that does not cause cytotoxicity and cell regeneration. This weight-of-evidence conclusion indicates that noncarcinogenic effects from exposure to chloroform are the primary concern for human health, while carcinogenicity is secondary. This conclusion is supported by the finding that chloroform is not a strong mutagen and is not likely to cause cancer through a genotoxic mode of action (EPA/635/R-01/001). Thus, an oral slope factor has not been derived for chloroform and exposures that occur at or below the RfD will not result in cancer incidence at levels in excess of target health goals.

The IRIS database (EPA 2007) reports an inhalation unit risk for chloroform of 2.3×10^{-5} $(\mu g/m^3)^{-1}$, which is equivalent to an inhalation slope factor of $0.081(mg/kg\text{-}day)^{-1}$. This inhalation slope factor is based on increased incidence hepatocellular carcinomas in female mice dosed with chloroform by oral gavage. However, EPA cautions the use of this slope factor in the evaluation of the carcinogenicity of chloroform through the inhalation pathway, because this value was derived in 1987 and does not incorporate newer data or the proposed guidelines for carcinogen risk assessment (EPA 1999). EPA is currently working to revise the assessment for inhalation exposure.

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EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

NCEA, 2002, *Risk Assessment Issue Paper for Derivation of Provisional Subchronic and Chronic RfCs for Chloroform*, SRC TR 02-085/1-22-03, National Center for Environmental Assessment, Washington, D.C.

CHROMIUM (TOTAL, HEXAVALENT)

Chromium is a naturally occurring element found in rocks, soil, plants, animals, and in volcanic dust and gases. The most common environmental forms are chromium (0), chromium (III), and chromium (VI). Chromium (0), the metal chromium, is a gray solid and has a high melting point. This form is primarily used to make steel and other alloys. Chromium (III) is used to line high-temperature industrial furnaces. Chromium-containing compounds are used in many industrial processes, such as, stainless steel welding, chrome plating, and leather tanning (ATSDR 2002).

Chromium (III) is considered an essential nutrient that helps to maintain normal metabolism of glucose, cholesterol, and fat in humans. The minimum human daily requirement of chromium for optimal health is not known, but a daily ingestion of 50 to 200 μg/day (0.0007 to 0.003 mg/kg bw/day) has been estimated to be safe and adequate. The long-term effects of eating diets low in chromium are difficult to evaluate (ATSDR 2002).

The three major forms differ in their effects on health. Chromium (VI) is irritating, and short-term, high-level exposure can result in adverse effects at the site of contact, such as ulcers of the skin, irritation of the nasal mucosa and perforation of the nasal septum, and irritation of the gastrointestinal tract. Chromium (VI) may also cause adverse effects in the kidney and liver. Chromium (III) does not result in these effects and is the form that is an essential food nutrient when ingested in small amounts, although very large doses may be harmful. For example, ingesting large amounts can cause stomach upset and ulcers, convulsions, kidney and liver damage. Very limited data suggest that chromium (III) may have respiratory effects on humans. No data on chronic or subchronic effects of inhaled chromium (III) in animals can be found. Adequate reproductive and developmental toxicity data do not exist. Information on chromium (0) health effects is limited. Animal studies have found that inhalation exposure had increased frequencies of chromosomal aberrations and sister chromatid exchanges in peripheral lymphocytes (ATSDR 2002).

The oral RfD for chromium (III) is 1.5 mg/kg-day based on a chronic rat feeding study and a NOAEL of 1,468 mg/kg-day. The uncertainty factor of 100 represents two 10-fold decreases in mg/kg bw-day dose that account for both the expected interhuman and interspecies variability to the toxicity of the chemical in lieu of specific data. An additional 10-fold modifying factor is applied to reflect database deficiencies. The overall confidence in this RfD assessment was rated low because of the lack of explicit detail on study protocol and results, the lack of high-dose supporting data, and the lack of an observed effect level. Thus, the RfD as given should be considered conservative (EPA 2007).

Data are considered to be inadequate for development of an inhalation RfD for chromium (III) due to the lack of a relevant toxicity study addressing respiratory effects of chromium (III) (EPA 2007). Data from animal studies have identified the respiratory tract as the primary target of chromium toxicity following inhalation of hexavalent chromium and these data have been used for development of an RfC for hexavalent chromium particulates. However, these data do not demonstrate that the effects observed following inhalation of hexavalent chromium particulates are relevant to inhalation of trivalent chromium, and these data are considered to be inappropriate for development of an RfC for trivalent chromium (EPA 2007).

The oral RfD for chromium (VI) is 0.003 mg/kg-day based on a one-year rat drinking water study and a NOAEL of 2.5 mg/kg-day. The uncertainty factor is 300. A factor of 10 each accounts for inter- and intra-species variability. An additional uncertainty factor of 3 was applied to compensate for the less-than-lifetime exposure duration of the principal study. A modifying factor of 3 was also applied to account for concerns raised by other studies. The overall confidence in this RfD assessment was rated low because of the lack of explicit detail on study protocol and results, the lack of high-dose supporting data, and the lack of an observed effect level. Thus, the RfD as given should be considered conservative (EPA 2006).

EPA (2007) has also derived an inhalation RfD for chromium (VI) of 2.9×10^{-5} mg/kg-day. This value is based on a subchronic rat study that showed increase incidences of adverse affects on lung function. The inhalation RfD was calculated using the benchmark dose approach. An uncertainty factor of 300 was applied to the benchmark dose to account for pharmacodynamic differences, less-than-lifetime exposure, and variation in the human population.

The oral toxicity factor is adjusted to characterize risk from the dermal exposure pathway. This adjustment is made to estimate the absorbed dose from the toxicity indices that are based on administered dose. The percent gastrointestinal absorption for chromium (VI) is 2.5% of the oral reference dose as recommended in the supplemental guidance for dermal risk assessment, resulting in a dermal RfD of 0.000075 mg/kg/day (EPA/540/R/99/005).

Of the three forms of chromium of toxicological importance, chromium (VI) is the most toxic. Chromium (VI) is classified by the EPA as a Group A, human carcinogen by inhalation, based on evidence that indicates sufficient cancer data in both animals and humans. Several epidemiological studies found an association between chromium exposure and lung cancer. The inhalation cancer SF for total chromium (one-sixth ratio of chromium [VI]:chromium [III]) is 42 $(\text{mg/kg-day})^{-1}$ and is based on benign and malignant stomach tumor data in female mice (EPA 2007). The inhalation SF for chromium (VI) was derived by multiplying the total chromium value by 7, yielding a inhalation slope factor of 209 $(\text{mg/kg-day})^{-1}$. This SF was used in this HHRA for assessing inhalation exposures to chromium at the site.

References

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EUROPIUM-152

Europium is a silvery-white metal found in ores including bastnasite, monazite, and xenotime. Present in the earth's crust at about 1.8 mg/kg, europium occurs as two stable isotopes and 14 major radioactive isotopes. One of these radioactive isotopes is europium-152, which has a half-life of 13 years (ANL 2007). This isotope emits beta particles and gamma rays as it decays.

The primary concern for exposure to europium-152 is the risk of exposure to ionizing radiation from beta particles and gamma rays. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for europium-152. The oral slope factor for europium-152 is 1.62×10^{-11} risk per pCi for soil ingestion, 9.10×10^{-11} risk per pCi for inhalation, and 5.30×10^{-6} risk per pCi for external effects.

Once absorbed into the bloodstream, europium preferentially deposits in the liver, on the bone surface, and in the kidneys. External and internal exposures can increase the likelihood of liver and bone cancer. No non-ionizing radiation effects of europium-152 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on europium-induced effects that are not attributable to ionizing radiation have not been derived.

References

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

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IODINE-129

Iodine is a naturally occurring element primarily found as iodine-127, its most stable form. Iodine-129 is one of two radioactive isotopes that form naturally in the upper atmosphere (EPA 2002). Iodine-129 and iodine-131 are emitted as beta and gamma radiation during iodine's decay process. Iodine-129 can be found in wastes from nuclear power facilities and defense-related government facilities (EPA 2002, ANL 2005). Both iodine nuclide forms have also been produced during nuclear weapons testing. However, the amount of anthropogenic iodine-129 is still less than naturally occurring levels. Of the two types, iodine-129 is the form with a long enough half-life to warrant long-term concern. The radiation and half-life information for iodine-129 and iodine-131 are presented in the table below. Iodine-129 has a half-life of 16 million years compared to approximately 8 days for iodine-131(ANL 2005).

Isotope	Half-Life	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha (α)	Beta (β)	Gamma (γ)
I-129	16 million yr	0.00018	β	-	0.064	0.025
I-131	8.0 days	130,000	β	-	0.19	0.38

Note: Values from (ANL 2005).

Iodine is a basic component of the human diet and is taken into the human body through all exposure pathways. Historically a significant pathway for iodine-129 and iodine-131 ingestion has been the consumption of fruits and vegetables or milk from an iodine-contaminated area. Incidents such as Chernobyl can expose populations in the fallout area to high concentrations of both types of iodine as well as long-term exposure to iodine-129 through all pathways. Following ingestion and inhalation iodine is readily absorbed by the bloodstream from both the gastrointestinal tract and lungs. Approximately 30% of iodine in the human body ends up in the thyroid gland where it is used in hormone production (ANL 2005). The primary radiological concern related to iodine-129 is the risk associated with exposure to beta radiation, which varies based on the dose of iodine isotopes (EPA 2002). As a result the main health concerns from iodine-129 and iodine-131 radiation are the development of thyroid tumors. In addition, the uptake of radioactive iodine by the thyroid gland is inversely related to the amount of stable iodine available (EPA 2002). As a result, exposures to accidental releases of iodine isotopes are often treated by the ingestion of large doses of stable iodine. Stable iodine has its own health effects related to large doses that must also be considered in this treatment.

Iodine-129 is a Group A radionuclide, which are classified by the EPA as known human carcinogens. The lifetime cancer mortality risk coefficients for iodine-129 are presented in the table. Epidemiological studies for iodine-129 have shown children to be the group most susceptible to thyroid cancer. Cancer treatment from radioactive iodine exposure must be evaluated on a case-by-case basis. Treatment concerns center around the use of radiation to treat tumors caused by radioactive isotopes. Treatments are typically only initiated when the benefits outweigh the risks.

Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for iodine-129. The slope factors for iodine-129 is 3.2×10^{-10} risk per pCi for food ingestion, 1.5×10^{-10} risk per pCi for water ingestion, 6.1×10^{-11} risk per pCi for inhalation, and 6.1×10^{-9} risk per pCi for external effects (EPA 2001).

References

ANL, 2005, *Human Health Fact Sheet, August 2005*, online database accessed in April 2007, http://www.ead.anl.gov/index.cfm, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington.

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MANGANESE

Manganese is an essential element in human nutrition, serving as a cofactor in several enzymatic reactions. When ingested, manganese is considered to be among the least toxic of the trace elements. The adverse health effects from manganese are principally associated with inhalation exposure in the workplace. Acute inhalation exposure can produce irritation of the respiratory tract. Chronic inhalation exposure can produce a central nervous system disorder resembling Parkinsonism, known as manganism (ATSDR 2000).

Toxic Effects

Daily intake of manganese ranges from 2 to 9 mg/day. Manganese is poorly absorbed following oral exposure, and reports of human intoxication following ingestion exposures are not common. However, some studies suggest that neurological effects may be associated with the consumption of drinking water with elevated levels of manganese (ATSDR 2000).

Several studies have shown that inhalation of manganese in occupational settings is associated with neurological effects. The principal signs of manganism include tremors, weakness in the legs, staggering gait, behavioral disorders, slurred speech, and a fixed facial expression. There is no evidence indicating that inhalation exposure to manganese is carcinogenic in humans; however, there is some evidence of male reproductive effects (ATSDR 2000).

Development of the oral RfD for manganese recognizes that disease states in humans have been associated with both deficiencies and excessive intakes of manganese. The oral RfD for manganese is set at 10 mg/day (0.14 mg/kg-day) and is based on the upper end of the normal dietary intake rate. This value is considered a NOAEL for dietary intake and has not been adjusted by an uncertainty factor. The EPA emphasizes that individual requirements for, as well as adverse reactions to, manganese may be highly variable. The RfD is estimated to be an intake for the general population that is not associated with adverse health effects; this is not meant to imply that intakes above the RfD are necessarily associated with toxicity (EPA 2007).

The oral RfD for manganese was evaluated further in other media (drinking water or soil) based on an epidemiological study of manganese in drinking water (EPA 2007). Whereas the results from this study do not allow a quantitative evaluation of dose response, they raise concerns about possible adverse neurological effects at doses not far from the range of essentially. For assessing exposure to manganese from drinking water or soil, EPA (1999) recommends adjustment by an uncertainty factor of 3, yielding an oral RfD of 0.024 mg/kg-day. Four reasons are provided for the use of an uncertainty factor to adjust the oral RfD for soil and water exposure: (1) in fasted individuals, there may be increased uptake of manganese from water; (2) the study raises some concern regarding possible adverse health effects associated with a lifetime consumption of drinking water with manganese concentration of about 2 mg/L; (3) because infant formula typically has a much higher concentration of manganese than that of human milk, manganese in the water could represent an additional source of intake for infants; and (4) neonates may absorb more manganese from the gastrointestinal tract and may be less able to excrete absorbed manganese, and absorbed manganese may more easily cross their blood-brain barrier.

For this risk assessment, the nonfood oral RfD of 0.07 mg/kg-day was used to evaluate the ingestion of manganese in soil (EPA 1999). For dermal exposures to the chemical in soil, the oral RfD was adjusted by a factor of 4% as recommended by EPA (EPA/540/R/99/005, Exhibit 4-1). This adjustment results in a dermal RfD of 0.0028 mg/kg-day.

The inhalation RfD of 0.000014 mg/kg-day for manganese (EPA 2007) suggest that inhaled manganese may be much more toxic than ingested manganese. Differences in absorption between the two routes cannot alone account for this large difference. The EPA reports that after absorption into blood via the respiratory tract, manganese is transported through the blood stream directly to the brain, bypassing the initial clearance effects of the liver. They state that this pathway from the respiratory tract to the brain is the primary reason for the differential toxicity between inhaled and ingested manganese. In addition, recent studies in animals have shown that manganese has a unique ability among metals to be taken up in the brain via olfactory pathways (Tjalve and Henriksson 1997). This process involves direct diffusion of manganese from the nasal cavity to the central nervous system without entering blood, therefore bypassing both the initial clearance effects of the liver and the blood-brain barrier (Tjalve and Henriksson 1997). This direct pathway to the central nervous system might account in part for the higher toxicity of inhaled manganese.

Carcinogenicity

Although ingestion exposure studies suggest that manganese may be weakly carcinogenic in laboratory animals, these data are inadequate to support a classification as carcinogenic by the EPA. The EPA has categorized manganese as Group D, not classifiable with regard to human carcinogenicity (EPA 2007).

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METHYLENE CHLORIDE

Methylene chloride, also known as dichloromethane, is a colorless liquid that has a mild sweet odor, evaporates easily, and does not easily burn. The odor threshold for methylene chloride in air is approximately 200 ppm. Methylene chloride is primarily used as an industrial solvent and paint stripper. It can be found in certain aerosol and pesticide products and is used in the manufacture of photographic film. The chemical may be found in some spray paints, automotive cleaners, and other household products. Methylene chloride does not appear to occur naturally in the environment. Most of the methylene chloride released to the environment results from its use as an end product by various industries and the use of aerosol products and paint removers in the home (ATSDR 2000).

In humans, acute inhalation exposure to methylene chloride at concentrations of 300 ppm or greater is known to impair hearing and vision (Winneke 1974). Exposure to 800 ppm or greater methylene chloride can slow reaction times, impair motor skills, and cause dizziness, nausea, and drunkenness (Stewart et al. 1972, Winneke 1974). Dermal exposure to methylene chloride causes intense burning and mild redness of the skin. Methylene chloride has not been shown to cause cancer in humans with chronic inhalation exposures to vapors in the workplace. In animals, inhalation of methylene chloride has been shown to adversely affect the liver and kidneys of rats (Stewart et al 1974), and the corneas of rabbits (Ballantyne et al. 1976).

EPA has established an oral reference dose (RfD) for methylene chloride of 0.06 mg/kg-day, based on a study reporting histological alterations of the liver in rats exposed to 50, 125, and 250 mg/kg-day methylene chloride for 2 years (NCA 1982). The oral RfD was calculated by applying an uncertainty factor of 100 (to account for interspecies extrapolation and intraspecies extrapolation to protect sensitive human populations) and a modifying factor of 1 to the reported NOAEL of 5.85 mg/kg-day. Although the study used to derive the RfD was given a high confidence rating, the overall confidence in the RfD is rated medium because only a few studies support the NOAEL (EPA 2007).

EPA has established an inhalation reference concentration (RfC) for methylene chloride of 3.0 mg/m^3, based on a 2-year chronic exposure study reporting hepatic toxicity in rats exposed to methylene chloride (Nitschke et al. 1988). The inhalation RfC was calculated by applying an uncertainty factor of 100 (to account for interspecies extrapolation and intraspecies extrapolation to protect sensitive individuals) to the reported NOAEL of 694.8 mg/m^3.

EPA has classified methylene chloride as a probable human carcinogen (Group B2) based on increased incidence of tumors in several organs of rats and mice, including the liver (NCA 1982, 1983), lung (NTP 1986), mammary and salivary glands (Burek et al. 1984, NTP 1986), and blood (NTP 1986). This classification is supported by some positive genotoxicity data, although results in mammalian systems are generally negative. The oral SF for methylene chloride (calculated using data from the NCA and NTP studies) is 0.0075 (mg/kg-day)-1. The inhalation SF for methylene chloride (calculated using data from the NTP study) is 4.7E-07 $(\mu g/cm^3)^{-1}$.

References

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NEPTUNIUM-237

Roughly twice as dense as lead, neptunium is an artificially-produced metal created through neutron capture reactions by uranium. All 17 known isotopes are radioactive. Neptunium-237 has a half-live of 2.1 million years and releases alpha, beta, and gamma radiation as it decays (ANL 2007).

The primary concern for exposure to neptunium-237 is the risk of exposure to ionizing alpha, beta, and gamma radiation. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for neptunium-237. The oral slope factor for neptunium-237 is 1.46×10^{-10} risk per pCi for soil ingestion, 1.77×10^{-8} risk per pCi for inhalation, and 5.36×10^{-8} risk per pCi for external effects (EPA 2001).

Neptunium entering the bloodstream tends to be deposited in the skeleton but is also preferentially deposited in the liver and other soft tissues. Cancer may result from ionizing radiation emitted by neptunium deposits on the bone surfaces, liver, and soft tissues. The external risk posed by neptunium is predominantly due to its gamma radiation emissions and the radiation released by its short-lived decay product, protactinium-233. No non-ionizing radiation effects of neptunium were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on neptunium-induced effects that are not attributable to ionizing radiation have not been derived.

References

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NICKEL-63

Usually found in combination with other elements, nickel is a naturally occurring metal in the earth's crust. Nickel is found in soil and emitted from volcanoes, comprises 6% of the earth's core, and is the 24th most abundant element. Nickel occurs in five stable isotopes: nickel-58, nickel-60, nickel-61, nickel-62, and nickel-64. Nickel-63 is one of six major radioactive isotopes. Nickel-63 has a half-life of 96 years and decays by emitting a beta particle (ANL 2007).

The primary concern for exposure to nickel-63 is the risk of exposure to ionizing radiation from beta particles. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for nickel-63. The oral slope factor for nickel-63 is 1.79×10^{-12} risk per pCi for soil ingestion, 1.64×10^{-12} risk per pCi for inhalation, and 0 risk per pCi for external effects.

Of nickel that is absorbed into the bloodstream, about 2% remains in the kidneys and 30% is distributed to all remaining tissues (ANL 2007). The remainder is excreted. Nickel can also be absorbed by and retained in the skin. Nickel also may produce nonradiological chemical effects in the 10% to 15% of the population that has nickel sensitivity (ANL 2007). These chemical effects may include skin allergies and asthma attacks. Acute toxicity from nickel dust exposure may adversely affect the gastrointestinal system, blood, and kidneys. Chronic exposure to airborne nickel dust may cause bronchitis, reduced lung function, and cancer of the lung and nasal sinus.

References

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NITRATE

Nitrate (NO_3^-) and nitrite (NO_2^-) are part of the naturally occurring nitrogen cycle. Microbial activity in soil or water breaks down wastes that contain organic nitrogen into ammonia which are later oxidized to nitrate and nitrite. Nitrogen containing compounds are generally soluble in soil and quickly enter the groundwater. Nitrite is then readily oxidized to its more toxic form (nitrate). Nitrate is naturally occurring in groundwater and surface waters. However, these levels can be raised significant by contamination with nitrogen-containing fertilizers (including animal or human natural organic wastes or anhydrous ammonia). The use of shallow groundwater wells in the United States means that many people have the potential to consume drinking water contaminated by nitrates. Nitrates are also naturally occurring in various foods including meats, vegetables, and prepared foods (e.g., sausages).

A condition known as blue baby syndrome which leads to bluish lips and sometimes death affects infants less than three months old (ATSDR 2001). This condition is often caused by formula that has been diluted with water from a water source with high nitrate levels. Since infants often have a higher gut pH, it enhances the conversion of ingested nitrate to the more toxic nitrite. It has been shown that the incidence of gastroenteritis with vomiting and diarrhea can exacerbate nitrite formation.

The toxicity associated with nitrate is the result of its conversion to nitrite. Nitrite in the bloodstream oxidizes the iron in hemoglobin from Fe(+2) to Fe(+3) resulting in methemoglobin (ATSDR 2001). Methoglobin leads to reduced oxygen transport from the lungs to tissues because it does not bind with oxygen. It is not uncommon for individuals to have low levels of methemoglobin from 0.5% to 2.0% because blood has a large capacity to carry oxygen (ATSDR 2001). As a result even levels under 10% are not associated with any significant clinical signs (ATSDR 2001). Concentrations that exceed 10% can lead to cyanosis (a bluish color to skin and lips), and concentrations that exceed 25% can lead to weakness, rapid pulse and tachypnea (ATSDR 2001). Methoglobin levels that exceed 50% to 60% may lead to death.

The NOAEL oral RfD of 1.6 mg/kg/day for nitrate was derived based on two studies in the 1950s, which determined that infantile methemoglobinemia only occurs at concentrations in water greater than 10 mg nitrate-nitrogen/L (EPA 2007). The typical daily intake of an adult in the United States is about 75 mg/day (about 0.2 to 0.3 mg nitrate- nitrogen/kg/day) (ATSDR 2001). The assigned uncertainty factor for nitrate is 1 because of the NOAEL value for humans is based on the most sensitive case (EPA 2007).

A RfC for chronic inhalation exposure is not available at this time

Carcinogenicity

The carcinogenicity of nitrate is not available at this time.

References

ATSDR, 2001, *Case Studies in Environmental Medicine Nitrate/Nitrite Toxicity*, dated January 2001, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

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PLUTONIUM-238, -239, AND -240

Plutonium is a radioactive metal that is produced when uranium absorbs an atomic particle. Small amounts of plutonium occur naturally, but large amounts have been produced in nuclear reactors. All plutonium isotopes are radioactive, and three common plutonium isotopes are plutonium-238, -239, and -240. Alpha, beta, and gamma radiation are released as plutonium decays (ATSDR 1990, ANL 2007). The half-lives of plutonium-238, plutonium-239, and plutonium-240 are 86 years, 24,000 years, and 6,500 years, respectively.

The primary concern for exposure to plutonium is the risk of exposure to ionizing alpha, beta, and gamma radiation. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for plutonium isotopes 238, 239, and 240. The oral slope factors for plutonium-238, plutonium-239, and plutonium-240 are $2.72 \times 10\text{-}^{10}$, 2.76×10^{-10}, and 2.77×10^{-10} risk per pCi. For inhalation, the slope factors for plutonium-238, plutonium-239, and plutonium-240 are 3.36×10^{-8}, 3.33×10^{-8}, and 3.33×10^{-8} risk per pCi, respectively. For external effects, slope factors for these isotopes are 7.22×10^{-11}, 2.00×10^{-10}, and 6.98×10^{-11} risk per pCi, respectively.

Although plutonium has not definitively been shown to cause adverse health effects in people, animal studies have reported increased lung, liver, and bone cancers as well as adverse effects on the blood and immune system from plutonium exposure. Animal studies have also found lung diseases from short-term exposure to high concentrations of plutonium. No non-ionizing radiation effects of plutonium were identified (ATSDR 1990). In the absence of relevant data, provisional non-cancer risk assessment values based on plutonium-induced effects that are not attributable to ionizing radiation have not been derived.

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PROTACTINIUM-231

One of the rarest naturally occurring elements, protactinium is present in uranium ores at a concentration of 1 part protactinium to 3 million parts uranium (ANL 2007). All three of its naturally occurring isotopes (protactinium-231, protactinium-234, and protactinium-234m) are radioactive. Of the three, protactinium-231 is the most common and with a half-life of 33,000 years, it has the longest half-life. Protactinium-231 is a decay product of uranium-235. Protactinium-231 emits alpha, beta, and gamma radiation as it decays to actinium-227. Much of the human health hazard associated with protactinium-231 is attributable to actinium-227. Actinium-227 has a half-life of 22 years and decays by emitting an alpha or beta particle.

The primary concern for exposure to protactinium is the risk of exposure to ionizing alpha, beta, and gamma radiation. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for protactinium isotope 231. The oral slope factor for protactinium-231 is 3.74×10^{-10} risk per pCi for soil ingestion, 4.55×10^{-8} risk per pCi for inhalation, and 1.39×10^{-7} risk per pCi for external effects (EPA 2001).

Protactinium causes the most concern for human health through internal exposures when it is ingested or inhaled. Once in the bloodstream, protactinium preferentially deposits in the skeleton with lesser amounts depositing in the liver and kidneys (ANL 2007). There is a small external risk associated with the gamma rays emitted by protactinium-231. Cancer may be induced from ionizing radiation emitted by protactinium deposited in the skeleton, liver, and kidneys. No non-ionizing radiation effects of protactinium-231 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on protactinium-induced effects that are not attributable to ionizing radiation have not been derived.

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RADIUM

Radium is an alkaline earth metal that has 25 isotopes with atomic weights ranging from 206 to 230; all of the radium isotopes are radioactive. The four naturally occurring radium isotopes are radium-223, radium-224, radium-226, and radium-228. Radium-223 and radium-224 are alpha emitters with relatively short half-lives of 11.4 and 3.6 days, respectively (ATSDR 1990). Radium-226 is also an alpha emitter but has a very long half-life (1,600 years). Radium-228 is a beta emitter with a half-life of 5.7 years.

The primary concern for exposure to radium is the risk of exposure to ionizing radiation from alpha or beta particles. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for radium isotopes. The oral slope factors for radium-223, radium-224, radium-226, and radium-228 are 2.34×10^{-10}, 1.49×10^{-10}, $2.95 \times 10\text{-}^{10}$, and 2.46×10^{-10} risk per pCi, respectively, and the inhalation slope factors are 3.60×10^{-9}, 2.25×10^{-9}, 2.72×10^{-9}, and 9.61×10^{-10} risk per pCi, respectively (EPA 2001).

A number of adverse effects (including death, anemia, leukemia, and osteosarcomas) were observed in humans and animals following oral, inhalation, and/or dermal exposure to radium isotopes. These effects have been attributed to the ionizing radiation. No studies examining non-ionizing radiation effects of radium were identified (ATSDR 1990, EPA 1988). In the absence of relevant data, provisional non-cancer and cancer risk assessment values based on radium-induced effects that are not attributable to ionizing radiation have not been derived.

References

ATSDR, 1990, *Toxicological Profile for Radium*, TP-90-22, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 1988, *Health Effects Assessment for Radium (226Ra, 228Ra, 224Ra)*, U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office, Cincinnati, Ohio.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

STRONTIUM-90

Strontium is a naturally occurring common element that is usually found in nature in the form of strontium-84, strontium-86, strontium-87, and strontium-88. The most common radioactive isotope, strontium-90, does not occur naturally and is found in spent fuel rods in nuclear reactors. Strontium-90 gives off beta particles and decays into yttrium-90, which is also radioactive (ATSDR 2004). Strontium-90 has a half-life of 29 years.

The primary concern for exposure to strontium is the risk of exposure to ionizing radiation from beta particles. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for strontium-90. The oral slope factor for strontium-90 is 9.18×10^{-11} risk per pCi for soil ingestion, 1.05×10^{-10} risk per pCi for inhalation, and 4.82×10^{-10} risk per pCi for external effects (EPA 2001).

A number of adverse effects (including leukemia and cancers of the bone, nose, lung, and skin) were observed in humans and animals following oral, inhalation, and/or dermal exposure to radioactive strontium isotopes. Oral exposure to absorbed radioactive strontium led to necrotic lesions, cancers of the bone and adjacent tissues, acute radiation syndrome, steosacroma, and immunosuppression. Inhalation of soluble particles tends to create effects similar to ingested doses. In animal studies, inhalation exposures of insoluble particles led to pneumonitis, necrosis of the pulmonary, vascular, and adjacent myocardial tissues, pulmonary fibrosis, and pulmonary and vascular cancers. Bone marrow effects are the most serious immediate consequences of exposure to high levels of radioactive strontium either by inhalation or oral route. If strontium-90 incorporates into the bone, irradiation of the bone marrow results in hypoplasia of the hemopoietic tissue and pancytopenia. At high doses, external doses of beta radiation can cause adverse effects such as erythema, ulceration, or tissue necrosis. All of these adverse effects have been attributed to the ionizing radiation. No studies examining non-ionizing radiation effects of strontium-90 were identified (ATSDR 2004). In the absence of relevant data, provisional non-cancer and cancer risk assessment values based on strontium-induced effects that are not attributable to ionizing radiation have not been derived.

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ATSDR, 2004, *Toxicological Profile for Strontium*, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TECHNETIUM-99

Essentially all of technetium found on earth is present as a result of human action. All isotopes of this silver-gray metal are radioactive and of its ten major isotopes, only three are long-lived. The most important of these isotopes is technetium-99 with a half-life of 213,000 years. This isotope decays to the stable isotope ruthenium-99 by emitting a beta particle. With its long half-life, the radiation produced by this isotope is someone of less concern than other radioactive materials.

The primary concern for exposure to technetium is the risk of exposure to ionizing radiation from beta particles. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for technetium-99. The oral slope factor for technetium-99 is 7.66×10^{-12} risk per pCi for soil ingestion, 1.41×10^{-11} risk per pCi for inhalation, and 8.14×10^{-11} risk per pCi for external effects (EPA 2001).

Technetium pertechnetate (TcO4) is well-absorbed by the intestines and lungs following ingestion or inhalation. After reaching the bloodstream, technetium pertechnetate preferentially deposits in the thyroid, stomach wall, and the liver (ANL 2007). Specific target organs for technetium deposits vary depending on the chemical form of technetium. With no associated gamma radiation, technetium poses little external hard. No non-ionizing radiation effects of technetium-99 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on technetium-induced effects that are not attributable to ionizing radiation have not been derived.

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ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TETRACHLOROETHYLENE

Tetrachloroethylene (PCE) is a synthetic chlorinated hydrocarbon used as an industrial solvent and degreaser. It is also extensively used in the dry cleaning and textile industries and as an intermediate in the manufacture of other chemicals (ATSDR 1997). Chronic inhalation exposure of mice and rats to concentration of PCE resulted in liver cell carcinomas in male and female mice, an increased incidence of mononuclear cell leukemia in male and female rats, and an increase of renal tubular cell tumors in male rats (ATSDR 1997).

The SFs for PCE are not available on the IRIS database though they are reported in the risk assessment issue paper for carcinogenicity information for tetrachloroethylene (NCEA in EPA 1998) and in EPA Region 6's HHSL tables (EPA 2006). The oral SF as listed was 0.54 $(mg/kg\text{-}d)^{-1}$ and the inhalation SF was 0.021 $(mg/kg\text{-}d)^{-1}$ for PCE.

The chronic oral RfD of 1.0×10^{-2} mg/kg-day for PCE was derived based on a 6-week gavage study in mice that resulted in liver toxicity (EPA 1998). The assigned uncertainty factor of 1,000 for PCE accounts for intraspecies variability and extrapolation of a subchronic effect level to its chronic equivalent. The RfD confidence level is considered medium (EPA 1998). The inhalation RfD of 0.114 mg/kg-day used in the risk assessment was reported in the EPA Region 6 HHSL tables (EPA 2006).

References

ATSDR, 1997, *Toxicological Profile for Tetrachloroethylene*, dated September 1997, U.S, Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 1998, *National Center for Environmental Assessment (NCEA) Risk Assessment Issue Papers on PCE and TCE*, dated November 1998, U.S. Environmental Protection Agency, Superfund Technical Support Center, Washington, D.C.

EPA, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*, dated December 14, 2006, U.S. Environmental Protection Agency, Dallas, Texas.

THALLIUM

Thallium is one of the more toxic metals. At varying concentrations, thallium affects the neurological, hepatic, and renal systems. Temporary hair loss and decreased visual abilities have occurred in the occupational setting after ingestion of thallium. Chronic effects from ingestion in humans have been reported (as case studies) to produce gastrointestinal effects, liver, and kidney damage, although the kidney evidence is weak (ATSDR 1992).

Toxic Effects

The oral RfD of 6.6×10^{-5} mg/kg-day for thallium and compounds is reported by EPA (2006). An IRIS record is available for thallium sulfate (EPA 2007). This compound was used by EPA (2006) to derive RfDs for thallium compounds. The RfD reported in IRIS for thallium sulfate is 8×10^{-5} mg/kg-day and is based on NOAEL from a 90-day study in rats by EPA (1986). The IRIS record notes that no histopathological effects were observed nor were there any differences between control and experimental groups in body weight, weight gain, food consumption, or absolute and relative organ weights. Dose-related increases were reported for alopecia (hair loss), lacrimation (tearing), and exophthalmos (bulging of eyes). Possible subtle changes in blood chemistry were also reported including increased enzyme levels of serum glutamic oxaloacetic transaminase (SGOT) and lactate dehydrogenase (LDH), increased sodium, and decreased glucose (EPA 1986). Not all changes were significantly different from controls for both sexes. EPA (1986) also concluded that liver function was probably not affected because of lack of changes in serum glutamic pyruvic transaminase (SGPT) levels, and none of the blood chemistry changes observed significantly affected the health of the animals. In addition, differences in blood chemistry parameters were greatest between treated animals receiving thallium sulfate and non-treated controls. Differences between animals receiving thallium sulfate and vehicle controls receiving water were more subtle.

The uncertainty factor is relatively high (3,000) and likely incorporates factors of 10 to account for interspecies conversion, extrapolation from a subchronic study, variation in individual sensitivity, and an additional modifying factor of 1. The chronic RfD was withdrawn from the IRIS database and is currently under review by the EPA. ATSDR (1992) reports general lack of animal and human data by all routes of exposure for thallium.

Carcinogenicity

Thallium is listed as a Class D carcinogen (EPA 2003). The basis for the classification is a lack of carcinogenicity data available for either human or animals. The two human studies reviewed by the EPA were judged inadequate to determine carcinogenic effects because one study had no exposure quantification data, a small sample size, and an unknown length of observation period, and the other study's evaluation of exposure did not include a measure of carcinogenic response.

References

ATSDR, 1992, *Toxicological Profile for Thallium*, dated July 1992, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2006, *U.S. EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*, dated December 14, 2006, U.S. Environmental Protection Agency, Dallas, Texas.

EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

THORIUM

Thorium is a metallic element in the actinide series; the atomic weight of the 12 thorium isotopes range from 223 to 234; all of the isotopes are radioactive. The predominant thorium isotope found in the environment is thorium-232; this isotope makes up 99.99% of the naturally occurring thorium. The other two thorium isotopes found in the environment are thorium-228 and thorium-230. Thorium-232, -228, and -230 are alpha emitters with half-lives of 1.4×10^{10} years, 1.91 years, and 7.54×10^{4} years, respectively.

The primary concern for exposure to thorium is the risk of exposure to ionizing radiation from alpha particles. Ionizing radiation has been shown to be a human carcinogen and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slopes factors have been derived for thorium isotopes. The oral slope factors for thorium-228, thorium-230, and thorium-232 are 6.29×10^{-11}, 3.75×10^{-11}, and 3.28×10^{-11} risk per pCi, respectively and the inhalation slope factors are 9.45×10^{-8}, 1.72×10^{-8}, and $1.93\times \times 10^{-8}$ risk per pCi, respectively (EPA 2001).

Most of the available data on the toxicity and carcinogenicity of thorium in humans are derived from individuals exposed to thorotrast (colloidal thorium-232 dioxide) administered intravenously as a radiological contrast medium. The most common adverse effects associated with Thorotrast exposure are cirrhosis of the liver, hepatic tumors, and blood dyscrasias; these effects have been attributed to the alpha radiation (ATSDR 1990). Respiratory effects and increased incidences of pancreatic, lung, and hematopoietic cancers have been reported in humans and animals following inhalation exposure to thorium (ATSDR 1990); these effects have also been attributed to alpha radiation. No non-ionizing radiation effects of thorium were identified (ATSDR 1990). In the absence of relevant data, provisional non-cancer and cancer risk assessment values were not derived for thorium-induced effects not attributable to ionizing radiation.

References

ATSDR, 1990, *Toxicological Profile for Thorium*, TP-90-25, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TRICHLOROETHYLENE

Trichloroethylene (TCE) has been in commercial production for more than 75 years in the United States. TCE has been extensively used for degreasing of fabricated metal parts, in dry cleaning, and as a solvent for oils, resins, waxes, paints, lacquers, printing inks, fabric dyes, disinfectants, and as an intermediate in the manufacture of other chemicals.

The EPA recently evaluated health risks from exposure to TCE in a document titled *Trichloroethylene Health Risk Assessment: Synthesis and Characterization* (EPA/600/P-01/002A). This document is an external review draft to which EPA is soliciting comments and its findings are subject to change; however, its findings are used in this report as the latest available information for TCE.

Previous investigations had suggested that TCE's cancer classification be on a B2 to C continuum, indicating that there was some evidence for its carcinogenicity in animals and no evidence in humans. However, EPA's recent review of the literature recommended that TCE be considered "highly likely" to produce cancer in humans and has proposed that TCE be classified as a B1 carcinogen – a probable human carcinogen with sufficient evidence in animals and limited evidence in humans. The reasons for the increased certainty in the chemical's ability to cause cancer in humans are due to new epidemiological evidence and new information on the ways in which TCE could be inducing cancer (modes of action). The information on TCE carcinogenicity is complex and consistent responses are not seen across species. The metabolism of TCE is also complex and various metabolites are likely involved in the carcinogenic process. In addition, humans are exposed to TCE metabolites from other sources than just TCE and some researchers consider that background exposures to these metabolites may affect a person's response to TCE. There is also some evidence that the human population could have subpopulations that are particularly sensitive to TCE because of (1) genetic predisposition, (2) environmental factors such as the consumption of alcohol, and (3) age (i.e., children may be more sensitive than adults).

Five types of cancer in humans are potentially linked with TCE exposure: liver, kidney, lymph-hematopoietic, cervical, and prostate. Given the complexity of the cancer data, several studies with liver, kidney, and lymphoma cancer data (for which there is supporting animal information) were used to derive a range of slope factors from 0.02 $(mg/kg\text{-}day)^{-1}$ to 0.4 $(mg/kg\text{-}day)^{-1}$. The EPA considers that these slope factors represent "a middle range of risk estimates where confidence is greatest." The lower end of this range, 0.02 $(mg/kg\text{-}day)^{-1}$ is based on the incidence of kidney cancer in German cardboard workers exposed to TCE in the workplace, while the higher end is based on the incidence of non-Hodgkin's lymphoma in females exposed to TCE in their drinking water.

The external review draft also evaluated the non-cancer effects associated with TCE exposures. An inhalation RfD of 0.011 mg/kg-day was derived from five studies (four in humans, one in rodents) based on effects in the central nervous system, liver, and endocrine system (EPA/600/P-01/002A). The EPA has selected an uncertainty factor of 1,000 for this RfD to account for subchronic to chronic extrapolation, interspecies variability and intraspecies variability.

EPA recommends an oral RfD of 0.0003 mg/kg-day based on CNS, liver and endocrine effects in a subchronic mouse study. NCEA used EPA's maximum uncertainty factor of 3,000 to adjust the study NOAEL to an oral RfD, by NCEA considered the data sufficiently equivocal that even an uncertainty factor of 5,000 might be appropriate (EPA/600/P-01/002A).

The U.S. Department of Defense (DOD) has published a critique of EPA's proposed slope factor range for TCE (AFIERA 2001). In particular they note that the upper end of the proposed recommended range, 0.4 $(mg/kg\text{-}day)^{-1}$, is based on a residential drinking water study where the confidence interval around the calculated relative risk included one. The relative risk is defined as the cancer incidence rate in the exposed population relative to an unexposed population. If the relative risk is one, then cancer incidence rates are equal for the exposed and unexposed populations and the study cannot conclude that there is an increased association between cancer and site exposures relative to an unexposed population. Generally, if the confidence interval around the relative risk includes one, then cancer incidence rates for the two populations (exposed and unexposed) are not significantly different. Therefore, the DOD review concluded that there was insufficient evidence to conclude that TCE exposures in drinking water were associated with an increase in non-Hodgkins lymphoma and thus, no slope factor should be calculated based on that study. Only one study had non-Hodgkins lymphoma associated with TCE exposure.

The DOD review also criticized the study on which the low end of EPA's proposed slope factor range was based, an inhalation study where TCE exposures were associated with an increase in kidney cancer. They noted that that particular study has been highly criticized in the open literature, and concluded that without that study, the remaining data do not confirm an increased relative risk of kidney cancer from TCE exposure (AFIERA 2001).

Because of the uncertainty surrounding the new proposed slope factor range, and because of the criticisms the health assessment document has received, currently the oral and inhalation slope factors derived by the California EPA (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) for are generally being recommended for use in risk assessment. The slope factors derived by OEHHA are an inhalation slope factor of 0.0007 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA (2002) and an oral slope factor of 0.013 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA (1999).

References

AFIERA, 2001, *Critique of the U.S. Environmental Protection Agency's Draft Trichloroethylene Health Risk Assessment (EPA/600/P-01/002A)*, dated December 2001, Air Force Institute for Environment, Safety and Occupational Health Risk Analysis, Brooks Air Force Base, Texas.

EPA/600/P-01/002A, 2001, *Trichloroethylene Health Risk Assessment: Synthesis and Characterization*, External Review Draft, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D,C.

OEHHA, 1999, *Public Health Goal for Trichloroethylene in Drinking Water*, dated February 1999, California Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Sacramento, California.

OEHHA, 2002, *Air Toxics Hot Spots Program Risk Assessment Guidelines. Part II: Technical Support Document for Describing Available Cancer Potency Factors*, dated December 2002, California Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Sacramento, California.

TRITIUM

Tritium (H-3) is the only radioactive isotope of hydrogen. The most common forms are tritium gas and tritium oxide or "tritiated water." Tritium has a high specific activity and is produced both naturally and artificially. Tritium emits low energy beta particles as it decays and has a half-life of 12 years (ANL 2007).

The primary concern for tritium exposure is only if it ingested (especially in the form of tritiated water) because it cannot penetrate deeply into tissue or travel far in air. Once ingested, tritium may cause cell damage and lead to cancer. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for tritium. The slope factor s for tritium are 5.1×10^{-14} risk per pCi for water ingestion, 1.4×10^{-13} risk per pCi for food ingestion, 2.2×10^{-13} risk per pCi for soil ingestion, 5.6×10^{-14} risk per pCi for vapor inhalation, and 2×10^{-13} risk per pCi for particulate inhalation (EPA 2001).

References

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Assessment Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

URANIUM

Uranium is an actinide element that occurs naturally as one of three radioactive isotopes: uranium-238, uranium-235, and uranium-234. All three natural uranium isotopes decay by alpha particle emission. The term "natural uranium" refers to uranium that has a uranium isotopic composition reflecting the natural abundance of uranium-238, uranium-235, and uranium-234, as presented in the table below. This distinguishes natural uranium from other anthropogenic uranium isotope mixtures. The term "enriched uranium" refers to isotope mixtures that contain a higher percentage of the fissionable isotope, uranium-235 (and also uranium-234, a byproduct of the enrichment process), and a lower percentage of uranium-238 than natural uranium. Enriched uranium is produced as fuel for reactors and nuclear fission weapons. Other isotopes of uranium are produced by humans in controlled or uncontrolled (explosive) nuclear reactions (e.g., isotopes uranium-227 through uranium-240).

Natural Abundances and Radioactive Half-Lives of Uranium Isotopes

Uranium Isotope	Natural Abundance	Radioactive Half-Life (years)
^{238}U	99.27%	4.46×10^{9}
^{235}U	0.72%	7.04×10^{8}
^{234}U	0.0055%	2.45×10^{5}

Note: Values from (EPA/600/P-95-002FA).

The primary radiological concern related to uranium is the risk associated with exposure to ionizing radiation, which will vary with the dose of uranium, the isotopic form, and other factors that affect uranium bioavailability, tissue distribution, and retention. Ionizing radiation has been shown to be a carcinogen in humans, and EPA classifies all radionuclides as Group A carcinogens (EPA 1997). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for the naturally-occurring isotopes of uranium (EPA 1997). Natural uranium has a relatively low radioactivity (less than 1 μCi/g) compared to enriched uranium, which has a higher abundance of the more highly radioactive isotopes uranium-235 and uranium-234 and can have a radioactivity that is approximately 100 times that of natural uranium. Therefore, the radiological hazard of enriched uranium can be considerably greater than that of natural uranium.

Uranium occurs naturally predominantly in valence states +4 and +6, although valence states +2, +3, and +5 can also occur naturally or be produced by humans (EPA 1988). Uranium compounds vary widely in their water solubility. Uranium oxides are practically soluble in water while salts of tetravalent (+4) and hexavalent (+6) uranium can be highly water soluble(Gindler 1973). Differences in water solubility and other chemical properties can be expected to give rise to differences in bioavailability and dose-response relationships when intakes occur through either the inhalation or oral routes (EPA 1988).

Non-cancer (RfD and RfC) and cancer risk values for natural uranium are not listed on IRIS (EPA 1998a) or in HEAST(EPA 1997). Based on the NOAEL of 0.2 mg U/kg-day (Gilman et al. 1998a 1998b, and 1998c), a provisional chronic oral RfD of 2×10^{-4} mg/kg-day was estimated by (Superfund Technical Support Center 2001). A chronic oral RfD of 3×10^{-3} mg U/kg-day for soluble uranium salts is on IRIS (EPA 2007).

The EPA developed a health effects assessment for natural uranium (EPA 1988) and drinking water standards for uranium (EPA 2000). The ATSDR (1997) derived a chronic-duration inhalation minimum risk level (MRL) for uranium of 1.0×10^{-3} mg U/m^3 and an intermediate-duration oral MRL of 1.0×10^{-3} mg U/kg-day.

Derivation of a Provisional Oral RfD for Soluble Uranium Salts

Non-cancer (RfD and RfC) and cancer risk values for natural uranium are not listed on IRIS or in HEAST (EPA 2007, 1997, 2001). A chronic oral RfD of 3×10^{-3} mg U/kg-day for soluble uranium salts is on IRIS (EPA 2007). The available data on the inhalation toxicology of natural uranium compounds do not provide an adequate basis for deriving inhalation RfCs (EPA 2007). The most substantial gap in the data are the lack of chronic inhalation studies of adequate quality that examine the respiratory tract as well as other suspected target organs such as the kidney. Based on chronic studies of natural uranium dioxide, it is possible that chronic exposures to 5 mg U/m^3 may have yielded either a chemical and/or radiological dose to the lung that was sufficient to induce injury to the respiratory tract.

Derivation of Provisional Cancer Risk Values for Inhalation of Soluble Uranium Salts

An increase risk of lung cancer has been observed in populations of uranium miners and uranium processing workers. However, this excess risk is thought to result, at least in part, if not primarily, from radiological exposures. Data are not adequate to assess the nonradiological carcinogenicity of natural uranium. The EPA classifies all radionuclides, including uranium, as Group A carcinogens (EPA 1997). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for the naturally occurring isotopes of uranium.

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APPENDIX A

ATTACHMENT 6

GROUNDWATER AND SOIL RISK CALCULATIONS

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ATTACHMENT 6
TABLE OF CONTENTS

RESIDENTIAL FARMER EXPOSURES TO GROUNDWATER – Nonradionuclides

Table 1 Residential Ingestion of Groundwater
Table 2 Residential Inhalation of Vapor
Table 3a Residential Intermediate Dermal Spreadsheet
Table 3b Residential Dermal Contact with Groundwater
Table 4 Agricultural Inhalation of Vapor
Table 5a Agricultural Intermediate Dermal Spreadsheet
Table 5b Agricultural Dermal Contact with Irrigation Water
Table 6 Ingestion of Plant Tissue (from Irrigation Water)
Table 7 Ingestion of Plant Tissue (from Garden Soil)
Table 8 Ingestion of Beef Tissue
Table 9 Ingestion of Dairy Products
Table 10 Summary of Cancer Risks from Residential Farmer Exposures to Groundwater
Table 11 Summary of Non-Cancer Hazards from Residential Farmer Exposures to Groundwater

RESIDENTIAL FARMER EXPOSURES TO GROUNDWATER –Radionuclides

Table 12 Residential Ingestion of Groundwater
Table 13 Residential Inhalation of Vapor (Tap Water)
Table 14 Residential Inhalation of Vapor (Irrigation Water)
Table 15 Ingestion of Plant Tissue (from Irrigation Water)
Table 16 Ingestion of Beef Tissue
Table 17 Ingestion of Dairy Products
Table 18 Summary of Cancer Risks from Residential Farmer Exposures to Groundwater

INDUSTRIAL EXPOSURES TO GROUNDWATER – Nonradionuclides

Table 19 Industrial Ingestion of Groundwater
Table 20 Industrial Inhalation of Vapor
Table 21 Summary of Cancer Risks from Industrial Worker Exposures to Groundwater
Table 22 Summary of Non-Cancer Hazards from Industrial Worker Exposures to Groundwater

INDUSTRIAL EXPOSURES TO GROUNDWATER –Radionuclides

Table 23 Industrial Ingestion of Groundwater
Table 24 Industrial Inhalation of Vapor
Table 25 Summary of Cancer Risks from Industrial Exposures to Groundwater

216-Z-9 TRENCH - RESIDENTIAL EXPOSURES TO SOIL

Table 26 Residential Ingestion of Soil
Table 27 Residential Dermal Contact with Soil
Table 28 Residential Inhalation of Fugitive Dust or Volatiles from Soil

216-Z-9 TRENCH - WELL DRILLER EXPOSURES TO SOIL

Table 29 Well Driller Incidental Ingestion of Soil
Table 30 Well Driller Dermal Contact with Soil
Table 31 Well Driller Inhalation of Fugitive Dust or Volatiles from Soil

216-A-8 CRIB - RESIDENTIAL EXPOSURES TO SOIL

Table 32 Residential Ingestion of Soil
Table 33 Residential Dermal Contact with Soil
Table 34 Residential Inhalation of Fugitive Dust or Volatiles from Soil

Residential Farmer Exposures to Groundwater – Nonradionuclides

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Table 1. Residential Exposures (Nonradioactive Chemicals).

Ingestion of Groundwater

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Children and Adults

Non-Cancer Hazard = CW x SIFnc / RfD
Cancer Risk = CW x SIFc x CSF

Parameter	Unit	RME Child	RME Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific	chem-specific
Ingestion Rate of Water (IR)	L/day	1	2
Exposure frequency (EF)	days/yr	350	350
Exposure duration (ED)	years	6	24
Body weight (BW)	kg	15	70
Conversion Factor (CF)	mg/ug	1.00E-03	1.00E-03
Averaging time (non-cancer) (ATnc)	days	2,190	8,760
Averaging time (cancer) (ATc)	days	25550	25550
SIFnc = (IR*EF*ED*CF)/(BW*ATnc)	L-mg/ug-kg-d	6.39E-05	2.74E-05
IngFadj (Ingestion Adjusted Factor) = (IRch*EDch/BWch)+ (IRa*EDa/BWa)	L-year/hr-kg	1.09	1.09
SIFc = (IngFadj*EF*CF)/ATc	L-mg/ug-kg-d	1.49E-05	1.49E-05

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.00E-04	1.30E-01
Chloroform	1.00E-02	--
Chromium III	1.50E+00	--
Chromium VI (groundwater)	3.00E-03	--
Methylene Chloride	6.00E-02	7.50E-03
Nitrate	1.60E+00	--
PCE	1.00E-02	5.40E-01
TCE	3.00E-04	1.30E-02
Uranium	3.00E-03	--

Total Inorganics Chemical	90th Percentile CW (ug/L)	Intake$_{nc}$ child (mg/kg-d)	Intake$_{nc}$ adult (mg/kg-d)	Intake$_{c}$ lifetime (mg/kg-d)	HQ child	HQ adult	Cancer Risk lifetime
Carbon Tetrachloride	2900.00	1.85E-01	7.95E-02	4.31E-02	264.840	113.503	5.6E-03
Chloroform	24.00	1.53E-03	6.58E-04	3.57E-04	0.153	0.066	--
Total Chromium	130.00	8.31E-03	3.56E-03	1.93E-03	0.006	0.002	--
Chromium VI	203.40	1.30E-02	5.57E-03	3.03E-03	4.334	1.858	--
Methylene Chloride	2.73	1.75E-04	7.49E-05	4.07E-05	0.003	0.001	3.0E-07
Nitrate	81050.00	5.18E+00	2.22E+00	1.21E+00	3.238	1.388	--
PCE	2.50	1.60E-04	6.85E-05	3.72E-05	0.016	0.007	2.0E-05
TCE	10.90	6.97E-04	2.99E-04	1.62E-04	2.323	0.995	2.1E-06
Uranium	5.06	3.23E-04	1.39E-04	7.53E-05	0.108	0.046	--
Total					**275**	**118**	**5.6E-03**

Table 2. Residential Exposures (Nonradioactive Chemicals).

Inhalation of Vapor

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Children and Adults

Non-Cancer Hazard = CA x SIFnc x VFw / RfD
Cancer Risk = CA x SIFc x VFw x CSF

Parameter	Unit	RME Child	RME Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific	chem-specific
Inhalation Rate (InhR)	m3/day	10	20
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	6	24
Body Weight (BW)	kg	15	70
Conversion Factor (CF)	mg/ug	1.0E-03	1.0E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	8,760
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc = (InhR*EF*ED*CF)/(BW*ATnc)	m^3-mg/ug-kg-day	6.39E-04	2.74E-04
InhFadj (Inhalation Adjusted Factor) = (InhRch*EDch/BWch) + (InhRa*EDa/BWa)	m^3-yr/hr-kg	1.09E+01	1.09E+01
SIFc = (InhFadj*EF*CF)/ATc	m^3-mg/ug-kg-day	1.49E-04	1.49E-04

Chemical	RfDi (mg/kg-d)	CSFi (mg/kg-d)-1	VFw[a] (L/m3)
Carbon Tetrachloride	--	5.3E-02	5.0E-01
Chloroform	1.3E-02	8.1E-02	5.0E-01
Chromium III	--	--	--
Chromium VI (groundwater)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	5.0E-01
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	5.0E-01
TCE	1.1E-02	7.0E-04	5.0E-01
Uranium	--	--	--

[a] A volitilazation factor (VFw) of 0.5 is only applicable for volatile chemicals.

Dissolved Inorganics Chemical	90th Percentile CW (ug/L)	$Intake_{nc}$ child (mg/kg-d)	$Intake_{nc}$ adult (mg/kg-d)	$Intake_c$ lifetime (mg/kg-d)	HQ child	HQ adult	Cancer Risk lifetime
Carbon Tetrachloride	2900.00	9.27E-01	3.97E-01	2.16E-01	--	--	1.1E-02
Chloroform	24.00	7.67E-03	3.29E-03	1.78E-03	0.59	0.25	1.4E-04
Total Chromium	130.00	--	--	--	--	--	--
Chromium VI	203.40	--	--	--	--	--	--
Methylene Chloride	2.73	8.74E-04	3.75E-04	2.03E-04	0.0010	0.00044	3.3E-07
Nitrate	81050.00	--	--	--	--	--	--
PCE	2.50	7.99E-04	3.42E-04	1.86E-04	0.0073	0.0031	3.9E-06
TCE	10.90	3.48E-03	1.49E-03	8.11E-04	0.32	0.14	5.7E-07
Uranium	5.06	--	--	--	--	--	--
Total					**0.92**	**0.39**	**1.2E-02**

Table 3a. Residential Exposures (Nonradioactive Chemicals).

Intermediate Dermal Spreadsheet

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Children and Adults

Exposure Parameters		Units
Fraction absorbed	FA	unitless
Dermal permeability coefficient	PC	cm/hr
Concentration in surface water	CW	mg/m3
Lag time per event	T event	hour/event
Time to reach steady state	t*	hours
Event duration	t event	hour/event
Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis	B	unitless
Absorbed dose per event	DA event	mg/cm2-event

Formulas Used to Calculate Absorbed Dose per Event (DAevent):

ORGANIC CHEMICALS:

If $t_{event} \leq t^*$, then $DA_{event} = 2\ FA \times PC \times Cw\ (6 \times T_{event} \times t_{event}/Pi)^{0.5}$

If $t_{event} > t^*$, then $DA_{event} = FA \times PC \times Cw\ [(t_{event}/1 + B) + (2 \times Tau_{event}) \times (1 + 3B + 3B^2/(1 + B)^2]$

INORGANIC CHEMICALS:

$DA_{event} = PC \times Cw \times t_{event}$

Chemical	FA	PC	Cw	T_{event}	t*	t_{event} hr/event		Pi	B	Daevent mg/cm2-event	
	unitless	cm/hr	mg/cm^3	hr/event	hours	Adult	Child	unitless	unitless	Adult	Child
Carbon Tetrachloride	1	1.60E-02	2.90E-03	0.78	1.86	0.17	0.33	3.14	0.1	4.67E-05	6.51E-05
Chloroform	1	6.80E-03	2.40E-05	0.5	1.19	0.17	0.33	3.14	0	1.32E-07	1.83E-07
Total Chromium	--	0.001	1.30E-04	--	--	0.17	0.33	3.14	--	2.21E-08	4.29E-08
Chromium VI	--	2.00E-03	2.03E-04	--	--	0.17	0.33	3.14	--	6.92E-08	1.34E-07
Methylene Chloride	1	3.50E-03	2.73E-06	0.32	0.76	0.17	0.33	3.14	0	6.17E-09	8.60E-09
Nitrate	--	--	8.11E-02	--	--	0.17	0.33	3.14	--	--	--
PCE	1	3.30E-02	2.50E-06	0.91	2.18	0.17	0.33	3.14	0.2	8.97E-08	1.25E-07
TCE	1	1.20E-02	1.09E-05	0.58	1.39	0.17	0.33	3.14	0.1	1.14E-07	1.58E-07
Uranium	--	2.00E-03	5.06E-06	--	--	0.17	0.33	3.14	--	1.72E-09	3.34E-09

Table 3b. Residential Exposures (Nonradioactive Chemicals).

Dermal Contact with Groundwater
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Children and Adults

Non-Cancer HQ =DAevent x SIFnc / RfD
Cancer Risk = DAevent x SIFc x CSF

Parameter	Units	RME Adult	RME Child
Absorbed dose per event (DAevent)	(mg/cm2-event)	chem-specific	chem-specific
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	24	6
Event Frequency (EV)	events/day	1	1
Surface Area Available for Contact (SA)	cm^2	18,000	6,600
Body Weight (BW)	days	70	15
Averaging Time (non-cancer) (ATnc)	days	8,760	2,190
Averaging Time (cancer) (ATc)		25,550	25,550
SIFnc(child) = ((EF*EDc*SAc)/(BWc*ATnc-c))	ev-cm2/kg-d	2.47E+02	4.22E+02
DFadj (Dermal Adjusted Factor) = (EDc*EFc*EVc*SAc/BWc)+(EDa*EFa*EVa*SAa/BWa)	ev-cm2/kg	3.08E+06	
SIFc(child/adult) = DFadj/ATc	ev-cm2/kg-d	1.21E+02	

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	2.0E-02	--
Chromium VI (groundwater)	7.5E-05	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	--	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	90th Percentile DA event (mg/cm2-event) child	DA event (mg/cm2-event) adult	$Intake_{nc}$ child (mg/kg-d)	$Intake_{nc}$ adult (mg/kg-d)	$Intake_{c}$ child/adult (mg/kg-d)	HQ child	HQ adult	Risk child/adult
Carbon Tetrachloride	6.51E-05	4.67E-05	2.75E-02	1.15E-02	5.64E-03	39	16	7.33E-04
Chloroform	1.83E-07	1.32E-07	7.73E-05	3.24E-05	1.59E-05	0.0077	0.0032	--
Total Chromium	4.29E-08	2.21E-08	1.81E-05	5.45E-06	2.67E-06	0.00093	0.00028	--
Chromium VI	1.34E-07	6.92E-08	5.66399E-05	1.71E-05	8.35E-06	0.76	0.23	--
Methylene Chloride	8.60E-09	6.17E-09	3.63E-06	1.52E-06	7.45E-07	0.000060	0.000025	5.59E-09
Nitrate	--	--	--	--	--	--	--	--
PCE	1.25E-07	8.97E-08	5.27E-05	2.21E-05	1.08E-05	0.0053	0.0022	5.85E-06
TCE	1.58E-07	1.14E-07	6.67E-05	2.80E-05	1.37E-05	0.22	0.09	1.78E-07
Uranium	3.34E-09	1.72E-09	1.41E-06	4.24E-07	2.08E-07	0.00047	0.00014	--
Total						40	17	7.4E-04

Table 4. Agricultural Exposures (Nonradioactive Chemicals).

Inhalation of Vapor
Future

Exposure Medium: Groundwater
Exposure Point: Irrigation Water
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer Hazard = CA x SIFnc x VFw / RfD
Cancer Risk = CA x SIFc x VFw x CSF

Parameter	Unit	RME Adult
Chemical Conc'n of Water (CW)	ug/L	chem-specific
Inhalation Rate (InhR)	m^3/hr	1.5
Exposure Time (ET)	hr/day	2
Exposure Frequency (EF)	days/yr	90
Exposure Duration (ED)	years	30
Conversion Factor (CF)	mg/ug	1.0E-03
Body Weight (BW)	kg	70
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (InhR*ET*EF*ED*CF)/(BW*ATnc)	m^3-mg/ug-kg-day	1.06E-05
SIFc = (InhR*ET*EF*ED*CF)/(BW*ATc)	m^3-mg/ug-kg-day	4.53E-06

Chemical	RfDi (mg/kg-d)	CSFi (mg/kg-d)-1	VFw[a] (L/m3)
Carbon Tetrachloride	--	5.3E-02	2.0E-02
Chloroform	1.3E-02	8.1E-02	2.0E-01
Chromium III	--	--	--
Chromium VI (groundwater)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	2.0E-02
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	2.0E-02
TCE	1.1E-02	7.0E-04	2.0E-02
Uranium	--	--	--

[a] A volitilazation factor (VFw) of 0.02 is only applicable for volatile chemicals.

Dissolved Inorganics Chemical	90th Percentile				
	CW (ug/L)	$Intake_{nc}$ adult (mg/kg-d)	$Intake_c$ adult (mg/kg-d)	HQ adult	Cancer Risk adult
Carbon Tetrachloride	2900	6.13E-04	2.63E-04	--	1.4E-05
Chloroform	24	5.07E-05	2.17E-05	0.00390	1.8E-06
Total Chromium	130	--	--	--	--
Chromium VI	203	--	--	--	--
Methylene Chloride	3	5.78E-07	2.48E-07	0.0000007	4.0E-10
Nitrate	81050	--	--	--	--
PCE	3	5.28E-07	2.26E-07	0.0000048	4.8E-09
TCE	11	2.30E-06	9.87E-07	0.00021	6.9E-10
Uranium	5	--	--	--	--
Total				0.0041	1.6E-05

Table 5a. Agricultural Exposures (Nonradioactive Chemicals).

Intermediate Dermal Spreadsheet

Exposure Medium: Groundwater
Exposure Point: Irrigation Water
Receptor Population: Resident
Receptor Age: Adults

Exposure Parameters		Units
Fraction absorbed	FA	unitless
Dermal permeability coefficient	PC	cm/hr
Concentration in surface water	CW	mg/m3
Lag time per event	T event	hour/event
Time to reach steady state	t*	hours
Event duration	t event	hour/event
Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis	B	unitless
Absorbed dose per event	DA event	mg/cm2-event

Formulas Used to Calculate Absorbed Dose per Event (DAevent):

ORGANIC CHEMICALS:

If $t_{event} \leq t^*$, then $DA_{event} = 2\ FA \times PC \times Cw\ (6 \times T_{event} \times t_{event}/Pi)^{0.5}$

If $t_{event} > t^*$, then $DA_{event} = FA \times PC \times Cw\ [(t_{event}/1 + B) + (2 \times Tau_{event}) \times (1 + 3B + 3B^2/(1 + B)^2]$

INORGANIC CHEMICALS:

$DA_{event} = PC \times Cw \times t_{event}$

Chemical	FA	PC	Cw	T_{event}	t*	t_{event} hr/event		Pi	B	Daevent mg/cm2-event	
	unitless	cm/hr	mg/cm^3	hr/event	hours	Adult	Child	unitless	unitless	Adult	Child
Carbon Tetrachloride	1	1.60E-02	2.90E-03	0.78	1.86	2	--	3.14	0.1	1.64E-04	--
Chloroform	1	6.80E-03	2.40E-05	0.5	1.19	2	--	3.14	0	4.90E-07	--
Total Chromium	--	0.001	1.30E-04	--	--	2	--	3.14	--	2.60E-07	--
Chromium VI	--	2.00E-03	2.03E-04	--	--	2	--	3.14	--	8.14E-07	--
Methylene Chloride	1	3.50E-03	2.73E-06	0.32	0.76	2	--	3.14	0	2.53E-08	--
Nitrate	--	--	8.11E-02	--	--	2	--	3.14	--	--	--
PCE	1	3.30E-02	2.50E-06	0.91	2.18	2	--	3.14	0.2	3.08E-07	--
TCE	1	1.20E-02	1.09E-05	0.58	1.39	2	--	3.14	0.1	4.05E-07	--
Uranium	--	2.00E-03	5.06E-06	--	--	2	--	3.14	--	2.02E-08	--

Table 5b. Agricultural Exposures (Nonradioactive Chemicals).

Dermal Contact with Groundwater
Future

Exposure Medium: Groundwater
Exposure Point: Irrigation Water
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer HQ =DAevent x SIFnc / RfD
Cancer Risk = DAevent x SIFc x CSF

Parameter	Units	RME Adult
Absorbed dose per event (DAevent)	(mg/cm2-event)	chem-specific
Exposure Frequency (EF)	days/yr	90
Exposure Duration (ED)	years	30
Event Frequency (EV)	events/day	1
Surface Area Available for Contact (SA)	cm^2	1,933
Body Weight (BW)	days	70
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)		25,550
SIFnc(adult) = ((EF*ED*EV*SA)/(BW*ATnc))	ev-cm2/kg-d	6.81E+00
SIFc(adult) = ((EF*ED*EV*SA)/(BW*ATc))	ev-cm2/kg-d	2.92E+00

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	2.0E-02	--
Chromium VI (groundwater)	7.5E-05	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	--	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

	90th Percentile				
Chemical	DA event (mg/cm2-event) adult	$Intake_{nc}$ adult (mg/kg-d)	$Intake_c$ adult (mg/kg-d)	HQ adult	Risk adult
Carbon Tetrachloride	1.64E-04	1.12E-03	4.78E-04	1.6	6.22E-05
Chloroform	4.90E-07	3.33E-06	1.43E-06	0.00033	--
Total Chromium	2.60E-07	1.77E-06	7.59E-07	0.000091	--
Chromium VI	8.14E-07	5.5398E-06	2.37E-06	0.074	--
Methylene Chloride	2.53E-08	1.72E-07	7.37E-08	0.0000029	5.53E-10
Nitrate	--	--	--	--	--
PCE	3.08E-07	2.10E-06	8.98E-07	0.00021	4.85E-07
TCE	4.05E-07	2.75E-06	1.18E-06	0.0092	1.53E-08
Uranium	2.02E-08	1.38E-07	5.91E-08	0.000046	--
Total				1.7	6.3E-05

Table 6. Agricultural Exposures (Nonradioactive Chemicals).

Ingestion of Plant Tissue
Future

Exposure Medium: Groundwater (used for irrigation)
Exposure Point: Fruits and Vegetables
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	RME child/adult
Chemical Conc'n in Tissue (CTi)	mg/kg	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/kg-day	4.6
Fracton of Plant from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
Conversion Factor (CF)	kg/g	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (IR*FC*EF*ED*CF)/(Atnc*BW)	$(day)^{-1}$	4.41E-03
SIFc = (FC*EF*CF/ATc)*(IRc*Edc/BWc+IRa*Eda/BWa)	$(day)^{-1}$	1.89E-03

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	90th Percentile				
	CTi (mg/kg)	$Intake_{nc}$ child/adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ child/adult	Cancer Risk lifetime
Carbon Tetrachloride	5.62E+01	2.48E-01	1.06E-01	354	1.4E-02
Chloroform	7.86E-01	3.47E-03	1.49E-03	0.35	--
Total Chromium	1.68E+00	7.42E-03	3.18E-03	0.0049	--
Chromium VI	2.63E+00	1.16E-02	4.98E-03	4	--
Methylene Chloride	1.77E-01	7.81E-04	3.35E-04	0.013	2.5E-06
Nitrate	--	--	--	--	--
PCE	3.97E-02	1.75E-04	7.50E-05	0.018	4.1E-05
TCE	2.59E-01	1.14E-03	4.90E-04	4	6.4E-06
Uranium	6.58E-02	2.90E-04	1.24E-04	0.10	--
Total				362	1.4E-02

Table 7. Agricultural Exposures (Nonradioactive Chemicals).

Ingestion of Plant Tissue
Future

Exposure Medium: Garden Soil
Exposure Point: Fruits and Vegetables
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	RME child/adult
Chemical Conc'n in Tissue (CTi)	mg/kg	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/day	4.6
Fracton of Plant from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
Conversion Factor (CF)	kg/g	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (IR*FC*EF*ED*CF)/(Atnc*BW)	$(day)^{-1}$	4.41E-03
SIFc = (FC*EF*CF/ATc)*(IRc*Edc/BWc+IRa*Eda/BWa)	$(day)^{-1}$	1.89E-03

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.0E-04	1.3E-01
1,2-Dibromo-3-chloropropane	2.0E-04	8.0E-01
Cadmium	1.0E-03	--
Manganese	7.0E-02	--
Thallium	6.6E-05	--

Chemical	90th Percentile				
	CTi (mg/kg)	$Intake_{nc}$ child/adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ child/adult	Cancer Risk lifetime
Z-9 Trench Soil					
Carbon Tetrachloride	5.52	2.43E-02	1.04E-02	35	1.4E-03
1,2-Dibromo-3-chloropropane	0.037	1.63E-04	6.99E-05	1	5.6E-05
Cadmium	0.83	3.68E-03	1.58E-03	4	--
Manganese	29.59	1.31E-01	5.59E-02	2	--
Total				41	1.4E-03
A-8 Soil					
Thallium	0.05	2.21E-04	9.45E-05	3	--
Total				3	--

Table 8. Agricultural Exposures (Nonradioactive Chemicals).

Ingestion of Beef Tissue
Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Beef Cattle
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	RME child/adult
Chemical Conc'n in Tissue (CTi)	mg/kg	chem-specific
Ingestion Rate of Beef Tissue (IR)	g/day	2.41
Fracton of Plant from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
Conversion Factor (CF)	kg/g	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (IR*FC*EF*ED*CF)/(Atnc*BW)	$(day)^{-1}$	2.31E-03
SIFc = (FC*EF*CF/ATc)*(IRc*Edc/BWc+IRa*Eda/BWa)	$(day)^{-1}$	9.90E-04

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	90th Percentile				
	CTi (mg/kg)	$Intake_{nc}$ child/adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ child/adult	Cancer Risk lifetime
Carbon Tetrachloride	1.38E-02	3.18E-05	1.36E-05	0.045	1.8E-06
Chloroform	2.45E-05	5.66E-08	2.43E-08	0.0000057	--
Total Chromium	2.40E-01	5.55E-04	2.38E-04	0.00037	--
Chromium VI	3.76E-01	8.69E-04	3.72E-04	0.29	--
Methylene Chloride	9.92E-07	2.29E-09	9.82E-10	0.000000038	7.4E-12
Nitrate	--	--	--	--	--
PCE	3.77E-05	8.70E-08	3.73E-08	0.0000087	2.0E-08
TCE	2.39E-05	5.52E-08	2.37E-08	0.00018	3.1E-10
Uranium	3.13E-04	7.23E-07	3.10E-07	0.00024	--
Total				0.34	1.8E-06

Table 9. Agricultural Exposures (Nonradioactive Chemicals).

Ingestion of Dairy Products
Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Dairy Cattle
Receptor Population: Resident
Receptor Age: Adults

Non-Cancer Hazard = CMi x SIFnc / RfD
Cancer Risk = CMi x SIFc x CSF

Parameter	Unit	RME child
Chemical Conc'n in Tissue (CTi)	mg/kg	chem-specific
Ingestion Rate of Dairy (IR)	g/day	10
Fracton of Plant from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
Conversion Factor (CF)	kg/g	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	10,950
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (IR*FC*EF*ED*CF)/(Atnc)	$(day)^{-1}$	9.59E-03
SIFc = (IR*FC*EF*CF/ATc)*(EDc+EDa)	$(day)^{-1}$	4.11E-03

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	90th Percentile				
	CM (mg/kg)	$Intake_{nc}$ child/adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ child/adult	Cancer Risk lifetime
Carbon Tetrachloride	6.49E-03	6.23E-05	2.67E-05	0.09	3.5E-06
Chloroform	1.14E-05	1.09E-07	4.69E-08	0.000011	--
Total Chromium	4.04E-04	3.87E-06	1.66E-06	0.0000026	--
Chromium VI	6.32E-04	6.06E-06	2.60E-06	0.0020	--
Methylene Chloride	4.54E-07	4.36E-09	1.87E-09	0.000000073	1.4E-11
Nitrate	--	--	--	--	--
PCE	1.78E-05	1.71E-07	7.33E-08	0.000017	4.0E-08
TCE	1.12E-05	1.07E-07	4.61E-08	0.00036	6.0E-10
Uranium	6.31E-04	6.05E-06	2.59E-06	0.0020	--
Total				0.09	3.5E-06

Table 10. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Residential Farmer. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water				Irrigation			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration											
Carbon Tetrachloride	2900	5.6E-03	1.1E-02	7.3E-04	1.8E-02	1.4E-05	6.2E-05	7.5E-05	1.8E-06	1.4E-02	3.5E-06
Chloroform	24	(a)	1.4E-04	(a)	1.4E-04	1.8E-06	(a)	1.6E-07	(a)	(a)	(a)
Chromium III	130	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Chromium VI (groundwater)	203.4	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Methylene Chloride	2.734	3.0E-07	3.3E-07	5.6E-09	6.4E-07	4.0E-10	5.5E-10	9.1E-10	7.4E-12	2.5E-06	1.4E-11
Nitrate	81050	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
PCE	2.5	2.0E-05	3.9E-06	5.8E-06	3.0E-05	4.8E-09	4.8E-07	4.9E-07	2.0E-08	4.1E-05	4.0E-08
TCE	10.9	2.1E-06	5.7E-07	1.78178E-07	2.9E-06	6.9E-10	1.5E-08	1.6E-08	3.1E-10	6.4E-06	6.0E-10
Uranium	5.06	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
TOTAL		5.6E-03	1.2E-02	7.4E-04	1.8E-02	1.6E-05	6.3E-05	7.8E-05	1.8E-06	1.4E-02	3.5E-06
50th Percentile Groundwater Concentration											
Carbon Tetrachloride	505	9.8E-04	2.0E-03	1.3E-04	3.1E-03	2.4E-06	1.1E-05	1.3E-05	3.1E-07	2.4E-03	6.0E-07
Chloroform	6.4	(a)	3.9E-05	(a)	3.9E-05	4.7E-07	(a)	4.7E-07	(a)	(a)	(a)
Chromium III	10.3	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Chromium VI (groundwater)	10.9	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Methylene Chloride	0.185	2.1E-08	2.2E-08	3.8E-10	4.3E-08	2.7E-11	3.7E-11	6.4E-11	5.0E-13	1.7E-07	9.5E-13
Nitrate	21900	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
PCE	0.36	2.9E-06	5.6E-07	8.4E-07	4.3E-06	6.8E-10	7.0E-08	7.1E-08	2.9E-09	5.8E-06	5.7E-09
TCE	1.7	3.3E-07	8.8E-08	2.8E-08	4.4E-07	1.1E-10	2.4E-09	2.5E-09	4.8E-11	9.9E-07	9.3E-11
Uranium	1.17	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
TOTAL		9.8E-04	2.0E-03	1.3E-04	3.1E-03	2.9E-06	1.1E-05	1.4E-05	3.1E-07	2.4E-03	6.1E-07

Table 10. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Residential Farmer. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water				Irrigation			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
25th Percentile Groundwater Concentration											
Carbon Tetrachloride	6.5	1.3E-05	2.6E-05	1.6E-06	4.0E-05	3.1E-08	1.4E-07	1.7E-07	4.0E-09	3.1E-05	7.8E-09
Chloroform	0.6	(a)	3.5E-06	(a)	3.5E-06	4.3E-08	(a)	4.3E-08	(a)	(a)	(a)
Chromium III	3.6	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Chromium VI (groundwater)	7.0	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Methylene Chloride	0.12	1.3E-08	1.4E-08	2.5E-10	2.8E-08	1.7E-11	2.4E-11	4.2E-11	3.2E-13	1.1E-07	6.1E-13
Nitrate	14000	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
PCE	0.18	1.4E-06	2.8E-07	4.2E-07	2.1E-06	3.4E-10	3.5E-08	3.5E-08	1.5E-09	2.9E-06	2.8E-09
TCE	0.16	3.0E-08	8.1E-09	2.5E-09	4.1E-08	9.8E-12	2.2E-10	2.3E-10	4.4E-12	9.1E-08	8.5E-12
Uranium	0.74	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
TOTAL		1.4E-05	3.0E-05	2.1E-06	4.6E-05	7.4E-08	1.8E-07	2.5E-07	5.4E-09	3.4E-05	1.1E-08
Average Groundwater Concentration											
Carbon Tetrachloride	1009	2.0E-03	4.0E-03	2.6E-04	6.2E-03	4.8E-06	2.2E-05	2.6E-05	6.2E-07	4.8E-03	1.2E-06
Chloroform	11	(a)	6.4E-05	(a)	6.4E-05	7.8E-07	(a)	7.8E-07	(a)	(a)	(a)
Chromium III	50	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Chromium VI (groundwater)	75	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Methylene Chloride	8.2	9.1E-07	9.7E-07	1.7E-08	1.9E-06	1.2E-09	1.7E-09	2.8E-09	2.2E-11	7.5E-06	4.2E-11
Nitrate	44750	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
PCE	2.5	2.0E-05	3.9E-06	5.9E-06	3.0E-05	4.8E-09	4.9E-07	5.0E-07	2.0E-08	4.1E-05	4.0E-08
TCE	4.7	9.2E-07	2.5E-07	7.8E-08	1.2E-06	3.0E-10	6.7E-09	7.0E-09	1.3E-10	2.8E-06	2.6E-10
Uranium	11	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
TOTAL		2.0E-03	4.0E-03	2.6E-04	6.3E-03	5.6E-06	2.2E-05	2.8E-05	6.4E-07	4.9E-03	1.2E-06
UCL95 Groundwater Concentration											
Carbon Tetrachloride	1491	2.9E-03	5.9E-03	3.8E-04	9.1E-03	7.2E-06	3.2E-05	3.9E-05	9.1E-07	7.1E-03	1.8E-06
Chloroform	19	(a)	1.1E-04	(a)	1.1E-04	1.4E-06	(a)	1.4E-06	(a)	(a)	(a)
Chromium III	74	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Chromium VI (groundwater)	176	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
Methylene Chloride	20	2.2E-06	2.4E-06	4.1E-08	4.7E-06	2.9E-09	4.1E-09	7.0E-09	5.4E-11	1.8E-05	1.0E-10
Nitrate	63187	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
PCE	5	3.9E-05	7.6E-06	1.1E-05	5.8E-05	9.3E-09	9.4E-07	9.5E-07	3.9E-08	7.9E-05	7.7E-08
TCE	7	1.4E-06	3.7E-07	1.2E-07	1.9E-06	4.5E-10	1.0E-08	1.1E-08	2.0E-10	4.2E-06	3.9E-10
Uranium	32	(a)	(a)	(a)	--	(a)	(a)	--	(a)	(a)	(a)
TOTAL		2.9E-03	6.0E-03	3.9E-04	9.3E-03	8.6E-06	3.3E-05	4.2E-05	9.5E-07	7.2E-03	1.9E-06

(a) Chemical not associated with carcinogenic effects through the pathways of exposure from groundwater.
-- - no value to sum

Table 11. Summary of Non-Cancer Hazards Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Residential Farmer. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water								Irrigation			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
90th Percentile Groundwater Concentration																		
Carbon Tetrachloride	2900	265	114	(b)	(b)	39	16	304	130	(b)	2	2	0.045	0.045	354	354	0.09	0.09
Chloroform	24	0.15	0.066	0.59	0.25	0.0077	0.0032	0.75	0.32	0.0039	0.00033	0.00068	0.0000057	0.0000057	0.35	0.35	0.000011	0.000011
Chromium III	130	0.0055	0.0024	(a)	(a)	0.00093	0.00028	0.0065	0.0027	(a)	0.000091	0.000091	0.00037	0.00037	0.0049	0.0049	0.0000026	0.0000026
Chromium VI (groundwater)	203.4	4	2	(a)	(a)	0.76	0.23	5	2	(a)	0.074	0.074	0.29	0.29	4	4	0.0020	0.0020
Methylene Chloride	2.734	0.0029	0.0012	0.0010	0.00044	0.000060	0.000025	0.0040	0.0017	0.0000007	0.0000029	0.0000035	0.000000038	0.000000038	0.013	0.013	0.000000073	0.000000073
Nitrate	81050	3.24	1.39	(b)	(b)	(b)	(b)	3	1	(b)	(b)	--	(b)	(b)	(b)	(b)	(b)	(b)
PCE	2.5	0.016	0.0068	0.0073	0.0031	0.0053	0.0022	0.029	0.012	0.0000048	0.00021	0.00021	0.0000087	0.0000087	0.018	0.018	0.000017	0.000017
TCE	10.9	2	1	0.32	0.14	0.22	0.09	2.86	1.22	0.00021	0.0092	0.0094	0.00018	0.00018	4	4	0.00036	0.00036
Uranium	5.06	0.11	0.05	(a)	(a)	0.00047	0.00	0.11	0.046	(a)	0.000046	0.000046	0.00024	0.00024	0.10	0.10	0.0020	0.0020
TOTAL		275	118	0.92	0.39	40	17	316	135	0.004	2	2	0.34	0.34	362	362	0.09	0.09
50th Percentile Groundwater Concentration																		
Carbon Tetrachloride	505	46	20	(b)	(b)	7	3	53	23	(b)	0.28	0.28	0.0079	0.0079	62	62	0.02	0.02
Chloroform	6.4	0.04	0.018	0.16	0.07	0.0021	0.0009	0.20	0.09	0.00104	0.00009	0.00113	0.0000015	0.0000015	0.092	0.092	0.000003	0.000003
Chromium III	10.3	0.0004	0.0002	(a)	(a)	0.00007	0.00002	0.0005	0.0002	(a)	0.000007	0.000007	0.00003	0.00003	0.0004	0.0004	0.0000002	0.0000002
Chromium VI (groundwater)	10.9	0.23	0.10	(a)	(a)	0.04	0.01	0.27	0.11	(a)	0.004	0.004	0.02	0.02	0.21	0.21	0.0001	0.0001
Methylene Chloride	0.185	0.0002	0.0001	0.00007	0.00003	0.000004	0.000002	0.0003	0.0001	0.000000045	0.00000019	0.0000002	0.000000003	0.000000003	0.00088	0.00088	0.000000005	0.000000005
Nitrate	21900	0.88	0.38	(b)	(b)	(b)	(b)	0.88	0.38	(b)	(b)	--	(b)	(b)	(b)	(b)	(b)	(b)
PCE	0.36	0.002	0.0010	0.0010	0.0004	0.0008	0.0003	0.004	0.002	0.0000007	0.00003	0.00003	0.0000013	0.0000013	0.0025	0.0025	0.000002	0.000002
TCE	1.7	0	0	0.05	0.02	0.03	0.01	0.45	0.19	0.00003	0.0014	0.0015	0.00003	0.00003	0.59	0.59	0.00006	0.00006
Uranium	1.17	0.02	0.01	(a)	(a)	0.00011	0.00	0.03	0.011	(a)	0.000011	0.000011	0.00006	0.00006	0.02	0.02	0.0005	0.0005
TOTAL		48	20	0.21	0.09	7	3	55	23	0.001	0.28	0.28	0.02	0.02	63	63	0.02	0.02

Table 11. Summary of Non-Cancer Hazards Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Residential Farmer. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water								Irrigation			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
25th Percentile Groundwater Concentration																		
Carbon Tetrachloride	6.525	0.6	0.26	(b)	(b)	0.09	0.04	0.68	0.29	(b)	0.004	0.004	0.0001	0.0001	1	1	0.0002	0.0002
Chloroform	0.58	0.004	0.002	0.014	0.006	0.0002	0.000078	0.02	0.0078	0.00009	0.00001	0.00010	0.0000001	0.0000001	0.01	0.01	0.0000003	0.0000003
Chromium III	3.6	0.0002	0.00007	(a)	(a)	0.00003	0.000008	0.0002	0.00007	(a)	0.000003	0.000003	0.00001	0.00001	0.0001	0.0001	0.00000007	0.00000007
Chromium VI (groundwater)	7	0.1	0.06	(a)	(a)	0.03	0.01	0.2	0.1	(a)	0.003	0.003	0.01	0.01	0.1	0.1	0.00007	0.00007
Methylene Chloride	0.12	0.0001	0.0001	0.0000	0.00002	0.000003	0.000001	0.0002	0.0001	0.00000003	0.0000001	0.0000002	0.000000002	0.000000002	0.001	0.001	0.000000003	0.000000003
Nitrate	14000	0.56	0.24	(b)	(b)	(b)	(b)	0.6	0.2	(b)	(b)	--	(b)	(b)	(b)	(b)	(b)	(b)
PCE	0.18	0.001	0.0005	0.0005	0.0002	0.0004	0.0002	0.002	0.001	0.0000003	0.00002	0.00002	0.0000006	0.0000006	0.001	0.001	0.000001	0.000001
TCE	0.155	0	0	0.00	0.00	0.00	0.00	0.04	0.02	0.00000	0.0001	0.0001	0.00000	0.00000	0.05	0.05	0.00001	0.00001
Uranium	0.74	0.02	0.01	(a)	(a)	0.00007	0.00	0.02	0.007	(a)	0.000007	0.000007	0.00004	0.00004	0.01	0.01	0.0003	0.0003
TOTAL		1	1	0.02	0.008	0.1	0.05	1	0.6	0.0001	0.006	0.006	0.01	0.01	1	1	0.0006	0.0006
Average Groundwater Concentration																		
Carbon Tetrachloride	1009.3	92	40	(b)	(b)	14	6	106	45	(b)	1	1	0.016	0.016	123	123	0.03	0.03
Chloroform	10.7	0.07	0.029	0.26	0.11	0.0034	0.0014	0.33	0.14	0.00173	0.00015	0.00188	0.0000025	0.0000025	0.15	0.15	0.000005	0.000005
Chromium III	50.5	0.0022	0.0009	(a)	(a)	0.00036	0.00011	0.0025	0.0010	(a)	0.000035	0.000035	0.00014	0.00014	0.0019	0.0019	0.0000010	0.0000010
Chromium VI (groundwater)	74.9	2	1	(a)	(a)	0.28	0.08	2	1	(a)	0.027	0.027	0.11	0.11	1	1	0.0007	0.0007
Methylene Chloride	8.2	0.0087	0.0037	0.0030	0.00130	0.000181	0.000076	0.0119	0.0051	0.0000020	0.0000086	0.0000106	0.000000114	0.000000114	0.039	0.039	0.000000217	0.000000217
Nitrate	44750.2	1.79	0.77	(b)	(b)	(b)	(b)	2	1	(b)	(b)	--	(b)	(b)	(b)	(b)	(b)	(b)
PCE	2.5	0.016	0.0069	0.0073	0.0031	0.0053	0.0022	0.029	0.012	0.0000049	0.00021	0.00022	0.0000088	0.0000088	0.018	0.018	0.000017	0.000017
TCE	4.7	1	0	0.14	0.06	0.10	0.04	1.25	0.53	0.00009	0.0040	0.0041	0.00008	0.00008	2	2	0.00016	0.00016
Uranium	11.3	0.24	0.10	(a)	(a)	0.00105	0.00	0.24	0.103	(a)	0.000102	0.000102	0.00054	0.00054	0.22	0.22	0.0045	0.0045
TOTAL		97	42	0	0	14	6	111	48	0.002	1	1	0.12	0.12	127	127	0.04	0.04
UCL95 Groundwater Concentration																		
Carbon Tetrachloride	1491.3	136	58	(b)	(b)	20	8	156	67	(b)	1	1	0.023	0.023	182	182	0.05	0.05
Chloroform	19.0	0.12	0.052	0.47	0.20	0.0061	0.0026	0.60	0.26	0.00310	0.00026	0.00336	0.0000045	0.0000045	0.28	0.28	0.000009	0.000009
Chromium III	74.3	0.0032	0.0014	(a)	(a)	0.00053	0.00016	0.0037	0.0015	(a)	0.000052	0.000052	0.00021	0.00021	0.0028	0.0028	0.0000015	0.0000015
Chromium VI (groundwater)	176.2	4	2	(a)	(a)	0.65	0.20	4	2	(a)	0.064	0.064	0.25	0.25	3	3	0.0018	0.0018
Methylene Chloride	20.0	0.0214	0.0092	0.0074	0.00319	0.000443	0.000186	0.0292	0.0125	0.0000049	0.0000210	0.0000259	0.000000280	0.000000280	0.095	0.095	0.000000532	0.000000532
Nitrate	63187.2	2.52	1.08	(b)	(b)	(b)	(b)	3	1	(b)	(b)	--	(b)	(b)	(b)	(b)	(b)	(b)
PCE	4.9	0.031	0.0133	0.0141	0.0061	0.0103	0.0043	0.056	0.024	0.0000093	0.00041	0.00042	0.0000169	0.0000169	0.034	0.034	0.000033	0.000033
TCE	7.2	2	1	0.21	0.09	0.15	0.06	1.88	0.81	0.00014	0.0060	0.0062	0.00012	0.00012	3	3	0.00024	0.00024
Uranium	31.9	0.68	0.29	(a)	(a)	0.00296	0.00	0.68	0.292	(a)	0.000289	0.000289	0.00152	0.00152	0.61	0.61	0.0127	0.0127
TOTAL		145	62	0.7	0.3	21	9	167	71	0.003	1	1	0.28	0.28	189	189	0.06	0.06

(a) - Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
(b) - No toxicity criteria available to quanitify exposures by this pathway.
-- - no value to sum

Residential Farmer Exposures to Groundwater – Radionuclides

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Table 12. Residential Exposures to Tap Water (Radioactive Chemicals).

Ingestion of Groundwater
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	RME Lifetime
Chemical Conc'n in Water (CW)	pCi/L	chem-specific
Ingestion Rate of Water (IR)	L/day	2
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
SIFc = (IR*EF*ED)	L	2.10E+04

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.5E-10
TC-99	2.75E-12
Tritium	5.07E-14

Chemical	90th Percentile CW (pCi/L)	90th Percentile Cancer Risk lifetime
Iodine-129	1.2	3.7E-06
Tc-99	1436	8.3E-05
Tritium	36200	3.9E-05
TOTAL		**1.3E-04**

Table 13. Residential Exposures to Tap Water (Radioactive Chemicals).

Inhalation of Vapor
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Resident
Receptor Age: Lifetime

Cancer Risk = CA x SIFc x VF x CSF

Parameter	Units	RME Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific
Inhalation Rate of Air (InhR)	m^3/day	20
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
SIFc = (InhR*EF*ED*VF)	m^3	2.1E+05

Chemical	CSFi (risk/pCi)	VF (L/m3)
I-129 (non-dairy)	1.60E-10	--
TC-99	--	--
Tritium	5.62E-14	0.011675

Chemical	90th Percentile CW (pCi/L)	90th Percentile Cancer Risk lifetime
Iodine-129	1.17	--
Tc-99	1436	--
Tritium	36200	5.0E-06
Total		**5.0E-06**

Table 14. Residential Exposures to Irrigation Groundwater (Radioactive Chemicals). (2 sheets)

Inhalation of Vapor
Future

Exposure Medium: Ground Water
Exposure Point: Irrigation Water
Receptor Population: Resident
Receptor Age: Lifetime

Parameter	Units	RME Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific
Inhalation Rate of Air (InhR)	m^3/hr	1.5
Exposure time (ET)	hr/day	2
Exposure Frequency (EF)	days/yr	90
Exposure Duration (ED)	years	30
SIFc = (InhR*ET*EF*ED*VF)	m^3	8.1E+03

Chemical	90th Percentile CW (pCi/L)	Cancer Risk lifetime
Iodine-129	1.17	--
Tc-99	1436	--
Tritium	36200	1.9E-07
Total		**1.9E-07**

Table 14. Residential Exposures to Irrigation Groundwater (Radioactive Chemicals). (2 sheets)

Cancer Risk = CA x SIFc x VF x CSF

Chemical	CSFi (risk/pCi)	VF (L/m3)
I-129 (non-dairy)	1.60E-10	--
TC-99	--	--
Tritium	5.62E-14	0.011675

Table 15. Residential Exposures to Plant Tissue (Radioactive Chemicals).

Ingestion of Plant Tissue
Current/Future

Exposure Medium: Plant Tissue
Exposure Point: Plants
Receptor Population: Resident
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	RME Lifetime
Chemical Conc'n in Tissue (CTi)	pCi/g	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/day	322
Fracton of Plant from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
SIFc = (IR*FC*EF*ED)	g	3.38E+06

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
TC-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	90th Percentile Cancer Risk lifetime
Iodine-129	1.53E-02	8.3E-06
Tc-99	1.95E+02	2.6E-03
Tritium	9.50E+02	4.6E-04
Total		**3.1E-03**

Table 16. Residential Exposures to Livestock (Radioactive Chemicals).

Ingestion of Livestock Animal Tissue
Future

Exposure Medium: Animal Tissue
Exposure Point: Livestock
Receptor Population: Resident
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	RME Lifetime
Chemical Conc'n in Tissue (CTi)	pCi/g	chem-specific
Ingestion Rate of Animal Tissue (IR)	g/day	169
Fracton of Tissue from Contaminated Source (FC)	unitless	1
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
SIFc = (IR*FC*EF*ED)	g	1.77E+06

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
TC-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	90th Percentile Cancer Risk lifetime
Iodine-129	9.82E-03	2.8E-06
Tc-99	2.42E+00	1.7E-05
Tritium	3.62E+01	9.3E-06
Total		**2.9E-05**

Table 17. Residential Exposures to Milk (Radioactive Chemicals).

Ingestion of Milk
Future

Exposure Medium: Milk
Exposure Point: Milk
Receptor Population: Resident
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	RME Lifetime
Chemical Conc'n in Milk (CM)	pCi/g	chem-specific
Ingestion Rate of Milk (IR)	g/day	700
Exposure Frequency (EF)	days/yr	350
Exposure Duration (ED)	years	30
SIFc = (IR*EF*ED)	g	7.35E+06

Chemical	CSFo (risk/pCi)
I-129 (dairy)	3.22E-10
TC-99	4.0E-12
Tritium	1.44E-13

Chemical	90th Percentile CM (pCi/g)	90th Percentile Cancer Risk lifetime
Iodine-129	0.004	1.1E-05
Tc-99	4.872	1.4E-04
Tritium	36.200	3.8E-05
Total		**1.9E-04**

Table 18. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Radionuclide COPCs Post-2150 Unrestricted Land Use - Residential Farmer.

COPC	Groundwater Concentration (ug/L)	Tap Water			Irrigation	Meat	Plant	Milk
		Ingestion	Inhalation	Total	Inhalation	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration								
I-129	1.2	3.7E-06	(a)	3.7E-06	(a)	2.8E-06	8.3E-06	1.1E-05
TC-99	1436	8.3E-05	(a)	8.3E-05	(a)	1.7E-05	2.6E-03	1.4E-04
Tritium	36200	3.9E-05	5.0E-06	4.4E-05	1.9E-07	9.3E-06	4.6E-04	3.8E-05
Total		1.3E-04	5.0E-06	1.3E-04	1.9E-07	2.9E-05	3.1E-03	1.9E-04
50th Percentile Groundwater Concentration								
I-129	0.03	9.5E-08	(a)	9.5E-08	(a)	7.2E-08	2.1E-07	2.7E-07
TC-99	173	1.0E-05	(a)	1.0E-05	(a)	2.1E-06	3.2E-04	1.7E-05
Tritium	3605	3.8E-06	5.0E-07	4.3E-06	1.9E-08	9.2E-07	4.6E-05	3.8E-06
Total		1.4E-05	5.0E-07	1.4E-05	1.9E-08	3.1E-06	3.6E-04	2.1E-05
25th Percentile Groundwater Concentration								
I-129	ND	(b)	(b)	(b)	(b)	(b)	(b)	(b)
TC-99	54.1	3.1E-06	(a)	3.1E-06	(a)	6.5E-07	9.9E-05	5.4E-06
Tritium	513.75	5.5E-07	7.1E-08	6.2E-07	2.7E-09	1.3E-07	6.6E-06	5.4E-07
Total		3.7E-06	7.1E-08	3.7E-06	2.7E-09	7.8E-07	1.1E-04	5.9E-06
Average Groundwater Concentration								
I-129	1.3	4.1E-06	(a)	4.1E-06	(a)	3.1E-06	9.3E-06	1.2E-05
TC-99	786	4.5E-05	(a)	4.5E-05	(a)	9.4E-06	1.4E-03	7.8E-05
Tritium	51030	5.4E-05	7.0E-06	6.1E-05	2.7E-07	1.3E-05	6.5E-04	5.4E-05
Total		1.0E-04	7.0E-06	1.1E-04	2.7E-07	2.6E-05	2.1E-03	1.4E-04
UCL95 Groundwater Concentration								
I-129	2	7.6E-06	(a)	7.6E-06	(a)	5.8E-06	1.7E-05	2.2E-05
TC-99	1145	6.6E-05	(a)	6.6E-05	(a)	1.4E-05	2.1E-03	1.1E-04
Tritium	87345	9.3E-05	1.2E-05	1.1E-04	4.6E-07	2.2E-05	1.1E-03	9.2E-05
Total		1.7E-04	1.2E-05	1.8E-04	4.6E-07	4.2E-05	3.2E-03	2.3E-04

(a) - Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.
(b) - I-129 was not detected in the 25th percentile of the groundwater concentrations.

Industrial Exposures to Groundwater – Nonradionuclides

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Table 19. Industrial Exposures (Nonradioactive Chemicals).

Ingestion of Groundwater
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Industrial Workers
Receptor Age: Adults

Non-Cancer Hazard = CW x SIFnc / RfD
Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific
Ingestion Rate of Water (IR)	L/day	1
Exposure frequency (EF)	days/yr	250
Exposure duration (ED)	years	25
Body weight (BW)	kg	70
Conversion Factor (CF)	mg/ug	1.00E-03
Averaging time (non-cancer) (ATnc)	days	9,125
Averaging time (cancer) (ATc)	days	25550
SIFnc = (IR*EF*ED*CF)/(BW*ATnc)	L-mg/ug-kg-d	9.78E-06
SIFc = (IngFadj*EF*CF)/ATc	L-mg/ug-kg-d	3.49E-06

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.00E-04	1.30E-01
Chloroform	1.00E-02	--
Chromium III	1.50E+00	--
Chromium VI (groundwater)	3.00E-03	--
Methylene Chloride	6.00E-02	7.50E-03
Nitrate	1.60E+00	--
PCE	1.00E-02	5.40E-01
TCE	3.00E-04	1.30E-02
Uranium	3.00E-03	--

Total Inorganics Chemical	90th Percentile				
	CW (ug/L)	$Intake_{nc}$ adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ adult	Cancer Risk lifetime
Carbon Tetrachloride	2900.00	2.84E-02	1.01E-02	41	1.3E-03
Chloroform	24.00	2.35E-04	8.39E-05	0.02	--
Total Chromium	130.00	1.27E-03	4.54E-04	0.0008	--
Chromium VI	203.40	1.99E-03	7.11E-04	0.66	--
Methylene Chloride	2.73	2.68E-05	9.55E-06	0.00045	7.2E-08
Nitrate	81050.00	7.93E-01	2.83E-01	0.50	--
PCE	2.50	2.45E-05	8.74E-06	0.0024	4.7E-06
TCE	10.90	1.07E-04	3.81E-05	0.36	5.0E-07
Uranium	5.06	4.95E-05	1.77E-05	0.017	--
Total				**42**	**1.3E-03**

Table 20. Industrial Exposures (Nonradioactive Chemicals).

Inhalation of Vapor
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Industrial Worker
Receptor Age: Adults

Non-Cancer Hazard = CA x SIFnc x VFw / RfD
Cancer Risk = CA x SIFc x VFw x CSF

Parameter	Unit	Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific
Inhalation Rate (InhR)	m3/hr	1.5
Exposure Time (ET)	hr/day	3
Exposure Frequency (EF)	days/yr	250
Exposure Duration (ED)	years	25
Body Weight (BW)	kg	70
Conversion Factor (CF)	mg/ug	1.0E-03
Averaging Time (non-cancer) (ATnc)	days	9,125
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = (InhR*EF*ED*ET*CF)/(BW*ATnc)	m^3-mg/ug-kg-day	4.40E-05
SIFc = (InhR*ED*ET*EF*CF)/ATc	m^3-mg/ug-kg-day	1.57E-05

Chemical	RfDi (mg/kg-d)	CSFi (mg/kg-d)-1	VFw[a] (L/m3)
Carbon Tetrachloride	--	5.3E-02	5.0E-01
Chloroform	1.3E-02	8.1E-02	5.0E-01
Chromium III	--	--	--
Chromium VI (groundwater)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	5.0E-01
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	5.0E-01
TCE	1.1E-02	7.0E-04	5.0E-01
Uranium	--	--	--

[a] A volitilazation factor (VFw) of 0.5 is only applicable for volatile chemicals.

Dissolved Inorganics Chemical	90th Percentile				
	CW (ug/L)	$Intake_{nc}$ adult (mg/kg-d)	$Intake_{c}$ lifetime (mg/kg-d)	HQ adult	Cancer Risk lifetime
Carbon Tetrachloride	2900.00	6.38E-02	2.28E-02	--	1.2E-03
Chloroform	24.00	5.28E-04	1.89E-04	0.041	1.5E-05
Total Chromium	130.00	--	--	--	--
Chromium VI	203.40	--	--	--	--
Methylene Chloride	2.73	6.02E-05	2.15E-05	0.000070	3.4E-08
Nitrate	81050.00	--	--	--	--
PCE	2.50	5.50E-05	1.97E-05	0.0005	4.1E-07
TCE	10.90	2.40E-04	8.57E-05	0.022	6.0E-08
Uranium	5.06	--	--	--	--
Total				**0.063**	**1.2E-03**

Table 21. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker. (3 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water		
		Ingestion	Inhalation	Total
90th Percentile Groundwater Concentration				
Carbon Tetrachloride	2900	1.3E-03	1.3E-03	2.6E-03
Chloroform	24	(a)	1.6E-05	1.6E-05
Chromium III	130	(a)	(a)	--
Chromium VI (groundwater)	203.4	(a)	(a)	--
Methylene Chloride	2.734	7.2E-08	3.7E-08	1.1E-07
Nitrate	81050	(a)	(a)	--
PCE	2.5	4.7E-06	4.4E-07	5.2E-06
TCE	10.9	5.0E-07	6.0E-08	5.6E-07
Uranium	5.06	(a)	(a)	--
TOTAL		1.3E-03	1.2E-03	2.5E-03
50th Percentile Groundwater Concentration				
Carbon Tetrachloride	505	2.3E-04	2.2E-04	4.5E-04
Chloroform	6.4	(a)	4.3E-06	4.3E-06
Chromium III	10.3	(a)	(a)	--
Chromium VI (groundwater)	10.9	(a)	(a)	--
Methylene Chloride	0.185	4.8E-09	2.5E-09	7.3E-09
Nitrate	21900	(a)	(a)	--
PCE	0.36	6.8E-07	6.3E-08	7.4E-07
TCE	1.7	7.7E-08	9.4E-09	8.7E-08
Uranium	1.17	(a)	(a)	--
TOTAL		2.3E-04	2.3E-04	4.6E-04

A-Attach 6-47

Table 21. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker. (3 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water		
		Ingestion	Inhalation	Total
25th Percentile Groundwater Concentration				
Carbon Tetrachloride	6.5	3.0E-06	2.9E-06	5.9E-06
Chloroform	0.6	(a)	3.9E-07	3.9E-07
Chromium III	3.6	(a)	(a)	--
Chromium VI (groundwater)	7.0	(a)	(a)	--
Methylene Chloride	0.12	3.1E-09	1.6E-09	4.8E-09
Nitrate	14000	(a)	(a)	--
PCE	0.18	3.4E-07	3.2E-08	3.7E-07
TCE	0.16	7.0E-09	8.5E-10	7.9E-09
Uranium	0.74	(a)	(a)	--
TOTAL		3.3E-06	3.3E-06	6.6E-06
Average Groundwater Concentration				
Carbon Tetrachloride	1009	4.6E-04	4.5E-04	9.1E-04
Chloroform	11	(a)	7.2E-06	7.2E-06
Chromium III	50	(a)	(a)	--
Chromium VI (groundwater)	75	(a)	(a)	--
Methylene Chloride	8.2	2.1E-07	1.1E-07	3.2E-07
Nitrate	44750	(a)	(a)	--
PCE	2.5	4.8E-06	4.5E-07	5.2E-06
TCE	4.7	2.2E-07	2.6E-08	2.4E-07
Uranium	11	(a)	(a)	--
TOTAL		4.6E-04	4.6E-04	9.2E-04

A-Attach 6-48

Table 21. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker. (3 sheets)

COPC	Groundwater Concentration (ug/L)	Tap Water		
		Ingestion	Inhalation	Total
UCL95 Groundwater Concentration				
Carbon Tetrachloride	1491	6.8E-04	6.6E-04	1.3E-03
Chloroform	19	(a)	1.3E-05	1.3E-05
Chromium III	74	(a)	(a)	--
Chromium VI (groundwater)	176	(a)	(a)	--
Methylene Chloride	20	5.3E-07	2.7E-07	7.9E-07
Nitrate	63187	(a)	(a)	--
PCE	5	9.2E-06	8.6E-07	1.0E-05
TCE	7	3.3E-07	3.9E-08	3.6E-07
Uranium	32	(a)	(a)	--
TOTAL		6.9E-04	6.8E-04	1.4E-03

-- - no value to sum

A-Attach 6-49

Table 22. Summary of Non-Cancer Hazards Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Ingestion	Inhalation
Carbon Tetrachloride	2900	41	(b)
Chloroform	24	0.02	0.04
Chromium III	130	0.0008	(a)
Chromium VI (groundwater)	203.4	0.7	(a)
Methylene Chloride	2.734	0.0004	0.00007
Nitrate	81050	0.5	(b)
PCE	2.5	0.002	0.0005
TCE	10.9	0.4	0.02
Uranium	5.06	0.02	(a)
TOTAL		42	0.067
Carbon Tetrachloride	505	7	(b)
Chloroform	6.4	0.006	0.01
Chromium III	10.3	0.00007	(a)
Chromium VI (groundwater)	10.9	0.04	(a)
Methylene Chloride	0.185	0.00003	0.000005
Nitrate	21900	0.1	(b)
PCE	0.36	0.0004	0.00008
TCE	1.7	0.06	0.004
Uranium	1.17	0.004	(a)
TOTAL		7	0.015
Carbon Tetrachloride	6.5	0.09	(b)
Chloroform	0.6	0.0006	0.001
Chromium III	3.6	0.00002	(a)
Chromium VI (groundwater)	7.0	0.02	(a)
Methylene Chloride	0.12	0.00002	0.000003
Nitrate	14000	0.09	(b)
PCE	0.18	0.0002	0.00004

A-Attach 6-50

Table 22. Summary of Non-Cancer Hazards Associated with Various Groundwater Concentrations for the Nonradionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker. (2 sheets)

COPC	Groundwater Concentration (ug/L)	Ingestion	Inhalation
TCE	0.16	0.005	0.0003
Uranium	0.74	0.002	(a)
TOTAL		0.2	0.0014
Carbon Tetrachloride	1009	14	(b)
Chloroform	11	0.01	0.02
Chromium III	50	0.0003	(a)
Chromium VI (groundwater)	75	0.2	(a)
Methylene Chloride	8.2	0.001	0.0002
Nitrate	44750	0.3	(b)
PCE	2.5	0.002	0.0005
TCE	4.7	0.2	0.01
Uranium	11	0.04	(a)
TOTAL		15	0.030
Carbon Tetrachloride	1491	21	(b)
Chloroform	19	0.02	0.03
Chromium III	74	0.0005	(a)
Chromium VI (groundwater)	176	0.6	(a)
Methylene Chloride	20	0.0033	0.00055
Nitrate	63187	0.4	(b)
PCE	5	0.005	0.001
TCE	7	0.2	0.02
Uranium	32	0.1	(a)
TOTAL		22	0.051

(b) - No toxicity criteria available to quanitify exposures by this pathway.

A-Attach 6-51

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Industrial Exposures to Groundwater – Radionuclides

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Table 23. Industrial Exposures to Tap Water (Radioactive Chemicals).

Ingestion of Groundwater
Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water

Receptor Population: Industrial Worker
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	RME Lifetime
Chemical Conc'n in Water (CW)	pCi/L	chem-specific
Ingestion Rate of Water (IR)	L/day	1
Exposure Frequency (EF)	days/yr	250
Exposure Duration (ED)	years	25
SIFc = (IR*EF*ED)	L	6.25E+03

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.5E-10
TC-99	2.75E-12
Tritium	5.07E-14

Chemical	90th Percentile CW (pCi/L)	90th Percentile Cancer Risk lifetime
Iodine-129	1.2	1.1E-06
Tc-99	1436	2.5E-05
Tritium	36200	1.1E-05
TOTAL		**3.7E-05**

Table 24. Industrial Exposures to Tap Water (Radioactive Chemicals).

Inhalation of Vapor

Future

Exposure Medium: Groundwater

Exposure Point: Drinking Water
Receptor Population: Industrial Worker

Receptor Age: Lifetime

Cancer Risk = CA x SIFc x VF x CSF

Parameter	Units	RME Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific
Inhalation Rate of Air (InhR)	m^3/hr	1.6
Exposure Time (ET)	hr/day	3
Exposure Frequency (EF)	days/yr	250
Exposure Duration (ED)	years	25
SIFc = (InhR*EF*ED*VF)	m^3	3.0E+04

Chemical	CSFi (risk/pCi)	VF (L/m3)
I-129 (non-dairy)	1.60E-10	--
TC-99	--	--
Tritium	5.62E-14	0.011675

Chemical	90th Percentile CW (pCi/L)	90th Percentile Cancer Risk lifetime
Iodine-129	1.17	--
Tc-99	1436	--
Tritium	36200	7.1E-07
Total		**7.1E-07**

Table 25. Summary of Cancer Risks Associated with Various Groundwater Concentrations for the Radionuclide COPCs Post-2150 Unrestricted Land Use - Industrial Worker.

COPC	Groundwater Concentration (ug/L)	Tap Water		
		Ingestion	Inhalation	Total
90th Percentile Groundwater Concentration				
I-129	1.2	1.1E-06	(a)	1.1E-06
TC-99	1436	2.5E-05	(a)	2.5E-05
Tritium	36200	1.1E-05	7.1E-07	1.2E-05
Total		3.7E-05	7.1E-07	3.8E-05
50th Percentile Groundwater Concentration				
I-129	0.03	2.8E-08	(a)	2.8E-08
TC-99	173	3.0E-06	(a)	3.0E-06
Tritium	3605	1.1E-06	7.1E-08	1.2E-06
Total		4.1E-06	7.1E-08	4.2E-06
25th Percentile Groundwater Concentration				
I-129	ND	(b)	(b)	(b)
TC-99	54.1	9.3E-07	(a)	9.3E-07
Tritium	513.75	1.6E-07	1.0E-08	1.7E-07
Total		1.1E-06	1.0E-08	1.1E-06
Average Groundwater Concentration				
I-129	1.3	1.2E-06	(a)	1.2E-06
TC-99	786	1.4E-05	(a)	1.4E-05
Tritium	51030	1.6E-05	1.0E-06	1.7E-05
Total		3.1E-05	1.0E-06	3.2E-05
UCL95 Groundwater Concentration				
I-129	2	2.3E-06	(a)	2.3E-06
TC-99	1145	2.0E-05	(a)	2.0E-05
Tritium	87345	2.8E-05	1.7E-06	2.9E-05
Total		5.0E-05	1.7E-06	5.1E-05

(a) - Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.

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216-Z-9 Trench - Residential Exposures to Soil

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Table 26. 216-Z-9 Trench, Residential Exposures.

Incidental Ingestion of Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = CS x SIFnc x ABSo / RfD
Cancer Risk = CS x SIFc x ABSo x CSF
Non-Cancer Cleanup Level = (THQ x RfD) / (SIFnc x ABSo)
Cancer Cleanup Level = (TCR) / (SIFc x CSF x ABSo)

Parameter	Units	RME Child	RME Adult
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Ingestion Rate of Soil (IR)	mg/day	200	100
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	6	24
Conversion Factor (CF)	kg/mg	1.00E-06	1.00E-06
Body Weight (BW)	kg	15	70
Averaging Time (non-cancer) (ATnc)	days	2,190	8,760
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc = (IR*EF*ED*CF)/(BW*AT)	$(day)^{-1}$	1.28E-05	1.37E-06
IngFadj (Ingestion Adjusted Factor)= (IRch*EDch/BWch)+(IRa*EDa/BWa)	mg-yr/ day-kg	114.29	
SIFc = (IngFadj*EF*CF)/ATc	$(day)^{-1}$	1.57E-06	

Chemical	RfD-O (mg/kg-d)	CSF-O $(mg/kg\text{-}d)^{-1}$	ABSo unitless
Cadmium	1.0E-03	--	1
Carbon tetrachloride	7.0E-04	1.3E-01	1
Manganese	7.0E-02	--	1

Risk Calculations - Reasonable Maximum Exposure

Chemical	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ adult	Risk child/adult Lifetime
Cadmium (a)	2.85	3.64E-05	3.90E-06	4.46E-06	0.036	0.0039	--
Carbon tetrachloride	12.67	1.62E-04	1.74E-05	1.98E-05	0.23	0.025	2.6E-06
Manganese (a)	94.05	1.20E-03	1.29E-04	1.47E-04	0.017	0.0018	--
Total					**0.29**	**0.031**	**2.6E-06**

(a) - The cancer slope factor is not available for this chemical to quantify cancer risks.

A-Attach 6-61

Table 27. 216-Z-9 Trench, Residential Exposures. (2 sheets)

Dermal Contact with Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = CS x SIFnc x Absd / RfD

Cancer Risk = CS x SIFc x Absd x CSF

Parameter	Units	RME child	RME adult
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	6	24
Surface Area Available for Contact (SA)	cm^2/day	2800	5700
Adherence Factor (AF)	mg/cm^2	0.2	0.07
Fraction of day for dermal exposures (FC)	unitless	1	1
Conversion Factor (CF)	kg/mg	1.0E-06	1.0E-06
Body Weight (BW)	kg	15	70
Averaging Time (non-cancer) (ATnc)	days	2190	8760
Averaging Time (cancer) (ATc)	days	25550	25550
SIFnc = (EF*ED*SA*AF*FC*CF)/(BW*ATnc)	$(day)^{-1}$	3.58E-05	5.47E-06
DFadj (Dermal Adjusted Factor) = (EDch*SAch*AFch /BWch) +(EDa*SAa*AFa/BWa)	mg-yr/day-kg	360.80	
SIFc = (DFadj*EF*FC*CF)/ATc	$(day)^{-1}$	4.94E-06	

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$	AbsD
Cadmium	2.5E-05	--	1.0E-03
Carbon tetrachloride	7.0E-04	1.3E-01	--
Manganese	2.8E-03	--	--

A-Attach 6-62

Table 27. 216-Z-9 Trench, Residential Exposures. (2 sheets)

Chemical	Risk Calculations - Reasonable Maximum Exposure						
	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ adult	Risk child/adult Lifetime
Cadmium (b)	2.85	1.02E-07	1.56E-08	1.41E-08	0.0041	0.00062	--
Carbon tetrachloride (a)	12.67	--	--	--	--	--	--
Manganese (a)	94.05	--	--	--	--	--	--
Total					**0.0041**	**0.00062**	--

(a) - The absorption factor is not available for this chemical to quantify hazards or risks.
(b) - The cancer slope factor is not available for this chemical to quantify cancer risks.

Table 28. 216-Z-9 Trench, Residential Exposures.

Inhalation of Fugitive Dust or Volatiles from Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = (CS x SIFnc) / (RfD x PEF(or VF))
Cancer Risk = CS x SIFc x CSF / PEF(or VF)
Non-Cancer Cleanup Level = (THQ x RfD x PEF) / (SIFnc)
Cancer Cleanup Level = (TCR x PEF) / (SIFc x CSF)

Parameter	Units	RME Adult	RME Child
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Inhalation Rate of Air (Inh)	m^3/day	20	10
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	24	6
Body Weight (BW)	kg	70	15
Averaging Time (non-cancer) (ATnc)	days	8760	2190
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc (child) = ((Inh-c*EF* EDc) /(BWc*ATnc-c))	m3/kg-d	6.39E-01	
InhFadj (Inhalation Adjusted Factor)= (Inh-c*EDc/BWc) + (Inh-a*EDa/BWa)	m3/kg-y	1.09E+01	
SIFnc (child/adult) = ((InhFadj*EF)/(ATnc))	m3/kg-d	3.47E-01	
SIFc (child/adult) = ((InhFadj*EF)/(ATc))	m3/kg-d	1.49E-01	

Chemical	RfD-I (mg/kg-d)	CSF-I $(mg/kg\text{-}d)^{-1}$	VF/PEF m3/kg
Cadmium	--	6.3E+00	2.7E+09
Carbon tetrachloride	--	5.3E-02	2.2E+03
Manganese	1.4E-05	--	2.7E+09

Chemical	Risk Calculations - Reasonable Maximum Exposure						
	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ adult	Risk child/adult Lifetime
Cadmium (a)	2.85	6.7E-10	3.6E-10	1.6E-10	--	--	9.83E-10
Carbon tetrachloride (a)	12.67	3.7E-03	2.0E-03	8.6E-04	--	--	4.54E-05
Manganese (b)	94.05	2.2E-08	1.2E-08	5.2E-09	0.0016	0.00086	--
Total					0.002	0.001	4.5E-05

(a) - The reference dose is not available for this chemical to quantify hazards.
(b) - The cancer slope factor is not available for this chemical to quantify cancer risks.

A-Attach 6-64

216-Z-9 Trench - Well Driller Exposures to Soil

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Table 29. 216-Z-9 Trench, Well Driller Exposures.

Incidental Ingestion of Soil
Future

Exposure Medium: Soil
Receptor Population: Well Driller
Receptor Age: Adults
Exposure Point: Well Tailings

Non-Cancer Hazard = CS x SIFnc x ABSo / RfD
Cancer Risk = CS x SIFc x ABSo x CSF
Non-Cancer Cleanup Level = (THQ x RfD) / (SIFnc x ABSo)
Cancer Cleanup Level = (TCR) / (SIFc x CSF x ABSo)

Parameter	Units	RME Value
Chemical Concentration in Soil (CS)	mg/kg	chem-specific
Ingestion Rate of Soil (IR-S)	mg/day	100
Exposure Frequency (EF)	days/yr	5
Exposure Duration (ED)	years	1
Conversion Factor (CF)	kg/mg	1.0E-06
Body Weight (BW)	kg	70
Averaging Time (non-cancer) (ATnc)	days	365
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = ((IR-S*EF*ED*CF)/(BW*ATnc))		1.96E-08
SIFc = ((IR-S*EF*ED*CF)/(BW*ATc))		2.80E-10
Target Hazard	unitless	1.00E+00
Target Risk	unitless	1.00E-04

Chemical	RfD-O (mg/kg-d)	CSF-O $(mg/kg\text{-}d)^{-1}$	ABSo unitless
Cadmium	1.0E-03	--	1
Carbon tetrachloride	1.0E-02	1.3E-01	1
Manganese	7.0E-02	--	1

Chemical	Risk Calculations - Reasonable Maximum Exposure				
	CS (mg/kg)	Intake nc (mg/kg-d)	Intake c (mg/kg-d)	Hazard Quotient	Cancer Risk
Cadmium (a)	8.12	1.59E-07	2.27E-09	0.00016	--
Carbon tetrachloride	36.07	7.06E-07	1.01E-08	0.000071	1.3E-09
Manganese (a)	267.78	5.24E-06	7.49E-08	0.000075	--
Total				0.00030	1.3E-09

(a) - The cancer slope factor is not available for this chemical to quantify cancer risks.

Table 30. 216-Z-9 Trench, Well Driller Exposures.

Dermal Contact with Soil
Future

Exposure Medium: Soil
Receptor Population: Well Driller
Receptor Age: Adults
Exposure Point: Well Tailings

Non-Cancer Hazard = CS x SIFnc x Absd/ RfD
Cancer Risk = CS x SIFc x Absd x CSF
Non-Cancer Cleanup Level = (THQ x RfD) / (SIFnc x ABSd)
Cancer Cleanup Level = (TCR) / (SIFc x CSF x ABSd)

Parameter	Units	RME Value
Chemical Concentration in Soil (CS)	mg/kg	chem-specific
Adherence Factor (AF)	mg/cm^2-event	0.2
Exposure Frequency (EF)	days/yr	5
Exposure Duration (ED)	years	1
Surface Area Available for Contact (SA)	cm^2	3,300
Conversion Factor (CF)	kg/mg	1.0E-06
Dermal Absorption (AbsD)	unitless	chem-specific
Body Weight (BW)	kg	70
Averaging Time (non-cancer) (ATnc)	days	365
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = ((EF*ED*SA*AF*CF)/(BW*ATnc))		1.29E-07
SIFc = ((EF*ED*SA*AF*CF)/(BW*ATc))		1.85E-09
Target Hazard	unitless	1.00E+00
Target Risk	unitless	1.00E-04

Chemical	RfD-D (mg/kg-d)	CSF-D (mg/kg-d)$^{-1}$	AbsD
Cadmium	2.5E-05	--	1.0E-03
Carbon tetrachloride	1.0E-02	1.3E-01	--
Manganese	2.8E-03	--	--

Chemical	Risk Calculations - Reasonable Maximum Exposure				
	CS (mg/kg)	Intake nc (mg/kg-d)	Intake c (mg/kg-d)	Hazard Quotient	Cancer Risk
Cadmium (b)	8.12	1.05E-09	1.50E-11	0.000042	--
Carbon tetrachloride (a)	36.07	--	--	--	--
Manganese (a)	267.78	--	--	--	--
Total				0.000042	--

(a) - The absorption factor is not available for this chemical to quantify hazards or risks.
(b) - The cancer slope factor is not available for this chemical to quantify cancer risks.

Table 31. 216-Z-9 Trench, Well Driller Exposures. (2 sheets)

Inhalation of Fugitive Dust or Volatiles from Soil

Future

Exposure Medium: Soil
Receptor Population: Well Driller
Receptor Age: Adults
Exposure Point: Well Tailings

Non-Cancer Hazard = (CS x SIFnc) / (RfD x PEF(or VF))

Cancer Risk = CS x SIFc x CSF / PEF(or VF)

Non-Cancer Cleanup Level = (THQ x RfD x PEF) / (SIFnc)

Cancer Cleanup Level = (TCR x PEF) / (SIFc x CSF)

Parameter	Units	RME Value
Chemical Concentration in Soil (Csoil)	mg/kg	chem-specific
Inhalation Rate of Air (Inh)	m^3/day	20
Exposure Frequency (EF)	days/yr	5
Exposure Duration (ED)	years	1
Body Weight (BW)	kg	70
Averaging Time (non-cancer) (ATnc)	days	365
Averaging Time (cancer) (ATc)	days	25,550
SIFnc = ((Inh*EF*ED)/(BW*ATnc))		3.91E-03
SIFc = ((Inh*EF*ED)/(BW*ATc))		5.59E-05
Target Hazard	unitless	1.00E+00
Target Risk	unitless	1.00E-04

Chemical	RfD-I (mg/kg-d)	CSF-I $(mg/kg\text{-}d)^{-1}$	PEF/VF m3/kg
Cadmium	--	6.3E+00	2.7E+09
Carbon tetrachloride	--	5.3E-02	5.0E+01
Manganese	1.4E-05	--	2.7E+09

Table 31. 216-Z-9 Trench, Well Driller Exposures. (2 sheets)

Chemical	Risk Calculations - Reasonable Maximum Exposure				
	Csoil mg/kg	**Intake nc** (mg/kg-d)	**Intake c** (mg/kg-d)	**Hazard Quotient**	**Cancer Risk**
Cadmium (a)	8.12	1.2E-11	1.7E-13	--	1.1E-12
Carbon tetrachloride (a)	36.07	2.8E-03	4.0E-05	--	2.1E-06
Manganese (b)	267.78	3.9E-10	5.5E-12	0.000028	--
Total				0.000028	2.1E-06

(a) - The reference dose is not available for this chemical to quantify hazards.

(b) - The cancer slope factor is not available for this chemical to quantify cancer risks.

216-A-8 Crib - Residential Exposures to Soil

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Table 32. 216-A-8 Crib, Residential Exposures. (2 sheets)

Incidental Ingestion of Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = CS x SIFnc x ABSo / RfD
Cancer Risk = CS x SIFc x ABSo x CSF
Non-Cancer Cleanup Level = (THQ x RfD) / (SIFnc x ABSo)
Cancer Cleanup Level = (TCR) / (SIFc x CSF x ABSo)

Parameter	Units	RME Child	RME Adult
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Ingestion Rate of Soil (IR)	mg/day	200	100
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	6	24
Conversion Factor (CF)	kg/mg	1.00E-06	1.00E-06
Body Weight (BW)	kg	15	70
Averaging Time (non-cancer) (ATnc)	days	2,190	8,760
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc = (IR*EF*ED*CF)/(BW*AT)	$(day)^{-1}$	1.28E-05	1.37E-06
IngFadj (Ingestion Adjusted Factor)= (IRch*EDch/BWch)+(IRa*EDa/BWa)	mg-yr/day-kg	114.29	
SIFc = (IngFadj*EF*CF)/ATc	$(day)^{-1}$	1.57E-06	

Chemical	RfD-O (mg/kg-d)	CSF-O $(mg/kg\text{-}d)^{-1}$	ABSo unitless
Thallium	6.6E-05	--	1

Table 32. 216-A-8 Crib, Residential Exposures. (2 sheets)

Chemical	Risk Calculations - Reasonable Maximum Exposure						
	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc child/adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ child/adult	Risk child/adult Lifetime
Thallium (a)	0.19	2.43E-06	2.60E-07	2.97E-07	0.037	0.0039	--
Total					**0.037**	**0.0039**	--

(a) - The cancer slope factor is not available for this chemical to quantify cancer risks.

Table 33. 216-A-8 Crib, Residential Exposures.

Dermal Contact with Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = CS x SIFnc x Absd / RfD
Cancer Risk = CS x SIFc x Absd x CSF

Parameter	Units	RME child	RME adult
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	6	24
Surface Area Available for Contact (SA)	cm^2/day	2800	5700
Adherence Factor (AF)	mg/cm^2	0.2	0.07
Fraction of day for dermal exposures (FC)	unitless	1	1
Conversion Factor (CF)	kg/mg	1.0E-06	1.0E-06
Body Weight (BW)	kg	15	70
Averaging Time (non-cancer) (ATnc)	days	2190	8760
Averaging Time (cancer) (ATc)	days	25550	25550
SIFnc = (EF*ED*SA*AF*FC*CF)/(BW*ATnc)	$(day)^{-1}$	3.58E-05	5.47E-06
DFadj (Dermal Adjusted Factor) = (EDch*SAch*AFch /BWch) +(EDa*SAa*AFa/BWa)	mg-yr/day-kg	360.80	
SIFc = (DFadj*EF*FC*CF)/ATc	$(day)^{-1}$	4.94E-06	

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$	AbsD
Thallium	6.6E-05	--	--

Chemical	Risk Calculations - Reasonable Maximum Exposure						
	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc child/adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ child/adult	Risk child/adult Lifetime
Thallium (a)	0.19	--	--	--	--	--	--
Total					--	--	--

(a) - The absorption factor is not available for this chemical to quantify hazards or risks.

Table 34: 216-A-8 Crib, Residential Exposures

Inhalation of Fugitive Dust or Volatiles from Soil
Future

Exposure Medium: Surface Soil
Exposure Point: Residential Yard/Garden
Receptor Population: Residential Farmer
Receptor Age: Children and Adults

Non-Cancer Hazard = (CS x SIFnc) / (RfD x PEF(or VF))
Cancer Risk = CS x SIFc x CSF / PEF(or VF)

Parameter	Units	RME Adult	RME Child
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific
Inhalation Rate of Air (Inh)	m^3/day	20	10
Exposure Frequency (EF)	days/yr	350	350
Exposure Duration (ED)	years	24	6
Body Weight (BW)	kg	70	15
Averaging Time (non-cancer) (ATnc)	days	8760	2190
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc (child) = ((Inh-c*EF* EDc) /(BWc*ATnc-c))	m3/kg-d		6.39E-01
InhFadj (Inhalation Adjusted Factor)= (Inh-c*EDc/BWc) + (Inh-a*EDa/BWa)	m3/kg-y	1.09E+01	
SIFnc (child/adult) = ((InhFadj*EF)/(ATnc))	m3/kg-d	3.47E-01	
SIFc (child/adult) = ((InhFadj*EF)/(ATc))	m3/kg-d	1.49E-01	

Chemical	RfD-I (mg/kg-d)	CSF-I $(mg/kg\text{-}d)^{-1}$	PEF m3/kg
Thallium	--	--	2.7E+09

Chemical	CS (mg/kg)	Intake nc child (mg/kg-d)	Intake nc child/adult (mg/kg-d)	Intake c child/adult Lifetime (mg/kg-d)	HQ child	HQ child/adult	Risk child/adult Lifetime
	Risk Calculations - Reasonable Maximum Exposure						
Thallium (a)	0.19	4.5E-11	2.4E-11	1.0E-11	--	--	--
Total					--	--	--

(a) - The reference dose and slope factor are not available for this chemical to quantify hazards and risks.

APPENDIX A

ATTACHMENT 7

SOIL RESRAD RISK SUMMARY TABLES

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ATTACHMENT 7
TABLE OF CONTENTS

216-Z-1A TILE FIELD – SUMMARY OF RISKS

Table 1 Residential Farmer from Soil - 150 years
Table 2 Residential Farmer from Soil - 500 years
Table 3 Residential Farmer from Soil - 1,000 years
Table 4 Residential Farmer from Produce - 150 years
Table 5 Residential Farmer from Produce - 500 years
Table 6 Residential Farmer from Produce - 1000 years
Table 7 Residential Farmer from Radon - 150 years
Table 8 Residential Farmer from Radon - 500 years
Table 9 Residential Farmer from Radon - 1,000 years
Table 10 Residential Farmer from External Radiation - 150 years
Table 11 Residential Farmer from External Radiation - 500 years
Table 12 Residential Farmer from External Radiation - 1,000 years
Table 13 Well Driller from Soil - 150 years
Table 14 Well Driller from Soil - 500 years
Table 15 Well Driller from Soil - 1000 years
Table 16 Well Driller from Radon - 150 years
Table 17 Well Driller from Radon - 500 years
Table 18 Well Driller from Radon - 1000 years
Table 19 Well Driller from External Radiation - 150 years
Table 20 Well Driller from External Radiation - 500 years
Table 21 Well Driller from External Radiation - 1000 years
Table 22 Construction Worker from Soil - Now
Table 23 Construction Worker from Soil – 17 years
Table 24 Construction Worker from Soil – 28 years
Table 25 Construction Worker from Soil – 150 years
Table 26 Construction Worker from Soil – 500 years
Table 27 Construction Worker from Soil – 1000 years
Table 28 Construction Worker from Radon - Now
Table 29 Construction Worker from Radon – 17 years
Table 30 Construction Worker from Radon – 28 years
Table 31 Construction Worker from Radon – 150 years
Table 32 Construction Worker from Radon – 500 years
Table 33 Construction Worker from Radon – 1000 years
Table 34 Construction Worker from External Radiation - Now
Table 35 Construction Worker from External Radiation – 17 years
Table 36 Construction Worker from External Radiation – 28 years
Table 37 Construction Worker from External Radiation – 150 years
Table 38 Construction Worker from External Radiation – 500 years
Table 39 Construction Worker from External Radiation – 1000 years

216-Z-8 FRENCH DRAIN – SUMMARY OF RISKS

Table 40 Residential Farmer from Soil - 150 years
Table 41 Residential Farmer from Soil - 500 years
Table 42 Residential Farmer from Soil - 1000 years
Table 43 Residential Farmer from Produce - 150 years
Table 44 Residential Farmer from Produce - 500 years
Table 45 Residential Farmer from Produce - 1000 years
Table 46 Residential Farmer from Radon - 150 years
Table 47 Residential Farmer from Radon - 500 years
Table 48 Residential Farmer from Radon - 1000 years
Table 49 Residential Farmer from External Radiation - 150 years
Table 50 Residential Farmer from External Radiation - 500 years
Table 51 Residential Farmer from External Radiation - 1000 years
Table 52 Well Driller from Soil - 150 years
Table 53 Well Driller from Soil - 500 years
Table 54 Well Driller from Soil - 1000 years
Table 55 Well Driller from Radon - 150 years
Table 56 Well Driller from Radon - 500 years
Table 57 Well Driller from Radon - 1000 years
Table 58 Well Driller from External Radiation - 150 years
Table 59 Well Driller from External Radiation - 500 years
Table 60 Well Driller from External Radiation - 1000 years
Table 61 Construction Worker from Soil - Now
Table 62 Construction Worker from Soil – 17 years
Table 63 Construction Worker from Soil – 28 years
Table 64 Construction Worker from Soil – 150 years
Table 65 Construction Worker from Soil – 500 years
Table 66 Construction Worker from Soil – 1000 years
Table 67 Construction Worker from Radon - Now
Table 68 Construction Worker from Radon – 17 years
Table 69 Construction Worker from Radon – 28 years
Table 70 Construction Worker from Radon – 150 years
Table 71 Construction Worker from Radon – 500 years
Table 72 Construction Worker from Radon – 1000 years
Table 73 Construction Worker from External Radiation - Now
Table 74 Construction Worker from External Radiation – 17 years
Table 75 Construction Worker from External Radiation – 28 years
Table 76 Construction Worker from External Radiation – 150 years
Table 77 Construction Worker from External Radiation – 500 years
Table 78 Construction Worker from External Radiation – 1000 years

216-Z-9 TRENCH – SUMMARY OF RISKS

Table 79 Residential Farmer from Soil - 150 years
Table 80 Residential Farmer from Soil - 500 years
Table 81 Residential Farmer from Soil - 1000 years
Table 82 Residential Farmer from Plant - 150 years
Table 83 Residential Farmer from Plant - 500 years
Table 84 Residential Farmer from Plant - 1000 years
Table 85 Residential Farmer from Radon - 150 years
Table 86 Residential Farmer from Radon - 500 years
Table 87 Residential Farmer from Radon - 1000 years
Table 88 Residential Farmer from External Radiation - 150 years
Table 89 Residential Farmer from External Radiation - 500 years
Table 90 Residential Farmer from External Radiation - 1000 years
Table 91 Well Driller from Soil - 150 years
Table 92 Well Driller from Soil - 500 years
Table 93 Well Driller from Soil - 1000 years
Table 94 Well Driller from Radon - 150 years
Table 95 Well Driller from Radon - 500 years
Table 96 Well Driller from Radon - 1000 years
Table 97 Well Driller from External Radiation - 150 years
Table 98 Well Driller from External Radiation - 500 years
Table 99 Well Driller from External Radiation - 1000 years

216-A-8 CRIB – SUMMARY OF RISKS

Table 100 Residential Farmer from Soil - 150 years
Table 101 Residential Farmer from Soil - 500 years
Table 102 Residential Farmer from Soil - 1000 years
Table 103 Residential Farmer from Produce - 150 years
Table 104 Residential Farmer from Produce - 500 years
Table 105 Residential Farmer from Produce - 1000 years
Table 106 Residential Farmer from Radon - 150 years
Table 107 Residential Farmer from Radon - 500 years
Table 108 Residential Farmer from Radon - 1000 years
Table 109 Residential Farmer from External Radiation - 150 years
Table 110 Residential Farmer from External Radiation - 500 years
Table 111 Residential Farmer from External Radiation - 1000 years
Table 112 Well Driller from Soil - 150 years
Table 113 Well Driller from Soil - 500 years
Table 114 Well Driller from Soil - 1000 years
Table 115 Well Driller from Radon - 150 years
Table 116 Well Driller from Radon - 500 years
Table 117 Well Driller from Radon - 1000 years
Table 118 Well Driller from External Radiation - 150 years
Table 119 Well Driller from External Radiation - 500 years

Table 120 Well Driller from External Radiation - 1000 years
Table 121 Construction Worker from Soil - Now
Table 122 Construction Worker from Soil – 17 years
Table 123 Construction Worker from Soil – 28 years
Table 124 Construction Worker from Soil – 150 years
Table 125 Construction Worker from Soil – 500 years
Table 126 Construction Worker from Soil – 1000 years
Table 127 Construction Worker from Radon - Now
Table 128 Construction Worker from Radon – 17 years
Table 129 Construction Worker from Radon – 28 years
Table 130 Construction Worker from Radon – 150 years
Table 131 Construction Worker from Radon – 500 years
Table 132 Construction Worker from Radon – 1000 years
Table 133 Construction Worker from External Radiation - Now
Table 134 Construction Worker from External Radiation – 17 years
Table 135 Construction Worker from External Radiation – 28 years
Table 136 Construction Worker from External Radiation – 150 years
Table 137 Construction Worker from External Radiation – 500 years
Table 138 Construction Worker from External Radiation – 1000 years

216-Z-1A Tile Field – Residential

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Table 1. Summary of Risks for the Residential Farmer from Soil - 150 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-14	2E-16	2E-14
Am-241	4E-05	4E-07	4E-05
Np-237	4E-09	5E-11	4E-09
Pa-231	3E-14	4E-16	3E-14
Pu-239	1E-03	1E-05	9E-04
Pu-240	2E-04	3E-06	2E-04
Ra-228	2E-18	3E-21	2E-18
Th-228	6E-19	8E-21	6E-19
Th-229	2E-15	2E-17	2E-15
Th-232	4E-19	5E-21	4E-19
U-233	2E-13	2E-15	2E-13
U-235	6E-11	6E-13	5E-11
U-236	3E-10	4E-12	3E-10
Total	1E-03	1E-05	1E-03

Table 2. Summary of Risks for the Residential Farmer from Soil - 500 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-14	1E-16	1E-14
Am-241	4E-05	4E-07	4E-05
Np-237	4E-09	5E-11	4E-09
Pa-231	1E-14	2E-16	1E-14
Pu-239	6E-04	7E-06	6E-04
Pu-240	1E-04	2E-06	1E-04
Ra-228	3E-17	4E-20	3E-17
Th-228	9E-18	1E-19	9E-18
Th-229	3E-14	4E-16	3E-14
Th-232	4E-18	5E-20	4E-18
U-233	1E-14	1E-16	1E-14
U-235	9E-12	9E-14	9E-12
U-236	6E-11	6E-13	6E-11
Total	8E-04	9E-06	8E-04

Table 3. Summary of Risks for the Residential Farmer from Soil - 1,000 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	6E-15	8E-17	6E-15
Am-241	4E-05	4E-07	4E-05
Np-237	4E-09	5E-11	4E-09
Pa-231	8E-15	1E-16	8E-15
Pu-239	4E-04	5E-06	4E-04
Pu-240	8E-05	1E-06	8E-05
Ra-228	4E-17	5E-20	4E-17
Th-228	1E-17	2E-19	1E-17
Th-229	3E-14	4E-16	3E-14
Th-232	5E-18	7E-20	5E-18
U-233	3E-16	4E-18	3E-16
U-235	6E-12	6E-14	6E-12
U-236	3E-11	4E-13	3E-11
Total	5E-04	6E-06	5E-04

Table 4. Summary of Risks for the Residential Farmer from Produce - 150 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Produce
Ac-227	3E-13
Am-241	3E-04
Np-237	6E-07
Pa-231	2E-12
Pu-239	7E-03
Pu-240	2E-03
Ra-228	7E-16
Th-228	7E-18
Th-229	1E-14
Th-232	3E-18
U-233	4E-12
U-235	1E-09
U-236	6E-09
Total	9E-03

Table 5. Summary of Risks for the Residential Farmer from Produce - 500 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Produce
Ac-227	2E-13
Am-241	2E-24
Np-237	9E-09
Pa-231	9E-13
Pu-239	4E-03
Pu-240	9E-04
Ra-228	9E-15
Th-228	1E-16
Th-229	2E-13
Th-232	3E-17
U-233	2E-13
U-235	2E-10
U-236	1E-09
Total	5E-03

Table 6. Summary of Risks for the Residential Farmer from Produce - 1000 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Produce
Ac-227	1E-13
Am-241	0E+00
Np-237	3E-10
Pa-231	6E-13
Pu-239	3E-03
Pu-240	6E-04
Ra-228	1E-14
Th-228	1E-16
Th-229	2E-13
Th-232	4E-17
U-233	6E-15
U-235	1E-10
U-236	6E-10
Total	3E-03

Table 7. Summary of Risks for the Residential Farmer from Radon - 150 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-18
Po-216	9E-20
Pb-212	3E-18
Bi-212	2E-18
Total	1E-17

Table 8. Summary of Risks for the Residential Farmer from Radon - 500 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-16
Po-216	1E-18
Pb-212	5E-17
Bi-212	3E-17
Total	2E-16

Table 9. Summary of Risks for the Residential Farmer from Radon - 1,000 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-16
Po-216	2E-18
Pb-212	8E-17
Bi-212	4E-17
Total	3E-16

Table 10. Summary of Risks for the Residential Farmer from External Radiation - 150 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	6E-12
Am-241	1E-03
Np-237	6E-06
Pa-231	3E-12
Pu-239	2E-04
Pu-240	2E-05
Ra-228	1E-15
Th-228	2E-15
Th-229	5E-13
Th-232	2E-19
U-233	4E-13
U-235	5E-08
U-236	9E-11
Total	2E-03

Table 11. Summary of Risks for the Residential Farmer from External Radiation - 500 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	4E-12
Am-241	1E-23
Np-237	1E-07
Pa-231	1E-12
Pu-239	1E-04
Pu-240	1E-05
Ra-228	2E-14
Th-228	2E-14
Th-229	8E-12
Th-232	2E-18
U-233	2E-14
U-235	9E-09
U-236	1E-11
Total	1E-04

Table 12. Summary of Risks for the Residential Farmer from External Radiation - 1,000 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	2E-12
Am-241	0E+00
Np-237	3E-09
Pa-231	9E-13
Pu-239	8E-05
Pu-240	6E-06
Ra-228	2E-14
Th-228	4E-14
Th-229	8E-12
Th-232	2E-18
U-233	6E-16
U-235	6E-09
U-236	9E-12
Total	8E-05

216-Z-1A Tile Field – Well Driller

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Table 13. Summary of Risks for the Well Driller from Soil - 150 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-20	5E-22	2E-20
Am-241	5E-08	9E-10	5E-08
Np-237	2E-12	4E-14	2E-12
Pa-231	8E-19	2E-20	8E-19
Pu-239	4E-07	9E-09	4E-07
Pu-240	1E-07	2E-09	1E-07
Ra-228	3E-24	7E-27	3E-24
Th-228	8E-26	2E-27	8E-26
Th-229	1E-21	2E-23	1E-21
Th-232	8E-24	2E-25	8E-24
U-233	5E-18	9E-20	4E-18
U-235	3E-14	6E-16	3E-14
U-236	2E-13	4E-15	2E-13
Total	6E-07	1E-08	6E-07

Table 14. Summary of Risks for the Well Driller from Soil - 500 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-19	2E-21	1E-19
Am-241	0E+00	0E+00	0E+00
Np-237	3E-17	7E-19	3E-17
Pa-231	3E-19	7E-21	3E-19
Pu-239	1E-07	3E-09	1E-07
Pu-240	3E-08	6E-10	3E-08
Ra-228	3E-21	7E-24	3E-21
Th-228	9E-22	2E-23	9E-22
Th-229	2E-18	4E-20	2E-18
Th-232	5E-22	1E-23	5E-22
U-233	2E-21	4E-23	2E-21
U-235	7E-16	1E-17	7E-16
U-236	4E-15	8E-17	4E-15
Total	2E-07	4E-09	2E-07

Table 15. Summary of Risks for the Well Driller from Soil - 1,000 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-20	6E-22	3E-20
Am-241	0E+00	0E+00	0E+00
Np-237	1E-21	2E-23	9E-22
Pa-231	8E-20	2E-21	8E-20
Pu-239	3E-08	7E-10	3E-08
Pu-240	7E-09	2E-10	7E-09
Ra-228	4E-21	8E-24	4E-21
Th-228	1E-21	2E-23	1E-21
Th-229	2E-18	3E-20	1E-18
Th-232	5E-22	1E-23	5E-22
U-233	5E-26	1E-27	5E-26
U-235	2E-16	3E-18	2E-16
U-236	1E-15	2E-17	1E-15
Total	4E-08	9E-10	4E-08

Table 16. Summary of Risks for the Well Driller from Radon - 150 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	6E-24
Po-216	8E-26
Pb-212	1E-26
Bi-212	6E-31
Total	6E-24

Table 17. Summary of Risks for the Well Driller from Radon - 500 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-20
Po-216	9E-22
Pb-212	1E-22
Bi-212	1E-26
Total	7E-20

Table 18. Summary of Risks for the Well Driller from Radon - 1,000 years
216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	8E-20
Po-216	1E-21
Pb-212	1E-22
Bi-212	1E-26
Total	8E-20

Table 19. Summary of Risks for the Well Driller from External Radiation - 150 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	8E-18
Am-241	2E-06
Np-237	3E-09
Pa-231	8E-17
Pu-239	9E-08
Pu-240	1E-08
Ra-228	1E-21
Th-228	2E-22
Th-229	3E-19
Th-232	5E-24
U-233	8E-18
U-235	3E-11
U-236	7E-14
Total	3E-06

Table 20. Summary of Risks for the Well Driller from External Radiation - 500 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	4E-17
Am-241	0E+00
Np-237	5E-14
Pa-231	3E-17
Pu-239	3E-08
Pu-240	3E-09
Ra-228	1E-18
Th-228	2E-18
Th-229	4E-16
Th-232	3E-22
U-233	3E-21
U-235	7E-13
U-236	1E-15
Total	3E-08

Table 21. Summary of Risks for the Well Driller from External Radiation - 1,000 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	9E-18
Am-241	0E+00
Np-237	1E-18
Pa-231	8E-18
Pu-239	7E-09
Pu-240	8E-10
Ra-228	1E-18
Th-228	2E-18
Th-229	4E-16
Th-232	3E-22
U-233	9E-26
U-235	2E-13
U-236	4E-16
Total	8E-09

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216-Z-1A Tile Field – Construction Worker

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Table 22. Summary of Risks for the Construction Worker from Soil - Now 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	3E-18	5E-19	2E-18
Am-241	3E-03	5E-04	3E-03
Np-237	4E-10	6E-11	3E-10
Pa-231	1E-16	2E-17	1E-16
Pu-239	3E-02	5E-03	2E-02
Pu-240	6E-03	1E-03	5E-03
Ra-228	3E-22	6E-24	3E-22
Th-228	7E-24	1E-24	6E-24
Th-229	1E-19	2E-20	8E-20
Th-232	1E-21	2E-22	9E-22
U-233	5E-16	8E-17	5E-16
U-235	7E-12	1E-12	6E-12
U-236	5E-11	7E-12	4E-11
Total	4E-02	6E-03	3E-02

Table 23. Summary of Risks for the Construction Worker from Soil - 17 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	5E-14	9E-15	4E-14
Am-241	3E-03	5E-04	3E-03
Np-237	1E-08	2E-09	1E-08
Pa-231	1E-13	2E-14	9E-14
Pu-239	3E-02	5E-03	2E-02
Pu-240	6E-03	1E-03	5E-03
Ra-228	4E-18	8E-20	4E-18
Th-228	1E-18	2E-19	8E-19
Th-229	2E-15	3E-16	2E-15
Th-232	1E-18	2E-19	9E-19
U-233	5E-13	8E-14	4E-13
U-235	3E-10	4E-11	2E-10
U-236	2E-09	2E-10	1E-09
Total	4E-02	6E-03	3E-02

Table 24. Summary of Risks for the Construction Worker from Soil - 28 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	2E-13	4E-14	2E-13
Am-241	3E-03	4E-04	3E-03
Np-237	2E-08	3E-09	2E-08
Pa-231	3E-13	5E-14	2E-13
Pu-239	3E-02	5E-03	2E-02
Pu-240	6E-03	1E-03	5E-03
Ra-228	1E-17	3E-19	1E-17
Th-228	4E-18	7E-19	3E-18
Th-229	9E-15	1E-15	7E-15
Th-232	3E-18	5E-19	2E-18
U-233	1E-12	2E-13	1E-12
U-235	4E-10	6E-11	4E-10
U-236	3E-09	4E-10	2E-09
Total	4E-02	6E-03	3E-02

Table 25. Summary of Risks for the Construction Worker from Soil - 150 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	2E-11	3E-12	1E-11
Am-241	2E-03	3E-04	2E-03
Np-237	9E-08	2E-08	8E-08
Pa-231	8E-12	1E-12	7E-12
Pu-239	3E-02	4E-03	2E-02
Pu-240	6E-03	1E-03	5E-03
Ra-228	6E-16	1E-17	6E-16
Th-228	2E-16	4E-17	2E-16
Th-229	1E-12	2E-13	1E-12
Th-232	8E-17	1E-17	6E-17
U-233	3E-11	5E-12	3E-11
U-235	2E-09	3E-10	2E-09
U-236	1E-08	2E-09	1E-08
Total	3E-02	6E-03	3E-02

Table 26. Summary of Risks for the Construction Worker from Soil - 500 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	2E-10	4E-11	2E-10
Am-241	1E-03	2E-04	9E-04
Np-237	2E-07	4E-08	2E-07
Pa-231	9E-11	2E-11	7E-11
Pu-239	3E-02	4E-03	2E-02
Pu-240	6E-03	1E-03	5E-03
Ra-228	7E-15	1E-16	7E-15
Th-228	2E-15	4E-16	2E-15
Th-229	4E-11	6E-12	3E-11
Th-232	8E-16	1E-16	7E-16
U-233	3E-10	4E-11	2E-10
U-235	7E-09	1E-09	6E-09
U-236	4E-08	6E-09	4E-08
Total	3E-02	6E-03	3E-02

Table 27. Summary of Risks for the Construction Worker from Soil - 1,000 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	9E-10	1E-10	7E-10
Am-241	4E-04	6E-05	3E-04
Np-237	3E-07	5E-08	2E-07
Pa-231	3E-10	6E-11	3E-10
Pu-239	3E-02	4E-03	2E-02
Pu-240	5E-03	9E-04	4E-03
Ra-228	3E-14	5E-16	3E-14
Th-228	1E-14	2E-15	8E-15
Th-229	2E-10	4E-11	2E-10
Th-232	3E-15	5E-16	3E-15
U-233	8E-10	1E-10	7E-10
U-235	1E-08	2E-09	1E-08
U-236	8E-08	1E-08	7E-08
Total	3E-02	5E-03	3E-02

Table 28. Summary of Risks for the Construction Worker from Radon – Now 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-23
Po-216	3E-25
Pb-212	2E-25
Bi-212	9E-29
Total	2E-23

Table 29. Summary of Risks for the Construction Worker from Radon - 17 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-18
Po-216	5E-20
Pb-212	3E-20
Bi-212	1E-23
Total	3E-18

Table 30. Summary of Risks for the Construction Worker from Radon - 28 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-17
Po-216	2E-19
Pb-212	1E-19
Bi-212	5E-23
Total	1E-17

Table 31. Summary of Risks for the Construction Worker from Radon - 150 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	6E-16
Po-216	9E-18
Pb-212	7E-18
Bi-212	2E-21
Total	6E-16

Table 32. Summary of Risks for the Construction Worker from Radon - 500 years 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-15
Po-216	1E-16
Pb-212	8E-17
Bi-212	3E-20
Total	7E-15

Table 33. Summary of Risks for the Construction Worker from Radon - 1,000 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-14
Po-216	4E-16
Pb-212	3E-16
Bi-212	1E-19
Total	3E-14

Table 34. Summary of Risks for the Construction Worker from External Radiation – Now, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	1E-17
Am-241	1E-03
Np-237	6E-09
Pa-231	2E-16
Pu-239	6E-05
Pu-240	5E-06
Ra-228	2E-21
Th-228	3E-22
Th-229	3E-19
Th-232	6E-24
U-233	1E-17
U-235	9E-11
U-236	1E-13
Total	1E-03

Table 35. Summary of Risks for the Construction Worker from External Radiation - 17 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	2E-13
Am-241	1E-03
Np-237	2E-07
Pa-231	1E-13
Pu-239	6E-05
Pu-240	5E-06
Ra-228	3E-17
Th-228	4E-17
Th-229	7E-15
Th-232	6E-21
U-233	1E-14
U-235	3E-09
U-236	5E-12
Total	1E-03

Table 36. Summary of Risks for the Construction Worker from External Radiation - 28 years, 216-Z-1A Tile Field..

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	1E-12
Am-241	1E-03
Np-237	4E-07
Pa-231	4E-13
Pu-239	6E-05
Pu-240	5E-06
Ra-228	1E-16
Th-228	2E-16
Th-229	3E-14
Th-232	1E-20
U-233	3E-14
U-235	5E-09
U-236	8E-12
Total	1E-03

Table 37. Summary of Risks for the Construction Worker from External Radiation - 150 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	7E-11
Am-241	1E-03
Np-237	2E-06
Pa-231	1E-11
Pu-239	6E-05
Pu-240	5E-06
Ra-228	5E-15
Th-228	8E-15
Th-229	4E-12
Th-232	4E-19
U-233	7E-13
U-235	3E-08
U-236	4E-11
Total	1E-03

Table 38. Summary of Risks for the Construction Worker from External Radiation - 500 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	1E-09
Am-241	5E-04
Np-237	4E-06
Pa-231	1E-10
Pu-239	6E-05
Pu-240	5E-06
Ra-228	5E-14
Th-228	9E-14
Th-229	1E-10
Th-232	4E-18
U-233	6E-12
U-235	8E-08
U-236	1E-10
Total	6E-04

Table 39. Summary of Risks for the Construction Worker from External Radiation - 1,000 years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Radionuclide (Parent and Decay)
Ac-227	4E-09
Am-241	2E-04
Np-237	5E-06
Pa-231	4E-10
Pu-239	6E-05
Pu-240	5E-06
Ra-228	2E-13
Th-228	4E-13
Th-229	7E-10
Th-232	2E-17
U-233	2E-11
U-235	2E-07
U-236	2E-10
Total	2E-04

216-Z-8 French Drain – Residential

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Table 40. Summary of Risks for the Residential Farmer from Soil - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-18	2E-20	1E-18
Am-241	2E-08	3E-10	2E-08
Np-237	3E-12	3E-14	3E-12
Pa-231	3E-18	4E-20	3E-18
Pb-210	8E-18	3E-21	8E-18
Pu-238	7E-09	9E-11	7E-09
Pu-239	1E-06	2E-08	1E-06
Pu-240	3E-07	4E-09	3E-07
Ra-226	7E-18	1E-20	7E-18
Ra-228	2E-22	2E-25	2E-22
Th-228	4E-23	6E-25	4E-23
Th-229	1E-18	1E-20	1E-18
Th-230	4E-16	4E-18	4E-16
Th-232	4E-23	5E-25	4E-23
U-233	1E-16	2E-18	1E-16
U-234	2E-12	2E-14	2E-12
U-235	8E-15	8E-17	8E-15
U-236	5E-14	5E-16	5E-14
Total	2E-06	2E-08	2E-06

Table 41. Summary of Risks for the Residential Farmer from Soil - 500 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-17	2E-19	1E-17
Am-241	3E-28	0E+00	3E-28
Np-237	9E-14	1E-15	9E-14
Pa-231	2E-17	2E-19	2E-17
Pb-210	4E-16	1E-19	4E-16
Pu-238	9E-11	1E-12	9E-11
Pu-239	8E-07	1E-08	8E-07
Pu-240	2E-07	2E-09	2E-07
Ra-226	1E-16	2E-19	1E-16
Ra-228	3E-20	4E-23	3E-20
Th-228	9E-21	1E-22	9E-21
Th-229	4E-17	5E-19	4E-17
Th-230	1E-15	2E-17	1E-15
Th-232	4E-21	4E-23	3E-21
U-233	1E-17	2E-19	1E-17
U-234	5E-15	6E-17	5E-15
U-235	1E-14	1E-16	1E-14
U-236	8E-14	9E-16	8E-14
Total	1E-06	1E-08	1E-06

Table 42. Summary of Risks for the Residential Farmer from Soil - 1,000 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	9E-18	1E-19	9E-18
Am-241	0E+00	0E+00	0E+00
Np-237	3E-15	3E-17	3E-15
Pa-231	1E-17	1E-19	1E-17
Pb-210	4E-16	1E-19	4E-16
Pu-238	1E-12	1E-14	1E-12
Pu-239	5E-07	6E-09	5E-07
Pu-240	1E-07	1E-09	1E-07
Ra-226	1E-16	2E-19	1E-16
Ra-228	5E-20	6E-23	5E-20
Th-228	1E-20	2E-22	1E-20
Th-229	4E-17	5E-19	4E-17
Th-230	1E-15	2E-17	1E-15
Th-232	6E-21	7E-23	6E-21
U-233	4E-19	5E-21	4E-19
U-234	6E-17	7E-19	6E-17
U-235	8E-15	8E-17	8E-15
U-236	5E-14	5E-16	5E-14
Total	6E-07	8E-09	6E-07

Table 43. Summary of Risks for the Residential Farmer from Produce - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Produce
Ac-227	2E-17
Am-241	2E-07
Np-237	4E-10
Pa-231	2E-16
Pb-210	6E-16
Pu-238	5E-08
Pu-239	9E-06
Pu-240	2E-06
Ra-226	2E-15
Ra-228	5E-20
Th-228	5E-22
Th-229	8E-18
Th-230	3E-15
Th-232	3E-22
U-233	3E-15
U-234	4E-11
U-235	1E-13
U-236	9E-13
Total	1E-05

Table 44. Summary of Risks for the Residential Farmer from Produce - 500 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Produce
Ac-227	2E-16
Am-241	2E-27
Np-237	1E-11
Pa-231	1E-15
Pb-210	3E-14
Pu-238	6E-10
Pu-239	6E-06
Pu-240	1E-06
Ra-226	3E-14
Ra-228	9E-18
Th-228	1E-19
Th-229	3E-16
Th-230	1E-14
Th-232	2E-20
U-233	2E-16
U-234	9E-14
U-235	2E-13
U-236	1E-12
Total	7E-06

Table 45. Summary of Risks for the Residential Farmer from Produce – 1,000 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Produce
Ac-227	2E-16
Am-241	0E+00
Np-237	4E-13
Pa-231	8E-16
Pb-210	3E-14
Pu-238	8E-12
Pu-239	4E-06
Pu-240	8E-07
Ra-226	3E-14
Ra-228	1E-17
Th-228	2E-19
Th-229	3E-16
Th-230	1E-14
Th-232	4E-20
U-233	8E-18
U-234	1E-15
U-235	1E-13
U-236	8E-13
Total	4E-06

Table 46. Summary of Risks for the Residential Farmer from Radon - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	9E-15
Po-218	2E-14
Pb-214	2E-14
Bi-214	5E-14
Rn-220	5E-22
Po-216	7E-24
Pb-212	2E-22
Bi-212	1E-22
Total	1E-13

Table 47. Summary of Risks for the Residential Farmer from Radon - 500 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	1E-13
Po-218	3E-13
Pb-214	4E-13
Bi-214	7E-13
Rn-220	1E-19
Po-216	1E-21
Pb-212	5E-20
Bi-212	3E-20
Total	1E-12

Table 48. Summary of Risks for the Residential Farmer from Radon - 1,000 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	1E-13
Po-218	3E-13
Pb-214	4E-13
Bi-214	7E-13
Rn-220	2E-19
Po-216	2E-21
Pb-212	8E-20
Bi-212	5E-20
Total	1E-12

Table 49. Summary of Risks for the Residential Farmer from External Radiation - 150 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	7E-15
Am-241	1E-12
Np-237	2E-09
Pa-231	3E-15
Pb-210	7E-17
Pu-238	2E-10
Pu-239	2E-07
Pu-240	2E-08
Ra-226	2E-13
Ra-228	5E-18
Th-228	8E-18
Th-229	7E-15
Th-230	2E-15
Th-232	5E-22
U-233	3E-16
U-234	6E-14
U-235	2E-11
U-236	3E-14
Total	3E-07

Table 50. Summary of Risks for the Residential Farmer from External Radiation - 500 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	5E-15
Am-241	1E-26
Np-237	1E-10
Pa-231	2E-15
Pb-210	9E-17
Pu-238	7E-12
Pu-239	2E-07
Pu-240	1E-08
Ra-226	3E-13
Ra-228	2E-17
Th-228	2E-17
Th-229	1E-14
Th-230	2E-15
Th-232	2E-21
U-233	3E-17
U-234	2E-15
U-235	1E-11
U-236	2E-14
Total	2E-07

Table 51. Summary of Risks for the Residential Farmer from External Radiation - 1,000 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	3E-15
Am-241	0E+00
Np-237	4E-12
Pa-231	1E-15
Pb-210	9E-17
Pu-238	9E-14
Pu-239	1E-07
Pu-240	8E-09
Ra-226	3E-13
Ra-228	2E-17
Th-228	4E-17
Th-229	1E-14
Th-230	2E-15
Th-232	3E-21
U-233	8E-19
U-234	3E-17
U-235	8E-12
U-236	1E-14
Total	1E-07

216-Z-8 French Drain – Well Driller

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Table 52. Summary of Risks for the Well Driller from Soil - 150 years
216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	6E-26	1E-27	6E-26
Am-241	3E-11	5E-13	3E-11
Np-237	1E-15	3E-17	1E-15
Pa-231	3E-24	6E-26	3E-24
Pb-210	3E-25	2E-28	3E-25
Pu-238	4E-12	8E-14	4E-12
Pu-239	6E-10	1E-11	6E-10
Pu-240	1E-10	3E-12	1E-10
Ra-226	5E-24	2E-26	5E-24
Ra-228	8E-30	0E+00	8E-30
Th-228	0E+00	0E+00	0E+00
Th-229	8E-25	2E-26	8E-25
Th-230	8E-21	2E-22	8E-21
Th-232	2E-29	3E-31	2E-29
U-233	3E-21	7E-23	3E-21
U-234	1E-15	3E-17	1E-15
U-235	2E-19	3E-21	2E-19
U-236	1E-18	2E-20	1E-18
Total	8E-10	2E-11	8E-10

Table 53. Summary of Risks for the Well Driller from Soil - 500 years
216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-22	3E-24	1E-22
Am-241	0E+00	0E+00	0E+00
Np-237	5E-20	1E-21	5E-20
Pa-231	5E-22	1E-23	5E-22
Pb-210	2E-20	1E-23	2E-20
Pu-238	2E-14	5E-16	2E-14
Pu-239	2E-10	4E-12	2E-10
Pu-240	4E-11	9E-13	4E-11
Ra-226	6E-21	2E-23	6E-21
Ra-228	3E-24	6E-27	3E-24
Th-228	9E-25	2E-26	9E-25
Th-229	2E-21	5E-23	2E-21
Th-230	3E-19	5E-21	3E-19
Th-232	5E-25	1E-26	5E-25
U-233	3E-24	5E-26	3E-24
U-234	4E-19	8E-21	4E-19
U-235	1E-18	2E-20	1E-18
U-236	6E-18	1E-19	6E-18
Total	2E-10	5E-12	2E-10

Table 54. Summary of Risks for the Well Driller from Soil - 1,000 years
216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	4E-23	8E-25	4E-23
Am-241	0E+00	0E+00	0E+00
Np-237	1E-24	3E-26	1E-24
Pa-231	1E-22	3E-24	1E-22
Pb-210	1E-20	9E-24	1E-20
Pu-238	1E-16	2E-18	1E-16
Pu-239	5E-11	1E-12	5E-11
Pu-240	1E-11	2E-13	1E-11
Ra-226	6E-21	2E-23	6E-21
Ra-228	4E-24	8E-27	4E-24
Th-228	1E-24	3E-26	1E-24
Th-229	2E-21	5E-23	2E-21
Th-230	3E-19	5E-21	2E-19
Th-232	6E-25	1E-26	5E-25
U-233	7E-29	1E-30	7E-29
U-234	2E-21	4E-23	2E-21
U-235	3E-19	5E-21	3E-19
U-236	2E-18	3E-20	1E-18
Total	6E-11	1E-12	6E-11

Table 55. Summary of Risks for the Well Driller from Radon - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	3E-24
Po-218	2E-26
Pb-214	5E-30
Rn-220	1E-29
Total	3E-24

Table 56. Summary of Risks for the Well Driller from Radon - 500 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	4E-21
Po-218	2E-23
Pb-214	6E-27
Rn-220	7E-23
Po-216	9E-25
Pb-212	1E-25
Bi-212	9E-30
Total	4E-21

Table 57. Summary of Risks for the Well Driller from Radon - 1,000 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	4E-21
Po-218	2E-23
Pb-214	6E-27
Rn-220	8E-23
Po-216	1E-24
Pb-212	1E-25
Bi-212	1E-29
Total	4E-21

Table 58. Summary of Risks for the Well Driller from External Radiation - 150 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	2E-23
Am-241	2E-09
Np-237	2E-12
Pa-231	3E-22
Pb-210	7E-26
Pu-238	5E-13
Pu-239	1E-10
Pu-240	2E-11
Ra-226	1E-20
Ra-228	3E-27
Th-228	3E-28
Th-229	2E-22
Th-230	1E-20
Th-232	1E-29
U-233	6E-21
U-234	9E-16
U-235	2E-16
U-236	3E-19
Total	2.E-09

Table 59. Summary of Risks for the Well Driller from External Radiation - 500 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	5E-20
Am-241	0E+00
Np-237	7E-17
Pa-231	5E-20
Pb-210	4E-21
Pu-238	3E-15
Pu-239	4E-11
Pu-240	5E-12
Ra-226	1E-17
Ra-228	1E-21
Th-228	2E-21
Th-229	6E-19
Th-230	4E-19
Th-232	3E-25
U-233	5E-24
U-234	2E-19
U-235	1E-15
U-236	2E-18
Total	5.E-11

Table 60. Summary of Risks for the Well Driller from External Radiation - 1,000 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-20
Am-241	0E+00
Np-237	2E-21
Pa-231	1E-20
Pb-210	4E-21
Pu-238	1E-17
Pu-239	1E-11
Pu-240	1E-12
Ra-226	1E-17
Ra-228	1E-21
Th-228	2E-21
Th-229	5E-19
Th-230	4E-19
Th-232	3E-25
U-233	1E-28
U-234	1E-21
U-235	3E-16
U-236	5E-19
Total	1.E-11

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216-Z-8 French Drain – Construction Worker

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Table 61. Summary of Risks for the Construction Worker from Soil – Now 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	7E-23	7E-23	2E-24
Am-241	5E-08	5E-08	1E-09
Np-237	7E-15	7E-15	2E-16
Pa-231	3E-21	3E-21	7E-23
Pb-210	4E-26	2E-26	2E-26
Pu-238	1E-08	1E-08	3E-10
Pu-239	7E-07	6E-07	2E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	4E-24	3E-24	4E-25
Ra-228	1E-27	8E-28	2E-28
Th-228	2E-28	2E-28	4E-30
Th-229	2E-24	2E-24	4E-26
Th-230	4E-20	3E-20	9E-22
Th-232	3E-26	3E-26	6E-28
U-233	1E-20	9E-21	2E-22
U-234	1E-14	9E-15	2E-16
U-235	1E-16	1E-16	4E-18
U-236	1E-15	1E-15	3E-17
Total	9E-07	8E-07	2E-08

Table 62. Summary of Risks for the Construction Worker from Soil - 17 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-18	1E-18	3E-20
Am-241	5E-08	5E-08	1E-09
Np-237	2E-13	2E-13	5E-15
Pa-231	3E-18	3E-18	6E-20
Pb-210	2E-20	9E-21	7E-21
Pu-238	1E-08	1E-08	3E-10
Pu-239	7E-07	6E-07	2E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	7E-20	6E-20	9E-21
Ra-228	1E-23	1E-23	3E-24
Th-228	3E-23	3E-23	6E-25
Th-229	4E-20	4E-20	9E-22
Th-230	3E-17	3E-17	8E-19
Th-232	3E-23	3E-23	6E-25
U-233	9E-18	8E-18	2E-19
U-234	3E-13	3E-13	8E-15
U-235	5E-15	5E-15	1E-16
U-236	4E-14	3E-14	9E-16
Total	9E-07	8E-07	2E-08

Table 63. Summary of Risks for the Construction Worker from Soil - 28 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	5E-18	5E-18	1E-19
Am-241	5E-08	5E-08	1E-09
Np-237	4E-13	4E-13	8E-15
Pa-231	7E-18	7E-18	2E-19
Pb-210	1E-19	6E-20	5E-20
Pu-238	1E-08	1E-08	2E-10
Pu-239	7E-07	6E-07	2E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	3E-19	3E-19	4E-20
Ra-228	5E-23	4E-23	1E-23
Th-228	1E-22	1E-22	2E-24
Th-229	2E-19	2E-19	4E-21
Th-230	8E-17	8E-17	2E-18
Th-232	7E-23	7E-23	2E-24
U-233	2E-17	2E-17	6E-19
U-234	5E-13	5E-13	1E-14
U-235	8E-15	8E-15	2E-16
U-236	6E-14	6E-14	1E-15
Total	9E-07	8E-07	2E-08

Table 64. Summary of Risks for the Construction Worker from Soil - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-16	3E-16	8E-18
Am-241	3E-08	3E-08	8E-10
Np-237	1E-12	1E-12	3E-14
Pa-231	2E-16	2E-16	4E-18
Pb-210	4E-17	2E-17	2E-17
Pu-238	4E-09	4E-09	9E-11
Pu-239	6E-07	6E-07	1E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	3E-17	3E-17	4E-18
Ra-228	2E-21	2E-21	4E-22
Th-228	5E-21	5E-21	1E-22
Th-229	2E-17	2E-17	5E-19
Th-230	2E-15	2E-15	4E-17
Th-232	2E-21	2E-21	4E-23
U-233	5E-16	5E-16	1E-17
U-234	2E-12	2E-12	4E-14
U-235	4E-14	4E-14	1E-15
U-236	3E-13	3E-13	7E-15
Total	8E-07	8E-07	2E-08

Table 65. Summary of Risks for the Construction Worker from Soil - 500 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	4E-15	4E-15	9E-17
Am-241	8E-09	7E-09	2E-10
Np-237	3E-12	3E-12	6E-14
Pa-231	2E-15	2E-15	4E-17
Pb-210	9E-16	5E-16	4E-16
Pu-238	2E-10	2E-10	6E-12
Pu-239	6E-07	6E-07	1E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	6E-16	5E-16	7E-17
Ra-228	2E-20	2E-20	4E-21
Th-228	6E-20	6E-20	1E-21
Th-229	5E-16	5E-16	1E-17
Th-230	8E-15	8E-15	2E-16
Th-232	2E-20	2E-20	4E-22
U-233	3E-15	3E-15	8E-17
U-234	2E-12	2E-12	4E-14
U-235	1E-13	1E-13	3E-15
U-236	8E-13	8E-13	2E-14
Total	8E-07	8E-07	2E-08

Table 66. Summary of Risks for the Construction Worker from Soil - 1,000 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-14	1E-14	3E-16
Am-241	1E-09	1E-09	3E-11
Np-237	3E-12	3E-12	7E-14
Pa-231	5E-15	5E-15	1E-16
Pb-210	4E-15	2E-15	2E-15
Pu-238	5E-12	4E-12	1E-13
Pu-239	6E-07	6E-07	1E-08
Pu-240	1E-07	1E-07	3E-09
Ra-226	2E-15	2E-15	3E-16
Ra-228	7E-20	6E-20	1E-20
Th-228	2E-19	2E-19	4E-21
Th-229	2E-15	2E-15	6E-17
Th-230	2E-14	2E-14	4E-16
Th-232	6E-20	6E-20	1E-21
U-233	7E-15	7E-15	2E-16
U-234	1E-12	1E-12	3E-14
U-235	2E-13	2E-13	5E-15
U-236	1E-12	1E-12	3E-14
Total	8E-07	7E-07	2E-08

Table 67. Summary of Risks for the Construction Worker from Radon – Now 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	9E-26
Po-218	8E-29
Pb-214	0E+00
Rn-220	5E-30
Po-216	0E+00
Pb-212	0E+00
Total	9E-26

Table 68. Summary of Risks for the Construction Worker from Radon - 17 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-21
Po-218	2E-24
Pb-214	7E-29
Rn-220	8E-25
Po-216	4E-27
Pb-212	8E-29
Total	2E-21

Table 69. Summary of Risks for the Construction Worker from Radon - 28 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	8E-21
Po-218	7E-24
Pb-214	3E-28
Rn-220	3E-24
Po-216	2E-26
Pb-212	3E-28
Total	8E-21

Table 70. Summary of Risks for the Construction Worker from Radon - 150 years 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	9E-19
Po-218	8E-22
Pb-214	3E-26
Rn-220	2E-22
Po-216	9E-25
Pb-212	2E-26
Total	9E-19

Table 71. Summary of Risks for the Construction Worker from Radon - 500 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-17
Po-218	1E-20
Pb-214	6E-25
Rn-220	2E-21
Po-216	1E-23
Pb-212	2E-25
Total	2E-17

Table 72. Summary of Risks for the Construction Worker from Radon - 1,000 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	6E-17
Po-218	5E-20
Pb-214	2E-24
Rn-220	6E-21
Po-216	3E-23
Pb-212	6E-25
Total	6E-17

Table 73. Summary of Risks for the Construction Worker from External Radiation – Now, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	8E-22
Am-241	7E-08
Np-237	3E-13
Pa-231	1E-20
Pb-210	5E-27
Pu-238	4E-11
Pu-239	4E-09
Pu-240	4E-10
Ra-226	2E-21
Ra-228	1E-25
Th-228	2E-26
Th-229	2E-23
Th-230	2E-21
Th-232	4E-28
U-233	6E-22
U-234	2E-16
U-235	6E-15
U-236	1E-17
Total	8E-08

Table 74. Summary of Risks for the Construction Worker from External Radiation - 17 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	2E-17
Am-241	7E-08
Np-237	1E-11
Pa-231	9E-18
Pb-210	2E-21
Pu-238	3E-11
Pu-239	4E-09
Pu-240	4E-10
Ra-226	3E-17
Ra-228	2E-21
Th-228	2E-21
Th-229	3E-19
Th-230	1E-18
Th-232	4E-25
U-233	5E-19
U-234	5E-15
U-235	2E-13
U-236	3E-16
Total	7E-08

Table 75. Summary of Risks for the Construction Worker from External Radiation - 28 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	6E-17
Am-241	7E-08
Np-237	2E-11
Pa-231	2E-17
Pb-210	1E-20
Pu-238	3E-11
Pu-239	4E-09
Pu-240	4E-10
Ra-226	1E-16
Ra-228	7E-21
Th-228	9E-21
Th-229	1E-18
Th-230	3E-18
Th-232	1E-24
U-233	1E-18
U-234	8E-15
U-235	3E-13
U-236	6E-16
Total	7E-08

Table 76. Summary of Risks for the Construction Worker from External Radiation - 150 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	4E-15
Am-241	4E-08
Np-237	7E-11
Pa-231	6E-16
Pb-210	5E-18
Pu-238	1E-11
Pu-239	4E-09
Pu-240	4E-10
Ra-226	1E-14
Ra-228	3E-19
Th-228	4E-19
Th-229	2E-16
Th-230	7E-17
Th-232	3E-23
U-233	3E-17
U-234	3E-14
U-235	2E-12
U-236	3E-15
Total	5E-08

Table 77. Summary of Risks for the Construction Worker from External Radiation - 500 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	5E-14
Am-241	1E-08
Np-237	1E-10
Pa-231	5E-15
Pb-210	1E-16
Pu-238	8E-13
Pu-239	4E-09
Pu-240	4E-10
Ra-226	3E-13
Ra-228	3E-18
Th-228	5E-18
Th-229	4E-15
Th-230	4E-16
Th-232	3E-22
U-233	2E-16
U-234	3E-14
U-235	4E-12
U-236	8E-15
Total	2E-08

Table 78. Summary of Risks for the Construction Worker from External Radiation - 1,000 years, 216-Z-8 French Drain.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-13
Am-241	1E-09
Np-237	1E-10
Pa-231	2E-14
Pb-210	5E-16
Pu-238	1E-14
Pu-239	4E-09
Pu-240	4E-10
Ra-226	1E-12
Ra-228	1E-17
Th-228	2E-17
Th-229	2E-14
Th-230	7E-16
Th-232	9E-22
U-233	4E-16
U-234	2E-14
U-235	7E-12
U-236	1E-14
Total	6E-09

216-Z-9 Trench – Residential

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Table 79. Summary of Risks for the Residential Farmer from Soil - 150 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-08	4E-10	3E-08
Am-241	1E-04	1E-06	1E-04
Eu-152	1E-12	1E-15	1E-12
Gd-152	2E-25	2E-27	2E-25
Ni-63	7E-09	2E-12	7E-09
Np-237	1E-07	1E-09	1E-07
Pa-231	2E-08	2E-10	2E-08
Pb-210	5E-07	2E-10	5E-07
Pu-238	1E-06	2E-08	1E-06
Pu-239	1E-02	2E-04	1E-02
Pu-240	3E-03	4E-05	3E-03
Ra-226	6E-08	1E-10	6E-08
Ra-228	8E-16	1E-18	8E-16
Sr-90	1E-10	3E-14	1E-10
Tc-99	3E-19	1E-22	3E-19
Th-228	4E-16	5E-18	4E-16
Th-229	5E-13	7E-15	5E-13
Th-230	2E-08	3E-10	2E-08
Th-232	6E-18	7E-20	6E-18
U-233	4E-11	5E-13	4E-11
U-234	5E-10	5E-12	5E-10
U-235	8E-10	8E-12	8E-10
U-236	5E-09	5E-11	5E-09
Total	2E-02	2E-04	2E-02

Table 80. Summary of Risks for the Residential Farmer from Soil - 500 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-13	2E-15	1E-13
Am-241	3E-24	4E-26	3E-24
Eu-152	2E-24	2E-27	2E-24
Gd-152	1E-25	1E-27	1E-25
Ni-63	8E-11	2E-14	8E-11
Np-237	3E-09	4E-11	3E-09
Pa-231	2E-13	2E-15	2E-13
Pb-210	7E-09	3E-12	7E-09
Pu-238	2E-08	2E-10	2E-08
Pu-239	8E-03	1E-04	8E-03
Pu-240	2E-03	2E-05	2E-03
Ra-226	2E-09	4E-12	2E-09
Ra-228	4E-16	5E-19	4E-16
Sr-90	9E-29	0E+00	9E-29
Tc-99	0E+00	0E+00	0E+00
Th-228	1E-16	2E-18	1E-16
Th-229	3E-12	3E-14	2E-12
Th-230	2E-08	3E-10	2E-08
Th-232	5E-17	6E-19	5E-17
U-233	5E-13	6E-15	5E-13
U-234	1E-12	1E-14	1E-12
U-235	1E-10	1E-12	1E-10
U-236	8E-10	8E-12	7E-10
Total	1E-02	1E-04	1E-02

Table 81. Summary of Risks for the Residential Farmer from Soil - 1,000 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	9E-14	1E-15	9E-14
Am-241	0E+00	0E+00	0E+00
Eu-152	0E+00	0E+00	0E+00
Gd-152	5E-26	4E-28	5E-26
Ni-63	8E-13	2E-16	8E-13
Np-237	9E-11	1E-12	9E-11
Pa-231	1E-13	2E-15	1E-13
Pb-210	7E-09	2E-12	7E-09
Pu-238	2E-10	3E-12	2E-10
Pu-239	5E-03	6E-05	5E-03
Pu-240	1E-03	1E-05	1E-03
Ra-226	2E-09	4E-12	2E-09
Ra-228	6E-16	7E-19	6E-16
Sr-90	0E+00	0E+00	0E+00
Tc-99	0E+00	0E+00	0E+00
Th-228	2E-16	2E-18	2E-16
Th-229	2E-12	3E-14	2E-12
Th-230	2E-08	3E-10	2E-08
Th-232	7E-17	9E-19	7E-17
U-233	1E-14	2E-16	1E-14
U-234	1E-14	1E-16	1E-14
U-235	8E-11	8E-13	8E-11
U-236	5E-10	5E-12	5E-10
Total	6E-03	8E-05	6E-03

Table 82. Summary of Risks for the Residential Farmer from Plant - 150 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Plant
Ac-227	6E-07
Am-241	8E-04
Eu-152	3E-11
Gd-152	4E-24
Ni-63	2E-06
Np-237	1E-05
Pa-231	1E-06
Pb-210	3E-05
Pu-238	1E-05
Pu-239	9E-02
Pu-240	2E-02
Ra-226	2E-05
Ra-228	2E-13
Sr-90	3E-07
Tc-99	1E-14
Th-228	3E-15
Th-229	4E-12
Th-230	2E-07
Th-232	4E-17
U-233	8E-10
U-234	8E-09
U-235	1E-08
U-236	8E-08
Total	1E-01

Table 83. Summary of Risks for the Residential Farmer from Plant - 500 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Plant
Ac-227	2E-12
Am-241	2E-23
Eu-152	4E-23
Gd-152	3E-24
Ni-63	3E-08
Np-237	4E-07
Pa-231	1E-11
Pb-210	5E-07
Pu-238	1E-07
Pu-239	6E-02
Pu-240	1E-02
Ra-226	5E-07
Ra-228	1E-13
Sr-90	2E-25
Tc-99	0E+00
Th-228	1E-15
Th-229	2E-11
Th-230	2E-07
Th-232	3E-16
U-233	9E-12
U-234	2E-11
U-235	2E-09
U-236	1E-08
Total	7E-02

Table 84. Summary of Risks for the Residential Farmer from Plant - 1,000 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Plant
Ac-227	2E-12
Am-241	0E+00
Eu-152	0E+00
Gd-152	8E-25
Ni-63	3E-10
Np-237	1E-08
Pa-231	8E-12
Pb-210	5E-07
Pu-238	1E-09
Pu-239	4E-02
Pu-240	7E-03
Ra-226	5E-07
Ra-228	2E-13
Sr-90	0E+00
Tc-99	0E+00
Th-228	2E-15
Th-229	2E-11
Th-230	2E-07
Th-232	5E-16
U-233	3E-13
U-234	2E-13
U-235	1E-09
U-236	8E-09
Total	4E-02

Table 85. Summary of Risks for the Residential Farmer from Radon - 150 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	9E-05
Po-218	2E-04
Pb-214	2E-04
Bi-214	4E-04
Rn-220	4E-15
Po-216	6E-17
Pb-212	2E-15
Bi-212	1E-15
Total	9E-04

Table 86. Summary of Risks for the Residential Farmer from Radon - 500 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-06
Po-218	5E-06
Pb-214	6E-06
Bi-214	1E-05
Rn-220	1E-15
Po-216	2E-17
Pb-212	7E-16
Bi-212	4E-16
Total	2E-05

Table 87. Summary of Risks for the Residential Farmer from Radon - 1,000 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-06
Po-218	5E-06
Pb-214	6E-06
Bi-214	1E-05
Rn-220	2E-15
Po-216	3E-17
Pb-212	1E-15
Bi-212	6E-16
Total	2E-05

Table 88. Summary of Risks for the Residential Farmer from External Radiation - 150 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-05
Am-241	4E-03
Eu-152	1E-07
Np-237	2E-04
Pa-231	2E-06
Pb-210	1E-07
Pu-238	1E-07
Pu-239	3E-03
Pu-240	2E-04
Ra-226	2E-04
Ra-228	4E-13
Sr-90	5E-09
Tc-99	1E-18
Th-228	9E-13
Th-229	1E-10
Th-230	3E-08
Th-232	3E-18
U-233	8E-11
U-234	2E-10
U-235	8E-07
U-236	1E-09
Total	7E-03

Table 89. Summary of Risks for the Residential Farmer from External Radiation - 500 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	5E-11
Am-241	1E-22
Eu-152	2E-19
Np-237	5E-06
Pa-231	2E-11
Pb-210	2E-09
Pu-238	1E-09
Pu-239	2E-03
Pu-240	1E-04
Ra-226	4E-06
Ra-228	2E-13
Sr-90	3E-27
Tc-99	0E+00
Th-228	3E-13
Th-229	7E-10
Th-230	3E-08
Th-232	2E-17
U-233	9E-13
U-234	5E-13
U-235	1E-07
U-236	2E-10
Total	2E-03

Table 90. Summary of Risks for the Residential Farmer from External Radiation - 1,000 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	3E-11
Am-241	0E+00
Eu-152	0E+00
Np-237	1E-07
Pa-231	1E-11
Pb-210	2E-09
Pu-238	2E-11
Pu-239	1E-03
Pu-240	8E-05
Ra-226	4E-06
Ra-228	3E-13
Sr-90	0E+00
Tc-99	0E+00
Th-228	5E-13
Th-229	7E-10
Th-230	3E-08
Th-232	3E-17
U-233	3E-14
U-234	6E-15
U-235	8E-08
U-236	1E-10
Total	1E-03

216-Z-9 Trench – Well Driller

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Table 91. Summary of Risks for the Well Driller from Soil - 150 years
216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-11	8E-13	3E-11
Am-241	1E-07	2E-09	1E-07
Eu-152	1E-15	2E-18	1E-15
Gd-152	5E-30	0E+00	5E-30
Ni-63	4E-12	2E-15	4E-12
Np-237	5E-11	1E-12	5E-11
Pa-231	1E-11	3E-13	1E-11
Pb-210	3E-10	2E-13	3E-10
Pu-238	7E-10	2E-11	7E-10
Pu-239	6E-06	1E-07	6E-06
Pu-240	1E-06	3E-08	1E-06
Ra-226	4E-11	2E-13	4E-11
Ra-228	1E-18	3E-21	1E-18
Sr-90	1E-13	5E-17	1E-13
Tc-99	1E-21	7E-25	1E-21
Th-228	5E-19	1E-20	5E-19
Th-229	1E-17	2E-19	1E-17
Th-230	1E-11	2E-13	1E-11
Th-232	1E-22	2E-24	1E-22
U-233	3E-14	6E-16	3E-14
U-234	3E-13	6E-15	3E-13
U-235	5E-13	8E-15	5E-13
U-236	3E-12	6E-14	3E-12
Total	8E-06	2E-07	7E-06

Table 92. Summary of Risks for the Well Driller from Soil - 500 years
216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-18	3E-20	1E-18
Am-241	0E+00	0E+00	0E+00
Eu-152	2E-28	0E+00	2E-28
Gd-152	7E-30	0E+00	7E-30
Ni-63	8E-15	3E-18	8E-15
Np-237	2E-15	4E-17	2E-15
Pa-231	5E-18	1E-19	5E-18
Pb-210	8E-13	5E-16	8E-13
Pu-238	5E-12	1E-13	4E-12
Pu-239	2E-06	4E-08	2E-06
Pu-240	4E-07	9E-09	4E-07
Ra-226	3E-13	1E-15	3E-13
Ra-228	4E-20	1E-22	4E-20
Sr-90	0E+00	0E+00	0E+00
Tc-99	0E+00	0E+00	0E+00
Th-228	1E-20	3E-22	1E-20
Th-229	3E-16	7E-18	3E-16
Th-230	1E-11	3E-13	1E-11
Th-232	7E-21	2E-22	7E-21
U-233	9E-20	2E-21	9E-20
U-234	8E-17	1E-18	7E-17
U-235	1E-14	2E-16	1E-14
U-236	6E-14	1E-15	6E-14
Total	2E-06	5E-08	2E-06

Table 93. Summary of Risks for the Well Driller from Soil - 1,000 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	4E-19	9E-21	4E-19
Am-241	0E+00	0E+00	0E+00
Eu-152	0E+00	0E+00	0E+00
Gd-152	0E+00	0E+00	0E+00
Ni-63	1E-17	6E-21	1E-17
Np-237	5E-20	1E-21	5E-20
Pa-231	1E-18	3E-20	1E-18
Pb-210	7E-13	5E-16	7E-13
Pu-238	2E-14	5E-16	2E-14
Pu-239	5E-07	1E-08	5E-07
Pu-240	1E-07	2E-09	1E-07
Ra-226	3E-13	1E-15	3E-13
Ra-228	5E-20	1E-22	5E-20
Sr-90	0E+00	0E+00	0E+00
Tc-99	0E+00	0E+00	0E+00
Th-228	2E-20	4E-22	1E-20
Th-229	3E-16	6E-18	3E-16
Th-230	1E-11	2E-13	1E-11
Th-232	8E-21	2E-22	8E-21
U-233	3E-24	5E-26	3E-24
U-234	4E-19	7E-21	4E-19
U-235	3E-15	5E-17	3E-15
U-236	1E-14	3E-16	1E-14
Total	6E-07	1E-08	6E-07

Table 94. Summary of Risks for the Well Driller from Radon - 150 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	3E-11
Po-218	1E-13
Pb-214	4E-17
Rn-220	4E-17
Po-216	5E-19
Pb-212	7E-20
Bi-212	6E-24
Total	3E-11

Table 95. Summary of Risks for the Well Driller from Radon - 500 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-13
Po-218	1E-15
Pb-214	3E-19
Rn-220	1E-18
Po-216	1E-20
Pb-212	2E-21
Bi-212	1E-25
Total	2E-13

Table 96. Summary of Risks for the Well Driller from Radon - 1,000 years 216-Z-9 Trench.

Radionuclide (Parent and Decay)	Inhalation
Rn-222	2E-13
Po-218	1E-15
Pb-214	3E-19
Rn-220	1E-18
Po-216	2E-20
Pb-212	2E-21
Bi-212	2E-25
Total	2E-13

Table 97. Summary of Risks for the Well Driller from External Radiation - 150 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-08
Am-241	7E-06
Eu-152	1E-10
Np-237	7E-08
Pa-231	1E-09
Pb-210	7E-11
Pu-238	9E-11
Pu-239	1E-06
Pu-240	2E-07
Ra-226	8E-08
Ra-228	5E-16
Sr-90	5E-12
Tc-99	5E-21
Th-228	1E-15
Th-229	3E-15
Th-230	2E-11
Th-232	6E-23
U-233	5E-14
U-234	2E-13
U-235	5E-10
U-236	1E-12
Total	8E-06

Table 98. Summary of Risks for the Well Driller from External Radiation - 500 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	5E-16
Am-241	0E+00
Eu-152	2E-23
Np-237	3E-12
Pa-231	5E-16
Pb-210	2E-13
Pu-238	6E-13
Pu-239	4E-07
Pu-240	5E-08
Ra-226	6E-10
Ra-228	2E-17
Sr-90	0E+00
Tc-99	0E+00
Th-228	3E-17
Th-229	8E-14
Th-230	2E-11
Th-232	4E-21
U-233	2E-19
U-234	5E-17
U-235	1E-11
U-236	2E-14
Total	5E-07

Table 99. Summary of Risks for the Well Driller from External Radiation - 1,000 years, 216-Z-9 Trench.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-16
Am-241	0E+00
Eu-152	0E+00
Np-237	7E-17
Pa-231	1E-16
Pb-210	2E-13
Pu-238	3E-15
Pu-239	1E-07
Pu-240	1E-08
Ra-226	6E-10
Ra-228	2E-17
Sr-90	0E+00
Tc-99	0E+00
Th-228	3E-17
Th-229	7E-14
Th-230	2E-11
Th-232	5E-21
U-233	5E-24
U-234	2E-19
U-235	3E-12
U-236	5E-15
Total	1E-07

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216-A-8 Crib – Residential

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Table 100. Summary of Risks for the Residential Farmer from Soil - 150 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-20	3E-22	3E-20
C-14	0E+00	0E+00	0E+00
Cs-137	1E-06	2E-10	1E-06
Np-237	2E-09	2E-11	2E-09
Pa-231	6E-20	9E-22	6E-20
Pu-239	3E-08	3E-10	3E-08
Pu-240	6E-09	7E-11	6E-09
Ra-228	1E-14	1E-17	1E-14
Tc-99	8E-25	3E-28	8E-25
Th-228	6E-15	8E-17	6E-15
Th-229	7E-16	9E-18	7E-16
Th-232	8E-25	1E-26	8E-25
U-233	1E-13	1E-15	9E-14
U-235	2E-16	2E-18	2E-16
U-236	1E-15	1E-17	1E-15
Total	1E-06	6E-10	1E-06

Table 101. Summary of Risks for the Residential Farmer from Soil - 500 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-19	4E-21	3E-19
C-14	0E+00	0E+00	0E+00
Cs-137	1E-11	1E-15	1E-11
Np-237	6E-11	7E-13	6E-11
Pa-231	4E-19	5E-21	4E-19
Pu-239	2E-08	2E-10	2E-08
Pu-240	4E-09	4E-11	4E-09
Ra-228	6E-22	8E-25	6E-22
Tc-99	0E+00	0E+00	0E+00
Th-228	2E-22	2E-24	2E-22
Th-229	2E-14	3E-16	2E-14
Th-232	7E-23	9E-25	7E-23
U-233	9E-15	1E-16	9E-15
U-235	3E-16	3E-18	3E-16
U-236	2E-15	2E-17	2E-15
Total	2E-08	3E-10	2E-08

Table 102. Summary of Risks for the Residential Farmer from Soil - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-19	2E-21	2E-19
C-14	0E+00	0E+00	0E+00
Cs-137	9E-17	1E-20	9E-17
Np-237	2E-12	2E-14	2E-12
Pa-231	2E-19	3E-21	2E-19
Pu-239	1E-08	1E-10	1E-08
Pu-240	2E-09	3E-11	2E-09
Ra-228	1E-21	1E-24	1E-21
Tc-99	0E+00	0E+00	0E+00
Th-228	3E-22	4E-24	3E-22
Th-229	2E-14	3E-16	2E-14
Th-232	1E-22	1E-24	1E-22
U-233	3E-16	3E-18	3E-16
U-235	2E-16	2E-18	2E-16
U-236	1E-15	1E-17	9E-16
Total	1E-08	2E-10	1E-08

Table 103. Summary of Risks for the Residential Farmer from Produce - 150 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Produce
Ac-227	5E-19
C-14	0E+00
Cs-137	4E-04
Np-237	3E-07
Pa-231	5E-18
Pu-239	2E-07
Pu-240	4E-08
Ra-228	3E-12
Tc-99	3E-20
Th-228	5E-14
Th-229	5E-15
Th-232	6E-24
U-233	2E-12
U-235	3E-15
U-236	2E-14
Total	4E-04

Table 104. Summary of Risks for the Residential Farmer from Produce - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Produce
Ac-227	5E-18
C-14	0E+00
Cs-137	3E-09
Np-237	8E-09
Pa-231	3E-17
Pu-239	1E-07
Pu-240	3E-08
Ra-228	2E-19
Tc-99	0E+00
Th-228	2E-21
Th-229	2E-13
Th-232	5E-22
U-233	2E-13
U-235	5E-15
U-236	3E-14
Total	2E-07

Table 105. Summary of Risks for the Residential Farmer from Produce – 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Produce
Ac-227	3E-18
C-14	0E+00
Cs-137	2E-14
Np-237	2E-10
Pa-231	2E-17
Pu-239	7E-08
Pu-240	2E-08
Ra-228	3E-19
Tc-99	0E+00
Th-228	3E-21
Th-229	2E-13
Th-232	8E-22
U-233	5E-15
U-235	3E-15
U-236	2E-14
Total	9E-08

Table 106. Summary of Risks for the Residential Farmer from Radon - 150 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	6E-14
Po-216	9E-16
Pb-212	3E-14
Bi-212	2E-14
Total	1E-13

Table 107. Summary of Risks for the Residential Farmer from Radon - 500 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-21
Po-216	3E-23
Pb-212	1E-21
Bi-212	6E-22
Total	4E-21

Table 108. Summary of Risks for the Residential Farmer from Radon - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-21
Po-216	5E-23
Pb-212	2E-21
Bi-212	9E-22
Total	6E-21

Table 109. Summary of Risks for the Residential Farmer from External Radiation - 150 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-17
C-14	0E+00
Cs-137	2E-02
Np-237	3E-06
Pa-231	7E-18
Pu-239	5E-09
Pu-240	5E-10
Ra-228	6E-12
Tc-99	3E-24
Th-228	2E-11
Th-229	2E-13
Th-232	4E-25
U-233	2E-13
U-235	2E-13
U-236	3E-16
Total	2E-02

Table 110. Summary of Risks for the Residential Farmer from External Radiation - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-16
C-14	0E+00
Cs-137	1E-07
Np-237	8E-08
Pa-231	4E-17
Pu-239	3E-09
Pu-240	3E-10
Ra-228	3E-19
Tc-99	0E+00
Th-228	5E-19
Th-229	7E-12
Th-232	3E-23
U-233	2E-14
U-235	3E-13
U-236	4E-16
Total	2E-07

Table 111. Summary of Risks for the Residential Farmer from External Radiation - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	7E-17
C-14	0E+00
Cs-137	1E-12
Np-237	3E-09
Pa-231	2E-17
Pu-239	2E-09
Pu-240	2E-10
Ra-228	5E-19
Tc-99	0E+00
Th-228	8E-19
Th-229	6E-12
Th-232	5E-23
U-233	5E-16
U-235	2E-13
U-236	2E-16
Total	5E-09

216-A-8 Crib – Well Driller

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Table 112. Summary of Risks for the Well Driller from Soil - 150 years
216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-27	2E-29	1E-27
Cs-137	8E-10	2E-13	8E-10
Np-237	8E-13	2E-14	8E-13
Pa-231	5E-26	1E-27	5E-26
Pu-239	1E-11	2E-13	1E-11
Pu-240	2E-12	5E-14	2E-12
Ra-228	2E-17	4E-20	2E-17
Th-228	9E-18	2E-19	9E-18
Th-229	4E-22	1E-23	4E-22
Th-232	1E-31	0E+00	1E-31
U-233	2E-18	4E-20	2E-18
U-235	3E-21	5E-23	3E-21
U-236	2E-20	4E-22	2E-20
Total	8E-10	5E-13	8E-10

Table 113. Summary of Risks for the Well Driller from Soil - 500 years
216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-24	5E-26	2E-24
Cs-137	4E-15	9E-19	4E-15
Np-237	2E-17	5E-19	2E-17
Pa-231	7E-24	2E-25	7E-24
Pu-239	3E-12	6E-14	3E-12
Pu-240	6E-13	1E-14	6E-13
Ra-228	4E-26	9E-29	4E-26
Th-228	1E-26	3E-28	1E-26
Th-229	1E-18	2E-20	1E-18
Th-232	7E-27	1E-28	6E-27
U-233	1E-21	2E-23	1E-21
U-235	1E-20	3E-22	1E-20
U-236	9E-20	2E-21	9E-20
Total	3E-12	7E-14	3E-12

Table 114. Summary of Risks for the Well Driller from Soil - 1,000 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	5E-25	1E-26	5E-25
Cs-137	2E-20	5E-24	2E-20
Np-237	6E-22	1E-23	6E-22
Pa-231	2E-24	4E-26	2E-24
Pu-239	7E-13	2E-14	7E-13
Pu-240	1E-13	3E-15	1E-13
Ra-228	5E-26	1E-28	5E-26
Th-228	2E-26	4E-28	2E-26
Th-229	1E-18	2E-20	1E-18
Th-232	8E-27	2E-28	8E-27
U-233	3E-26	7E-28	3E-26
U-235	4E-21	7E-23	4E-21
U-236	2E-20	4E-22	2E-20
Total	9E-13	2E-14	8E-13

Table 115. Summary of Risks for the Well Driller from Radon - 150 years 216-A-8 Crib

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-16
Po-216	9E-18
Pb-212	1E-18
Bi-212	9E-23
Total	7E-16

Table 116. Summary of Risks for the Well Driller from Radon - 500 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-24
Po-216	1E-26
Pb-212	2E-27
Bi-212	0E+00
Total	1E-24

Table 117. Summary of Risks for the Well Driller from Radon - 1,000 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-24
Po-216	2E-26
Pb-212	2E-27
Bi-212	0E+00
Total	1E-24

Table 118. Summary of Risks for the Well Driller from External Radiation - 150 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	4E-25
Cs-137	7E-06
Np-237	1E-09
Pa-231	4E-24
Pu-239	2E-12
Pu-240	3E-13
Ra-228	8E-15
Th-228	2E-14
Th-229	1E-19
Th-232	0E+00
U-233	3E-18
U-235	3E-18
U-236	6E-21
Total	7E-06

Table 119. Summary of Risks for the Well Driller from External Radiation - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	7E-22
Cs-137	4E-11
Np-237	3E-14
Pa-231	7E-22
Pu-239	6E-13
Pu-240	7E-14
Ra-228	2E-23
Th-228	3E-23
Th-229	3E-16
Th-232	4E-27
U-233	2E-21
U-235	1E-17
U-236	3E-20
Total	4E-11

Table 120. Summary of Risks for the Well Driller from External Radiation - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	2E-22
Cs-137	2E-16
Np-237	9E-19
Pa-231	2E-22
Pu-239	2E-13
Pu-240	2E-14
Ra-228	2E-23
Th-228	3E-23
Th-229	2E-16
Th-232	5E-27
U-233	6E-26
U-235	4E-18
U-236	7E-21
Total	2E-13

216-A-8 Crib – Construction Worker

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Table 121. Summary of Risks for the Construction Worker from Soil – Now, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	1E-23	2E-24	8E-24
Cs-137	3E-04	6E-07	3E-04
Np-237	4E-09	6E-10	3E-09
Pa-231	4E-22	7E-23	4E-22
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	4E-09	2E-08
Ra-228	1E-08	3E-10	1E-08
Th-228	4E-09	7E-10	3E-09
Th-229	2E-18	3E-19	2E-18
Th-232	4E-27	7E-28	3E-27
U-233	9E-15	1E-15	7E-15
U-235	3E-17	3E-18	2E-17
U-236	2E-16	2E-17	1E-16
Total	3E-04	6E-07	3E-04

Table 122. Summary of Risks for the Construction Worker from Soil - 17 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	2E-19	3E-20	2E-19
Cs-137	2E-04	4E-07	2E-04
Np-237	4E-09	6E-10	3E-09
Pa-231	4E-19	7E-20	3E-19
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	4E-09	2E-08
Ra-228	2E-09	4E-11	2E-09
Th-228	1E-09	2E-10	8E-10
Th-229	2E-15	3E-16	2E-15
Th-232	4E-24	6E-25	3E-24
U-233	3E-13	5E-14	3E-13
U-235	9E-16	1E-16	8E-16
U-236	6E-15	9E-16	5E-15
Total	2E-04	4E-07	2E-04

Table 123. Summary of Risks for the Construction Worker from Soil - 28 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	7E-19	1E-19	6E-19
Cs-137	2E-04	3E-07	2E-04
Np-237	4E-09	6E-10	3E-09
Pa-231	1E-18	2E-19	9E-19
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	4E-09	2E-08
Ra-228	5E-10	1E-11	5E-10
Th-228	3E-10	5E-11	2E-10
Th-229	5E-15	8E-16	4E-15
Th-232	1E-23	2E-24	8E-24
U-233	5E-13	8E-14	4E-13
U-235	1E-15	2E-16	1E-15
U-236	9E-15	1E-15	8E-15
Total	2E-04	3E-07	2E-04

Table 124. Summary of Risks for the Construction Worker from Soil - 150 years 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	5E-17	9E-18	4E-17
Cs-137	1E-05	2E-08	1E-05
Np-237	4E-09	6E-10	3E-09
Pa-231	3E-17	5E-18	2E-17
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	3E-09	2E-08
Ra-228	2E-16	4E-18	2E-16
Th-228	1E-16	2E-17	9E-17
Th-229	1E-13	2E-14	1E-13
Th-232	3E-22	4E-23	2E-22
U-233	3E-12	4E-13	2E-12
U-235	7E-15	1E-15	6E-15
U-236	5E-14	7E-15	4E-14
Total	1E-05	4E-08	1E-05

Table 125. Summary of Risks for the Construction Worker from Soil - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	7E-16	1E-16	6E-16
Cs-137	3E-09	6E-12	3E-09
Np-237	4E-09	6E-10	3E-09
Pa-231	3E-16	5E-17	2E-16
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	3E-09	2E-08
Ra-228	2E-20	5E-22	2E-20
Th-228	9E-21	2E-21	7E-21
Th-229	1E-12	2E-13	1E-12
Th-232	3E-21	5E-22	2E-21
U-233	8E-12	1E-12	7E-12
U-235	2E-14	3E-15	2E-14
U-236	1E-13	2E-14	1E-13
Total	1E-07	2E-08	1E-07

Table 126. Summary of Risks for the Construction Worker from Soil - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	Inhalation	Ingestion
Ac-227	3E-15	5E-16	2E-15
Cs-137	3E-14	6E-17	3E-14
Np-237	4E-09	6E-10	3E-09
Pa-231	1E-15	2E-16	9E-16
Pu-239	9E-08	2E-08	8E-08
Pu-240	2E-08	3E-09	2E-08
Ra-228	9E-20	2E-21	9E-20
Th-228	3E-20	6E-21	3E-20
Th-229	5E-12	9E-13	4E-12
Th-232	1E-20	2E-21	9E-21
U-233	1E-11	2E-12	1E-11
U-235	4E-14	6E-15	4E-14
U-236	3E-13	4E-14	2E-13
Total	1E-07	2E-08	9E-08

Table 127. Summary of Risks for the Construction Worker from Radon – Now, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	1E-08
Po-216	2E-10
Pb-212	1E-10
Bi-212	4E-14
Total	1E-08

Table 128. Summary of Risks for the Construction Worker from Radon - 17 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-09
Po-216	4E-11
Pb-212	3E-11
Bi-212	1E-14
Total	3E-09

Table 129. Summary of Risks for the Construction Worker from Radon - 28 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-10
Po-216	1E-11
Pb-212	8E-12
Bi-212	3E-15
Total	8E-10

Table 130. Summary of Risks for the Construction Worker from Radon - 150 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-16
Po-216	5E-18
Pb-212	3E-18
Bi-212	1E-21
Total	3E-16

Table 131. Summary of Risks for the Construction Worker from Radon - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-20
Po-216	4E-22
Pb-212	2E-22
Bi-212	8E-26
Total	2E-20

Table 132. Summary of Risks for the Construction Worker from Radon - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	9E-20
Po-216	1E-21
Pb-212	9E-22
Bi-212	3E-25
Total	9E-20

Table 133. Summary of Risks for the Construction Worker from External Radiation – Now, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	4E-23
Cs-137	5E-02
Np-237	7E-08
Pa-231	5E-22
Pu-239	2E-10
Pu-240	2E-11
Ra-228	1E-07
Th-228	1E-07
Th-229	7E-18
Th-232	2E-29
U-233	2E-16
U-235	3E-16
U-236	5E-19
Total	5E-02

Table 134. Summary of Risks for the Construction Worker from External Radiation - 17 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	8E-19
Cs-137	4E-02
Np-237	7E-08
Pa-231	5E-19
Pu-239	2E-10
Pu-240	2E-11
Ra-228	1E-08
Th-228	4E-08
Th-229	6E-15
Th-232	2E-26
U-233	7E-15
U-235	1E-14
U-236	2E-17
Total	4E-02

Table 135. Summary of Risks for the Construction Worker from External Radiation - 28 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	3E-18
Cs-137	3E-02
Np-237	7E-08
Pa-231	1E-18
Pu-239	2E-10
Pu-240	2E-11
Ra-228	4E-09
Th-228	1E-08
Th-229	2E-14
Th-232	5E-26
U-233	1E-14
U-235	2E-14
U-236	3E-17
Total	3E-02

Table 136. Summary of Risks for the Construction Worker from External Radiation - 150 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	2E-16
Cs-137	2E-03
Np-237	7E-08
Pa-231	4E-17
Pu-239	2E-10
Pu-240	2E-11
Ra-228	2E-15
Th-228	4E-15
Th-229	5E-13
Th-232	1E-24
U-233	6E-14
U-235	9E-14
U-236	1E-16
Total	2E-03

Table 137 Summary of Risks for the Construction Worker from External Radiation - 500 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	3E-15
Cs-137	5E-07
Np-237	7E-08
Pa-231	4E-16
Pu-239	2E-10
Pu-240	2E-11
Ra-228	2E-19
Th-228	3E-19
Th-229	5E-12
Th-232	2E-23
U-233	2E-13
U-235	3E-13
U-236	4E-16
Total	6E-07

Table 138. Summary of Risks for the Construction Worker from External Radiation - 1,000 years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	External Radiation
Ac-227	1E-14
Cs-137	5E-12
Np-237	7E-08
Pa-231	1E-15
Pu-239	2E-10
Pu-240	2E-11
Ra-228	7E-19
Th-228	1E-18
Th-229	2E-11
Th-232	6E-23
U-233	3E-13
U-235	5E-13
U-236	8E-16
Total	7E-08

APPENDIX A

ATTACHMENT 8

RISK-BASED CONCENTRATIONS FOR GROUNDWATER AND SOIL RESRAD SUMMARIES

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ATTACHMENT 8
TABLE OF CONTENTS

Table 1 Industrial Exposures to Tap Water (Radioactive Chemicals) Ingestion of Groundwater

Table 2 Industrial Exposures to Tap Water (Radioactive Chemicals) Inhalation of Vapor

Table 3 Industrial Exposures to Tap Water (Nonradioactive Chemicals) Ingestion of Groundwater

Table 4 Industrial Exposures to Tap Water (Nonradioactive Chemicals) Inhalation of Vapor

Table 5 RESRAD Summary of Pathway Risks for the Construction Worker Risk-Based Concentration (Based on Risk of 1×10^{-4}).

Table 6 Risk-Based Concentrations for the Construction Worker Based on Dose (100 mrem/yr).

Table 7 RESRAD Summary of Pathway Dose for the Construction Worker Risk-Based Concentration (Based on 100 mrem/yr).

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Table 1. Industrial Exposures to Tap Water (Radioactive Chemicals).

Ingestion of Groundwater

Cleanup Level Calculation

Exposure Medium: Groundwater

Exposure Point: Drinking Water

Receptor Population: Industrial

Receptor Age: Lifetime

Cancer CUL = TCR / (CSF x SIFc)

combined CUL =(CUL_{ing} x CUL_{inh}) / (CUL_{ing} + CUL_{inh})

Parameter	Unit	RME Lifetime
Chemical Conc'n in Water (CW)	pCi/L	chem-specific
Ingestion Rate of Water (IR)	L/day	1
Exposure Frequency (EF)	days/yr	250
Exposure Duration (ED)	years	25
SIFc = (IR*EF*ED)	L	6.25E+03

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.5E-10
TC-99	2.75E-12
Tritium	5.07E-14

Chemical	Target Cancer Risk	CUL Cancer (pCi/L)
I-129	1.00E-04	107
TC-99	1.00E-04	5818
Tritium	1.00E-04	315582

CULs for Combined Exposures to Contaminants in Groundwater (ingestion and inhalation)	
Chemical	**Cancer**
I-129	107
TC-99	5818
Tritium	297125

Table 2. Industrial Exposures to Tap Water (Radioactive Chemicals).

Inhalation of Vapor

Cleanup Level Calculation

Exposure Medium: Groundwater

Exposure Point: Drinking Water

Receptor Population: Industrial

Receptor Age: Lifetime

Cancer CUL = TCR / (CSF x SIFc x VFw)

Parameter	Units	RME Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific
Inhalation Rate of Air (InhR)	m^3/hr	1.6
Exposure Time (ET)	hr/day	3
Exposure Frequency (EF)	days/yr	250
Exposure Duration (ED)	years	25
SIFc = (InhR*EF*ED*VF)	m^3	3.0E+04

Chemical	CSFi (risk/pCi)	VF (L/m3)
I-129 (non-dairy)	1.60E-10	--
TC-99	--	--
Tritium	5.62E-14	0.011675

Chemical	Target Cancer Risk	ACL Cancer (pCi/L)
I-129	1.00E-04	--
TC-99	1.00E-04	--
Tritium	1.00E-04	5080255

Table 3. Industrial Exposures to Tap Water (Nonradioactive Chemicals). (2 sheets)

Ingestion of Groundwater
Cleanup Level Calculation

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Industrial Workers
Receptor Age: Adults

Non-Cancer CUL = RfD x THQ / SIFnc
Cancer CUL = TCR / (CSF x SIFc)

Parameter	Unit	Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific
Ingestion Rate of Water (IR)	L/day	1
Exposure frequency (EF)	unitless	250
Exposure Duration non-cancer (ED-nc)	years	25
Exposure duration-cancer (ED-ca)	years	25
Body weight (BW)	kg	70
Conversion Factor (CF)	mg/ug	1.00E-03
Averaging time (non-cancer) (ATnc)	years	9,125
Averaging time (cancer) (ATc)	years	25550
Drinking Water Fraction (DWF)	unitless	1
SIFnc = (IR*EF*ED-nc*DWF*CF)/(BW*ATnc)	L-mg/ug-kg-d	9.78E-06
SIFc = (IR*ED-ca*EF*DWF*CF)/(BW*Atc)	L-mg/ug-kg-d	3.49E-06

Chemical	RfDo (mg/kg-d)	CSFo (mg/kg-d)-1
Carbon Tetrachloride	7.00E-04	1.30E-01
Chloroform	1.00E-02	--
Chromium III	1.50E+00	--
Chromium VI (groundwater)	3.00E-03	--
Methylene Chloride	6.00E-02	7.50E-03
Nitrate	1.60E+00	--
PCE	1.00E-02	5.40E-01
TCE	3.00E-04	3.10E-02
Uranium	3.00E-03	--

	THQ unitless	TCR unitless	NC ACL-adult ug/L	CA ACL ug/L
Carbon Tetrachloride	1	1.0E-04	7.2E+01	2.2E+02
Chloroform	1	1.0E-04	1.0E+03	--
Total Chromium	1	1.0E-04	1.5E+05	--
Chromium VI	1	1.0E-04	3.1E+02	--
Methylene Chloride	1	1.0E-04	6.1E+03	3.8E+03
Nitrate	1	1.0E-04	1.6E+05	--
PCE	1	1.0E-04	1.0E+03	5.3E+01
TCE	1	1.0E-04	3.1E+01	9.2E+02

Table 3. Industrial Exposures to Tap Water (Nonradioactive Chemicals). (2 sheets)

Ingestion of Groundwater
Cleanup Level Calculation

Uranium	1	1.0E-04	3.1E+02	--

THQ = target hazard quotient
TCR = target cancer risk
NC = non cancer
ACL = alternative cleanup level
CA = cancer

Cleanup Levels

Industrial Use of Tap Water

combined CUL for VOCs =(CUL_{ing} x CUL_{inh}) / (CUL_{ing} + CUL_{inh})

combined CUL for Metals = CUL_{ing}

	Chemical Class	NC CUL-adult ug/L	CA CUL ug/L	Tap Water CUL ug/L
Carbon Tetrachloride	VOC	62	111	62
Chloroform	VOC	359	147	147
Total Chromium	Metal	153300	--	153300
Chromium VI	Metal	307	--	307
Methylene Chloride	VOC	5253	2523	2523
Nitrate	Other	163520	--	163520
PCE	VOC	839	48	48
TCE	VOC	29	374	28.8
Uranium	Metal	307	--	307

Table 4. Industrial Exposures to Tap Water (Nonradioactive Chemicals).

Inhalation of Vapor
Cleanup Level Calculation

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Industrial Worker
Receptor Age: Adults

Non-Cancer CUL = (RfD x THQ) / (SIFnc x VFw)
Cancer CUL = TCR / (CSF x SIFc x VFw)

Parameter	Unit	Adult
Chemical Conc'n in Water (CW)	ug/L	chem-specific
Inhalation Rate (InhR)	m3/hr	1.6
Exposure Time (ET)	hr/day	3
Exposure Frequency (EF)	untiless	250
Exposure Duration (non-cancer) (ED-nc)	years	25
Exposure Duration (ED)	years	25
Body Weight (BW)	kg	70
Conversion Factor (CF)	mg/ug	1.0E-03
Averaging Time (non-cancer) (ATnc)	years	9,125
Averaging Time (cancer) (ATc)	years	25,550
SIFnc = (InhR*EF*ED*ET*CF)/(BW*ATnc)	m^3-mg/ug-kg-day	4.70E-05
SIFc = (InhR*ED*ET*EF*CF)/ATc	m^3-mg/ug-kg-day	1.68E-05

Chemical	RfDi (mg/kg-d)	CSFi (mg/kg-d)-1	VFw[a] (L/m3)
Carbon Tetrachloride	1.1E-02	5.3E-02	5.0E-01
Chloroform	1.3E-02	8.1E-02	5.0E-01
Chromium III	--	--	--
Chromium VI (groundwater)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	5.0E-01
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	5.0E-01
TCE	1.1E-02	1.9E-02	5.0E-01
Uranium	--	--	--

[a] A volitilazation factor (VFw) of 0.5 is only applicable for volatile chemicals.

	THQ unitless	TCR unitless	NC ACL-adult ug/L	CA ACL ug/L
Carbon Tetrachloride	1	1.0E-04	468	225.0
Chloroform	1	1.0E-04	554	147.2
Total Chromium	1	1.0E-04	--	--
Chromium VI	1	1.0E-04	--	--
Methylene Chloride	1	1.0E-04	36622	7452.1
Nitrate	1	1.0E-04	--	--
PCE	1	1.0E-04	4684	567.8
TCE	1	1.0E-04	468	627.5
Uranium	1	1.0E-04	--	--

THQ = target hazard quotient
TCR = target cancer risk
NC = non cancer

ACL = alternative cleanup level
CA = cancer
SIF = Summary intake factor

VFw = volatilization factor for water
CSF = cancer slope factor
RfD = reference dose

Table 5. RESRAD Summary of Pathway Risks for the Construction Worker Risk-Based Concentration (Based on Risk of 1 x 10^{-4}).

Chemical	RBC (pCi/g)	Total	Inhalation	Ingestion	External Radiation
Americium-241	45000	1E-04	1E-05	6E-05	3E-05
Plutonium-239	50000	1E-04	2E-05	9E-05	2E-07
Plutonium-240	50000	1E-04	2E-05	9E-05	9E-08
Cesium-137	1600	1E-04	1E-09	6E-07	1E-04

RBC = risk-based concentration

Table 6. Risk-Based Concentrations for the Construction Worker Based on Dose (100 mrem/yr).

Chemical	RESRAD Dose Output-Combined Inhalation and Ingestion (pCi/g)	RESRAD Dose Output-External Radiation (pCi/g)	Calculated Combined RBC(a) (pCi/g)	Final RBC (pCi/g)
Americium-241	2580	91200	2509	2510
Plutonium-239	2649	1.30E+07	2648	2650
Plutonium-240	2649	2.60E+07	2649	2650
Cesium-137	204300	1228	1221	1220

(a) The combined RBC was calculated using the following equation:

$$\text{Combined RBC} = \text{Dose}_{\text{ingestion+inhalation}} \times \text{Dose}_{\text{external}} / \text{Dose}_{\text{ingestion+inhalation}} + \text{Dose}_{\text{external}}$$

RBC = risk-based concentration

Table 7. RESRAD Summary of Pathway Dose for the Construction Worker Risk-Based Concentration (Based on 100 mrem/yr).

Chemical	RBC (pCi/g)	Total	Inhalation	Ingestion	External Radiation
Americium-241	2510	100	7	90	3
Plutonium-239	2650	100	7	93	<1
Plutonium-240	2650	100	7	93	<1
Cesium-137	1220	100	<1	1	99

RBC = risk-based concentration

APPENDIX B

POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

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TABLE OF CONTENTS

B1.0 IDENTIFICATION OF POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS FOR THE 200-ZP-1 GROUNDWATER OPERABLE UNIT 1

B1.1 WAIVERS FROM APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS 3

B1.2 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS APPLICABLE TO REMEDIAL ACTIONS FOR GROUNDWATER IN THE 200-ZP-1 GROUNDWATER OPERABLE UNIT 3

B2.0 REFERENCES/BIBLIOGRAPHY 17

TABLES

Table B-1. Identification of Potential Federal Applicable or Relevant and Appropriate Requirements and To Be Considered for the Remedial Action Sites. (2 sheets) 6

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets) 8

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APPENDIX B

POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

B1.0 IDENTIFICATION OF POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS FOR THE 200-ZP-1 GROUNDWATER OPERABLE UNIT

This appendix identifies and evaluates the potential applicable or relevant and appropriate requirements (ARARs) for waste site remediation in the 200-ZP-1 Groundwater Operable Unit (OU). The potential ARARs identified in this appendix have been used to form the basis for the levels to which contaminants must be remediated to protect human health and the environment, as required by the National Contingency Plan (40 *Code of Federal Regulations* [CFR] 300). Independent of the ARARs identification process at the Hanford Site, the requirements of U.S. Department of Energy (DOE) directives must be met.

Because the groundwater encompassed by the 200-ZP-1 Groundwater OU will be remediated under a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) decision document, any remedial and corrective actions will be required to meet ARARs. As required by the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 2003), this CERCLA remedial investigation/feasibility study process for groundwater remediation will also satisfy *Resource Conservation and Recovery Act of 1976* (RCRA) corrective action requirements. This appendix identifies and evaluates potential ARARs for this groundwater remedial action. Final ARARs for remediation will be established in the Record of Decision. In many cases, the ARARs form the basis for the preliminary remediation goals to which contaminants must be remediated to protect human health and the environment. In other cases, the ARARs define or constrain how specific remedial measures can be implemented.

The ARARs identification process is based on CERCLA guidance (*CERCLA Compliance with Other Laws Manual: Interim Final* [EPA/540/G-89-006] and *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final* [EPA/540/G-89/004]). Section 121 of CERCLA (as amended) requires, in part, that any applicable or relevant and appropriate standard, requirement, criterion, or limitation promulgated under any Federal environmental law, or any more stringent state requirement promulgated pursuant to a state environmental statute, be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain onsite after completion of remedial action.

"Applicable" means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than Federal requirements may be applicable.

"Relevant and appropriate" requirements means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than Federal requirements may be relevant and appropriate. In evaluating the relevance and appropriateness of a requirement, the eight comparison factors in 40 CFR 300.400(g)(2), "Identification of Applicable or Relevant and Appropriate Requirements," are considered:

(i) The purpose of the requirement and the purpose of the CERCLA action

(ii) The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site

(iii) The substances regulated by the requirement and the substances found at the CERCLA site

(iv) The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site

(v) Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site

(vi) The type of place regulated and the type of place affected by the release or CERCLA action

(vii) The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action

(viii) Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site.

In addition, potential ARARs were evaluated to determine if they fall into one of three categories: chemical-specific, location-specific, or action-specific. These categories are defined as follows.

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of public and worker safety levels and site cleanup levels.
- Location-specific requirements are restrictions placed on the concentration of dangerous substances or the conduct of activities solely because they occur in special geographic areas.
- Action-specific requirements are usually technology- or activity-based requirements or limitations triggered by the remedial actions performed at the site.

Further details on potential ARARs for these categories are provided in Section B.1.2.

In summary, a requirement is applicable if the specific terms or jurisdictional prerequisites of the law or regulations directly address the circumstances at a site. If not applicable, a requirement may nevertheless be relevant and appropriate if (1) circumstances at the site are, based on best professional judgment, sufficiently similar to the problems or situations regulated by the

requirement; and (2) the requirement's use is well suited to the site. Only the substantive requirements (e.g., use of control/containment equipment or compliance with numerical standards) associated with ARARs apply to CERCLA onsite activities. The ARARs associated with administrative requirements (e.g., permitting) are not applicable to CERCLA onsite activities (CERCLA, Section 121[e][1]). In general, this CERCLA permitting exemption will be extended to all remedial and corrective action activities conducted at the 200-ZP-1 Groundwater OU.

The to-be-considered (TBC) information is nonpromulgated advisories or guidance issued by Federal or state government that is not legally binding and does not have the status of potential ARARs. In some circumstances, TBCs will be considered along with ARARs in determining the remedial action necessary for protection of human health and the environment. The TBCs complement the ARARs in determining protectiveness at a site or implementation of certain actions. For example, because soil cleanup standards do not exist for all contaminants, health advisories, which would be TBCs, may be helpful in defining appropriate remedial action goals.

B1.1 WAIVERS FROM APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The U.S. Environmental Protection Agency (EPA) may waive ARARs and select a remedial action that does not attain the same level of site cleanup as that identified by the ARARs. Section 121 of the *Superfund Amendments and Reauthorization Act of 1986* identifies six circumstances in which the EPA may waive ARARs for onsite remedial actions. The six circumstances are as follows:

- The remedial action selected is only a part of a total remedial action (e.g., an interim action), and the final remedy will attain the ARAR upon its completion.
- Compliance with the ARAR will result in a greater risk to human health and the environment than alternative options.
- Compliance with the ARAR is technically impracticable from an engineering perspective.
- An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach.
- The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
- In the case of Section 104 (Superfund-financed remedial actions), compliance with the ARAR will not provide a balance between protecting human health and the environment and the availability of Superfund money for response at other facilities.

B1.2 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS APPLICABLE TO REMEDIAL ACTIONS FOR GROUNDWATER IN THE 200-ZP-1 GROUNDWATER OPERABLE UNIT

Potential Federal and state ARARs are presented in Tables B-1 and B-2, respectively. The chemical-specific ARARs likely to be most relevant to remediation of the 200-ZP-1 OU are

elements of the Federal regulations that implement drinking water standards (40 CFR 141, "National Primary Drinking Water Regulations").

Action-specific ARARs that could be pertinent to remediation are state solid and dangerous waste regulations (for management of characterization and remediation of wastes). Washington State air emission standards are likely to be important in identifying air emission limits and control requirements for any remedial actions that produce air emissions.

Regarding waste management activities during remediation, a variety of waste streams may be generated under the proposed remedial action alternatives. It is anticipated that most of the waste will be designated as low-level waste. However, quantities of dangerous or mixed waste could also be generated

The identification, storage, treatment, and disposal of hazardous waste and the hazardous component of mixed waste generated during the remedial action would be subject to the substantive provisions of RCRA. In the state of Washington, RCRA is implemented through *Washington Administrative Code* (WAC) 173-303, "Dangerous Waste Regulations," which is an EPA-authorized state RCRA program. The substantive portions of the dangerous waste standards for generation and storage would apply to the management of any dangerous or mixed waste generated during this remedial action. Treatment standards for dangerous or mixed waste that is subject to RCRA land-disposal restrictions are specified in WAC 173-303-140, "Land Disposal Restrictions," which incorporates 40 CFR 268, "Land Disposal Restrictions," by reference.

Waste (e.g., investigation-derived wastes) designated as low-level waste that meets Environmental Restoration Disposal Facility (ERDF) waste acceptance criteria is assumed to be disposed at ERDF, which is engineered to meet appropriate performance standards of 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste." In addition, waste designated as dangerous or mixed waste would be treated as appropriate to meet land-disposal restrictions and ERDF acceptance criteria and would be disposed at ERDF. The ERDF is engineered to meet minimum technical requirements for landfills under WAC 173-303-665, "Landfills." Applicable packaging and pre-transportation requirements for dangerous or mixed waste generated at the 200-ZP-1 OU would be identified and implemented before any waste was moved. Alternate disposal locations may be considered when the remedial action occurs if a suitable and cost-effective location is identified. Any potential alternate disposal location will be evaluated for appropriate performance standards to ensure that it is adequately protective of human health and the environment.

Waste designated as transuranic waste will be stored at the Central Waste Complex (CWC) with eventual disposal at a geologic repository (e.g., the Waste Isolation Pilot Plant).

CERCLA, Section 104(d)(4) states that where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the threat or potential threat to the public health or welfare or the environment, the facilities can be treated as one for purposes of CERCLA response actions. Consistent with this, the 200-ZP-1 OU, ERDF, and the 200 Area Effluent Treatment Facility would be considered to be one site for purposes of Section 104 of CERCLA, and waste may be transferred between the facilities without requiring a permit. Liquid effluent discharged to the ground after treatment in any remedial alternative must comply with the requirements of WAC 173-216, "State Waste Discharge Program." In the event that the treated effluent is reinjected to the aquifer, it may be necessary to comply with WAC 173-218, "Underground Injection Control."

All alternative actions will be performed in compliance with the waste management ARARs. Waste streams will be evaluated, designated, and managed in compliance with ARARs. Before disposal, waste will be managed in a protective manner to prevent releases to the environment or unnecessary exposure to personnel.

The proposed remedial action alternatives have the potential to generate airborne emissions of both radioactive and criteria/toxic pollutants.

The *Revised Code of Washington* (RCW) 70.94, "Washington Clean Air Act," requires regulation of radioactive air pollutants. The state implementing regulation WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides," sets standards that are as stringent, or more so, than the Federal standards under the *Clean Air Act of 1990* and under the Federal implementing regulation 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities." The Washington State standards protect the public by conservatively establishing exposure standards applicable to the maximally exposed public individual, be that individual real or hypothetical. To that end, the standards address any member of the public, at the point of maximum annual air concentration in an unrestricted area where any member of the public may be. Radionuclide airborne emissions from the facility are not to exceed amounts that would cause an exposure to any said member of the public of greater than 10 mrem/yr effective dose equivalent. The state implementing regulation WAC 246-247, "Radiation Protection – Air Emissions," which adopts the WAC 173-480 standards, and 40 CFR 61, Subpart H require verification of compliance with the 10 mrem/yr standard and would be applicable to the remedial action.

WAC 246-247 further addresses emission sources emitting radioactive airborne emissions by requiring monitoring of such sources. Such monitoring requires physical measurement of the effluent or ambient air. The substantive provisions of WAC 246-247 that require monitoring of radioactive airborne emissions would be applicable to the remedial action.

The above-stated implementing regulations further address control of radioactive airborne emissions where economically and technologically feasible (WAC 246-247-040[3] and -040[4], "Radiation Protection - Air Emissions," "General Standards," and associated definitions). To address the substantive aspect of these requirements, best or reasonably achieved control technology will be addressed by ensuring that applicable emission control technologies (those successfully operated in similar applications) will be used when economically and technologically feasible (i.e., based on cost/benefit). If it is determined that there are substantive aspects of the requirement for control of radioactive airborne emissions, then controls will be administered as appropriate using reasonable and effective methods.

Table B-1. Identification of Potential Federal Applicable or Relevant and Appropriate Requirements and To Be Considered for the Remedial Action Sites. (2 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"National Primary Drinking Water Regulations," 40 CFR 141			
"Maximum Contaminant Levels for Organic Contaminants," 40 CFR 141.61	ARAR	Establishes MCLs that are drinking water criteria designed to protect human health from the potential adverse effects of organic contaminants in drinking water.	The groundwater in the 200-ZP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and, because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.61 for organic constituents are applicable. This requirement is chemical-specific.
"Maximum Contaminant Levels for Inorganic Contaminants," 40 CFR 141.62	ARAR	Establishes MCLs that are drinking water criteria designed to protect human health from the potential adverse effects of inorganic contaminants in drinking water.	The groundwater in the 200-ZP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and, because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.62 for inorganic constituents are applicable. This requirement is chemical-specific.
"Maximum Contaminant Levels for Radionuclides," 40 CFR 141.66	ARAR	Establishes MCLs that are drinking water criteria designed to protect human health from the potential adverse effects of radionuclides in drinking water.	The groundwater in the 200-ZP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.66 for radionuclides are applicable. This requirement is chemical-specific.
Archeological and Historic Preservation Act, 16 U.S.C. 469aa-mm, et seq.	ARAR	Requires that remedial actions at the 200-ZP-1 Groundwater OU do not cause the loss of any archaeological or historic data. This act mandates preservation of the data and does not require protection of the actual historical sites.	Archeological and historic sites have been identified within the 200 Areas; therefore, the substantive requirements of this act are applicable to actions that might disturb these sites. This requirement is action-specific.
National Historic Preservation Act of 1966, 16 U.S.C. 470, Section 106, et seq.	ARAR	Requires Federal agencies to consider the impacts of their undertaking on cultural properties through identification, evaluation and mitigation processes, and consultation with interested parties.	Cultural and historic sites have been identified within the 200 Areas; therefore, the substantive requirements of this act are applicable to actions that might disturb these types of sites. This requirement is location-specific.

Table B-1. Identification of Potential Federal Applicable or Relevant and Appropriate Requirements and To Be Considered for the Remedial Action Sites. (2 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
Native American Graves Protection and Repatriation Act, 25 U.S.C. 3001, et seq.	ARAR	Establishes Federal agency responsibility for discovery of human remains, associated and unassociated funerary objects, sacred objects, and items of cultural patrimony.	Substantive requirements of this act are applicable if remains and sacred objects are found during remediation and will require Native American Tribal consultation in the event of discovery. This is a location-specific requirement.
Endangered Species Act of 1973, 16 U.S.C. 1531, et seq., subsection 16 USC 1536(c)	ARAR	Prohibits actions by Federal agencies that are likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification or critical habitat. If remediation is within critical habitat or buffer zones surrounding threatened or endangered species, mitigation measures must be taken to protect the resource.	Substantive requirements of this act are applicable if threatened or endangered species are identified in areas where remedial actions will occur. This is a location-specific requirement.

NOTE: Regulations pursuant to the *Resource Conservation and Recovery Act of 1976* and implemented through WAC 173-303, "Dangerous Waste Regulations" (see Table B-2).

ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
MCL = maximum contaminant level
OU = operable unit
TBC = to-be-considered
WAC = *Washington Administrative Code*

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Dangerous Waste Regulations," WAC 173-303			
"Identifying Solid Waste," WAC 173-303-016	ARAR	Identifies those materials that are and are not solid wastes.	Substantive requirements of these regulations are applicable because they define how to determine which materials are subject to the designation regulations. Specifically, materials that are generated for removal from the CERCLA site during the remedial action would be subject to the procedures for identification of solid waste to ensure proper management. This requirement is action-specific.
"Recycling Processes Involving Solid Waste," WAC 173-303-017	ARAR	Identifies materials that are and are not solid wastes when recycled.	Substantive requirements of these regulations are applicable because they define how to determine which materials are subject to the designation regulations. Specifically, materials that are generated for removal from the CERCLA site during the remedial action would be subject to the procedures for identification of solid waste to ensure proper management. This requirement is action-specific.
"Designation of Dangerous Waste," WAC 173-303-070(3)	ARAR	Establishes the method for determining whether a solid waste is, or is not, a dangerous waste or an extremely hazardous waste.	Substantive requirements of these regulations are applicable to materials encountered during the remedial action. Specifically, solid waste that is generated for removal from the CERCLA site during this remedial action would be subject to the dangerous waste designation procedures to ensure proper management. This requirement is action-specific.
"Excluded Categories of Waste," WAC 173-303-071	ARAR	Describes those categories of wastes that are excluded from the requirements of WAC 173-303 (excluding WAC 173-303-050).	The conditions of this requirement are applicable to remedial actions in the 200-ZP-1 Groundwater OU should wastes identified in WAC 173-303-071 be encountered. This requirement is action-specific.
"Conditional Exclusion of Special Wastes," WAC 173-303-073	ARAR	Establishes the conditional exclusion and the management requirements of special wastes, as defined in WAC 173-303-040.	Substantive requirements of these regulations are applicable to materials encountered during the remedial action. Specifically, the substantive standards for management of special waste are applicable to the interim management of certain waste that will be generated during the remedial action. This requirement is action-specific.
"Requirements for Universal Waste," WAC 173-303-077	ARAR	Identifies those wastes exempted from regulation under WAC 173-303-140 and WAC 173-303-170 through 173-303-9907 (excluding WAC 173-303-960). These wastes are subject to regulation under WAC 173-303-573.	Substantive requirements of these regulations are applicable to materials encountered during the remedial action. Specifically, the substantive standards for management of universal waste are applicable to the interim management of certain waste that will be generated during the remedial action. This requirement is action-specific.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Recycled, Reclaimed, and Recovered Wastes," WAC 173-303-120 Specific subsections: WAC 173-303-120(3) WAC 173-303-120(5)	ARAR	These regulations define the requirements for recycling materials that are solid and dangerous waste. Specifically, WAC 173-303-120(3) provides for the management of certain recyclable materials, including spent refrigerants, antifreeze, and lead-acid batteries. WAC 173-303-120(5) provides for the recycling of used oil.	Substantive requirements of these regulations are applicable to certain materials that might be encountered during the remedial action. Recyclable materials that are exempt from regulation as dangerous waste and that are not otherwise subject to CERCLA as hazardous substances can be recycled and/or conditionally excluded from certain dangerous waste requirements. This requirement is action-specific.
"Land Disposal Restrictions," WAC 173-303-140(4)	ARAR	This regulation establishes state standards for land disposal of dangerous waste and incorporates, by reference, Federal land-disposal restrictions of 40 CFR 268 that are applicable to solid waste that is designated as dangerous or mixed waste in accordance with WAC 173-303-070(3).	The substantive requirements of this regulation are applicable to materials encountered during the remedial action. Specifically, dangerous/mixed waste that is generated and removed from the CERCLA site during the remedial action for offsite (as defined by CERCLA) land disposal would be subject to the identification of applicable land-disposal restrictions at the point of generation of the waste. The actual offsite treatment of such waste would not be ARAR to this remedial action, but instead would be subject to all applicable laws and regulations. This requirement is action-specific.
"Requirements for Generators of Dangerous Waste," WAC 173-303-170	ARAR	Establishes the requirements for dangerous waste generators.	Substantive requirements of these regulations are applicable to materials encountered during the remedial action. Specifically, the substantive standards for management of dangerous/mixed waste are applicable to the interim management of certain waste that will be generated during the remedial action. For purposes of this remedial action, WAC 173-303-170(3) includes the substantive provisions of WAC 173-303-200 by reference. WAC 173-303-200 further includes certain substantive standards from WAC 173-303-630 and -640 by reference. This requirement is action-specific.
"Minimum Functional Standards for Solid Waste Handling," WAC 173-304			
"On-Site Containerized Storage, Collection and Transportation Standards for Solid Waste," WAC 173-304-200(2)	ARAR	Establishes the requirements for the onsite storage of solid wastes that are not radioactive or dangerous wastes.	Substantive requirements of these regulations are applicable to materials encountered during the remedial action. Specifically, nondangerous, nonradioactive solid wastes (i.e., hazardous substances that are only regulated as solid waste) that will be containerized for removal from the CERCLA site would be managed onsite according to the substantive requirements of this standard. This requirement is action-specific.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Solid Waste Handling Standards," WAC 173-350			
"On-Site Storage, Collection and Transportation Standards," WAC 173-350-300	ARAR	Establishes the requirements for the temporary storage of solid waste in a container onsite and the collecting and transporting of the solid waste.	The substantive requirements of this newly promulgated rule are relevant and appropriate to the onsite collection and temporary storage of solid wastes at the 200-ZP-1 Groundwater OU remediation activities. Compliance with this regulation is being implemented in phases for existing facilities.
"Minimum Standards for Construction and Maintenance of Wells," WAC 173-160			
WAC 173-160-161	ARAR	Identifies well planning and construction requirements.	The substantive requirements of this regulation are applicable to actions that include construction of wells used for groundwater extraction, monitoring, or injection of treated groundwater or wastes. The requirements of WAC 173-160-161, 173-160-171, 173-160-181, 173-160-400, 173-160-420, 173-303-430, 173-160-440, 173-160-450, and 173-160-460 are applicable to groundwater well construction, monitoring, or injection of treated groundwater or wastes in the 200-ZP-1 Groundwater OU. These requirements are action-specific.
WAC 173-160-171	ARAR	Identifies the requirements for locating a well.	
WAC 173-160-181	ARAR	Identifies the requirements for preserving natural barriers to groundwater movement between aquifers.	
WAC 173-160-400	ARAR	Identifies the minimum standards for resource protection wells and geotechnical soil borings.	
WAC 173-160-420	ARAR	Identifies the general construction requirements for resource protection wells.	
WAC 173-160-430	ARAR	Identifies the minimum casing standards.	
WAC 173-160-440	ARAR	Identifies the equipment cleaning standards.	
WAC 173-160-450	ARAR	Identifies the well sealing requirements.	
WAC 173-160-460	ARAR	Identifies the decommissioning process for resource protection wells.	

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"State Waste Discharge Permit Program," WAC 173-216			
WAC 173-216-050	ARAR	Identifies discharges not required subject to permitting requirements.	The substantive requirements of this regulation are applicable to actions that potentially include the discharge of liquid effluents to the soil column. This requirement is action-specific.
WAC 173-216-060	ARAR	Identifies discharges that are prohibited.	
WAC 173-216-070	ARAR	Identifies the process to be used in applying for a discharge permit.	
WAC 173-216-125	ARAR	Identifies the requirements for discharge monitoring.	
"Underground Injection Control," WAC 173-218			
WAC 173-218-040	ARAR	Identifies what an injection well is and types of prohibited wells.	The substantive requirements of this regulation are applicable to actions that discharge liquid effluents to injection wells. This requirement is action-specific.
WAC 173-218-060	ARAR	Identifies the requirements for operating injection wells.	
WAC 173-218-070	ARAR	Identifies the requirements for authorizing and registering injection wells.	
WAC 173-218-080	ARAR	Identifies the nonendangerment standard for emplacing subsurface fluids in order to meet water quality standards.	
WAC 173-218-090	ARAR	Identifies the requirements for Class V wells to meet the nonendangerment standard.	
WAC 173-218-120	ARAR	Identifies the requirements for decommissioning a UIC well.	

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"General Regulations for Air Pollution Sources," WAC 173-400			
"General Standards for Maximum Emissions," WAC 173-400-040 WAC 173-400-113	ARAR	Methods of control shall be employed to minimize the release of air contaminants associated with fugitive emissions resulting from materials handling, construction, demolition, or other operations. Emissions are to be minimized through application of best available control technology.	Substantive requirements of these standards are relevant and appropriate to this remedial action because there may be visible, particulate, fugitive, and hazardous air emissions and odors resulting from remedial activities. As a result, standards established for the control and prevention of air pollution are relevant and appropriate. This requirement is action-specific.
"Controls for New Sources of Toxic Air Pollutants," WAC 173-460			
"Control Technology Requirements," WAC 173-460-030 WAC 173-460-060	ARAR	Requires that new sources of air emissions provide the emission estimates identified in this regulation.	Substantive requirements of these standards are applicable to this remedial action because there is the potential for toxic air pollutants to become airborne as a result of remedial activities. As a result, standards established for the control of toxic air contaminants are relevant and appropriate. This requirement is action-specific.
"Ambient Impact Requirement," WAC 173-460-070	ARAR	Requires that when applying for a notice of construction, the owner/operator of a new toxic air pollutant source that is likely to increase toxic air pollutant emissions shall demonstrate that emissions from the source are sufficiently low to protect human health and safety from potential carcinogenic and/or other toxic effects.	The substantive requirements of this standard are applicable to remedial actions in the 200-ZP-1 Groundwater OU, should the remedial action result in the treatment of the soil or debris that contains contaminants of concern identified in the regulation as a toxic air pollutant. This requirement is action-specific.
"Radiation Protection – Air Emissions," WAC 246-247			
WAC 246-247-035(1)(a)(ii)	ARAR	This regulation establishes requirements of 40 CFR 61, Subpart H by reference. Radionuclide airborne emissions from the facility shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent.	Substantive requirements of this standard are applicable because this remedial action may provide airborne emissions of radioactive particulates to unrestricted areas. As a result, requirements limiting emissions apply. This is a risk-based standard for the purposes of protecting human health and the environment. This requirement is action-specific.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Ambient Air Quality Standards and Emission Limits for Radionuclides," WAC 173-480			
"Standards," WAC 173-480-050	ARAR	Whenever another Federal or state regulation or limitation in effect controls the emission of radionuclides to the ambient air, the more stringent control of emissions shall govern.	The substantive requirements of this standard are applicable in that the more stringent aspect of Federal or state emission limitation is specified as governing. This requirement is action-specific.
"Compliance," WAC 173-480-070(2)	ARAR	Requires that radionuclide emissions compliance shall be determined by calculating the dose to members of the public at the point of maximum annual air concentration in an unrestricted area where any member of the public may be.	The substantive requirements of this standard are applicable to remedial actions involving disturbance or ventilation of radioactively contaminated areas or structures, because airborne radionuclides may be emitted to unrestricted areas where any member of the public may be. This requirement is action-specific.
"Radiation Protection -- Air Emissions," WAC 246-247; and "Ambient Air Quality Standards and Emission Limits for Radionuclides," WAC 173-480			
WAC 246-247-035(1)(a)(ii) WAC 173-480-040	ARAR	This regulation establishes requirements equivalent to 40 CFR 61, Subpart H. Radionuclide airborne emissions from the facility shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent.	Substantive requirements of this standard are applicable because a remedial action may include activities such as excavation, decontamination and stabilization of contaminated areas and equipment, and operation of exhausters and vacuums, each of which may provide airborne emissions of radioactive particulates to unrestricted areas. As a result, requirements limiting emissions apply. This is a risk-based standard for the purposes of protecting human health and the environment.
"Standards," WAC 246-247-040(3) WAC 246-247-040(4)	ARAR	Emissions shall be controlled to ensure that emission standards are not exceeded. Actions creating new sources or significantly modified sources shall apply best available controls. All other actions shall apply reasonably achievable controls.	Substantive requirements of this standard are applicable because fugitive, diffuse and point source emissions of radionuclides to the ambient air may result from remedial activities, such as excavation of contaminated soils and operation of exhauster and vacuums, performed during the remedial action. This standard exists to ensure compliance with emission standards.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(1) and –(2) and –(4)	ARAR	Establishes the monitoring, testing, and quality assurance requirements for radioactive air emissions from major sources. Effluent flow-rate measurements shall be made and the effluent stream shall be directly monitored continuously with an in-line detector or representative samples of the effluent stream shall be withdrawn continuously from the sampling site following the specified guidance. The requirements for continuous sampling are applicable to batch processes when the unit is in operation. Periodic sampling (grab samples) may be used only with lead agency prior approval. Such approval may be granted in cases where continuous sampling is not practical and radionuclide emission rates are relatively constant. In such cases, grab samples shall be collected with sufficient frequency so as to provide a representative sample of the emissions. When it is impractical to measure the effluent flow rate at a source in accordance with the requirements or to monitor or sample an effluent stream at a source in accordance with the site selection and sample extraction requirements, the facility owner or operator may use alternative effluent flow rate measurement procedures or site selection and sample extraction procedures as approved by the lead agency. Emissions from non-point and fugitive sources of airborne radioactive material shall be measured.	Substantive requirements of this standard are applicable when fugitive and non-point source emissions of radionuclides to the ambient air may result from activities, such as excavation of contaminated soils and operation of exhauster and vacuums, performed during a remedial action. This standard exists to ensure compliance with emission standards.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
		Measurement techniques may include, but are not limited to, sampling, calculation, smears, or other reasonable method for identifying emissions as determined by the lead agency	
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(3)	ARAR	Methods to implement periodic confirmatory monitoring for minor sources may include estimating the emissions or other methods as approved by the lead agency.	Substantive requirements are applicable when fugitive and diffuse emissions from any excavation and related activities occur and will require periodic confirmatory measurements to verify low emissions.
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(8)	ARAR	Facility (site) emissions resulting from non-point and fugitive sources of airborne radioactive material shall be measured. Measurement techniques may include ambient air measurements, or in-line radiation detector or withdrawal of representative samples from the effluent stream, or other methods as determined by the lead agency.	Substantive requirements are applicable when fugitive and diffuse emissions of airborne radioactive material due to excavation and related activities occur and will require measurement.
"General Standards," WAC 246-247-040(4) "General Standards for Maximum Permissible Emissions," WAC 173-480-050(1)	ARAR	At a minimum all emission units shall make every reasonable effort to maintain radioactive materials in effluents to unrestricted areas, as low as reasonably achievable (ALARA). Control equipment of facilities operating under ALARA shall be defined as reasonably available control technology (RACT) and ALARACT.	Substantive requirements are applicable when the potential for fugitive and diffuse emissions due to excavation and related activities occur and will require efforts to minimize those emissions.
"Emission Monitoring and Compliance Procedures," WAC 173-480-070(2)	ARAR	Determine compliance with the public dose standard by calculating exposure at the point of maximum annual air concentration in an unrestricted area where any member of the public may be.	Substantive requirements are applicable when fugitive and diffuse emissions resulting from excavation occur and related activities will require assessment and reporting.

Table B-2. Identification of Potential State Applicable and Relevant or Appropriate Requirements and To Be Considered for the Remedial Action Sites. (9 sheets)

ARAR Citation	ARAR or TBC	Requirement	Rationale for Use
"Washington Clean Air Act of 1967," RCW 70.94 and RCW 43.21A			
"General Regulation for Air Pollution Sources," WAC 173-400 Specific subsection: WAC 173-400-040 WAC 173-400-113	ARAR	Requires all sources of air contaminants to meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. Requires use of reasonably available control technology. Requires controls to minimize the release of air contaminants resulting from new or modified sources of regulated emissions. Emissions are to be minimized through application of best available control technology.	Substantive requirements would be applicable. Requires all sources of air contaminants to meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. Requires use of reasonably available control technology. Substantive requirements would be applicable. Requires controls to minimize the release of air contaminants resulting from new or modified sources of regulated emissions. Emissions are to be minimized through application of best available control technology.
"Controls for New Sources of Toxic Air Pollutants," WAC 173-460 Specific subsections: WAC 173-460-030 WAC 173-460-060 WAC 173-460-070	ARAR	Requires specific controls for new regulated air emissions.	The substantive requirements are applicable when using a treatment technology (e.g., to treat generated waste to meet disposal facility standards) that emits toxic air emissions.

ALARA = as low as reasonably achievable
ARAR = applicable or relevant and appropriate requirement
CFR = *Code of Federal Regulations*
DOE = U.S. Department of Energy
OU = operable unit
TBC = to-be-considered
UIC = Underground Injection Control (Program)
WAC = *Washington Administrative Code*

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APPENDIX C

COST ESTIMATE BACKUP

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TABLE OF CONTENTS

C1.0 INTRODUCTION C-1

C2.0 ALTERNATIVE COST ESTIMATES C-2

C2.1 ALTERNATIVE #0 – NO ACTION C-2

C2.2 ALTERNATIVE #1 – INSTITUTIONAL CONTROLS SUPPLEMENTED BY MONITORIED NATURAL ATTENTUATION C-3

C2.3 ALTERNATIVE #2 – FULL-SCALE PUMP-AND-TREAT, INSTITUTIONAL CONTROLS, MONITORED NATURAL ATTENUATION, PLUS FLOW-PATH CONTROLS C-4

C2.4 CONTINGENCY MEASURES TO IMPLEMENT IN SITU TECHNOLOGIES C-5

C3.0 ASSUMPTIONS C-5

C3.1 GLOBAL ASSUMPTIONS C-5

C3.1.1 Labor C-5
C3.1.2 Markups C-6
C3.1.3 General Assumptions C-6
C3.1.4 Long-Term Groundwater Monitoring Costs C-7

C3.2 ALTERNATIVE #1 –INSTITUTIONAL CONTROLS SUPPLEMENTED BY MONITORED NATURAL ATTENUATION C-8

C3.2.1 Institutional Controls Implementation C-8
C3.2.2 Site Inspection and Surveillance C-8
C3.2.3 Existing Site Maintenance C-9
C3.2.4 Weed and Pest Control C-9
C3.2.5 Waste Site/Fence Maintenance C-9
C3.2.6 Natural Attenuation Monitoring C-9
C3.2.7 Reporting C-10
C3.2.8 Site Reviews C-10
C3.2.9 Monitoring C-10

C3.3 ALTERNATIVE 2 – FULL-SCALE PUMP-AND-TREAT, INSTITUTIONAL CONTROLS, MONITORED NATURAL ATTENUATION, PLUS FLOW-PATH CONTROLS C-11

C3.3.1 Special Site Conditions C-12

C3.4 CONTINGENCY MEASURES –IN SITU TREATMENT TECHNOLOGIES C-14

C3.4.1 Electrical Resistance Heating C-14
C3.4.2 Anaerobic Bioremediation C-15

C3.5 PRESENT WORTH C-16

C4.0 REFERENCES C-20

TABLES

Table C-1. 200-ZP-1 Operable Unit Capital, Annual, and Periodic Costs Reference.....C-17
Table C-2. Alternative #1 – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs. C-18
Table C-3. Alternative #2 – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs. C-18
Table C-4. Contingency Measures – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs.....C-18
Table C-5. Alternatives #0, #1, #2, and Contingency Measures – Present-Worth and Non-Discounted Comparison Costs.....C-19

APPENDIX C

COST ESTIMATE BACKUP

C1.0 INTRODUCTION

Cost estimates for the feasibility study (FS) have an accuracy of +50%, to -30%, which is the accuracy specified in *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA/540/R-00/002). The cost estimates provide a discriminator for deciding between similar protective and implemental alternatives for a specific waste site. Therefore, the costs are relational, not absolute, for the evaluation of the alternatives.

The various cost elements are taken from U.S. Environmental Protection Agency (EPA) guidance (EPA/540/R-00/002); the Fluor Hanford, Inc. (FH) contract with the U.S. Department of Energy (*Contract Between the U.S. Department of Energy, Richland Operations Office, and Fluor Daniel Hanford, Inc.* [DE-AC06-96RL13200]); R.S. Means cost data (Means 2001, 2006); and technical and historical site information. Contingency is applied to the cost estimate to cover potential cost over-runs. Contingency covers two types: scope and bid. "Scope" covers the unknown elements of the alternative as remedial design proceeds, while "bid" contingency covers the unknown elements of remedial action operations and maintenance (O&M) as they proceed. A contingency of 25% is applied based on the level of engineering information available at this time. This FS does not evaluate the economies associated with implementing multiple sites or groups with a common alternative or aggregated remediation, as they will be considered in the future as part of long-range planning and through the post-Record of Decision activities (e.g., remedial design). Potential areas of cost sharing to reduce overall remediation costs include the following:

- Remediating all waste sites with a common preferred alternative at the same time
- Sharing mobilization/demobilization costs
- Sharing surveillance and maintenance (S&M) costs
- Sharing O&M costs
- Sharing well performance monitoring costs
- Sharing training costs.

Present net-worth costs were estimated using the real discount rate published in Appendix C of Office of Management and Budget Circular No. A-94, (*Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* [OMB 2002]), which is effective through the end of January 2008. Programs with durations longer than 30 years use the 30-year interest rate of 3.0%. Present net-worth costs are discussed for each alternative in the following subsections.

Non-discounted costs were calculated because of recommendations presented in EPA guidance (EPA/540/R-00/002). Non-discounted constant dollar costs demonstrate the impact of a discount rate on the total present-value cost. The non-discounted costs are presented for comparison purposes only.

Section C2.0 provides a basic breakdown of the cost types used to determine the present-worth costs for each alternative. Major assumptions are discussed in Section C3.0. These assumptions are necessary to provide the level of detail necessary for independent review.

C2.0 ALTERNATIVE COST ESTIMATES

This section summarizes the scope and cost components used for determining the present net-worth cost of each of the alternatives in terms of the remedial alternatives developed in Section 5.0 of the FS.

The alternatives are as follows:

- Alternative #0: No action
- Alternative #1: Institutional controls supplemented by monitored natural attenuation (MNA)
- Alternative #2: Full-scale pump-and-treat, institutional controls, MNA, plus flow-path controls
- Contingency measures: In situ treatment of possible source zones.

For the purpose of this FS, the present net-worth costs represent three cost types, which may include the following:

- Capital:
  - Remediation process system engineering, procurement, and construction
  - Pump-and-treat interconnecting piping
  - New well construction
  - Institutional controls
- Periodic:
  - MNA
  - Groundwater monitoring
  - Well decommissioning
  - Utility (electrical usage)
- Annual:
  - O&M
  - Sampling
  - S&M.

Present-worth cost and/or supporting cost estimates were prepared by FH's Project Controls Estimating department. Table C-1 provides a summary of the workscope (by alternative) and identifies the cost source, where applicable. In addition, the table includes the year (year 0, year 1, year 2, etc.) of cost expenditure to ensure the accurate application of the discount rate.

The duration until all of preliminary remediation goals (PRGs) are reached at each site is assumed to be 30-80 years. For cost estimating purposes, a 30-year timeframe has been assumed.

C2.1 ALTERNATIVE #0 – NO ACTION

The National Contingency Plan (NCP) (40 *Code of Federal Regulations* [CFR] 300) requires consideration of a no action alternative. The no action alternative represents a situation where no legal restrictions, access controls, or active remedial measures are applied to the waste site.

Taking no action implies "walking away from the waste site" and allowing the waste to remain in its current configuration, affected only by natural processes. No maintenance or other activities would be instituted or continued. Because the no action alternative assumes that no further actions will be taken at a waste site, costs are assumed to be zero.

C2.2 ALTERNATIVE #1 – INSTITUTIONAL CONTROLS SUPPLEMENTED BY MONITORIED NATURAL ATTENTUATION

Section 5.2.1 of the FS provides a detailed description of the alternative for institutional controls and MNA. The cost details for this alternative are discussed in detail in Section C3.2.

Institutional controls are non-engineering or legal/administrative measures to reduce or minimize the potential for exposure to site contamination or hazards by limiting or restricting site access. Examples include an institutional control plan, restrictive covenants, property easements, zoning, deed notices, advisories, groundwater-use restrictions, and site information database. An institutional control plan would describe the controls for a site and the implementation of these controls. A site information database would provide a system for managing the data necessary to characterize the current nature and extent of contamination. For the purpose of this FS, institutional controls will be considered as a capital, one-time occurring cost. The duration for institutional controls only considers the initial "year-zero" period. The annual/periodic activities will occur for a 30-year period.

The primary annual/periodic costs associated with this alternative are surveillance, well site maintenance, and MNA costs. This alternative also includes the cost of long-term groundwater monitoring. The costs for these annual/periodic activities are estimated based on the location and number of the individual well sites.

The unit cost for S&M accounts for activities such as site radiation surveys and the repair of existing cover on material sites where cover is required. Because the existing well pad and roads are maintained annually, the costs for replacing all or large portions of the existing site at specified intervals (i.e., every 20 years) are considered unnecessary.

The costs associated with MNA are divided into three components: radiological surveys of surface soils, spectral-gamma logging of vadose zone boreholes, and groundwater monitoring.

The costs to perform radiological surveys of surface soils at waste sites are assumed to be similar to those for current survey practices at the sites and are included in the S&M costs.

Vadose zone monitoring costs assume spectral-gamma logging of one borehole per waste site to a 15.2–m (50-ft) depth once every 5 years until the site meets all PRGs. This monitoring is considered for sites with high concentrations of contaminants in the shallow zone or near the bottom of crib and trench structures. It also assumes that the service life of vadose zone boreholes is 30 years. Costs are included for logging and periodic replacement of these boreholes until all of the PRGs are met for the site (assumed to be 30 years).

Groundwater monitoring costs will likely be incurred for sites that have high concentrations of mobile contaminants deep within the vadose zone and/or where groundwater contamination is known to have occurred. However, for the purpose of this FS, the groundwater sampling activity will be considered a periodic cost.

The combined present net-worth costs for institutional controls, S&M, and MNA activities represent the present-worth cost for this alternative.

C2.3 ALTERNATIVE #2 – FULL-SCALE PUMP-AND-TREAT, INSTITUTIONAL CONTROLS, MONITORED NATURAL ATTENUATION, PLUS FLOW-PATH CONTROLS

Section 5.2.2 of this FS provides a description of the alternative for full-scale pump-and-treat, institutional controls, MNA, plus flow-path controls. The cost details used for each site are discussed in detail in Section C3.5.

A pump-and-treat system is currently operating in the 200-ZP-1 Operable Unit (OU) as an interim control measure. Implementation of the pump-and-treat alternative as a final remedial action would involve replacing the existing system with a full-scale, robust system. This more extensive and robust system would incorporate between 14 and 27 injection and 14 and 27 extraction wells. For cost-estimating purposes, 14 injection and 14 extraction have been assumed according to the logic presented in Section 5.2.2 of the FS. For purposes of comparison, it is assumed that the present-worth cost of the 27 extraction wells is twice the cost of the 14-well system.

The major cost components for this alternative are as follows:

- Capital:
  - Remediation process system scope:
    - Pump-and-treat: Pump-and-treat systems consist of a groundwater well withdrawal system and a treatment train to remove the contaminants from the groundwater system or aquifer and to control the plume from further migration. The treatment train will include ion exchange (IX), granular activated carbon (GAC), and onsite air stripping.
    - Flow-path control
  - Institutional control activities
  - Pump-and-treat interconnecting piping
  - New well construction activities
- Periodic:
  - MNA
  - Groundwater monitoring
  - Well decommissioning
  - Utility (electrical)
- Annual:
  - O&M
  - Sampling
  - S&M.

The combined present net-worth costs for the pump-and-treat, well, and piping capital construction activities; O&M; sampling; S&M; well decommissioning; natural attenuation monitoring; and institutional control activities represent the present-worth cost for this alternative.

C2.4 CONTINGENCY MEASURES TO IMPLEMENT IN SITU TECHNOLOGIES

Section 5.2.2.1 of this FS provides a description of the in situ technologies that are considered for contingency action, should a persistent source zone be identified. The cost details used for each site are discussed in detail in Section C3.4.

The contingency measures assume that a baseline pump-and-treat system (e.g., Alternative #2) is ongoing. The two supplemental in situ treatment technologies that would be used as contingencies are in situ electrical resistive heating (ERH) and in situ anaerobic bioremediation.

The major cost components of the contingency measures are as follows and are supplemental to the costs of the selected alternative:

- Capital:
  - Remediation process system scope:
    - In situ ERH
    - In situ anaerobic bioremediation.
  - New well construction activities
- Periodic:
  - Groundwater monitoring
  - Well decommissioning
  - Utility (electrical)
- Annual:
  - O&M
  - Sampling.

The combined present net-worth costs for the in situ remediation equipment, additional well, and piping capital construction activities; O&M; sampling; and well decommissioning represent the present-worth cost for the possible contingency measures.

C3.0 ASSUMPTIONS

The assumptions used for Alternatives #1 and #2, as well as the contingency measures, are discussed in this section.

C3.1 GLOBAL ASSUMPTIONS

C3.1.1 Labor

Fixed-price construction craft labor rates listed in Appendix A of the *Site Stabilization Agreement for All Construction Work for the U.S. Department of Energy at the Hanford Site* (hereinafter referred to as the Hanford Site Stabilization Agreement [HSSA]) were used in this estimate. The HSSA rates include base wage, fringe benefits, and other compensation, as negotiated between FH and the National Building and Construction Trades Department AFL-CIO. Other factors to cover additional costs for workman's compensation, FICA, state and Federal unemployment insurance to develop a fully burdened rate by craft have been incorporated. The labor rates used are for 2007.

The FH labor rates for management, engineering, safety oversight, and technical support are based on the FH approved planning rates for fiscal year 2007 (FY07).

C3.1.2 Markups

The markups considered are listed below:

- Direct cost factors:
  - Sales tax (8.3%) has been applied to all materials and equipment purchases.
  - Construction consumables are estimated at 3.5% of fixed-price direct craft labor costs to allow for small tools, tape, plastics, gloves, etc.
  - General supervisor factor of 3% has been applied to fixed-price craft labor hours.
- Indirect cost factors:
  - Fixed-price contractor overhead, profit, bond, and insurance costs have been applied at 26.5% on fixed-price labor, materials, and equipment.
  - FH's general and administrative (G&A) cost of 16.5% has been applied to all FH labor, materials, and equipment. The G&A cost is also applied to the fixed-price contractor costs.

C3.1.3 General Assumptions

General assumptions are as follows:

- Construction labor, materials, and equipment units have been estimated based upon standard commercial estimating resources and databases: *Facility Construction Cost Data 2006* (Means 2006); *ECHOS Environmental Remediation Cost Data 2001* (Means 2001); *Process Plant Construction Estimating Standards, Volume I;* and *Rental Rate Blue Book for Construction Equipment 2007*. The units may have been factored or adjusted by the estimator, as appropriate, to reflect influences by contract, work site, or other identified project or special conditions.
- Quotes from local commercial sources have been used for materials that need to be acquired for the construction of barriers or temporary improvements.
- Equipment rates are based on 21 working days/month.
- Equipment operation is based on one shift of 8 hours/day.
- Work week equals 5 days/week.
- Work stoppages or shutdowns due to inclement weather are not factored into the estimates or planning schedules for this study.
- Work delays or stoppages due caused by waiting for laboratory results or approval for backfilling waste site excavations are not factored into the estimates or planning schedules for this study.
- The cost estimates do include costs for design, work plan preparation, or any other preparation costs normally associated with activities occurring before field mobilization.

- Remedial design capital costs are based on EPA guidance (EPA/540/R-00/002, Exhibit 5-8). The following guidance is used in this study:
  - For projects with construction costs less than $100,000: Remedial design is planned at 20% of construction costs.
  - For projects with construction costs from $100,000 to $500,000: Remedial design is planned at 15% of construction costs.
  - For projects with construction costs from $500,000 to $2 million: Remedial design is planned at 12% of construction costs.
  - For projects with construction costs from $2 million to $10 million: Remedial design is planned at 8% of construction costs.
  - For projects with construction costs greater than $10 million: Remedial design is planned at 6% of construction costs.
- Escalation has not been included in the calculations. All costs are present day (FY07).
- Contingency rates are based on Section 5.4 of EPA/540/R-00/002.

C3.1.4 Long-Term Groundwater Monitoring Costs

Alternative #2 includes annual inspections and maintenance costs for periodic groundwater monitoring. The costs associated with periodic groundwater monitoring are distributed equally over applicable closure zones. The following is a description of the periodic groundwater costs.

Periodic groundwater sampling will be performed in each closure zone located at the facility. Each closure zone will contain three monitoring wells that will be sampled during the periodic sampling event. The present-worth cost for the periodic groundwater monitoring program will be the same for each closure zone. That cost will then be divided equally among the sites within that closure zone. A summary of the facility closure zones associated with this FS is as follows:

Closure Zone	Number of Sites in Each Closure Zone
200 East Area	50
Plutonium Finishing Plant	40

Based on historical information from similar Hanford Site planning, the cost to install a compliant monitoring well is approximately $180,000/well. It is assumed that this cost includes all required labor and material:

- Cost to install wells (3 wells) = $180,000/well x 3 wells = $540,000.

Maintenance will be performed on each of the wells every 5 years during the 30-year active monitoring period. In addition, each of the wells will be replaced once every 20 years:

- Maintenance costs (3 wells) = $5,000/well x 3 wells = $15,000 every 5 years
- Replacement costs (3 wells) = $180,000/well x 3 wells = $540,000 every 20 years.

During each sampling event, three groundwater samples will be collected for analysis. The analyses and cost per analysis are listed below:

- Americium-241 = $125/sample x 3 samples/event = $375/event
- Plutonium-238, plutonium-239, plutonium-240, and plutonium-241 = $300/sample x 3 samples/event = $900/event
- Volatile organic compounds = $85/sample x 3 samples/event = $255/event
- Technetium-99 = $150/sample x 3 samples/event = $450/event
- Total analytical cost per sampling event = $1,980.

The labor cost for doing all of the paperwork, labeling, monitoring, and delivering to the laboratory is approximately $300 per well sampled:

- Total labor cost = $300/well x 3 wells = $900/sampling event
- Total cost to collect and analyze samples per sampling event = $2,880.

Sampling events will occur at the following frequencies:

- Year 1 through year 30 years (lifetime)
- Semi-annually (i.e., two sampling events).

The present-worth cost to conduct a periodic groundwater monitoring program for each closure zone for 30 years was calculated as follows:

- Present-worth cost for long-term groundwater program = $558,930.

As a comparison, the non-discounted, present-worth cost for long-term groundwater program was calculated to compare the effect of a discount rate on the total project cost:

- Present-worth non-discounted costs for long-term groundwater program = $787,800.

C3.2 ALTERNATIVE #1 –INSTITUTIONAL CONTROLS SUPPLEMENTED BY MONITORED NATURAL ATTENUATION

Section 5.2.1 of the FS describes the alternative for institutional controls and MNA. The present-worth and capital cost reports for this alternative are provided in Table C-2.

Alternative #1 consists of seven general activities: institutional controls, site inspection and surveillance, existing site maintenance, MNA, reporting, site reviews, and monitoring. These activities are described following subsections.

C3.2.1 Institutional Controls Implementation

Preparing and implementing institutional controls is a capital cost and includes the office or administrative costs to implement deed restrictions, land-use restrictions, and groundwater-use restrictions. Costs presented in the cost estimates are based on the following assumptions:

- Time to produce institutional controls: 200 hours (assumption)
- Labor rate: $56/hr (assumption).

C3.2.2 Site Inspection and Surveillance

The cost associated with site inspection and surveillance is an annual cost and occurs as long as the alternative is being used. The activities performed under site inspection and surveillance

include radiation surveys of surface soil and physical site inspection. Activities may include control of deeply burrowing animals and deep-rooted plants by using herbicide or by physical removal (the costs for these items are not included):

- Site radiation surveys: For costing purposes, sites 1 acre (43,560 ft^2) or smaller are assumed to cost $8,712 for every surveying event. An additional $1,000 will be required for site radiation surveys for every additional 5,000 ft^2 of site area above 1 acre.
- Physical site inspection: For costing purposes, sites 1 acre (43,560 ft^2) or smaller are assumed to require a team of two inspectors to perform the activities associated with site inspection and surveillance. An additional crew/time will be needed for site inspection and surveillance for site areas larger than 1 acre.

The cost for site inspection and surveillance for 1 acre is $781 and $896 for each additional 1.15 acre (50,000 ft^2) of waste area.

C3.2.3 Existing Site Maintenance

The cost associated with existing well site maintenance is an annual cost and occurs as long as the alternative is being used. Because site maintenance is performed annually, including costs for replacing all or large portions of the existing site at specified intervals is unnecessary. Activities include transportation, spreading, and revegetation costs; it is assumed that FH will have a site engineer onsite during site activities to provide oversight. For planning purposes, the repair of a 1-acre well site will require 31 m^3 (40 yd^3) of silt loam/pea gravel mixture, 2 hours to load and transport, 1 hour to spread, and 1 hour to re-seed. With supervisory over site the cost per site is approximately $1,400.

C3.2.4 Weed and Pest Control

The cost associated with weed and pest control is an annual cost and occurs as long as the alternative is being used. The work involves controlling weeds by spraying and removal or trapping of animals from the waste site. Radiological control technician (RCT) time is included in the cost for this work. For costing purposes, sites 1 acre or smaller are assumed to cost $1,036/yr. For sites larger than 1 acre, the cost will increase by $248/acre over the initial $1,036/acre.

C3.2.5 Waste Site/Fence Maintenance

The cost associated with waste site/fence maintenance is an annual cost and occurs four times each year for as long as the alternative is being used. The work involves removal of windblown trash/weeds and repair of the existing perimeter fences and signs. RCT time is included in the cost for this work. It is expected that a crew can maintain 5-acre site per day. The costs are assumed to be $2,135/acre per year.

C3.2.6 Natural Attenuation Monitoring

The cost associated with natural attenuation monitoring is an annual cost and occurs as long as the alternative is being used. The cost for natural attenuation monitoring includes spectral-gamma logging of vadose zone boreholes.

Vadose zone monitoring costs assume spectral-gamma logging of one borehole per waste site to a depth of 50 ft once every 5 years. The service life of a vadose zone borehole is assumed to be 30 years. Therefore, every 30 years, a replacement borehole will be drilled. Costs are based on the following:

- Unit cost for vadose zone monitoring: $75/ft of borehole
- Length of borehole drilling: 50 ft
- Cost of vadose zone monitoring : $75/ft x 50 ft = $3,750
- Installation cost of borehole: $50/ft of borehole
- Length of borehole installation: 50 ft
- Cost of borehole installation: 50/ft x 50 ft = $2,500
- Oversight (assumption): 1 day = 8 hours ($56/hr).

Other costs associated with installing replacement boreholes are included on the cost estimate sheets. These items include, but are not limited to, mobilization of a drill rig, decontamination of a drill rig, and handling of investigation-derived waste.

C3.2.7 Reporting

Annual and periodic activities will be recorded in annual reports. The annual report will contain descriptions of activities that occurred during the year. Reports will contain all appropriate/ required backup and material purchase information. The cost for the annual reports is based on the following assumption:

- Annual reports: $10,000/report.

C3.2.8 Site Reviews

The cost associated with site reviews is a periodic cost and occurs every 5 years as long as the alternative is being used. Site reviews will be conducted to assess site conditions and to evaluate the selected alternative and determine whether additional steps toward remediation are required. The cost for the 5-year site reviews is based on the following assumption:

- 5-year site review: $20,000/review.

C3.2.9 Monitoring

Monitoring includes collecting groundwater samples from downgradient wells to evaluate the performance of the remediation system. Groundwater monitoring would likely be a part of the remediation capital costs. However, the present-worth cost process considers groundwater sampling as periodic costs; therefore, they are not considered in the capital cost estimates. See Section C3.1.4 for these periodic cost details.

The prices that make up the cost estimate were obtained from one of the following sources:

- *ECHOS Environmental Remediation Cost Data – Unit Price* (Means 2001)
- *Facility Construction Cost Data* (Means 2006)
- Experience on similar projects.

The real discount rate of 3.0% is used for discounting real (constant-dollar) flows for the duration until all PRGs are reached at each site (assume to be 30 years). The non-discounted cost for the 30-year project duration is presented for comparison purposes.

C3.3 ALTERNATIVE 2 – FULL-SCALE PUMP-AND-TREAT, INSTITUTIONAL CONTROLS, MONITORED NATURAL ATTENUATION, PLUS FLOW-PATH CONTROLS

Section 5.2.2 of this FS describes the full-scale pump-and-treat alternative. The present-worth and capital cost reports for this alternative are included in Table C-3.

The current pump-and-treat system is set up for 1,136 L/min (300 gallons per minute [gpm]) and provides removal of carbon tetrachloride through an air stripper and GAC canisters. As the new system is installed, the system capacity will be increased to 3,028 to 6,057 L/min (800 to 1,600 gpm), using 14 to 27 injection wells and 14 to 27 extraction wells. For costing purposes for decision making, 14 injection and 14 extraction wells have been used in the estimates. The 27-well extraction system is assumed to have a present-worth cost of twice that of the 14-well extraction system.

Using the design costs of $2.8 million in 1995 and $4 million for installation of the current system in 1996 (*Fiscal Year 2005 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations* [DOE/RL-2005-91]), the new treatment system (which will treat 3,028 L/min [800 gpm]) is estimated to cost $3 million for design and $7 million for actual installation. The new treatment train system will be modular for mobile relocation, as appropriate given the new well configurations.

Some of the wells will be capturing and recovering technetium-99 in the groundwater. The treatment train for these wells will include an IX system to remove the technetium-99 prior to reinjection. The estimated costs for the IX unit is $2 million based on surveying of existing IX systems and current pilot-scale testing.

Annual O&M costs for the current 1,135 L/min (300 gpm) 200-ZP-1 pump-and-treat system were $724,800, $703,400, and $766,200 in years 2003, 2004, and 2005, respectively (DOE/RL-2005-91). Scaling these values up for the 3,028 L/min (800 gpm) system, the new average annual O&M costs are estimated at $1.9 million/yr. These costs are assumed to include the annual utility requirements and all by-product disposal costs.

Performance monitoring (sampling) of the existing 1,135 L/min (300 gpm) pump-and-treat system has ranged between $256,900 and $127,600 from 2000 to 2004. The performance monitoring costs jumped significantly in 2005 to $990,500 due to the installation of new monitoring wells. Since the costs for the installation of new monitoring wells are captured elsewhere in the estimate, an average cost of $200,000/yr based upon the 2000 to 2004 performance monitoring costs of the current system, has been scaled to $450,000/yr for the increased capacity system.

Monitoring well construction will be performed as part of this remediation alternative. This work is planned to address monitoring and treatment requirements. Wells will typically be completed as unconfined aquifer monitoring wells and are assumed to be a mixture of low risk to high risk. Planned total depths are estimated at 200 to 400 ft. The estimates are based on the current well-planning costs used for the FH cost baseline. The estimates have been based on actual pricing information derived from historical experience. The units used may have been factored/adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other identified special conditions. The average base cost for each well is $309,000, without cost adjustments of 5% to 15% for depth and risk (hazard) factors. Table C-3 provides the capital costs for this alternative.

The interconnecting piping between the wells and the pump-and-treat process system enclosure will consist of buried, double-wall, high-density polyethylene pipe and fittings with leak detection. The length of pipe run for each well to the pump-and-treat enclosure is 15,000 ft. Manholes will be spaced every 600 ft. A unit rate of $46.69/linear foot was estimated using a "bottoms-up" approach and uses the R. S. Means *Facility Construction Cost Data* (Means 2006).

Well decommissioning of 28 wells will be required immediately upon completion of remediation. Decommissioning is considered as a periodic cost for the purpose of present-worth calculations. The scope of this work includes the following:

- Support planning prior to notice to proceed in field
- Package/manage decommissioning water
- Decommissioning subcontract.

The estimates are based on the current well-planning costs used for the FH cost baseline. The estimates have been based on actual pricing information derived from historical experience. The units used may have been factored/adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other identified special conditions. The average cost for each well decommissioning activity is $65,000.

Typical activities for non-capital cost elements are described in Section C3.2. These elements include the following:

- Institutional controls
- Site inspection and surveillance
- Existing site maintenance
- MNA
- Reporting
- Site reviews
- Monitoring.

These activities are priced out and factored into the present-worth cost as annual and periodic costs.

The real discount rate of 3.0% is used for discounting real (constant-dollar) flows. The non-discounted cost for the 30-year project duration is presented for comparison purposes.

C3.3.1 Special Site Conditions

- Well installation:
  - The cost of well installation
  - The general scope basis is as follows:
    - Work activities include planning and documentation, technical coordination, procurement, labor, subcontracts, materials, equipment, field support during construction waste management, and project closeout.
- Well planning: Prepare and/or obtain the necessary documentation to support well installations. Where possible, use or modify existing documentation to plan the work. Subtasks include, but are not limited to, the following:

- Stake wells and walkdown
- Prepare description of work for installation of wells with data sheets
- Prepare sampling and analysis instructions and data quality objective waste summary report
- Conduct cultural resources review
- Conduct ecological resources review
- Perform ground-penetrating radar surveys for underground utilities
- Update site-specific waste management instructions
- Prepare drilling contract from description of work and data sheets
- Prepare necessary permits (e.g., excavation and radiological work permits)
- Prepare preliminary hazard classification, hazard survey, and radiological assessment.

Well installation tasks include preparing subcontract documents; preparing well pads; drilling and installing groundwater monitoring wells; conducting civil surveys of well locations; providing management support, labor support, and associated documentation; and performing closeout activities.

The fieldwork (e.g., mobilization/demobilization, site preparation, drilling, well completion, development, and some of the post-construction work) will be contracted to a fixed-price contractor.

The FH work activities also include planning and documentation, technical coordination, procurement, labor, subcontracts, materials, equipment, field support during construction (e.g., buyer's technical representative, well site geologist, and purgewater truck and driver), waste management and project closeout. Project management, RCT support, sampling, and safety oversight will be performed by FH.

Waste management activities include providing management oversight for waste associated with the installation of groundwater monitoring wells. Waste management includes the disposal of soil, groundwater, and miscellaneous sampling waste as needed during well installations, well operations, and miscellaneous waste disposal. Waste management support includes waste sampling and evaluations, profiling, labeling, disposal costs, and management.

- Provide office and field supervision, and RCT and industrial hygiene technicians as required to support waste management activities. This includes manual/non-manual labor, subcontracts, and project management for those activities.
- Two soil samples will be collected from waste containers from each boring.
- Assumes approximately three-quarters of soil cuttings will be returned to the environment at the wellhead and approximately one-quarter of the soil will be disposed at the Environmental Restoration Disposal Facility.
- Soils from below the water table will be collected and placed in drums.

All well drilling and development purgewater will be transported and disposed at the Effluent Treatment Facility or the Purgewater Storage and Treatment Facility.

Fixed-price contractor mobilization and startup include site training, crew medical exams, documentation of driller registrations, mobilization of equipment and personnel, installation of temporary construction fences/access control, and the construction of drill pads, access roads, and decontamination areas. The length and width of the access roads and the size of the drill pads will vary as a function of the topography and building/utility constraints. The contractor will clear and grub vegetation for the well pads and roads. The roads and drill pads will be constructed of pit-run gravel and topped with 1.25 in. minus crushed rock.

The fixed-price contractor shall provide and manage all labor, material, equipment, construction design, testing, inspection, and service required to provide a complete and fully functional monitoring well in accordance with the contract documents. The drilling equipment will be steam cleaned or decontaminated prior to use at a drill site and before removal from the site. The fixed-price contactor will supply and install the temporary and permanent well casing and screens, as well as the sand, filter packs, grout, sealing bentonite clay, and sampling pumps/equipment. The fixed-price contractor will be required to handle the drumming of drilling waste and purgewater for turn over to Waste Management; this will also include a forklift operator for drum handling after the drums turned over to Waste Management. The contractor will provide the crew and equipment for required soil and water sampling during drill operations. After the completing installation of the permanent casing, the fixed-price contractor will install a concrete well pad, survey marker, four bollards, and a protective casing and cover assembly at the well head. The last field activity for the fixed-price contractor will be installing a temporary pump and developing the well. Purgewater will be collect and turned over to FH. After the groundwater turbidity is within acceptable limits and other testing has been completed, a permanent sampling pump will be installed.

The estimates are based on the current well-planning costs used for the FH cost baseline. The estimates have been based on actual pricing information derived from historical experience. The units used may have been factored/adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other identified special conditions.

Historical information from similar Hanford Site planning, construction, and well drilling efforts has been applied to this estimate.

C3.4 CONTINGENCY MEASURES –IN SITU TREATMENT TECHNOLOGIES

Section 5.2.2.1 of this FS describes the in situ technologies that are proposed for contingency measures, should a persistent source be identified. The present-worth and capital cost reports for these contingencies are included in Table C-4. Both contingencies include system design and construction.

C3.4.1 Electrical Resistance Heating

The in situ ERH treatment system costs were estimated assuming installation of 345 new wells to cover a basic 5-acre area. These wells require that conductors are placed within each well to transmit electricity. The costs of graphite materials and the conductors are estimated at $15,000/well. This adds an additional capital cost of $5.2 million over the standard cost for installing 345 wells. In addition to the wells, power-monitoring equipment, control equipment, and other surface installations are required to operate and control the system. These surface controls and installations are estimated at $350,000.

The construction of 345 wells will be performed as part of this contingency. This work is planned to address treatment requirements and is assumed to be a mixture of low risk to high risk. Planned total depths are estimated at 200 to 400 ft. The estimates are based on the current well-planning costs used for the FH cost baseline. The estimates have been based on actual pricing information derived from historical experience. The units used may have been factored/adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other identified special conditions. The average base cost for each well is $309,000, without cost adjustments of 5% to 15% for depth and risk (hazard) factors. Table C-4 provides the capital costs for this alternative. Initial system startup is estimated at approximately $500,000 (capital) and then annual operations are estimated at $1 million/yr for the 3-year duration of the ERH operations

The EPA guidance document, *In Situ Thermal Treatment of Chlorinated Solvents, Fundamentals and Field Applications* (EPA 542-R-04-010), shows a requirement of 200 kwh/m^3. Assuming that there are 5 acres by 30 m to treat, 121.4 million kwh are needed using the EPA number and spread over 3 years. Therefore, the annual electrical costs are 40.5 million kwh/yr at $0.034 for a total of $1.377 million/yr.

Decommissioning of 345 wells will be required immediately upon completion of ERH remediation. Decommissioning is considered to be a periodic cost for the purposes of the present-worth calculations.

The real discount rate of 3.0% is used for discounting real (constant-dollar). The non-discounted cost is also presented for comparison purposes. Note that the duration of the ERH operation is 3 years and well decommissioning occurs in year four.

C3.4.2 Anaerobic Bioremediation

The in situ bioremediation system has been designed for a 5-acre treatment zone, just as with the ERH system. The major advantage of the bioremediation approach is that fewer wells are required, thereby reducing costs compared to the ERH approach. To cover the 5-acre area for the bioremediation approach, only 35 injection wells are required. These wells will be decommissioned immediately following the 4-year treatment period.

The treatment will consist of approximately 2.3 million lb of vegetable oil at $1.35/lb and 2 million lb of sodium lactate at $0.85/lb, which is a total of $5 million for injection materials. Operating labor and other miscellaneous control and performance-monitoring equipment are estimated at another $3 million. An allowance of $2 million (of the $3 million) has been made for capital cost for process equipment, engineering, procurement, and installation. Therefore, the average annual operating cost of the system will be $1.5 million/yr ([$5 million + $1 million] / 4 years = $1.5 million/yr).

This contingency contains similar scope of work, which can be found in the ERH contingency measure. This scope includes the following the construction of 35 wells and the decommissioning of 35 wells.

The real discount rate of 3.0% is used for discounting real (constant-dollar) flows. The non-discounted cost is presented for comparison purposes. Note that the duration of the ERH process operation is 4 years and well decommissioning occurs in year five.

Typical activities for non-capital cost elements common to both ERH and bioremediation options are described in Section C3.2. These elements include the following:

- Institutional controls
- Site inspection and surveillance
- Existing site maintenance
- MNA
- Reporting
- Site reviews
- Monitoring.

These non-capital cost activities are priced out by alternative are then factored into the present-worth cost as annual and periodic type costs.

C3.5 PRESENT WORTH

The present-worth costs are summarized by alternative and are shown in Table C-6.

Table C-1. 200-ZP-1 Operable Unit Capital, Annual, and Periodic Costs Reference.

Description	Alternative #0	Alternative #1	Alternative #2	Contingency Measure – ERH		Contingency Measure – In Situ Bio	
Capital							
New wells			28	345		35	
New well ($/each)			$309,000	$309,000		$309,000	
Conductors/well				$15,000			
Pump-and-treat system			$10,000,000				
Technetium-99 train			$2,000,000				
Pump-and-treat interconnection piping			15,000 LF/well				
Pump-and-treat interconnection piping ($/LF)			$46.69/LF				
In situ ERH system				$350,000			
In situ ERH system startup				$500,000			
In situ bioremediation system						$2,000,000	
Annual Expense							
Sampling – pump-and-treat			$450,000	$0		$0	
(Year)				**Years 1 to 3**			
Utility (electrical usage/yr)				40,500,000 kwh			
Utility (electrical rate)				$0.034/kwh			
Utility (electrical cost/yr)				$1,377,000			
(Year)				**Years 1 to 3**	**Years 4 to 30**	**Years 1 to 3**	**Years 5 to 30**
Operation and maintenance/yr			$1,900,000	$1,500,000	$0	$1,500,000	$0
Periodic Expense							
Well decommissioning (year)			Year 30	Year 4		Year 5	
Groundwater monitoring wells maintenance			Year 20				

ERH = electrical resistance heating
LF = linear foot

Table C-2. Alternative #1 – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs.

Site	Alternative	Total Capital Cost	Non-Discounted Annual and Periodic Cost	Non-Discounted Cost	Total Present-Worth Cost
200-ZP-1 Operable Unit	Alternative #1, Institutional Controls Supplemented by MNA	$35,400	$4,741,448	$4,776,848	$3,070,634

MNA = monitored natural attenuation

Table C-3. Alternative #2 – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs.

Site	Alternative	Total Capital Cost	Non-Discounted Annual and Periodic Cost	Non-Discounted Cost	Total Present-Worth Cost
200-ZP-1 Operable Unit	Alternative #4, Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Flow-Path Controls	$43,462,096	$77,088,578	$120,550,674	$93,319,523

MNA = monitored natural attenuation

Table C-4. Contingency Measures – Capital Costs, Periodic Costs, Non-Discounted Costs, and Present-Worth Costs.

Site	Site Description	Option	Alternative	Total Capital Cost	Non-Discounted Annual and Periodic Cost	Non-Discounted Cost	Total Present-Worth Cost
200-ZP-1 Operable Unit	ERH	a	In situ electrical resistive heating	$147,114,750	$27,510,781	$174,625,531	$172,047,965
	In situ bioremediation	b	In situ anaerobic bioremediation	$16,666,250	$8,774,848	$25,441,098	$24,669,246

ERH = electrical resistance heating

Table C-5. Alternatives #0, #1, #2, and Contingency Measures – Present-Worth and Non-Discounted Comparison Costs.

	Alternative #0, No Action	Alternative #1, Institutional Controls Supplemented by MNA	Alternative #2, Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Flow-Path Controls	Contingency Measure, In Situ ERH	Contingency Measure, In Situ Bioremediation
Present Worth	$0	$3,070,634	$93,319,523 (800 gpm) $180,000,000 (1,600 gpm)	$172,047,965	$24,669,246
Non-Discounted Cost		$4,776,848	$120,550,674	$174,625,531	$25,441,098

ERH = electrical resistance heating
MNA = monitored natural attenuation
OU = operable unit

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APPENDIX D

GROUNDWATER MODELING DETAILS

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TABLE OF CONTENTS

D1.0 INTRODUCTION D-1

D2.0 COMPILATION AND EVALUATION OF DATA D-2

D2.1 BACKGROUND D-2

D2.2 APPROACH D-2

D2.3 DISCUSSION D-3

D3.0 IDENTIFICATION OF CURRENTLY IMPACTED GROUNDWATER D-4

D3.1 BACKGROUND D-4

D3.2 APPROACH D-4

D3.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-5

D3.4 RESULTS D-6

D3.5 DISCUSSION D-7

D4.0 INTERPRETATION OF HISTORIC GROUNDWATER FLOW D-7

D4.1 BACKGROUND D-7

D4.2 APPROACH D-8

D4.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-9

D4.4 RESULTS D-10

D4.5 DISCUSSION D-11

D5.0 EVALUATION OF CONTAMINANT TRANSPORT D-11

D5.1 BACKGROUND D-11

D5.2 APPROACH D-12

D5.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-13

D5.4 RESULTS D-13

D5.5 DISCUSSION D-14

D6.0 INTERPRETATION OF HYDRAULIC RESPONSE TO THE EXISTING 200-ZP-1 PUMP-AND-TREAT SYSTEM D-14

D6.1 BACKGROUND D-14

D6.2 APPROACH D-14

D6.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-15

D6.4 RESULTS D-16

D6.5 DISCUSSION D-16

D7.0 EVALUATION OF PUMP-AND-TREAT REMEDY SCENARIOS D-17
D7.1 BACKGROUND D-17
D7.2 APPROACH D-18
D7.3 GROUNDWATER HEAD CALCULATIONS D-18
D7.4 ASSUMPTIONS, ADVANTAGES AND DISADVANTAGES D-19
D7.5 RESULTS D-20
D7.6 DISCUSSION D-20
D8.0 ESTIMATION OF RELATIVE CLEANUP TIMES USING PARTICLE TRACKING D-21
D8.1 BACKGROUND D-21
D8.2 COMMON METHODS FOR ESTIMATING CLEANUP TIMES FOR PUMP-AND-TREAT SYSTEMS D-21
D8.2.1 Particle-Tracking Method D-22
D8.3 APPROACH D-23
D.8.3.1 Step-Wise Analysis D-23
D8.3.2 Feasibility of Optimization D-23
D8.4 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-24
D8.5 RESULTS D-24
D9.0 EVALUATION OF CONTAMINANTS OF CONCERN NOT CAPTURED BY PUMP-AND-TREAT ALTERNATIVES D-25
D9.1 BACKGROUND D-25
D9.2 APPROACH D-25
D9.3 ADVECTION-DISPERSION TRANSPORT CALCULATIONS D-26
D9.4 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES D-27
D9.5 RESULTS D-28
D9.6 DISCUSSION D-28
D10.0 EVALUATION OF THE IMPACT OF PRINCIPAL ASSUMPTIONS D-29
D10.1 BACKGROUND D-29
D10.2 ASSUMPTION: FLOW IS DOMINANTLY TWO-DIMENSIONAL D-30
D10.2.1 Vertical Gradients D-30
D10.2.2 Partial Penetration D-30
D10.3 ASSUMPTION: AQUIFER IS HOMOGENEOUS AND ISOTROPIC D-33
D10.3.1 Hydraulic Capture D-33

D11.0 REFERENCES/BIBLIOGRAPHY D-34

FIGURES

Figure D-1. Hydraulic Conductivity Distribution – Ringold Unit 5. ..... D-38
Figure D-2. Transmissivity Distribution – Ringold Unit 5. ..... D-38
Figure D-3. Effective Porosity Distribution – Ringold Unit 5 ..... D-39
Figure D-4. Composite Extent of Groundwater Contamination Above 1 x 10^{-4} Risk. D-39
Figure D-5. Composite Extent of Groundwater Contamination Above Maximum Contaminant Levels. D-40
Figure D-6. Composite Extent of Groundwater Contamination Above Ten Times Maximum Contamination Levels. D-40
Figure D-7. Composite Extent of Groundwater Contamination for Preferred Pump-and-Treat Alternative. D-41
Figure D-8. Wells Sampled for Chloroform. D-41
Figure D-9. Wells Sampled for Hexavalent Chromium. D-42
Figure D-10. Wells Sampled for Total Chromium. D-42
Figure D-11. Wells Sampled for Carbon Tetrachloride D-43
Figure D-12. Wells Sampled for Iodine-129. ..... D-43
Figure D-13. Wells Sampled for Methylene Chloride. D-44
Figure D-14. Wells Sampled for Nitrate. D-44
Figure D-15. Wells Sampled for Tetrachloroethylene D-45
Figure D-16. Wells Sampled for Technetium-99. ..... D-45
Figure D-17. Wells Sampled for Trichloroethylene. D-46
Figure D-18. Wells Sampled for Tritium. D-46
Figure D-19. Wells Sampled for Uranium (Total) D-47
Figure D-20a. Measured and Modeled Groundwater Elevations. D-48
Figure D-21. Calculated Hydraulic Heads in 1945 ..... D-61
Figure D-22. Calculated Hydraulic Heads in 1950 ..... D-62
Figure D-23. Calculated Hydraulic Heads in 1955 ..... D-63
Figure D-24. Calculated Hydraulic Heads in 1960 ..... D-64
Figure D-25. Calculated Hydraulic Heads in 1965 ..... D-65
Figure D-26. Calculated Hydraulic Heads in 1970 ..... D-66
Figure D-27. Calculated Hydraulic Heads in 1975 ..... D-67
Figure D-28. Calculated Hydraulic Heads in 1980 ..... D-68
Figure D-29. Calculated Hydraulic Heads in 1985 ..... D-69
Figure D-30. Calculated Hydraulic Heads in 1990 ..... D-70
Figure D-31. Calculated Hydraulic Heads in 1995 ..... D-71
Figure D-32 .Calculated Hydraulic Heads in 2000 ..... D-72
Figure D-33. Calculated Hydraulic Heads in 2005 ..... D-73
Figure D-34. Historic Transport of Carbon Tetrachloride. D-74
Figure D-35. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2003 ..... D-75
Figure D-36. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2004 ..... D-76
Figure D-37. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2005 ..... D-77

Figure D-38. Approximate Extent of Hydraulic Capture of the 200-ZP-1 Interim Remedial Measure in 2003. ..... D-78
Figure D-39. Approximate Extent of Hydraulic Capture of the 200-ZP-1 Interim Remedial Measure in 2004. ..... D-79
Figure D-40. Approximate Extent of Hydraulic Simulated Capture of the 200-ZP-1 Interim Remedial Measure in 2005 ..... D-80
Figure D-41. Calculated Hydraulic Heads – 1 x 10^{-4} Capture. D-81
Figure D-42. Maximum Contaminant Level Capture – Calculated Hydraulic Heads. D-82
Figure D-43. Ten Times Maximum Contaminant Level Capture – Calculated Hydraulic Heads D-83
Figure D-44. Preferred Pump-and-Treat Alternative – Calculated Hydraulic Heads. D-84
Figure D-45. Preferred Pump-and-Treat Alternative (1,615 gpm) – Calculated Hydraulic Heads D-85
Figure D-46. Calculated Capture Time of Groundwater Above 1 x 10^{-4} Risk. D-86
Figure D-47. Calculated Capture Time of Groundwater Above Maximum Contaminant Levels. D-87
Figure D-48. Calculated Capture Time of Groundwater Above Ten Times Maximum Contaminant Levels. D-88
Figure D-49. Calculated Capture Time of Groundwater for the Preferred Pump-and-Treat Alternative (840 gpm). D-89
Figure D-50. Calculated Capture Time of Groundwater for the Preferred Pump-and-Treat Alternative (1,615 gpm). D-90
Figure D-51. Preferred Pump-and-Treat Remedy Relative Cleanup Times. D-91

TABLES

Table D-1. Parameter Data Sources. (5 sheets) D-92
Table D-2. Total Porosity – Ringold Unit 5. (2 sheets) D-97
Table D-3. Effective Mobile Porosity – Ringold Unit 5. (3 sheets) D-101
Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets) D-107
Table D-5. Transmissivity – Ringold Unit 5. ..... D-121
Table D-6. Aquifer Storage – Ringold Unit 5 ..... D-123
Table D-7. Hydraulic Gradient – Ringold Unit 5. ..... D-125
Table D-8. Kh/Kv Anisotropy Ratio – Ringold Unit 5 ..... D-127
Table D-9. Groundwater Velocity – Ringold Unit 5. ..... D-129
Table D-10. Dispersivity – Ringold Unit 5 ..... D-131
Table D-11. Fraction of Organic Carbon – Ringold Unit 5. ..... D-133
Table D-12. Distribution Coefficient (K_d) – Ringold Unit 5. ..... D-135
Table D-13. Soil Bulk Density – Ringold Unit 5 ..... D-137
Table D-14. Soil Particle Size – Ringold Unit 5 ..... D-139
Table D-15. Soil Particle Density – Ringold Unit 5. ..... D-141
Table D-16. Total Porosity – Hydraulically Downgradient of 200-ZP-1. ..... D-143
Table D-17. Effective Porosity – Hydraulically Downgradient of 200-ZP-1 ..... D-145
Table D-18. Hydraulic Conductivity – Hydraulically Downgradient of 200-ZP-1. (3 sheets) D-147
Table D-19. Transmissivity – Hydraulically Downgradient of 200-ZP-1. ..... D-153
Table D-20. Aquifer Storage – Hydraulically Downgradient of 200-ZP-1. ..... D-155

Table D-21. Hydraulic Gradient - Hydraulically Downgradient of 200-ZP-1. ..... D-157
Table D-22. Kn/Kv Anisotropy Ratio - Hydraulically Downgradient of 200-ZP-1. ..... D-159
Table D-23. Groundwater Velocity - Hydraulically Downgradient of 200-ZP-1. ..... D-161
Table D-24. Fraction of Organic Carbon - Hydraulically Downgradient of 200-ZP-1. ..... D-163
Table D-25. Soil Bulk Density - Hydraulically Downgradient of 200-ZP-1. ..... D-165
Table D-26. Soil Particle Size - Hydraulically Downgradient of 200-ZP-1. ..... D-167
Table D-27. Soil Particle Density - Hydraulically Downgradient of 200-ZP-1. ..... D-169
Table D-28. Chloroform Data. (4 sheets) D-171
Table D-29. Hexavalent Chromium Data. D-175
Table D-30. Total Chromium Data. (3 sheets) D-176
Table D-31. Carbon Tetrachloride Data – 0 to 10 m Below Water Table. (4 sheets) D-179
Table D-32. Carbon Tetrachloride Data – 10 to 20 m Below Water Table. (2 sheets) D-183
Table D-33. Carbon Tetrachloride Data – 20 to 30 m Below Water Table. (2 sheets) D-185
Table D-34. Carbon Tetrachloride Data – 30 to 40 m Below Water Table. D-187
Table D-35. Carbon Tetrachloride Data – 40 to 50 m Below Water Table. (2 sheets) D-188
Table D-36. Carbon Tetrachloride Data – >50 m Below Water Table. D-190
Table D-37. Iodine-129 Data. (3 sheets) D-191
Table D-38. Methylene Chloride Data. (4 sheets) D-194
Table D-39. Nitrate Data. (4 sheets) D-198
Table D-40. Tetrachloroethylene Data. (4 sheets) D-202
Table D-41. Technetium-99 Data – 0 to 10 m Below Water Table. (2 sheets) D-206
Table D-42. Technetium-99 Data – 10 to 20 m Below Water Table. (2 sheets) D-208
Table D-43. Technetium-99 Data – 20 to 30 m Below Water Table. D-210
Table D-44. Technetium-99 Data – 30 to 40 m Below Water Table. D-211
Table D-45 Technetium-99 Data – 40 to 50 m Below Water Table. D-212
Table D-46. Technetium-99 Data – >50 m Below Water Table. D-212
Table D-47. Trichloroethylene Data – 0 to 10 m Below Water Table. (2 sheets) D-213
Table D-48. Trichloroethylene Data – 10 to 20 m Below Water Table. (2 sheets) D-215
Table D-49. Trichloroethylene Data – 20 to 30 m Below Water Table. (2 sheets) D-217
Table D-50. Trichloroethylene Data – 30 to 40 m Below Water Table. D-219
Table D-51. Trichloroethylene Data – 40 to 50 m Below Water Table. D-220
Table D-52. Trichloroethylene Data – >50 m Below Water Table. D-221
Table D-53. Tritium Data. (4 sheets) D-222
Table D-54. Uranium (Total) Data. (2 sheets) D-226
Table D-55. Historic Wastewater Discharges Sites Used for Calculations. D-228
Table D-56. Target Cleanup Levels for Preferred Pump-and-Treat Alternative. D-229
Table D-57. Evaluation of Partial Penetration Impacts on Current and Future Groundwater Remedies. (2 sheets) D-231
Table D-58. Contaminant Fate and Transport Parameters. (2 sheets) D-235

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APPENDIX D

GROUNDWATER MODELING DETAILS

D1.0 INTRODUCTION

This appendix outlines the data analysis and modeling methods used to evaluate groundwater hydraulic conditions at the Hanford Site's 200-ZP-1 Operable Unit (OU) to support the comparative analysis of the 200-ZP-1 feasibility study (FS) and remedy selection. The location of the 200-ZP-1 OU is shown in Figure 1-1 of the main text of the FS. The objectives of the analysis were (1) to compile, summarize, and analyze data to support modeling calculations; and (2) to conduct the calculations with sufficient detail to meet the requirements of the FS. The evaluation and design of a groundwater pump-and-treat remedy and/or alternate remedies at the 200-ZP-1 OU required data and calculation methods that could approximately describe the following:

- Extent of contaminated groundwater to be actively remediated (hereinafter referred to as the "target treatment zone[s]")
- Direction(s) and rate(s) of groundwater flow
- Extent of groundwater capture developed by (1) modifying pumping rates at existing groundwater recovery wells, and/or (2) the addition of new groundwater recovery wells.

Considering these requirements, the groundwater data analysis and modeling included evaluations of the following:

- Likely mechanisms leading to the current distribution of contaminants
- Extent of hydraulic capture of the current 200-ZP-1 OU interim remedial measure (IRM)
- Configuration of alternative groundwater pump-and-treat scenarios to be considered during the evaluation of remedial actions as part of the FS
- Possible fate of contaminants not remedied by alternate pump-and-treat scenarios.

Concurrent with the development and performance of these calculations, comprehensive tables of inputs (i.e., parameters) required to perform or support the calculations were prepared using site-specific data sources. The compilation and evaluation of data and modeling calculations focused on the area within the 200-ZP-1 OU boundaries, although calculations of the possible fate of contaminants not remedied by alternate pump-and-treat remedies extend beyond the 200-ZP-1 OU boundaries. These tables of compiled parameter data include summary statistics (i.e., means, standard deviations, etc.) used to approximately describe the central tendency (most likely or most commonly occurring) value for each parameter and the general range of values of each parameter encountered at the site.

The analyses were completed using parameters representative of the central tendency described by the summary statistics. However, the analyses considered the contrasting roles of uncertainty and variability in the evaluation of the parameters. Uncertainty refers to things that are unknown or uncertain (e.g., the date that a single event occurred). Variability refers to true diversity or heterogeneity in a variable (e.g., the range in hydraulic conductivity).

This appendix details the following components of the 200-ZP-1 OU groundwater data and modeling analyses:

- Compilation and evaluation of data
- Identification of currently impacted groundwater
- Interpretation of historic groundwater flow
- Evaluation of historic contaminant transport
- Interpretation of groundwater system response to the existing 200-ZP-1 pump-and-treat system
- Evaluation of pump-and-treat remedy scenarios
- Evaluation of contaminants of potential concern (COPCs) not captured by pump-and-treat remedial scenarios
- Evaluation of the impact of principal assumptions.

D2.0 COMPILATION AND EVALUATION OF DATA

D2.1 BACKGROUND

A compilation and evaluation of data were completed to accomplish the following:

- Compile available data sources
- Assess the quantity of available data
- Assess the quality of available data
- Develop parameter statistics describing the following:
  - Spatial variability
  - Central tendency and variability in key parameters.

D2.2 APPROACH

Sources of available site data were compiled into Microsoft Excel® spreadsheets for each model/ calculation parameter, together with some additional supporting parameters. The following parameters were summarized: total porosity, mobile/ effective porosity, hydraulic conductivity, transmissivity, storage (storativity), dispersion length (dispersivity), horizontal hydraulic gradient (a discussion of vertical gradients included in Section D2.10), groundwater velocity, fraction of organic carbon (FOC), distribution coefficient (K_d), bulk density, anisotropy ratio, particle density, and particle size. Summary tables for each parameter were grouped by aquifer unit.

Data sources used to compile the parameters are summarized in Table D-1 of this appendix. Parameters for the Ringold Unit E aquifer, which is the principal aquifer beneath the 200-ZP-1 OU, are summarized in Tables D-2 through D-15. Parameters for aquifer units downgradient of the 200-ZP-1 OU are summarized in Tables D-16 through D-27. Compiled parameter values

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included data from laboratory measurements, field data (i.e., pumping test data, slug testing, etc.), empirically derived results (e.g., van Genuchten curve matching), and parameters used as part of previous modeling efforts at the Hanford Site. The data were summarized for each aquifer unit using common descriptive statistics (i.e., mean, standard deviation, minimum value, maximum value, etc.). These summary statistics were used to guide evaluations of the uncertainty and/or variability in the outputs of the modeling calculations.

The groundwater analyses that form the basis of the comparative remedy analysis require the explicit definition of mobile/effective porosity, hydraulic conductivity, transmissivity, storage (storativity), and dispersion length (dispersivity). The results of the groundwater analyses can be compared with independent sources of information on hydraulic gradient and groundwater velocity. The FOC, K_d, and bulk density are used to define approximate retardation rates for use in the groundwater analyses. The possible impact of anisotropy ratios on conclusions reached in the comparative remedy analysis is discussed in this appendix as well. Discussion of the assumptions incorporated into the modeling and calculations are presented in the following sections.

D2.3 DISCUSSION

Summary statistics for key model parameters are provided below:

Parameter	Units	No. of Measurements	Minimum	Maximum	Average	Standard Deviation
Bulk density	g/cm^3	30	1.41	2.32	1.95	0.22
Effective porosity	cm^3/cm^3	64	0.02	0.46	0.14	0.10
Total porosity	cm^3/cm^3	49	0.07	0.46	0.23	0.10
Hydraulic conductivity	m/day	244	8.E-05	1,280	21	96
Transmissivity	m^2/day	61	0.6	5,295	673	1,160
Storage		26	2.3E-05	4.0E-02	4.4E-03	9.2E-03

NOTE: Values for storage presented are for storativity (S) and do not include values of specific storage (S_s) presented in Table D-6.

Histogram figures showing the distribution of hydraulic conductivity, transmissivity, and effective porosity are provided in Figures D-1, D-2, and D-3.

Section D4.0 discusses the parameters used during calibration of the analytical flow model equations to historic groundwater elevations. As shown in Section D4.0, there is relatively good agreement between the mean values for parameters from the compilation of field measurements and the values used in matching historic groundwater heads, providing two independent sources of hydraulic parameters for the 200-ZP-1 FS area.

D3.0 IDENTIFICATION OF CURRENTLY IMPACTED GROUNDWATER

D3.1 BACKGROUND

The identification of currently impacted groundwater was performed to address the following issues:

- What is the current three-dimensional configuration of 200-ZP-1 COPCs in groundwater?
- What volume and mass of groundwater is impacted by the COPCs?
- What portion of the current extent of COPCs is captured by the current 200-ZP-1 IRM pump-and-treat system?
- What portion of the current extent of COPCs may not be captured by active remediation?

D3.2 APPROACH

The approximate volume of aquifer that is contaminated by each COPC was summarized by mapping the approximate extent of groundwater contaminated above target cleanup levels. The approximate extent of groundwater contamination was mapped for the following 12 COPCs:

- Volatile organic compounds (VOCs) and decay products:
  - Carbon tetrachloride
  - Chloroform
  - Methylene chloride
  - Tetrachloroethylene (PCE)
  - Trichloroethylene (TCE)
- Radionuclides:
  - Iodine-129
  - Technetium-99
  - Total uranium
  - Tritium
- Inorganics:
  - Hexavalent chromium (chromium [VI])
  - Total chromium
  - Nitrate.

Groundwater concentration data from 2000 to 2006 were obtained and tabulated from monitoring wells, borings, and groundwater recovery wells for these 12 COPCs from the Hanford Environmental Information System (HEIS) database. Data from wells covering an area from 560800m easting, 12940 m northing to 560800m easting, 143600m northing were included in the data tabulation. These data are maintained on secure project directory in accordance with a project quality assurance plan (PQAP). Maps of the VOCs were prepared by interpolating VOC concentrations in micrograms per liter (µg/L). Maps of radionuclides were prepared by interpolating radionuclide activities in picocuries per liter (pCi/L). Maps of the remaining inorganics were prepared by interpolating inorganic concentrations in milligrams per liter (mg/L) or µg/L. Representative concentrations for each COPC at each sampled location were obtained using the following approach:

- For COPCs with sufficient depth-discrete data (carbon tetrachloride, TCE, and technetium-99), the data were sorted in the following six depth intervals:
  - 0 to 10 m below the water table (bwt)
  - 10 to 20 m bwt
  - 20 to 30 m bwt
  - 30 to 40 m bwt
  - 40 to 50 m bwt
  - >50 m bwt.

  For each depth interval with multiple sample results, the maximum measured value of each COPC from each well was selected:
  - For COPCs for which sufficient depth-discrete data were not available, the maximum measured value of each COPC from each well was selected.
  - For wells with sample results that reported nondetects using method reporting limits exceeding reported detects in samples from other occasions, an average of the detected and nondetected (method reporting limit) values was selected for that COPC.

In order to produce a continuous spatial illustration of the distribution of each COPC, the summarized concentrations of each COPC were interpolated to a grid suitable for contouring. The interpolation technique employed was a quantile-kriging method based upon that described by Deutsch and Journel (1992), Journel and Deutsch (1997), and Reed et al. (2004), among others. The quantile-kriging approach is based upon two-dimensional ordinary kriging of a nonparametric (uniform-score) transform of the concentration or activity values, and a subsequent back-transform of the interpolated scores into the original units of measured concentration or activity. The quantile kriging was accomplished using an open-source program (QUANTILE) based upon the U.S. Geological Survey (USGS) kriging routines of Skrivan and Karlinger (1980), which incorporates routines to conduct the uniform-score transform/back-transform. The quantile kriging produced summaries of the extents of each COPCs in terms of one Surfer ASCII grid (GRD file extension) file and one ArcMAP ASCII grid file (ASC file extension) for each COPC for each vertical interval with sufficient data to prepare a map. Data used to prepare each contour interval are summarized in Tables D-28 through D-54. Figures showing the locations of the wells used in contouring each COPC are provided in Figures D-8 through D-19.

D3.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

The quantile-kriging approach used to approximate the extent of groundwater contamination rests upon the following general assumptions:

- The distribution of contaminants in groundwater is fairly accurately reflected by the available measured data (together with the conceptual model of contaminant transport, as described in Sections D4.0 and D5.0).
- For purposes of mass and volume calculations, the aquifer is homogenous and isotropic.

The quantile-kriging approach used to approximate the extent of groundwater contamination has the following general advantages:

- Because the method is based on ordinary kriging, it is an exact interpolator. That is, in the absence of replicates (i.e., multiple values at one location), it honors the measured data.
- Studies by other investigators (e.g., Reed et al. [2004]) suggest quantile kriging produces robust interpolation results, which show the least bias due to highly skewed data and/or variations in the spacing of measured data (i.e., data support).
- The uniform-score transform mitigates extrapolation outside the convex hull of the measured data that is a common result of ordinary kriging of highly skewed data.
- Additional outputs from the mapping approach and programs used include (1) total calculated dissolved mass and (2) distribution of this dissolved mass between specified concentration intervals (contours).

The use of the quantile kriging approach to approximate the extent of groundwater contamination has the following general disadvantage:

- The uniform-score transform leads to a median-unbiased estimator that may, depending on the true distribution of the data, under-estimate the contaminant mass.

Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D3.4 RESULTS

Approximate contaminant distributions for the 12 COPCs are presented in Figures 2-8 through 2-34 of the main text of this FS. In order to illustrate the approximate extents of groundwater contaminated above target cleanup levels for *any* COPC, it was necessary to combine the COPC-specific contaminant maps to produce composite illustrations of the impacted groundwater. These composite maps provide a two-dimensional (i.e., plan-view) depiction of the lateral extent of groundwater contaminated at any of the six depth intervals by any COPC exceeding specified target cleanup levels. Composite maps are illustrated assuming the following target cleanup levels:

- Extent of groundwater contaminated above the 1×10^{-4} risk level for any COPC (Figure D-4)
- Extent of groundwater contaminated above the maximum contaminant level (MCL) for any COPC (Figure D-5)
- Extent of groundwater contaminated above a concentration of 10 times the MCL for any COPC (Figure D-6).

The maps were prepared by contouring areas from the 200-ZP-1 OU boundary into adjacent operable units (e.g., into the area of 200-UP-1) using well data from adjacent OU(s). Areas of contamination for the COPCs that appeared to originate from adjacent OUs or were solely contained geographically within adjacent OUs were not included on the maps.

These maps illustrate the approximate extent of groundwater contamination at the specified target cleanup level. It is clear from the differences between the extents of contamination illustrated in Figures D-5 and D-6, and by review of the COPC-specific maps of groundwater contamination, that while for some COPCs there are areas exhibiting concentrations orders-of-magnitude higher than their target cleanup levels, for some COPCs there are also large volumes of groundwater contaminated by COPCs that are at lower concentrations. In particular,

Figures D-5 and D-6 illustrate the differing extents of groundwater contaminated above MCLs and contaminated above a concentration equivalent to 10 times the MCL. This pattern is also reflected in Figures 2-5 through 2-10 (see main text of this FS), which illustrate the extent of groundwater contaminated by carbon tetrachloride at various depth intervals.

D3.5 DISCUSSION

As described in Section D7.0, the volume of groundwater to be extracted ultimately determines the number and location of recovery and injection wells, as well as the likely required operating life of the remedy. For this reason, several analyses were made of alternative maps of groundwater contamination, constructed by combining maps of COPCs using specified target cleanup levels. The focus of this effort was to enable comparative analyses of the relative remedy capital costs and operational lifetime when recovering groundwater contaminated at various defined concentration levels that differ from those described above. However, Figure D-7 shows a smaller extent than Figure D-4 since, for the contaminants carbon tetrachloride and TCE, the target cleanup levels were defined on the basis of the portion of the aquifer contaminated with a dissolved mass above 95% for carbon tetrachloride and 90% for TCE.

The maps presented in Figures D-4 through D-7 were used to define initial conditions for particle-tracking techniques subsequently used to compare the alternative remedies described in Section D7.0.

D4.0 INTERPRETATION OF HISTORIC GROUNDWATER FLOW

D4.1 BACKGROUND

The evaluation of the feasibility of a groundwater pump-and-treat remedy requires an understanding of the following:

- How the current distribution of contaminants developed
- For advectively dominated systems, whether the principal groundwater hydraulics can be represented using relatively simple methods
- Whether future changes in groundwater flow directions and/or rates are expected to occur in response to past activities.

An initial review of previously completed reports, analyses, and data suggested that groundwater containing carbon tetrachloride at concentrations greater than 1,000 µg/L is oriented broadly north-south and is generally found north and northeast of the principal documented sources of carbon tetrachloride (216-Z-9, 216-Z-1A, and 216-Z-18) (*Hanford Site Groundwater Monitoring for Fiscal Year 2005* [PNNL-15670]). However, groundwater levels throughout the 200-ZP-1 OU currently exhibit a hydraulic gradient oriented broadly east-west. Therefore, it is likely groundwater flow directions were different (i.e., more northerly) in the past than is reflected by current groundwater elevations. Review of historic wastewater disposal activities (as well as the correspondence of these activities with changes in groundwater levels recorded in several monitoring wells throughout and beyond the 200-ZP-1 OU) suggests that historic wastewater disposal at various ponds and drains led to increases in groundwater elevations of up to and greater than 15 m in some locations, and that this wastewater disposal constituted a primary

driving force in the historic migration of contaminants and the current disposition of contaminants.

- It is, therefore, likely that regardless of the mechanisms leading to contaminants reaching the groundwater, it is expected once contaminants reached groundwater, their historic migration was largely determined by the location and rates of wastewater discharge. It is expected the pattern of historic groundwater flow is the primary mechanism leading to the current distribution of carbon tetrachloride and the other COPCs. In order to test the effects of wastewater discharge on historic migration, an evaluation of groundwater flow was completed. Since aerial groundwater recharge from precipitation is typically very low at the 200-ZP-1 OU area, it is concluded historic and future groundwater flow directions and rates can be largely described by the following:
  - Uniform ("background") hydraulic gradient
  - Aquifer transmissivity and storativity
  - Effects of wastewater disposal practices.

The objectives of the evaluation of the effects of wastewater discharge on historic contaminant migration were as follows.

- The first objective of this evaluation was to determine the following:
  - Can the current extent and orientation of contamination be understood and adequately described using fairly simple methods?
  - Do the parameters estimated from the mapping based techniques, and from calibration of the Theis superposition model (Theis 1935) (discussed below) correspond fairly well despite the potential violation(s) of simplifying assumptions?
  - The second objective was to construct a simulation/calculation approach to evaluate alternate remedies by superimposing the effects of possible future groundwater extraction and reinjection scenarios on current and future conditions, and re-evaluate capture.

D4.2 APPROACH

Modeling analyses conducted to evaluate historic groundwater elevations and groundwater flow directions are based upon the assumption that the majority of the variability in groundwater elevations in the vicinity of the 200-ZP-1 OU can be described using analytical equations, that superimpose the Theis equation for transient changes in head in response to extraction and/or injection (Theis 1935, Rouse 1949) upon a planar surface:

Theis equation:

$$h = a + bx + cy + d\sum_{1}^{n} QW(u) \qquad \text{(Equation 1)}$$

$$u = \frac{r^2 S}{4Tt} \qquad \text{(Equation 2)}$$

where:

h = hydraulic head (L)

a	=	mean-adjustment regression coefficient or offset (L)
b	=	regression coefficient for east-west component of hydraulic gradient (-)
c	=	regression coefficient for north-south component of hydraulic gradient (-)
r	=	radial distance to an extraction or injection location (L)
Q	=	extraction or injection rate (L^3/T)
T	=	aquifer transmissivity (L^2/T)
t	=	time (T)
S	=	storage coefficient (-)
u	=	dimensionless variable (-)
W(u)	=	exponential integral (Theis well function) at time t and distance r
d	=	regression coefficient for extraction/injection (proportional to $1/(4\pi T)$).

In preparation for the analysis, the following data were compiled from various sources into Microsoft Excel spreadsheets and a Microsoft Access™ database:

- Historic wastewater disposal rates and locations throughout and beyond the 200-ZP-1 OU area.
- Groundwater elevations from various time periods and well groups, including time-series data (hydrographs) and annual average elevations
- Groundwater extraction and injection rates at the 200-ZP-1 IRM, including time-series data and annual average rates
- Partial information on the 200-UP-1 IRM.

The historic impact of wastewater disposal activities on groundwater elevations and on groundwater flow directions and rates were approximated using an open-source program "THEIS-GRID" which incorporates Equation (1) and a polynomial approximation to Equation (2) (Abramowitz and Stegun 1972). The THEIS-GRID code uses superposition to sum the effects of multiple sources of groundwater extraction and/or injection through time. Model input and output files consist of ASCII text files. The out put files include the following:

- Gridded files of the calculated groundwater elevation
- Hydrographs of the calculated groundwater elevation
- Calculated equivalents to measured data at specified locations and times

The program THEIS-GRID is executed as part of a parameter estimation process using the open-source parameter estimation program PEST (Doherty 2005). The advantage of this is each time the program THEIS-GRID is executed, hydrographs are produced, and calculated equivalents to measured groundwater elevations are written that can be graphed and evaluated.

D4.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

The use of the Theis equation to approximate groundwater elevations and flow rests on the following principal assumptions:

- Flow is dominantly two-dimensional.
- The aquifer is homogeneous and isotropic.

The use of the Theis equation to approximate groundwater elevations and flow has the following general advantages:

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- Rapid calculation
- Conceptually straightforward
- Open source codes (THEIS-GRID) with simple input and output file formats
- The effects of historic wastewater disposal and groundwater response are explicitly accounted for
- Calibration of Equation (1) to measured groundwater elevations provides an independent estimate of aquifer transmissivity and storage that are important to the design of groundwater pump-and-treat scenarios.

The use of the Theis equation to approximate groundwater elevations and flow has the following general disadvantage:

- Three-dimensional flow is not explicitly accounted for.
- The effects of partial penetration of extraction or injection wells is not explicitly accounted for.
- Heterogeneity and anisotropy are not explicitly accounted for.

Use of the Theis equation to predict the response of an aquifer to a stress (e.g., pumping) assumes that the transmissivity is constant and that the release of water from storage is instantaneous. Both assumptions are typically applicable for confined aquifers. In particular, in confined aquifers, the release of water from storage can be considered instantaneous, whereas in unconfined aquifers, the release of water is typically dominated by drainage of pore water which is not instantaneous which shows a delayed response. Give the time-period (e.g., approximately 60 years) used for the calculations, the relative simplicity of the modeling approach used, and the purpose of the analysis (e.g., to provide information of the likely relative performance of alternate pump-and-treat remedies), the use of a calibrated storage value that is more representative of unconfined conditions encountered at the Site best represents field conditions, and the impact of the delayed yield in response to pore space drainage on the calculated future extent of hydraulic capture is limited. Secondly, under quasi-steady-state conditions, the extent of hydraulic capture is not a function of the storage capacity of the aquifer, but rather of the aquifer transmissivity. Therefore, although a storage value was estimated during history-matching to water level data, the long-term performance of a pump-and-treat remedy will depend principally on the distribution and rates of extraction and injection wells as well as the aquifer transmissivity, rather than on aquifer storage.

Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D4.4 RESULTS

Outputs from these calculations include potentiometric surfaces over a specified area of interest and hydrographs at specified geographic coordinates. Groundwater elevations for site monitoring wells were assembled from the Hanford Virtual Library, Hanford Well Information System, and an electronic data summary provided in the 2005 annual groundwater monitoring report (found at http://groundwater.pnl.gov/reports/gwrep05/html/data2005.exe). Wastewater discharge sites input into the model are summarized in Table D-55. Calculated and observed hydrographs for several wells are presented in Figure D-20. Simulated water table contour maps for 5-year intervals from 1945 to 2005 are provided in Figures D-21 to D-33.

The values of transmissivity and storage used to match historic hydraulic heads were 576 m^2/day and 8.2 $x10^{-2}$, respectively. These values compare favorably to the average values for these parameters presented in Section D2.0.

D4.5 DISCUSSION

Figures D-20 through D-33 illustrate the following.

- Groundwater flow has been, and continues to be, influenced by historic discharges from waste sites, particularly from 216-U-10 (i.e., U Pond) and the 216-Z-19 and 216-Z-20 Ditches.
- Groundwater flow was northerly in the vicinity of 216-Z-9, 216-Z-1A, and 216-Z-18 from the 1950s to the 1980s.
- Groundwater flow direction has been rotating clockwise from the 1980s to the present. The current rate of the rotation is slowing.
- Groundwater mounding from historic wastewater discharges continue to deflate, and groundwater levels have not yet reached pre-disposal levels.
- The calculated groundwater elevations and patterns compare favorably to the measured water level values and observed patterns. Variability in the calculated and observed water levels may be due to heterogeneity and uncertainty in wastewater disposal rates.

D5.0 EVALUATION OF CONTAMINANT TRANSPORT

D5.1 BACKGROUND

The evaluation and design of a groundwater pump-and-treat remedy requires an understanding of the following:

- How the current distribution of contaminants developed
- Whether future changes in migration rates and/or directions are expected due to past activities
- Whether the principal directions and rates of migration can be approximated using relatively simple computational methods
- The likely fate of contaminants that will not be recovered by the remedy.

Evaluations of contaminant transport were made for two purposes:

- Considering the transport of contaminants within and proximal to the 200-ZP-1 OU and planned remedy, these evaluations focused on contaminants addressed by the remedy. This is termed as the "near field."
- Considering the transport of contaminants beyond and distal to the 200-ZP-1 OU and planned remedy, these evaluations focused on the fate of contaminants not directly addressed by the remedy. This is termed as the "far field."

Contaminant transport was accomplished using two different but complimentary approaches:

- Two-dimensional/three-dimensional analytical advective-dispersive-reactive (ADR) transport using an open-source transport simulator, ATRANS (Neville 1998).
- Particle tracking using standard and industry-accepted particle-tracking techniques.

ATRANS was used only for far-field calculations and for this reason is discussed in Section D8.0. Since the particle tracking was used for both near-field and far-field calculations, this technique is described below.

D5.2 APPROACH

The migration of contaminants dissolved in groundwater was approximated using standard and industry-accepted particle-tracking techniques. The particle tracking was used to indicate (1) the approximate horizontal historic migration pathways taken by COPCs, (2) the approximate extent of groundwater capture developed by the 200-ZP-1 IRM, (3) the approximate extent of groundwater capture developed by alternate remedy configurations of groundwater pumping and injection wells, and (4) the approximate relative timing of the arrival of COPCs at potential receptors and/or other points of calculation. Particle tracking was accomplished using the fourth-order Runge-Kutta (RK4) (Press et al. 1992) numerical integration scheme. The RK4 particle-tracking approach adopted is based upon that implemented in the widely used MODFLOW-compatible particle-tracking code, Path3D (Zheng 1989), which has been demonstrated to provide results comparable to the USGS particle-tracking program MODPATH (Pollock 1994). The particle tracking scheme being employed also incorporates the Random-Walk (RW) approach for representing the spreading of contaminants over time due to dispersive effects (Prickett et al. 1981).

The particle tracking is accomplished using an open-source program, "GRIDTRACK," which requires as ASCII text corresponding input file that lists grid definitions, the grid file, particle initial locations, and, if necessary, a file listing groundwater extraction/injection rates. The main outputs from the particle-tracking analyses are ASCII files that list the initial location and final location of each particle and the reason for the particle stopping. These files are used to make maps illustrating the path of each particle and the calculated time-of-travel at various intervals. These methods are suitable to support the 200-ZP-1 OU FS since, based on historic groundwater conditions at the site described in Section D4.0, advective transport appears to be the principal mechanism in the determination of contamination and the likely extent of hydraulic capture.

In order to evaluate historic groundwater flow directions and rates, and the approximate historic migration pathways taken by COPCs, particle tracking was performed on groundwater elevation surfaces calculated by the application of Equations (1) and (2) using the program THEIS-GRID, as described in Section D4.0 and illustrated in Figures D-22, D-22, and D-23. These results are described below. A grid spacing of 18.2 m by 18.2m (60 ft by 60 ft) was used in the calculations.

In order to evaluate the approximate extent of groundwater capture developed by the 200-ZP-1 IRM, particle tracking was performed on groundwater elevation surfaces calculated by the application of Equation (3) (steady-state calculations) (see Section D6.2) within a kriging routine; these results are described in Section D6.0. In order to evaluate the approximate extent of groundwater capture developed by alternate remedy configurations of groundwater pumping and injection wells, particle tracking was performed on groundwater elevation surfaces calculated by the application of Equations (1) and (2) using the program THEIS-GRID; these results are described in Section D7.0. In order to evaluate the approximate relative timing of the

arrival of COPCs at potential receptors and/or other points of calculation, particle tracking was performed on groundwater elevation surfaces calculated by mapping measured groundwater elevations; these results are described in Section D8.0.

D5.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

The use of the RK4 and RW tracking techniques to approximate the transport of COPCs dissolved in groundwater rests on the following principal assumption:

- Transport is dominated by advection, dispersion, and retardation.

The use of the RK4 and RW tracking techniques to approximate the transport of COPCs dissolved in groundwater has the following general advantages:

- Rapid calculation
- Conceptually straightforward
- Open source codes with ASCII text input and output files
- Spatial variability in hydraulic gradients is directly translated into travel and arrival-time variability.

The use of the RK4 and RW tracking techniques to approximate the transport of COPCs dissolved in groundwater has the following general disadvantages:

- Mass is not explicitly considered or conserved (i.e., not mass conservative).
- Historic three-dimensional flow is not explicitly accounted for.
- Contaminants are considered to be uniformly distributed in the vertical dimension.

Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D5.4 RESULTS

As discussed above, the THEIS-GRID program was used to calculate historic groundwater elevations and flow directions in response to the infiltration of large volumes of wastewater. Figure D-34 illustrates the paths calculated for particles released from the location of the principal carbon tetrachloride waste site areas (216-Z-1A, 216-Z-18, and 216-Z-9) during periods of active disposal using groundwater levels calculated using THEIS-GRID and illustrated in Figures D-21 (1945) through D-33 (2005). These particle paths were calculated assuming contaminants reached the water table soon after disposal activities commenced, and they assume the advective-dispersive transport of ideal (non-retarded, non-reactive) dissolved contaminants in groundwater.

Figure D-34 illustrates the path taken by the particles together with the mapped extent of the dominant (by mass and volume) COPC (carbon tetrachloride) with no dispersion (blue toned particles) and dispersion (red toned particles). This figure illustrates that the path taken by particles released at the principal waste sites broadly mimics the distribution of the contaminants (i.e., the majority of the particles are distributed in the areas of high concentrations, with particles generally distributed throughout the area depicted as showing elevated concentrations of carbon tetrachloride).

D5.5 DISCUSSION

The particle tracking analysis suggests that historic groundwater flow patterns described using Equations (1) and (2) and illustrated in Figures D-21 through D-33 explain the current distribution of carbon tetrachloride in groundwater at the 200-ZP-1 OU. This suggests that the principal features of groundwater flow at the site can be described using Equations (1) and (2), acknowledging the assumptions and limitations described in Section D4.0 of this appendix.

This conclusion is used to support the use of Equations (1) and (2) (and a closely related steady-state approximation to groundwater head described in Section D6.0), together with the RK4/RW particle-tracking techniques to evaluate the current extent of hydraulic capture developed by the 200-ZP-1 IRM (Section D6.0) and the likely extent of hydraulic capture develop by alternate pump-and-treat groundwater remedies (Section D7.0).

D6.0 INTERPRETATION OF HYDRAULIC RESPONSE TO THE EXISTING 200-ZP-1 PUMP-AND-TREAT SYSTEM

D6.1 BACKGROUND

The evaluation of the pump-and-treat remedy scenarios was completed after an evaluation of the performance of the current pump-and-treat system in order to determine the following:

- How the groundwater system responds to pumping
- The approximate extent of hydraulic capture
- The approximate extent of contaminants that are not currently captured
- Where the enhancement and/or development of a groundwater remedy should focus.

D6.2 APPROACH

Groundwater levels in the vicinity of the existing 200-ZP-1 IRM groundwater recovery and reinjection wells were evaluated using a kriging technique that combines the effects of groundwater extraction and/or injection together with interpolation of measured water-level data to prepare maps that can be used to help evaluate the approximate extent of hydraulic capture (Tonkin and Larson 2002). This kriging technique, referred to as "universal kriging," combines the commonly used regional linear trend together with a logarithmic trend that is centered on groundwater extraction and/or injection wells. As discussed by Tonkin and Larson (2002), this approach can help to construct a more rigorous map of groundwater levels that illustrates the cone of depression (or impression) in the vicinity of each extraction (or injection) well in a more accurate manner than can be typically obtained from other methods of mapping measured groundwater elevations. This combined regional-linear and point-logarithmic trend model (i.e., drift) is referred to as the linear-log drift.

The linear-log drift superimposes the effects of groundwater extraction and/or injection in a manner that is closely related to that described by the Theis superposition model in Equation (1). However, because the Theis equation is non-linear whereas the kriging technique is linear, the linear-log drift uses the logarithmic pattern that underpins the Thiem equation for steady-state drawdown in response to pumping (Thiem 1906, Rouse 1949) to represent the following:

Linear-log drift:

$$h = a + bx + cy + d\sum_{1}^{n} QLn(r) \qquad \text{(Equation 3)}$$

where:

- h = hydraulic head (L)
- a = mean-adjustment regression coefficient or *offset* (L)
- b = regression coefficient for east/west component of hydraulic gradient (-)
- c = regression coefficient for north/south component of hydraulic gradient (-)
- r = radial distance to an extraction or injection location (L)
- Q = extraction or injection rate (L3/T)
- d = regression coefficient for extraction and injection, proportional to $1/(4\pi T)$
- π = PI (~3.14159).

Comparison of Equation (3) with Equation (1) indicates the two equations are very similar, as each superimposes the effects of pumping upon a planar surface. In the steady-state case (as in Equation [3]), the regression coefficient (d) can be shown to be related to $1/(2\pi T)$. Although the Thiem equation describes only steady-state drawdown or mounding due to extraction or injection, Equation (3) can also be derived from the Cooper-Jacob approximation to the Theis equation, which is transient (Tonkin and Larson 2002, Brochu and Marcotte 2003). This suggests that although the kriging method is linear, the drift described by Equation (3) also approximately describes the effects of groundwater extraction and/or injection in transient systems at sufficiently large times and small radii (Rouse 1949).

The linear-log kriging approach was used to prepare maps of groundwater elevations for the years 2003, 2004, and 2005, for which comprehensive groundwater-level and extraction/ injection data are available. These groundwater elevations are illustrated in Figures D-35, D-36, and D-37, respectively. The water-level mapping was accomplished using an open-source program (KT3D_H20), based upon the Stanford Geostatistical Software Library (GSLIB) program KT3D (Deutsch and Journel 1992), which incorporates routines to superimpose the effects of pumping upon the standard linear drift. For each of the three years (2003, 2004, 2005), KT3D_H20 requires an ASCII text GSLIB-format parameter (PAR) file defining the problem parameters, an ASCII text GEOEASE-format file listing the water-level data, and a corresponding ASCII text file listing pumping data.

The maps produced using this kriging technique were used together with particle tracking using the RK4 and RW methods described above to approximate the extent of hydraulic capture during the years 2003, 2004, and 2005. Particle tracking is accomplished using the program "GRIDTRACK" (previously described above). The main outputs from the particle-tracking analyses are ASCII text files that can be used to make classed-post maps in Surfer® illustrating the capture extents for each year.

D6.3 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

Since the universal kriging technique described above is based upon the Thiem and/or Cooper-Jacob equation, the use of this technique to approximate the current extent of groundwater capture rests on the same principal assumptions and has the same general advantages and

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disadvantages as those described following the presentation of Equations (1) and (2). Use of this linear-log universal kriging technique has one additional advantage: it results in a map of groundwater elevations that respects the measured data but also reflects the drawdown and/or mounding due to groundwater recovery and/or reinjection at the pump-and-treat remedy. Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D6.4 RESULTS

Figures D-38 to D-40 show calculated capture zones for the IRM from 2003 to 2005. In each case, these capture zones are illustrated together with the approximate mapped distribution of contaminants that is described as the 1×10^{-4} risk distribution (Figure D-41). Figures D-42 through D-45 present calculated hydraulic heads for the different pump-and-treat scenarios. It is evident from these figures that although the extent of the hydraulic capture developed by the existing 200-ZP-1 IRM likely laterally encompasses areas of very high concentration for many COPCs, it does not laterally encompass the full extent of contaminants described at their 1×10^{-4} risk level. Furthermore, it appears likely from the maps that the reinjected water is not fully recovered by the extraction wells. This is an undesirable consequence since groundwater containing technetium-99 and tritium, and possibly other contaminants that are not removed by the above-ground treatment system, are reinjected into the aquifer.

D6.5 DISCUSSION

A review of annual 200-ZP-1 IRM pump-and-treat reports indicates some extraction well capacities are decreasing over time, suggestive of partial penetration effects. In addition, the current IRM extraction wells have relatively short screen intervals and are likely to be less effective than longer screened recovery wells due to partial penetration effects (see Section D9.0). Based on these factors and the evaluations presented in Section D7.0, the following recommendations are made with respect to future pump-and-treat remedy scenarios:

- The current extraction wells should be replaced with new extraction wells at different locations.
- New recovery wells should meet two primary objectives:
  - Containing and ultimately recovering groundwater contaminated above target cleanup levels
  - Removing mass in areas of high concentrations in order to expedite improvement in the overall groundwater quality throughout the 200-ZP-1 OU and mitigate potential risk.

Finally, as described above, the universal kriging technique provides an estimate of the regression coefficients described in Equation (3); it calculates the regression offset term, the gradient in the easting direction, the gradient in the northing direction, and the regression coefficient for the combined effects of groundwater extraction and injection. The latter regression coefficient is proportional to $1/(2\pi T)$, from which an estimate of the transmissivity (T) can be derived. The regression coefficients estimated from mapping the 2003, 2004, and 2005 water levels (with the exception of the offset term) are tabulated below:

Year	dX	dY	1/(2πT)	T (ft^2/day)	T (m^2/day)	Direction (from E)	Magnitude
2003	-0.00142	-4.71E-05	3.06E-05	5,197	483	1.8957	0.001423
2004	-0.00145	-9.27E-06	3.32E-05	4,792	445	0.3658	0.001452
2005	-0.00141	3.00E-06	3.20E-05	4,973	462	-0.1219	0.001409
Averages	**-0.00143**	**-1.78E-05**	**3.19E-05**	**4,987**	**463**	**0.7132**	**0.001428**

While these regression coefficients only provide very approximate estimates, the following general features of the regression coefficients are noted:

- The regression coefficients are broadly consistent from the 3 years.
- The magnitude of the hydraulic gradient appears to be about 0.0014.
- The direction of the hydraulic gradient appears to be toward the east.
- The direction of the hydraulic gradient appears to be rotating slightly from north of east to south of east, at a rate of about 1 degree per year.

These estimates are broadly consistent with those obtained through mapping of the historic groundwater-level data, the data summaries provided in Section D2.0, and the estimates provide substantiation for the parameters used in the pump-and-treat remedy scenario evaluations, which are presented in the following section.

D7.0 EVALUATION OF PUMP-AND-TREAT REMEDY SCENARIOS

D7.1 BACKGROUND

The evaluation of the pump-and-treat remedy scenarios was an iterative approach designed to accomplish the following:

- Estimate the flux of groundwater through the 200-ZP-1 OU to be targeted for remediation
- Estimate the approximate number and location of pump-and-treat wells (recovery and/or injection, as appropriate) necessary to hydraulically capture the target capture area and minimize remediation time
- Evaluate the likely vertical extent of the open-screened interval for each pump-and-treat recovery and/or reinjection well
- Approximate the fate of contaminants not recovered by the alternative remedies
- Assist the FS costing process in finding the most cost-effective pump-and-treat recovery and/or reinjection well configuration.

D7.2 APPROACH

The evaluation of pump-and-treat scenarios consisted of the following three components:

- Head calculations
- Particle-tracking calculations
- Advection-dispersion transport calculations.

Several remedy scenarios were evaluated during the preparation of this FS. This section describes the methods used to conduct these analyses and presents some of the results from the no action alternative and six groundwater pump-and-treat remedy scenarios that together illustrate a range of potential designs and lifecycles.

Remedy Scenarios	Description
No action	--
Remedy A1	1E-4 risk; minimum extraction rate to hydraulically capture target area
Remedy A2	Remedy 1A with additional focused extraction in high-concentration areas
Remedy B	MCL; minimum extraction rate to hydraulically capture target area
Remedy C	Ten times the MCL; minimum extraction rate to hydraulically capture target area
Selected remedy A	Minimum extraction rate to hydraulically capture target area, "Q"
Selected remedy B	Selected Remedy A, with additional focused extraction in high-concentration areas or to decrease relative clean-up time

Note that the theoretical maximum pumping rate for any recovery (and correspondingly, reinjection) well was limited to 227 L/min (60 gallons per minute [gpm]). This limitation was enforced based on the observation of specific capacities in the existing 200-ZP-1 IRM recovery (and reinjection) wells, The 227 L/min (60 gpm) extraction rate is expected to be a lower-bound estimate, and is discussed further in Section D9.0.

D7.3 GROUNDWATER HEAD CALCULATIONS

Results of the current 200-ZP-1 IRM capture mapping were used to identify areas that should be the focus of additional remedy development/installation, etc. The Theis model superposition approach described by Equations (1) and (2) were then used to evaluate the effect of modifying pumping rates at existing wells and/or adding additional hypothetical pumping wells at key locations that are identified through the IRM capture-zone evaluation analysis. Focus areas for additional hypothetical recovery wells were identified during the universal kriging calculations completed to interpret the groundwater system response to the existing 200-ZP-1 pump-and-treat remedy (as described in Section D6.0). The extent of the capture of the COPCs created using various configurations of hypothetical groundwater recovery and reinjection wells was calculated by generating surfaces that incorporate the hypothetical pumping scenario using Equation (1) or Equation (2) and using the RK4 and RW particle-tracking methods to delineate the approximate extent of capture.

In order to evaluate the likely effectiveness of additional extraction and injection wells, these alternate groundwater pump-and-treat remedies were simulated using the "THEIS-GRID" program. The input files required for this analysis were based on those used to evaluate estimated historic groundwater conditions as described in Section D4.0, including the values for the parameters described by Equation (1). For each remedy simulation, two modifications were made to the input files used to calculate historic groundwater conditions, in order to evaluate the potential remedy:

- The main input file to the program "THEIS-GRID" is supplemented with entries that describe the location and extraction or injection rates of any hypothetical groundwater extraction and/or injection wells.
- The input file to the program "GRIDTRACK" lists extraction well locations in order to record capture of particles supplemented with entries that describe the location and extraction rates of any hypothetical groundwater extraction wells.

Once these files have been prepared, the program "THEIS-GRID" can be executed to calculate the groundwater elevations at some future time under the revised remedy conditions. This produces a Surfer grid file that can then be used together with the program "GRIDTRACK" to track particles on this surface and calculate the approximate extent of hydraulic capture developed by the remedial scenario.

The parameters used for these calculations are based upon (in descending order of priority) the data summaries provided in Section D2.0, the parameters estimated through mapping of the current extent of capture developed by the current 200-ZP-1 IRM (Section 6.0), and the parameters estimated through modeling of historic groundwater flow described in Section D4.0. The parameters used are tabulated below:

T (m^2/day)	T (ft^2/day)	S	Dx	Dy
463	4,987	0.082	0.001428	0.000018

The storage value was estimated through calibration of the water levels calculated with the "THEIS-GRID" program to the historic changes in groundwater levels in response to waste-water disposal to the subsurface, and is consistent with the value used for calibration to historic groundwater levels (see Section D4.0 above).

D7.4 ASSUMPTIONS, ADVANTAGES AND DISADVANTAGES

Since the method used to calculate the approximate future groundwater elevations is based on Equations (1) and (2) as described in Section D4.0, it rests upon the same general assumptions and has the same general advantages and disadvantages as those described for the application of Equations (1) and (2) for evaluating groundwater flow. Since the method used to define the likely extent of hydraulic capture is based on the use of the RK4/RW particle-tracking methods described in Section D5.0, the same assumptions apply to particle-tracking calculations performed to evaluate the pump-and-treat scenarios as those described in Section D5.0. Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D7.5 RESULTS

Fate and transport of COPCs and the results of the preferred FS alternative are presented in Sections 2.6 and 9.2 in the main text of this FS.

D7.6 DISCUSSION

Because groundwater pump-and-treat remediation is based upon the extraction, treatment, and reinjection of the treated water, a primary driver in the design, cost, and operational lifetime of pump-and-treat remedies is the volume of groundwater that must be pumped and treated (e.g., NRC 1994). The volume of groundwater to be pumped ultimately determines the number and location of recovery and injection wells and required operational life of the remedy. For this reason, several analyses were made of hypothetical alternative pump-and-treat remedies designed to recover groundwater contaminated at several defined concentration levels. The focus of this effort was to enable comparative analyses of the relative remedy capital costs and projected operational lifetime when different concentration drivers are considered.

Locations of extraction and injection wells for evaluated pump-and-treat scenarios are shown in Figures D-41 through D-45. In particular, Figures D-44 and D-45 illustrate the well configuration for a preferred pump-and-treat remedy scenario. The preferred pump-and-treat remedy developed during this FS consists of between 14 and 27 injection wells and between 14 and 27 extraction wells at the locations shown in Figures D-44 and D-45. Groundwater flow is generally from west to east under non-pumping conditions. Injection wells near the upgradient portion of the plume (west portion) are located upgradient of the extraction wells in order to facilitate groundwater flow toward the extraction wells. Injection wells near the downgradient portion of the plume (east portion) are located downgradient of the extraction wells to minimize interference with the extraction well capture zones. Each extraction well is expected to pump at a rate of 227 L/min (60 gpm), for a total system extraction rate ranging from 3,180 to 6,113 L/min (840 to 1,615 gpm). The preferred remedy hydraulically captures 90% of the mass of TCE, 95% of the mass of carbon tetrachloride, and all remaining contaminants of concern (COCs) at concentrations greater than their respective 1×10^{-4} risk level (see Table D-56).

The preferred pump-and-treat alternative (840 gpm scenario) was compared to an alternative that could hydraulically capture the 1×10^{-4} risk for all COPCs. The pump-and-treat scenario to capture the 1×10^{-4} risk would consist of 16 injection wells and 16 extraction wells. Similar to the preferred pump-and-treat scenario, each well is expected to pump at a rate of 227 L/min (60 gpm), for a total system extraction rate of 3,634 L/min (960 gpm). The advantages of the preferred pump-and-treat scenario as compared to the other pump-and-treat scenarios evaluated are as follows:

- The capture time is expected to be less for the preferred scenario. The maximum time to hydraulically capture the 1×10^{-4} risk is approximately 40% more than the maximum time to hydraulically capture the volume of the preferred scenario.
- The total cost to operate the preferred scenario remedy is expected to be less that than pump-and-treat scenario to capture the 1×10^{-4} risk. The operating capacity of the preferred scenario is approximately 13% less than the scenario to capture the 1×10^{-4} risk, resulting in less treatment of and less cost to treat reinjected water. In addition, the shorter capture times for the preferred scenario will lead to less operation and maintenance costs over the lifetime of the pump-and-treat system.

0076368
4 of 4

- The preferred scenario is expected to remove sufficient mass to allow monitored natural attenuation processes to reduce the concentration and mass of contaminants in groundwater to acceptable levels at the projected points of compliance.
- The preferred scenario is expected to meet the remedial action objectives within a more reasonable timeframe than the pump-and-treat scenario to hydraulically capture the 1×10^{-4} risk area.

D8.0 ESTIMATION OF RELATIVE CLEANUP TIMES USING PARTICLE TRACKING

D8.1 BACKGROUND

In order to evaluate the possible benefits of increased groundwater recovery (and injection) rates on the relative cleanup time required to remediate the target area defined by the preferred pump-and-treat scenario described above, additional calculations were performed with higher total pumping rates. The additional preferred pump-and-treat scenario evaluated consisted on a 6,113-L/min (1,615-gpm system), which is approximately twice the capacity of the minimum requirements to capture the preferred remedy area.

The comparison of the low range (3,180 L/min [840 gpm]) and the high range (6,113 L/min [1,615 gpm]) preferred pump-and-treat remedy scenarios used the particle-tracking methods described in Section D5.0 and focused on the quantifying, in an approximate manner, the following cleanup metrics: mass reduction, risk reduction, and cleanup time. These results are presented for the 3,180-L/min (840-gpm) and 6,113-L/min (1,615-gpm) remedies to illustrate the potential benefits of increased pumping and alternative recovery and injection well placements. The final design of the proposed pump-and-treat remedy is expected to be somewhere between the low-range (3,180-L/min [840-gpm]) and high-range (6,113-L/min [1,615-gpm) scenarios.

D8.2 COMMON METHODS FOR ESTIMATING CLEANUP TIMES FOR PUMP-AND-TREAT SYSTEMS

Since all pump-and-treat remedies rely upon the ultimate recovery and possibly reintroduction to the aquifer of groundwater, estimates of cleanup times are explicitly or implicitly based upon the rate of withdrawal of groundwater, which is in turn commonly presented in terms of the number of pore-volumes recovered (where one pore volume equals the amount of water stored in the contaminated portion of the aquifer). Two common approaches to estimating cleanup times are the batch-flush model, and numerical modeling, which are described below (ITRC 2005).

Batch-Flush Models: The "batch-flushing model" assumes that contaminant removal is by simple mass transfer from the aquifer materials to the clean water and extraction of the contaminated water. These methods consider advective transport (i.e., no dispersion) with instantaneous equilibrium mixing and sorption (EPA/540/G-88-003). The U.S. Environmental Protection Agency's (EPA's) batch-flush model is an explicit, finite-difference approximation of the solution to the governing differential equation, whose exact solution is given by (EPA/600/8-90-003):

$$PV = - R \times Ln(C_{wt} / C_{wo})$$

where:

PV = number of pore volumes required to reach the cleanup concentration
C_{wt} = cleanup concentration in groundwater (mass/volume)
R = retardation factor (dimensionless)
C_{wo} = initial contaminant concentration in groundwater (mass/volume).

Ideally, site-specific and contaminant-specific sorption effects are considered. Regardless, batch-flush methods often under-estimate cleanup times, as they focus only on the average concentration: hence, at the time required to attain cleanup targets according to a batch-flush analysis, point concentrations are often both (considerably) higher and (considerably) lower than the cleanup goal.

Numerical Models: Numerical models are more complex computer models that are capable of including the major processes that affect groundwater flow and contaminant transport (e.g., Harbaugh et al. 2000, Zheng and Wang 1999, NRC 1990, EPA/540/2-85-001). Depending on the simulation technique used, these models may incorporate aquifer heterogeneity, nonlinear sorption processes, and/or the existence of a nonaqueous phase liquid source. It is commonly recommended (e.g., ITRC 2005) that numerical models should be used where processes that are not considered by batch-flush models are determined to be significant. However, a great deal more effort and time is required in order to develop, calibrate, predict, and validate a useful numerical model than are required for a batch-flush model.

D8.2.1 Particle-Tracking Method

The 200-ZP-1 OU FS modeling analyses focused on the combination of analytical calculations of groundwater elevation and drawdown, together with numerical particle-tracking techniques, to approximate the migration of contaminants in groundwater. These analyses were developed principally to provide information on relative travel time only.

However, particles can be assigned an appropriate property that can help to provide additional information on the progress of a pump-and-treat remedy. Example properties that a particle can be assigned include the following:

- Initial concentration/activity
- Mass
- Individual risk (single chemical species)
- Cumulative risk (multiple chemical species).

The particle-tracking analyses can then be processed to determine the approximate amount of time required until the entire target zone, or some focused subset of the target zone, is likely to be remediated. For example, if particles are assigned an initial concentration for a contaminant based on their starting location within the target zone, and the saturated thickness is assumed constant and uniform, then the particle tracking can be post-processed to approximate the time required to recover a specified fraction of the initial dissolved mass, or to recover all groundwater contaminated above a specified concentration. As described, this only explicitly accounts for the movement and recovery of contaminants dissolved in groundwater. If sorption of contaminants to the aquifer matrix is assumed to be an instantaneous linear reversible process, then the travel times, cleanup times, and recovered mass can be scaled by contaminant-specific retardation coefficients.

Using the particle-tracking technique, and accepting certain assumptions described below, it is possible to quantify the relative attainment of different types of cleanup goals by different remedies. This approach provides an intermediate level of analysis between the batch-flush models and numerical methods; that is, it explicitly considers the relative distribution of contaminants at the commencement of the remedy; the placement and rates of pumping for each extraction and injection well; and can consider changing pumping rates and locations over time (i.e., dynamic remedy design). For a homogenous, isotropic aquifer of constant and uniform thickness, the Theis-superposition analysis combined with particle tracking should lead to analogous conclusions regarding relative cleanup times for alternate pump-and-treat remedies as would a numerical analysis; while a batch-flush analysis, by its definition, would not be able to explicitly accommodate alternative well configurations and contaminant distributions.

While the particle-tracking analysis described above can be accomplished as a post-processing step from any analytical or numerical simulation of groundwater levels, the following step-wise analysis approach was developed as part of this FS.

D8.3 APPROACH

D.8.3.1 Step-Wise Analysis

The following outlines the step-wise analysis approach that was employed for evaluating relative cleanup times at the 200-ZP-1 OU for the range in the preferred pump-and-treat remedy scenarios. This discussion uses the initial concentration of a COC as the example property assigned to the particles:

1. Assign the particle starting locations. This is defined as a regularly spaced grid of particles that encompasses the footprint of the combined target zone for all COCs.
2. Assign the desired property to each particle. For example, in this analysis, the particles are assigned a representative concentration of the COC carbon tetrachloride.
3. Track the particles from their initial location to their ultimate recovery at a pumping well, or exit from the calculation domain.
4. Illustrate the following using maps and/or graphs:
   a. Relative travel times, such as presented in Section D7.0
   b. Relative cleanup times, calculated as the maximum travel time for any particles passing through each of the regularly spaced grid intervals
   c. Relative attainment of other goals, such as mass recovery.
5. Revise remedy as necessary and recalculate by returning to step #3.

D8.3.2 Feasibility of Optimization

The optimization of remedy performance in this manner is a multi-objective problem that naturally leads to trade-offs between different objectives. That is, attaining the minimum cleanup time may require a significantly different remedy design than attaining a 95% mass reduction within a short timeframe. If the various objectives of the remedy can be described and quantified using approaches such as those described above, then they can be incorporated in the analysis described above to define a formal multi-objective optimization problem. This may be evaluated manually, by conducting many different remedy analyses and plotting the results, or

this may be evaluated using formal multi-objective optimization techniques. In the example analyses that follow, adjustments to the remedy design were made manually. Under either circumstance, it is typical that numerous "candidate solutions" will be identified that appear to meet or approach the multiple objectives, and these must be evaluated on the basis of other, often more qualitative, criteria.

D8.4 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

The use of the tracking techniques to approximate the cleanup time for COCs dissolved in groundwater and/or sorbed on the aquifer matrix has the following assumptions in addition to those described in Section D5.3:

- The migration of groundwater toward recovery wells leads to flushing of contaminated water by cleaner, but *not* necessarily clean, water.
- De-sorption of sorbed contaminant mass from the aquifer matrix is an instantaneous process.
- The concentration of the contaminant in the dissolved and sorbed phases are in equilibrium and can be represented by a retardation factor, R, described by:

$$R = 1 + (\rho b)\,(Kd) / n$$

The use of the tracking techniques to approximate the transport of COCs dissolved in groundwater has the following general disadvantages:

- Mass conservation is not an explicit part of the analysis, although mass transport and recovery is approximated.
- Three-dimensional flow and transport is not explicitly accounted for.
- Contaminants are uniformly distributed in the vertical dimension, unless specific analyses of individual hydraulic units are completed.

The use of this approach to the comparative analysis of remedy performance has the following advantages:

- The spatial distribution of COCs is explicitly accounted for.
- The assumption of a perfectly mixed reactor with instantaneous mixing, which is explicit in batch-flush analyses, are not required.
- Calculations provide a spatial illustration of remedy performance (e.g., cleanup time), whereas batch-flush/pore-volume methods provide only a volume-averaged analysis.

D8.5 RESULTS

The results are presented for two alternative remedies, comprising 3,180 and 6,113 L/min (840 and 1,615 gpm). Figure D-45 illustrates the approximate groundwater elevations calculated for the 6,113-L/min (1,615-gpm) remedy; Figure 7-3 illustrates the relative capture time for the 6,113-L/min (1,615-gpm remedy). While it is clear from Figure 7-3 that the increased pumping leads to a broader area of the target zone that is likely to be captured within a shorter timeframe, comparison of this figure with Figure 7-2, illustrating the relative capture time for the 3,180-L/min (840-gpm) remedy, is not definitive. However, Figure 7-6 and Figure D-51 compare the relative times required by the 3,180- and 6,113-L/min (840- and 1,615-gpm)

remedies to recover the carbon tetrachloride contamination throughout the extent of the target capture zone. This was calculated by the following:

- Assigning each particle an initial concentration equal to the average concentration throughout the vertical aquifer interval where contaminant data was available
- Assuming that the aquifer is of constant and uniform thickness, such that initial particle concentration is a surrogate for contaminant mass
- Post-processing the particle-tracking analyses to calculate the fraction of the contaminant mass recovered through time

Figure 7-6 suggests that the effect of increasing the rate of groundwater recovery from about 3,180 to 6,113 L/min (about 840 to 1,615 gpm) (i.e., nearly doubling the groundwater recovery rate), together with strategic placement of recovery and injection wells, could lead to a reduction in the time required to recover the dissolved contaminant mass of 50% or more. Although this analysis appears to indicate that doubling the pumping rate leads to an approximately (linear) corresponding decrease in the cleanup time, this relationship is more complex and a linear relationship between pumping rate and cleanup time is not necessarily valid. Furthermore, the analysis approach used does not account for the following possible consequences of increasing groundwater recovery rates:

- Reduced aquifer transmissivity due to the drawdown of the groundwater table
- Reduced well performance over time
- Increased time for storage depletion to establish quasi-steady-state conditions

Nonetheless, this simple, comparative analysis illustrates the potential benefits of increased groundwater recovery, alternative well placement strategies, and of the particle-tracking method as an analysis tool.

D9.0 EVALUATION OF CONTAMINANTS OF CONCERN NOT CAPTURED BY PUMP-AND-TREAT ALTERNATIVES

D9.1 BACKGROUND

The approximate fate of contaminants that would not be recovered by each/any remedial alternative (i.e., within the far field) were evaluated using two distinctly different approaches:

- Two-dimensional/three-dimensional analytical ADR transport using a popular open-source transport simulator, ATRANS (Neville 1998)
- Particle tracking using the standard and industry-accepted RK4/RW particle-tracking techniques encompassed in the program GRID-TRACK.

D9.2 APPROACH

Within the far field, which is mainly downgradient of the 200-ZP-1 OU to the north and east, the distribution and contrasting hydraulic properties of different aquifer units (e.g., Hanford formation and Ringold Unit E) lead to areas of differing transmissivities and hydraulic gradients and, therefore, differing groundwater and contaminant transport velocities. Under the assumption that throughout the area of likely future contaminant migration (i.e., from the 200-ZP-1 OU to the Columbia River), recent historic measured groundwater levels broadly

reflect future groundwater levels and, therefore, likely reflect approximate future hydraulic gradients (and, therefore, groundwater flow directions), a map was prepared of an approximate groundwater elevation surface to be used together with particle tracking to indicate approximate directions and rates of groundwater and contaminant transport. These calculations were then used to define approximate long-term average groundwater velocities for use in the analytical transport analysis using ATRANS. Since the particle-tracking methods and program are described in Section D5.0, they are not described further here. Use of the analytical transport program ATRANS is described below.

D9.3 ADVECTION-DISPERSION TRANSPORT CALCULATIONS

ATRANS simulates transient, three-dimensional advective-dispersive transport from a patch of specified concentration along the inflow boundary of an aquifer. ATRANS considers the following transport processes: advection, dispersion, transformation reactions, and sorption. The assumptions that underlie the analytical solutions solved by ATRANS are summarized below. ATRANS is similar to other programs that solve three-dimensional transport equations analytically (i.e., BIOSCREEN and BIOCHLOR); however, ATRANS uses an exact solution to the equations rather than the Domenico solution (Domenico 1987), which can produce misleading results.

ATRANS requires the following general parameters as inputs to a simulation, in addition to those that describe the spatial and temporal frequency for producing outputs from the calculations:

- Hydraulic conductivity
- Porosity
- Hydraulic gradient
- Longitudinal dipersivity
- Transverse dipersivity
- Vertical dipersivity
- Aquifer thickness
- Source concentration decay rate (for exponentially decaying source)
- Retardation rate (R)
- Source width
- Initial concentration
- Contaminant decay rate.

ATRANS produces the following general outputs (ASCII text files) from a simulation:

- Concentration breakthrough curves at specified locations
- Maps of contaminant concentrations at specified times
- A mass-balance accounting (dissolved mass in the aquifer) at specified times.

ATRANS was executed to approximate the fate and transport of five COCs (i.e., carbon tetrachloride, chloroform, PCE, technetium-99, and tritium) after 10, 25, 50, 100, 250, and 500 years of transport. For each of these COCs, ATRANS was first executed assuming the no action remedy scenario. ATRANS was subsequently executed for remedy scenario #1 (1×10^{-4} risk) and for the selected remedy scenario. All hydraulic parameters used in the ATRANS simulations were consistent with those used in the simulation of the pump-and-treat remedy scenarios (Section D7.0) and in the particle-tracking analyses (Section D6.0). The values of longitudinal and transverse dispersivity were defined on the basis of the data summaries

(Section D2.0). The vertical dispersivity was set equal to 0.0, under the assumption that due to the longitudinal and lateral scales of transport from the 200-ZP-1 OU vertical dispersion is negligible and far-field fate is sufficiently well approximated by two-dimensional transport calculations.

The remaining, contaminant-specific transport parameters were defined in the following manner:

- Initial concentration: Defined as the maximum concentration of the COPC that is not recovered by the remedy. In the case of no action, this is the maximum measured concentration of the COPC.
- Retardation rate, contaminant decay rate: Defined on the basis of the data summaries described in Section D2.0, with supporting literature values where appropriate.
- Source decay rate: Defined by constraining the total dissolved contaminant mass at late times (>50 years) to be no greater than the current mapped contaminant mass estimated and described in Section D3.0.

A summary of parameters used in the ATRANS calculations is provided in Table D-58.

D9.4 ASSUMPTIONS, ADVANTAGES, AND DISADVANTAGES

Since the method used to evaluate likely migration paths of noncaptured contaminants is based on the use of the RK4/RW particle-tracking methods (described in Section D5.0), the same assumptions apply to particle-tracking calculations performed to evaluate the likely future migration paths of unrecovered contaminants. In addition, it is acknowledged that properties of the aquifer(s) encountered by contaminants migrating from the 200-ZP-1 OU toward the Columbia River may not be well-characterized at present and are considered as isotropic and homogenous for purposes of this approximate transport analysis. In particular, since contrasts in the hydraulic conductivity of aquifer materials are not explicitly included in this analysis, it is likely the exact timing of contaminant migration is not accurately reflected in this analysis, although the relative timing is approximated. Furthermore, it is likely future groundwater flow directions are reasonably reliable in so far as the groundwater level data naturally integrate the effects of contrasts in transmissivity.

The following general assumptions underlie the use of ATRANS to evaluate contaminant fate and transport:

- The aquifer is semi-infinite in the longitudinal direction ($0 \leq x < \infty$).
- The aquifer is infinite in the horizontal transverse direction ($-\infty < y < \infty$).
- The aquifer is finite in the vertical direction ($0 \leq z \leq B$).
- Groundwater flow is steady, uniform, and one-dimensional; this implicitly assumes that the aquifer is homogeneous and isotropic.
- Dispersion is assumed to be a Fickian process.
- Transformation reactions are represented by a first-order decay/production reaction.
- Sorption is assumed to be instantaneous and reversible, governed by a linear isotherm.
- The aquifer is initially devoid of contaminants.

- Contaminants enter the aquifer through a rectangular source of specified concentration located on the upstream boundary.
- The top and bottom boundaries (z= 0,z=B) are zero mass flux boundaries.

The use of ATRANS to approximate the transport of COPCs dissolved in groundwater has the following general advantages:

- Mass explicitly considered and conserved (i.e., mass conservative)
- Rapid calculation
- Conceptually straightforward
- Open source codes with ASCII text input and output files.

The use of ATRANS to approximate the transport of COPCs dissolved in groundwater is a deliberately simplified approach that has the following general disadvantages stemming from the assumptions outlined above:

- The aquifer is assumed to be homogeneous and isotropic. The effects of small-scale heterogeneity and anisotropy are assumed to be negligible, and/or are accommodated in general terms on the scale of the calculated contaminant transport pathways within the longitudinal and transverse dispersion terms.
- Groundwater flow is assumed to be uniform. This implies the effects of groundwater recharge, extraction, and/or injection are assumed to be negligible on the scale of the calculated contaminant transport pathways, and/or are simulated in a large-scale average sense using the single average linear groundwater velocity along the interpreted contaminant transport pathway(s).

Additional discussion of modeling and calculation assumptions is provided in Section D9.0.

D9.5 RESULTS

A discussion of the results is presented in Section 6.3.1 of the main text. ATRANS simulation results for the preferred pump-and-treat scenario are shown in Figure 6-1, and a discussion of the results is presented in Section 7.3 in the main text.

D9.6 DISCUSSION

- Conclude no action is not acceptable alternative
- Conclude travel time to the river is on the order of hundreds of years (it should be noted that the Columbia River is not an established point of compliance for the 200-ZP-1 OU)
- This gives opportunity for intervention technologies (e.g., in situ mass reduction, etc.).

Therefore, this further substantiates the approach taken in this FS of focusing on developing a remedy that addresses the relatively high-concentration areas in the very short term, to be protective of receptors, etc., and then addresses, monitors, and evaluates remaining mass over time.

Finally, it should be noted the no action alternative simulation implicitly assumes that there is no continuing source of contaminants to groundwater (i.e., the absence of a free-phase contaminant source [nonaqueous phase liquid]). This is not a limitation of the ATRANS simulation technique, which can incorporate an arbitrary time-varying, source-term concentration reflective

of contaminants to groundwater. However, this assumption does require that if a continuing source is present, it will be remediated within a relatively short timeframe compared to the timeframe of the projected simulations.

D10.0 EVALUATION OF THE IMPACT OF PRINCIPAL ASSUMPTIONS

D10.1 BACKGROUND

The methods used to evaluate historic groundwater conditions and to evaluate potential alternative remedies at the 200-ZP-1 OU are approximate. They are not intended to represent, nor are they capable of representing, all aspects of the groundwater conditions at the Hanford Site. However, the principal assumptions that underlie the modeling approach are as follows:

- Groundwater flow is dominantly two-dimensional
- The aquifer is homogeneous and isotropic.

The FS team performed calculations to evaluate the impact of the principal assumptions that underlie the use of Equations (1), (2), and (3) on the conclusions drawn regarding pump-and-treat remedy design, including the effects of partial penetration (e.g., Bair and Lahm 1996, Faybishenko et al. 1995); the relative scales of the problem in the vertical and horizontal directions (e.g., Hantush 1964, Haitjema 1995, Haitjema and Mitchell-Bruker 2005); and the possible effects of variable aquifer properties (e.g., transmissivity, storage, effective porosity, etc.). These evaluations focused on identifying the relative magnitude of the impacts of the various assumptions on the hypothetical remedy design(s). The table below summarizes the methods used to evaluate the impact of these assumptions. It should be noted these evaluations provided relative measures of the reliability of the relatively simple calculations that underlie the 200-ZP-1 FS comparative remedy analysis. Additional discussion of principal assumptions is provided below:

Guide to Evaluating the Impact of Principal Assumptions.

Assumption	Analysis Aspect	Basis of Analysis
Flow is dominantly two-dimensional	Migration and fate of COPCs	Evaluate the historic and present-day distribution, magnitude, and persistence of vertical hydraulic gradients in well pairs.
		Completed a range of analytical and/or numerical future vertical migration.
	Hydraulic capture	Evaluate the likely relative effects of partial penetration using empirical partial-penetration nomographs (Bair and Lahm 1996).
Aquifer is homogeneous and isotopic	Migration and fate of COPCs	Complete COPC fate calculations using ranges of hydraulic properties based on the site-specific data summary statistics.
	Hydraulic capture	Complete hydraulic capture calculations using ranges of hydraulic properties based on site-specific data summary statistics.

D10.2 ASSUMPTION: FLOW IS DOMINANTLY TWO-DIMENSIONAL

D10.2.1 Vertical Gradients

Evaluations of vertical leakage and two-dimensional flow were performed by analyzing available data from piezometers or well pairs near the principal waste sites (216-Z-1A, 216-Z-18, and 216-Z-9) within the Ringold aquifer and between the Ringold aquifer and basalt bedrock.

The following well pairs and piezometers were used to calculate vertical gradients within the Ringold aquifer and between the Ringold aquifer and basalt bedrock within the 200-ZP-1 OU geographic boundaries:

- 299-W15-5 (portion open to bedrock), 299-W15-32, 299-W15-39, and 299-W15-9
- 299-W22-24 (multiple-screened well)
- 299-W19-4 (multiple-screened well)
- 299-W11-2 (multiple-screened well).

For the wells evaluated, vertical gradients were relatively low, indicating that the current groundwater flow system beneath the 200-ZP-1 OU is primarily horizontal and, therefore, the modeling assumption of horizontal aquifer flow appears to be valid. These well pairs, however, generally do not represent ideal well pair data due to the horizontal distance between some of the wells. Available well and piezometer pairs are relatively sparse at the Site. Vertical gradients calculated from well 299-W15-5 and associated wells ranged from 0.001 m/m downward to 0.005 m/m upward. Vertical gradients calculated from screened intervals from well 299-W22-24 decreased from 0.17 m/m downward in 1989 to 0.004 m/m downward in 2004. Calculated vertical gradients calculated from screened intervals in well 299-W19-4 ranged from 0.00 m/m to 0.06 m/m downward. Vertical gradients calculated in well 299-W11-2 ranged from 0.001 m/m upward to 0.007 m/m upward. The vertical gradient data suggest that the magnitude of the vertical gradients within the 200-ZP-1 OU area have diminished through time, suggesting that groundwater flow is returning to dominantly horizontal pre-Hanford development flow patterns.

D10.2.2 Partial Penetration

Pumping wells that are operated as part of the 200-ZP-1 IRM and extraction wells that will be installed as part of a pump-and-treat 200-ZP-1 groundwater treatment alternative do not or will not fully penetrate the aquifer thickness beneath the 200-ZP-1 OU. A detailed discussion of the expected effects of partial penetration on pump-and-treat wells is presented below. In general, relatively long well screens (e.g., greater than 25% aquifer penetration) are recommended to effectively capture the 200-ZP-1 COCs.

Section D4.0 describes the use of the Theis superposition model to reasonably represent historic groundwater flow directions and rates in the vicinity of the 200-ZP-1 OU. The model approximates changes in groundwater elevations at several monitoring wells located throughout the 200-ZP-1 OU. Section D6.0 describes the use of the linear-log kriging approach to prepare maps that approximate the groundwater elevations in the vicinity of the 200-ZP-1 IRM and are suitable for approximating the extent of hydraulic capture developed by the IRM. Finally, Section D7.0 describes the use of the Theis superposition model to compare the approximate extent of hydraulic capture developed by various alternative groundwater pump-and-treat remedies.

The two-dimensional calculations used to approximate historic groundwater heads, the extent of hydraulic capture of the current 200-ZP-1 IRM, and the likely extent of hydraulic capture would

be developed by alternative groundwater pump-and-treat strategies do not explicitly account for the fact that the open-screened intervals of the groundwater recovery wells are only open to a portion of the aquifer thickness (i.e., they are partially penetrating). Partial penetration impacts the two-dimensional estimates of hydraulic capture in three principal ways:

- When a two-dimensional map of groundwater elevations is prepared, that exhibits a convergent singularity (e.g., produced by drawdown in response to pumping), this singularity will appear to completely capture all groundwater that approaches the well. However, if the well penetrates a small fraction of the saturated thickness of the aquifer in which the groundwater flow occurs, the well may actually not form a sufficiently strong sink to groundwater to induce flow toward the well screen throughout the entire aquifer thickness. Therefore, some groundwater may bypass the well either above or below the well screen (e.g., Zheng 1994).
- Two-dimensional maps of groundwater elevations are liable to be in error in the vicinity of pumping wells because the actual three-dimensional flow cannot be properly represented in a two-dimensional map. The magnitude of the error depends on the relative magnitude of the pumping and the regional flow rate, the location(s) of the pumping well screen(s), and the screen location of monitoring wells used in the mapping.
- When used to calculate the approximate extent of hydraulic capture developed by alternative pump-and-treat remedies, these methods are unable to provide feedback on the appropriate open-screened intervals for the hypothetical recovery wells.

Faybishenko et al. (1995) and Bair and Lahm (1996) present analyses and rule-of-thumb guidelines for assessing the effect of partial penetration on the geometry of three-dimensional capture zones in the presence of regional flow for confined and unconfined aquifers. In particular, Bair and Lahm (1996) present nomographs that describe the relationship between the ratio of the groundwater recovery rate (Q) to the aquifer specific discharge (q) induced by the regional flow; and how this ratio (Q/q) affects the (relative) maximum capture zone depth (CZd), (relative) maximum capture zone width (CZw), and relative distance to the stagnation point (CZs) for various well partial penetration factors and aquifer anisotropies. These nomographs were developed using simple, parametric-flow modeling analyses that, although differing in geometry from the conditions encountered at the 200-ZP-1 OU, nonetheless offer insight into the likely relative geometries of existing and hypothetical partially-penetrating groundwater recovery wells at the 200-ZP-1 OU.

Table D-56 summarizes the open-screen elevations of the existing 200-ZP-1 IRM groundwater recovery wells and the degree to which they penetrate the assumed approximate saturated thickness of the principal aquifer at the site (estimated at 60 m saturated thickness). This is summarized in terms of partial penetration factors, where the partial penetration factor is the fraction of the saturated aquifer thickness that is intercepted by the recovery well. Table D-57 compares the (relative) maximum capture zone CZw, CZs, and CZd with calculations made using the basic formula for the geometry of a fully-penetrating well within an unconfined aquifer (e.g., Yang et al. 1995). Note the partial penetration factors presented in this table were calculated assuming that the full open-screened length of each well intercepts the saturated aquifer; however, the water table is actually within the open-screened interval of several of the current 200-ZP-1 IRM recovery wells, which would lead to a lower actual partial-penetration factor.

To evaluate the results provided in Table D-57, it is also useful to approximate the distance from the pumped well at which the relative maximum capture zone CZw, and CZd may be reached. Hantush (1964) suggests that beyond a certain distance from a partially penetrating well, it is not possible (on the basis of water levels measured in the aquifer) to distinguish between a fully and partially penetrating pumping well. In other words, beyond this distance, vertical gradients are negligible and flow is effectively horizontal. The equation presented by Hantush is as follows:

$$r = 1.5 \times B \times \sqrt{\frac{K_h}{K_v}} \qquad \text{(Equation 4)}$$

where:

r = radial distance to the monitoring well
B = saturated aquifer thickness
Kh = aquifer horizontal hydraulic conductivity
Kv = aquifer vertical hydraulic conductivity.

Assuming a horizontal hydraulic conductivity of 60 ft/day, and an anisotropy (Kh/Kv) of 10, Equation (4) suggests that flow is effectively horizontal at a distance of about 950 ft from the pumped well. Although this is not a direct indicator of the distance at which the CZd and CZw are reached, it does suggest that the full width and thickness of the capture zone are not developed until several hundred, and possibly greater than a thousand, feet upgradient of partially penetrating wells in the current 200-ZP-1 IRM.

Table D-56 suggests that under conditions broadly representative of the 200-ZP-1 IRM, the hydraulic capture zones are likely to be vertically thinner (ranging from about 40% to about 90% of the saturated thickness) and laterally wider (ranging from about 130% to about 240% of the assumed full width) than for a fully penetrating well pumping from the same aquifer sequence. Furthermore, the maximum capture zone thickness may not be reached for several hundred, to possibly greater than 1,000 ft, upgradient of the recovery well.

The interpretation of the effect of partial penetration on the existing IRM wells and inferences for the hypothetical pump-and-treat remedy, are summarized below:

- This suggests the following:
  - The lateral extents of capture zones based on two-dimensional mapping are likely unaffected by partial penetration effects.
  - The vertical extents of capture inferred from two-dimensional mapping are likely to be in error considerably less than the maximum extent and within several hundred feet, to perhaps over 1,000 ft for wells that exhibit relatively low partial penetration factors (e.g., 25% or less) and relatively low pumping rates (e.g., Q/q ratios of less than about 40). This indicates that an assumption that a partially penetrating well recovers the full saturated thickness of an aquifer is likely in error.

  Therefore, it is recommended further evaluation of partial penetration effects is warranted prior to the final design of the pump-and-treat system; and more specifically that methods be used during final design that explicitly incorporate partial penetration effects.
- Evaluation of the potential use of longer screened recovery wells be performed as part of analysis completed during the design phase.

Finally, it is noted that partial penetration effects of wells in the unconfined aquifer at 200-ZP-1 are affected by the effects of drawdown on the saturated zone thickness, and that the partial penetration factors listed in Table D-56 are calculated assuming a constant saturated aquifer thickness. However, as discussed earlier in this appendix, the saturated thickness has decreased in response to termination of wastewater injection and increasing groundwater extraction.

Final locations and screened intervals of injection and extraction wells will be based on the final design of the pump-and-treat system.

D10.3 ASSUMPTION: AQUIFER IS HOMOGENEOUS AND ISOTROPIC

Since the modeling analyses presented in this report assume two-dimensional groundwater flow, isotropy is implicitly assumed. The most significant impact of the assumption of isotropic conditions is on the effects of partial penetration on the vertical extent of hydraulic capture developed by recovery wells, which are detailed above. Principal impacts of the assumption of homogeneity on the remedy evaluations are described below.

D10.3.1 Hydraulic Capture

The use of Equations (1) and (2) to evaluate historic groundwater flow patterns and of future alternative pump-and-treat remedies assumes that the aquifer is homogeneous and isotropic and, furthermore, that the transmissivity is constant in time. While the calculations were made using parameters that generally reflect the central tendency (described in Section D2.0), it is clear from the data presented in Section D2.0 that the contaminated portion of the saturated aquifer exhibits variations in hydraulic conductivity, transmissivity, and effective porosity over about an order of magnitude. The effect of these variations is primarily accounted for in the comparative remedy evaluations in the following manner.

First, the theoretical maximum pumping rate for any recovery (and correspondingly, reinjection) well was limited to 60 gpm, equivalent to about 11,500 ft^3/day. This limitation was enforced based on the observation of capacities in the existing 200-ZP-1 IRM recovery (and reinjection) wells (see Table D-29). As described in Section D7.0, this limitation assumes that recovery wells constructed for any proposed remedy would respond similarly to the existing IRM wells. However, as discussed elsewhere in this appendix, the saturated screen intervals for the existing wells range from less than 10 m to a maximum of 20 m due to declining water levels through time; whereas, the proposed remedy assumes longer screened wells ranging from a minimum of 20 m to a maximum of 40 m of open-screened interval, screened entirely below the water table within the saturated aquifer. Under the assumption that new recovery wells encounter similar materials to those encountered at the location of the current IRM wells, it is expected that the capacities of these wells would approximately reflect the relative screen lengths of the wells. It is therefore expected that the longer screened wells will actually have significantly greater capacities than the limitations used in the comparative remedy analysis.

Second, the limitation on pumping described above implicitly assumes the transmissivity is constant spatially. Equation (5) describes the theoretical steady-state width of hydraulic capture for a well (fully penetrating) within an unconfined aquifer (Yang et al. 1995):

$$W = \left[\frac{2QL}{K\left(H_1^2 - H_2^2\right)} \right] \qquad \text{(Equation 5)}$$

where:

L = distance between two monitoring wells that exhibit heads of H_1 and H_2, respectively
K = aquifer hydraulic conductivity
Q = well recovery rate.

Equation (5) reduces to the more familiar equation for confined aquifers if the transmissivity is assumed equal to $(H_1+H_2)/2$. At the distance at which the maximum width occurs, the flow through the aquifer per unit width of aquifer equals the transmissivity times the background hydraulic gradient (i.e., "T*i," where "i" is the hydraulic gradient and "T" is the transmissivity). According to Equation (5), the width of capture increases linearly with the pumping rate and decreases linearly with the aquifer hydraulic conductivity and/or transmissivity. Under these circumstances, should the transmissivity at the location of a proposed recovery well prove to be greater than that used in the remedy evaluations, a correspondingly greater pumping rate would be required to recover the same width of saturated aquifer. As described above, the theoretical well capacities were limited to 227 L/min (60 gpm), assuming conditions similar to those encountered by the existing 200-ZP-1 IRM wells. Should the hydraulic conductivity (and transmissivity) prove to be higher than used in the remedy calculations, then the capacity of the recovery wells should increase correspondingly. Similarly, should the transmissivity at the location of a proposed recovery well prove to be smaller than used in the remedy evaluations, a correspondingly smaller pumping rate would be required to recover the same width of saturated aquifer. Should the hydraulic conductivity (and transmissivity) prove to be higher than used in the remedy calculations, then the capacity of the recovery wells should decrease correspondingly (assuming a 60 gpm pumping rate). Therefore, it is likely the most significant impact of the assumption of homogeneity will actually be upon (1) the design of the recovery wells, with regard to screened intervals, screen diameters, and gravel packs required to obtain acceptable entrance velocities; and (2) the sizing of the ex situ treatment system required to treat the pumped water.

The use of Equation (3) to evaluate the extent of hydraulic capture developed by the existing 200-ZP-1 IRM is somewhat less impacted by the assumption of homogeneous isotropic conditions since the mapping technique reflects the measured groundwater-level data that naturally integrate the effects of aquifer heterogeneity and, therefore, indicate the approximate magnitude and directions of hydraulic gradients within the area encompassed by the monitoring wells.

D11.0 REFERENCES/BIBLIOGRAPHY

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Figure D-1. Hydraulic Conductivity Distribution – Ringold Unit 5.

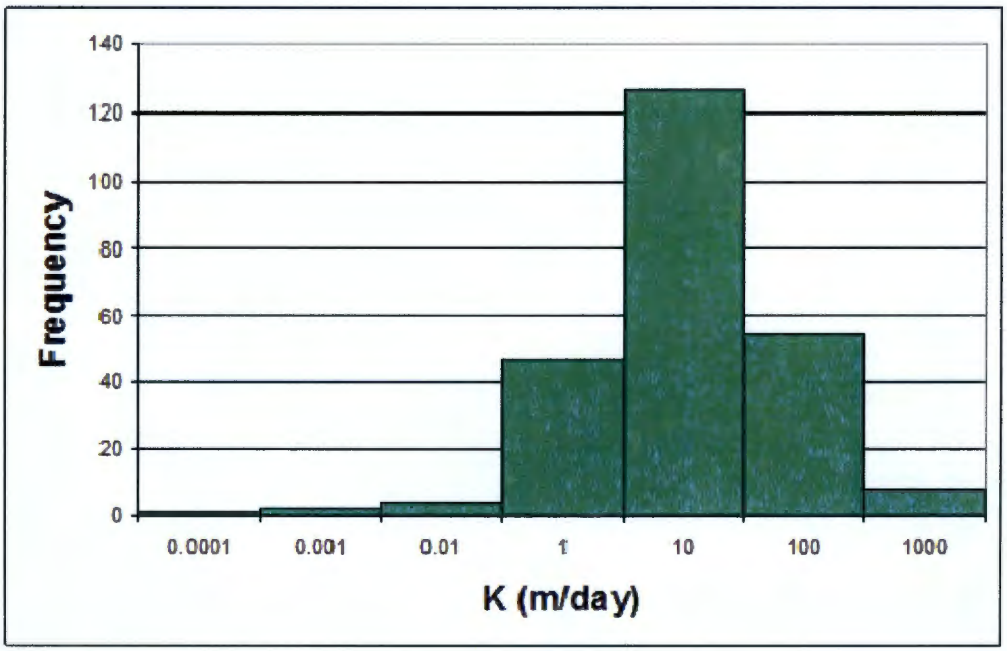


Figure D-2. Transmissivity Distribution – Ringold Unit 5.

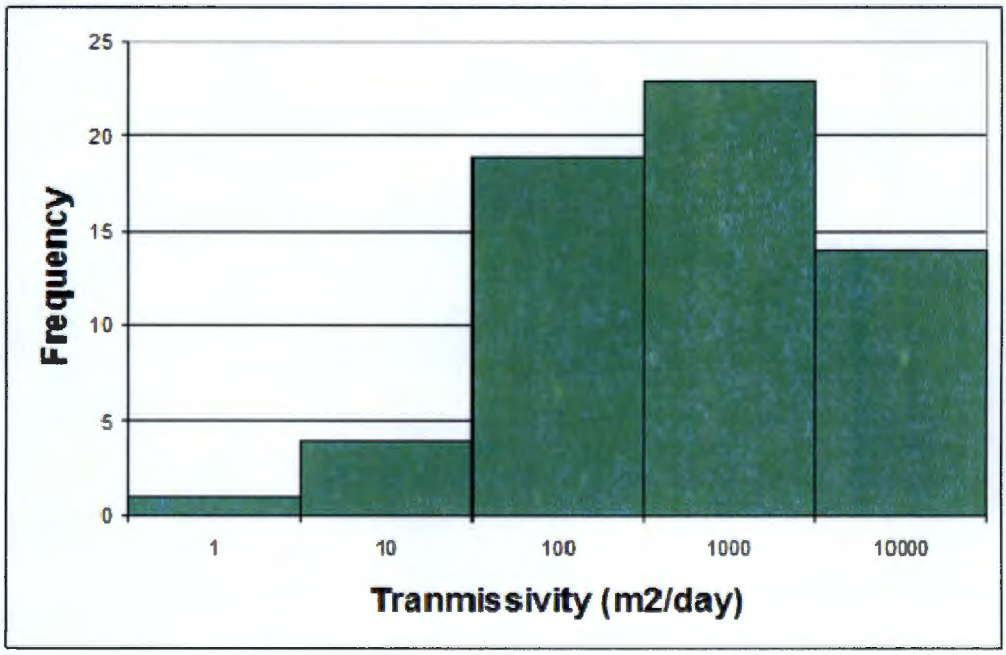


Figure D-3. Effective Porosity Distribution – Ringold Unit 5.

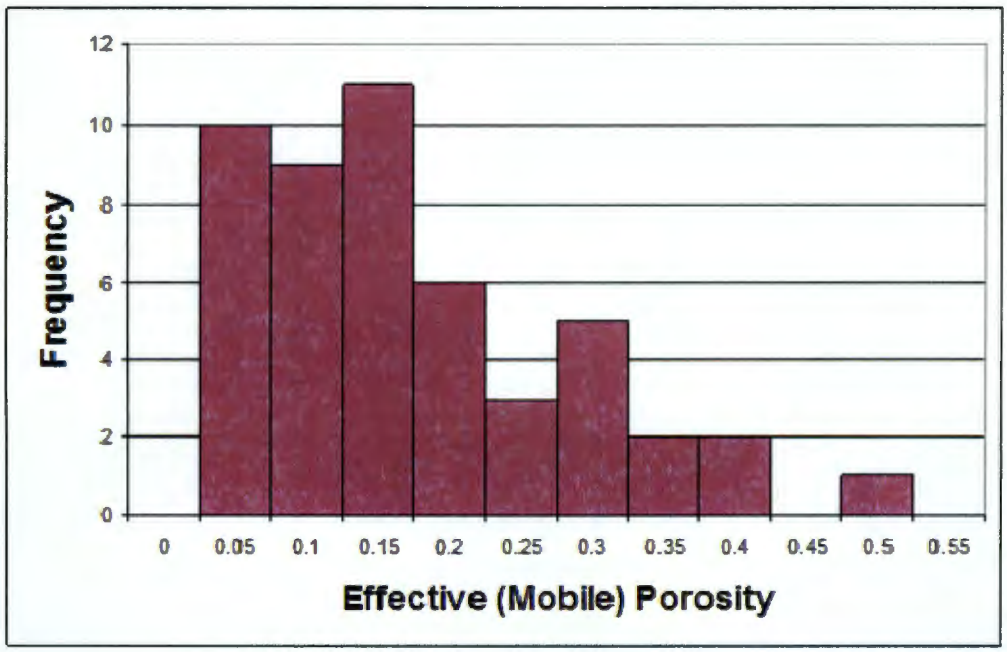


Figure D-4. Composite Extent of Groundwater Contamination Above 1 x 10^{-4} Risk.

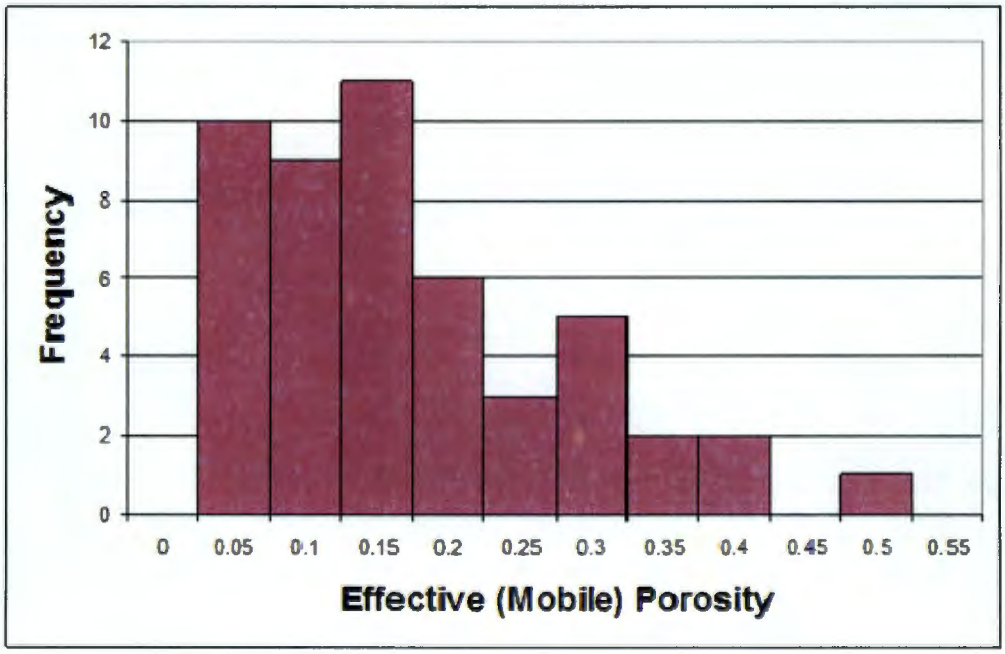


Figure D-5. Composite Extent of Groundwater Contamination Above Maximum Contaminant Levels.

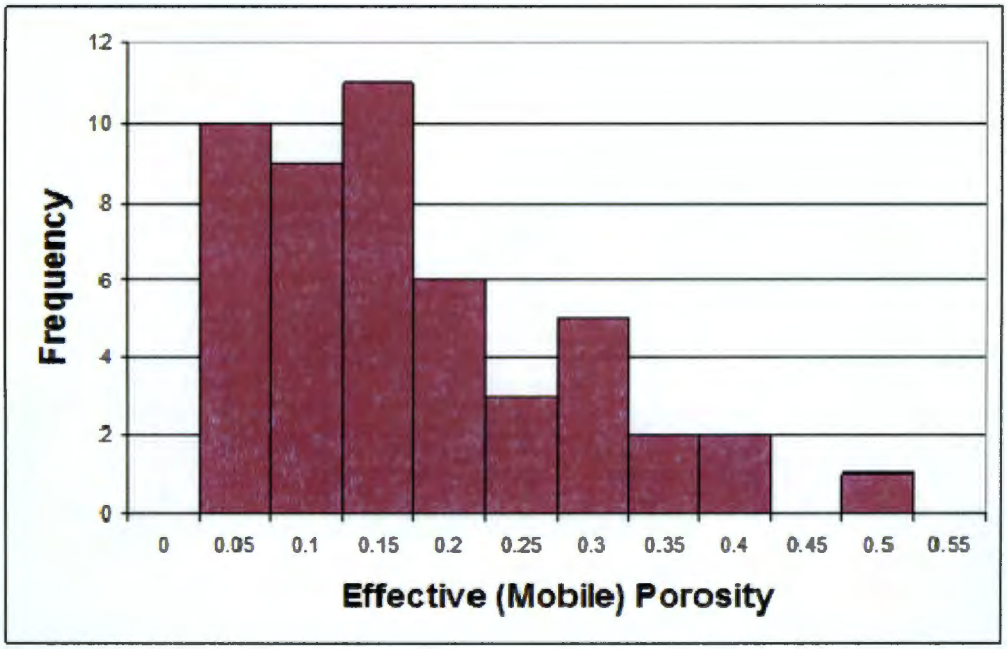


Figure D-6. Composite Extent of Groundwater Contamination Above Ten Times Maximum Contamination Levels.

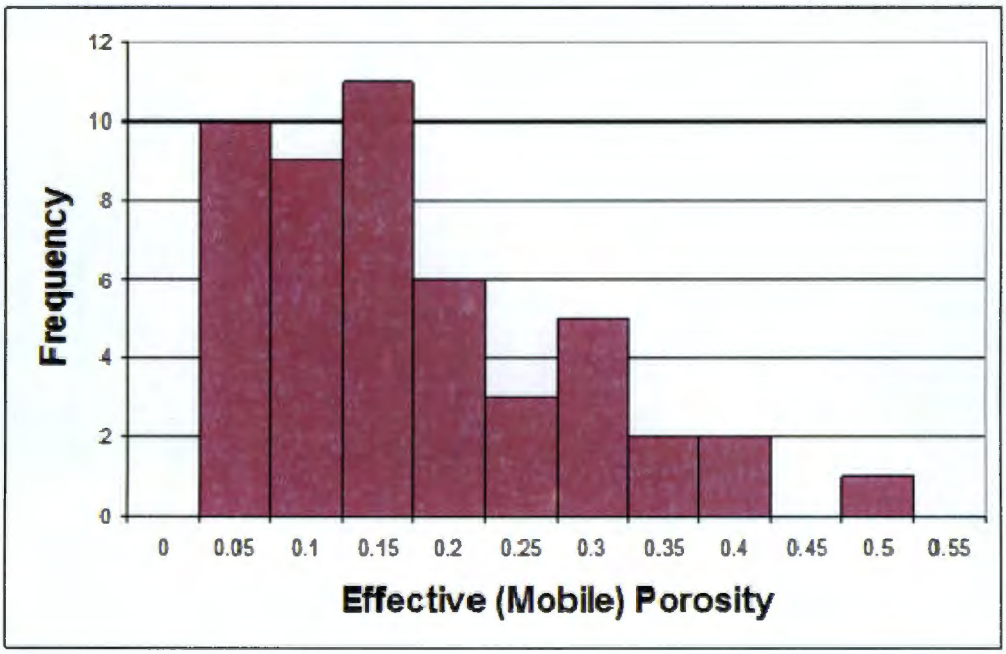


Figure D-7. Composite Extent of Groundwater Contamination for Preferred Pump-and-Treat Alternative.

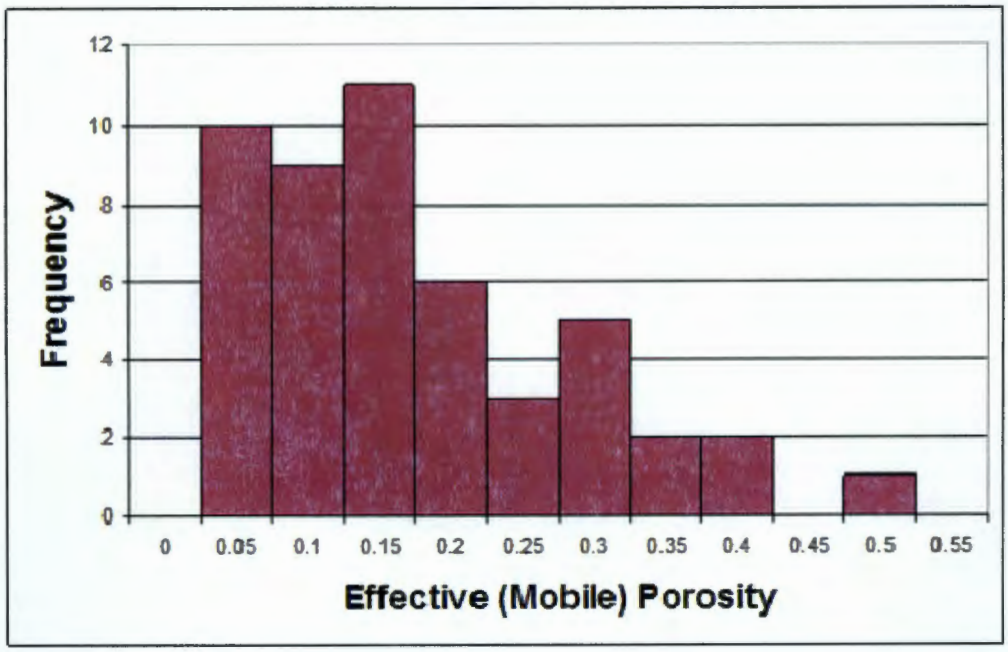


Figure D-8. Wells Sampled for Chloroform.

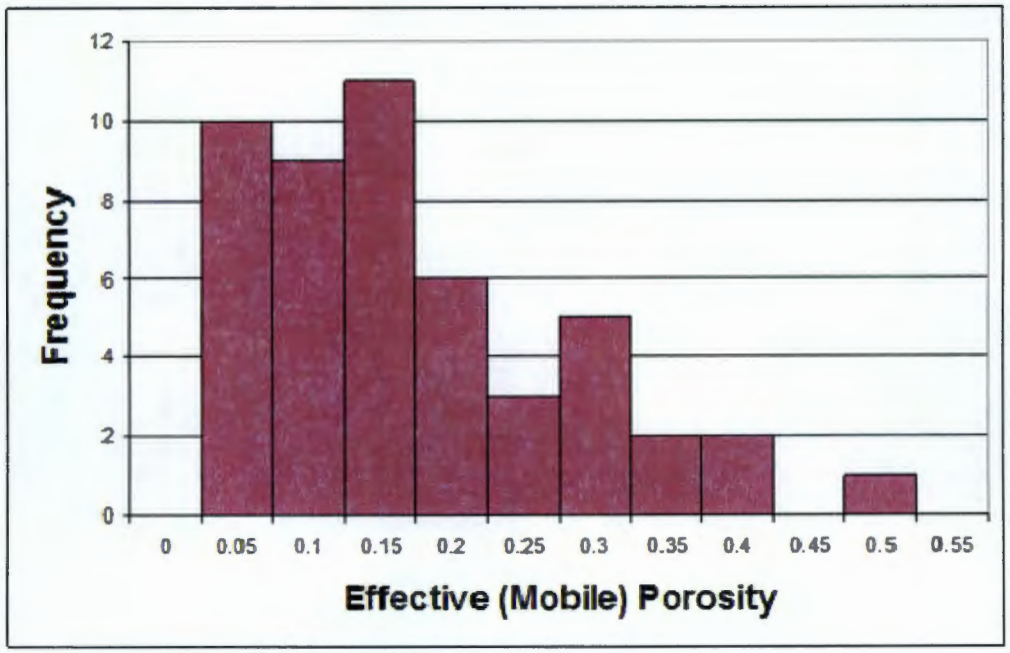


Figure D-9. Wells Sampled for Hexavalent Chromium.

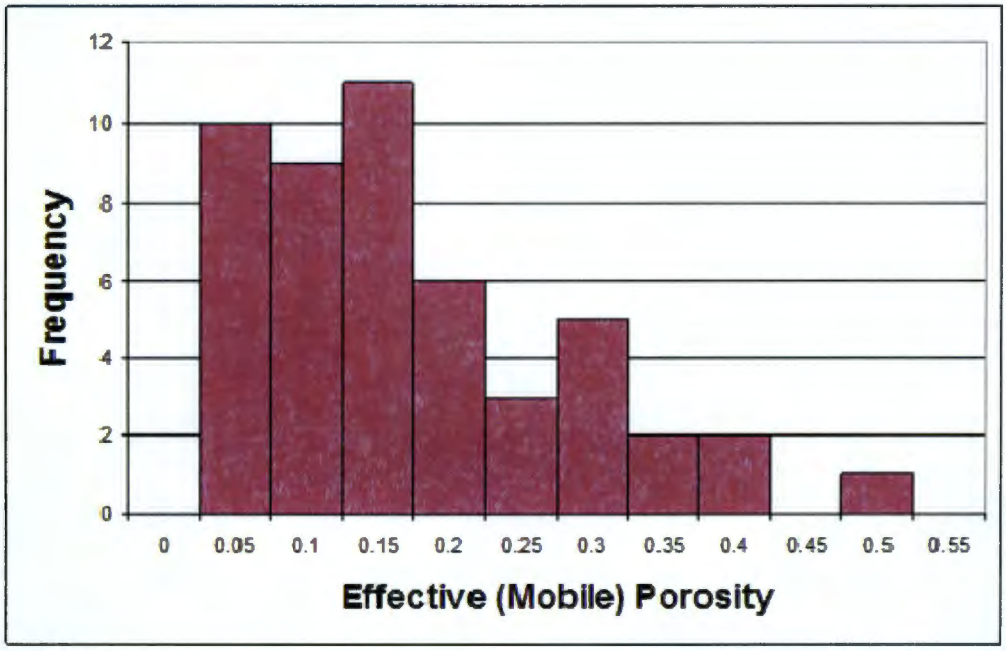


Figure D-10. Wells Sampled for Total Chromium.

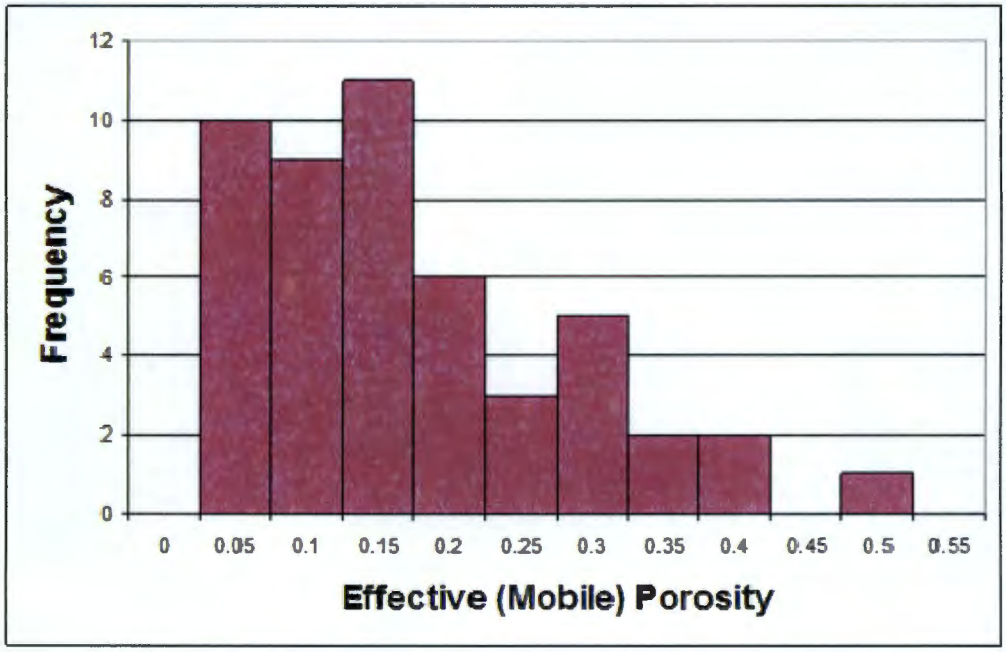


Figure D-11. Wells Sampled for Carbon Tetrachloride.

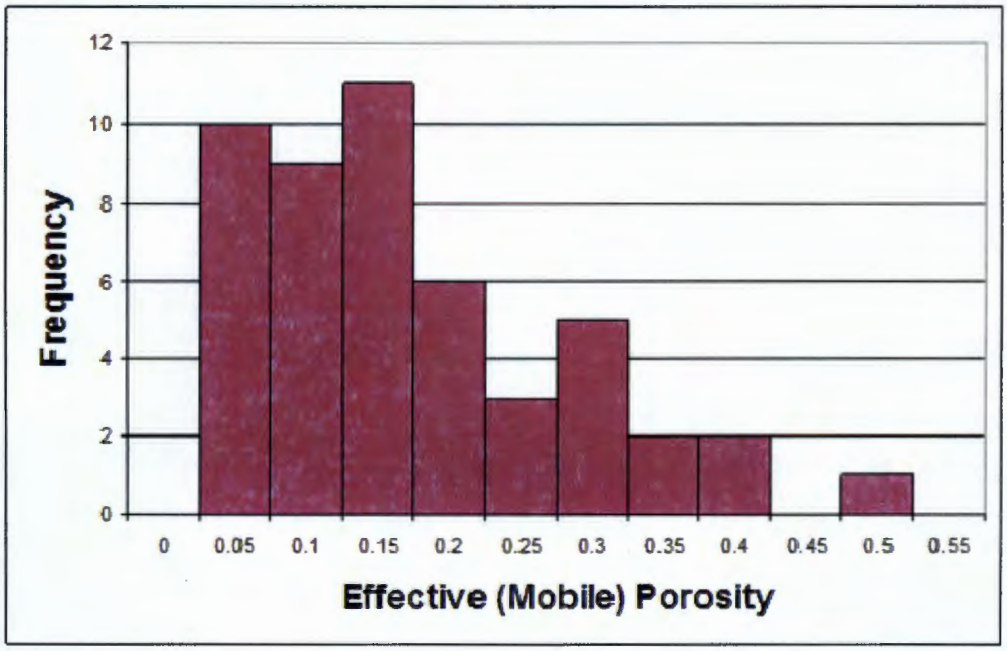


Figure D-12. Wells Sampled for Iodine-129.

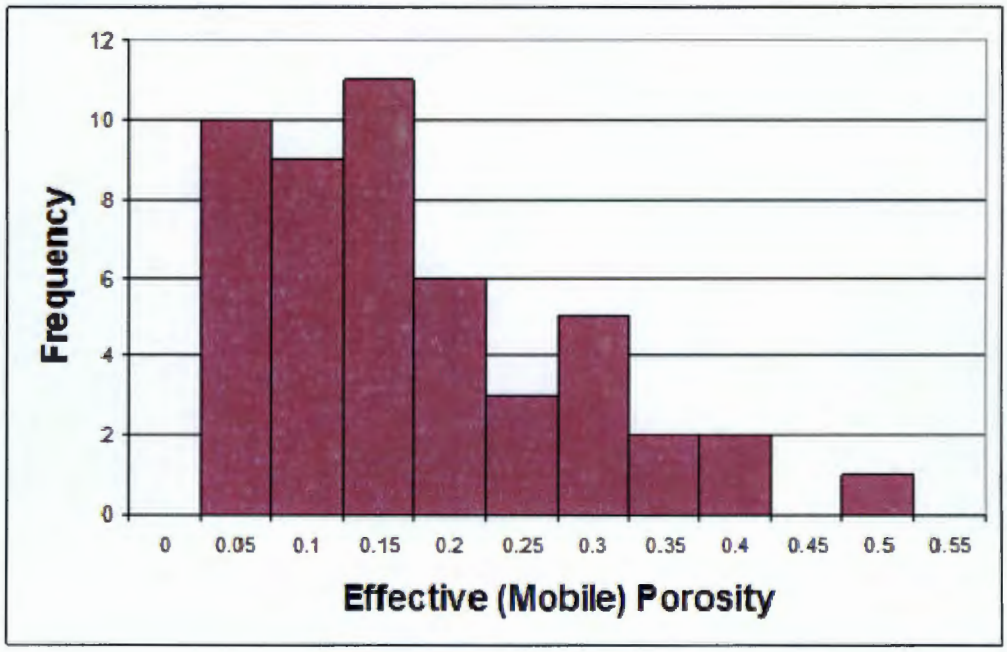


Figure D-13. Wells Sampled for Methylene Chloride.

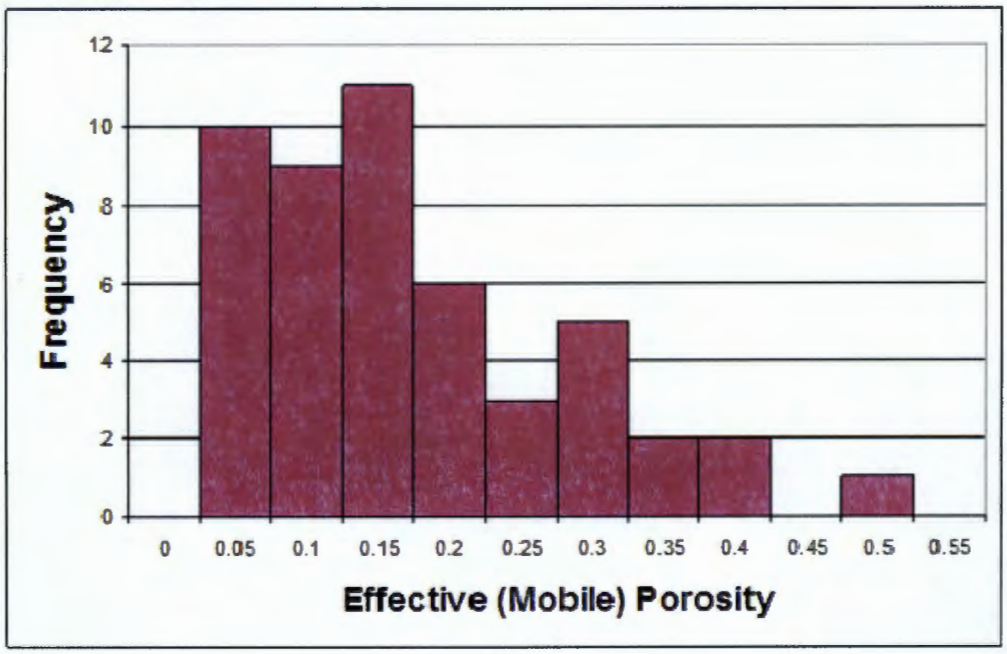


Figure D-14. Wells Sampled for Nitrate.

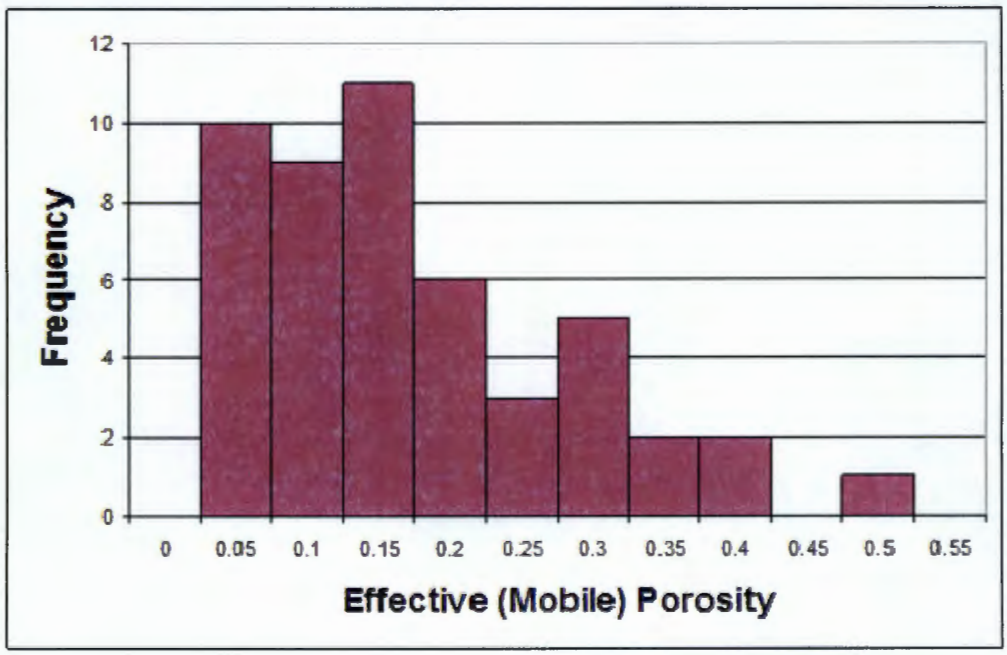


Figure D-15. Wells Sampled for Tetrachloroethylene.

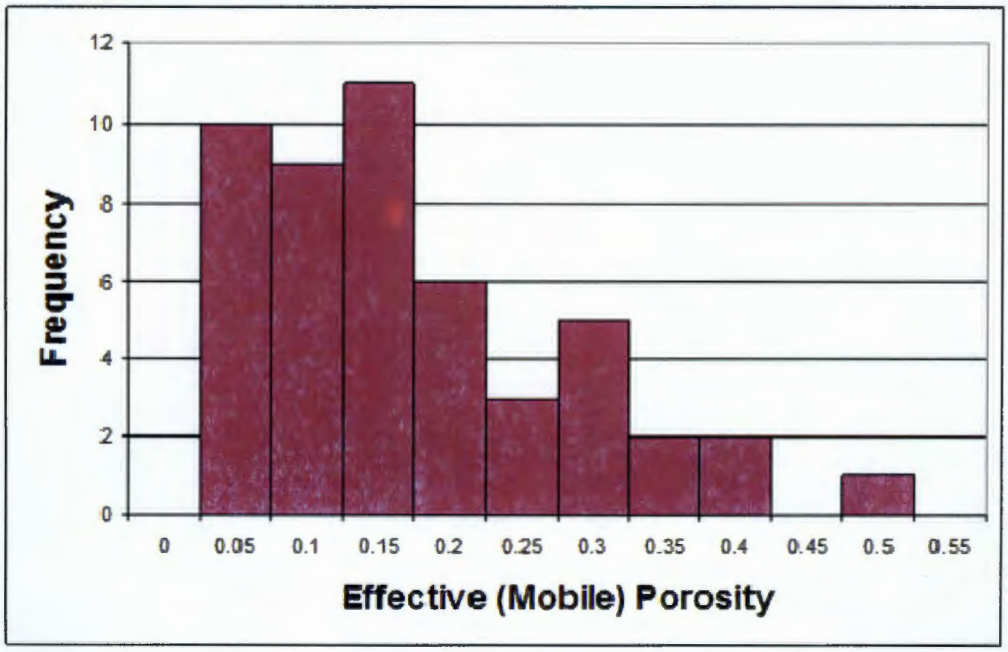


Figure D-16. Wells Sampled for Technetium-99.

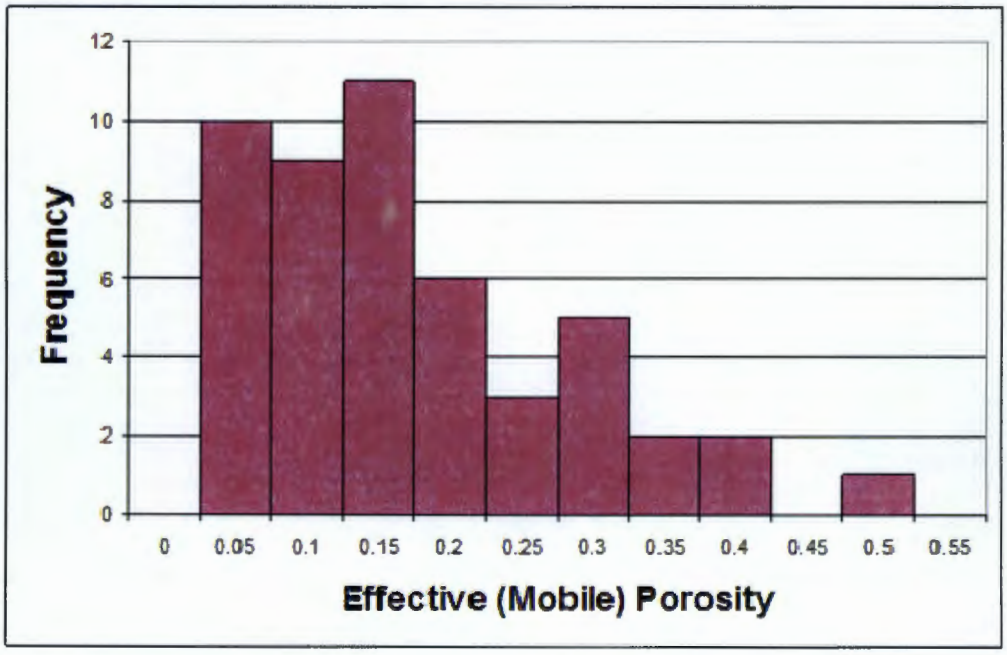


Figure D-17. Wells Sampled for Trichloroethylene.

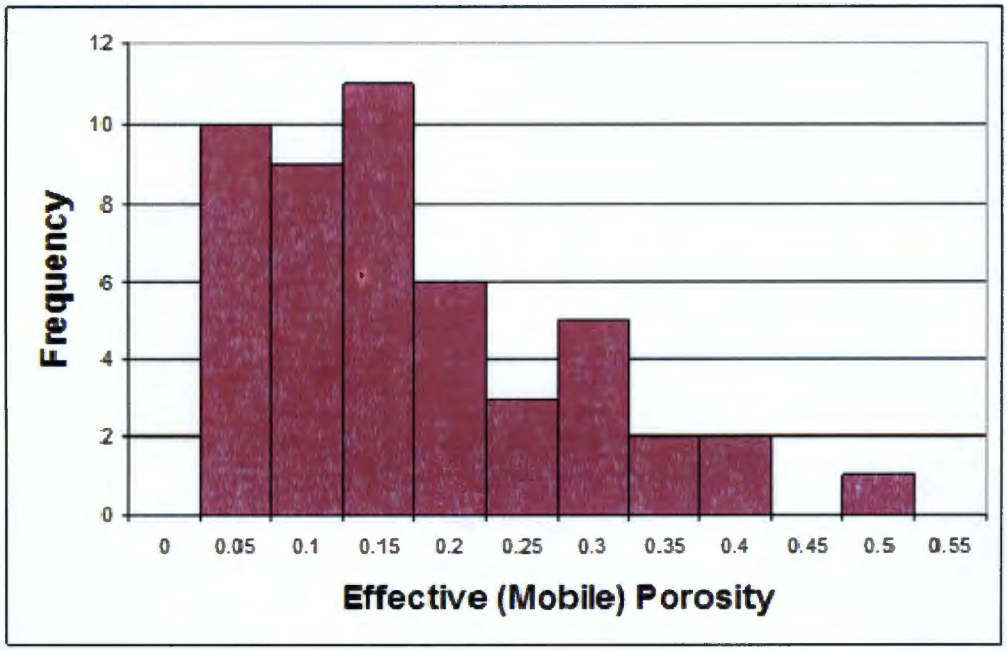


Figure D-18. Wells Sampled for Tritium.

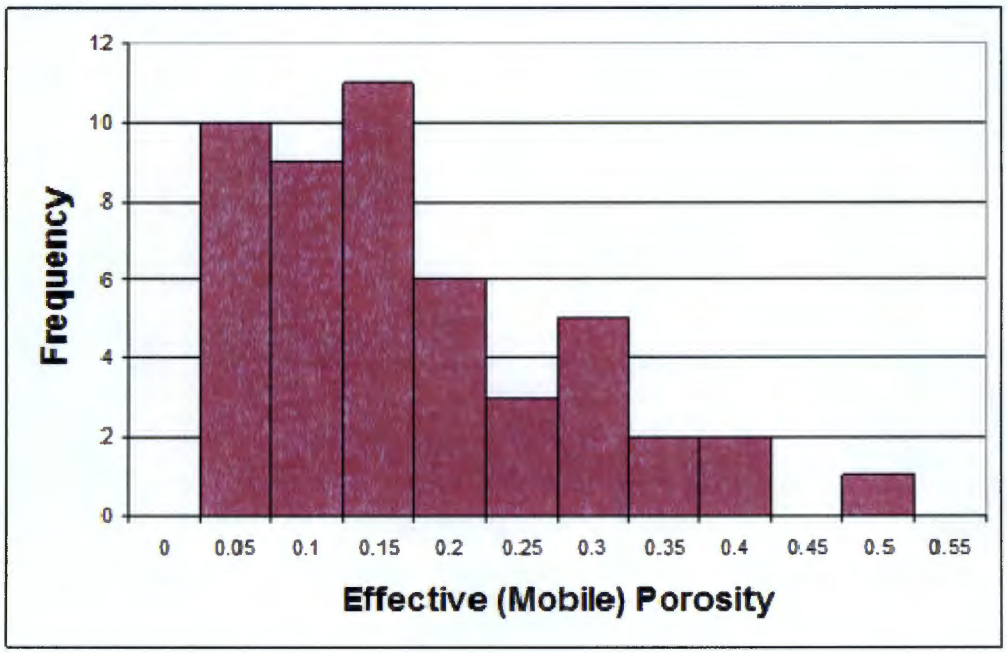


Figure D-19. Wells Sampled for Uranium (Total).

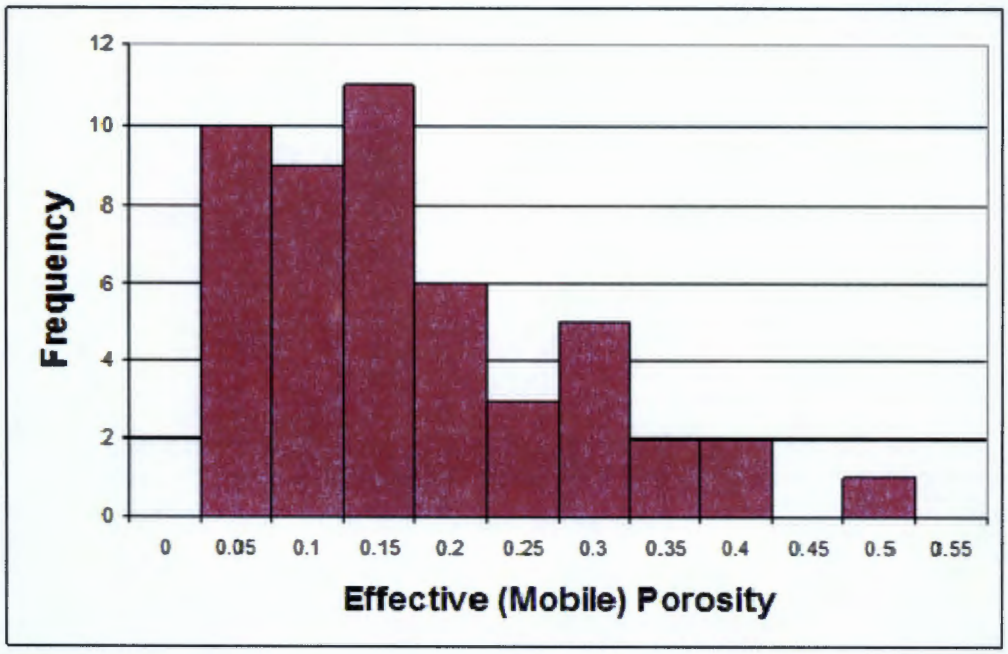


Figure D-20a. Measured and Modeled Groundwater Elevations.

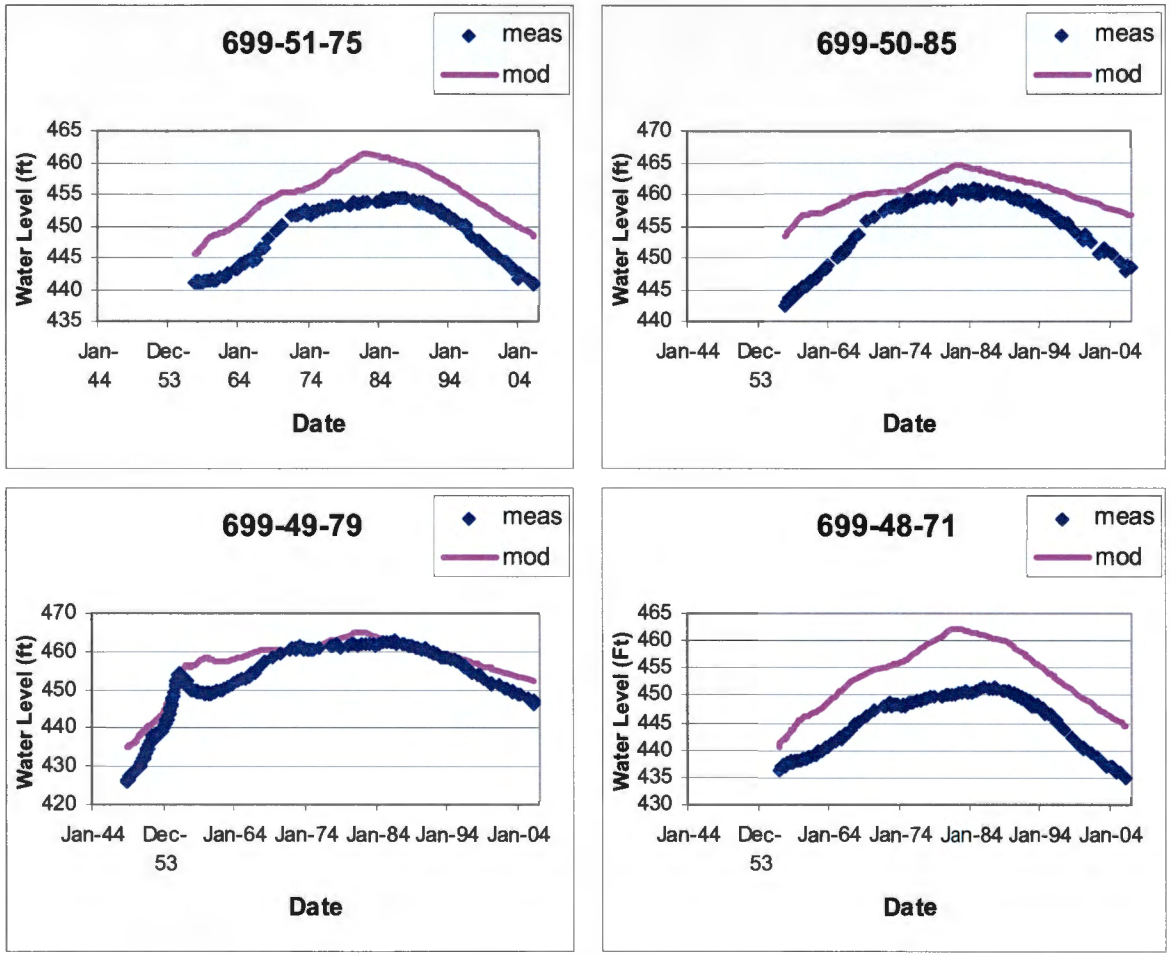


Figure D-20b. Measured and Modeled Groundwater Elevations.

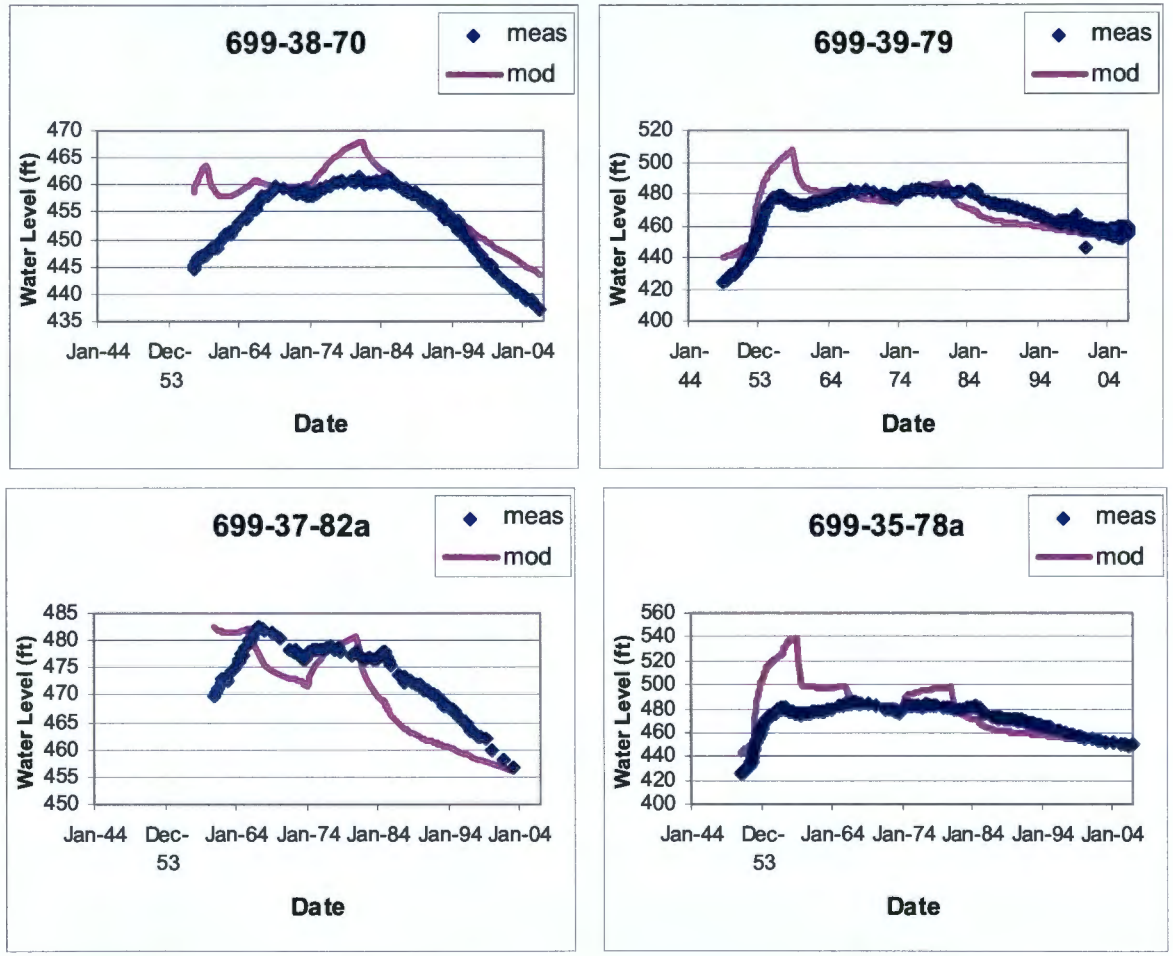


Figure D-20c. Measured and Modeled Groundwater Elevations.

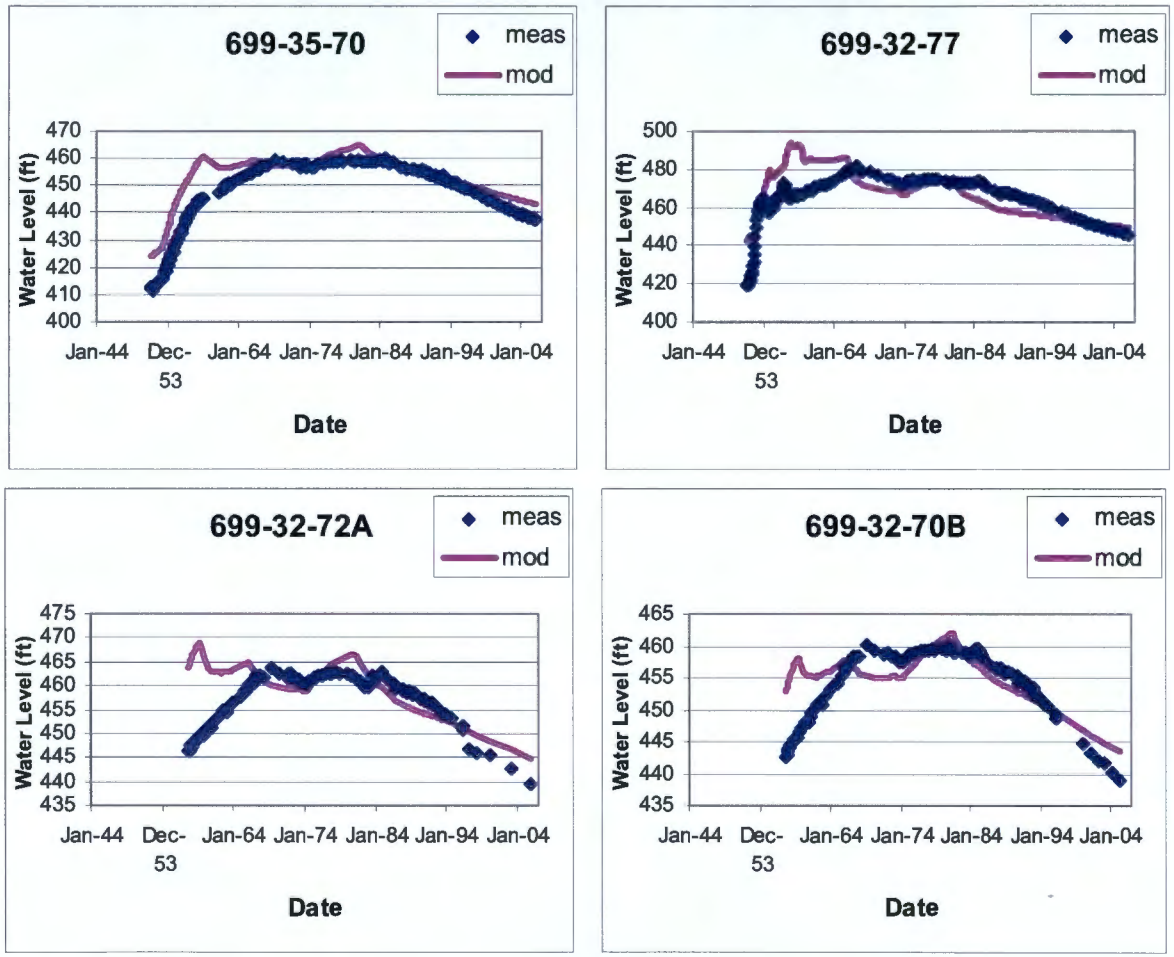


Figure D-20d. Measured and Modeled Groundwater Elevations.

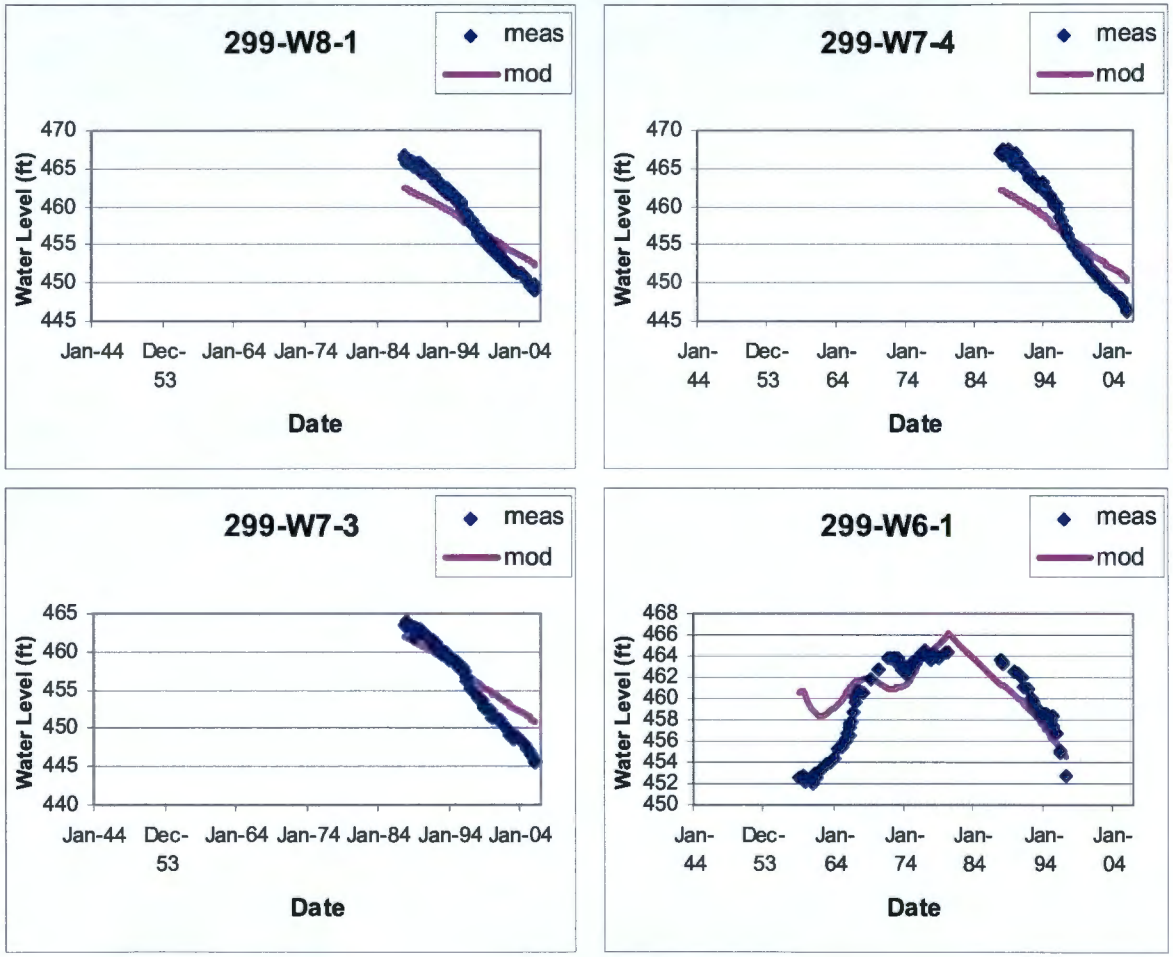


Figure D-20e. Measured and Modeled Groundwater Elevations.

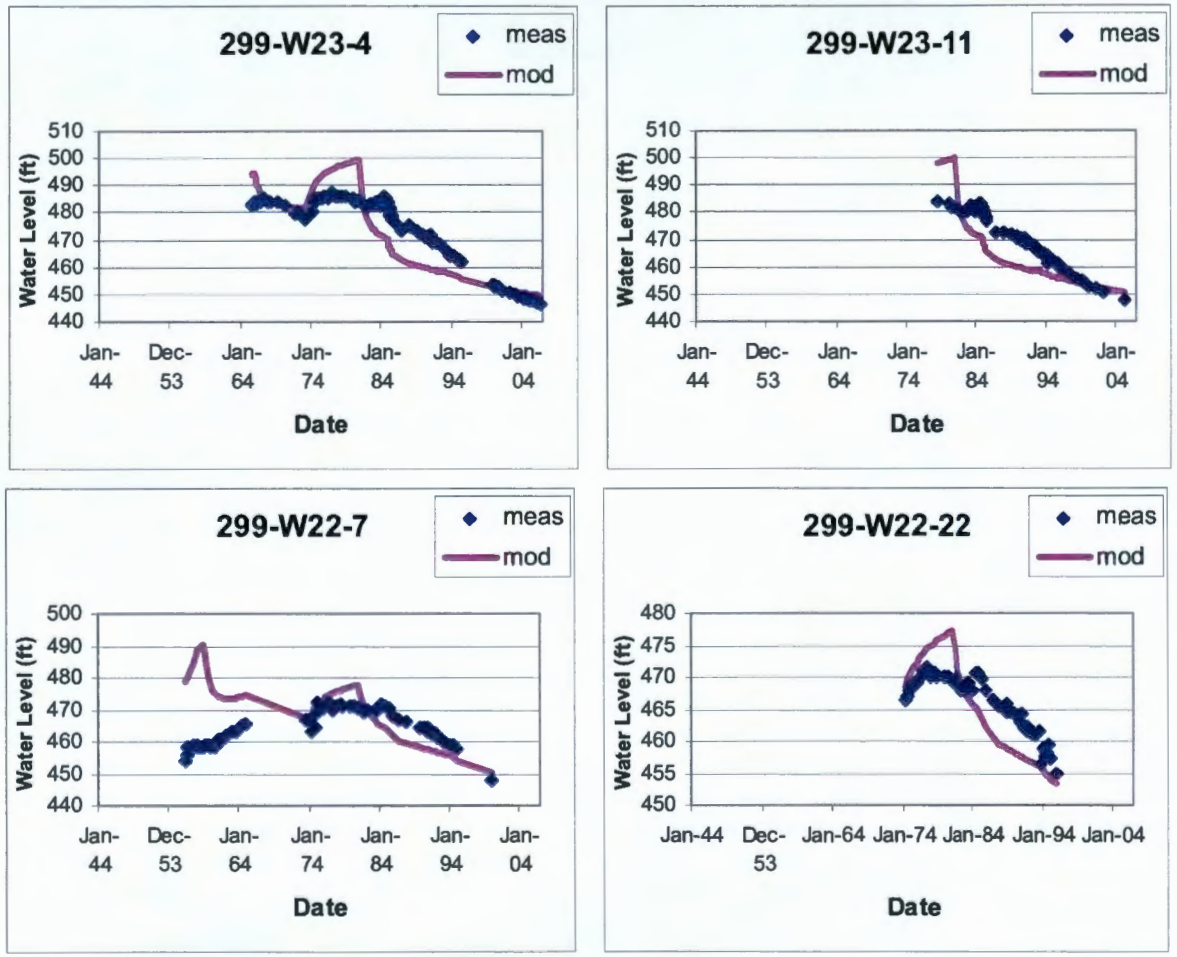
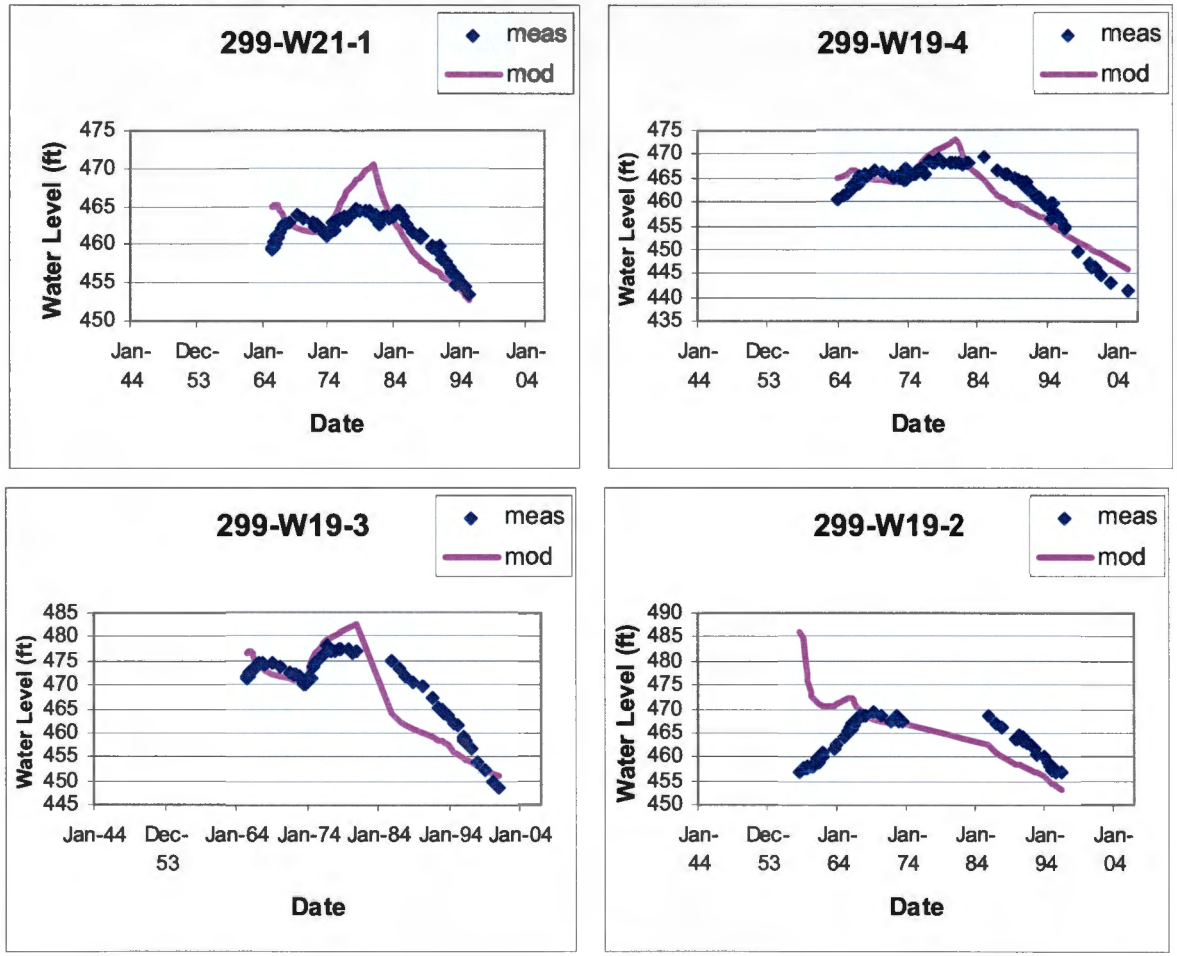


Figure D-20f. Measured and Modeled Groundwater Elevations.



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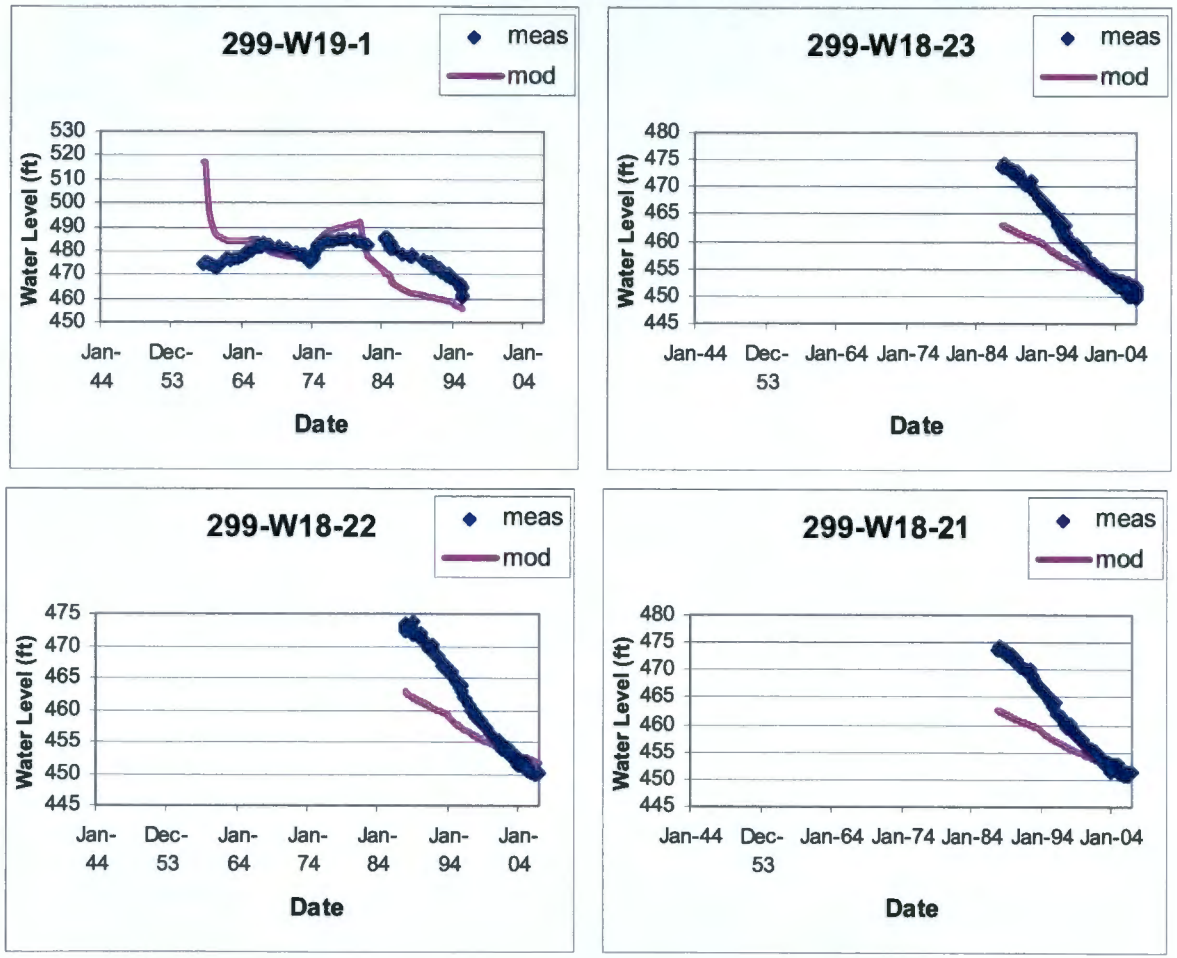


Figure D-20h. Measured and Modeled Groundwater Elevations.

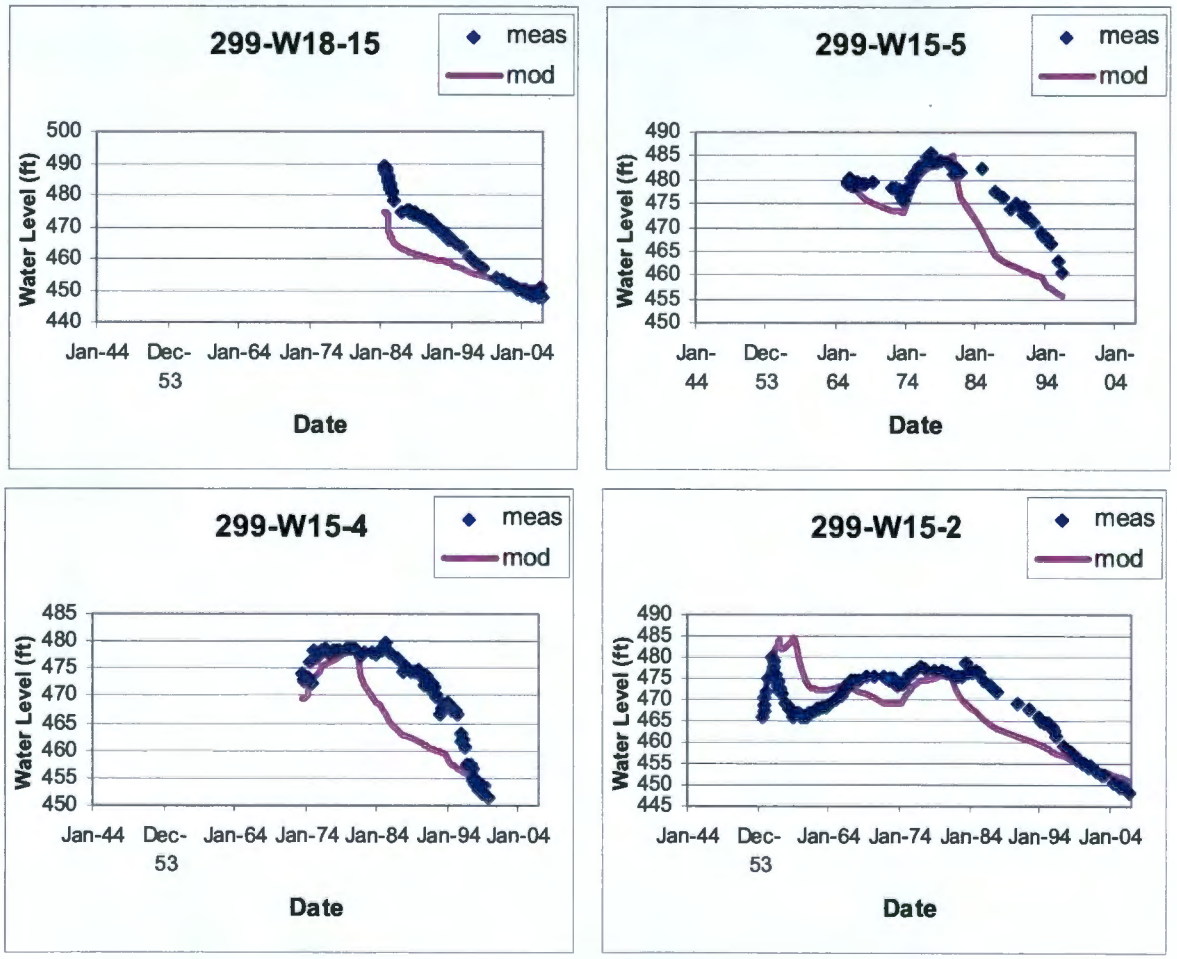


Figure D-20i. Measured and Modeled Groundwater Elevations.

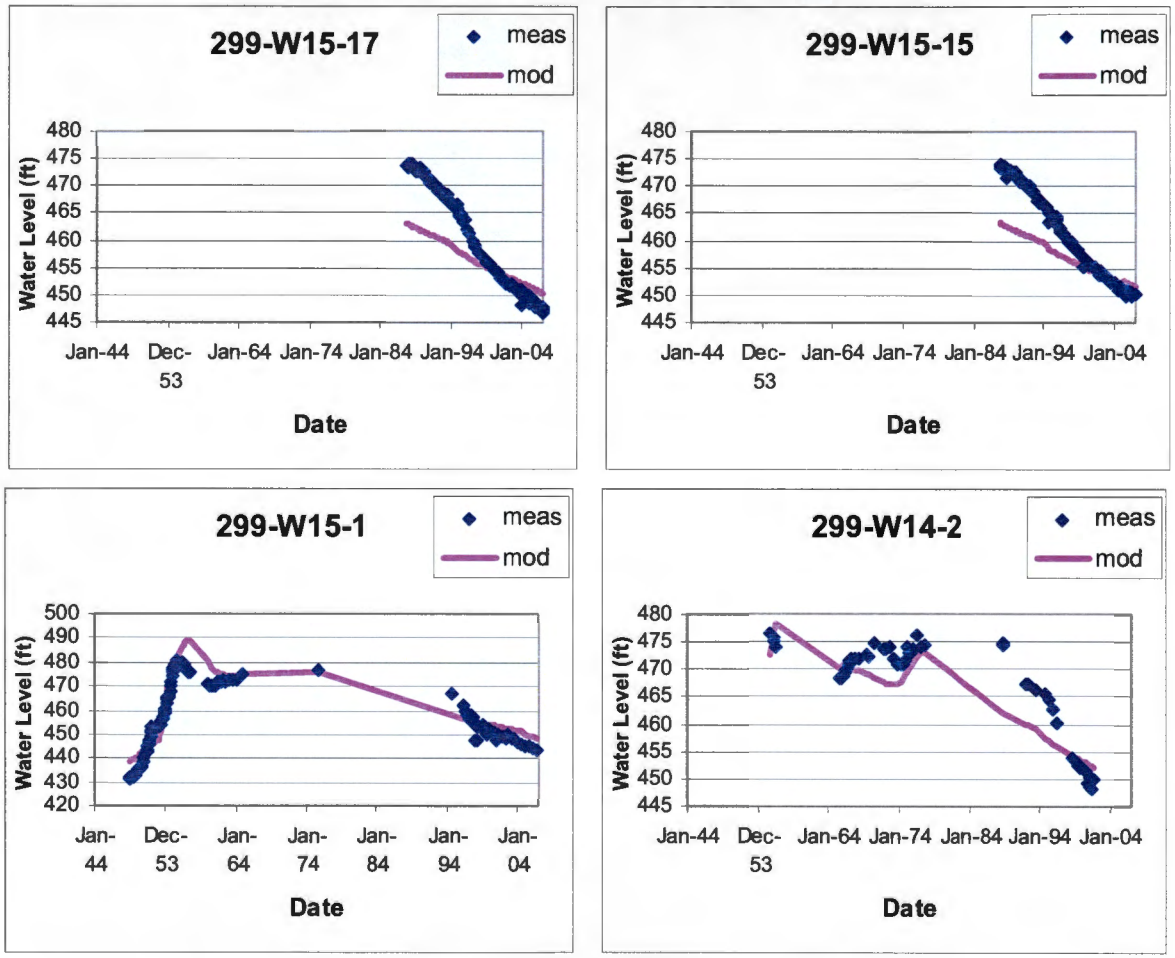


Figure D-20j. Measured and Modeled Groundwater Elevations.

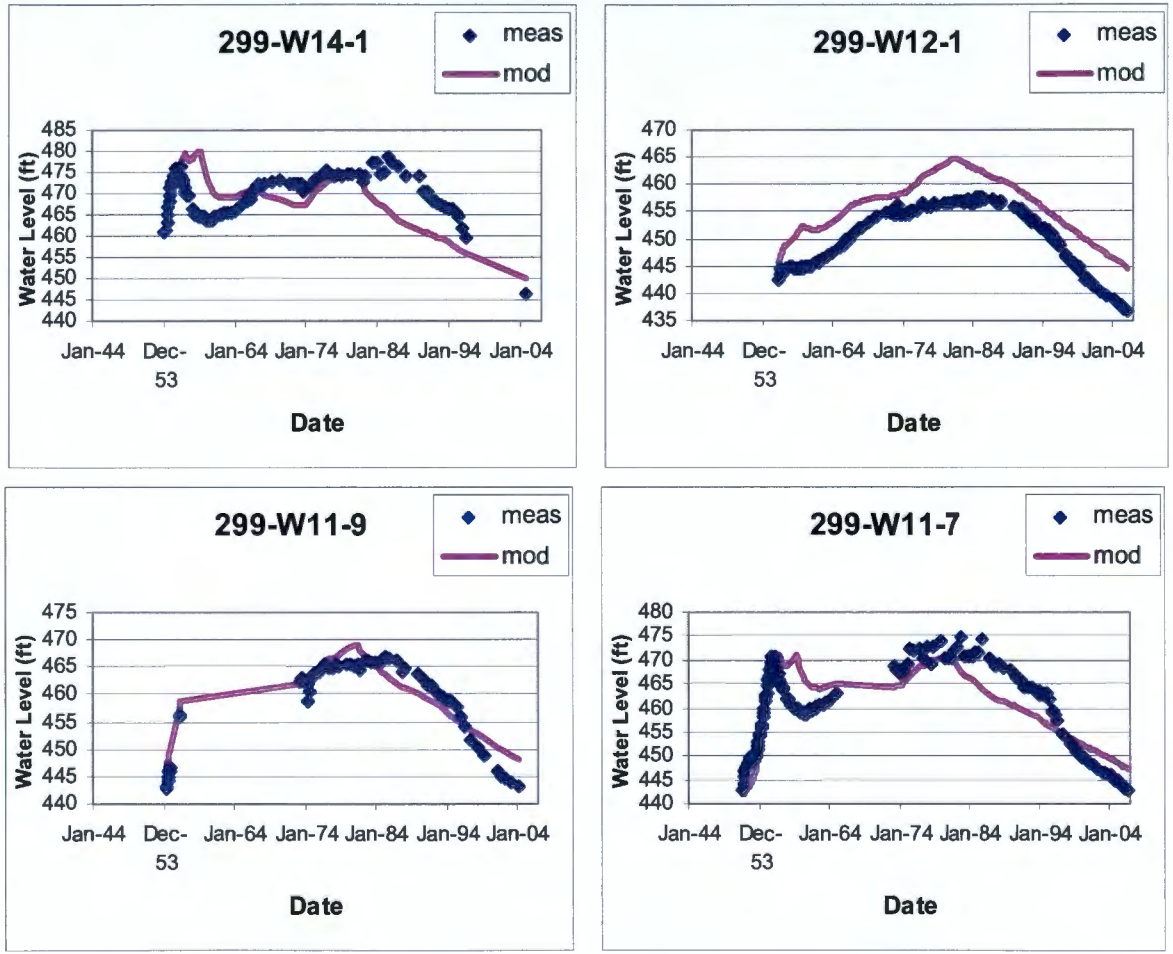


Figure D-20k. Measured and Modeled Groundwater Elevations.

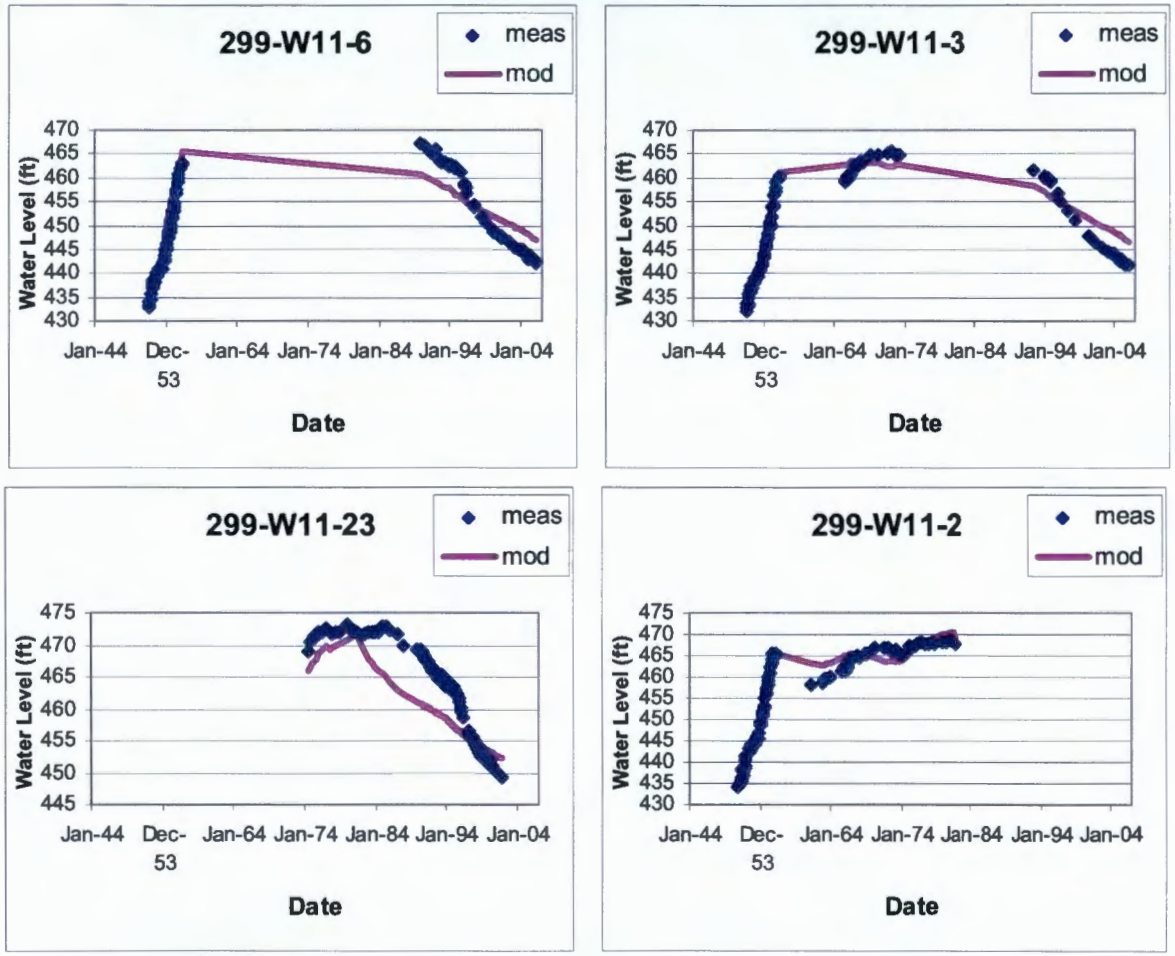


Figure D-20l. Measured and Modeled Groundwater Elevations.

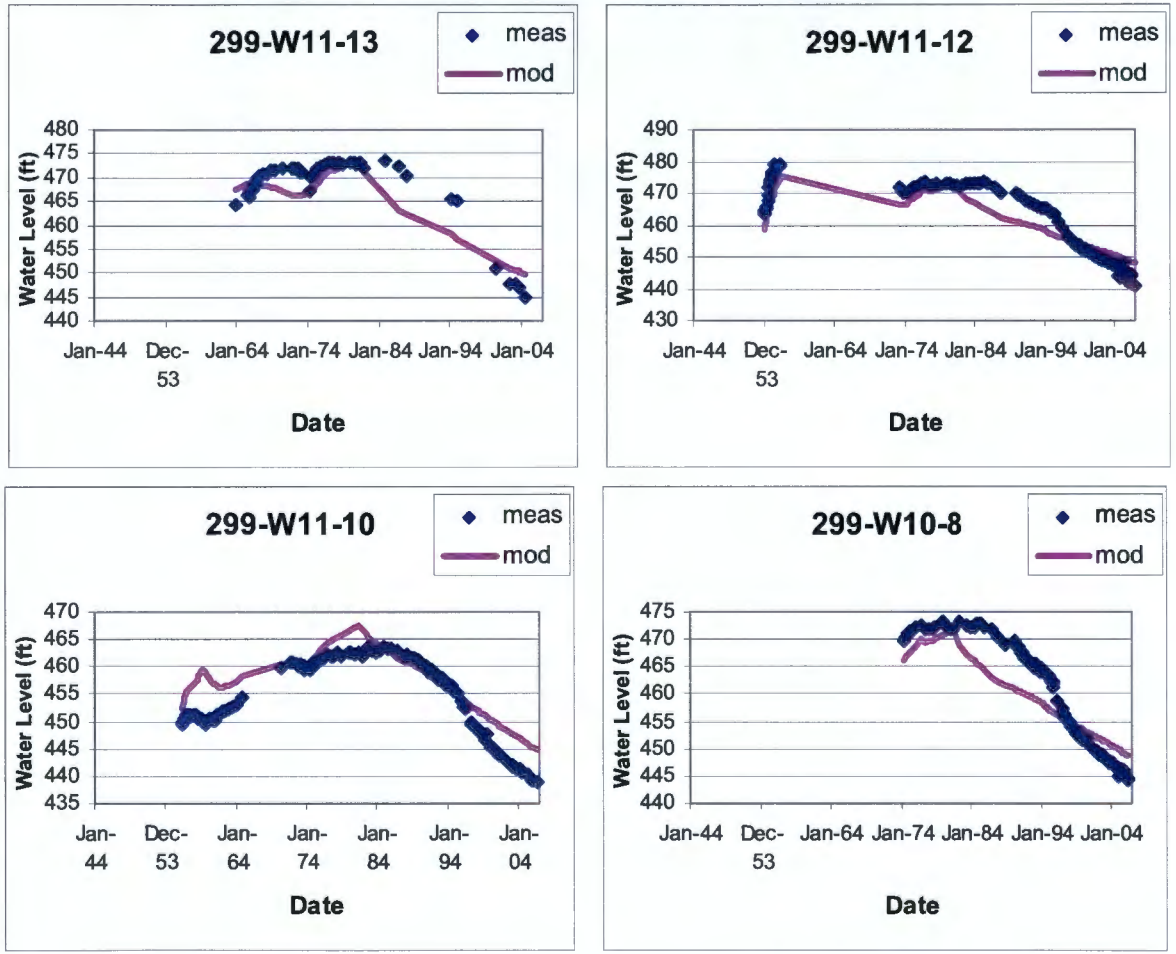


Figure D-20m. Measured and Modeled Groundwater Elevations.

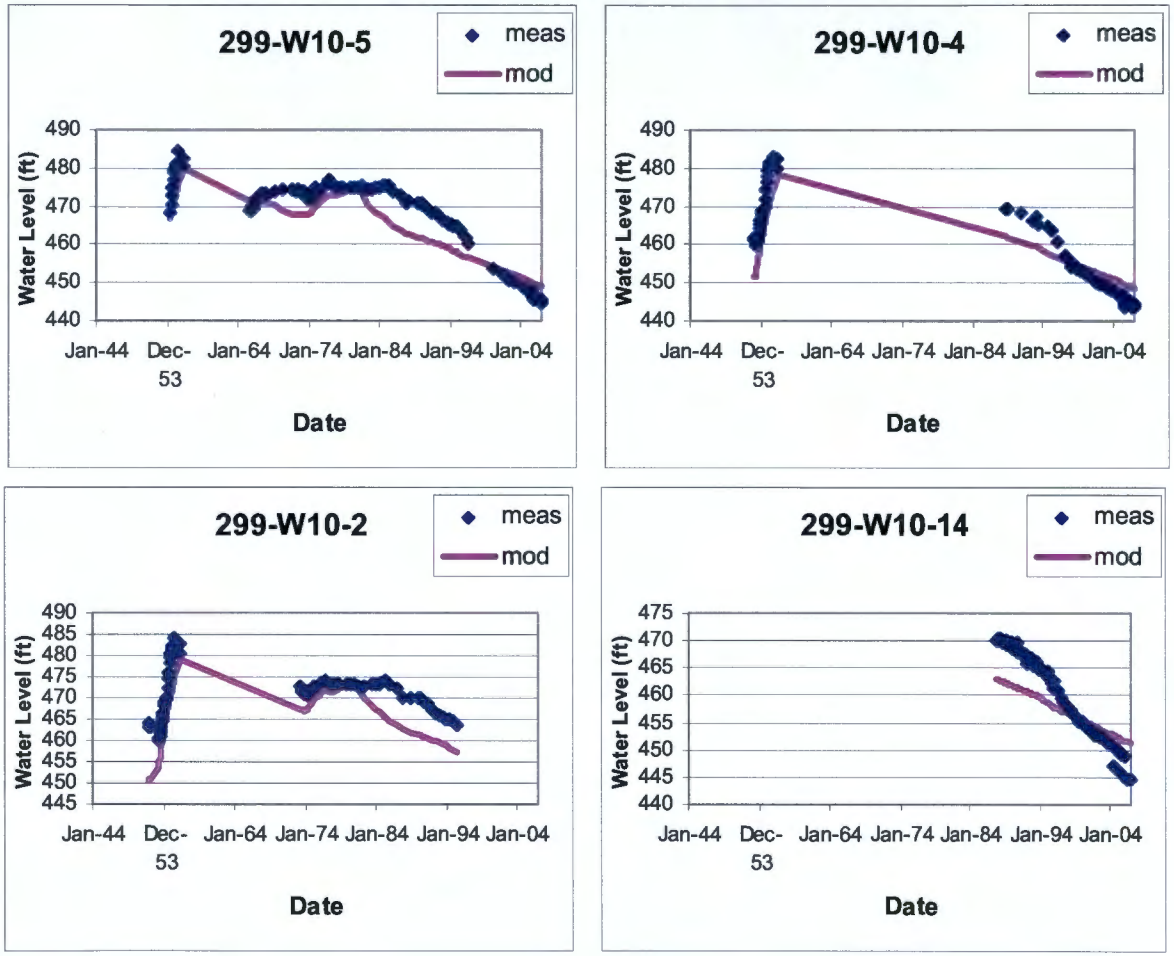


Figure D-20n. Measured and Modeled Groundwater Elevations.

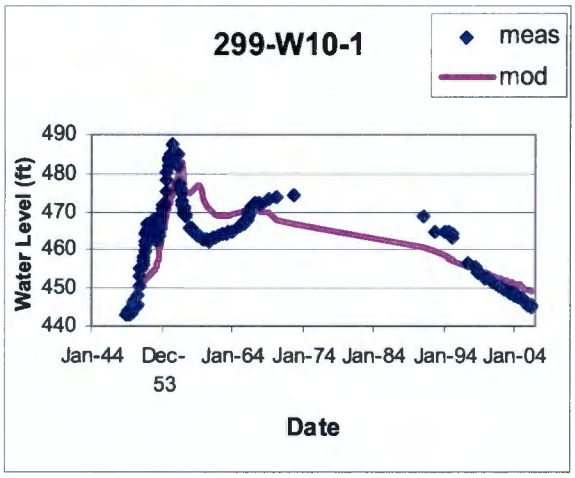


Figure D-21. Calculated Hydraulic Heads in 1945.

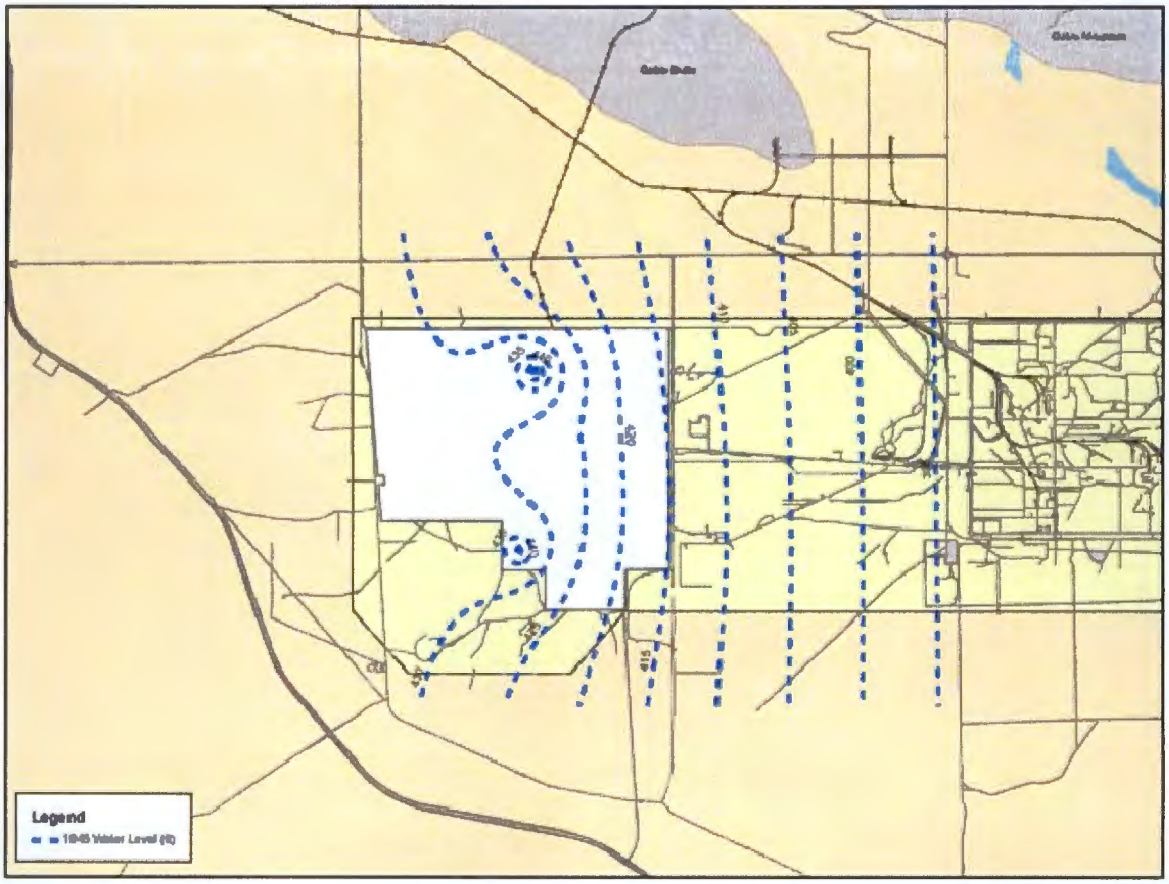


Figure D-22. Calculated Hydraulic Heads in 1950.

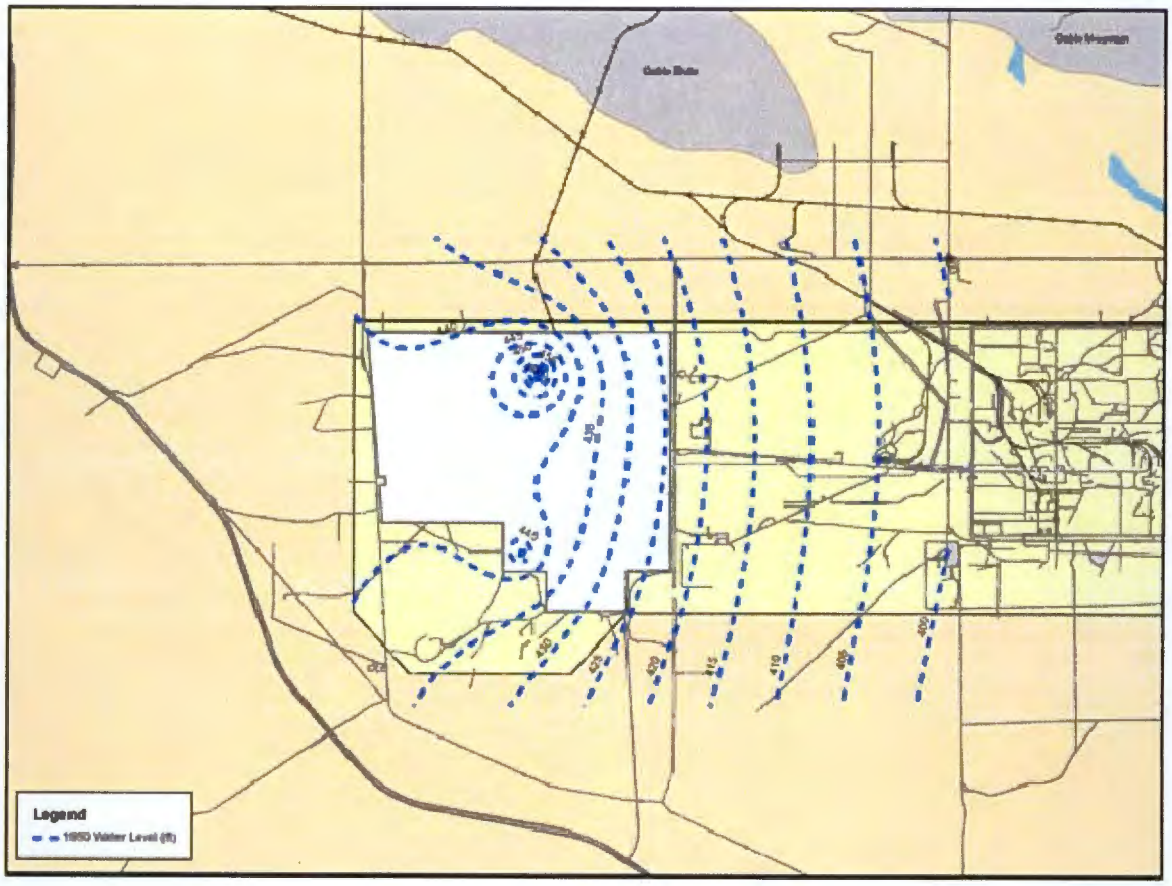


Figure D-23. Calculated Hydraulic Heads in 1955.

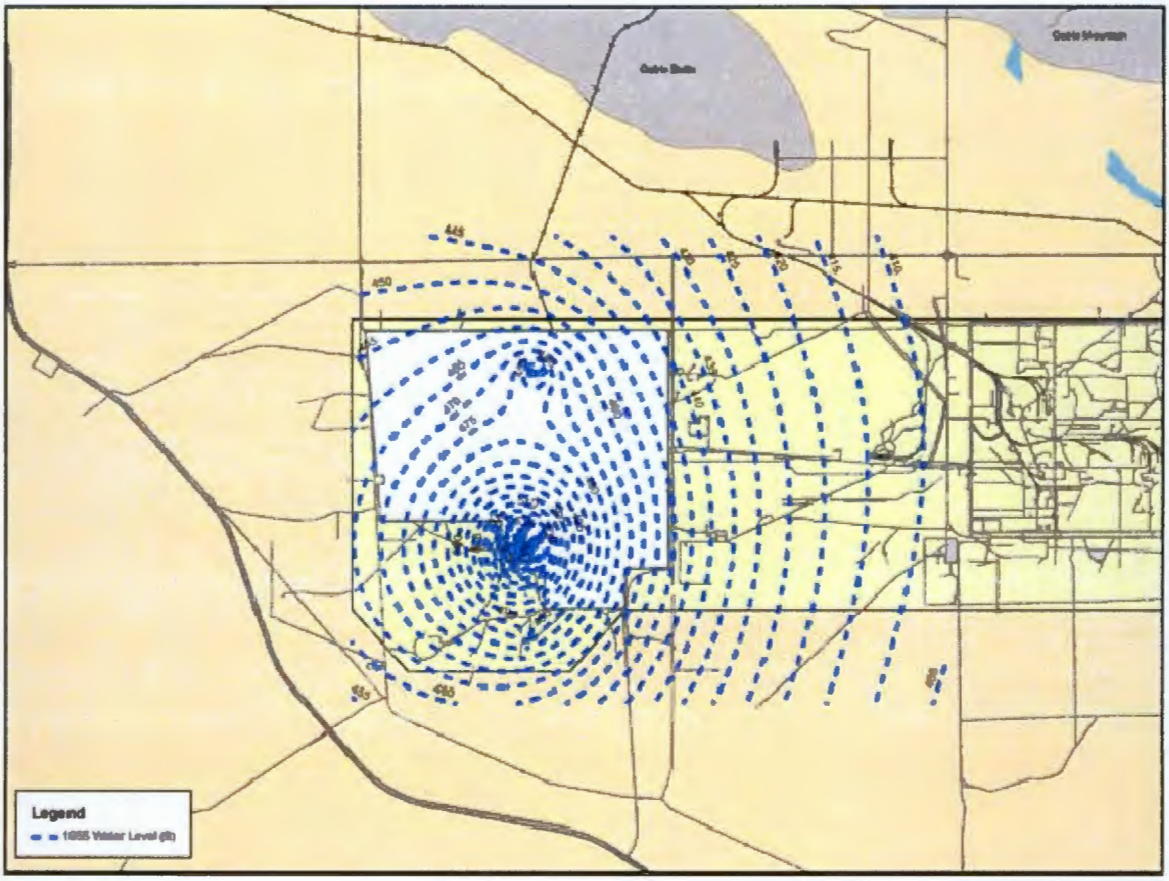


Figure D-24. Calculated Hydraulic Heads in 1960.

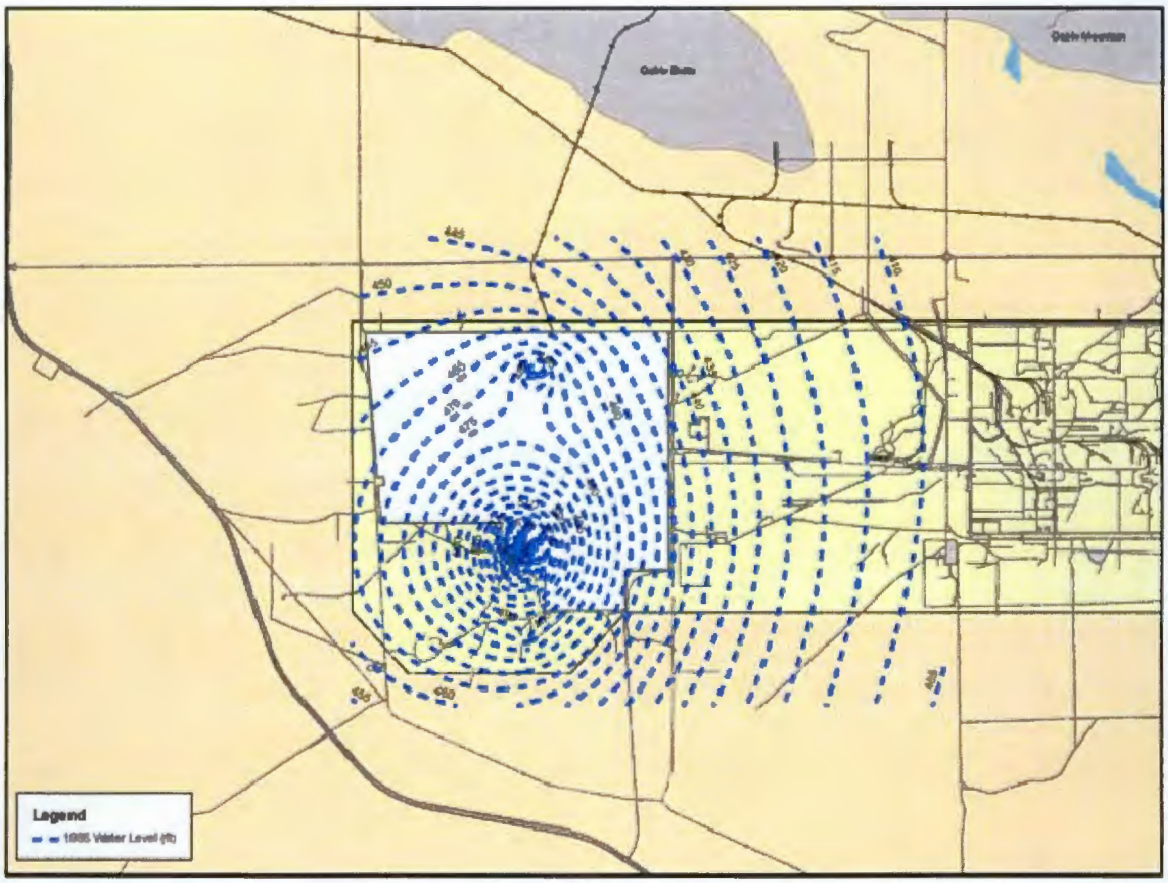


Figure D-25. Calculated Hydraulic Heads in 1965.

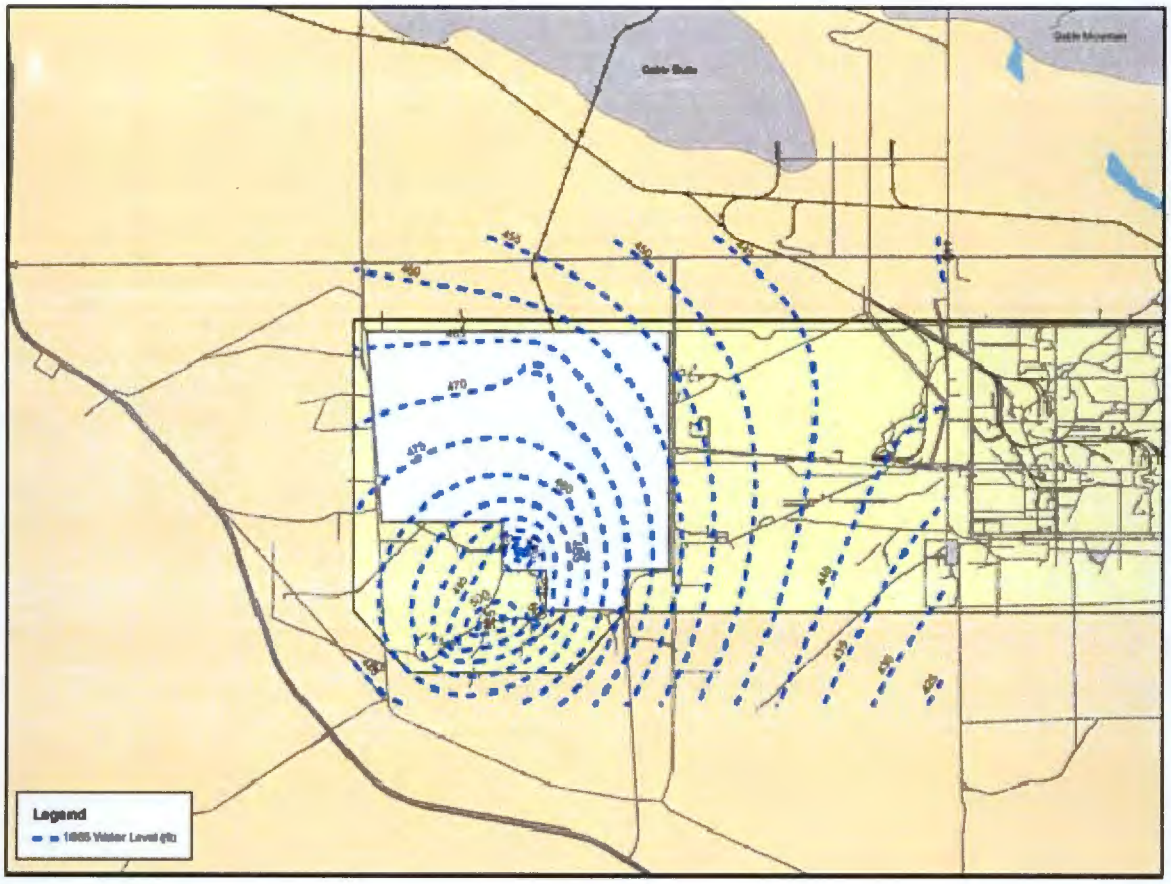


Figure D-26. Calculated Hydraulic Heads in 1970.

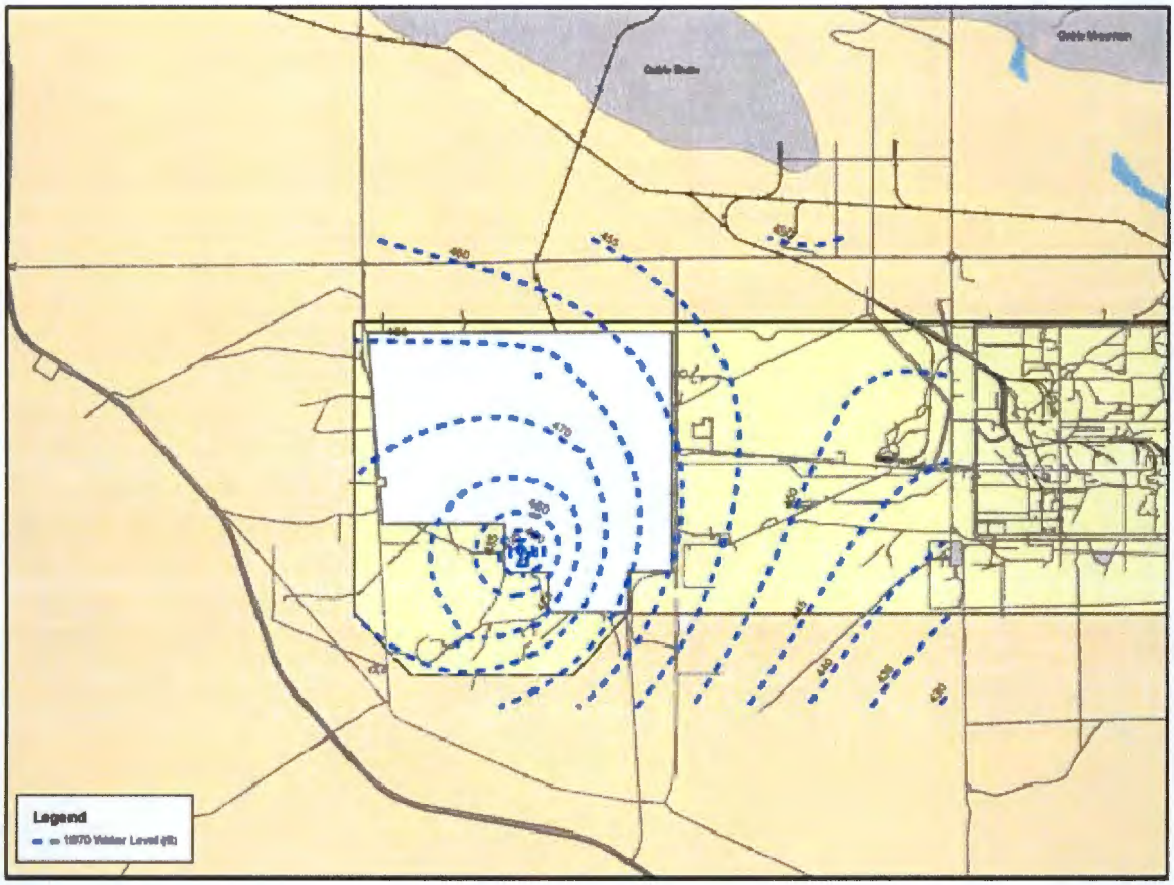


Figure D-27. Calculated Hydraulic Heads in 1975.

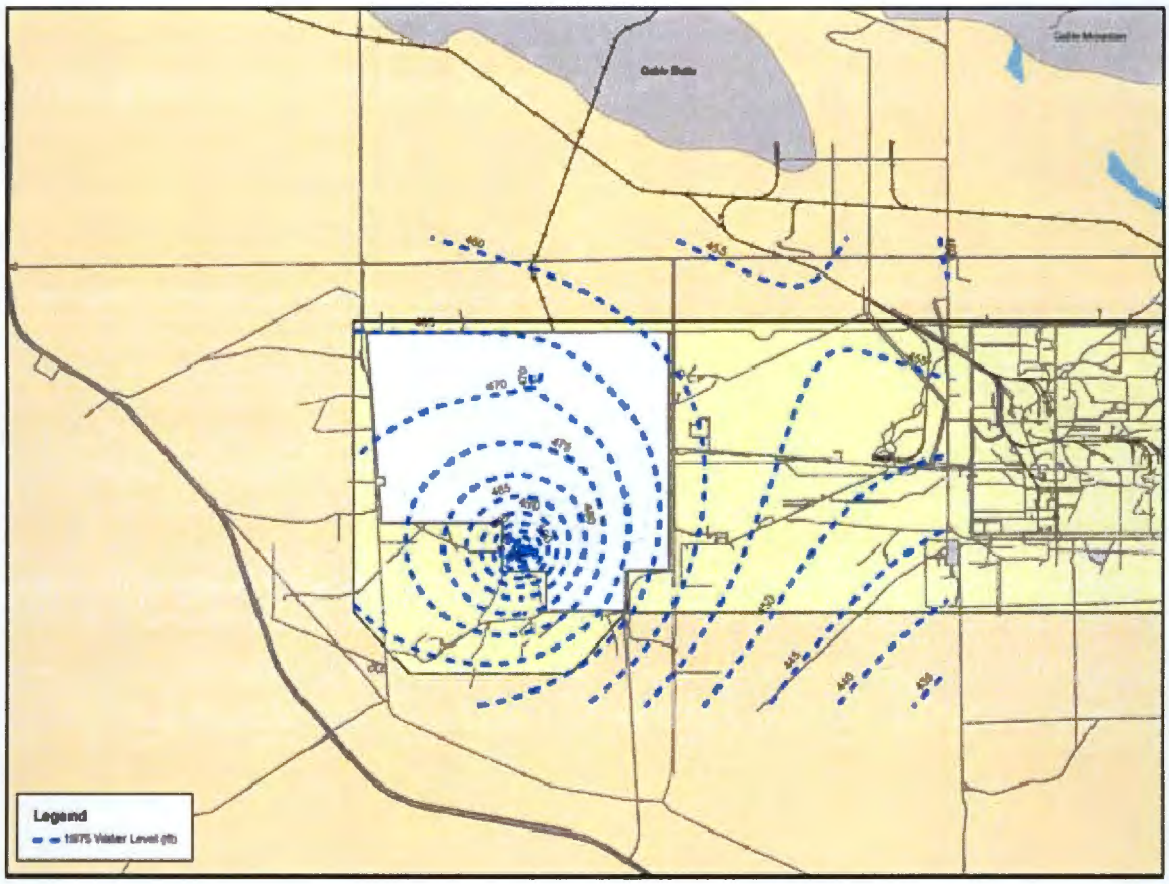


Figure D-28. Calculated Hydraulic Heads in 1980.

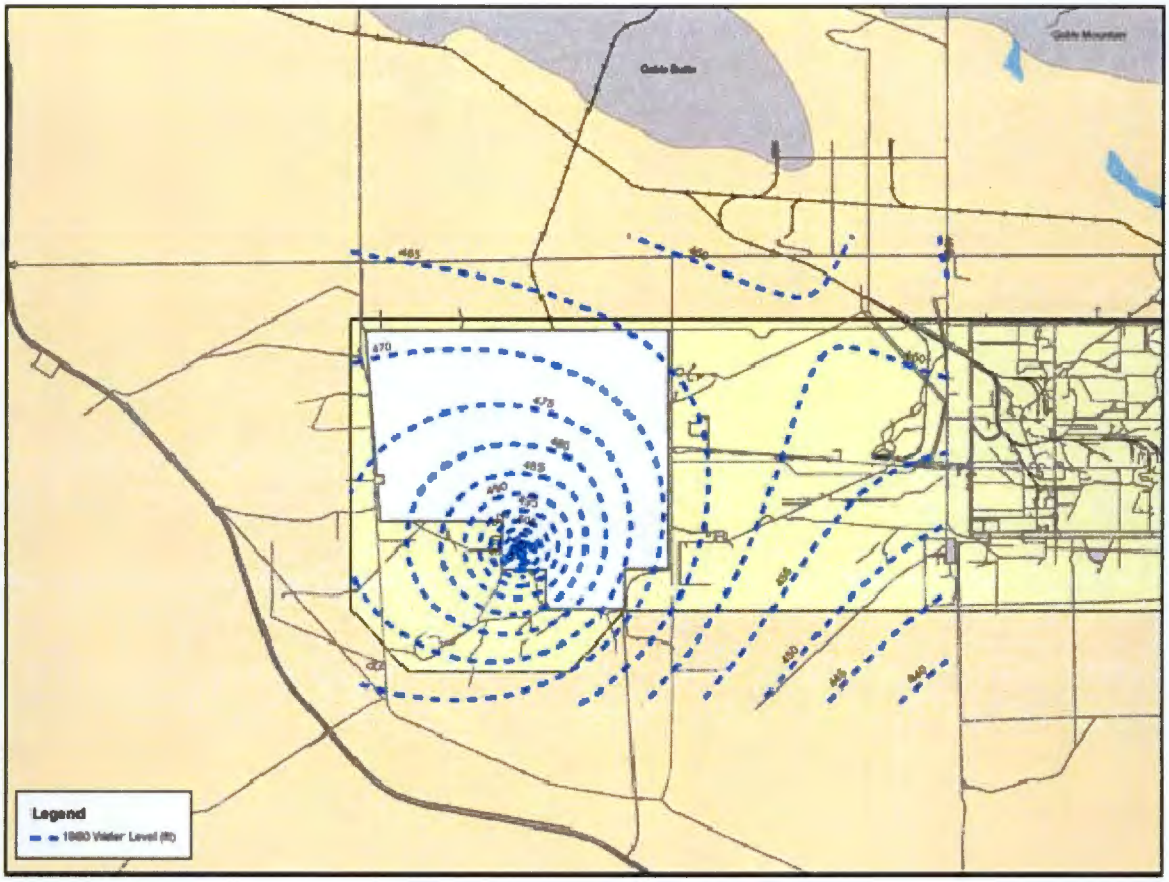


Figure D-29. Calculated Hydraulic Heads in 1985.

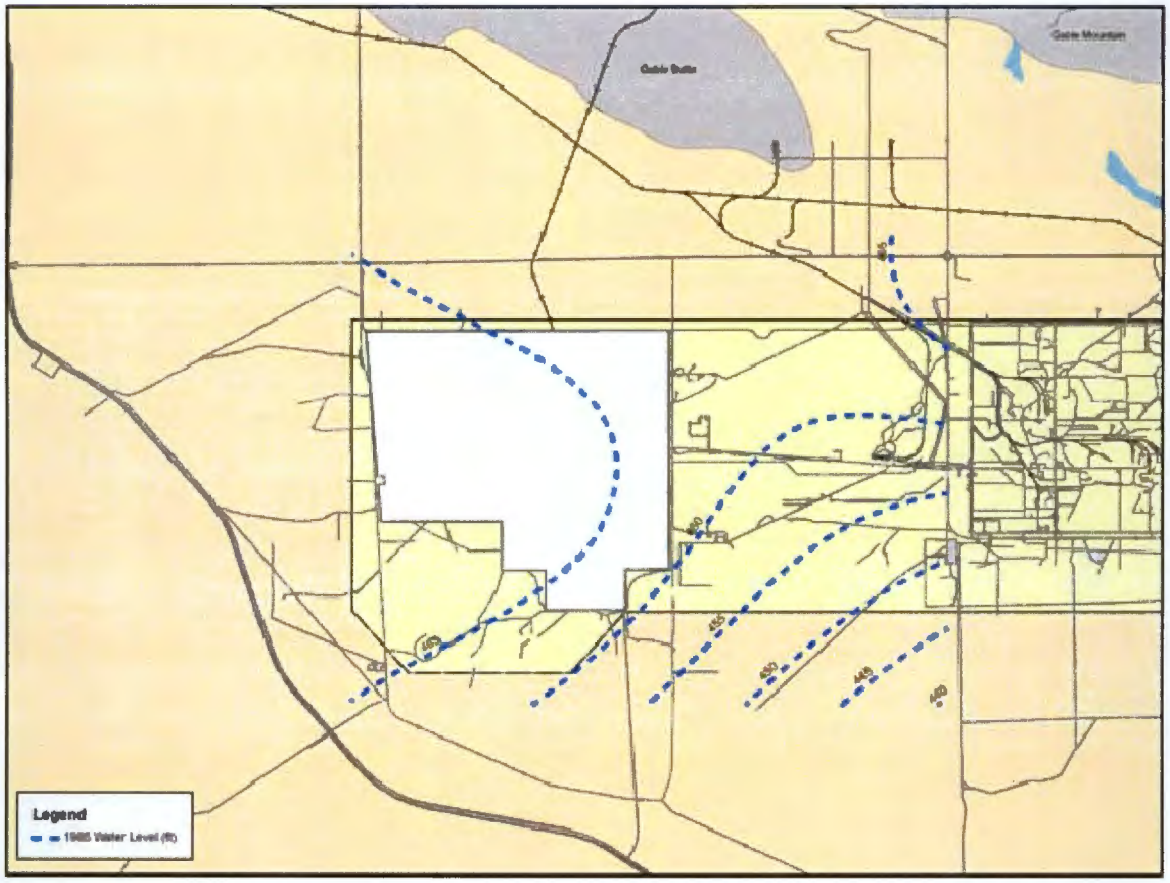


Figure D-30. Calculated Hydraulic Heads in 1990.

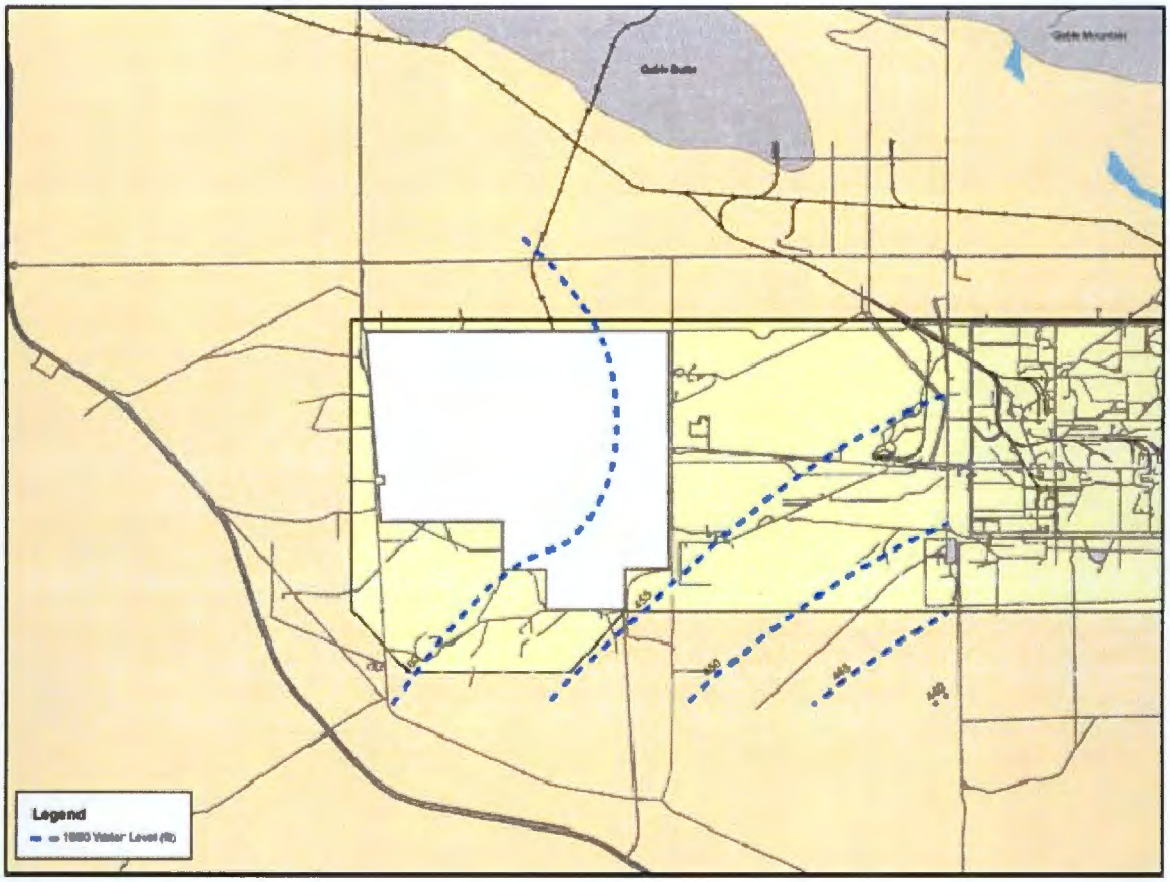


Figure D-31. Calculated Hydraulic Heads in 1995.

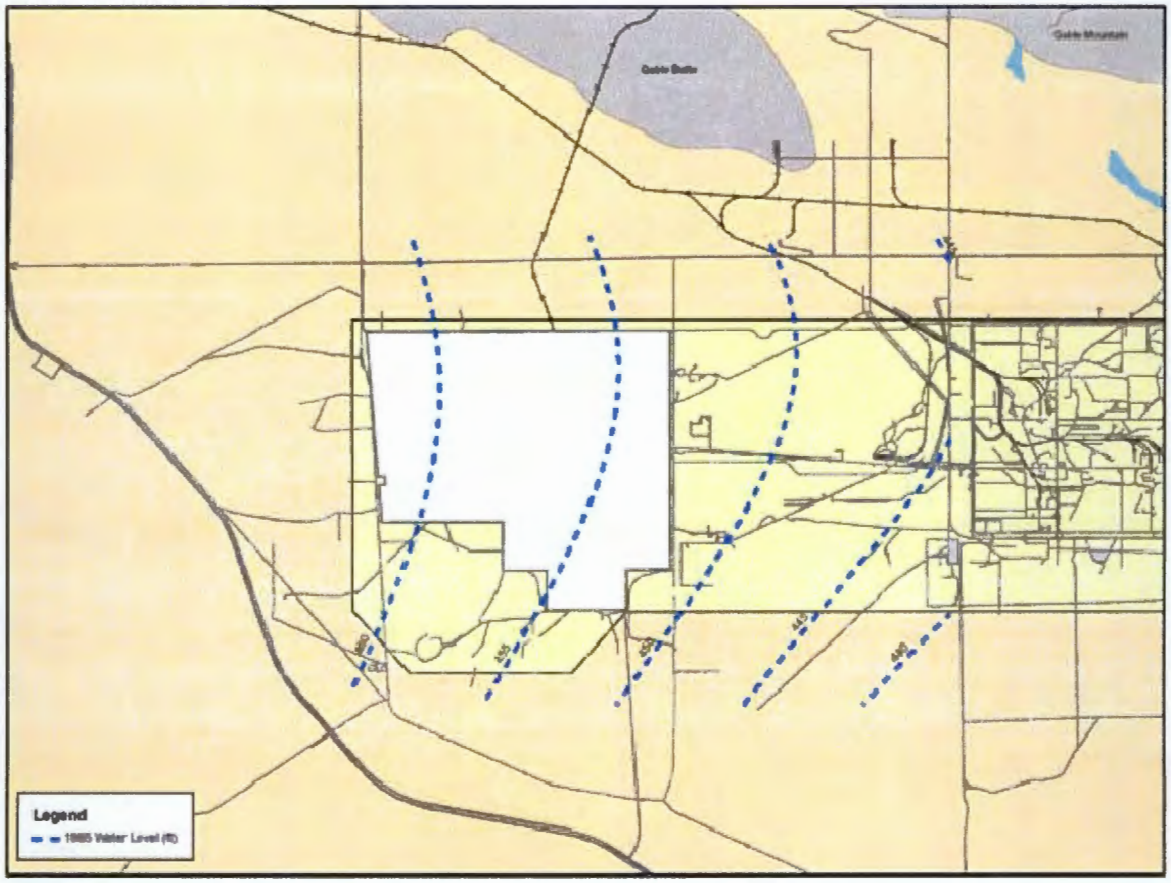


Figure D-32 .Calculated Hydraulic Heads in 2000.

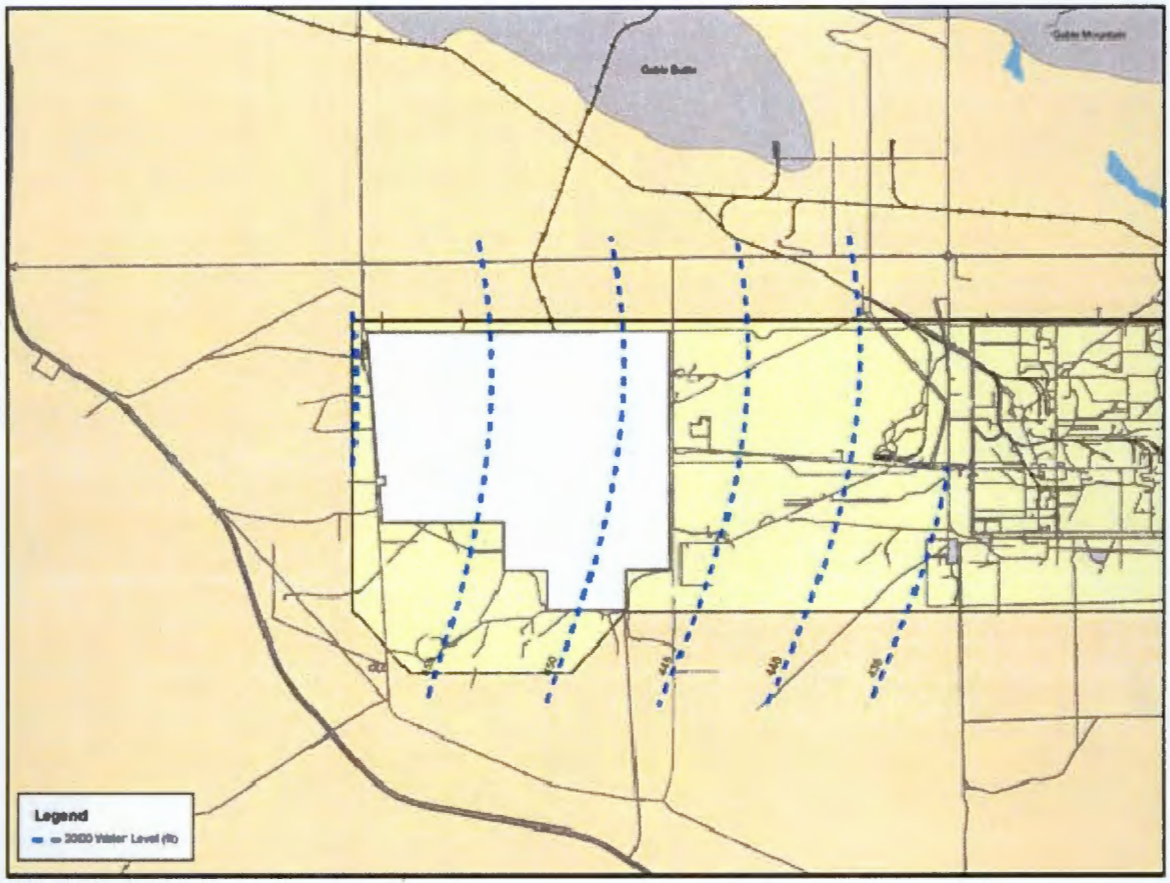


Figure D-33. Calculated Hydraulic Heads in 2005.

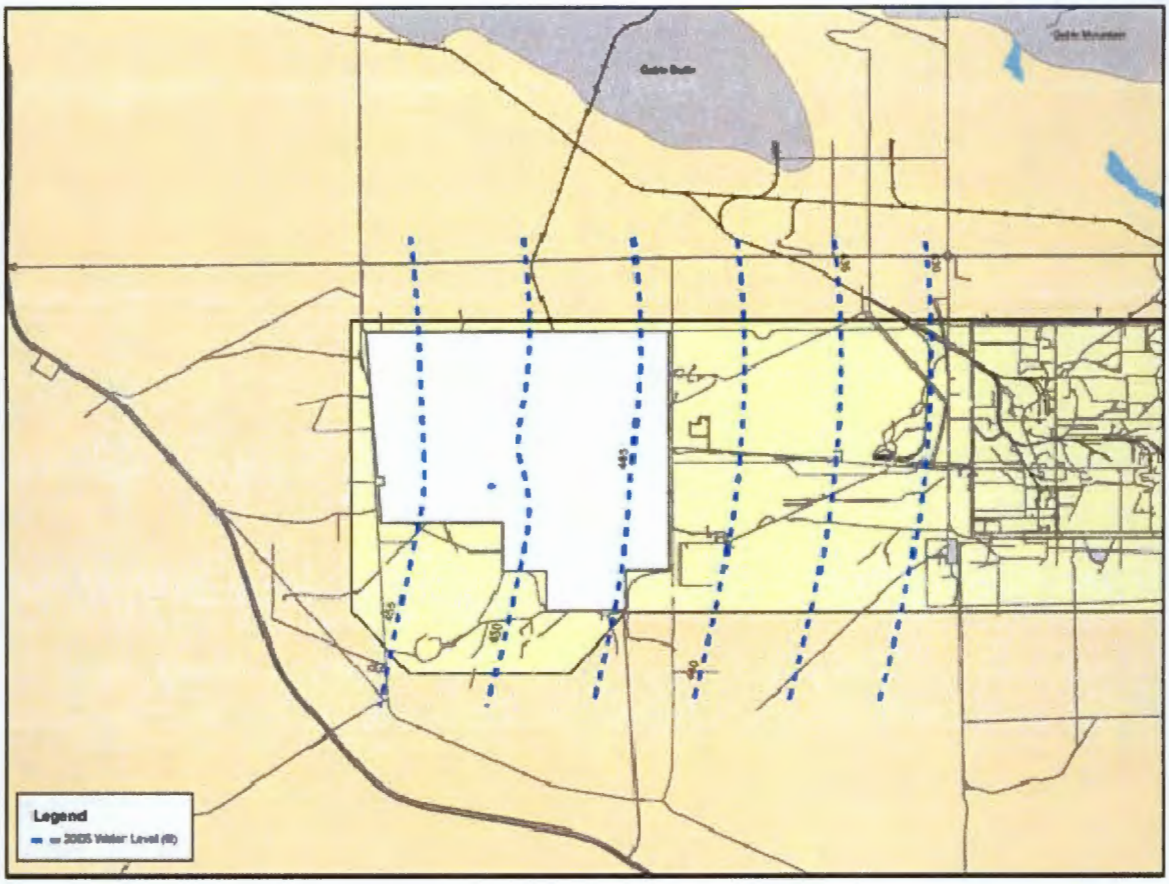
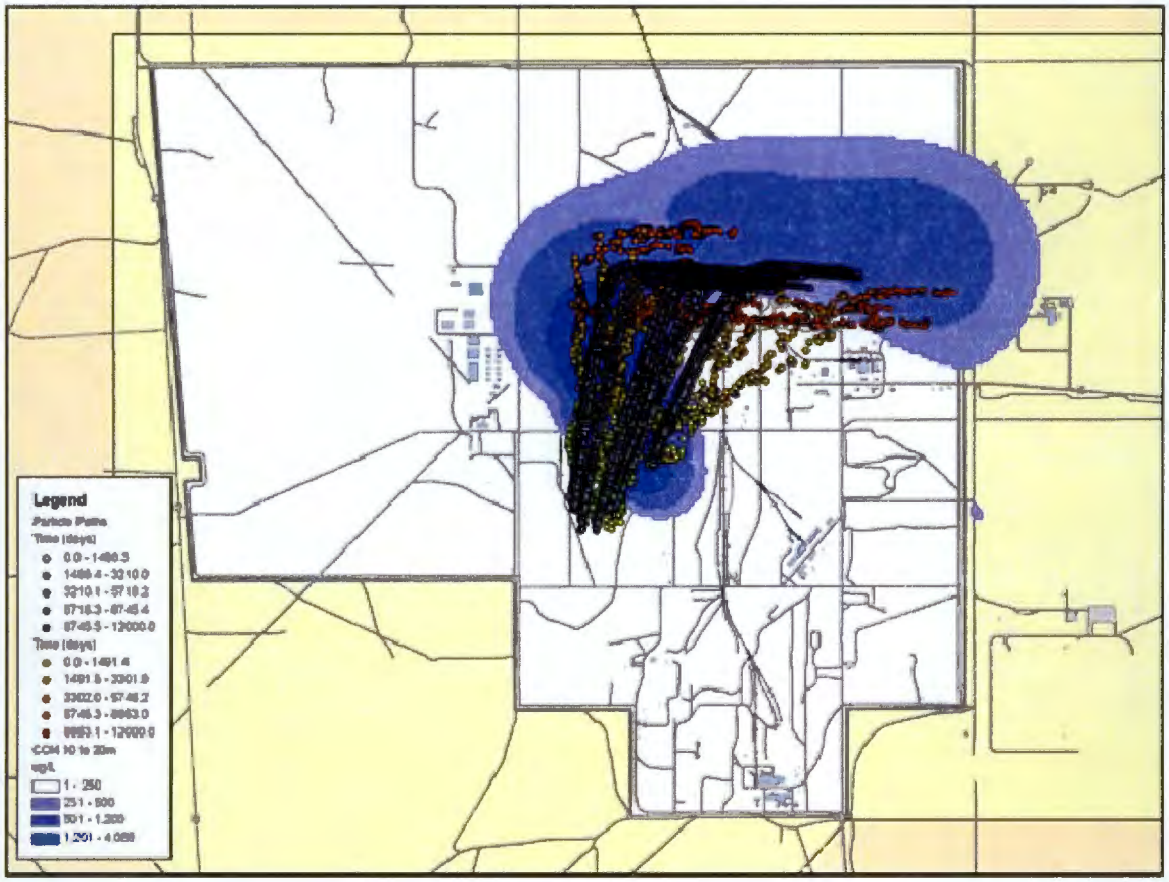


Figure D-34. Historic Transport of Carbon Tetrachloride.



NOTE: Blue toned particles represent transport with no dispersion, red toned particles represent transport with dispersion.

Figure D-35. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2003.

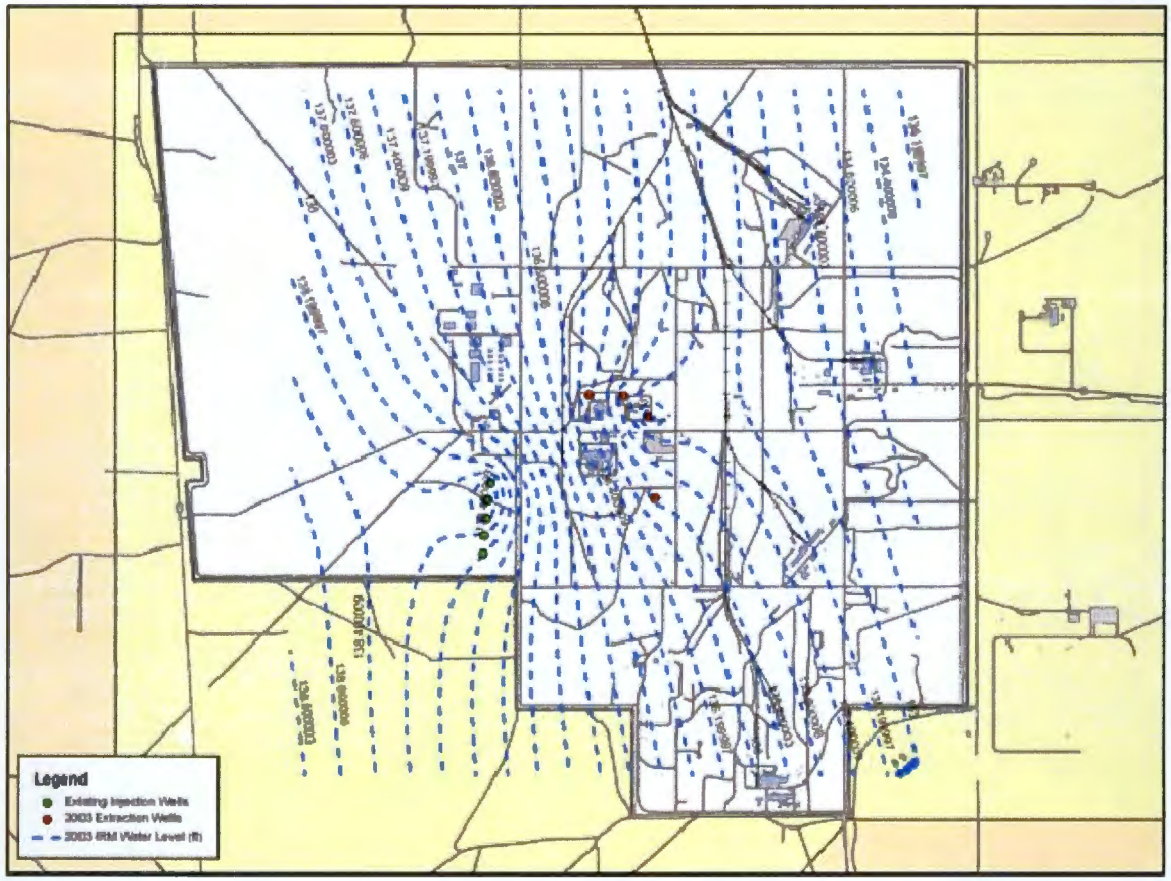


Figure D-36. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2004.

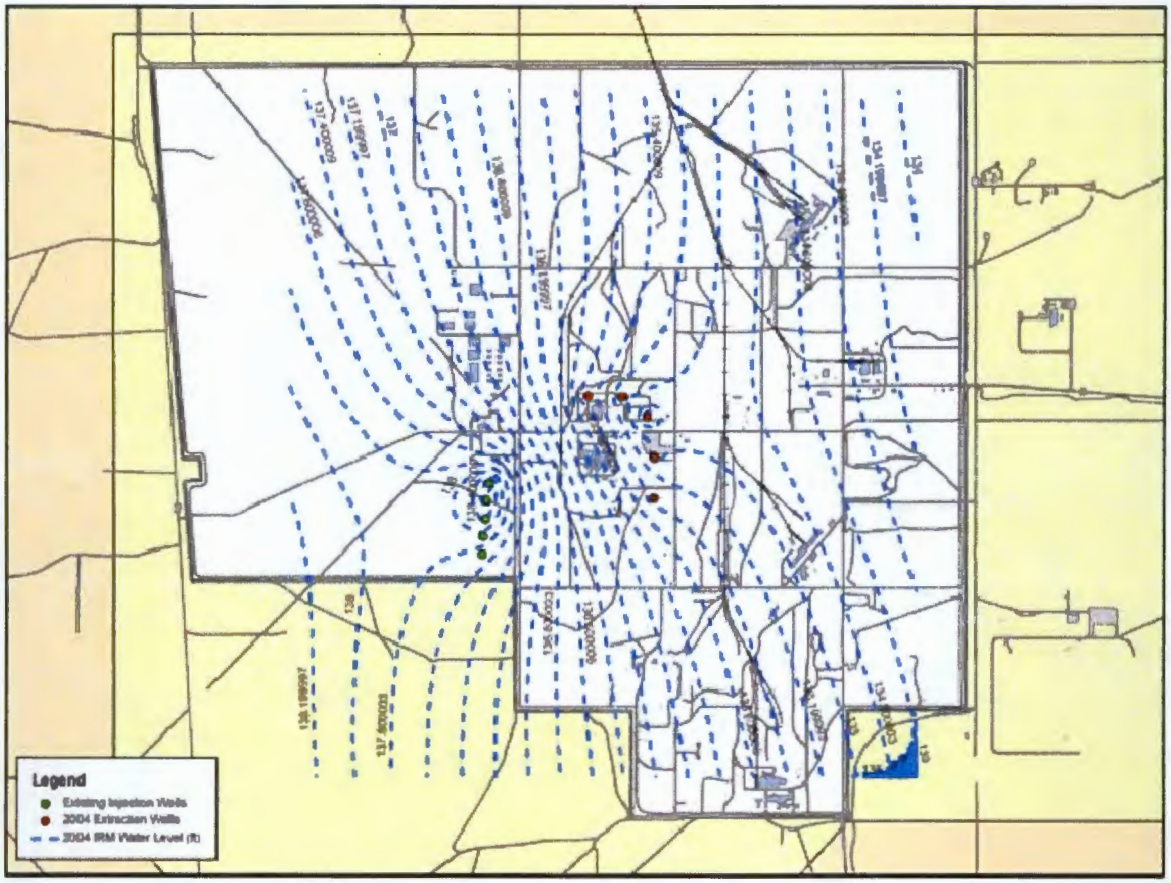


Figure D-37. Mapped Hydraulic Heads Near the 200-ZP-1 Interim Remedial Measure in 2005.

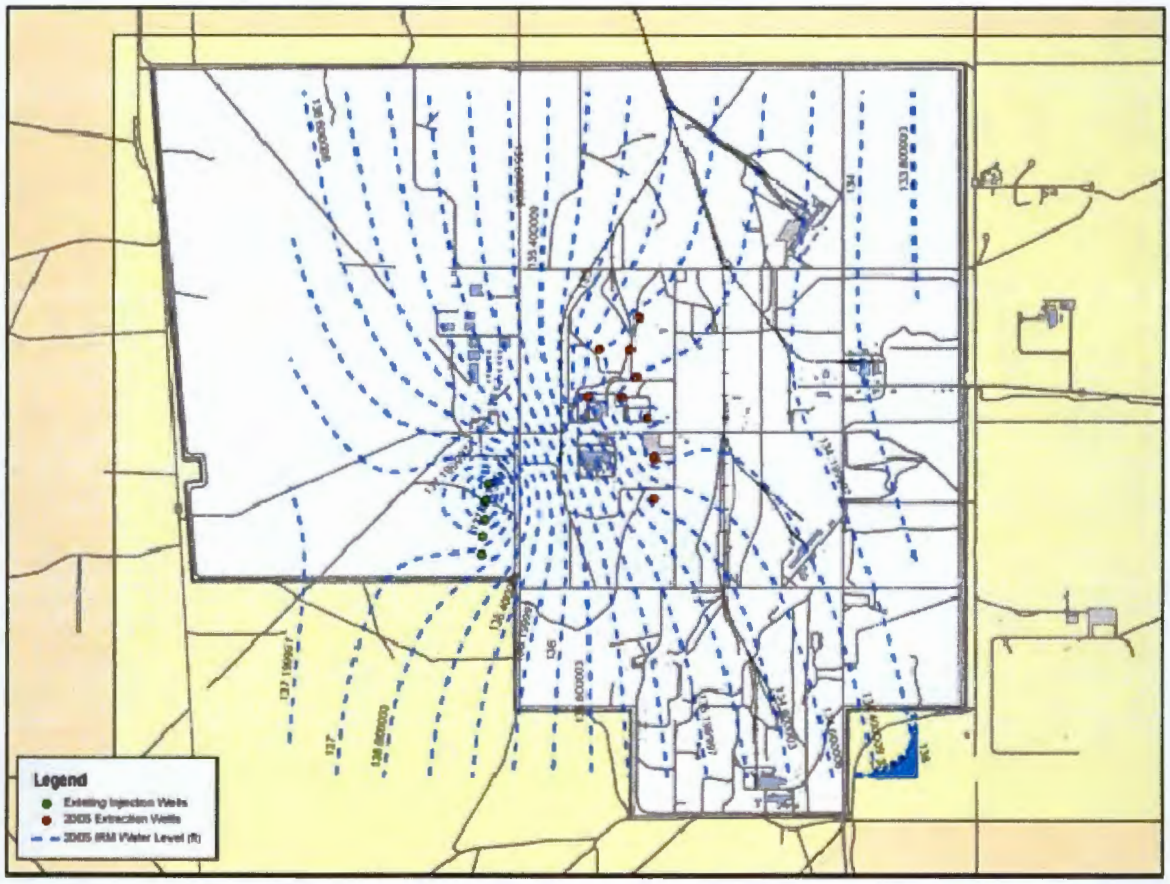


Figure D-38. Approximate Extent of Hydraulic Capture of the 200-ZP-1 Interim Remedial Measure in 2003.

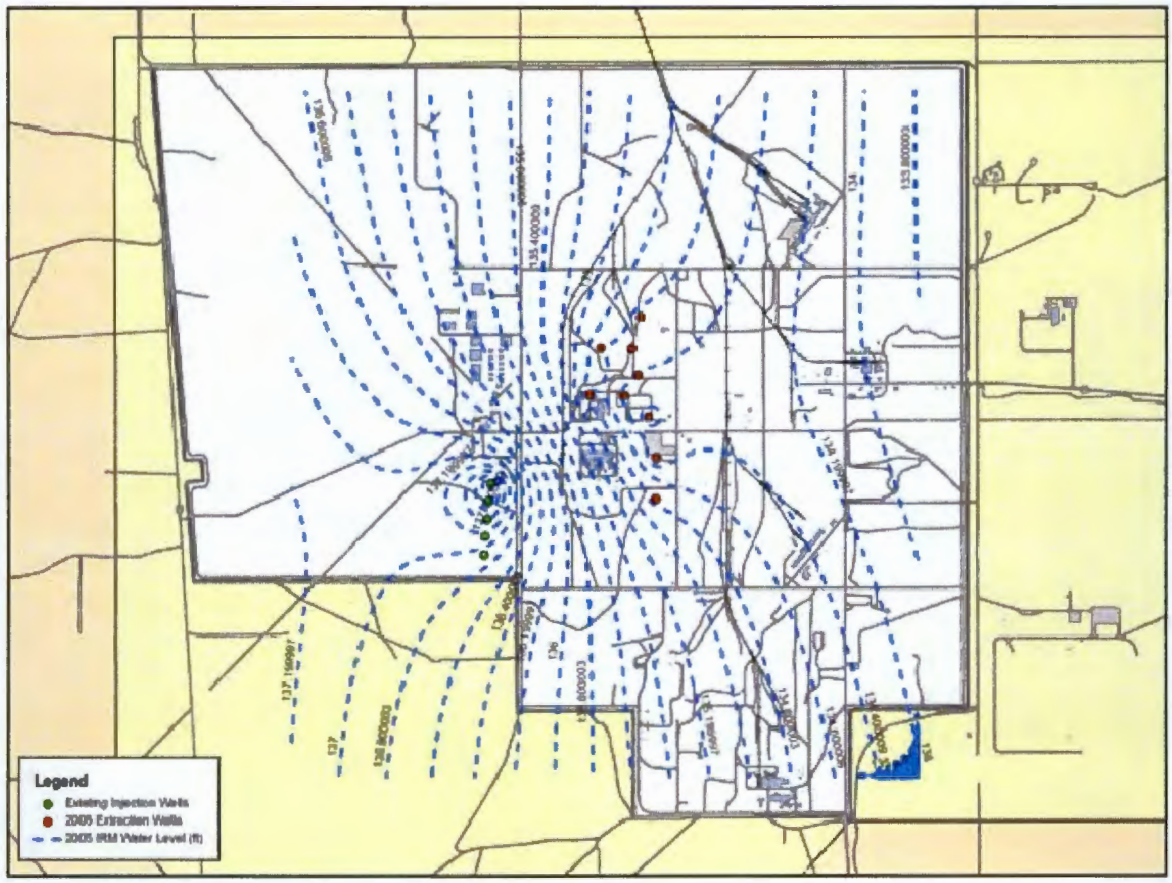


Figure D-39. Approximate Extent of Hydraulic Capture of the 200-ZP-1 Interim Remedial Measure in 2004.

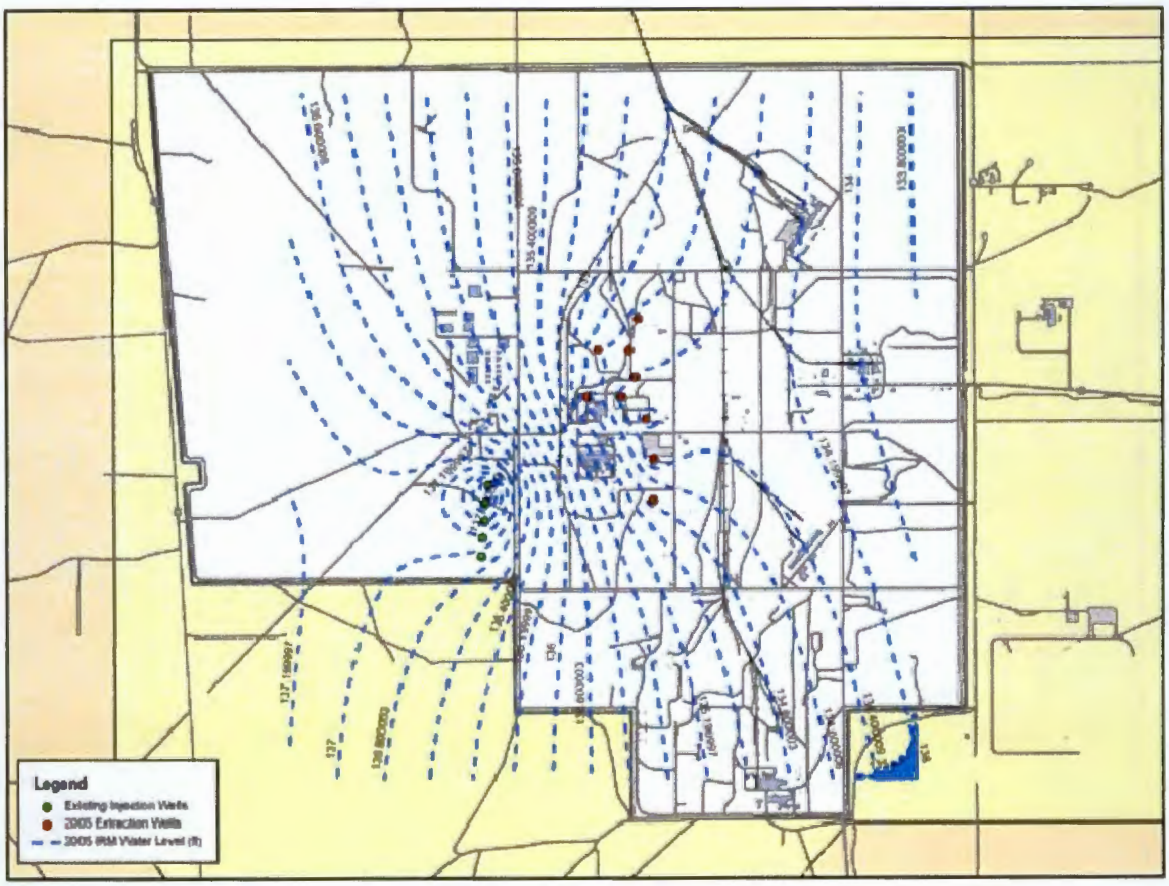


Figure D-40. Approximate Extent of Hydraulic Simulated Capture of the 200-ZP-1 Interim Remedial Measure in 2005.

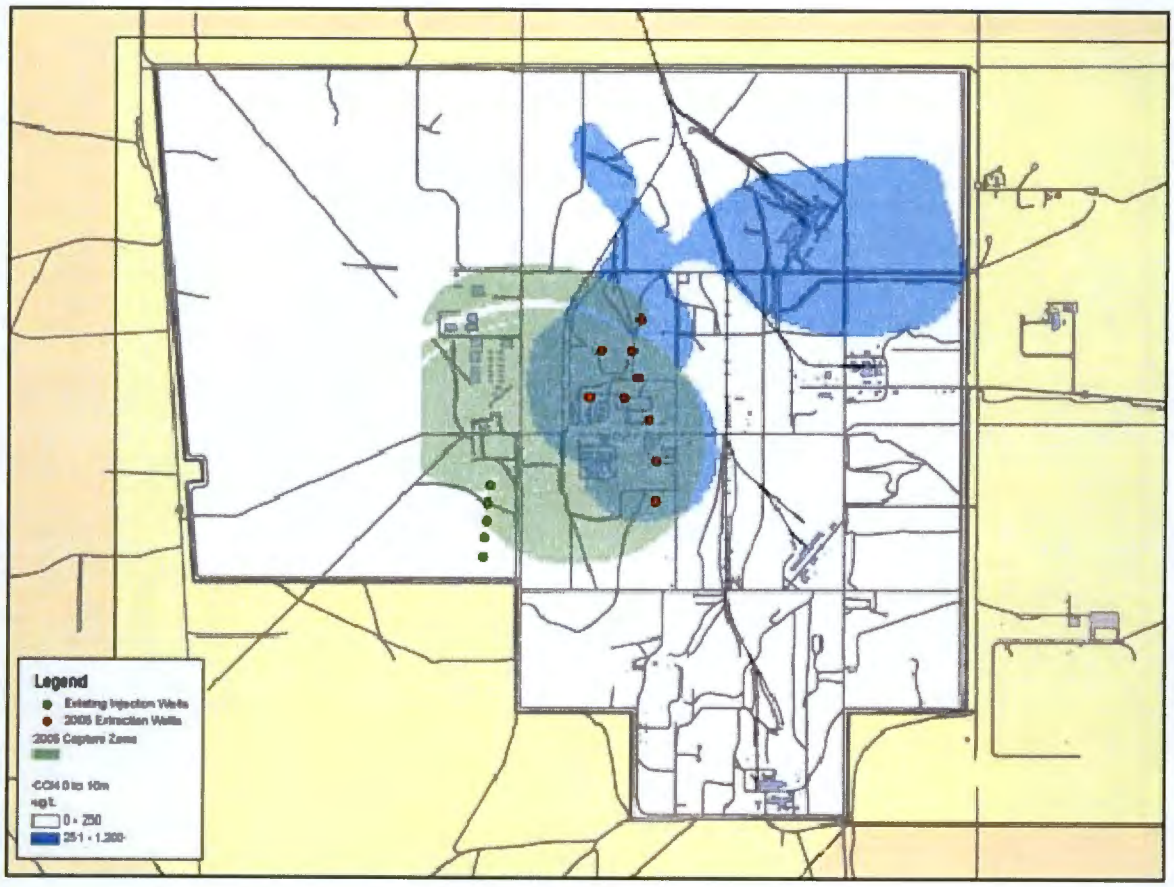


Figure D-41. Calculated Hydraulic Heads – 1 x 10^{-4} Capture.

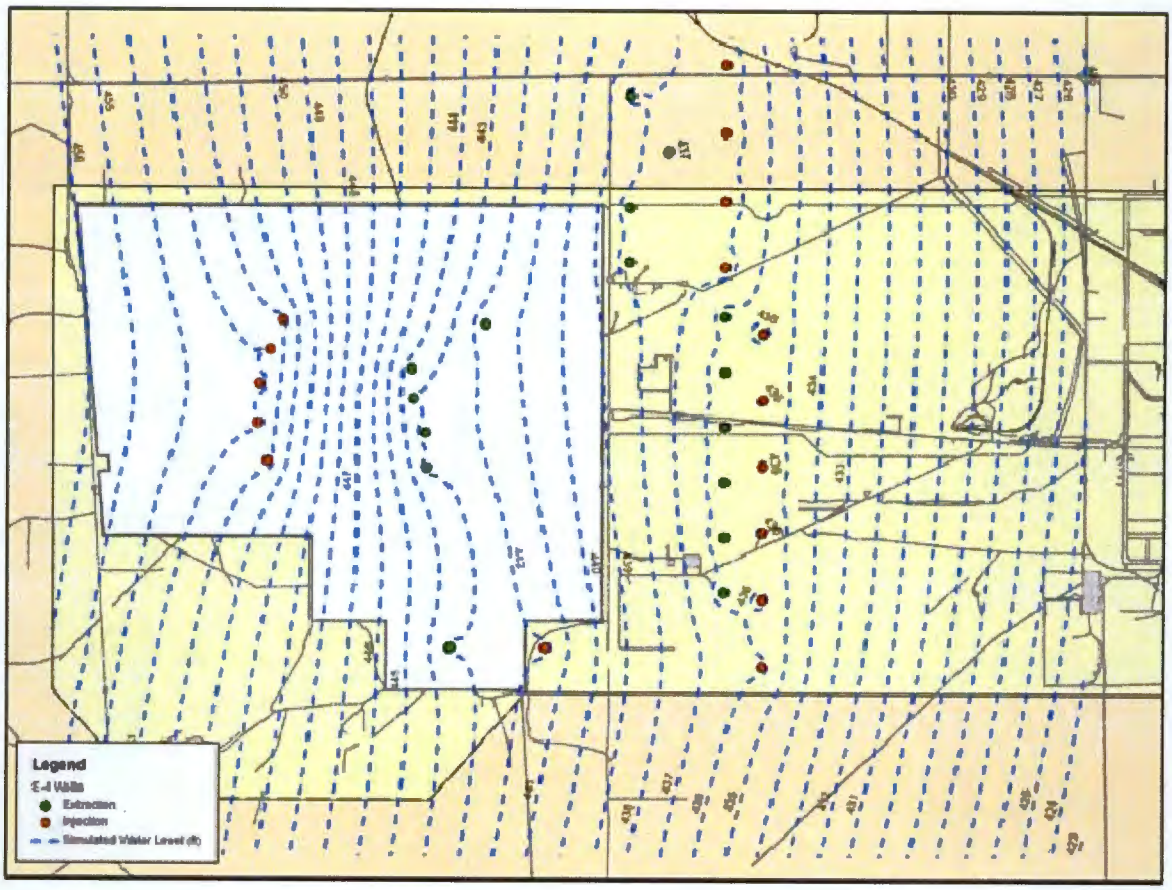


Figure D-42. Maximum Contaminant Level Capture – Calculated Hydraulic Heads.

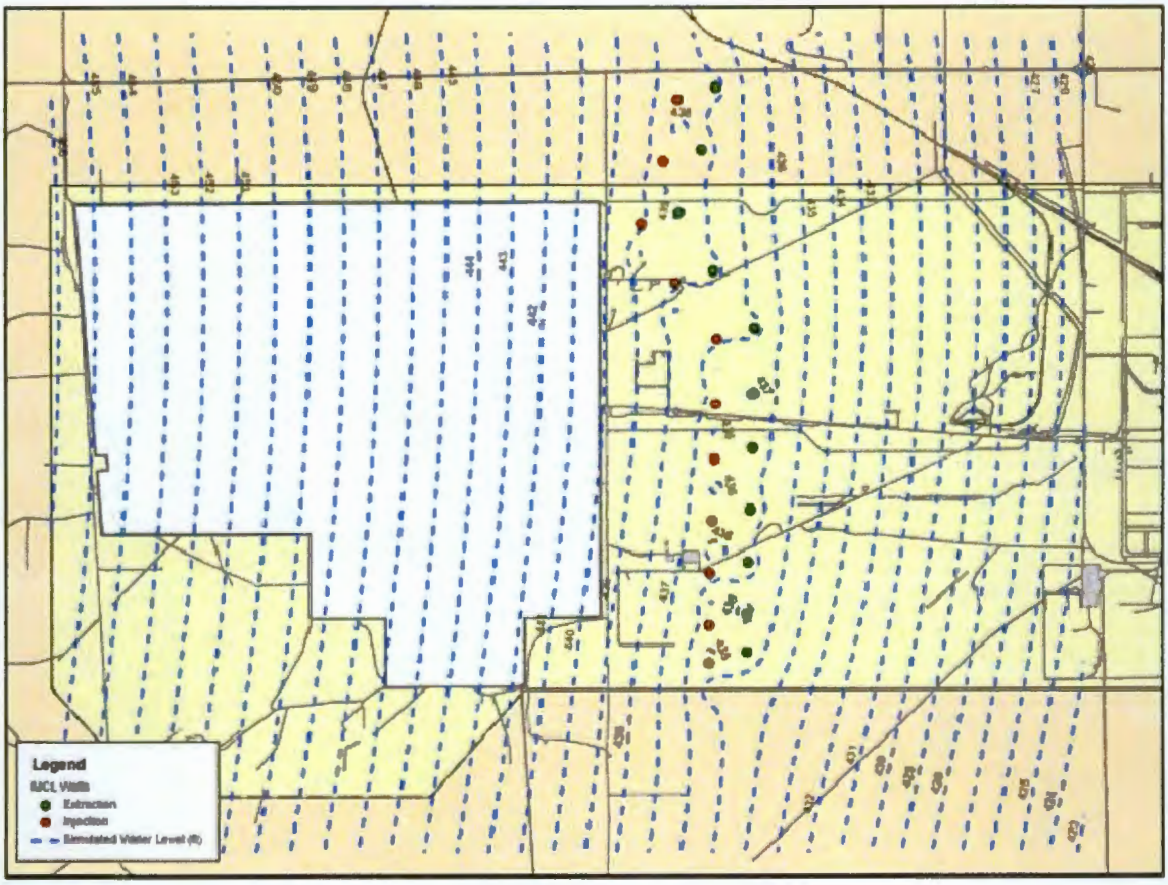


Figure D-43. Ten Times Maximum Contaminant Level Capture – Calculated Hydraulic Heads.

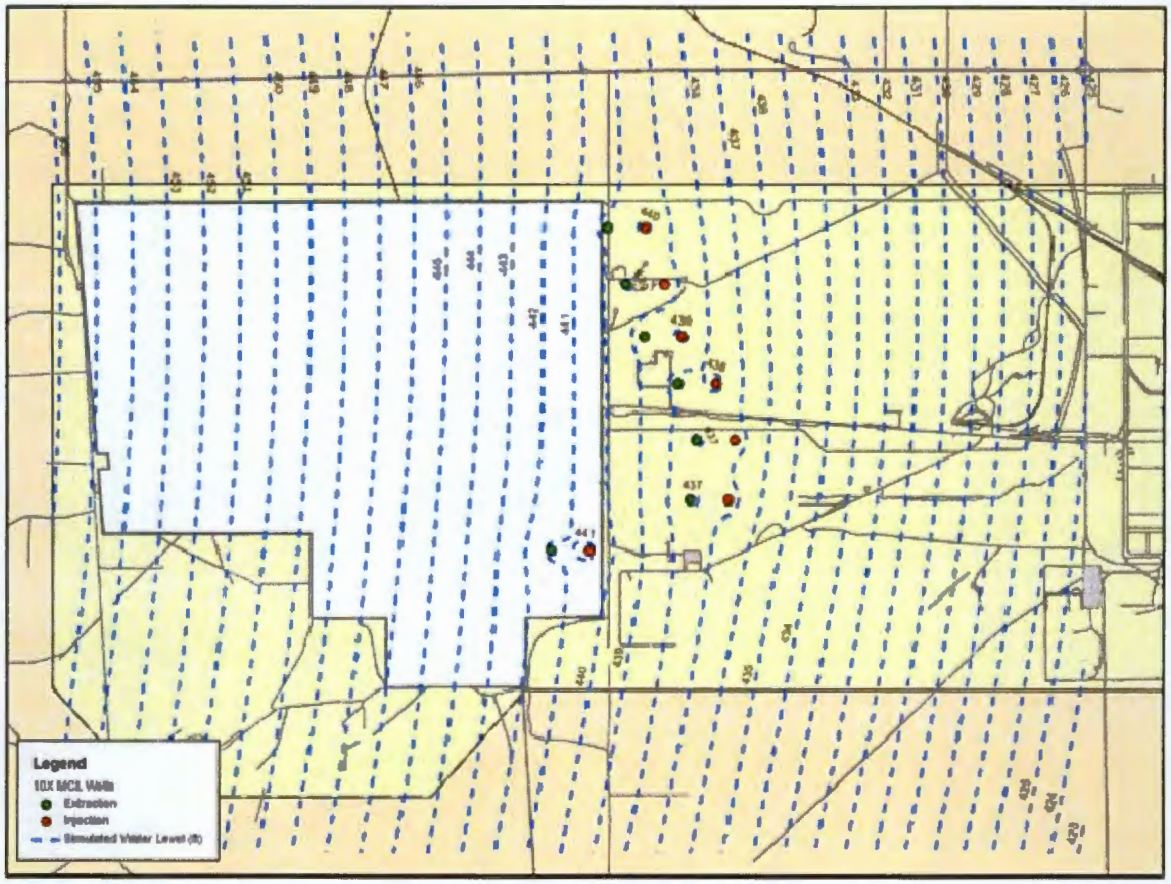


Figure D-44. Preferred Pump-and-Treat Alternative – Calculated Hydraulic Heads.

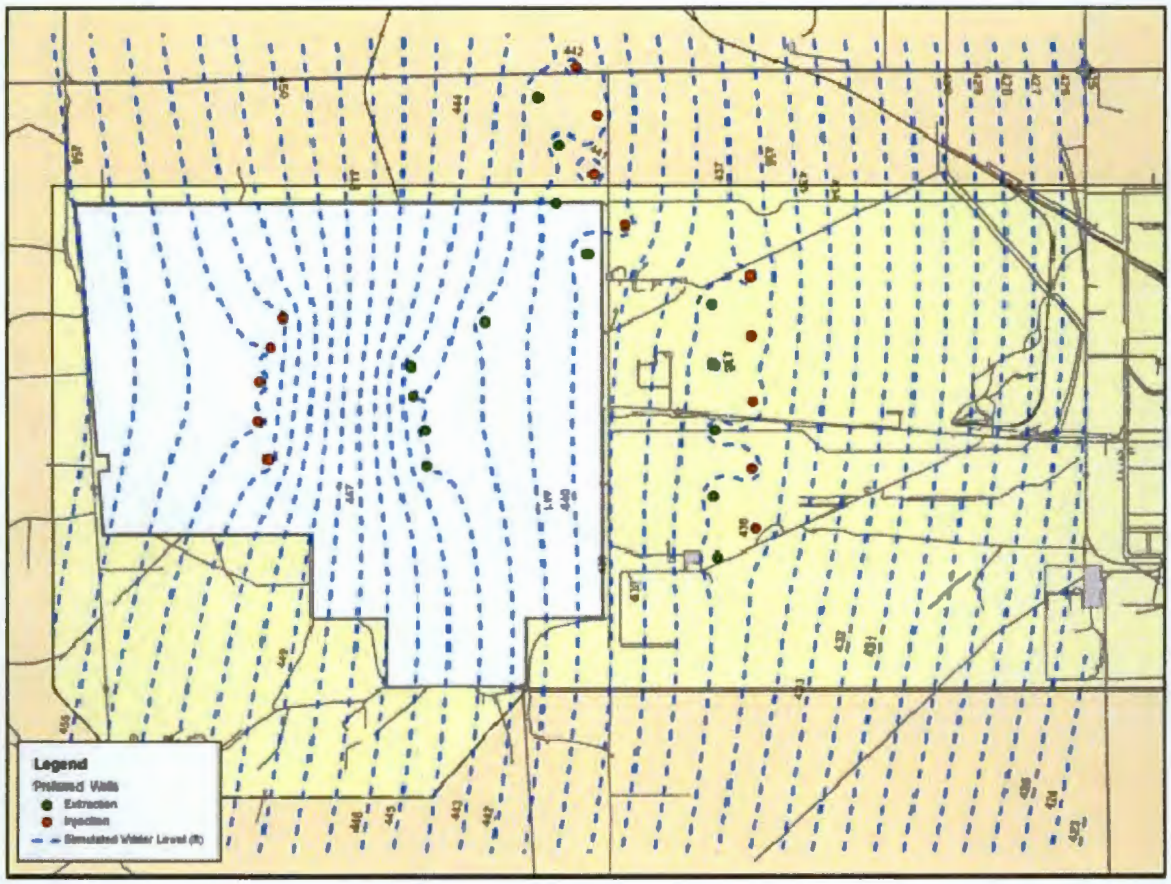


Figure D-45. Preferred Pump-and-Treat Alternative (1,615 gpm) – Calculated Hydraulic Heads.

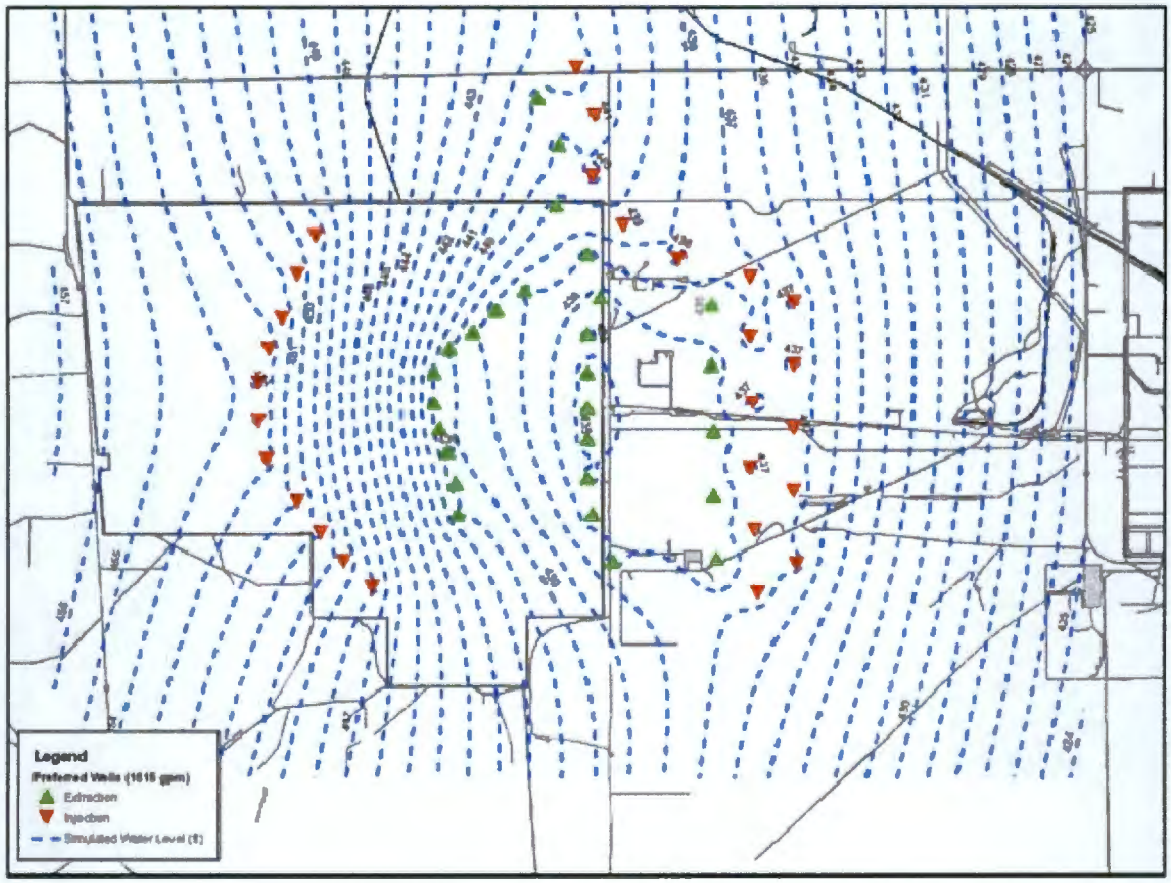


Figure D-46. Calculated Capture Time of Groundwater Above 1 x 10^{-4} Risk.

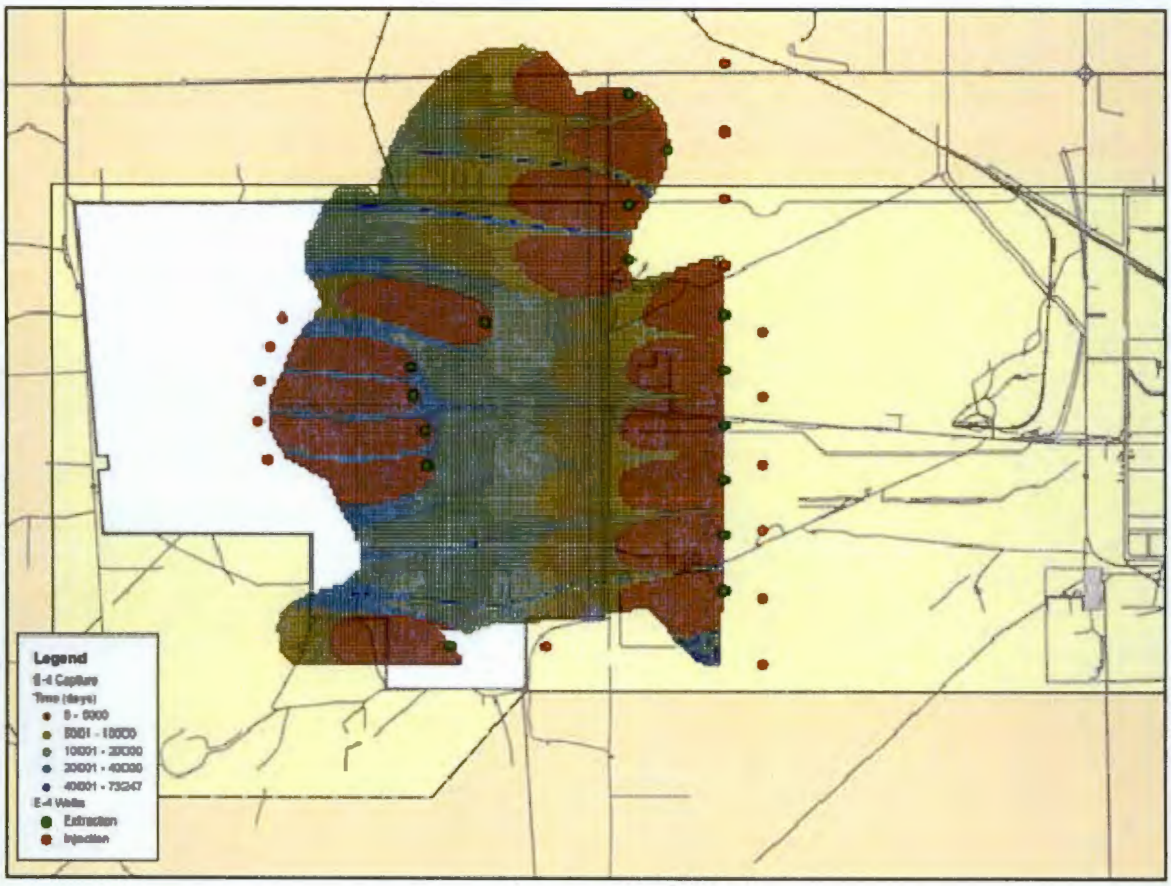


Figure D-47. Calculated Capture Time of Groundwater Above Maximum Contaminant Levels.

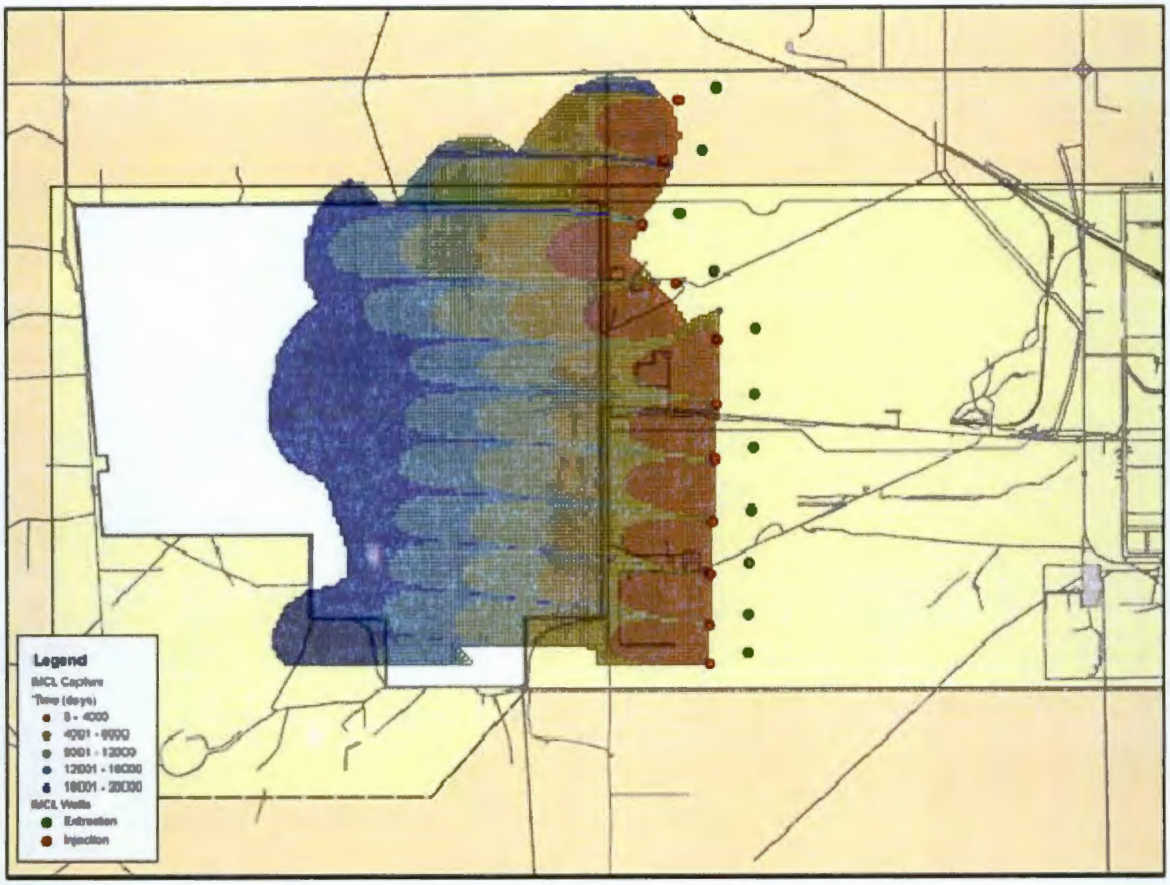


Figure D-48. Calculated Capture Time of Groundwater Above Ten Times Maximum Contaminant Levels.

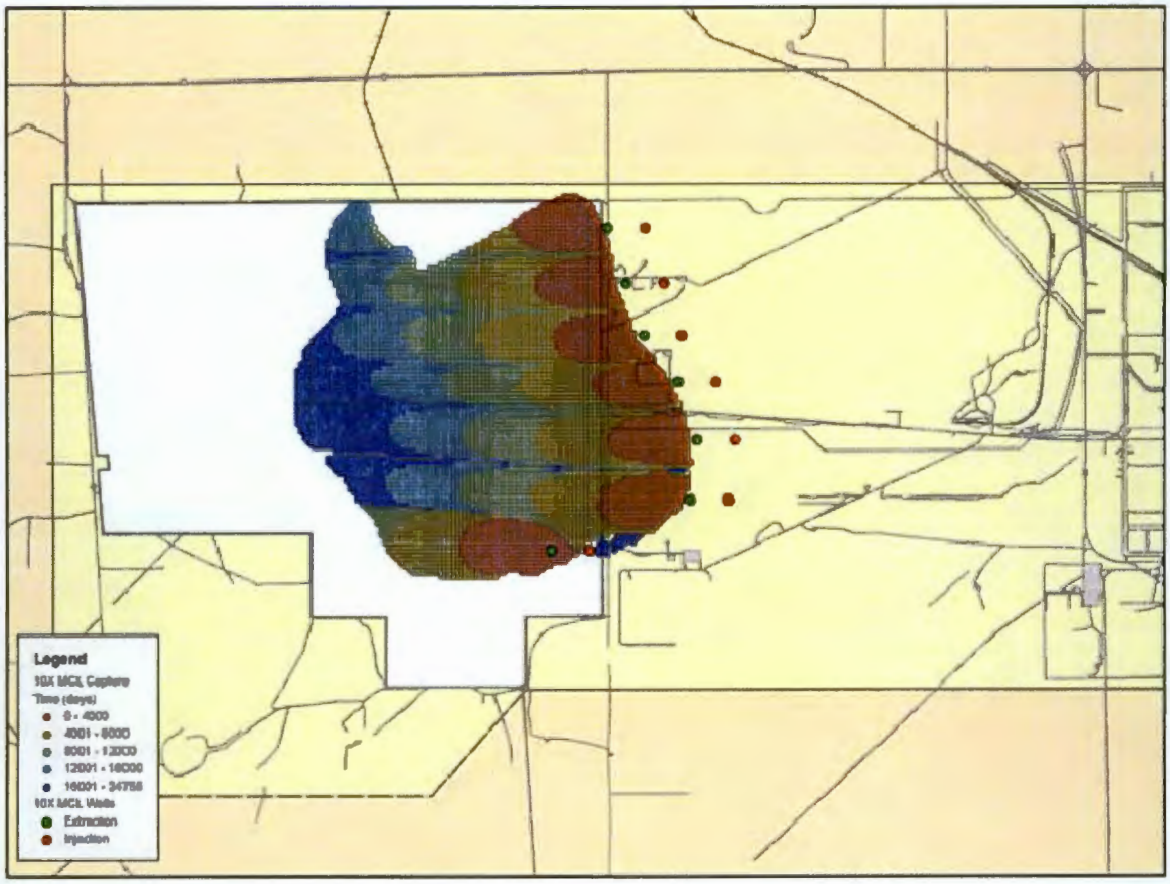


Figure D-49. Calculated Capture Time of Groundwater for the Preferred Pump-and-Treat Alternative (840 gpm).

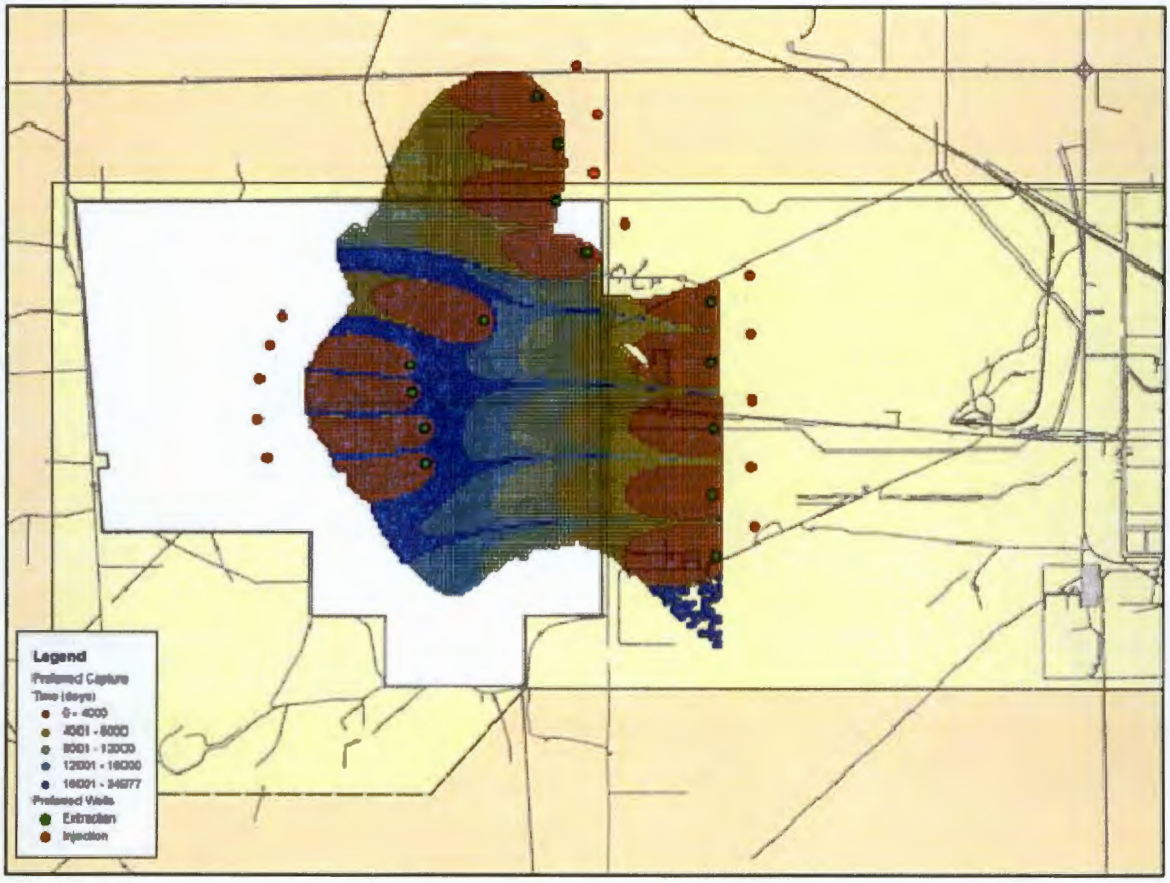


Figure D-50. Calculated Capture Time of Groundwater for the Preferred Pump-and-Treat Alternative (1,615 gpm).

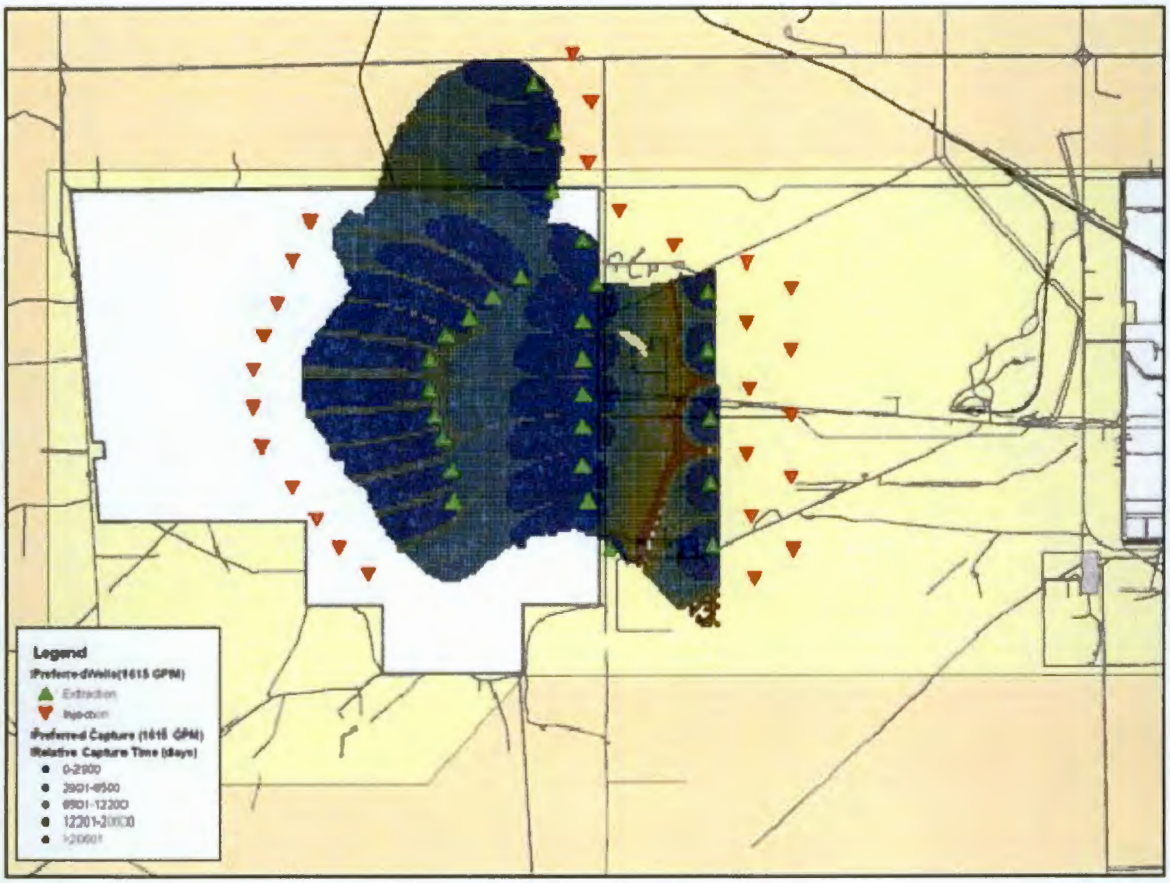


Figure D-51. Preferred Pump-and-Treat Remedy Relative Cleanup Times.

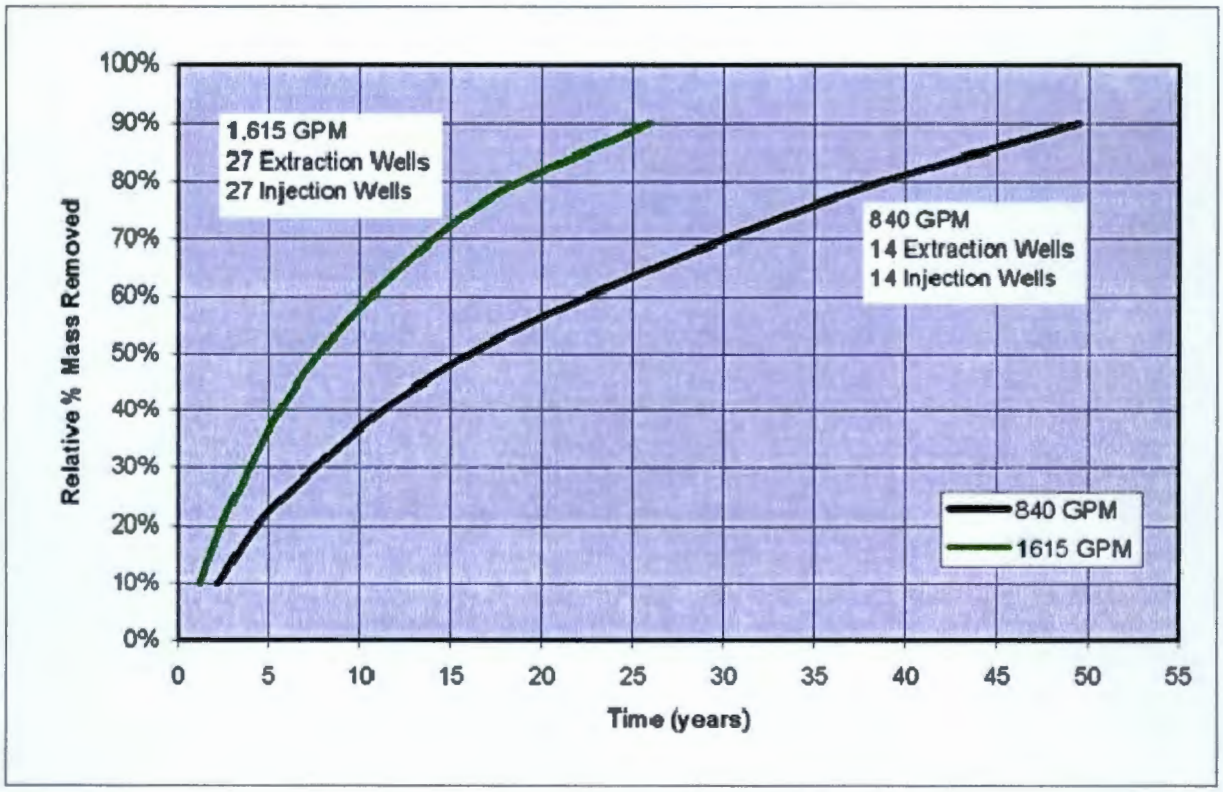


Table D-1. Parameter Data Sources. (5 sheets)

Ref No.	Document Number	Organization	Report Title	Author(s)	Year
1	BHI-00459, Rev. 0	BHI	*Numerical Analysis of Carbon Tetrachloride Movement in the Saturated and Unsaturated Zones in the 200 West Area, Hanford Site*	M. G. Piepho	1996
2	BHI-01126, Rev. 0	BHI	*Fiscal Year 1997 Annual Report for the 100-NR-2, 200 UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units*		1998
3	DOE/RL-2000-71, Rev. 0	RL	*Fiscal Year 2000 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2001
4	DOE/RL-2001-53, Rev. 0	RL	*Fiscal Year 2001 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2002
5	DOE/RL-2002-67, Rev. 0	RL	*Fiscal Year 2002 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2003
6	DOE/RL-2003-58, Rev. 0	RL	*Fiscal Year 2003 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2004
7	DOE/RL-2004-72, Rev. 0	RL	*Fiscal Year 2004 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2005
8	DOE/RL-2005-91, Rev. 0	RL	*Fiscal Year 2005 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*		2006
9	DOE/RL-91-61, Rev. 0	RL	*T Plant Source Aggregate Area Management Study Report*		1992
10	DOE/RL-96-07, Rev. 1	RL	*200-ZP-1 IRM Phase II and III Remedial Design Report*		1996
11	DOE/RL-98-38, Rev. 0	RL	*Fiscal Year 1997 Annual Report for the 100-NR-2, 200 UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units*		1998
12	DOE/RL-99-02, Rev. 0	RL	*Fiscal Year 1998 Annual Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units*		1999
13	DOE/RL-99-79, Rev. 0	RL	*Fiscal Year 1998 Annual Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units*		2000

Table D-1. Parameter Data Sources. (5 sheets)

Ref No.	Document Number	Organization	Report Title	Author(s)	Year
14	PNL-10698	PNL	*Groundwater Monitoring Report for 1994*	P. E. Dresel, P. D. Thorne, S. P. Luttrell, B. M. Gillespie, W. D. Webber, J. K. Merz, J. T. Rieger, M. A. Chamness, S. K. Wurstner, and B. E. Opitz	1995
15	PNNL-10886	PNNL	*Development of a Three-Dimensional Ground-water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*	S. K. Wurstner, P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams	1995
16	PNL-11470	PNL	*Hanford Site Groundwater Monitoring Report for Fiscal Year 1996*	M. J. Hartman (ed.)	1997
17	PNL-11973	PNL	*Hanford Site Groundwater Monitoring Report for Fiscal Year 1997*	M. J. Hartman (ed.)	1998
18	PNL-12086	PNL	*Hanford Site Groundwater Monitoring Report for Fiscal Year 1998*	M. J. Hartman (ed.)	1999
19	PNL-13116	PNL	*Hanford Site Groundwater Monitoring Report for Fiscal Year 1999*	M. J. Hartman (ed.)	2000
20	PNL-7144	PNL	*An Initial Inverse Calibration of the Ground-Water Flow Model for the Hanford Unconfined Aquifer*	E. A. Jacobsen and M. D. Freshley	1990
21	PNNL-13404	PNNL	*Summary of Hanford Site Groundwater Monitoring for Fiscal Year 2000*	M. J. Hartman (ed.)	2001
22	PNNL-13447	PNNL	*Transient Inverse Calibration of Hanford Site-Wide Groundwater Model to Hanford Operational Impact - 1943 to 1996*	C. R. Cole, M. P. Bergeron, S. K. Wurstner, P. K. Thorne, S. Orr, and M. I. McKinley	2001
23	PNNL-13560	PNNL	*Assessment of Carbon Tetrachloride Groundwater Transport in Support of the Hanford Carbon Tetrachloride Innovative Technology Demonstration Program*	M. J. Truex, C. J. Murray, C. R. Cole, R. J. Cameron, M. D. Johnson, R. S. Skeen, C. and D. Johnson	2001
24	PNNL-13788	PNNL	*Summary of Hanford Site Groundwater Monitoring for Fiscal Year 2001*	M. J. Hartman (ed.)	2002
25	PNNL-13858, Rev. 0	PNNL	*Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford, Washington*	B. A. Williams, B. N. Bjornstad, R. Schalla, and W. D. Webber	2002

Table D-1. Parameter Data Sources. (5 sheets)

Ref No.	Document Number	Organization	Report Title	Author(s)	Year
26	PNNL-14187	PNNL	*Summary of Hanford Site Groundwater Monitoring for Fiscal Year 2002*	M. J. Hartman (ed.)	2003
27	PNNL-14548	PNNL	*Summary of Hanford Site Groundwater Monitoring for Fiscal Year 2003*	M. J. Harman (ed.)	2004
28	PNNL-14618, Rev. 0	PNNL	*A Geostatistical Analysis of Historical Field Data on Tritium, Technetium-99, Iodine-129, and Uranium*	C. J. Murray, Y. Chien, and P. D. Thorne	2004
29	PNNL-14702, Rev. 1	PNNL	*Vadose Zone Hydrogeology Data Package for the 2004 Composite Analysis*	G. V. Last, E. J. Freeman, K. J. Cantrell, M. J. Fayer, G. W. Gee, W. E. Nichols, B. N. Bjornstad, and D. G. Horton	2006
30	PNNL-14804	PNNL	*Results of Detailed Hydrologic Characterization Tests Fiscal Year 2003*	F. A. Spane and D. R. Newcomer	2004
31	PNNL-14855, Rev. 1	PNNL	*Recent Site-Wide Transport Modeling Related to Carbon Tetrachloride Plume at the Hanford Site*	M. P. Bergeron and C. R. Cole	2005
32	PNNL-14895	PNNL	*Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*	M. Oostrom, M. L. Rockhold, P. D. Thorne, G. V. Last, and M. J. Truex	2004
33	PNNL-15301 (Draft)	PNNL	*RCRA Assessment Plan for Single-Shell Tank Waste Management Area T*	D. G. Horton	2005
34	PNNL-15760	PNNL	*Summary of Hanford Site Groundwater Monitoring for Fiscal Year 2005*	M. J. Hartman (ed.)	2006
35	PNNL-15914	PNNL	*Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*	M. Oostrom, M. L. Rockhold, P. D. Thorne, G. V. Last, and M. J. Truex	2006
36	PNNL-16198	PNNL	*Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and the 216-Z1-A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*	M. Oostrom, M. L. Rockhold, P. D. Thorne, G. V. Last, and M. J. Truex	2006

Table D-1. Parameter Data Sources. (5 sheets)

Ref No.	Document Number	Organization	Report Title	Author(s)	Year
37	RPP-6296, Rev. 0	CHG	*Modeling Data Package For S-SX Field Investigation Report (FIR)*	R. Khaleel, T. E. Jones, A. J. Kneep, F. M. Mann, D. A. Myers, P. M. Rogers, R. J. Serne, and M. I. Wood	2000
38	WHC-EP-0883, Rev. 0	WHC	*Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site*	R. Khaleel and E. J. Freeman	1995
39	WHC-SD-EN-TI-112, Rev. 0	WHC	*Vadose Zone Modeling of Carbon Tetrachloride in 200 West Area at the Hanford Site*	M. G. Piepho, A. G. Law, M. P. Connelly and K. A. Lindsey	1993
40	WMP-22817, Rev. 0	FH	*Geologic Contacts Database for the 200 Areas of the Hanford Site*	B. N. Bjornstad	2004
41	PNNL-16509, Rev. 0	PNNL	*Letter Report: Geostatistical Analysis of the Inventory of Carbon Tetrachloride in the 200 West Area of the Hanford Site*	C. Murray, Y.-J Bott, and M. Truex	2007
42	PNL-10422	PNL	*Geology, Hydrology, Chemistry, and Microbiology of the In Situ Bioremediation Demonstration Site*	D. R. Newcomer, L. A. Doremus, S. H. Hall, M. J. Truex, V. R. Vermeul, and R. E. Engelman	1995
43	ARH-CD-745	ARH	*Input and Decayed Values of Radioactive Liquid Wastes Discharged to the Groundwater in the 200 Areas Through 1975*	J. D. Anderson	1976
44	BHI-00861, Rev. 0	BHI	*Hanford Soil Partitioning and Vapor Extraction Study*	D. Yonge, A. Hossain, R. Cameron, H. Ford, and C. Storey	1996
45	PNNL-13672, Rev.1	PNNL	*A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site*	E. J. Freeman, R. Khaleel, and P. R. Heller	2004
46	WMP-17524, Rev. 0	FH	*Vadose Zone Hydraulic Property Letter Reports*	E. J. Freeman and G. V. Last	2003
47	PNL-8337	PNL	*Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System*	P. D. Thorne and D. R. Newcomer	1992
48	WHC-SD-EN-TI-014, Rev. 0	WHC	*Hydrogeologic Model for the 200 West Groundwater Aggregate Area*	M.J. Connelly, B.H. Ford, and J.V. Borghese	1992
49	PNNL-14058	PNNL	*Prototype Database and User's Guide of Saturated Zone Hydraulic Properties for the Hanford Site*	P. D. Thorne and D. R. Newcomer	2002
50	PNNL-13378	PNNL	*Results of Detailed Hydrologic Characterization Tests - Fiscal Year 1999*	F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer	2001

Table D-1. Parameter Data Sources. (5 sheets)

Ref No.	Document Number	Organization	Report Title	Author(s)	Year
51	PNNL-13514	PNNL	*Results of Detailed Hydrologic Characterization Tests - Fiscal Year 2000*	F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer	2001
52	PNNL-14113	PNNL	*Results of Detailed Hydrologic Characterization Tests - Fiscal Year 2001*	F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer	2002
53	PNNL-14186	PNNL	*Results of Detailed Hydrologic Characterization Tests - Fiscal Year 2002*	F. A. Spane, Jr., P. D. Thorne, and D. R. Newcomer	2003
54	PNNL-13342	PNNL	*Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System*	F. A. Spane, Jr. and P. D. Thorne	2000
55	PNNL-14804	PNNL	*Results of Detailed Hydrologic Characterization Tests Fiscal Year 2003*	F. A. Spane, Jr. and D. R. Newcomer	2004
57	DOE/RL-2006-51, Draft A	RL	*Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units*		2006
58	PNNL-15239	PNNL	*Carbon Tetrachloride and Chloroform Partition Coefficients Derived from Aqueous Desorption of Contaminated Hanford Sediments*	R. G. Riley, D. S. Sklarew, C. F. Brown, P. M. Gent, J. E. Szecsody, A. V. Mitroshkov, and C. J. Thompson	2005

BHI = Bechtel Hanford, Inc.
CHG = CH2M Hill Hanford Group
FH = Fluor Hanford, Inc.
PNL = Pacific Northwest Laboratory
PNNL = Pacific Northwest National Laboratory
RL = U.S. Department of Energy, Richland Operations Office
WHC = Westinghouse Hanford Company

Table D-2. Total Porosity – Ringold Unit 5. (2 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
39	WHC-SD-EN-TI-112, Rev. 0	1993	Northwest edge of 200 West near 216-Z-9 Trench	299-W7-5	Small	1	Van Genuchten curve match to sediment sample(s)	2 (1 wetting and 1 drying)				2.51E-01	3.74E-01	3.12E-01	3.12E-01	3.06E-01	8.70E-02	Point values based on wetting and drying curve van Genuchten parameters listed in Table 2 of the report.
1	BHI-00459	1996	Northwest edge of 200 West Area near 216-Z-9 Trench	299-W7-5	Small	1	Van Genuchten curve match to sediment sample(s)	1 drying	Uniform			4.14E-01	4.14E-01	4.14E-01	4.14E-01	4.14E-01		Cites VISTA#39 but lists differing value.
38	WHC-EP-0883, Rev. 0	1995	Within 200-ZP-1 and 200-UP-1 boundary	299-W10-196, 299-W7-2, 299-W15-216, 299-W18-246, 699-35-58, 699-35-61A, 699-35-65A, 699-35-69A, 699-48-77A	Small	11	Van Genuchten curve match to sediment sample(s)					5.60E-02	1.07E-01	7.70E-02			1.60E-02	Also known as Khaleel and Freeman after authors: these are the summary stats reported in the document; Table 3 for soil type "SG2" which includes both Ringold and Hanford samples.
						17						7.18E-02	4.33E-01	1.96E-01	1.47E-01	1.71E-01	1.09E-01	Also known as Khaleel and Freeman after authors: these are the summary stats calculated on the basis of the actual tabulated values for middle Ringold from Appendix A.
37	RPP-6296 Rev. 0	2000	WMA-S/SX (tank farms)	699-35-65A, 699-35-69A, 699-35-61A, 299-W10-196	Small	10	Van Genuchten curve match to sediment sample(s)					1.00E-01	2.36E-01	1.74E-01	1.77E-01	1.70E-01	4.03E-02	Data from Appendix C of report.
				Clastic dike	Small	1	Van Genuchten curve match to sediment sample(s)					4.35E-01	4.35E-01	4.35E-01	4.35E-01	4.35E-01		Data from Appendix C of report.
42	PNL-10422	1995	T Plant	299-W11-32	Small	5	Calculated ratio	5				2.10E-01	3.30E-01	2.66E-01	2.60E-01	2.63E-01		According to the report porosity was calculated "as the ratio of the difference between the bulk density and the particle density to the entire bulk density" (p. 4.7). Porosity values listed in Table 4.2.

Table D-2. Total Porosity – Ringold Unit 5. (2 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
32	PNNL-14895	2004	200 West Area		Medium				Log-normal			5.60E-02	1.07E-01	7.70E-02			1.60E-02	References WHC-EP-0883, soil category SG2; However, SG2 includes both Hanford and Ringold soils.
28	PNNL-14618, Rev. 0	2004	Sitewide		?				Log-normal					1.30E-01			3.30E-02	Data reported based on 10 pumping tests, but supporting data or source not listed.
29	PNNL-14702, Rev. 1	2006	200 West Area	299-W15-218, 299-W15-96, 299-W18-246, 299-W18-247, 299-W18-248?	Medium	8								2.97E-01				Actual data sources unclear. Data sources may be WHC-SD-EN-TI-063 and WHC-SD-EN-TI-202 (based on PNNL-13672, Rev. 1). These samples are from the Hanford formation. Data from two sources cited in report (WMP-17524 and PNNL-13672) have more than eight samples listed for the middle Ringold.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-246, 299-W15-216, 699-48-77A, 299-W22-45	Small	9	Van Genuchten curve match to sediment sample(s)	9				7.18E-02	4.33E-01	2.34E-01	1.81E-01	2.00E-01	1.29E-01	Data presented in Appendix A, 200 West Area.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-46, 299-W15-216, 699-48-77A, 299-W22-45	Small	10	Calculated ratio	10				1.96E-01	4.52E-01	2.56E-01	2.14E-01	2.44E-01	8.89E-02	Data presented in Appendix A, 200 West Area, porosity.
48	WHC-SD-EN-TI-014, Rev. 0	1992	200 West Area	299-W7-2	Small	2	Van Genuchten curve match to sediment sample(s)	2				2.62E-01	4.62E-01	3.62E-01	3.62E-01	3.48E-01	1.41E-01	Data from Table 3-1, saturated volumetric water content, raw data in Appendix A.
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	3	Laboratory	3				3.02E-01	3.19E-01	3.11E-01	3.11E-01	3.11E-01	8.50E-03	Values from Table 6.3. Value for sample T19 not included because sample from Ringold Lower Mud.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated.

Table D-3. Effective Mobile Porosity – Ringold Unit 5. (3 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
39	WHC-SD-EN-TI-112	1993	Northwest edge of 200 West Area near 216-Z-9 Trench	299-W7-5	Small	1	Van Genuchten curve match to sediment sample(s)	2 (1 wetting and 1 drying)				2.17E-01	3.47E-01	2.82E-01	2.82E-01	2.74E-01	9.23E-02	From Table 2 for Middle Ringold soils.
							PORFLOW	1				3.76E-01	3.76E-01	3.76E-01	3.76E-01	3.76E-01	N/A	
38	WHC-EP-0883 Rev. 0	1995	Within 200-ZP-1/ 200-UP-1 boundary	299-W10-196, 299-W7-2, 299-W15-46, 299-W18-246, 699-35-58, 699-35-61A, 699-35-65A, 699-35-69A, 699-48-77A	Small	17	Van Genuchten curve match to sediment sample(s)					7.18E-02	3.82E-01	1.73E-01	1.37E-01	1.49E-01	9.95E-02	Also known as Khaleel and Freeman after authors: these summary stats are calculated on the basis of the actual tabulated values for middle Ringold.
15	PNL-10886	1995	200 West Area, Unit 5	699-32-72A, 699-36-61A, 699-37-82A, 699-43-89	Medium	N/A	Pumping test (type uncertain)	4				5.00E-02	1.80E-01	8.25E-02	5.00E-02	6.89E-02	6.50E-02	Table 2.2. These are actually specific yield numbers determined from aquifer tests, and are considered to approximate mobile porosity.
37	RPP-6296 Rev. 0	2000	WMA-S/SX (tank farms)	699-35-65A, 699-35-69A, 699-35-61A, 299-W10-196	Small	10	Van Genuchten curve match to sediment sample(s)					9.16E-02	2.36E-01	1.70E-01	1.70E-01	1.65E-01	4.33E-02	Data from Appendix C of report.
				Clastic dike	Small	2	Van Genuchten curve match to sediment sample(s)					3.61E-01	3.88E-01	3.75E-01	3.75E-01	3.74E-01		Data from Appendix C of report.

Table D-3. Effective Mobile Porosity – Ringold Unit 5. (3 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
23	PNNL-13560	2001	Sitewide	N/A	Large				Uniform			5.00E-02	1.50E-01	1.00E-01	1.00E-01			These are parameters of a distribution developed by PNNL for modeling purposes. Porosity provided based on conversation with F. Spane; no reference or supporting data included.
32	PNNL-14895	2004	200 West Area		Medium				Normal			3.63E-02	1.07E-01	6.70E-02			1.60E-02	References WHC-EP-0883, soil category SG2. However, SG2 includes both Hanford and Ringold soils. Calculated by CCA based on subtration of θr from θs.
29	PNNL-14702, Rev. 1	2006	200 West Area	299-W15-218, 299-W15-96, 299-W18-246, 299-W18-247, 299-W18-248?	Medium	8								1.71E-01				Actual data sources unclear. Data sources may be WHC-SD-EN-TI-063 and WHC-SD-EN-TI-202 (based on PNNL-13672, Rev. 1). These samples are from the Hanford formation. Data from two sources cited in report (WMP-17524 and PNNL-13672) have more than eight samples listed for the middle Ringold.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-246, 299-W15-216, 699-48-77A	Small	9	Van Genuchten curve match to sediment sample(s)	9				7.18E-02	3.82E-01	2.11E-01	1.72E-01	1.83E-01	1.10E-01	Data presented in Appendix A, 200 West Area, porosity. Calculated by CCA based on subtration of θr from θs. Data is same as part of WHC-EP-0883 data set.
48	WHC-SD-EN-TI-014, Rev. 0	1992	200 West Area	299-W7-2	Small	2	Van Genuchten curve match to sediment sample(s)	2				2.62E-01	4.62E-01	3.62E-01	3.62E-01	3.48E-01	1.41E-01	Data from Table 3-1, saturated volumetric water content minus residual volumetric water content (calculated by CCA based on table values). Raw data in Appendix A.
22	PNNL-13447	2001	200 West Area		Large		Inverse model calibration fit (UCODE)					2.00E-01	2.10E-01	2.05E-01	2.05E-01	2.05E-01	7.07E-03	Specific yield of Ringold formation presented in report based on model fit to UCODE.

Table D-3. Effective Mobile Porosity – Ringold Unit 5. (3 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
50	PNNL-13378	2001	200 West Area	299-W10-24, 299-W10-26, 299-W14-13, 299-W19-42	Small	6	Tracer/ pumping test, pumping tests	6				2.70E-02	1.70E-01	1.07E-01	1.15E-01	9.21E-02	5.07E-02	Values are from Tables 6.1 and 7.1 of report. Values for 299-W10-26 and 299-W14-13 in Table 6.1 not included because report lists them as highly questionable. Values from Table 7.1 are from best estimate specific yield data listed in table.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-22-48, 299-22-49, 299-22-50	Small	8	Tracer/ pumping test, pumping tests	8				6.80E-02	3.54E-01	1.70E-01	1.15E-01	1.44E-01	1.08E-01	Values are from Table 6.1, 7.1 of report. Values for 699-43-44 in Table 6.1 not included because well not within 200-ZP-1/200-UP-1 boundary. Values from Table 7.1 are from best estimate specific yield data listed in table.
52	PNNL-14113	2002	200 West Area	299-W22-80, 299-W22-81, 299-W11-39, 299-W11-40, 299-W14-15	Small	7	Tracer/ pumping test, pumping tests	7				4.00E-02	1.20E-01	9.13E-02	1.00E-01	8.46E-02	3.31E-02	Values are from Tables 6.1 and 7.1 of report. Values for 299-W22-80, 299-W11-39, and 299-W11-40 in Table 6.1 not included because report lists them as highly questionable. Values from Table 7.1 are from best estimate specific yield data listed in table.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W22-84	Small	4	Tracer/ pumping test, pumping tests	4				2.00E-02	1.20E-01	6.25E-02	5.50E-02	4.56E-02	5.06E-02	Values are from Tables 6.1 and 7.1 of report. Values from Table 7.1 are from best estimate specific yield data listed in table.
54	PNNL-13342	2000	200 West Area	299-W15-1, 299-W15-7, 299-W15-11, 299-W15-31A	Medium	4	Pumping test	4				2.30E-02	3.50E-02	2.88E-02	2.85E-02	2.84E-02	5.06E-03	Point values are specific yield values listed in Table 4.1 of the report.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.
N/A = not applicable/not available

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
39	WHC-SD-EN-TI-112	1993	Northwest edge of 200 West Area near 216-Z-9 Trench	299-W7-5	Small	1	Van Genuchten curve match to sediment sample(s)	1	Uniform	cm/sec		3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	N/A	Value from Table 3 of the report.
1	BHI-00459	1996	Northwest edge of 200 West Area near 216-Z-9 Trench	299-W7-5	Small	1	Van Genuchten curve match to sediment sample(s)	1	Uniform	cm/sec		2.10E-02	2.10E-02	2.10E-02	2.10E-02	2.10E-02	N/A	Cites WHC-SD-EN-TI-112 (VISTA Source #39) but lists differing value.
38	WHC-EP-0883, Rev. 0	1995	Within 200-ZP-1/ 200-UP-1 boundary	699-35-58, 699-35-61A, 699-35-69A, 299-W7-2, 299-W10-196, 299-W15-46, 299-W15-216, 299-W18-246, 699-48-77A	Small	11	Van Genuchten curve match to sediment sample(s)			cm/sec		2.85E-05	1.30E-01	1.40E-02			4.10E-02	Also known as Khaleel and Freeman after authors: these are the summary stats reported in the document for soil type SG2.
						14				cm/sec		1.90E-07	2.10E-02	4.56E-03	1.03E-03	2.96E-04	6.90E-03	Also known as Khaleel and Freeman after authors: these are the summary stats calculated on the basis of the actual tabulated values for middle Ringold, as listed in Appendix A of the report.
15	PNL-10886	1995	200 West Area, Unit 5	N/A		N/A				m/day		1.00E-01	2.00E+02					Summary provided in report. Not all supporting data available.
15	PNL-10886	1995	Ringold Units 5, 7, and 9 within 200-ZP-1/ 200-UP-1 boundary	299-W7-1, 299-W7-2, 299-W7-4, 299-W7-5, 299-W7-6, 299-W10-13, 299-W15-15, 299-W15-16, 299-W15-18, 299-W18-21, 299-W18-23, 299-W18-24, 299-W21-1, 699-37-82, 32-72B, 40-62, 47-60		17		17		m/day		3.00E+00	6.40E+02	1.30E+02	5.40E+01	5.74E+01	1.58E+02	Data from Appendix C, 299- prefix wells, and 699- prefix wells within 200-ZP-1/200-UP-1 boundary.
37	RPP-6296 Rev. 0	2000	WMA-S/SX (tank farms)	699-35-65A, 699-35-69A, 699-35-61A, 299-W10-196	Small	10	Van Genuchten curve match to sediment sample(s)			cm/sec		1.06E-06	3.42E-04	1.03E-04	4.54E-05	4.44E-05	1.13E-04	Data listed in Table C-1 of report.
				Clastic dike	Small	1	Van Genuchten curve match to sediment sample(s)			cm/sec		1.20E-03	1.20E-03	1.20E-03	1.20E-03	1.20E-03		Data listed in Table 4 of report.

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	299-W11-32	Small	8	Laboratory (falling head permeameter on intact samples)	8		cm/sec		2.75E-07	2.14E-04	5.89E-05	3.34E-05	1.52E-05	7.45E-05	Vertical conductivity.
42	PNL-10422	1995	T Plant	299-W11-30, 299-W11-32	Small	2	Transmissivity/ tested interval thickness	3		m/day		3.00E-01	1.10E+01	6.10E+00	7.00E+00	2.85E+00	5.41E+00	Data listed in report text from pp. 5.14 to 5.25.
42	PNNL-10422	1995	T Plant	299-W11-32	Small	2	Bouwer and Rice	7		m/day		2.30E+00	2.80E+01	1.49E+01	2.20E+01	9.12E+00		Data listed in Table 5.4 of report.
42	PNNL-10422	1995	T Plant	299-W11-32	Small	2	Type curve	7		m/day		3.00E+00	4.30E+01	2.14E+01	3.00E+01	1.26E+01		Data listed in Table 5.4 of report.
32	PNNL-14895	2004	200 West Area		Medium				Log-normal			2.83E-05	1.30E-01	1.40E-02			4.10E-02	References WHC-EP-0883, soil category SG2. However, SG2 includes both Hanford and Ringold soils in the 200 West Area.
29	PNNL-14702, Rev. 1	2006	200 West Area		Medium	8		8		cm/sec				1.06E-04				Actual data sources unclear. Data from two sources cited in report (WMP-17524 and PNNL-13672) have more than eight samples listed for the middle Ringold.
48	WHC-SD-EN-TI-014, Rev. 0	1992	200 West Area	299-W7-2	Small	2	Van Genuchten curve match to sediment sample(s)	2		cm/sec		2.70E-03	2.10E-02	1.19E-02	1.19E-02	7.53E-03	1.29E-02	Data summarized in Table 3-1. Raw data in Appendix A.
48	WHC-SD-EN-TI-014, Rev. 0	1992	200 West Area	299-W7-2	Small	1	Pumping test	1	Uniform	ft/day		7.40E+01	7.40E+01	7.40E+01	7.40E+01	7.40E+01		Data summarized in Table 3-2. Raw data in Appendix B.

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
47	PNL-8337	1992	Within 200-ZP-1/ 200-UP-1 boundary	299-W6-2, 299-W7-1, 299-W7-2, 299-W7-4, 299-W7-5, 299-W7-6, 299-W8-1, 299-W10-13, 299-W10-14, 299-W15-15, 299-W15-16, 299-W15-18, 299-W18-21, 299-W18-22, 299-W18-23, 299-W18-24, 299-W21-1, 699-17-5, 699-32-77, 699-47-60, 699-36-61A, 699-37-82A, 699-44-42	Small	23	Pumping test	23		ft/day		1.60E-01	4.20E+03	2.27E+02	2.50E+01	1.62E+01	8.68E+02	Summary of data collected at site from 1956 to 1988. Data summarized in Table 1. Data listed is for wells within 200-ZP-1/ 200-UP-1 boundary.
47	PNL-8337	1992	Within 200-ZP-1/ 200-UP-1 boundary	299-W7-7, 299-W7-9, 299-W7-10, 299-W9-1, 299-W10-15, 299-W10-16, 299-W10-18, 299-W15-19, 299-W15-20, 299-W15-22, 299-W15-23, 299-W15-25, 299-W18-25, 299-W19-31, 299-W19-32, 299-W22-40, 299-W22-41, 299-W22-42, 299-W22-43, 299-W23-13, 299-W23-14, 299-W26-8, 299-W26-9, 299-W26-10, 299-W26-11, 299-W26-12	Small	26	Slug test	26		ft/day		6.00E-03	1.40E+02	3.19E+01	1.85E+01	9.65E+00	3.79E+01	Summary of data collected at site from 1987 to 1991. Data summarized in Table 2. Data listed is for wells within 200-ZP-1/ 200-UP-1 boundary.

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
49	PNNL-14058	2002		299-W7-7, 299-W8-1, 299-W9-1, 299-W10-15, 299-W10-16, 299-W10-17, 299-W10-18, 299-W10-23, 299-W10-24, 299-W10-26, 299-W14-13, 299-W14-14, 299-W15-19, 299-W15-20, 299-W15-22, 299-W15-24, 299-W15-40, 299-W15-41, 299-W18-25, 299-W18-26, 299-W19-31, 299-W19-32, 299-W19-41, 299-W19-42, 299-W22-45, 299-W22-46, 299-W22-48, 299-W22-49, 299-W22-50, 299-W22-80, 299-W22-81, 299-W22-82, 299-W22-83, 299-W22-84, 299-W22-85, 299-W23-13, 299-W23-14, 299-W23-15, 299-W23-20, 299-W23-21, 299-W26-8, 299-W26-9, 299-W26-10, 299-W26-11, 299-W26-12, 299-W26-13, 699-S22-E9A, 699-S22-E9D, 699-S27-E10A, 699-S27-E10B, 699-S31-E8A, 699-S31-E10A, 699-S31-E10C, 699-S31-E10D, 699-S32-E8, 699-S34-E10, 699-S37-E11, 699-S38-E11, 699-S38-E12A, 699-S38-E12B, 699-S41-E11A, 699-S41-E12, 699-S41-E13C, 699-43-44, 699-44-43B, 699-44-43B, 699-77-54, 699-87-55	Small		Pumping test or slug test			m/day		1.20E-05	1.16E+02	9.34E+00	2.31E+00	2.42E+00	1.85E+01	12/6/06 e-mail from Paul Thorne states "… only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
50	PNNL-13378	2001	200 West Area	299-W10-23, 299-W10-24, 299-W10-26, 299-W14-13, 299-W14-14, 299-W15-40, 299-W19-41, 299-W19-42, 299-W22-79	Small	9	Bouwer and Rice	9		m/day		8.80E-01	7.06E+00	2.33E+00	1.62E+00	1.83E+00	2.03E+00	Point value listed in this table is average of analysis for each well as listed in Table 4.1 of the report.
50	PNNL-13378	2001	200 West Area	299-W10-23, 299-W10-24, 299-W10-26, 299-W14-13, 299-W14-14, 299-W15-40, 299-W19-41, 299-W19-42, 299-W22-79	Small	9	Type curve	9		m/day		1.22E+00	9.50E+00	3.21E+00	2.35E+00	2.59E+00	2.65E+00	Point value listed in this table is average of analysis for each well as listed in Table 4.1 of the report.
50	PNNL-13378	2001	200 West Area	299-W10-24, 299-W10-26, 299-W14-13, 299-W19-42	Small	4	Pumping test	4		m/day		1.22E+00	6.12E+00	2.82E+00	1.97E+00	2.28E+00	2.26E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 7.1 of the report.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-W22-45, 299-W22-46, 299-W22-48, 299-W22-49, 299-W22-50, 299-W23-15, 299-W26-13, 699-43-44	Small	9	Bouwer and Rice	12		m/day		3.00E-01	1.42E+01	3.14E+00	1.94E+00	1.78E+00	3.86E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-W22-45, 299-W22-46, 299-W22-48, 299-W22-49, 299-W22-50, 299-W23-15, 299-W26-13, 699-43-44	Small	9	Type curve	12		m/day		5.00E-02	1.99E+01	3.98E+00	2.17E+00	1.43E+00	5.53E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-W22-48, 299-W22-49, 299-W22-50, 699-43-44	Small	5	Pumping tests	5		m/day		1.70E+00	1.96E+01	7.18E+00	5.24E+00	4.73E+00	7.37E+00	Point value listed in this table is "average" of analysis for each well as listed in Table 7.1 of the report.

Table D-4. Hydraulic Conductivity – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
52	PNNL-14113	2002	200 West Area	299-W10-27, 299-W11-39, 299-W11-40, 299-W11-41, 299-W14-15, 299-W14-16, 299-W14-17, 299-W15-763, 299-W22-80, 299-W22-81, 299-W22-82, 299-W22-83, 299-W23-20, 299-W23-21	Small	14	Bouwer and Rice	23		m/day		5.00E-02	1.72E+01	4.32E+00	3.10E+00	2.47E+00	4.34E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
52	PNNL-14113	2002	200 West Area	299-W10-27, 299-W11-39, 299-W11-40, 299-W11-41, 299-W11-42, 299-W14-15, 299-W14-16, 299-W14-17, 299-W15-763, 299-W22-80, 299-W22-81, 299-W22-82, 299-W22-83, 299-W23-20, 299-W23-21	Small	15	Type curve	24		m/day		7.00E-02	2.81E+01	5.80E+00	4.12E+00	3.21E+00	6.50E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
52	PNNL-14113	2002	200 West Area	299-W11-39, 299-W11-40, 299-W14-15, 299-W22-80, 299-W22-81	Small	5	Pumping test	5		m/day		8.50E-01	1.44E+01	4.60E+00	2.02E+00	2.78E+00	5.61E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 7.1 of the report.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W14-18, 299-W22-84, 299-W22-85	Small	4	Bouwer and Rice	7		m/day		3.90E-01	2.57E+01	6.19E+00	3.59E+00	3.05E+00	8.80E+00	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
53	PNNL-14186	2003	200 West Area	299-W10-28, 299-W14-14, 299-W14-18, 299-W22-84, 299-W22-85	Small	5	Type curve	8		m/day		5.40E-01	2.98E+01	1.01E+01	4.93E+00	5.02E+00	1.18E+01	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W22-84	Small	2	Pumping test	2		m/day		1.33E+00	2.21E+00	1.77E+00	1.77E+00	1.71E+00	6.22E-01	Point value listed in this table are listed in Table 7.1 of the report

Table D-4. Hydraulic Conductivity – Ringold Unit 5. (7 sheets)

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55	PNNL-14804	2004	200 West Area	299-W19-46, 299-W26-14	Small	2	Bouwer and Rice	3		m/day		3.01E+00	3.80E+01	1.48E+01	3.28E+00	7.21E+00	2.01E+01	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.2 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
55	PNNL-14804	2004	200 West Area	299-W19-46, 299-W26-14	Small	2	Type Curve	3		m/day		4.02E+00	6.41E+01	2.41E+01	4.06E+00	1.02E+01	3.47E+01	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.2 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
54	PNNL-13342	2000	200 West Area	299-W15-1, 299-W15-7, 299-W15-11, 299-W15-31A	Small	4	Pumping test	4		m/day		3.50E+00	6.60E+00	4.95E+00	4.85E+00	4.76E+00	1.58E+00	Values listed in Table 4.1 of the report.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-246, 299-W15-216, 699-48-77A, 299-W22-45,	Small	12	Van Genuchten curve match to sediment sample(s)	12		cm/sec		8.80E-08	1.40E-02	3.49E-03	2.18E-04	1.85E-04	5.44E-03	Values listed in Appendix A for "middle Ringold." Values for 299-W10-196 (138.5 m, 127.6, 151.2, 176.2), 299-W15-216, 200-W18-246, and 699-48-77A also listed in WHC-EP-0883.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.
N/A = not applicable/not available

Table D-5. Transmissivity – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	299-W11-29, 299-W11-30, 299-W11-32	Medium	4	Constant rate pumping test	7		m^2/day		6.00E-01	6.90E+01	5.07E+01	6.70E+01	2.82E+01	2.90E+01	Data from pp. 5.14 to 5.29 of report.
15	PNL-10886	1995	Within 200-ZP-1/ 200-UP-1 boundary	299-W7-1, 299-W7-2, 299-W7-4, 299-W7-5, 299-W7-6, 299-W10-13, 299-W11-30, 299-W15-15, 299-W15-16, 299-W15-18, 299-W18-21, 299-W18-23, 299-W18-24, 299-W21-1, 699-32-72B	Medium	15	Pumping tests	15		m^2/day		3.70E+00	4.74E+03	1.06E+03	3.72E+02	3.39E+02	1.33E+03	Values listed in Appendix C.
48	WHC-SD-EN-TI-014, Rev. 0	1992	200 West Area	299-W7-2	Small	1	Pumping test	1	Uniform	ft^2/day		7.40E+02	7.40E+02	7.40E+02	7.40E+02	7.40E+02		Data summarized in Table 3-2. Raw data in Appendix B.
47	PNL-8337	1992	Within 200-ZP-1/ 200-UP-1 boundary	299-W6-2, 299-W7-1, 299-W7-2, 299-W7-4, 299-W7-5, 299-W7-6, 299-W8-1, 299-W10-13, 299-W10-14, 299-W15-15, 299-W15-16, 299-W15-18, 299-W18-21, 299-W18-22, 299-W18-23, 299-W18-24, 299-W21-1, 699-32-77, 699-37-82A	Small	19	Pumping tests	19		ft^2/day		4.00E+01	5.70E+04	1.06E+04	3.00E+03	2.19E+03	1.68E+04	Summary of data collected at site from 1956 to 1988. Data summarized in Table 1.
49	PNNL-14058	2002	200 West Area	299-W7-1, 299-W7-2, 288-W7-4, 299-W7-5, 299-W7-6, 299-W8-1, 299-W10-13, 299-W10-14, 299-W10-24, 299-W10-26, 299-W14-13, 299-15-15, 299-W15-16, 299-W15-18, 299-W15-41, 299-W18-21, 299-W18-22, 299-W18-23, 299-W18-24, 299-W19-42, 299-W22-48, 299-W22-49, 299-W22-50	Small	23	Pumping tests	30		m^2/day		1.30E+00	4.74E+03	7.39E+02	1.98E+02	1.99E+02	1.18E+03	12/6/06 e-mail from Paul Thorne states "… only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.
50	PNNL-13378	2001	200 West Area	299-W10-24, 299-W10-26, 299-W14-13, 299-W19-42	Small	4	Tracer/ pumping test, pumping tests	4		m^2/day		6.60E+01	3.45E+02	1.57E+02	1.09E+02	1.26E+02	1.29E+02	Values listed in Table 6.1 of the report.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-22-48, 299-22-49, 299-22-50, 699-43-44	Small	5	Tracer/ pumping test, pumping tests	5		m^2/day		8.85E+00	1.13E+03	4.40E+02	3.85E+02	1.93E+02	4.41E+02	Values listed in Table 6.1 of the report.
52	PNNL-14113	2002	200 West Area	299-W22-80, 299-W22-81, 299-W22-82, 299-W11-39, 299-W11-40, 299-W14-15	Small	5	Tracer/ pumping test, pumping tests	5		m^2/day		4.40E+01	1.04E+03	3.04E+02	1.12E+02	1.64E+02	4.14E+02	Values listed in Table 6.1 of the report.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W22-84	Small	2	Tracer/ pumping test, pumping tests	2		m^2/day		9.10E+01	1.21E+02	1.06E+02	1.06E+02	1.05E+02	2.12E+01	Values listed in Table 6.1 of the report.
54	PNNL-13342	2000	200 West Area	299-W15-1, 299-W15-7, 299-W15-11, 299-W15-31A	Small	4	Pumping test	4		m^2/day		2.30E+02	4.30E+02	3.23E+02	3.15E+02	3.10E+02	1.02E+02	Values listed in Table 4.1 of the report.

NOTE: The yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results

Table D-6. Aquifer Storage – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
50	PNNL-13378	2001	200 West Area	299-W10-23, 299-W10-24, 299-W10-26, 299-W14-13, 299-W14-14, 299-W15-40, 299-W19-41, 299-W19-42, 299-W22-79	Small	9	Slug test (type-curve analysis)	9		1/m		1.00E-05	9.90E-04	5.28E-04	6.60E-04	2.83E-04	3.54E-04	Data from Table 4.1 of report (largest value in range listed).
50	PNNL-13378	2001	200 West Area	299-W10-24, W10-26, W14-13, W10-42	Small	4	Pumping test (constant rate)	4				1.10E-04	1.40E-03	7.20E-04	6.85E-04	4.21E-04	6.75E-04	Data from Table 7.1 of report (best estimate used).
47	PNL-8337	1992	Within 200-ZP-1/ UP-1 boundary	299-W10-13, 299-W15-16, 299-W18-24, 699-37-82A	Small	4	Pumping test	4				1.00E-03	4.00E-02	1.75E-02	1.45E-02	9.21E-03	1.69E-02	Data from Table 1 of report.
54	PNNL-13342	2000	200 West Area	299-W15-1, 299-W15-7, 299-W15-11, 299-W15-31A	Small	4	Pumping test	4				2.30E-05	3.50E-05	2.88E-05	2.90E-05	2.85E-05	4.38E-06	Data from Table 4.1 of report.
52	PNNL-14113	2002	200 West Area	299-W10-27, 299-W11-39, 299-W11-40, 299-W11-41, 299-W14-15, 299-W14-16, 299-W14-17, 299-W15-763, 299-W22-80, 299-W22-81, 299-W22-82, 299-W22-83, 299-W23-20, 299-W23-21	Small	14	Slug test (type-curve analysis)	23		1/m		1.00E-06	2.00E-03	1.95E-04	5.00E-05	3.63E-05	4.58E-04	Point value listed in this table is from Table 4.1 of the report. Maximum values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
52	PNNL-14113	2002	200 West Area	299-W11-39, 299-W11-40, 299-W14-15, 299-W22-80, 299-W22-81	Small	5	Pumping test (constant rate)	5				1.20E-04	3.00E-03	1.05E-03	6.20E-04	6.45E-04	1.14E-03	Data from Table 7.1 of report (best estimate used).
51	PNNL-13514	2001	Within 200-ZP-1/ 200-UP-1 boundary	299-W15-41, 299-W22-45, 299-W22-46, 299-W22-48, 299-W22-49, 299-W22-50, 299-W23-15, 299-W26-13, 699-43-44	Small	9	Slug test (type-curve analysis)	12		1/m		2.10E-06	1.70E-04	3.91E-05	2.00E-05	2.01E-05	5.01E-05	Point value listed in this table is from Table 4.1 of the report. Maximum values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
51	PNNL-13514	2001	Within 200-ZP-1/ 200-UP-1 boundary	299-W15-41, 299-W22-48, 299-W22-49, 299-W22-50, 699-43-44	Small	6	Pumping test (constant rate)	6				9.00E-05	1.60E-04	1.15E-04	1.15E-04	1.13E-04	2.59E-05	Data from Table 7.1 of report (best estimate used).
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W14-18, 299-W22-84, 299-W22-85	Small	4	Slug test (type-curve analysis)	7		1/m		1.00E-06	6.60E-04	1.14E-04	1.00E-05	1.65E-05	2.43E-04	Point value listed in this table is from Table 4.1 of the report. Maximum values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W22-84	Small	2	Pumping test (constant rate)	2				9.00E-05	3.50E-03	1.80E-03	1.80E-03	5.61E-04	2.41E-03	Data from Table 7.1 of report.
15	PNL-10886	1995	200 West Area	299-W10-13, 699-37-82A	Medium	2	Pumping test	2				9.00E-03	2.00E-02	1.45E-02	1.45E-02	1.34E-02	7.78E-03	Data from Table 2.2 of report.
55	PNNL-14804	2004	200 West Area	299-W19-46, W26-14	Small	2	Slug test (type-curve analysis)	3		1/m		5.00E-06	5.00E-05	2.50E-05	2.00E-05	1.71E-05	2.29E-05	Point value listed in this table is from Table 4.2 of the report. Maximum values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
49	PNNL-14058	2002	200 West Area	299-W10-23, 299-W10-24, 299-W10-26, 299-W14-13, 299-W14-14, W15-40,15-41, 19-41, 19-42, 22-45, 22-46, 22-48, 22-49, 22-50, 22-79, 23-15, 26-13	?	17	Pumping test	25				9.00E-05	5.00E-02	5.28E-04	1.20E-03	1.94E-03	1.84E-02	12/6/06 e-mail from Paul Thorne states "… only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.

NOTE: The yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.

Table D-7. Hydraulic Gradient – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	299-W6-4, 299-W6-2, 299-W11-31, 299-W11-21, 299-W11-30, 299-W11-29, 299-W11-14, 299-W11-2, 299-W11-9, 299-W11-4, 299-W11-31	Medium	3	Water table maps	3		m/m		1.80E-03	2.50E-03	2.13E-03	2.10E-03	2.11E-03	3.51E-04	Data from p. 5.43 of report.
50	PNNL-13378	2001	200 West Area	299-W10-26, 299-W14-13, 299-W10-24, 299-W19-42	Small	4	Tracer/pump testing	4		m/m		7.30E-04	1.84E-03	1.26E-03	1.23E-03	1.14E-03	6.08E-04	Data from Table 9.3 of report.
51	PNNL-13514	2001	200 West Area	299-W15-41, 299-W22-48, 299-W22-49, 299-W22-50	Small	5	Tracer/pump testing	5		m/m		1.29E-03	2.06E-03	1.85E-03	2.04E-03	1.82E-03	3.32E-04	Data from Table 9.3 of report.
52	PNNL-14113	2002	200 West Area	299-W11-39, 299-W11-40, 299-W14-15, 299-W22-80, 299-W22-81	Small	9	Tracer/pump testing	9		m/m		1.14E-03	2.09E-03	1.53E-03	1.40E-03	1.50E-03	3.57E-04	Data from Table 9.3 of report.
53	PNNL-14186	2003	200 West Area	299-W14-14, 299-W22-84	Small	4	Tracer/pump testing	4		m/m		1.09E-03	1.83E-03	1.47E-03	1.48E-03	1.43E-03	4.10E-04	Data from Table 9.3 of report.

Table D-8. Kh/Kv Anisotropy Ratio – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
54	PNNL-13342	2000	200 West Area	299-W15-1, 299-W15-7, 299-W15-11, 299-W15-31A	Small	4	Pumping test	4				1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	0.00E+00	Data from Table 4.1 of report. Report states values assumed.
52	PNNL-14113	2002	200 West Area	299-W11-39, 299-W11-40, 299-W14-15, 299-W22-80, 299-W22-81	Small	5	Pumping test	5				1.50E-02	1.00E-01	8.30E-02	1.00E-01	6.84E-02	3.80E-02	Data from Table 7.1 of report. Value listed is "best estimate."
51	PNNL-13514	2001	Within 200-ZP-1/ 200-UP-1 boundary	299-W15-41, 299-W22-48, 299-W22-49, 299-W22-50, 699-43-44	Small	5	Pumping test	5				1.00E-01	5.00E-01	1.80E-01	1.00E-01	1.38E-01	1.79E-01	Data from Table 7.1 of report. Value listed is "best estimate."

Table D-9. Groundwater Velocity – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	2	Medium	1	Tracer testing	1		m/day		3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02		Upper bounding limit calculated (p. 5.37 of report).
50	PNNL-13378	2001	200 West	299-W10-24, 299-W10-26, 299-W19-42	Small	5	Tracer-dilution test, tracer-pumpback test	5		m/day		1.20E-02	4.19E-01	1.43E-01	8.60E-02	7.34E-02	1.66E-01	Values listed in Table 5.1, 5.2, 5.3, and 6.1. Average values listed from Tables 5.1, 5.2, and 5.3.
52	PNNL-14113	2002	200 West	299-W14-15, 299-W22-81	Small	2	Tracer-dilution test, tracer-pumpback test	4		m/day		3.50E-02	1.19E-01	8.38E-02	9.05E-02	7.51E-02	4.01E-02	Values listed in Table 5.1, 5.2, and 6.1. Average values listed from Tables 5.1 and 5.2.
51	PNNL-13514	2001	Within 200-ZP-1/ 200-UP-1 boundary	299-W15-41, 299-W22-48, 22-50	Small	3	Tracer-dilution test, tracer-pumpback test	6		m/day		7.00E-03	3.74E-01	1.29E-01	3.50E-02	4.83E-02	1.67E-01	Values listed in Table 5.1, 5.2, and 6.1. Average values listed from Tables 5.1 and 5.2.
53	PNNL-14186	2003	200 West	299-W14-14, 299-W22-84	Small	2	Tracer-dilution test, tracer-pumpback test	4		m/day		4.10E-02	1.22E-01	9.35E-02	1.06E-01	8.59E-02	3.80E-02	Values listed in Table 5.1, 5.2, and 6.1. Average values listed from Tables 5.1 and 5.2.

Table D-10. Dispersivity – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
15	PNL-10886	1995	200 West Area, Unit 5	1	Small	1	Single-well tracer test to determine DL	1		meters		4.60E+02	4.60E+02	4.60E+02	4.60E+02	4.60E+02		DL only was determined (p. 2.26 of report).
			200 East Area	N/A	20,000 m (large)	1	Transport modeling	1		meters		3.05E+01	3.05E+01	3.05E+01	3.05E+01	3.05E+01		DL= 30.5, DT=18.5 (p. 2.27 of report).
23	PNNL-13560	2001	Sitewide	N/A	Large				Log-triangular	meters		1.00E+01	1.00E+02	n/a	3.00E+01	3.00E+01		These are parameters of a distribution developed by PNNL for modeling purposes (p. 2.27 of report).
37	RPP-6296, Rev. 0	2000	200 West Area	N/A	Small		Calculated			cm		1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02		DL= 150, DT=15. Values listed in Table 6 of report for sandy gravel Unit 5.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results

Table D-11. Fraction of Organic Carbon – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	299-W11-30, 299-W11-32	Small	9	Laboratory	9		%		0.00E+00	5.15E-01	8.32E-02	2.20E-02	#NUM!	1.64E-01	TOC analyses summarized in Figures 4.5 and 4.6.
57	DOE/RL-2006-51, Draft A	2006	200 West Area	299-W15-46	Small	4	Laboratory	4		µg/kg		3.95E+04	2.80E+05	1.32E+05	7.65E+04	9.46E+04	1.30E+05	Values listed in Appendix B of the report. Only values for soil included.
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	3	Laboratory	3		%		1.70E-02	5.90E-02	3.33E-02	2.40E-02	2.89E-02	2.25E-02	Values listed in Table 6.2 of the report. Value for sample T19 not included since it was from the Lower Mud.

Table D-12. Distribution Coefficient (K_d) – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Compound	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
23	PNNL-13560	2001	Sitewide	N/A	Large				Carbon tetrachloride	Log-triangular	L/KG		1.60E-02	8.30E-01	N/A	1.20E-01	1.20E-01		These are parameters of a distribution developed by PNNL for modeling purposes (p. 2.27 of report).
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	3	Experimentally determined	3	Carbon tetrachloride		L/KG		1.06E-01	3.67E-01	2.06E-01	1.44E-01	1.78E-01	1.41E-01	Values listed in Table 6.7 of the report, and were experimentally derived using Hanford soils.
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	2	Experimentally determined	2	Chloroform		L/KG		8.40E-02	4.32E-01	2.58E-01	2.58E-01	1.90E-01	2.46E-01	Values listed in Table 6.7 of the report, and were experimentally derived using Hanford soils.
37	RPP-6296, Rev. 0	2000	200 West Area	N/A	Medium		Experimentally determined		Cs-137		cm3/g		5.00E+02	5.00E+02	5.00E+02	5.00E+02	5.00E+02		Values listed in Table 5 of report for sandy gravel (Unit 5). Based on PNNL-13037.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.

Table D-13. Soil Bulk Density – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
37	RPP-6296 Rev. 0	2000	WMA-S/SX (tank farms)	699-35-65A, 699-35-69A, 699-35-61A, 299-W10-196	Small	10	Laboratory	10		g/cm3		1.93E+00	2.32E+00	2.13E+00	2.16E+00	2.13E+00	1.11E-01	Data from Table C-1e for upper/middle Ringold sequence.
42	PNL-10422	1995	T Plant	299-W11-32	Small	5	Laboratory	5		g/cm3		1.78E+00	2.12E+00	1.98E+00	1.98E+00	1.97E+00	1.27E-01	Data from Table 4.2 of report.
29	PNNL-14702, Rev. 1	2006	200 West Area		Small	8	Laboratory	8		g/cm3				1.84E+00				Actual data sources unclear. Data from 2 sources cited in report (WMP-17524 and PNNL-13672) have more than eight samples listed for the middle Ringold.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-46, 299-W15-216, 699-48-77A, 299-W22-45	Small	12	Laboratory	12		g/cm3		1.41E+00	2.00E+00	1.74E+00	1.73E+00	1.73E+00	1.68E-01	Data presented in Appendix A, 200 West Area.
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	3	Laboratory	3		g/cm3		2.01E+00	2.12E+00	2.06E+00	2.06E+00	2.06E+00	5.51E-02	Data from Table 6.3. Value for sample T19 not included because it is from Ringold Lower Mud.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.

Table D-14. Soil Particle Size – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	Unit	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	200 West Area (T Plant)	299-W11-32	Small	9	Wet sieve	Sand	9		%		64.000	82.000	72.000	73.000	71.797	5.745	Samples from Well 299-W11-32, Table 4.1 of report.
					Small	9	Wet sieve	Silt	9		%		13.000	27.000	20.667	21.000	20.248	4.243	
					Small	9	Wet sieve	Clay	9		%		5.000	10.000	7.000	6.000	6.752	2.000	
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-246, 299-W15-216, 299-W22-45, 699-48-77A	Small	9	Sieve	Gravel	12		%		0.000	80.000	28.500	21.000	#NUM!	31.286	From Appendix A.
					Small	9	Sieve	Sand	12		%		19.000	88.000	52.167	56.500	47.637	21.281	
					Small	9	Sieve	Silt	12		%		1.000	35.000	17.083	14.500	11.727	12.266	
					Small	9	Sieve	Clay	12		%		0.000	9.000	2.250	0.000		3.334	
58	PNNL-15239	2005	200 West Area	299-W15-46	Small	4	Sieve	Gravel	3		%		1.880	66.500	41.960	57.500	19.300	35.001	Data from Table 6.1, sample D not included since it is from the Ringold lower Mud.
					Small	4	Sieve	Sand	3		%		25.600	83.500	46.033	29.000	39.577	32.492	
					Small	4	Sieve	Silt	3		%		6.020	10.200	8.807	10.200	8.556	2.413	
					Small	4	Sieve	Clay	3		%		1.970	4.420	3.260	3.390	3.091	1.230	

Table D-15. Soil Particle Density – Ringold Unit 5.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
42	PNL-10422	1995	T Plant	299-W11-32	Small	5	Laboratory	5				2.64E+00	2.78E+00	2.68E+00	2.66E+00	2.68E+00	5.67E-02	Data from Table 4.2 of report.
46	WMP-17524, Rev. 0	2003	200 West Area	299-W10-196, 299-W18-46, 299-W15-216, 699-48-77A, 299-W22-45	Small	12	Laboratory	12		g/cm3		2.57E+00	2.82E+00	2.68E+00	2.67E+00	2.68E+00	6.17E-02	Data presented in Appendix A, 200 West Area, porosity.

Table D-16. Total Porosity – Hydraulically Downgradient of 200-ZP-1.

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.1953	0.1953	0.1953	0.1953	0.1953		Data presented in Appendix A, 200 East Area. Only values from 5 m above water table to bottom of borehole included in table.
46	Ringold Lower Mud (Lower Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.6772	0.6772	0.6772	0.6772	0.6772		Data presented in Appendix A, 200 East Area. Only values from 5 m above water table to bottom of borehole included in table.
46	Hanford Gravel	WMP-17524, Rev. 0	2003	200 East Area	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.0641	0.0641	0.0641	0.0641	0.0641		Data presented in Appendix A, 200 East Area. Only values from 5 m above water table to bottom of borehole included in table.
					216-B-57A	Small	1	Calculated ratio	1			0.2051	0.2051	0.2051	0.2051	0.2051		Data presented in Appendix A, 200 East Area. Only values from 5 m above water table to bottom of borehole included in table.
38	Hanford Gravel	WHC-EP-0883 Rev. 0	1995	Downgradient of 200-ZP-1	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1			6.41E-02	6.41E-02	6.41E-02	6.41E-02	6.41E-02		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.
38	Ringold Lower Mud (Lower Ringold)	WHC-EP-0883 Rev. 0	1995	North of 200-ZP-1	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1			6.77E-01	6.77E-01	6.77E-01	6.77E-01	6.77E-01		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.
38	Ringold A (Basal Ringold)	WHC-EP-0883 Rev. 0	1995	Downgradient of 200-ZP-1	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1			1.95E-01	1.95E-01	1.95E-01	1.95E-01	1.95E-01		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.

Table D-17. Effective Porosity – Hydraulically Downgradient of 200-ZP-1.

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55		PNNL-14804	2004	200 East	299-E26-10	Medium	1	Tracer-pumpback test	1			0.373	0.373	0.373	0.373	0.373		Data from Table 6.1 of the report.
55		PNNL-14804	2004	200 East	299-E26-10	Small	1	Pumping test (constant rate)	1			0.128	0.128	0.128	0.128	0.128		Specific yield estimate listed in Table 7.1 of the report.
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.1415	0.1415	0.1415	0.1415	0.1415		Data presented in Appendix A, 200 East Area, porosity. Calculated by CCA based on subtraction of θr from θs. Only values from 5 m above water table to bottom of borehole included in table.
46	Ringold Lower Mud (Lower Ringold)	WMP-17524, Rev. 0	2003	200 East	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.4067	0.4067	0.4067	0.4067	0.4067		Data presented in Appendix A, 200 East Area, porosity. Calculated by CCA based on subtraction of θr from θs. Only values from 5 m above water table to bottom of borehole included in table.
46	Hanford Gravel	WMP-17524, Rev. 0	2003	200 East	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1			0.0567	0.0567	0.0567	0.0567	0.0567		Data presented in Appendix A, 200 East Area, porosity. Calculated by CCA based on subtraction of θr from θs. Only values from 5 m above water table to bottom of borehole included in table.
51		PNNL-13514	2001	North of ZP-1	699-43-44	Small	1	Pumping test (constant rate)	1			0.16	0.16	0.16	0.16	0.16		Specific yield estimate listed in Table 9.1 of the report.
15		PNL-10886	1995	Downgradient of 200-ZP-1	199-K-10, 699-S27-E9A, S22-E9B, S14-20C, 31-53B, 32-72, 47-35C, 55-50A, 62-43B	Medium	9	Pumping test	9			0.02	0.38	0.168889	0.15	0.110868	0.140396	Values listed in Table 2.2 of report. Values are specific yield numbers determined from aquifer tests, and are considered to approximate mobile porosity.
38	Hanford Gravel	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1			5.67E-02	5.67E-02	5.67E-02	5.67E-02	5.67E-02		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0. Calculated by CCA based on subtration of θr from θs.
38	Ringold Lower Mud (Lower Ringold)	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1			4.07E-01	4.07E-01	4.07E-01	4.07E-01	4.07E-01		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0. Calculated by CCA based on subtration of θr from θs.
38	Ringold A (Basal Ringold)	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1			1.42E-01	1.42E-01	1.42E-01	1.42E-01	1.42E-01		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0. Calculated by CCA based on subtration of θr from θs.

Table D-18. Hydraulic Conductivity – Hydraulically Downgradient of 200-ZP-1. (3 sheets)

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
50		PNNL-13378	2001	200 East Area	299-E33-44		1	Slug test (Bouwer and Rice)	1			22.00	22.00	22.00	22.00	22		Value listed in Table 4.1 of report.
50		PNNL-13378	2001	200 East Area	299-E33-44		1	Slug test (type-curve analysis method)	1			24.20	24.20	24.20	24.20	24.2		Value listed in Table 4.1 of report.
51		PNNL-13514	2001	200 East Area	299-E33-334, 299-E33-335, 699-43-44		3	Slug test (Bouwer and Rice)	3		m/day	1.74	49.30	30.95	41.80	15.30585107	25.57018837	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided. Value listed as 89.3 in summary Table 9.1 of report.
51		PNNL-13514	2001	200 East Area	299-E33-334, 299-E33-335, 699-43-44		3	Type-curve analysis method	3		m/day	1.95	52.10	32.85	44.50	16.53525062	27.02864222	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided. Value listed as 89.3 in summary Table 9.1 of report.
51		PNNL-13514	2001	200 East area	699-43-44		1	Pumping test	1		m/day	1.70	1.70	1.70	1.70	1.7		Value listed on Page 7.10 report. Value derived by dividing T by total aquifer thickness.
53		PNNL-14186	2003	North of 200-ZP-1	299-E33-338		1	Slug test (type-curve analysis method)	1			89	89	89	89	89		Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.1 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided. Value listed as 89.3 in summary Table 9.1 of report.
55		PNNL-14804	2004	200 East Area	299-E24-22, 299-E25-93, 299-E27-23		3	Slug test (high-K analysis)	3		m/day	49.30	104	82.30	93.6	78.29223706	29.04806362	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.2 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
55		PNNL-14804	2004	200 East Area	299-E26-10, 299-E26-11		2	Slug test (Bouwer and Rice)	2		m/day	5.85	51.1	28.48	28.475	17.28973684	31.99658185	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.2 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
55		PNNL-14804	2004	200 East Area	299-E26-10, 299-E26-11		2	Type-curve analysis method	2		m/day	6.80	39.8	23.30	23.3	16.45113978	23.33452378	Point value listed in this table is "best estimate" of analysis for each well as listed in Table 4.2 of the report. Average values for the "inner zone" and "outer zone" are included in the point values on wells where two sets of averages were provided.
55		PNNL-14804	2004	200 East Area	299-E26-10		1	Tracer-pumpback test	1		m/day	36.20	36.2	36.20	36.2	36.2		Table 6.1.
55		PNNL-14804	2004	200 East Area	299-E26-10		1	Constant rate pumping	1		m/day	36.2	36.2	36.2	36.2	36.2		Table 7.1.

Table D-18. Hydraulic Conductivity – Hydraulically Downgradient of 200-ZP-1. (3 sheets)

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
49		PNNL-14058	2002	Sitewide		Small		Pumping test or slug test			m/day							12/6/06 e-mail from Paul Thorne states "… only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.
47		PNL-8337	1992	Downgradient of 200-ZP-1	199-H3-2A, H4-10, H4-11, H4-12A, H4-15A, K-10, 299-E27-10, E27-8, E27-9, E28-15, E28-27, E32-4, E33-28, E33-29, E33-30, E34-2, E34-3, 499-S0-7, S1-7A, S1-7B, 699-10-54A, 1-18, 15-26, 17-47, 17-5, 20-20, 2-3, 2-33A, 24-33, 24-34A, 24-35, 25-33A, 26-15, 26-35C, 26-89, 31-31, 31-53B, 32-77, 33-56, 35-9, 36-61A, 37-82A, 40-1, 40-33A, 41-23, 42-12A, 43-43, 43-88, 44-42, 46-21B, 47-35C, 53-55A, 55-50B, 60-57, 61-66, 62-43B, 63-90, 65-50, 71-52, 71-77, 8-17, 8-32, S12-3, S3-25, S8-19	Small to medium	66	Pumping test or slug test	66		ft/day	1.00	8,600	1,291.25	255	239.229643	2005.522852	Summary of data collected at site from 1957 to 1992. Data summarized in Table 1.
47		PNL-8337	1992	Downgradient of 200-ZP-1	299-E24-19, E25-40, E25-41, E26-9, E26-11, E27-13, E27-14, E27-15, E32-5, E33-33, E34-7, E35-2	Small	12	Slug test (Bouwer and Rice)	12		ft/day	19.00	590	211.92	130	132.6442547	182.8323665	Summary of data collected at site in 1990. Data summarized in Table 2. If range listed, average value calculated by CCA.
15		PNL-10886	1995	Downgradient of 200-ZP-1	199-D2-5, 199-D8-3, 199-F7-1, 199-H4-3, 199-H4-10, H4-12A, H4-15A, K-10, N-14, 299-E28-27, E32-4, E33-28, E33-30, E34-2, E34-3, 399-1-16A, 399-8-2, 499-S1-7B, 699-S30-E15A, S27-E9A, S27-E9D, S22-E9B, S18-E2A, 699-S12-3, 699-S8-19, 1-18, 2-3, 2-7, 2-33A, 8-17, 10-54A, 11-45A, 15-26, 17-47, 699-26-15A, 26-36C, 31-11, 31-31, 31-53B, 33-56, 35-9, 40-1, 40-33A, 42-12A, 46-21B, 47-35C, 48-18, 55-50A, 60-67, 61-66, 62-43B, 63-58, 63-90, 65-50, 71-30, 71-52, 71-77, 72-73	Small to medium	61	Pump testing	61		m/day	2.00	3524	578.22	235.5	153.5977141	802.52586	Data from Appendix C of report. Data listed for wells outside of 200-ZP-1 OU.

Table D-18. Hydraulic Conductivity – Hydraulically Downgradient of 200-ZP-1. (3 sheets)

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	6.30E-07	6.30E-07	6.30E-07	6.30E-07	6.30E-07		Values listed in Appendix A. Only values from 5 m above water table to bottom of borehole included in table.
46	Ringold Lower Mud (Lower Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	1.40E-08	1.40E-08	1.40E-08	1.40E-08	1.40E-08		Values listed in Appendix A. Only values from 5 m above water table to bottom of borehole included in table.
46	Hanford Gravel	WMP-17524, Rev. 0	2003	200 East Area	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	4.10E-04	4.10E-04	4.10E-04	4.10E-04	4.10E-04		Values listed in Appendix A. Only values from 5 m above water table to bottom of borehole included in table.
38	Hanford Gravel	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	216-B-57A	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	4.10E-04	4.10E-04	4.10E-04	4.10E-04	4.10E-04		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.
38	Ringold Lower Mud (Lower Ringold)	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	699-41-35	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	1.40E-08	1.40E-08	1.40E-08	1.40E-08	1.40E-08		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.
38	Ringold A (Basal Ringold)	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1	699-40-36	Small	1	Van Genuchten curve match to sediment sample(s)	1		cm/sec	6.30E-07	6.30E-07	6.30E-07	6.30E-07	6.30E-07		Also known as Khaleel and Freeman (authors). Values in Appendix A downgradient of 200-ZP-1 OU within 5 m above the water table to below the water table. This value also listed in WMP-17524, Rev. 0.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results

Table D-19. Transmissivity – Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55	PNNL-14804	2004	200 West Area	299-E26-10		1	Constant rate pumping	1		m^2/day	71.6	71.6	71.6	71.6	71.6		Data from Table 7.1 of the report
49	PNNL-14058	2002	Sitewide		Small		Pumping tests			m^2/day							12/6/06 e-mail from Paul Thorne states "… only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.
51	PNNL-13514	2001	North of 200-ZP-1	699-43-44	Medium	1	Tracer-pumpback test	1		m^2/day	8.85	8.85	8.85	8.85	8.85		Data from Table 6.1 of the report.
15	PNL-10886	1995	Downgradient of 200-ZP-1	199-D2-5, D8-3, F7-1, H3-2A, H4-10, H4-11, H4-12A, H4-14, H4-15A, H4-3, K-10, N-14, N-15, N-32, 299-E-18-1, E18-3, E25-22, E25-34, E27-10, E27-8, E27-9, E28-15, E28-27, E32-4, E33-28, E33-29, E33-30, E34-2, E24-3, 399-1-10A, 1-13A, 1-14A, 1-16A, 1-18A, 8-2, 499-S1-7A, S1-7B, 699-10-54A, 11-45A, 1-18, 15-15B, 15-26, 17-47, 18-21, 20-20, 2-3, 2-33A, 24-33, 24-34A, 24-35, 26-15A, 26-35C, 2-7, 29-4, 31-11, 31-31, 31-53B, 33-56, 33-72B, 35-9, 40-1, 40-33A, 40-62, 41-23, 42-12A, 42-37, 42-40A, 42-40C, 42-42B, 43-104, 43-41G, 43-42K, 43-43, 46-21B, 47-35C, 48-18, 48-77C, 4-E6, 52-64, 52-67, 53-55A, 55-50A, 55-60A, 57-83A, 60-67, 61-66, 62-43B, 63-58, 63-90, 65-50, 71-30, 71-52, 71-77, 72-73, 8-17, 8-32, 86-60, S12-3, S14-20, S18-E2A, S19-11, S22-E9B, S27-E9D, S30-E15A, S3-25, S8-19, 299-E25-35	Small to medium	107	Pumping test	107		ft^2/day	8.8	41800	4599.895	855	#NUM!	7996.403	Values listed in Appendix C.
47	PNL-8337	1992	Downgradient of 200-ZP-1	199-H3-2A, H4-10, H4-11, H4-12A, H4-15A, K-10, 299-E26-8, E27-10, E27-8, E27-9, E28-15, E28-27, E32-4, E33-28, E33-29, E33-30, E34-2, E34-3, 399-1-4, 8-1, 8-2, 499-S0-7, S1-7A, S1-7B, 699-10-54A, 1-18, 15-26, 17-47, 17-5, 20-20, 2-3, 2-33A, 24-33, 24-34A, 24-35, 25-33A, 26-15, 26-35C, 26-89, 31-31, 31-53B, 32-77, 33-56, 35-9, 36-61A, 37-82A, 40-1, 40-33A, 41-23, 42-12A, 43-43, 43-88, 44-42, 46-21B, 47-35C, 53-55A, 55-50B, 60-57, 61-66, 62-43B, 63-90, 65-50, 71-52, 71-77, 8-17, 8-32, S12-3, S3-25, S8-19, E33-12, 42-40C, 42-42B, 56-53	Small to medium	74	Pumping test or slug test	70		ft^2/day	6.6	400000	53840.29	16950	10560.4103	93376.47	Summary of data collected at site from 1957 to 1992. Data summarized in Table 1..

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.

Table D-20. Aquifer Storage – Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
15	PNL-10886	1995	Downgradient of 200-ZP-1	199-K-10, 699-S27-E9A, S22-E9B, S14-20C, 26-35C, 42-40C, 42-42B, 47-35C	Small to medium	8	Pumping test	8			3.00E-05	2.00E-02	5.83E-03	3.50E-03	0.001590493	0.007109	Storativity (S) data from Table 2.2 of report. Values for wells 199-K-10, 699-26-35C, 699-37-82A, 699-42-40C, and 699-47-35C also included in PNL-8337.
55	PNNL-14804	2004	200 East Area	299-E26-10, 299-E26-11		2	Type-curve analysis	2		1/m	1.00E-05	5.00E-03	2.51E-03	2.51E-03	0.000223607	0.003528	Specific storage data from Table 4.2 of the report.
55	PNNL-14804	2004	200 East Area	299-E26-10		1	Constant rate pumping	1			1.00E-03	1.00E-03	1.00E-03	1.00E-03	0.001		Storativity (S) value listed in Table 7.1 of the report.
49	PNNL-14058	2002	Sitewide		Small		Pumping test										12/6/06 e-mail from Paul Thorne states "... only some of the available test information is included in the tables and the quality of the analysis results have not been evaluated. A lot of the tests have been incorrectly analyzed and the reported values are not valid." Results summarized in Appendix A.
50	PNNL-13378	2001	200 East Area	299-E33-44		1	Slug test (type-curve analysis)	1		1/m	3.30E-05	3.30E-05	3.30E-05	3.30E-05	0.000033		Specific storage value from Table 4.1 of report.
51	PNNL-13514	2001	200 East Area	North of 200-ZP-1		2	Type-curve analysis method	2		1/m	2.00E-05	2.00E-05	2.00E-05	2.00E-05	0.00002	0	Specific storage Table 4.1.
51	PNNL-13514	2001	North of 200-ZP-1	699-43-44		1	Constant rate pumping	1			1.60E-04	1.60E-04	1.60E-04	1.60E-04	0.00016		Value listed on p. 7.10 of report.
47	PNL-8337	1992	Downgradient of 200-ZP-1	199-K-10, 699-26-35C, 31-53B, 37-82A, 42-40C, 47-35C, 53-55A, 55-50B, 62-43B	Small	9	Slug testing	9			7.00E-05	4.50E-01	8.93E-02	2.00E-02	0.013365252	0.149357	Storativity values listed in Table 1 of report. Values for wells 199-K-10, 699-26-35C, 699-37-82A, 699-42-40C, and 699-47-35C also included in PNL-10886.

NOTE: Yellow-highlighted data suspect, incorrect, and values or sources could not be validated, or data based on modeling results.

Table D-21. Hydraulic Gradient - Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55	PNNL-14804	2004	200 East Area	299-E26-9, 299-E26-10, 299-E26-11, 299-E27-10, 299-E34-3, 299-E34-7, 299-E35-2	Medium	8	Trend-surface analysis	8		m/m	8.71E-04	1.04E-03	9.35E-04	9.22E-04	0.000933711	5.79E-05	Data listed in Table 8.2 of the report.
55	PNNL-14804	2004	200 East Area	299-E26-9, 299-E26-10, 299-E26-11, 299-E27-10, 299-E34-3, 299-E35-2	Medium	7	Trend-surface analysis	7		m/m	8.72E-04	1.07E-03	9.49E-04	9.30E-04	0.000947078	7.08E-05	Data listed in Table 8.3 of the report.
55	PNNL-14804	2004	200 East Area	299-E26-9, 299-E26-10, 299-E27-10, 299-E34-3, 299-E34-7, 299-E35-2	Medium	4	Trend-surface analysis	4		m/m	1.51E-04	2.03E-04	1.87E-04	1.96E-04	0.000185972	2.09E-05	Data listed in Table 8.4 of the report.
55	PNNL-14804	2004	200 East Area	299-E26-9, 299-E26-10, 299-E27-10, 299-E34-3, 299-E35-2	Medium	4	Trend-surface analysis	4		m/m	4.59E-05	1.93E-04	1.10E-04	1.10E-04	9.74706E-05	5.85E-05	Data listed in Table 8.5 of the report.
55	PNNL-14804	2004	200 East Area	299-E26-10	Small	1	Tracer-pumpback test	1		m/m	1.90E-04	1.90E-04	1.90E-04	1.90E-04	0.00019		Data from Table 6.1 of the report.

Table D-22. Kn/Kv Anisotropy Ratio - Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55	PNNL-14804	2004	200 East Area	299-E26-10	Small	1	Pumping test (constant rate)	1			1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01		Data from Table 7.1 of report. Report states estimate is not as reliable as estimate of T, K, and Sy.

Table D-23. Groundwater Velocity - Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
55	PNNL-14804	2004	200 East Area	1	Small	1	Tracer-pumpback test	1		m/day	0.018	0.018	0.018	0.018	0.018		Data from Table 6.1 of the report

Table D-24. Fraction of Organic Carbon - Hydraulically Downgradient of 200-ZP-1.

Vista#	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	Notes
59	PNNL-13560	2001	Hanford Site									1.00E-03	1.00E-03	1.00E-03	1.00E-03	0.001		Table 4 maximum.
57	DOE/RL-2006-51, Draft A	2006	200 East Area	C4545	Small					µg/kg		2.24E+05	2.24E+05	2.24E+05	2.24E+05	224000		Table B-15.

Table D-25. Soil Bulk Density - Hydraulically Downgradient of 200-ZP-1.

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	StErr(5)	CoeffVar(6)	Notes
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-40-36	Small	1	Laboratory measurement	1		g/cm3		1.98E+00	1.98E+00	1.98E+00	1.98E+00	1.98				
46	Ringold Lower Mud (Lower Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-41-35	Small	1	Laboratory measurement	1		g/cm3		1.66E+00	1.66E+00	1.66E+00	1.66E+00	1.66				
46	Ringold E (Middle Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-35-65A, 35-69A, 35-61A	Small	5	Laboratory measurement	5		g/cm3		1.80E+00	2.30E+00	1.98E+00	1.92E+00	1.97118544	0.212603			
46	Upper Ringold	WMP-17524, Rev. 0	2003	200 East Area	699-35-68A	Small	1	Laboratory measurement	1		g/cm3		1.73E+00	1.73E+00	1.73E+00	1.73E+00	1.73				
46	Plio-Pleistocene	WMP-17524, Rev. 0	2003	200 East Area	699-35-69A	Small	1	Laboratory measurement	1		g/cm3		1.55E+00	1.55E+00	1.55E+00	1.55E+00	1.55				
46	Hanford Gravel	WMP-17524, Rev. 0	2003	North of 200-ZP-1	216-B-57A	Small	1	Laboratory measurement	1		g/cm3		2.17E+00	2.17E+00	2.17E+00	2.17E+00	2.17				
46	Hanford Sand	WMP-17524, Rev. 0	2003	200 East Area	699-36-63A, 35-61A	Small	2	Laboratory measurement	2		g/cm3		1.58E+00	1.70E+00	1.64E+00	1.64E+00	1.63890207	0.084853			
57	Hanford Sand	DOE/RL-2006-51, Draft A	2006	200 East Area	C4545	Small	4	Laboratory measurement	4		kg/m3		1.88E+03	2.47E+03	2.15E+03	2.13E+03	2137.45955	282.1293			Table B-20 dry and wet values.

Table D-26. Soil Particle Size - Hydraulically Downgradient of 200-ZP-1.

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	Unit	No. of Analyses	Distribution	Units	StErr(5)
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-40-36	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
46	Ringold Lower Mud	WMP-17524, Rev. 0	2003	200 East, north of 200-ZP-1	699-41-35	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
46	Ringold E (Middle Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-35-65A, 35-69A, 35-61A	Small	5	Sieve	Gravel	5		%	
						Small	5	Sieve	Sand	5		%	
						Small	5	Sieve	Silt	5		%	
						Small	5	Sieve	Clay	5		%	
46	Upper Ringold	WMP-17524, Rev. 0	2003	200 East Area	699-35-68A	Small	1	Sieve	Gravel	5		%	
						Small	1	Sieve	Sand	5		%	
						Small	1	Sieve	Silt	5		%	
						Small	1	Sieve	Clay	5		%	
46	Plio-Pleistocene	WMP-17524, Rev. 0	2003	200 East Area	699-35-69A	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
46	Hanford Gravel	WMP-17524, Rev. 0	2003	200 East Area	216-B-57A	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
46	Hanford Sand	WMP-17524, Rev. 0	2003	200 East Area	699-36-63A, 35-61A	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
38	Hanford Gravel	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1 OU	216-B-57A	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
38	Ringold Lower Mud	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1 OU	699-41-35	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	
38	Ringold A (Basal Ringold)	WHC-EP-0883, Rev. 0	1995	Downgradient of 200-ZP-1 OU	699-40-36	Small	1	Sieve	Gravel	1		%	
						Small	1	Sieve	Sand	1		%	
						Small	1	Sieve	Silt	1		%	
						Small	1	Sieve	Clay	1		%	

Table D-27. Soil Particle Density - Hydraulically Downgradient of 200-ZP-1.

Vista#	Unit	Source(s)(3)	Publication Year	Area of Site (and Assumption)	Well(s)	Relative Representative Volume(2)	No. Samples	Type(s) of Analyses	No. of Analyses	Distribution	Units	UCL	Min	Max	Mean	Median	Geomean	StDev(4)	StErr(5)	CoeffVar(6)	Notes
46	Ringold A (Basal Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-40-36	Small	1	Laboratory measurement	1		g/cm3		2.57E+00	2.57E+00	2.57E+00	2.57E+00	2.57				
46	Ringold Lower Mud (Lower Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-41-35	Small	1	Laboratory measurement	1		g/cm3		2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71				
46	Ringold E (Middle Ringold)	WMP-17524, Rev. 0	2003	200 East Area	699-35-65A, 35-69A, 35-61A	Small	5	Laboratory measurement	5		g/cm3		2.68E+00	2.75E+00	2.70E+00	2.69E+00	2.69987505	0.029155			
46	Plio-Pleistocene	WMP-17524, Rev. 0	2003	200 East Area	699-35-69A	Small	1	Laboratory measurement	1		g/cm3		2.69E+00	2.69E+00	2.69E+00	2.69E+00	2.69				
46	Hanford Gravel	WMP-17524, Rev. 0	2003	200 East Area	216-B-57A	Small	1	Laboratory measurement	1		g/cm3		2.73E+00	2.73E+00	2.73E+00	2.73E+00	2.73				
46	Hanford Sand	WMP-17524, Rev. 0	2003	North of 200-ZP-1	699-36-63A, 35-61A	Small	2	Laboratory measurement	2		g/cm3		2.62E+00	2.70E+00	2.66E+00	2.66E+00	2.65969923	0.056569			

Table D-28. Chloroform Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Chloroform (µg/L)
299-W10-1	1859127.174	448603.3187	17
299-W10-14	1857008.077	448191.0164	1
299-W10-17	1859495.753	447805.0296	11
299-W10-19	1858087.458	449596.0168	5.1
299-W10-20	1857770.874	449036.5265	11
299-W10-21	1858867.644	449981.7805	9
299-W10-22	1859683.328	449090.4798	7.8
299-W10-23	1859654.184	448868.3247	14
299-W10-24	1859856.602	448813.9974	1
299-W10-4	1859361.908	448089.9142	20
299-W10-5	1858849.94	447751.178	19
299-W10-8	1859736.517	448854.8175	9
299-W11-10	1863997.292	448194.7631	9.7
299-W11-12	1859993.458	448174.9895	2
299-W11-13	1860558.493	447584.5149	6.3
299-W11-14	1861734.849	449191.8903	12
299-W11-18	1860829.336	450003.9688	12
299-W11-25B	1859944.902	448735.1918	110
299-W11-3	1862337.867	448371.4687	12
299-W11-37	1862316.433	449533.2118	6.3
299-W11-41	1860020.919	448417.0198	1
299-W11-42	1859971.461	448639.7359	12
299-W11-43	1861117.472	449379.1537	54
299-W11-45	1860209	448738.1	65
299-W11-6	1861812.615	447810.2724	12
299-W11-7	1861088.417	448408.9916	8.1
299-W12-1	1864600.103	450150.3989	5.4
299-W13-1	1864001.324	446352.7818	82.3
299-W14-11	1859909.961	447136.9666	17
299-W14-13	1859910.053	447119.7587	1.5
299-W14-14	1859899.121	446787.3217	6.7
299-W14-16	1860236.877	447238.2197	3.6
299-W14-6	1859901.772	446524.1562	6
299-W14-9	1860336.683	445047.3219	11

Table D-28. Chloroform Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Chloroform (µg/L)
299-W15-1	1858770.249	446006.1257	29
299-W15-11	1858304.341	446195.6824	25
299-W15-15	1857243.021	445378.0233	1.7
299-W15-152	1857966.756	444716.9583	4
299-W15-16	1857958.902	445319.4014	25
299-W15-17	1857958.525	445271.2814	2.9
299-W15-2	1857259.284	447296.4709	2.5
299-W15-30	1857951.064	445369.6342	15
299-W15-31A	1858188.885	445721.228	35
299-W15-32	1859489.155	444995.8226	120
299-W15-33	1858373.242	446084.0914	120
299-W15-34	1858964.159	446063.5469	250
299-W15-35	1859377.059	445711.2739	250
299-W15-36	1859490.713	444321.9099	120
299-W15-37	1859302.279	443727.1834	16
299-W15-38	1859618.718	445120.1793	20
299-W15-39	1859639.25	444726.6926	21
299-W15-40	1859092.417	446865.809	26
299-W15-41	1859437.183	446297.2767	12
299-W15-42	1858860.538	444969.6416	680
299-W15-43	1858559.702	446882.4068	29
299-W15-44	1859199.103	446411.4103	22
299-W15-45	1858372.071	446065.9058	30
299-W15-46	1859419.608	444837.2665	1,100
299-W15-47	1859499.07	445020.0089	27
299-W15-49	1857959.539	446104.4556	53
299-W15-50	1859554.909	445506.7205	119
299-W15-6	1859581.291	445059.4609	274
299-W15-7	1859169.126	445931.536	28
299-W15-765	1859238.473	447417.281	36
299-W17-1	1854690.123	443039.5995	2
299-W18-1	1858334.587	444438.7765	12
299-W18-16	1858936.735	444309.1179	120
299-W18-23	1857229.005	444035.982	1.9

Table D-28. Chloroform Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Chloroform (µg/L)
299-W18-24	1858168.341	444048.7051	12
299-W18-27	1857247.562	443655.7433	1.2
299-W18-4	1857954.171	444276.6246	14
299-W19-49	1862096.145	442565.9784	7
299-W19-50	1863314.056	442951.3451	4
299-W6-10	1861588.6	450960.5482	7.7
299-W6-12	1859955.381	451558.0175	0.7
299-W6-7	1861253.823	451569.963	1.2
299-W7-1	1856728.724	451597.2759	0.65
299-W7-11	1857562.558	451560.7767	0.4
299-W7-12	1857085.525	451561.7609	3.8
299-W7-4	1858292.776	450485.4606	6.7
299-W7-5	1858513.429	451559.7531	2.8
299-W7-6	1859110.711	451561.8069	0.23
299-W7-7	1858811.076	451561.0227	1.6
299-W7-8	1859449.67	451562.9584	0.38
299-W7-9	1856441.294	451594.9039	0.23
299-W8-1	1856129.562	451595.6815	0.53
699-19-88	1847539.3	424585.3746	0.23
699-34-88	1847147.057	439468.7602	0.23
699-38-70B	1865052.372	443998.5871	22
699-38-70C	1867070.118	443980.6737	5
699-39-79	1856593.718	444263.7867	0.07
699-40-65	1870263.582	445803.4391	2
699-43-89	1846837.852	448227.4303	0.23
699-44-64	1871356.661	449137.6647	0.82
699-45-69A	1865906.045	450073.506	4.1
699-47-60	1874912.195	452652.4149	0.23
699-48-71	1864786.015	452941.8139	2.1
699-48-77A	1858307.399	452652.825	1
699-48-77D	1858373.258	453146.2984	1
699-49-100C	1834982.341	454406.0236	0.23
699-49-79	1856200.759	453644.4602	0.64
699-50-74	1861412.025	454876.8133	1

Table D-28. Chloroform Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Chloroform (µg/L)
699-50-85	1850817.151	454950.9372	0.23
699-51-75	1860160.571	455728.3733	0.42
699-55-60A	1875202.792	460193.8762	0.26
699-55-89	1846737.048	459971.0322	0.23
299-W11-86	1863989.21	448195.9974	100
299-W14-71	1862641.73	444770.41	27
299-W14-72	1861309.81	446002.62	35.5
299-W11-47	1860015.372	448426.596	144.00000
299-W19-101	1863989.21	448195.9974	8.80000
299-W19-104	1863542.454	443592.126	5.50000
299-W19-105	1862086.663	442077.3311	5.40000
299-W19-107	1863510.072	443588.1234	9.70000
299-W19-46	1862800.31	442395.6375	8.00000
299-W19-48	1862932.396	442669.6855	12.00000
299-W21-2	1863921.436	441514.176	3.60000
299-W22-47	1859933.091	439881.9286	3.90000
299-W22-50	1859918.396	440090.1828	2.30000
299-W22-69	1860825.459	440773.7205	2.00000
299-W22-72	1861014.993	440311.9423	2.00000
299-W22-86	1860848.885	439768.0774	2.00000
299-W22-87	1862009.891	441402.923	2.00000
699-30-66	1870045.407	435495.1592	19.00000
699-36-70B	1864916.841	441685.4027	7.00000

Table D-29. Hexavalent Chromium Data.

Well Name	Easting (ft)	Northing (ft)	Hexavalent Chromium (µg/L)
299-W10-20	1857770.87	449036.53	7.00
299-W10-23	1859654.18	448868.32	75.90
299-W10-28	1859253.34	448522.50	323.00
299-W11-14	1861734.85	449191.89	37.00
299-W11-39	1859931.92	448752.11	88.50
299-W11-41	1860020.92	448417.02	166.00
299-W11-42	1859971.46	448639.74	181.00
299-W11-43	1861117.47	449379.15	43.00
299-W14-11	1859909.96	447136.97	95.00
299-W14-13	1859910.05	447119.76	730.00
299-W14-14	1859899.12	446787.32	4.95
299-W14-15	1859903.38	446950.07	89.80
299-W15-15	1857243.02	445378.02	8.00
299-W15-35	1859377.06	445711.27	16.70
299-W15-42	1858860.54	444969.64	14.00
299-W15-46	1859419.61	444837.27	5.00
299-W15-49	1857959.54	446104.46	3.00
299-W15-50	1859554.91	445506.72	10.00
299-W18-16	1858936.73	444309.12	3.00
299-W7-4	1858292.78	450485.46	5.62
299-W7-7	1858811.08	451561.02	293.00
299-W8-1	1856129.56	451595.68	26.00
299-W11-86	1863989.21	448196.00	27.00
299-W19-48	1862932.40	442669.69	3.00
699-30-66	1870045.41	435495.16	52.60
699-36-70B	1864916.84	441685.40	60.00

Table D-30. Total Chromium Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Total Chromium (µg/L)
299-W10-1	1859127.00	448603.00	22.00
299-W10-17	1859496.00	447805.00	42.00
299-W10-19	1858087.00	449596.00	9.00
299-W10-20	1857771.00	449037.00	9.00
299-W10-21	1858868.00	449982.00	8.00
299-W10-22	1859683.00	449090.00	62.00
299-W10-23	1859654.00	448868.00	67.00
299-W10-24	1859857.00	448814.00	65.00
299-W10-26	1859719.00	447508.00	11.00
299-W10-27	1859721.00	447643.00	12.00
299-W10-28	1859253.00	448522.00	240.00
299-W10-4	1859362.00	448090.00	685.00
299-W10-5	1858850.00	447751.00	3.00
299-W10-8	1859737.00	448855.00	49.00
299-W11-12	1859993.00	448175.00	43.00
299-W11-13	1860558.00	447585.00	11.00
299-W11-14	1861735.00	449192.00	34.00
299-W11-18	1860829.00	450004.00	71.00
299-W11-24	1859947.00	448636.00	32.00
299-W11-37	1862316.00	449533.00	21.00
299-W11-39	1859932.00	448752.00	75.00
299-W11-40	1859992.00	448522.00	57.00
299-W11-41	1860021.00	448417.00	155.00
299-W11-42	1859971.00	448640.00	185.00
299-W11-43	1861117.00	449379.00	4.00
299-W11-7	1861088.00	448409.00	10.00
299-W12-1	1864600.00	450150.00	39.00
299-W13-1	1864001.00	446353.00	4.00
299-W14-11	1859910.00	447137.00	52.00
299-W14-13	1859910.00	447120.00	573.00
299-W14-14	1859899.00	446787.00	4.00
299-W14-15	1859903.00	446950.00	43.00
299-W14-16	1860237.00	447238.00	4.00

Table D-30. Total Chromium Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Total Chromium (µg/L)
299-W14-17	1860255.00	446910.00	3.00
299-W14-18	1859896.00	447322.00	7.00
299-W14-19	1859900.00	446636.00	3.00
299-W14-5	1859902.00	446324.00	5.00
299-W14-6	1859902.00	446524.00	4.00
299-W15-15	1857243.00	445378.00	10.00
299-W15-16	1857959.00	445319.00	7.00
299-W15-17	1857959.00	445271.00	7.00
299-W15-2	1857259.00	447296.00	4.00
299-W15-30	1857951.00	445370.00	4.00
299-W15-32	1859489.00	444996.00	6.00
299-W15-35	1859377.00	445711.00	6.00
299-W15-38	1859619.00	445120.00	6.00
299-W15-39	1859639.00	444727.00	7.00
299-W15-40	1859092.00	446866.00	18.00
299-W15-41	1859437.00	446297.00	8.00
299-W15-42	1858861.00	444970.00	6.00
299-W15-43	1858560.00	446882.00	8.00
299-W15-44	1859199.00	446411.00	11.00
299-W15-46	1859420.00	444837.00	19.00
299-W15-49	1857960.00	446104.00	4.00
299-W15-50	1859555.00	445507.00	4.00
299-W15-763	1859607.00	446288.00	4.00
299-W15-765	1859238.00	447417.00	22.00
299-W17-1	1854690.00	443040.00	3.00
299-W18-1	1858335.00	444439.00	7.00
299-W18-16	1858937.00	444309.00	3.00
299-W18-23	1857229.00	444036.00	5.00
299-W18-24	1858168.00	444049.00	7.00
299-W18-27	1857248.00	443656.00	9.00
299-W6-10	1861589.00	450961.00	45.00
299-W7-1	1856729.00	451597.00	9.00
299-W7-11	1857563.00	451561.00	12.00
299-W7-12	1857086.00	451562.00	6.00

Table D-30. Total Chromium Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Total Chromium (µg/L)
299-W7-4	1858293.00	450485.00	4.00
299-W7-5	1858513.00	451560.00	9.00
299-W7-6	1859111.00	451562.00	14.00
299-W7-7	1858811.00	451561.00	91.00
299-W7-8	1859450.00	451563.00	17.00
299-W7-9	1856441.00	451595.00	10.00
299-W8-1	1856130.00	451596.00	6.00
699-19-88	1847539.00	424585.00	4.00
699-39-79	1856594.00	444264.00	6.00
699-43-89	1846838.00	448227.00	3.00
699-45-69A	1865906.00	450074.00	3.00
699-47-60	1874912.00	452652.00	5.00
699-48-71	1864786.00	452942.00	12.00
699-48-77A	1858307.00	452653.00	3.00
699-48-77D	1858373.00	453146.00	9.00
299-W11-45	1860209.00	448738.10	80.30
299-W11-47	1860015.37	448426.60	121.00
299-W19-46	1862800.31	442395.64	3.40
299-W19-48	1862932.40	442669.69	3.30
299-W22-50	1859918.40	440090.18	3.00
699-30-66	1870045.41	435495.16	26.50
699-36-70B	1864916.84	441685.40	17.80

Table D-31. Carbon Tetrachloride Data – 0 to 10 m Below Water Table. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-1	1859127.17	448603.32	330
299-W10-24	1859856.60	448814.00	54
299-W10-8	1859736.52	448854.82	320
299-W11-12	1859993.46	448174.99	83
299-W11-25B	1859944.90	448735.19	890
299-W11-41	1860020.92	448417.02	99
299-W11-42	1859971.46	448639.74	900
299-W11-43	1861117.47	449379.15	900
299-W11-45	1860209.00	448738.10	1,500
299-W11-47	1860015.37	448426.60	1,400
299-W11-86	1863989.21	448196.00	1,433
299-W13-1	1864001.32	446352.78	51
299-W14-11	1859909.96	447136.97	530
299-W14-14	1859899.12	446787.32	553
299-W14-6	1859901.77	446524.16	245
299-W14-71	1862641.73	444770.41	80.70
299-W14-72	1861309.81	446002.62	86.70
299-W15-1	1858770.25	446006.13	3,321
299-W15-11	1858304.34	446195.68	2,600
299-W15-152	1857966.76	444716.96	38
299-W15-2	1857259.28	447296.47	94
299-W15-30	1857951.06	445369.63	1,542
299-W15-31A	1858188.89	445721.23	2,081
299-W15-34	1858964.16	446063.55	3,200
299-W15-36	1859490.71	444321.91	600
299-W15-37	1859302.28	443727.18	136
299-W15-40	1859092.42	446865.81	3,170
299-W15-42	1858860.54	444969.64	2,800
299-W15-43	1858559.70	446882.41	2,700
299-W15-44	1859199.10	446411.41	3,770
299-W15-46	1859419.61	444837.27	2,430

Table D-31. Carbon Tetrachloride Data – 0 to 10 m Below Water Table. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W15-50	1859554.91	445506.72	1,696
299-W15-6	1859581.29	445059.46	1,000
299-W15-7	1859169.13	445931.54	2,665
299-W15-765	1859238.47	447417.28	3,837
299-W17-1	1854690.12	443039.60	2
299-W18-1	1858334.59	444438.78	250
299-W18-16	1858936.74	444309.12	670
299-W19-104	1863542.45	443592.13	156
299-W19-105	1862086.66	442077.33	88
299-W19-48	1862932.40	442669.69	240
299-W19-49	1862096.15	442565.98	24
299-W19-50	1863314.06	442951.35	35
299-W21-2	1863921.44	441514.18	16
299-W22-47	1859933.09	439881.93	93
299-W22-50	1859918.40	440090.18	13
299-W22-69	1860825.46	440773.72	4
299-W22-72	1861014.99	440311.94	7.8
299-W22-86	1860848.89	439768.08	32
299-W22-87	1862009.89	441402.92	3.80
699-30-66	1870045.41	435495.16	2
699-36-70B	1864916.84	441685.40	14
699-38-70B	1865052.37	443998.59	64
699-38-70C	1867070.12	443980.67	25
699-40-65	1870263.58	445803.44	2
699-50-74	1861412.03	454876.81	1
299-W10-14	1857008.08	448191.02	0.33
299-W10-21	1858867.64	449981.78	610
299-W12-1	1864600.10	450150.40	140
299-W18-22	1857242.45	442880.21	0.33
299-W22-9	1862659.29	439771.86	0.33

Table D-31. Carbon Tetrachloride Data – 0 to 10 m Below Water Table. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W26-12	1859907.60	438614.15	3.80
299-W26-6	1858471.92	437682.86	0.33
299-W26-7	1858019.41	437146.17	0.40
299-W27-1	1862119.37	438812.59	2.30
299-W6-3	1860620.23	450455.56	1.10
299-W6-4	1860666.39	450427.22	11
299-W7-10	1859767.32	450975.26	1.10
299-W7-4	1858292.78	450485.46	630
299-W7-5	1858513.43	451559.75	71
299-W7-6	1859110.71	451561.81	0.79
299-W7-7	1858811.08	451561.02	22
299-W7-8	1859449.67	451562.96	0.33
299-W7-9	1856441.29	451594.90	0.23
299-W8-1	1856129.56	451595.68	3.40
299-W9-1	1855828.49	449552.15	0.70
699-35-66A	1869608.67	439957.27	5
699-35-70	1865371.87	439590.93	3.70
699-35-78A	1857160.28	440521.66	49
699-36-67	1867711.16	441026.05	6.01
699-36-70A	1865044.43	440644.92	9
699-37-68	1867692.04	441696.92	10
699-37-82A	1853365.57	442058.89	0.23
699-38-65	1870370.88	443043.23	0.62
699-39-79	1856593.72	444263.79	2
699-44-64	1871356.66	449137.66	2.30
699-45-69A	1865906.05	450073.51	1.60
699-48-71	1864786.02	452941.81	41
699-51-75	1860160.57	455728.37	0.82
299-W10-29	1856752	448798	91
299-W10-30	1856752	448505	16

Table D-31. Carbon Tetrachloride Data – 0 to 10 m Below Water Table. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-31	1857354	449256	220
299-W15-224	1857490	445838	140
299-W15-94	1857489	444900	1,200
299-W22-86	1860373	439655	32
299-W11-46	1859481	448616	1,000

Table D-32. Carbon Tetrachloride Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-24	1859856.60	448814.00	490
299-W11-25B	1859944.90	448735.19	1,400
299-W11-43	1861117.47	449379.15	980
299-W11-45	1860209.00	448738.10	1,500
299-W11-47	1860015.37	448426.60	1,400
299-W11-86	1863989.21	448196.00	1,200
299-W13-1	1864001.32	446352.78	147
299-W14-14	1859899.12	446787.32	180
299-W14-71	1862641.73	444770.41	79
299-W14-72	1861309.81	446002.62	71
299-W15-1	1858770.25	446006.13	4,152
299-W15-11	1858304.34	446195.68	3,100
299-W15-152	1857966.76	444716.96	95
299-W15-35	1859377.06	445711.27	2,300
299-W15-37	1859302.28	443727.18	132
299-W15-42	1858860.54	444969.64	1,896
299-W15-43	1858559.70	446882.41	3,300
299-W15-45	1858372.07	446065.91	2,000
299-W15-46	1859419.61	444837.27	5,000
299-W15-47	1859499.07	445020.01	1,500
299-W15-49	1857959.54	446104.46	640
299-W15-50	1859554.91	445506.72	1,856
299-W15-6	1859581.29	445059.46	1,100
299-W15-7	1859169.13	445931.54	2,688
299-W17-1	1854690.12	443039.60	2
299-W18-1	1858334.59	444438.78	89
299-W18-16	1858936.74	444309.12	390
299-W19-105	1862086.66	442077.33	24
299-W19-107	1863510.07	443588.12	220
299-W19-46	1862800.31	442395.64	98
299-W19-48	1862932.40	442669.69	240

Table D-32. Carbon Tetrachloride Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W19-49	1862096.15	442565.98	130
299-W19-50	1863314.06	442951.35	120
299-W21-2	1863921.44	441514.18	6.50
299-W22-47	1859933.09	439881.93	145
299-W22-50	1859918.40	440090.18	0.94
299-W22-69	1860825.46	440773.72	4
299-W22-72	1861014.99	440311.94	7.8
299-W22-86	1860848.89	439768.08	32
299-W22-87	1862009.89	441402.92	6.40
699-30-66	1870045.41	435495.16	2.40
699-36-70B	1864916.84	441685.40	14
699-38-70B	1865052.37	443998.59	309
699-38-70C	1867070.12	443980.67	28
699-50-74	1861412.03	454876.81	1
299-W10-29	1856752	448798	91
299-W10-30	1856752	448505	16
299-W10-31	1857354	449256	363
299-W15-224	1857490	445838	140
299-W11-46	1859481	448616	1,000

Table D-33. Carbon Tetrachloride Data – 20 to 30 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-24	1859856.60	448814.00	1,600
299-W11-25B	1859944.90	448735.19	1,500
299-W11-43	1861117.47	449379.15	450
299-W11-45	1860209.00	448738.10	1,175
299-W11-47	1860015.37	448426.60	871
299-W11-86	1863989.21	448196.00	2,300
299-W13-1	1864001.32	446352.78	238
299-W14-11	1859909.96	447136.97	690
299-W14-14	1859899.12	446787.32	380
299-W14-71	1862641.73	444770.41	109
299-W14-72	1861309.81	446002.62	628
299-W15-152	1857966.76	444716.96	190
299-W15-43	1858559.70	446882.41	2,900
299-W15-46	1859419.61	444837.27	5,100
299-W15-49	1857959.54	446104.46	388
299-W15-50	1859554.91	445506.72	1,540
299-W15-6	1859581.29	445059.46	1,700
299-W15-7	1859169.13	445931.54	2,564
299-W17-1	1854690.12	443039.60	2
299-W18-1	1858334.59	444438.78	57
299-W18-16	1858936.74	444309.12	850
299-W19-101	1863313.66	442958.66	69
299-W19-105	1862086.66	442077.33	19
299-W19-107	1863510.07	443588.12	212
299-W19-46	1862800.31	442395.64	46
299-W19-48	1862932.40	442669.69	87
299-W19-49	1862096.15	442565.98	120
299-W21-2	1863921.44	441514.18	17
299-W22-47	1859933.09	439881.93	3.40
299-W22-50	1859918.40	440090.18	1.50
299-W22-69	1860825.46	440773.72	2

Table D-33. Carbon Tetrachloride Data – 20 to 30 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W22-72	1861014.99	440311.94	4.40
299-W22-86	1860848.89	439768.08	2
299-W22-87	1862009.89	441402.92	2
699-30-66	1870045.41	435495.16	2
699-36-70B	1864916.84	441685.40	2
699-38-70B	1865052.37	443998.59	311
699-38-70C	1867070.12	443980.67	32
699-50-74	1861412.03	454876.81	1

Table D-34. Carbon Tetrachloride Data – 30 to 40 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W11-25B	1859944.90	448735.19	1,341
299-W11-45	1860209.00	448738.10	63
299-W11-47	1860015.37	448426.60	380
299-W11-86	1863989.21	448196.00	1,292
299-W13-1	1864001.32	446352.78	1,160
299-W14-11	1859909.96	447136.97	1,200
299-W14-14	1859899.12	446787.32	920
299-W14-71	1862641.73	444770.41	308
299-W14-72	1861309.81	446002.62	731
299-W15-152	1857966.76	444716.96	390
299-W15-43	1858559.70	446882.41	800
299-W15-46	1859419.61	444837.27	32
299-W15-50	1859554.91	445506.72	2,000
299-W15-6	1859581.29	445059.46	2,300
299-W17-1	1854690.12	443039.60	2
299-W18-1	1858334.59	444438.78	57
299-W18-16	1858936.74	444309.12	3
299-W19-101	1863313.66	442958.66	120
299-W19-105	1862086.66	442077.33	2
299-W19-46	1862800.31	442395.64	75
299-W19-49	1862096.15	442565.98	100
299-W21-2	1863921.44	441514.18	16
299-W22-47	1859933.09	439881.93	5.20
299-W22-72	1861014.99	440311.94	7.10
299-W22-86	1860848.89	439768.08	2.50
299-W22-87	1862009.89	441402.92	2
699-30-66	1870045.41	435495.16	2
699-36-70B	1864916.84	441685.40	8.50
699-38-70B	1865052.37	443998.59	470
699-38-70C	1867070.12	443980.67	31
699-40-65	1870263.58	445803.44	2
699-50-74	1861412.03	454876.81	1

Table D-35. Carbon Tetrachloride Data – 40 to 50 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-24	1859856.60	448814.00	780
299-W11-25B	1859944.90	448735.19	1,050
299-W11-43	1861117.47	449379.15	1000
299-W11-45	1860209.00	448738.10	363
299-W11-86	1863989.21	448196.00	486
299-W13-1	1864001.32	446352.78	1,238
299-W14-71	1862641.73	444770.41	1600
299-W14-72	1861309.81	446002.62	930
299-W15-46	1859419.61	444837.27	1,300
299-W15-6	1859581.29	445059.46	1,478
299-W19-107	1863510.07	443588.12	115
299-W19-48	1862932.40	442669.69	100
299-W22-69	1860825.46	440773.72	11
699-30-66	1870045.41	435495.16	5.40
699-36-70B	1864916.84	441685.40	2
699-38-70B	1865052.37	443998.59	428
299-W10-19	1858087.46	449596.02	6.20
299-W10-21	1858867.64	449981.78	2.50
299-W12-1	1864600.10	450150.40	0.15
299-W18-23	1857229.01	444035.98	2.30
299-W6-3	1860620.23	450455.56	1.10
299-W7-10	1859767.32	450975.26	1.10
299-W7-4	1858292.78	450485.46	2.50
299-W9-1	1855828.49	449552.15	0.70
699-38-65	1870370.88	443043.23	0.49
699-38-68A	1867385.72	442688.10	7.60
699-44-64	1871356.66	449137.66	2.30
699-45-69A	1865906.05	450073.51	1.60
699-47-60	1874912.20	452652.41	0.09
699-48-71	1864786.02	452941.81	9.90
699-51-63	1872254.79	456522.74	2

Table D-35. Carbon Tetrachloride Data – 40 to 50 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
699-55-70	1865252.04	460363.14	2.50
699-35-66A	1869608.67	439957.27	2.50
299-W22-19	1862277.20	439550.58	2.56
299-W27-1	1862119.37	438812.59	2.30
299-W26-8	1859070.03	438527.63	0.50
699-35-78A	1857160.28	440521.66	3
299-W11-47	1860015.37	448426.60	22

Table D-36. Carbon Tetrachloride Data – >50 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Carbon Tetrachloride (µg/L)
299-W10-14	1857008.08	448191.02	1
299-W10-24	1859856.60	448814.00	220
299-W11-25B	1859944.90	448735.19	884
299-W11-43	1861117.47	449379.15	1,100
299-W11-45	1860209.00	448738.10	77
299-W11-86	1863989.21	448196.00	160
299-W13-1	1864001.32	446352.78	643
299-W14-14	1859899.12	446787.32	590
299-W14-72	1861309.81	446002.62	988
299-W14-9	1860336.68	445047.32	258
299-W15-17	1857958.53	445271.28	18
299-W15-46	1859419.61	444837.27	206
299-W15-49	1857959.54	446104.46	2.20
299-W15-6	1859581.29	445059.46	1,389
299-W19-48	1862932.40	442669.69	40
299-W22-50	1859918.40	440090.18	5.60
699-38-70B	1865052.37	443998.59	14

Table D-37. Iodine-129 Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Iodine-129 (pCi/L)
299-W11-24	1859946.95	448636.01	0.20666
299-W15-49	1857959.54	446104.46	-0.10842
299-W11-43	1861117.47	449379.15	1.50000
299-W15-34	1858964.16	446063.55	-0.54500
299-W15-41	1859437.18	446297.28	0.02994
299-W15-30	1857951.06	445369.63	-0.31800
299-W10-20	1857770.87	449036.53	-0.01072
299-W11-13	1860558.49	447584.51	0.09271
299-W11-7	1861088.42	448408.99	1.11883
299-W7-5	1858513.43	451559.75	0.02681
299-W7-8	1859449.67	451562.96	-0.04080
299-W8-1	1856129.56	451595.68	-0.03021
699-43-89	1846837.85	448227.43	0.00796
299-W11-18	1860829.34	450003.97	0.71557
299-W15-46	1859419.61	444837.27	0.11082
299-W15-44	1859199.10	446411.41	-0.02066
299-W11-10	1863997.29	448194.76	0.12630
299-W15-15	1857243.02	445378.02	0.01656
699-39-79	1856593.72	444263.79	-0.13300
699-55-60A	1875202.79	460193.88	0.85950
299-W15-765	1859238.47	447417.28	0.05149
299-W11-39	1859931.92	448752.11	3.55000
299-W10-28	1859253.34	448522.50	0.16500
299-W10-5	1858849.94	447751.18	0.01774
299-W11-25B	1859944.90	448735.19	6.66667
299-W10-24	1859856.60	448814.00	0.07989
299-W18-24	1858168.34	444048.71	0.08715
699-44-64	1871356.66	449137.66	-0.01885
299-W14-18	1859896.12	447322.43	0.27858
299-W14-11	1859909.96	447136.97	72.00000
299-W10-26	1859718.71	447507.62	0.01806
299-W15-36	1859490.71	444321.91	0.21800

Table D-37. Iodine-129 Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Iodine-129 (pCi/L)
699-40-65	1870263.58	445803.44	0.00000
299-W10-8	1859736.52	448854.82	0.16097
299-W10-1	1859127.17	448603.32	-0.01628
699-45-69A	1865906.05	450073.51	0.01086
699-48-71	1864786.01	452941.81	0.18663
299-W11-40	1859992.47	448521.63	0.20000
299-W15-50	1859554.91	445506.72	0.15384
299-W18-23	1857229.01	444035.98	0.00416
299-W7-7	1858811.08	451561.02	-0.02198
299-W14-16	1860236.88	447238.22	0.03268
299-W15-40	1859092.42	446865.81	0.03491
299-W17-1	1854690.12	443039.60	0.00285
299-W10-22	1859683.33	449090.48	0.05647
299-W11-37	1862316.43	449533.21	2.21444
299-W14-14	1859899.12	446787.32	0.00281
299-W7-4	1858292.78	450485.46	-0.03120
699-48-77A	1858307.40	452652.83	-0.05130
299-W15-32	1859489.16	444995.82	-0.33950
299-W14-19	1859899.82	446636.44	0.08150
299-W12-1	1864600.10	450150.40	1.63000
299-W14-13	1859910.05	447119.76	26.32143
299-W14-5	1859901.94	446324.14	0.01010
299-W14-6	1859901.77	446524.16	-0.03378
299-W6-7	1861253.82	451569.96	0.13310
299-w14-15	1859903.38	446950.07	1.51600
699-38-70C	1867070.12	443980.67	0.66666
299-W15-2	1857259.28	447296.47	0.01360
299-W15-16	1857958.90	445319.40	-0.00416
299-W7-1	1856728.72	451597.28	0.00347
699-49-100C	1834982.34	454406.02	0.01505
299-W10-21	1858867.64	449981.78	0.03681
299-W11-12	1859993.46	448174.99	0.87675
299-W11-41	1860020.92	448417.02	0.25720
299-W15-33	1858373.24	446084.09	-0.24213

Table D-37. Iodine-129 Data. (3 sheets)

Well Name	Easting (ft)	Northing (ft)	Iodine-129 (pCi/L)
299-W15-35	1859377.06	445711.27	0.04620
299-W13-1	1864001.32	446352.78	0.00000
299-W11-3	1862337.87	448371.47	0.66375
299-W7-12	1857085.52	451561.76	0.00199
699-47-60	1874912.20	452652.41	-0.00873
299-W14-17	1860254.72	446909.70	0.05163
299-W15-17	1857958.52	445271.28	-0.03372
299-W10-19	1858087.46	449596.02	0.02083
299-W10-4	1859361.91	448089.91	0.51364
299-W11-14	1861734.85	449191.89	3.02000
299-W11-6	1861812.61	447810.27	0.56312
299-W10-17	1859495.75	447805.03	0.11100
299-W6-10	1861588.60	450960.55	1.38650
299-W11-42	1859971.46	448639.74	0.21425
299-W18-16	1858936.73	444309.12	0.50000
699-38-70B	1865052.37	443998.59	0.00000
299-W10-23	1859654.18	448868.32	0.15002
299-W11-47	1860015.37	448426.60	0.39500
299-W11-86	1863989.21	448196.00	2.36000
299-W19-46	1862800.31	442395.64	1.16000
299-W19-48	1862932.40	442669.69	1.62000
699-30-66	1870045.41	435495.16	0.58100
699-36-70B	1864916.84	441685.40	0.50500

Table D-38. Methylene Chloride Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Methylene Chloride (µg/L)
299-W10-1	1859127.17	448603.32	1.00
299-W10-14	1857008.08	448191.02	2.00
299-W10-17	1859495.75	447805.03	0.37
299-W10-19	1858087.46	449596.02	7.60
299-W10-20	1857770.87	449036.53	4.50
299-W10-21	1858867.64	449981.78	1.30
299-W10-22	1859683.33	449090.48	1.40
299-W10-23	1859654.18	448868.32	1.10
299-W10-24	1859856.60	448814.00	1.00
299-W10-4	1859361.91	448089.91	0.57
299-W10-5	1858849.94	447751.18	86.00
299-W10-8	1859736.52	448854.82	1.00
299-W11-10	1863997.29	448194.76	1.00
299-W11-12	1859993.46	448174.99	1.00
299-W11-13	1860558.49	447584.51	1.10
299-W11-14	1861734.85	449191.89	0.67
299-W11-18	1860829.34	450003.97	55.00
299-W11-25B	1859944.90	448735.19	8.00
299-W11-3	1862337.87	448371.47	73.00
299-W11-37	1862316.43	449533.21	25.00
299-W11-41	1860020.92	448417.02	1.00
299-W11-42	1859971.46	448639.74	1.00
299-W11-43	1861117.47	449379.15	1.00
299-W11-45	1860209.00	448738.10	1.00
299-W11-6	1861812.62	447810.27	56.00
299-W11-7	1861088.42	448408.99	3.00
299-W12-1	1864600.10	450150.40	0.37
299-W13-1	1864001.32	446352.78	1.00
299-W14-11	1859909.96	447136.97	1.00
299-W14-13	1859910.05	447119.76	0.37
299-W14-14	1859899.12	446787.32	1.00
299-W14-16	1860236.88	447238.22	0.12

Table D-38. Methylene Chloride Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Methylene Chloride (µg/L)
299-W14-6	1859901.77	446524.16	1.00
299-W14-9	1860336.68	445047.32	1.00
299-W15-1	1858770.25	446006.13	7.00
299-W15-11	1858304.34	446195.68	6.00
299-W15-15	1857243.02	445378.02	1.50
299-W15-152	1857966.76	444716.96	1.00
299-W15-16	1857958.90	445319.40	1.90
299-W15-17	1857958.53	445271.28	1.00
299-W15-2	1857259.28	447296.47	1.00
299-W15-30	1857951.06	445369.63	1.00
299-W15-31A	1858188.89	445721.23	7.00
299-W15-32	1859489.16	444995.82	400.00
299-W15-33	1858373.24	446084.09	740.52
299-W15-34	1858964.16	446063.55	353.35
299-W15-35	1859377.06	445711.27	347.64
299-W15-36	1859490.71	444321.91	320.00
299-W15-37	1859302.28	443727.18	5.00
299-W15-38	1859618.72	445120.18	0.30
299-W15-39	1859639.25	444726.69	1.50
299-W15-40	1859092.42	446865.81	1.00
299-W15-41	1859437.18	446297.28	25.00
299-W15-42	1858860.54	444969.64	16.00
299-W15-43	1858559.70	446882.41	1.00
299-W15-44	1859199.10	446411.41	1.00
299-W15-45	1858372.07	446065.91	1.00
299-W15-46	1859419.61	444837.27	77.00
299-W15-47	1859499.07	445020.01	1.00
299-W15-49	1857959.54	446104.46	2.00
299-W15-50	1859554.91	445506.72	1.00
299-W15-6	1859581.29	445059.46	7.00
299-W15-7	1859169.13	445931.54	7.00
299-W15-765	1859238.47	447417.28	1.00
299-W17-1	1854690.12	443039.60	1.40

Table D-38. Methylene Chloride Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Methylene Chloride (µg/L)
299-W18-1	1858334.59	444438.78	58.00
299-W18-16	1858936.74	444309.12	8.00
299-W18-23	1857229.01	444035.98	2.30
299-W18-24	1858168.34	444048.71	18.00
299-W18-27	1857247.56	443655.74	1.90
299-W18-4	1857954.17	444276.62	1.60
299-W19-49	1862096.15	442565.98	1.00
299-W19-50	1863314.06	442951.35	1.00
299-W6-10	1861588.60	450960.55	0.37
299-W6-12	1859955.38	451558.02	0.50
299-W6-7	1861253.82	451569.96	0.37
299-W7-1	1856728.72	451597.28	3.30
299-W7-11	1857562.56	451560.78	0.69
299-W7-12	1857085.53	451561.76	0.80
299-W7-4	1858292.78	450485.46	2.00
299-W7-5	1858513.43	451559.75	3.70
299-W7-6	1859110.71	451561.81	1.40
299-W7-7	1858811.08	451561.02	0.43
299-W7-8	1859449.67	451562.96	0.37
299-W7-9	1856441.29	451594.90	0.37
299-W8-1	1856129.56	451595.68	1.70
699-19-88	1847539.30	424585.37	0.38
699-34-88	1847147.06	439468.76	0.38
699-38-70B	1865052.37	443998.59	0.00
699-38-70C	1867070.12	443980.67	0.00
699-39-79	1856593.72	444263.79	0.30
699-40-65	1870263.58	445803.44	0.00
699-43-89	1846837.85	448227.43	0.37
699-44-64	1871356.66	449137.66	0.37
699-45-69A	1865906.05	450073.51	0.37
699-47-60	1874912.20	452652.41	0.37
699-48-71	1864786.02	452941.81	0.46
699-48-77A	1858307.40	452652.83	1.40

Table D-38. Methylene Chloride Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Methylene Chloride (µg/L)
699-48-77D	1858373.26	453146.30	1.00
699-49-100C	1834982.34	454406.02	1.20
699-49-79	1856200.76	453644.46	0.46
699-50-74	1861412.03	454876.81	1.00
699-50-85	1850817.15	454950.94	0.37
699-51-75	1860160.57	455728.37	0.37
699-55-60A	1875202.79	460193.88	0.67
699-55-89	1846737.05	459971.03	0.37
299-W11-86	1863989.21	448196.00	2.00
299-W19-101	1863313.66	442958.66	1.00
299-W19-46	1862800.31	442395.64	0.35
299-W19-48	1862932.40	442669.69	1.00
299-W22-47	1859933.09	439881.93	1.00
299-W22-50	1859918.40	440090.18	0.37
699-30-66	1870045.41	435495.16	1.00
699-36-70B	1864916.84	441685.40	1.00

Table D-39. Nitrate Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Nitrate (µg/L)
299-W10-1	1859127.174	448603.3187	39,800
299-W10-17	1859495.753	447805.0296	55,800
299-W10-19	1858087.458	449596.0168	12,600
299-W10-20	1857770.874	449036.5265	22,500
299-W10-21	1858867.644	449981.7805	35,200
299-W10-22	1859683.328	449090.4798	66,000
299-W10-23	1859654.184	448868.3247	96,700
299-W10-24	1859856.602	448813.9974	400,000
299-W10-26	1859718.708	447507.6155	36,000
299-W10-27	1859720.588	447642.7333	33,100
299-W10-28	1859253.335	448522.4953	452,000
299-W10-4	1859361.908	448089.9142	1,720,000
299-W10-5	1858849.94	447751.178	21,900
299-W10-8	1859736.517	448854.8175	44,900
299-W11-10	1863997.292	448194.7631	17,000
299-W11-12	1859993.458	448174.9895	35,400
299-W11-13	1860558.493	447584.5149	18,200
299-W11-14	1861734.849	449191.8903	56,000
299-W11-18	1860829.336	450003.9688	38,600
299-W11-24	1859946.946	448636.0089	94,500
299-W11-3	1862337.867	448371.4687	31,200
299-W11-37	1862316.433	449533.2118	43,200
299-W11-39	1859931.92	448752.111	134,000
299-W11-40	1859992.468	448521.6292	352,000
299-W11-41	1860020.919	448417.0198	192,000
299-W11-42	1859971.461	448639.7359	252,000
299-W11-43	1861117.472	449379.1537	317,000
299-W11-6	1861812.615	447810.2724	15,800
299-W11-7	1861088.417	448408.9916	39,900
299-W11-86	1863989.21	448195.9974	105,000
299-W12-1	1864600.103	450150.3989	53,900
299-W13-1	1864001.324	446352.7818	79,200

Table D-39. Nitrate Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Nitrate (µg/L)
299-W14-11	1859909.961	447136.9666	147,000
299-W14-13	1859910.053	447119.7587	131,000
299-W14-14	1859899.121	446787.3217	25,600
299-W14-15	1859903.383	446950.0707	21,600
299-W14-16	1860236.877	447238.2197	20,400
299-W14-17	1860254.721	446909.7	41,100
299-W14-18	1859896.116	447322.4321	34,100
299-W14-19	1859899.823	446636.4427	23,700
299-W14-5	1859901.94	446324.1369	25,500
299-W14-6	1859901.772	446524.1562	25,800
299-W15-1	1858770.249	446006.1257	30,400
299-W15-11	1858304.341	446195.6824	20,700
299-W15-15	1857243.021	445378.0233	29,800
299-W15-16	1857958.902	445319.4014	13,800
299-W15-17	1857958.525	445271.2814	5,900
299-W15-2	1857259.284	447296.4709	3,800
299-W15-30	1857951.064	445369.6342	13,900
299-W15-31A	1858188.885	445721.228	17,600
299-W15-32	1859489.155	444995.8226	75,223.63
299-W15-33	1858373.242	446084.0914	25,074.54
299-W15-34	1858964.159	446063.5469	24,700
299-W15-35	1859377.059	445711.2739	30,270.17
299-W15-36	1859490.713	444321.9099	22,700
299-W15-38	1859618.718	445120.1793	42,800
299-W15-39	1859639.25	444726.6926	5,800
299-W15-40	1859092.417	446865.809	24,900
299-W15-41	1859437.183	446297.2767	22,600
299-W15-42	1858860.538	444969.6416	46,600
299-W15-43	1858559.702	446882.4068	13,1000
299-W15-44	1859199.103	446411.4103	30,900
299-W15-45	1858372.071	446065.9058	32,900
299-W15-46	1859419.608	444837.2665	1,040,000
299-W15-47	1859499.07	445020.0089	85,200
299-W15-49	1857959.539	446104.4556	78,400

Table D-39. Nitrate Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Nitrate (µg/L)
299-W15-50	1859554.909	445506.7205	92,500
299-W15-7	1859169.126	445931.536	43,800
299-W15-763	1859606.54	446287.6999	29,000
299-W15-765	1859238.473	447417.281	42,100
299-W17-1	1854690.123	443039.5995	23,900
299-W18-1	1858334.587	444438.7765	27,000
299-W18-16	1858936.735	444309.1179	877,000
299-W18-23	1857229.005	444035.982	27,600
299-W18-24	1858168.341	444048.7051	19,600
299-W18-27	1857247.562	443655.7433	800
299-W19-46	1862800.31	442395.6375	179,000
299-W19-48	1862932.396	442669.6855	313,000
299-W19-49	1862096.145	442565.9784	15,100
299-W6-10	1861588.6	450960.5482	25,400
299-W6-7	1861253.823	451569.963	32,400
299-W7-1	1856728.724	451597.2759	7,700
299-W7-11	1857562.558	451560.7767	6,700
299-W7-12	1857085.525	451561.7609	8,600
299-W7-4	1858292.776	450485.4606	19,000
299-W7-5	1858513.429	451559.7531	11,400
299-W7-6	1859110.711	451561.8069	1,200
299-W7-7	1858811.076	451561.0227	9,000
299-W7-8	1859449.67	451562.9584	1,800
299-W7-9	1856441.294	451594.9039	6,100
299-W8-1	1856129.562	451595.6815	10,000
699-19-88	1847539.3	424585.3746	510
699-26-89	1846383.102	431019.8237	540
699-30-66	1870045.407	435495.1592	20,700
699-34-88	1847147.057	439468.7602	7,200
699-36-70B	1864916.841	441685.4027	103,000
699-36-93	1842351.597	440995.1908	11,000
699-38-70B	1865052.372	443998.5871	17,300
699-38-70C	1867070.118	443980.6737	202,000
699-39-79	1856593.718	444263.7867	26,100

Table D-39. Nitrate Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Nitrate (µg/L)
699-40-65	1870263.582	445803.4391	247,000
699-43-89	1846837.852	448227.4303	7,200
699-44-64	1871356.661	449137.6647	20,400
699-45-69A	1865906.045	450073.506	1,900
699-47-60	1874912.195	452652.4149	8,500
699-48-71	1864786.015	452941.8139	51,000
699-48-77A	1858307.399	452652.825	250
699-48-77D	1858373.258	453146.2984	370
699-49-100C	1834982.341	454406.0236	3,000
699-49-79	1856200.759	453644.4602	10,900
699-50-85	1850817.151	454950.9372	5,700
699-51-75	1860160.571	455728.3733	670
699-55-60A	1875202.792	460193.8762	8,900
699-55-76	1859325.09	460057.5313	630
699-55-89	1846737.048	459971.0322	980

Table D-40. Tetrachloroethylene Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tetrachloroethylene (µg/L)
299-W10-1	1859127.17	448603.32	1.80
299-W10-14	1857008.08	448191.02	1.00
299-W10-17	1859495.75	447805.03	0.57
299-W10-19	1858087.46	449596.02	0.57
299-W10-20	1857770.87	449036.53	0.73
299-W10-21	1858867.64	449981.78	0.66
299-W10-22	1859683.33	449090.48	0.57
299-W10-23	1859654.18	448868.32	0.81
299-W10-24	1859856.60	448814.00	1.00
299-W10-4	1859361.91	448089.91	0.68
299-W10-8	1859736.52	448854.82	1.00
299-W11-10	1863997.29	448194.76	1.00
299-W11-12	1859993.46	448174.99	1.00
299-W11-13	1860558.49	447584.51	0.57
299-W11-14	1861734.85	449191.89	0.63
299-W11-25B	1859944.90	448735.19	5.00
299-W11-41	1860020.92	448417.02	1.00
299-W11-42	1859971.46	448639.74	1.00
299-W11-43	1861117.47	449379.15	1.00
299-W11-45	1860209.00	448738.10	2.00
299-W11-7	1861088.42	448408.99	0.57
299-W12-1	1864600.10	450150.40	0.57
299-W13-1	1864001.32	446352.78	16.00
299-W14-11	1859909.96	447136.97	1.00
299-W14-13	1859910.05	447119.76	0.57
299-W14-14	1859899.12	446787.32	1.00
299-W14-16	1860236.88	447238.22	0.17
299-W14-6	1859901.77	446524.16	1.00
299-W14-9	1860336.68	445047.32	1.00
299-W15-1	1858770.25	446006.13	5.00
299-W15-1	1858770.25	446006.13	1.00
299-W15-11	1858304.34	446195.68	1.60

Table D-40. Tetrachloroethylene Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tetrachloroethylene (µg/L)
299-W15-15	1857243.02	445378.02	2.00
299-W15-152	1857966.76	444716.96	1.00
299-W15-16	1857958.90	445319.40	0.80
299-W15-17	1857958.52	445271.28	1.00
299-W15-2	1857259.28	447296.47	1.00
299-W15-30	1857951.06	445369.63	1.00
299-W15-30	1857951.06	445369.63	0.44
299-W15-31A	1858188.89	445721.23	1.60
299-W15-31A	1858188.89	445721.23	1.00
299-W15-37	1859302.28	443727.18	1.00
299-W15-38	1859618.72	445120.18	1.00
299-W15-39	1859639.25	444726.69	2.00
299-W15-40	1859092.42	446865.81	1.90
299-W15-42	1858860.54	444969.64	5.00
299-W15-43	1858559.70	446882.41	1.40
299-W15-44	1859199.10	446411.41	2.60
299-W15-45	1858372.07	446065.91	2.50
299-W15-46	1859419.61	444837.27	6.00
299-W15-47	1859499.07	445020.01	2.40
299-W15-49	1857959.54	446104.46	2.00
299-W15-50	1859554.91	445506.72	16.00
299-W15-6	1859581.29	445059.46	1.00
299-W15-7	1859169.13	445931.54	1.70
299-W15-765	1859238.47	447417.28	2.60
299-W17-1	1854690.12	443039.60	2.00
299-W18-1	1858334.59	444438.78	1.00
299-W18-16	1858936.73	444309.12	2.00
299-W18-23	1857229.01	444035.98	0.57
299-W18-27	1857247.56	443655.74	0.67
299-W18-4	1857954.17	444276.62	2.00
299-W19-49	1862096.14	442565.98	1.00
299-W19-50	1863314.06	442951.35	1.00
299-W6-10	1861588.60	450960.55	0.72
299-W6-12	1859955.38	451558.02	0.57

Table D-40. Tetrachloroethylene Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tetrachloroethylene (µg/L)
299-W6-7	1861253.82	451569.96	0.57
299-W7-1	1856728.72	451597.28	0.57
299-W7-11	1857562.56	451560.78	0.57
299-W7-12	1857085.52	451561.76	0.57
299-W7-4	1858292.78	450485.46	0.57
299-W7-5	1858513.43	451559.75	2.80
299-W7-6	1859110.71	451561.81	0.57
299-W7-7	1858811.08	451561.02	0.57
299-W7-8	1859449.67	451562.96	0.57
299-W7-9	1856441.29	451594.90	0.57
299-W8-1	1856129.56	451595.68	0.57
699-19-88	1847539.30	424585.37	0.57
699-34-88	1847147.06	439468.76	0.57
699-38-70B	1865052.37	443998.59	4.00
699-38-70C	1867070.12	443980.67	2.00
699-39-79	1856593.72	444263.79	0.17
699-40-65	1870263.58	445803.44	2.00
699-43-89	1846837.85	448227.43	0.57
699-44-64	1871356.66	449137.66	0.57
699-45-69A	1865906.05	450073.51	0.57
699-47-60	1874912.20	452652.41	0.57
699-48-71	1864786.01	452941.81	0.57
699-48-77A	1858307.40	452652.83	1.00
699-48-77D	1858373.26	453146.30	1.00
699-49-100C	1834982.34	454406.02	0.57
699-49-79	1856200.76	453644.46	0.57
699-50-74	1861412.03	454876.81	1.00
699-50-85	1850817.15	454950.94	0.57
699-51-75	1860160.57	455728.37	0.57
699-55-60A	1875202.79	460193.88	0.36
699-55-89	1846737.05	459971.03	0.57
299-W11-47	1860015.37	448426.60	2.00
299-W11-86	1863989.21	448196.00	2.10
299-W19-101	1863313.66	442958.66	1.00

Table D-40. Tetrachloroethylene Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tetrachloroethylene (µg/L)
299-W19-105	1862086.66	442077.33	2.00
299-W19-46	1862800.31	442395.64	0.17
299-W19-48	1862932.40	442669.69	2.00
299-W21-2	1863921.44	441514.18	2.00
299-W22-47	1859933.09	439881.93	2.00
299-W22-50	1859918.40	440090.18	0.57
299-W22-87	1862009.89	441402.92	2.00
699-30-66	1870045.41	435495.16	2.00
699-36-70B	1864916.84	441685.40	2.00
299-W19-104	1863542.45	443592.13	2.00
299-W19-107	1863510.07	443588.12	2.00
299-W22-69	1860825.46	440773.72	2.00
299-W22-72	1861014.99	440311.94	2.00
299-W22-86	1860848.89	439768.08	2.00

Table D-41. Technetium-99 Data – 0 to 10 m Below Water Table.
(2 sheets)

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W11-25B	1859949.00	448736.00	185,000.00
299-W11-43	1861121.00	449380.00	855.00
299-W11-45	1860213.00	448739.00	23,500.00
299-W11-47	1860019.00	448427.00	4,670.00
299-W14-11	1859914.00	447138.00	4,321.00
299-W14-19	1859904.00	446637.00	265.00
299-W15-43	1858563.00	446883.00	19.00
299-W15-44	1859203.00	446412.00	89.00
299-W15-46	1859423.00	444838.00	54.00
299-W15-50	1859559.00	445508.00	53.00
299-W15-42	1858864.00	444971.00	1.00
299-W14-71	1861310.00	446003.00	82.10
299-W14-72	1862642.00	444770.00	81.00
299-W11-86	1863989.21	448196.00	51.2
299-W19-104	1863542.45	443592.13	58.50
299-W19-105	1862086.66	442077.33	205.00
299-W19-50	1863314.06	442951.35	992.00
299-W21-2	1863921.44	441514.18	0.00
299-W22-50	1859918.40	440090.18	4,240.00
299-W22-69	1860825.46	440773.72	1,080.00
299-W22-72	1861014.99	440311.94	140.00
299-W22-86	1860848.89	439768.08	3,500.00
299-W22-87	1862009.89	441402.92	342.00
699-30-66	1870045.41	435495.16	17.10
699-36-70B	1864916.84	441685.40	358.00
299-W15-94	1857964.50	445014.24	106.00
299-W15-152	1857970.47	444717.8	157.00
299-W10-30	1857226.97	448619.8491	5.13

Table D-41. Technetium-99 Data – 0 to 10 m Below Water Table.
(2 sheets)

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W10-29	1857227.63	448913.189	8.60
299-W10-31	1857829.50	449371.2	9.50
299-W15-224	1857965.52	445951.706	140.00
299-W19-48	1862936.12	442670.5709	325.00
299-W11-46	1859956.89	448731.2008	101,000.00

Table D-42. Technetium-99 Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W11-25B	1859949.00	448736.00	153,000.00
299-W11-43	1861121.00	449380.00	645.00
299-W11-45	1860213.00	448739.00	23,500.00
299-W11-47	1860019.00	448427.00	4,670.00
299-W14-11	1859914.00	447138.00	2,250.00
299-W14-19	1859904.00	446637.00	25.00
299-W15-42	1858864.00	444971.00	14.00
299-W15-44	1859203.00	446412.00	58.00
299-W15-50	1859559.00	445508.00	52.00
299-W18-16	1858940.00	444310.00	71.00
299-W11-86	1861310.00	446003.00	41.00
299-W14-72	1861310.00	446003.00	65.90
299-W14-71	1862642.00	444770.00	17.00
299-W10-24	1859860.00	448815.00	388.00
299-W14-14	1859903.00	446788.00	555.00
299-W15-49	1857963.00	446105.00	55.00
299-W11-86	1863989.21	448196.00	51.20
299-W19-105	1862086.66	442077.33	120.00
299-W19-107	1863510.07	443588.12	68.30
299-W19-46	1862800.31	442395.64	1,360.00
299-W19-48	1862932.40	442669.69	1,520.00
299-W19-50	1863314.06	442951.35	513.00
299-W21-2	1863921.44	441514.18	0.00
299-W22-50	1859918.40	440090.18	7.03
299-W22-69	1860825.46	440773.72	764.00
299-W22-72	1861014.99	440311.94	140.00
299-W22-86	1860848.89	439768.08	3,500.00
299-W22-87	1862009.89	441402.92	17.10
699-30-66	1870045.41	435495.16	34.20
699-36-70B	1864916.84	441685.40	358.00
299-W10-30	1857227.00	448620.00	5.13
299-W10-29	1857228.00	448913.00	8.60

Table D-42. Technetium-99 Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W10-31	1857830.00	449371.00	9.50
299-W15-224	1857965.50	445951.70	140.00
299-W15-94	1857964.50	445014.20	106.00
299-W15-152	1857970.50	444717.80	157.00
299-W15-224	1857965.50	445951.70	140.00
299-W11-46	1859956.90	448731.20	101,000.00
299-W19-104	1863542.50	443592.10	58.50

Table D-43. Technetium-99 Data – 20 to 30 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W10-24	1859860.00	448815.00	50,600.00
299-W11-25B	1859949.00	448736.00	42,330.00
299-W11-43	1861121.00	449380.00	250.00
299-W11-45	1860213.00	448739.00	710.00
299-W11-47	1860019.00	448427.00	296.00
299-W14-11	1859914.00	447138.00	1,103.00
299-W14-14	1859903.00	446788.00	80.00
299-W14-19	1859904.00	446637.00	37.00
299-W15-43	1858563.00	446883.00	31.00
299-W15-44	1859203.00	446412.00	11.00
299-W15-46	1859423.00	444838.00	555.00
299-W15-49	1857963.00	446105.00	26.00
299-W18-16	1858940.00	444310.00	68.00
299-W11-86	1861310.00	446003.00	45.00
299-W14-72	1861310.00	446003.00	24.00
299-W14-71	1862642.00	444770.00	65.00
299-W19-101	1863313.66	442958.66	85.50
299-W19-105	1862086.66	442077.33	205.00
299-W19-107	1863510.07	443588.12	38.00
299-W19-46	1862800.31	442395.64	715.00
299-W19-48	1862932.40	442669.69	154.00
299-W21-2	1863921.44	441514.18	24.00
299-W22-50	1859918.40	440090.18	-6.06
299-W22-69	1860825.46	440773.72	171.00
299-W22-72	1861014.99	440311.94	342.00
299-W22-86	1860848.89	439768.08	167.00
299-W22-87	1862009.89	441402.92	342.00
699-30-66	1870045.41	435495.16	257.00
699-36-70B	1864916.84	441685.40	17.10

Table D-44. Technetium-99 Data – 30 to 40 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W11-25B	1859949.00	448736.00	39,500.00
299-W11-45	1860213.00	448739.00	855.00
299-W11-47	1860019.00	448427.00	197.00
299-W14-11	1859914.00	447138.00	395.00
299-W14-19	1859904.00	446637.00	44.00
299-W15-43	1858563.00	446883.00	33.00
299-W15-44	1859203.00	446412.00	43.00
299-W15-46	1859423.00	444838.00	11.00
299-W15-50	1859559.00	445508.00	11.00
299-W14-71	1862642.00	444770.00	48.00
299-W14-72	1861310.00	446003.00	171.00
299-W19-101	1863313.66	442958.66	137.00
299-W19-105	1862086.66	442077.33	34.20
299-W19-46	1862800.31	442395.64	215.00
299-W21-2	1863921.44	441514.18	51.30
299-W22-72	1861014.99	440311.94	17.10
299-W22-86	1860848.89	439768.08	113.00
299-W22-87	1862009.89	441402.92	51.30
699-36-70B	1864916.84	441685.40	34.20
299-W11-43	1861121.00	449380.00	250.00
699-30-66	1870045.41	435495.16	12.20

Table D-45 Technetium-99 Data – 40 to 50 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W11-25B	1859949.00	448736.00	30770.00
299-W11-43	1861121.00	449380.00	190.00
299-W11-45	1860213.00	448739.00	125.00
299-W15-46	1859423.00	444838.00	16.00
299-W11-86	1863989.21	448196.00	15.00
299-W14-72	1861310.00	446003.00	170.00
299-W14-71	1862642.00	444770.00	171.00
299-W11-47	1860015.37	448426.60	41.16
299-W11-86	1863989.21	448196.00	17.10
299-W19-107	1863510.07	443588.12	171.00
299-W19-48	1862932.40	442669.69	34.20
299-W22-69	1860825.46	440773.72	17.10
699-30-66	1870045.41	435495.16	342.00
699-36-70B	1864916.84	441685.40	-0.10

Table D-46. Technetium-99 Data – >50 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Technetium-99 (pCi/L)
299-W10-24	1859860.00	448815.00	127.00
299-W11-43	1861121.00	449380.00	220.00
299-W11-45	1860213.00	448739.00	782.00
299-W14-14	1859903.00	446788.00	34.00
299-W15-46	1859423.00	444838.00	3.00
299-W15-49	1857963.00	446105.00	3.00
299-W11-86	1863989.21	448196.00	51.00
299-W14-71	1862642.00	444770.00	170.00
299-W19-48	1862932.40	442669.69	37.00
299-W22-50	1859918.40	440090.18	0.58
299-W11-25B	1859949.00	448736.00	21,600.00
299-W14-72	1861310.00	446003.00	71.00

Table D-47. Trichloroethylene Data – 0 to 10 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W10-1	1859127.17	448603.32	2.00
299-W10-24	1859856.60	448814.00	1.00
299-W10-8	1859736.52	448854.82	2.00
299-W10-8	1859736.52	448854.82	2.00
299-W11-12	1859993.46	448174.99	1.00
299-W11-25B	1859944.90	448735.19	5.00
299-W11-41	1860020.92	448417.02	1.00
299-W11-42	1859971.46	448639.74	4.00
299-W11-43	1861117.47	449379.15	5.00
299-W11-45	1860209.00	448738.10	8.00
299-W11-86	1863989.21	448196.00	3.50
299-W13-1	1864001.32	446352.78	2.00
299-W14-11	1859909.96	447136.97	1.00
299-W14-14	1859899.12	446787.32	1.00
299-W14-6	1859901.77	446524.16	1.00
299-W15-1	1858770.25	446006.13	3.00
299-W15-11	1858304.34	446195.68	2.00
299-W15-152	1857966.76	444716.96	1.00
299-W15-2	1857259.28	447296.47	1.00
299-W15-30	1857951.06	445369.63	1.00
299-W15-31A	1858188.89	445721.23	1.00
299-W15-34	1858964.16	446063.55	6.80
299-W15-35	1859377.06	445711.27	7.90
299-W15-36	1859490.71	444321.91	2.00
299-W15-37	1859302.28	443727.18	1.00
299-W15-40	1859092.42	446865.81	17.00
299-W15-42	1858860.54	444969.64	5.00
299-W15-43	1858559.70	446882.41	7.00
299-W15-44	1859199.10	446411.41	16.00
299-W15-46	1859419.61	444837.27	5.00
299-W15-6	1859581.29	445059.46	9.00
299-W15-7	1859169.13	445931.54	5.00

Table D-47. Trichloroethylene Data – 0 to 10 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W15-765	1859238.47	447417.28	19.00
299-W17-1	1854690.12	443039.60	2.00
299-W18-1	1858334.59	444438.78	25.00
299-W18-16	1858936.74	444309.12	1.00
299-W19-104	1863542.45	443592.13	2.30
299-W19-105	1862086.66	442077.33	2.00
299-W19-49	1862096.15	442565.98	1.00
299-W19-50	1863314.06	442951.35	1.00
299-W21-2	1863921.44	441514.18	2.00
299-W22-47	1859933.09	439881.93	2.00
299-W22-50	1859918.40	440090.18	0.16
299-W22-69	1860825.46	440773.72	2.00
299-W22-72	1861014.99	440311.94	2.00
299-W22-86	1860848.89	439768.08	2.00
299-W22-87	1862009.89	441402.92	2.00
699-30-66	1870045.41	435495.16	2.00
699-38-70B	1865052.37	443998.59	3.00
699-38-70C	1867070.12	443980.67	5.00
699-40-65	1870263.58	445803.44	2.00
699-50-74	1861412.03	454876.81	1.00

Table D-48. Trichloroethylene Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W10-1	1859127.17	448603.32	2.00
299-W10-24	1859856.60	448814.00	1.00
299-W10-8	1859736.52	448854.82	2.00
299-W11-12	1859993.46	448174.99	1.00
299-W11-25B	1859944.90	448735.19	7.00
299-W11-41	1860020.92	448417.02	1.00
299-W11-42	1859971.46	448639.74	4.00
299-W11-43	1861117.47	449379.15	7.00
299-W11-45	1860209.00	448738.10	8.00
299-W11-86	1863989.21	448196.00	3.50
299-W13-1	1864001.32	446352.78	2.00
299-W14-11	1859909.96	447136.97	1.00
299-W14-14	1859899.12	446787.32	1.00
299-W14-6	1859901.77	446524.16	1.00
299-W15-1	1858770.25	446006.13	4.00
299-W15-11	1858304.34	446195.68	2.00
299-W15-152	1857966.76	444716.96	1.00
299-W15-2	1857259.28	447296.47	1.00
299-W15-30	1857951.06	445369.63	1.00
299-W15-31A	1858188.89	445721.23	1.00
299-W15-34	1858964.16	446063.55	6.80
299-W15-35	1859377.06	445711.27	7.90
299-W15-36	1859490.71	444321.91	2.00
299-W15-37	1859302.28	443727.18	1.00
299-W15-40	1859092.42	446865.81	17.00
299-W15-42	1858860.54	444969.64	5.00
299-W15-43	1858559.70	446882.41	7.00
299-W15-44	1859199.10	446411.41	16.00
299-W15-45	1858372.07	446065.91	2.60
299-W15-46	1859419.61	444837.27	147.00
299-W15-47	1859499.07	445020.01	5.50
299-W15-49	1857959.54	446104.46	2.00

Table D-48. Trichloroethylene Data – 10 to 20 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W15-50	1859554.91	445506.72	33.00
299-W15-6	1859581.29	445059.46	12.00
299-W15-7	1859169.13	445931.54	5.00
299-W15-765	1859238.47	447417.28	19.00
299-W17-1	1854690.12	443039.60	2.00
299-W18-1	1858334.59	444438.78	25.00
299-W18-16	1858936.74	444309.12	2.00
299-W19-104	1863542.45	443592.13	2.30
299-W19-105	1862086.66	442077.33	2.00
299-W19-49	1862096.15	442565.98	1.00
299-W19-50	1863314.06	442951.35	6.00
299-W21-2	1863921.44	441514.18	2.00
299-W22-47	1859933.09	439881.93	2.00
299-W22-50	1859918.40	440090.18	0.16
299-W22-69	1860825.46	440773.72	2.00
299-W22-72	1861014.99	440311.94	2.00
299-W22-86	1860848.89	439768.08	2.00
299-W22-87	1862009.89	441402.92	2.00
699-30-66	1870045.41	435495.16	2.00
699-38-70B	1865052.37	443998.59	5.00
699-38-70C	1867070.12	443980.67	9.00
699-40-65	1870263.58	445803.44	2.00
699-50-74	1861412.03	454876.81	1.00

Table D-49. Trichloroethylene Data – 20 to 30 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W11-25B	1859944.90	448735.19	8.00
299-W11-43	1861117.47	449379.15	2.00
299-W11-45	1860209.00	448738.10	11.00
299-W11-47	1860015.37	448426.60	7.50
299-W11-86	1863989.21	448196.00	5.40
299-W13-1	1864001.32	446352.78	2.00
299-W14-11	1859909.96	447136.97	4.00
299-W15-152	1857966.76	444716.96	1.00
299-W15-43	1858559.70	446882.41	6.00
299-W15-46	1859419.61	444837.27	11.00
299-W15-49	1857959.54	446104.46	2.00
299-W15-50	1859554.91	445506.72	26.00
299-W15-6	1859581.29	445059.46	11.00
299-W15-7	1859169.13	445931.54	5.00
299-W17-1	1854690.12	443039.60	2.00
299-W18-1	1858334.59	444438.78	5.00
299-W18-16	1858936.74	444309.12	2.00
299-W19-101	1863313.66	442958.66	4.20
299-W19-105	1862086.66	442077.33	2.00
299-W19-107	1863510.07	443588.12	5.10
299-W19-46	1862800.31	442395.64	2.10
299-W19-48	1862932.40	442669.69	2.40
299-W19-49	1862096.15	442565.98	1.00
299-W21-2	1863921.44	441514.18	2.00
299-W22-47	1859933.09	439881.93	2.00
299-W22-50	1859918.40	440090.18	0.16
299-W22-69	1860825.46	440773.72	2.00
299-W22-72	1861014.99	440311.94	2.00
299-W22-86	1860848.89	439768.08	2.00

Table D-49. Trichloroethylene Data – 20 to 30 m Below Water Table. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W22-87	1862009.89	441402.92	2.00
699-30-66	1870045.41	435495.16	2.00
699-38-70B	1865052.37	443998.59	6.00
699-38-70C	1867070.12	443980.67	8.00
699-50-74	1861412.03	454876.81	1.00

Table D-50. Trichloroethylene Data – 30 to 40 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W11-25B	1859944.90	448735.19	9.00
299-W11-45	1860209.00	448738.10	2.60
299-W11-47	1860015.37	448426.60	3.90
299-W11-86	1863989.21	448196.00	3.70
299-W13-1	1864001.32	446352.78	7.04
299-W14-11	1859909.96	447136.97	7.00
299-W15-152	1857966.76	444716.96	1.00
299-W15-43	1858559.70	446882.41	3.00
299-W15-46	1859419.61	444837.27	3.00
299-W15-50	1859554.91	445506.72	11.00
299-W15-6	1859581.29	445059.46	10.00
299-W17-1	1854690.12	443039.60	2.00
299-W18-1	1858334.59	444438.78	4.00
299-W18-16	1858936.74	444309.12	2.00
299-W19-101	1863313.66	442958.66	4.90
299-W19-105	1862086.66	442077.33	2.00
299-W19-46	1862800.31	442395.64	4.00
299-W19-49	1862096.15	442565.98	2.00
299-W21-2	1863921.44	441514.18	2.00
299-W22-47	1859933.09	439881.93	2.00
299-W22-72	1861014.99	440311.94	2.00
299-W22-86	1860848.89	439768.08	2.00
299-W22-87	1862009.89	441402.92	2.00
699-30-66	1870045.41	435495.16	2.00
699-38-70B	1865052.37	443998.59	8.00
699-38-70C	1867070.12	443980.67	7.00
699-40-65	1870263.58	445803.44	2.00
699-50-74	1861412.03	454876.81	1.00

Table D-51. Trichloroethylene Data – 40 to 50 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W11-25B	1859944.90	448735.19	9.00
299-W11-43	1861117.47	449379.15	2.00
299-W11-45	1860209.00	448738.10	5.40
299-W11-47	1860015.37	448426.60	2.00
299-W11-86	1863989.21	448196.00	2.00
299-W13-1	1864001.32	446352.78	10.20
299-W15-46	1859419.61	444837.27	8.00
299-W15-50	1859554.91	445506.72	5.30
299-W15-6	1859581.29	445059.46	7.00
299-W19-107	1863510.07	443588.12	7.00
299-W19-48	1862932.40	442669.69	3.50
299-W22-69	1860825.46	440773.72	2.00
699-30-66	1870045.41	435495.16	2.00
699-38-70B	1865052.37	443998.59	7.00

Table D-52. Trichloroethylene Data – >50 m Below Water Table.

Well Name	Easting (ft)	Northing (ft)	Trichloroethylene (µg/L)
299-W10-14	1857008.08	448191.02	1.00
299-W11-25B	1859944.90	448735.19	9.00
299-W11-43	1861117.47	449379.15	14.00
299-W11-45	1860209.00	448738.10	2.00
299-W11-86	1863989.21	448196.00	2.00
299-W13-1	1864001.32	446352.78	3.45
299-W14-9	1860336.68	445047.32	6.00
299-W15-17	1857958.53	445271.28	1.00
299-W15-46	1859419.61	444837.27	4.50
299-W15-49	1857959.54	446104.46	2.00
299-W15-6	1859581.29	445059.46	6.00
299-W19-48	1862932.40	442669.69	2.00
299-W22-50	1859918.40	440090.18	0.16
699-38-70B	1865052.37	443998.59	2.00

Table D-53. Tritium Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tritium (pCi/L)
299-W11-24	1859946.95	448636.01	17,300.00
699-26-89	1846383.10	431019.82	17.80
299-W15-49	1857959.54	446104.46	1,330.00
299-W11-43	1861117.47	449379.15	48,000.00
299-W15-34	1858964.16	446063.55	3,275.00
299-W15-41	1859437.18	446297.28	6,716.96
299-W15-30	1857951.06	445369.63	323.40
299-W10-20	1857770.87	449036.53	97.90
299-W11-13	1860558.49	447584.51	8,352.22
299-W11-7	1861088.42	448408.99	18,925.00
299-W6-12	1859955.38	451558.02	434.00
299-W7-5	1858513.43	451559.75	46.30
299-W7-8	1859449.67	451562.96	254.83
299-W8-1	1856129.56	451595.68	-34.80
699-43-89	1846837.85	448227.43	7.00
299-W11-18	1860829.34	450003.97	16,450.00
299-W15-46	1859419.61	444837.27	330.00
299-W15-44	1859199.10	446411.41	3,730.00
299-W15-43	1858559.70	446882.41	3,411.58
299-W11-10	1863997.29	448194.76	174.57
299-W7-11	1857562.56	451560.78	340.00
299-W15-15	1857243.02	445378.02	1,770.00
699-39-79	1856593.72	444263.79	2,053.33
699-48-77D	1858373.26	453146.30	47,000.00
699-55-60A	1875202.79	460193.88	5,000.00
299-W15-765	1859238.47	447417.28	3,350.00
299-W11-39	1859931.92	448752.11	2,780.00
299-W10-28	1859253.34	448522.50	3,490.00
299-W15-42	1858860.54	444969.64	206.00
299-W10-5	1858849.94	447751.18	1,230.00
299-W7-9	1856441.29	451594.90	347.00
299-W11-25B	1859944.90	448735.19	6,798.33

Table D-53. Tritium Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tritium (pCi/L)
299-W10-24	1859856.60	448814.00	3,910.00
299-W18-24	1858168.34	444048.71	2,083.33
699-44-64	1871356.66	449137.66	908.50
699-49-79	1856200.76	453644.46	-0.60
299-W14-18	1859896.12	447322.43	6,630.00
299-W14-11	1859909.96	447136.97	217,000.00
299-W10-26	1859718.71	447507.62	6,210.00
299-W15-36	1859490.71	444321.91	226.00
699-40-65	1870263.58	445803.44	14,483.33
299-W10-8	1859736.52	448854.82	4,710.00
299-W10-1	1859127.17	448603.32	1,620.00
699-45-69A	1865906.05	450073.51	163.00
699-48-71	1864786.01	452941.81	421.00
299-W11-40	1859992.47	448521.63	13,000.00
299-W15-50	1859554.91	445506.72	107.00
299-W18-23	1857229.01	444035.98	1,000.43
299-W7-6	1859110.71	451561.81	347.00
299-W7-7	1858811.08	451561.02	200.83
699-55-76	1859325.09	460057.53	3.59
299-W14-16	1860236.88	447238.22	5,000.00
299-W15-40	1859092.42	446865.81	4,242.17
299-W10-27	1859720.59	447642.73	10,800.00
299-W17-1	1854690.12	443039.60	-13.20
299-W10-22	1859683.33	449090.48	8,190.00
299-W11-37	1862316.43	449533.21	10,500.00
299-W14-14	1859899.12	446787.32	3,630.00
299-W7-4	1858292.78	450485.46	126.00
299-W15-763	1859606.54	446287.70	3,610.00
699-48-77A	1858307.40	452652.83	105,157.35
299-W15-32	1859489.16	444995.82	156.48
299-W14-19	1859899.82	446636.44	3,100.00
299-W12-1	1864600.10	450150.40	8,080.00
299-W14-13	1859910.05	447119.76	1,847,037.04
299-W14-5	1859901.94	446324.14	888.78

Table D-53. Tritium Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tritium (pCi/L)
299-W14-6	1859901.77	446524.16	572.00
299-W6-7	1861253.82	451569.96	10,000.00
299-W14-15	1859903.38	446950.07	43,500.00
699-38-70C	1867070.12	443980.67	9,220.00
299-W15-2	1857259.28	447296.47	120.63
299-W15-16	1857958.90	445319.40	121.00
299-W6-11	1860765.69	451556.92	26,600.00
299-W7-1	1856728.72	451597.28	1.73
699-49-100C	1834982.34	454406.02	-210.00
299-W15-39	1859639.25	444726.69	-39.00
299-W10-21	1858867.64	449981.78	522.00
299-W11-12	1859993.46	448174.99	41,300.00
299-W11-41	1860020.92	448417.02	14,500.00
299-W15-33	1858373.24	446084.09	1,190.00
299-W15-35	1859377.06	445711.27	2,110.00
299-W13-1	1864001.32	446352.78	-22.00
299-W11-3	1862337.87	448371.47	582.00
299-W7-12	1857085.52	451561.76	32.80
699-36-93	1842351.60	440995.19	6.35
699-47-60	1874912.20	452652.41	51.22
299-W14-17	1860254.72	446909.70	2,170.00
299-W15-17	1857958.52	445271.28	140.00
299-W10-19	1858087.46	449596.02	167.76
299-W10-4	1859361.91	448089.91	4,290.00
299-W11-14	1861734.85	449191.89	58,980.00
299-W11-6	1861812.61	447810.27	627.67
299-W10-17	1859495.75	447805.03	8,190.00
699-34-88	1847147.06	439468.76	44.50
299-W6-10	1861588.60	450960.55	26,600.00
699-19-88	1847539.30	424585.37	28.60
699-50-85	1850817.15	454950.94	78.20
699-51-75	1860160.57	455728.37	14.70
299-W11-42	1859971.46	448639.74	5,070.00
299-W18-16	1858936.73	444309.12	450.00

Table D-53. Tritium Data. (4 sheets)

Well Name	Easting (ft)	Northing (ft)	Tritium (pCi/L)
699-38-70B	1865052.37	443998.59	272.00
299-W10-23	1859654.18	448868.32	7,220.00
299-W15-11	1858304.34	446195.68	42.40
299-W11-45	1860209.00	448738.10	665.00
299-W22-50	1859918.40	440090.18	31,400.00
699-36-70B	1864916.84	441685.40	8,800.00
299-W19-48	1862932.40	442669.69	490.00
299-W19-46	1862800.31	442395.64	282.00
699-30-66	1870045.41	435495.16	18,000.00
299-W11-45	1860209.00	448738.10	20,200.00
299-W11-86	1863989.21	448196.00	305.00
299-W11-47	1860015.37	448426.60	19,400.00

Table D-54. Uranium (Total) Data. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Uranium (µg/L)
299-W10-19	1858087.46	449596.02	1.59
299-W10-20	1857770.87	449036.53	1.37
299-W10-21	1858867.64	449981.78	2.14
299-W10-22	1859683.33	449090.48	4.78
299-W10-23	1859654.18	448868.32	1.37
299-W11-14	1861734.85	449191.89	56.60
299-W11-18	1860829.34	450003.97	2.60
299-W11-3	1862337.87	448371.47	9.11
299-W11-37	1862316.43	449533.21	433.00
299-W11-43	1861117.47	449379.15	3.00
299-W11-6	1861812.62	447810.27	1.59
299-W11-7	1861088.42	448408.99	2.08
299-W11-86	1863989.21	448196.00	1.35
299-W12-1	1864600.10	450150.40	1.57
299-W14-14	1859899.12	446787.32	0.87
299-W15-15	1857243.02	445378.02	12.70
299-W15-16	1857958.90	445319.40	1.08
299-W15-17	1857958.53	445271.28	0.92
299-W15-30	1857951.06	445369.63	0.73
299-W15-35	1859377.06	445711.27	1.28
299-W15-46	1859419.61	444837.27	3.00
299-W15-49	1857959.54	446104.46	1.00
299-W15-50	1859554.91	445506.72	1.00
299-W18-16	1858936.74	444309.12	3.00
299-W18-23	1857229.01	444035.98	7.48
299-W18-24	1858168.34	444048.71	0.88
299-W18-27	1857247.56	443655.74	0.93
299-W19-46	1862800.31	442395.64	134.00
299-W19-48	1862932.40	442669.69	147.00
299-W19-49	1862096.15	442565.98	42.00
299-W21-2	1863921.44	441514.18	1.49
299-W6-10	1861588.60	450960.55	2.94

Table D-54. Uranium (Total) Data. (2 sheets)

Well Name	Easting (ft)	Northing (ft)	Uranium (µg/L)
299-W7-1	1856728.72	451597.28	0.82
299-W7-12	1857085.53	451561.76	0.79
299-W7-4	1858292.78	450485.46	1.64
299-W7-5	1858513.43	451559.75	1.12
299-W7-7	1858811.08	451561.02	0.81
299-W7-8	1859449.67	451562.96	0.82
299-W8-1	1856129.56	451595.68	1.10
699-19-88	1847539.30	424585.37	0.65
699-30-66	1870045.41	435495.16	1.47
699-36-70B	1864916.84	441685.40	1.59
699-38-70B	1865052.37	443998.59	1.00
699-38-70C	1867070.12	443980.67	3.00
699-40-65	1870263.58	445803.44	4.00
699-43-89	1846837.85	448227.43	0.72
699-44-64	1871356.66	449137.66	2.28
699-47-60	1874912.20	452652.41	2.97
699-48-71	1864786.02	452941.81	1.20
699-48-77A	1858307.40	452652.83	0.30
699-48-77D	1858373.26	453146.30	1.61
699-49-100C	1834982.34	454406.02	2.40
699-55-60A	1875202.79	460193.88	8.18

Table D-55. Historic Wastewater Discharges Sites Used for Calculations.

Site ID	Area	Start (yr)	Stop (yr)	Operation Time (yrs)
216-S-11	200 West	1954	1984	31
216-S-16D	200 West	1957	1972	16
216-S-17	200 West	1951	1954	4
216-S-5	200 West	1954	1957	4
216-S-6	200 West	1954	1972	19
216-S-7	200 West	1956	1965	10
216-T-19	200 West	1960	1976	17
216-T-4A	200 West	1946	1976	31
216-U-10	200 West	1944	1984	41
216-U-14	200 West	1985	1993	9
216-U-16	200 West	1984	1985	2
216-Z-20	200 West	1981	1993	13

Table D-56. Target Cleanup Levels for Preferred Pump-and-Treat Alternative.

Contaminant	Concentration	Units	Descriptor of Concentration	Comment
Chloroform	17		1E-4 risk	
Carbon tetrachloride	93.9		95% mass	
Chromium (VI)	N/A		N/A	Poorly defined.
I-129	32		1E-4 risk	
Methylene chloride	430		1E-4 risk	
Trichloroethylene (PCE)	8		1E-4 risk	
Tc-99	1,732		1E-4 risk	
Tetrachloroethylene (TCE)	4.2		90% mass	Poorly defined from 40 to 50 m below the water table.
Chromium (total)	20,137		1E-4 risk	
Tritium	83,161		1E-4 risk	
Uranium (total)	47		1E-4 risk	

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Table D-57. Evaluation of Partial Penetration Impacts on Current and Future Groundwater Remedies. (2 sheets)

											Unconfined Calculations[4]			Partial Penetration Evaluation[5,6]							
Well	Type[3]	East	North	Screen Top	Screen Bottom	Screen Length	Rate (2005)	Saturated Thickness	Gradient	HHK	Full Width	Half Width	Stag	Q (HHK X Gradient)	Rate / Q X 1,000	ANISO	PPF (%)	Czw	Czd (%)	STAG	HANTUSH[7]
299-W15-32	RW	1859489	444996	194	234	40	0	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	10	n/a	n/a	n/a	n/a	n/a
299-W15-33	RW	1858373	446084	211	259	47	0	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	10	n/a	n/a	n/a	n/a	n/a
299-W15-34	RW	1858964	446064	210	261	50	-2,977	197	0.0015	60	169	84	26.8	0.09	33.1	10	2	260	8	60	934
299-W15-35	RW	1859377	445711	206	256	50	-7695	197	0.0015	60	436	218	69	0.09	85.5	10	25	609	92	141	934
299-W15-36	RW	1859491	444322	?	?	?	-2,112	197	0.0015	60	120	60	19	0.09	23.5	10	?	?	?	?	934
299-W15-37	RW	1859302	443727	?	?	?	0	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W15-40	RW	1859092	446866	218	253	35	-646	197	0.0015	60	37	18	6	0.09	7.2	10	18	87.5	46	19	934
299-W15-43	RW	1858560	446882	226	261	35	-3,963	197	0.0015	60	224	112	36	0.09	44.0	10	18	326	89	77	934
299-W15-44	RW	1859199	446411	216	251	35	-713	197	0.0015	60	40	20	6	0.09	7.9	10	18	95	92	21	934
299-W15-45[1]	RW	1858372	446066	233	243	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W15-45[2]	RW			243	283	50	-6,784	197	0.0015	60	384	192	61	0.09	75.4	10	25	537	92	125	934
299-W15-47	RW	1859499	445020	218	278	60	-7,127	197	0.0015	60	404	202	64	0.09	79.2	10	30	556	93	127	934
299-W15-6	RW	1859581	445059	?	?	?	0	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W15-765	RW	1859238	447417	220	255	35	-2,168	197	0.0015	60	123	61	20	0.09	24.1	10	18%	223	75%	52.5	934
299-W18-37	IW	1856638	443974	n/a	n/a	n/a	3,885	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W18-39	IW	1856576	443375	n/a	n/a	n/a	0	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W15-29	IW	1856693	444573	n/a	n/a	n/a	19,848	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W18-36	IW	1856652	444288	n/a	n/a	n/a	9,076	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
299-W18-38	IW	1856598	443677	n/a	n/a	n/a	1,271	197	0.0015	60	n/a	n/a	n/a	0.09	n/a	n/a	n/a	n/a	n/a	n/a	n/a
							Total Q_{out}	**-34,186**													
							Total Q_{in}	**34,081**													
							Error	**0.31%**													

NOTES: All units are FEET and DAYS, except where indicated otherwise.

1. Upper screen of well 299-W15-45.
2. Lower screen of well 299-W15-45.
3. RW = recovery well; IW = injection wells.

Table D-57. Evaluation of Partial Penetration Impacts on Current and Future Groundwater Remedies. (2 sheets)

											Unconfined Calculations[4]			Partial Penetration Evaluation[5,6]							
Well	Type[3]	East	North	Screen Top	Screen Bottom	Screen Length	Rate (2005)	Saturated Thickness	Gradient	HHK	Full Width	Half Width	Stag	Q (HHK X Gradient)	Rate / Q X 1,000	ANISO	PPF (%)	Czw	Czd (%)	STAG	HANTUSH[7]

4. Unconfined calculations assume the following:
   - L = 1,000 ft
   - H_1 = 197 ft
   - H_2 = 195.5 ft
   - $H_1 - H_2$ 1.5 ft
   - $(H_1 - H_2)/L$ 0.0015 - $H_1^2 - H_2^2$ 588.75 ft
   - FW_FT = full width in units of feet calculated using:

$$W = \left[\frac{2QL}{K\left(H_1^2 - H_2^2\right)}\right]$$

   - HW_FT= half width in units of feet = W/2
   - STAG = stagnation in units of feet = W/π.
5. Partial penetration factor calculations assume the following:
   - PPF = screen length divided by saturated thickness
     - PPF calculated assuming full screen length is within saturated aquifer
   - CZd = relative maximum capture zone depth
   - CZw = relative maximum capture zone width
   - STAG = stagnation in units of feet
   - Bair and Lahm (1996) assumes B ~ 100 ft: results for CZw and CZs for Hanford are scaled assuming B ~ 200 ft.
6. Where Q/q > 47, CZw and CZd are approximated from Bair and Lahm (1996) using ((Q/q)/47).
7. Hantush guide states that flow is indistinguishable from horizontal at:

$$r = 1.5 \times B \times \sqrt{\frac{K_h}{K_v}}$$

   Hantush guideline is used here as indicator of distance from well at which CZd occurs.

Table D-58. Contaminant Fate and Transport Parameters. (2 sheets)

Remedy	Contaminant	Source Type[1]	Initial Concentration[2]	Units	Units	Retardation Rate[3]	Units	Contaminant Decay Rate	Units
No Action	Carbon tetrachloride	C	5,100	µg/L	-	1.11	-	100	years
	Chloroform	E	1,100	µg/L	-	1.031	-	-	-
	PCE	E	16	µg/L	-	1.36	-	-	-
	Tc-99	E	77,010	pCi	years	-	-	213,000	years
	Tritium	E	1,847,037	pCi	years	-	-	12.3	years
Remedy 1A, B	Carbon tetrachloride	C	7	µg/L	-	1.11	-	100	years
	Chloroform	E	17	µg/L	-	1.031	-	-	-
	PCE	E	8	µg/L	-	1.36	-	-	-
	Tc-99	E	1,732	pCi	years	-	-	213,000	years
	Tritium	E	83,161	pCi	years	-	-	12.3	years
Remedy 2	Carbon tetrachloride	C	5	µg/L	-	1.11	-	100	years
	Chloroform	E	5	µg/L	-	1.031	-	-	-
	PCE	E	5	µg/L	-	1.36	-	-	-
	Tc-99	E	900	pCi	years	-	-	213,000	years
	Tritium	E	20,000	pCi	years	-	-	12.3	years
Remedy 3	Carbon tetrachloride	C	50	µg/L	-	1.11	-	100	years
	Chloroform	E	50	µg/L	-	1.031	-	-	-
	PCE	E	50	µg/L	-	1.36	-	-	-
	Tc-99	E	9,000	pCi	years	-	-	213,000	years
	Tritium	E	200,000	pCi	years	-	-	12.3	years

Table D-58. Contaminant Fate and Transport Parameters. (2 sheets)

Remedy	Contaminant	Source Type[1]	Initial Concentration[2]	Units	Units	Retardation Rate[3]	Units	Contaminant Decay Rate	Units
Selected Remedy A, B	Carbon tetrachloride	C	93.9	µg/L	-	1.11	-	100	years
	Chloroform	E	17	µg/L	-	1.031	-	-	-
	PCE	E	8	µg/L	-	1.36	-	-	-
	Tc-99	E	1,732	pCi	years	-	-	213,000	years
	Tritium	E	83,161	pCi	years	-	-	12.3	years

NOTES:

1. C = constant; E = exponential decay function.
2. Source-term concentration determined as maximum concentration that is not recovered by the corresponding remedy.
3. Sources for decay rate of dissolved species provided in Section 2.5.2 of this report.

PCE = tetrachloroethylene

Contaminant retardatjon calculated assuming first-order decay according to:

$R = 1 + (\rho b)(K_d) / n$

$K_d = (Foc)(Koc)$

where:
- n = porosity
- ρb = bulk density
- Koc = soil organic carbon-water partitioning coefficient
- Foc = mass fraction of soil organic carbon content
- K_d = soil-water partitioning coefficient

and:
- n = 0.20
- ρb = 2.00
- Foc = 1.00E+05 µg/kg

	Carbon Tetrachloride	Chloroform	PCE	Tc-99
Koc (mL/g)	110	31	360	
K_d (L/kg)	0.011	0.0031	0.036	
R	1.11	1.031	1.36	

	T1/2 Years	T1/2 Days	Clambda
Tc-99	213,000	7.7E+07	8.95157E-09
Tritium	12.3	4492.58	0.000154287

APPENDIX E

SUPPLEMENTARY REMEDIAL INVESTIGATION DATA

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TABLE OF CONTENTS

E1.0 ADDITIONAL DATA COLLECTION E-1

E1.1 INTRODUCTION E-1

E1.2 CONTAMINANT OF CONCERN AND DATA SUPPORTING ADDITONAL CONSTITUENTS E-2

E1.3 WELLS INSTALLED POST-REMEDIAL INVESTIGATION REPORT IN THE 200-ZP-1 OPERABLE UNIT E-2

E1.4 WELLS INSTALLED IN THE 200-UP-1 GROUNDWATER OPERABLE UNIT E-2

E2.0 MINIMUMS, MAXIMUMS, AND MEAN VALUES FOR CONSTITUENTS IN THE 200-ZP-1 AND 200-UP-1 GROUNDWATER OPERABLE UNITS E-3

E2.1 MINIMUM, MAXIMUM, AND MEAN VALUES FOR THE ELEVEN TARGETED CONSTITUENTS E-3

E2.1.1 Carbon Tetrachloride E-3
E2.1.2 Technetium-99 ..... E-3
E2.1.3 Trichloroethylene E-4
E2.1.4 Tritium E-4
E2.1.5 Iodine-129 ..... E-4
E2.1.6 Total Chromium E-4
E2.1.7 Hexavalent Chromium E-4
E2.1.8 Nitrogen in Nitrate E-4
E2.1.9 Chloroform E-4
E2.1.10 Methylene Chloride E-5
E2.1.11 Chloromethane E-5

E3.0 DEPTH PROFILES FOR TECHNETIUM-99, CARBON TETRACHLORIDE, AND ITS DEGRADATION PRODUCTS E-5

E3.1 DEPTH PROFILES FOR TECHNETIUM-99 IN 200-ZP-1 AND 200-UP-1 OPERABLE UNIT GROUNDWATER E-5

E3.2 DEPTH PROFILES FOR CARBON TETRACHLORIDE AND DEGRADATION PRODUCTS CHLOROFORM, METHYLENE CHLORIDE, AND CHLOROMETHANE WITHIN 200-ZP-1 AND 200-UP-1 OPERABLE UNIT GROUNDWATER E-6

E4.0 GEOPHYSICAL LOG DATA REPORTS E-6

E5.0 REFERENCES E-7

FIGURES

Figure E-1. Location of 200-ZP-1 and 200-UP-1 Operable Unit Wells Presented in This Appendix. E-9
Figure E-2. Depth Profile for Technetium-99 in Well 299-W11-25B. E-11
Figure E-3. Depth Profile for Technetium-99 in Well 299-W11-43. ..... E-11
Figure E-4. Depth Profile for Technetium-99 in Well 299-W11-47. ..... E-12
Figure E-5. Depth Profile for Technetium-99 in Well 299-W11-86. ..... E-12
Figure E-6. Depth Profile for Technetium-99 in Well 299-W14-71. ..... E-13
Figure E-7. Depth Profile for Technetium-99 in Well 299-W14-72. ..... E-13
Figure E-8. Depth Profile for Technetium-99 in Well 299-W19-104. ..... E-14
Figure E-9. Depth Profile for Technetium-99 in Well 299-W19-105. ..... E-14
Figure E-10. Depth Profile for Technetium-99 in Well 299-W19-107. ..... E-15
Figure E-11. Depth Profile for Technetium-99 in Well 299-W19-48. ..... E-15
Figure E-12. Depth Profile for Technetium-99 in Well 299-W22-69. ..... E-16
Figure E-13. Depth Profile for Technetium-99 in Well 299-W22-72. ..... E-16
Figure E-14. Depth Profile for Technetium-99 in Well 299-W22-86. ..... E-17
Figure E-15. Depth Profile for Technetium-99 in Well 299-W22-87. ..... E-17
Figure E-16. Depth Profile for Technetium-99 in Well 699-30-66. ..... E-18
Figure E-17. Depth Profile for Technetium-99 in Well 699-36-70B. E-18
Figure E-18. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W10-31. ..... E-19
Figure E-19. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-25B. E-19
Figure E-20. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-43. ..... E-20
Figure E-21. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-45. ..... E-20
Figure E-22. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-47. ..... E-21
Figure E-23. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-86. ..... E-21
Figure E-24. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W14-71. ..... E-22
Figure E-25. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W14-72. ..... E-22
Figure E-26. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W15-152. ..... E-23
Figure E-27. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-104. ..... E-23
Figure E-28. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-105. ..... E-24
Figure E-29. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-107. ..... E-24
Figure E-30. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-48. ..... E-25

Figure E-31. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-69. ..... E-25
Figure E-32. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-72. ..... E-26
Figure E-33. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-86. ..... E-26
Figure E-34. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-87. ..... E-27
Figure E-35. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-105. ..... E-27
Figure E-36. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 699-30-66. ..... E-28
Figure E-37. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 699-36-70B. E-28

TABLES

Table E-1. Standards for Chemicals and Radionuclides in 200-ZP-1 Operable Unit Groundwater. E-29
Table E-2 . Well Names, Drill Dates, and Physical Parameters for 200-ZP-1 Operable Unit. E-30
Table E-3. Well Names, Drill Dates, and Physical Parameters for 200-UP-1 Operable Unit. E-31
Table E-4. Maximum Concentrations of Eleven Analytes in 200-ZP-1 and 200-UP-1 Wells. (2 sheets) E-32
Table E-5. Minimum, Maximum, and Mean Values for Carbon Tetrachloride in the 200-ZP-1 and 200-UP-1 Operable Units. E-34
Table E-6. Minimum, Maximum, and Mean Values for Technetium-99 in the 200-ZP-1 and 200-UP-1 Operable Units. E-35
Table E-7. Minimum, Maximum, and Mean Values for Trichloroethylene in the 200-ZP-1 Operable Unit. E-36
Table E-8. Minimum, Maximum, and Mean Values for Tritium in the 200-ZP-1 Operable Unit. E-37
Table E-9. Minimum, Maximum, and Mean Values for Iodine-129 in the 200-ZP-1 Operable Unit. E-38
Table E-10. Minimum, Maximum, and Mean Values for Total Chromium in the 200-ZP-1 Operable Unit. E-39
Table E-11. Minimum, Maximum, and Mean Values for Hexavalent Chromium in the 200-ZP-1 Operable Unit. E-40
Table E-12. Minimum, Maximum, and Mean Values for Nitrate in the 200-ZP-1 Operable Unit. E-41
Table E-13. Minimum, Maximum, and Mean Values for Methylene Chloride in the 200-ZP-1 and 200-UP-1 Operable Units. E-42
Table E-14. Minimum, Maximum, and Mean Values for Chloroform in the 200-ZP-1 and 200-UP-1 Operable Units. E-43

Table E-15. Minimum, Maximum, and Mean Values for Chloromethane in the 200-ZP-1 and 200-UP-1 Operable Units.....E-44

LIST OF TERMS

COC	contaminant of concern
DWS	drinking water standard
FS	feasibility study
FY	fiscal year
MCL	maximum contaminant level
NA	not applicable
ND	no data
OU	operable unit
ppb	parts per billion
RI	remedial investigation
TCE	trichloroethylene
WMA	waste management area

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APPENDIX E
SUPPLEMENTAL REMEDIAL INVESTIGATION DATA

E1.0 ADDITIONAL DATA COLLECTION

E1.1 INTRODUCTION

The purpose of this appendix is to present new groundwater analytical data that were not included in the *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit* (hereinafter referred to as the 200-ZP-1 remedial investigation [RI] report) (DOE/RL-2006-24). Data are summarized in this appendix for 11 targeted constituents: carbon tetrachloride, trichloroethylene [TCE], total chromium, hexavalent chromium, nitrate, technetium-99, iodine-129, tritium, chloroform, methylene chloride, and chloromethane.

Carbon tetrachloride is the primary targeted constituent in this appendix. As described in the baseline human health risk assessment in Appendix A of this feasibility study(FS), carbon tetrachloride is the single contaminant of concern (COC) for the 200-ZP-1 Operable Unit (OU) at this time. The following six additional targeted constituents were detected in the new groundwater samples at concentrations exceeding maximum contaminant levels (MCLs): TCE, total chromium, nitrate, technetium-99, iodine-129, and tritium. Although an MCL is not established for hexavalent chromium, it is a targeted constituent since it is included in total chromium analyses. The MCLs are listed in Table E-1.

The remaining three targeted constituents (chloroform, methylene chloride, and chloromethane) are potential degradation products of carbon tetrachloride. The new groundwater analytical data in this appendix were included in the baseline human health risk assessment of this FS.

One of the objectives of the 200-ZP-1 RI report (DOE/RL-2006-24) was to develop a comprehensive distribution model of the carbon tetrachloride plume underlying the 200-ZP-1 and 200-UP-1 OUs by combining data from both OUs. Carbon tetrachloride is found in groundwater under most of the 200 West Area at concentrations greater than the drinking water standard (DWS) of 5 µg/L. New groundwater analytical data for carbon tetrachloride and its degradation products are presented in this appendix for new wells within both the 200-ZP-1 and 200-UP-1 OUs.

Data from 15 groundwater monitoring wells in the 200-ZP-1 OU are presented in this appendix. Nine of the 15 groundwater monitoring wells were added to the 200-ZP-1 OU following the 200-ZP-1 RI report. The other six wells in the 200-ZP-1 OU were included in the 200-ZP-1 RI report, but analytical data trends for the wells were not available at that time since they were recently installed. These six wells are included here for completeness. The 15 wells in the 200-ZP-1 OU are listed in Table E-2.

Additional data from 11 wells in the 200-UP-1 OU are included in this appendix to help define the carbon tetrachloride groundwater plume. The 11 wells in the 200-UP-1 OU are listed in Table E-3.

The minimum, maximum, and mean value for the 11 targeted constituents (i.e., carbon tetrachloride, six analytes with concentrations exceeding the applicable MCL, hexavalent chromium, and three potential degradation products of carbon tetrachloride) are presented in Section E2.0 for each groundwater monitoring well. Section E3.0 presents depth-distribution

profiles for technetium-99, carbon tetrachloride, and the potential degradation products of carbon tetrachloride. Available references for the geophysical log data reports are presented in Section E4.0 for each well.

E1.2 CONTAMINANT OF CONCERN AND DATA SUPPORTING ADDITONAL CONSTITUENTS

The baseline human health risk assessment in Appendix A of this FS concluded that carbon tetrachloride is the only COC in the 200-ZP-1 OU. Ongoing data collection and evaluation efforts are currently focused on carbon tetrachloride, its potential degradation products, contaminants that exceed MCLs, and hexavalent chromium. The 11 targeted constituents in this appendix are those listed in Table E-1, as well as chloroform, methylene chloride, and chloromethane.

E1.3 WELLS INSTALLED POST-REMEDIAL INVESTIGATION REPORT IN THE 200-ZP-1 OPERABLE UNIT

The 15 groundwater monitoring wells listed below were installed between February 2005 and March 2007 in the 200-ZP-1 OU and are the subject of the analysis presented in the following sections. The geographical locations of these wells are shown in Figure E-1:

- 299-W11-25B
- 299-W11-45
- 299-W10-25
- 299-W10-30
- 299-W11-43
- 299-W11-87
- 299-W15-152
- 299-W15-94.
- 299-W11-46
- 299-W11-47
- 299-W10-29
- 299-W10-31
- 299-W11-86 (DD)
- 299-W14-72 (AA)
- 299-W15-224.

Table E-2 lists the well names, drilling dates, total depth drilled, screened intervals, screened lengths, inside well diameters, depth to the water table, and the status of the wells chosen for analysis in the 200-ZP-1 OU. The status represents whether the well is decommissioned or active. Wells 299-W11-25B, 299-W10-25, and 299-W11-86 were decommissioned and replaced with wells 299-W11-46, 299-W10-31, and 299-W11-87, respectively.

E1.4 WELLS INSTALLED IN THE 200-UP-1 GROUNDWATER OPERABLE UNIT

Analytical results from the following 11 new groundwater monitoring wells in the 200-UP-1 OU are presented in this appendix:

- 699-36-70B
- 699-30-66
- 299-W22-87
- 299-W22-72
- 299-W19-104
- 299-W14-71 (EE)
- 299-W19-48
- 299-W19-105
- 299-W22-69
- 299-W22-86
- 299-W19-107.

The 11 new groundwater monitoring wells in the 200-UP-1 OU are included in this appendix to more fully describe the distribution of carbon tetrachloride in the unconfined aquifer of the 200 West Area. Table E-3 lists the well names, drilling dates, total depth drilled, screened intervals, screened lengths, inside well diameters, depth to the water table, and the status of the wells in the 200-UP-1 OU. Well 299-W19-104 was decommissioned and was replaced with well 299-W19-107. The geographical locations of these wells are shown in Figure E-1.

E2.0 MINIMUMS, MAXIMUMS, AND MEAN VALUES FOR CONSTITUENTS IN THE 200-ZP-1 AND 200-UP-1 GROUNDWATER OPERABLE UNITS

The maximum concentrations of the 11 targeted constituents are presented in Table E-4 for the new groundwater analytical data.

E2.1 MINIMUM, MAXIMUM, AND MEAN VALUES FOR THE ELEVEN TARGETED CONSTITUENTS

Minimum, maximum, and mean values for the 11 targeted constituents are shown in Tables E-5 through E-15; the values are obtained from groundwater analytical data that were reported for the 200-ZP-1 wells listed above in Section E1.3 and/or the 200-UP-1 wells listed in Section E1.4. Tables E-5 and E-6 show the minimum, maximum, and mean values for carbon tetrachloride and technetium-99, respectively, for both 200-ZP-1 and 200-UP-1 OU wells. Tables E-7 through E-12 summarize the same values for TCE, tritium, iodine-129, total chromium, hexavalent chromium, and nitrate, respectively, in 200-ZP-1 wells. Tables E-13 through E-15 present the minimum, maximum, and mean values for the carbon tetrachloride potential degradation products in both 200-ZP-1 and 200-UP-1 OU wells. The only reported targeted constituents for the 200-UP-1 OU wells were technetium-99, carbon tetrachloride, and carbon tetrachloride's potential degradation products..

E2.1.1 Carbon Tetrachloride

The maximum values reported (2,300 µg/L; 1,600 µg/L; 1,500 µg/L; 1,500 µg/L; 1,400 µg/L; 1,200 µg/L; 1,100 µg/L; and 1,000 µg/L) for carbon tetrachloride were in monitoring wells 299-W11-86, 299-W14-71, 299-W11-25B, 299-W11-45, 299-W11-47, 299-W15-94, 299-W11-43, and 299-W11-46, respectively. Five of these wells are located east and northeast of the T Tank Farm (299-W11-25B, 299-W11-43, 299-W11-45, 299-W11-46, and 299-W11-47). The maximum values reported for all other wells range from 5.4 to 988 µg/L. The MCL for carbon tetrachloride is 5.0 µg/L.

E2.1.2 Technetium-99

The maximum values reported (185,000 pCi/L; 101,000 pCi/L; 23,500 pCi/L; and 4,670 pCi/L) for technetium-99 were in monitoring wells 299-W11-25B, 299-W11-46, 299-W11-45, and 299-W11-47, respectively. All four of these wells are located east and northeast of the T Tank Farm. The maximum values reported for all other wells range from 12.2 to 3,500 pCi/L. The MCL for technetium-99 is 900 pCi/L.

E2.1.3 Trichloroethylene

The maximum values reported (14 µg/L, 13 µg/L, 13 µg/L, 12 µg/L, and 9.1 µg/L) for TCE were in monitoring wells 299-W11-43, 299-W11-47, 299-W14-71, 299-W11-45, and 299-W11-25B, respectively. The maximum values reported for all other wells range from 0.32 to 5.52 µg/L. The MCL for TCE is 5.0 µg/L.

E2.1.4 Tritium

The maximum values reported (61,000 pCi/L; 36,300 pCi/L; and 24,800 pCi/L) for tritium were in monitoring wells 299-W11-43, 299-W11-45, and 299-W11-47, respectively. The maximum values reported for all other wells range from 305 to 10,100 pCi/L. The MCL for tritium is 20,000 pCi/L.

E2.1.5 Iodine-129

The maximum values reported (10.9 pCi/L, 4.64 pCi/L, and 3.65 pCi/L) for iodine-129 were in monitoring wells 299-W11-46, and 699-36-70B, and 299-W11-45, respectively. No detected concentrations were reported for iodine-129 other than those listed above. The maximum reported values for all other wells were below laboratory detection limits. The MCL for iodine-129 is 1.0 pCi/L.

E2.1.6 Total Chromium

The maximum value reported (708 µg/L) for total chromium was in monitoring well 299-W11-46. The maximum values reported for all other wells range from 7.4 to 182 µg/L. The MCL for total chromium is 100 µg/L.

E2.1.7 Hexavalent Chromium

The maximum values reported (43 and 27 µg/L) for hexavalent chromium were in monitoring wells 299-W11-43 and 299-W11-86, respectively. No detected concentrations were reported for hexavalent chromium other than those listed above. The maximum reported values for all other wells were below laboratory detection limits. There is no specific MCL for hexavalent chromium.

E2.1.8 Nitrogen in Nitrate

The maximum values reported (863,000 µg/L; 664,000 µg/L; and 619,000 µg/L) for nitrogen in nitrate were in monitoring wells 299-W11-47, 299-W11-25B, and 299-W11-45, respectively. The maximum values reported for all other wells range from 2,940 to 132,000 µg/L. The MCL for nitrogen in nitrate is 10,000 µg/L.

E2.1.9 Chloroform

The maximum values reported (144 µg/L; 110 µg/L; 100 µg/L, and 69 µg/L) for chloroform were in monitoring wells 299-W11-47, 299-W11-25B, 299-W11-86, and 299-W14-72, respectively. The maximum values reported for the other new wells range from 0.4 to 65 µg/L. There is no specific MCL for chloroform.

E2.1.10 Methylene Chloride

The maximum values reported (19 µg/L, 8 µg/L, and 7.2 µg/L) for methylene chloride were in monitoring wells 299-W14-71 and 299-W11-25B, respectively. The maximum values reported for the other new wells range from 0.51 to 2 µg/L. The MCL for methylene chloride is 5.0 µg/L.

E2.1.11 Chloromethane

The maximum values reported (1.3 µg/L, 1.2 µg/L and 0.5 µg/L) for chloromethane were in monitoring wells 299-W19-48, 699-36-70B, and 699-30-66, respectively. No concentrations were reported above laboratory detection limits in the other new wells. There is no specific MCL for chloroform.

E3.0 DEPTH PROFILES FOR TECHNETIUM-99, CARBON TETRACHLORIDE, AND ITS DEGRADATION PRODUCTS

The understanding of contaminant distribution in 200-ZP-1 OU groundwater was refined as additional wells were installed after the *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit* (EPA et al. 1995) was issued. Data were acquired to enhance the evaluation of the vertical distribution of technetium-99, carbon tetrachloride, and its potential degradation products in the saturated zone of the 200-ZP-1 and 200-UP-1 OUs. The three-dimensional distribution of these constituents in groundwater within the unconfined aquifer is based on the analysis of depth-discrete groundwater samples collected during the drilling of new wells in the 200-ZP-1 and 200-UP-1 OUs. The following sections describe changes in the understanding of carbon tetrachloride and technetium-99 distribution in the 200 West Area unconfined aquifer as new data became available.

E3.1 DEPTH PROFILES FOR TECHNETIUM-99 IN 200-ZP-1 AND 200-UP-1 OPERABLE UNIT GROUNDWATER

The three-dimensional distribution of technetium-99 within the 200-ZP-1 OU unconfined aquifer was estimated by collecting depth-discrete groundwater samples from selected wells during drilling. Figures E-2 through E-17 present vertical profiles of the new depth-discrete analytical data for technetium-99 in the 200-ZP-1 and 200-UP-1 OU groundwater monitoring wells.

The depth-discrete analytical data indicate that technetium-99 impacted groundwater in the 200-ZP-1 OU east of Waste Management Area T (WMA-T) and in the vicinity of Waste Management Area TX-TY (WMA-TX/TY). The highest technetium-99 concentrations occur at wells 299-W11-25B (185,000 pCi/L) and 299-W11-47 (approximately 4,000 pCi/L) at depths of 10 m (33 ft) and approximately 15 m (50 ft) below the water table, respectively. The extent of technetium-99 in groundwater for each 10-m (33-ft) depth interval is shown in Figures 2-26 through 2-31 in the main body of this FS. Additional investigation activities are ongoing to further evaluate the extent of technetium-99 groundwater contamination and possible source areas.

E3.2 DEPTH PROFILES FOR CARBON TETRACHLORIDE AND DEGRADATION PRODUCTS CHLOROFORM, METHYLENE CHLORIDE, AND CHLOROMETHANE WITHIN 200-ZP-1 AND 200-UP-1 OPERABLE UNIT GROUNDWATER

The extent of carbon tetrachloride in groundwater for each 10-m (33-ft) depth interval is shown in Figures 2-8 through 2-13 in the main body of the FS. The isopleths in the figures are based on depth-discrete analytical data that were collected for 10-m (33-ft) intervals of the unconfined aquifer underlying the 200-ZP-1 and 200-UP-1 OUs. The isopleths represent the estimated plume boundaries for the maximum carbon tetrachloride concentrations that were detected in depth-discrete data for each of the selected depth intervals. The plotted depths are the bottom of each sample interval with respect to the water table.

The concentrations used to generate these contours were the maximum concentrations that were detected for each depth interval in each well. The results from the additional sampling show that the highest concentrations of carbon tetrachloride in groundwater within the 200-ZP-1 OU are located east of WMA-T. Wells 299-W11-86 (2,300 µg/L), 299-W11-25B (1,500 µg/L), 299-W11-45 (1,300 µg/L), and 299-W11-43 (1,100 µg/L) show the highest concentrations of carbon tetrachloride at 28 m (90 ft), 24 m (80 ft), 19 m (60 ft), and 55 m (180 ft) below the water table, respectively. Plots of the depth-discrete data for carbon tetrachloride and its potential degradation compounds (i.e., chloroform, methylene chloride, and chloromethane) are shown in Figures E-18 through E-37

E4.0 GEOPHYSICAL LOG DATA REPORTS

Geophysical log data reports present the following information: well casing diameter and type, type of logging system used, pertinent log-run information (start and finish depth, and sample intervals), and graphic results from logging. The references for log data reports are provided below for each well (if available):

- 299-W19-48 (C4300), DOE-EM/GJ772-2004
- 299-W11-25B (C4669), DOE-EM/GJ837-2005
- 299-W11-43 (C4694), DOE-EM/GJ936-2005
- 299-W10-29 (C4988), DOE-EM/GJ1278-2006
- 299-W10-30 (C4989), DOE-EM/GJ1275-2006
- 299-W10-31 (C5194), DOE-EM/GJ1276-2006
- 299-W11-45 (C4948), DOE-EM/GJ1129-2006
- 299-W11-47 (C4990), HGLP-LDR-012
- 299-W11-86 (C5101), HGLP-LDR-069
- 299-W14-71 (C5102), HGLP-LDR-030
- 299-W14-72 (C5103), HGLP-LDR-039
- 299-W15-94 (C4684), DOE-EM/GJ1247-2006
- 299-W15-152 (C4685), DOE-EM/GJ1248-2006
- 299-W15-224 (C4986), DOE-EM/GJ1249-2006
- 299-W19-107 (C5193), HGLP-LDR-001
- 299-W22-69 (C4969), DOE-EM/GJ1244-2006
- 299-W22-72 (C4970), DOE-EM/GJ1277-2006

- 299-W22-86 (C4971), DOE-EM/GJ1279-2006
- 299-W22-87 (C4977), DOE-EM/GJ1226-2006.

E5.0 REFERENCES

DOE-RL-2006-24, 2006, *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA, Ecology, and DOE, 1995, *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit*, U.S Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

References for Log Data Reports:

DOE-EM/GJ1129-2006, 2006, *299-W11-45 (C4948) Log Data Report*, S. M. Stoller Corporation, Hanford Office, Richland, Washington.

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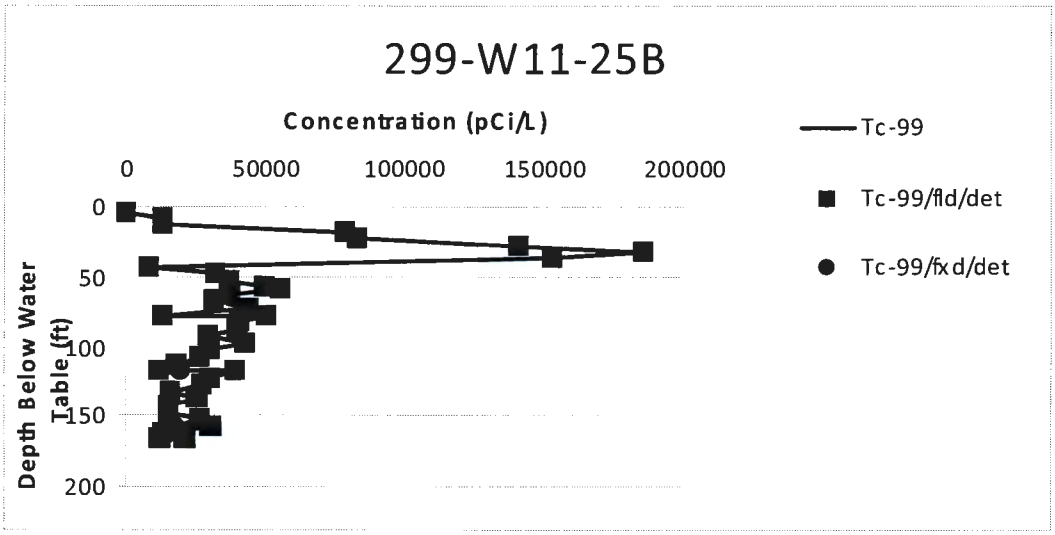
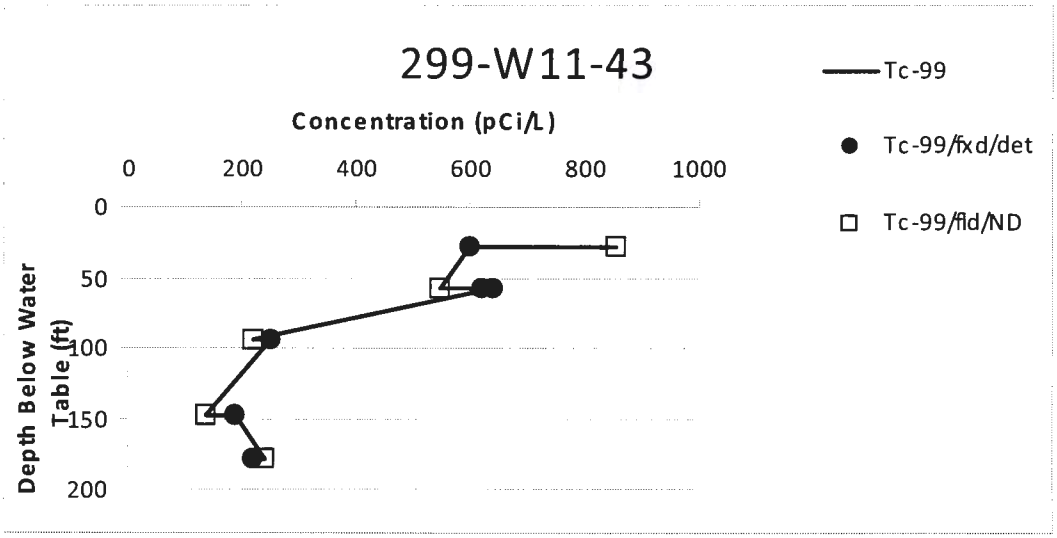
Figure E-1. Location of 200-ZP-1 and 200-UP-1 Operable Unit Wells Presented in This Appendix.

Figure E-2. Depth Profile for Technetium-99 in Well 299-W11-25B.



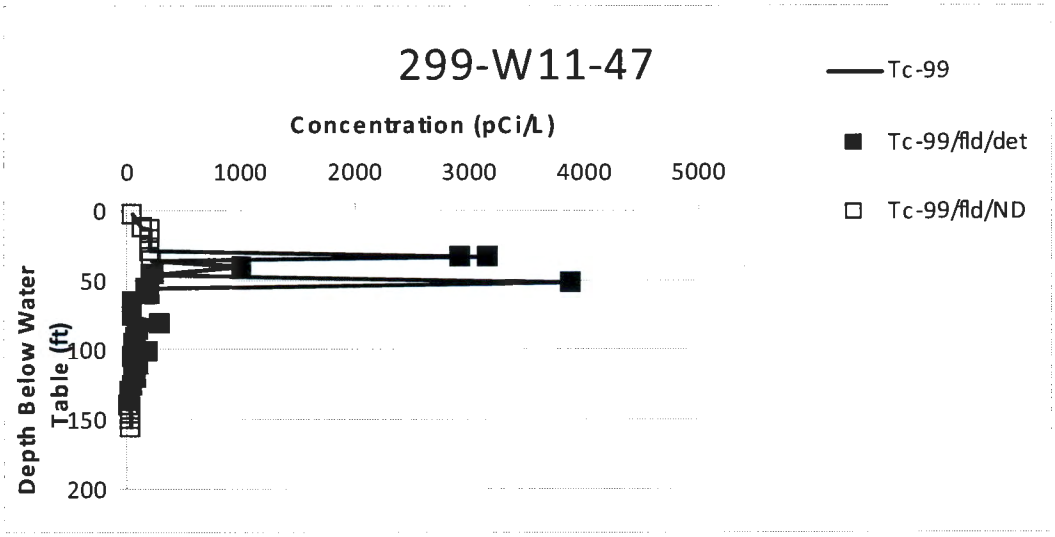
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-3. Depth Profile for Technetium-99 in Well 299-W11-43.



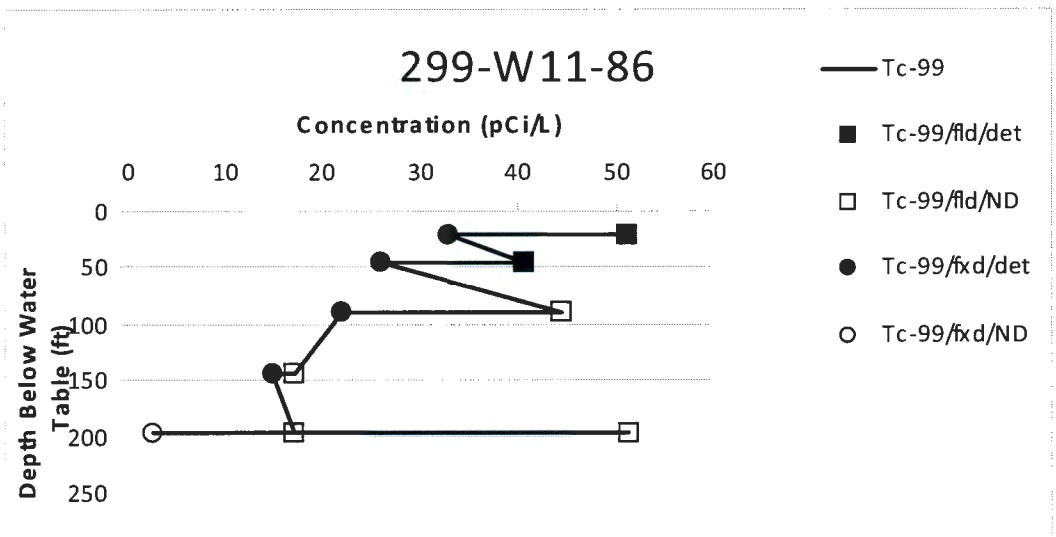
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-4. Depth Profile for Technetium-99 in Well 299-W11-47.



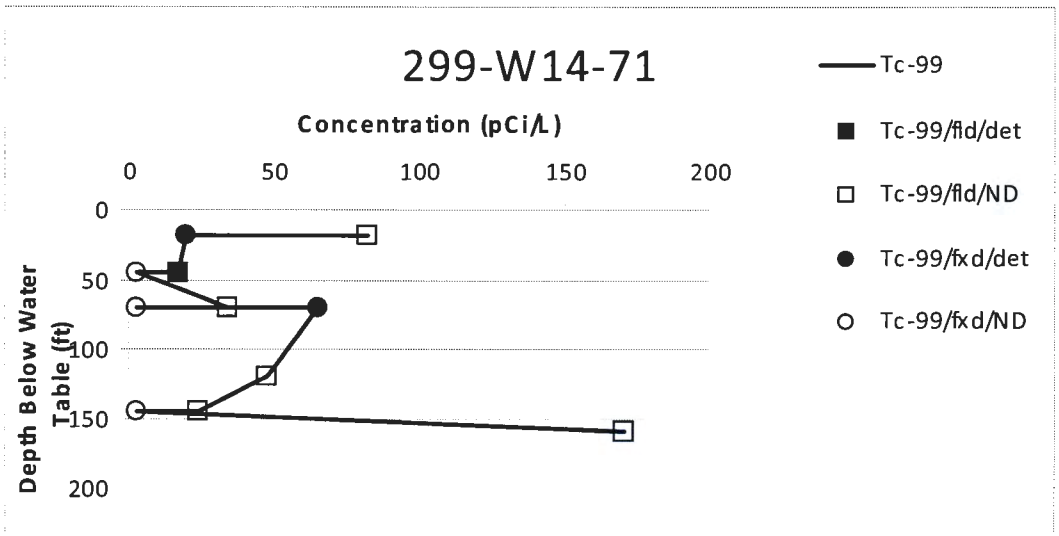
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-5. Depth Profile for Technetium-99 in Well 299-W11-86.



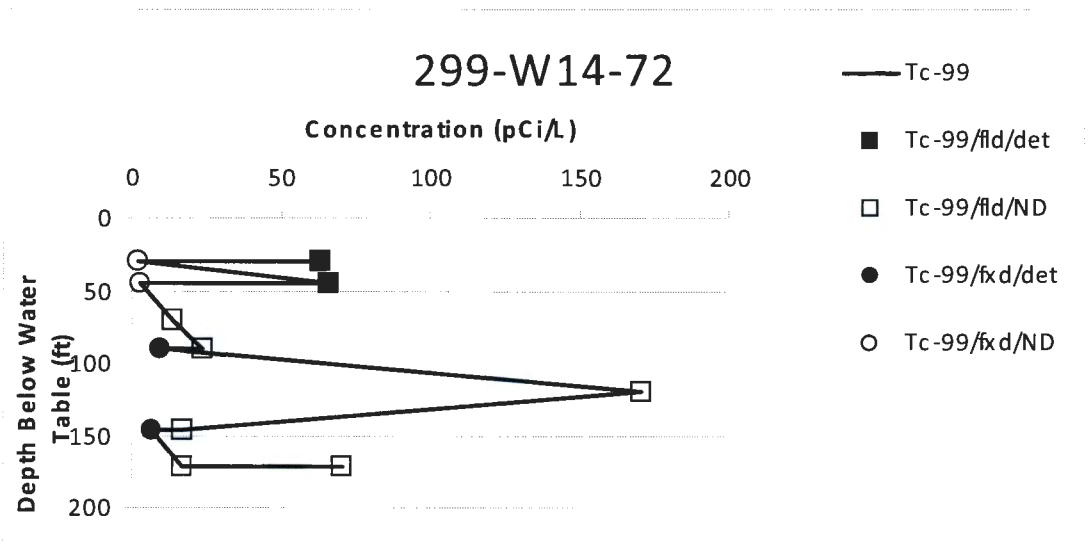
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-6. Depth Profile for Technetium-99 in Well 299-W14-71.



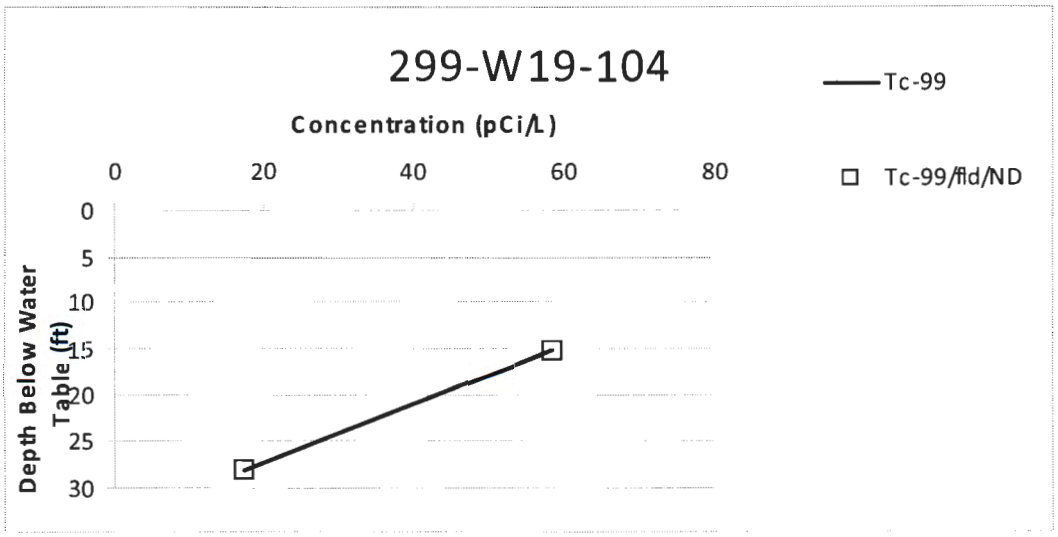
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-7. Depth Profile for Technetium-99 in Well 299-W14-72.



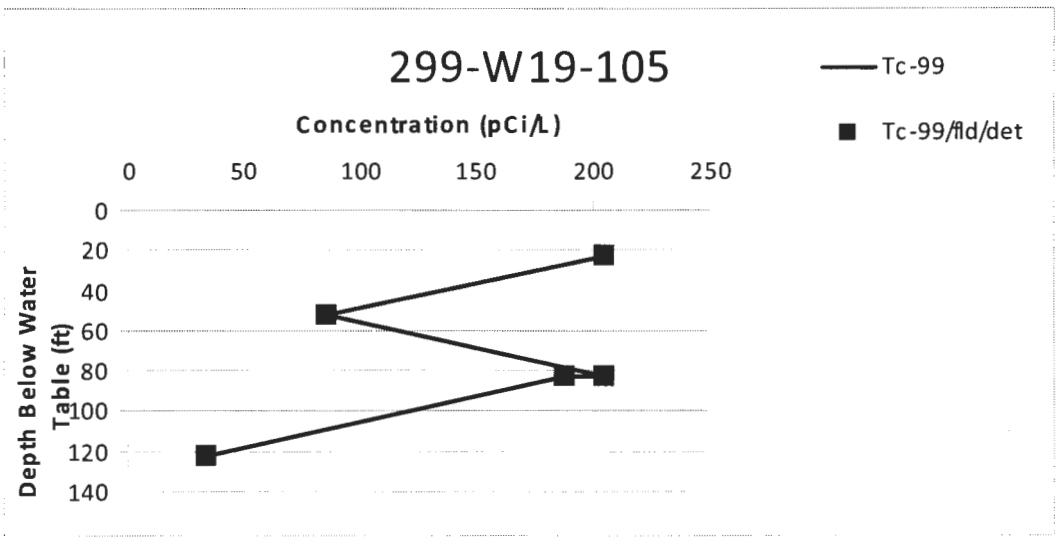
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-8. Depth Profile for Technetium-99 in Well 299-W19-104.



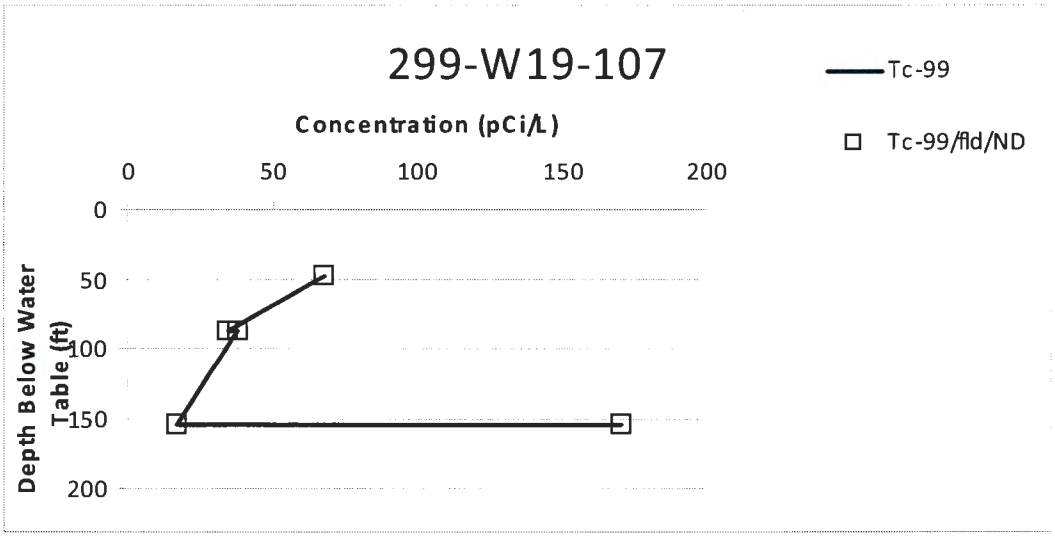
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-9. Depth Profile for Technetium-99 in Well 299-W19-105.



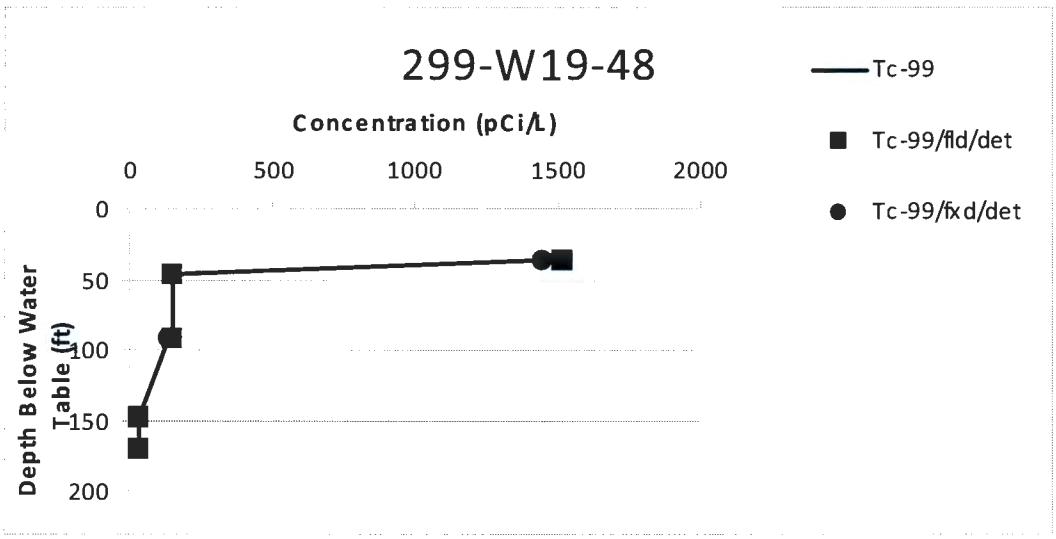
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-10. Depth Profile for Technetium-99 in Well 299-W19-107.



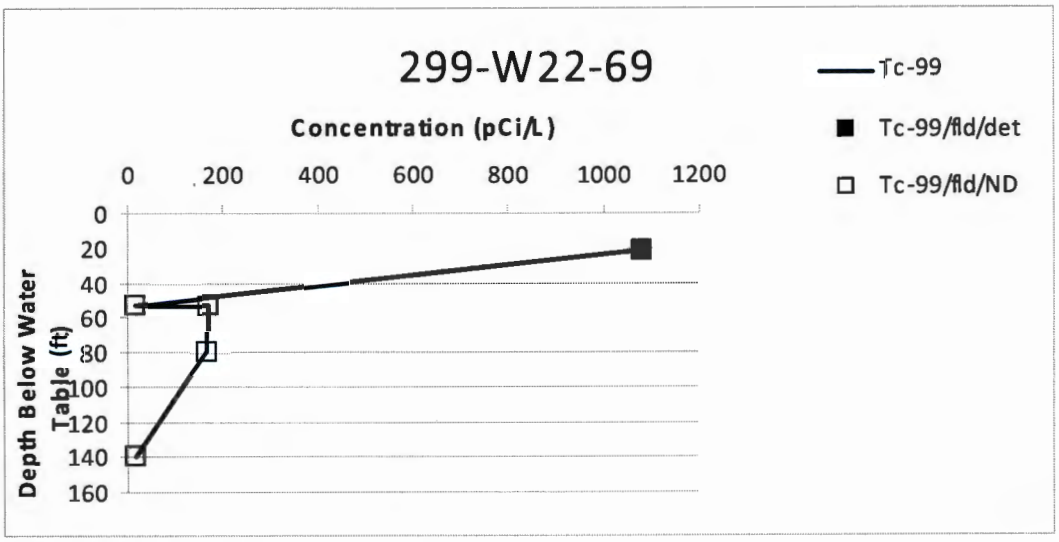
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-11. Depth Profile for Technetium-99 in Well 299-W19-48.



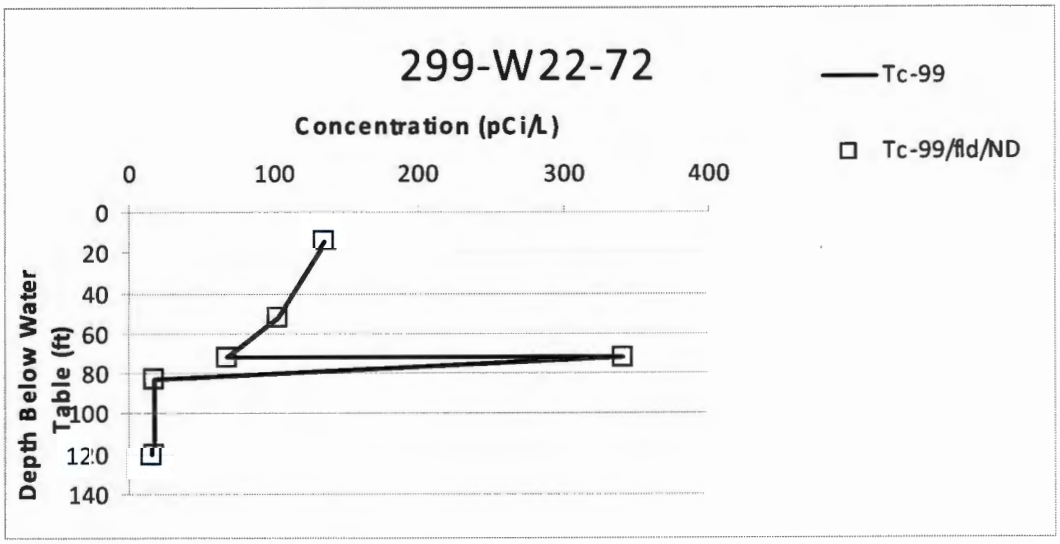
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-12. Depth Profile for Technetium-99 in Well 299-W22-69.



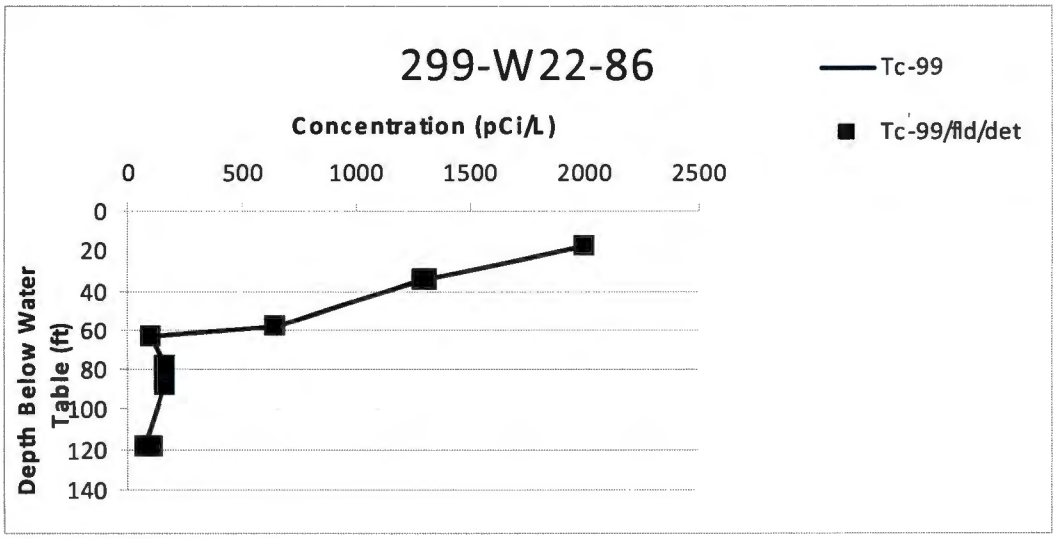
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-13. Depth Profile for Technetium-99 in Well 299-W22-72.



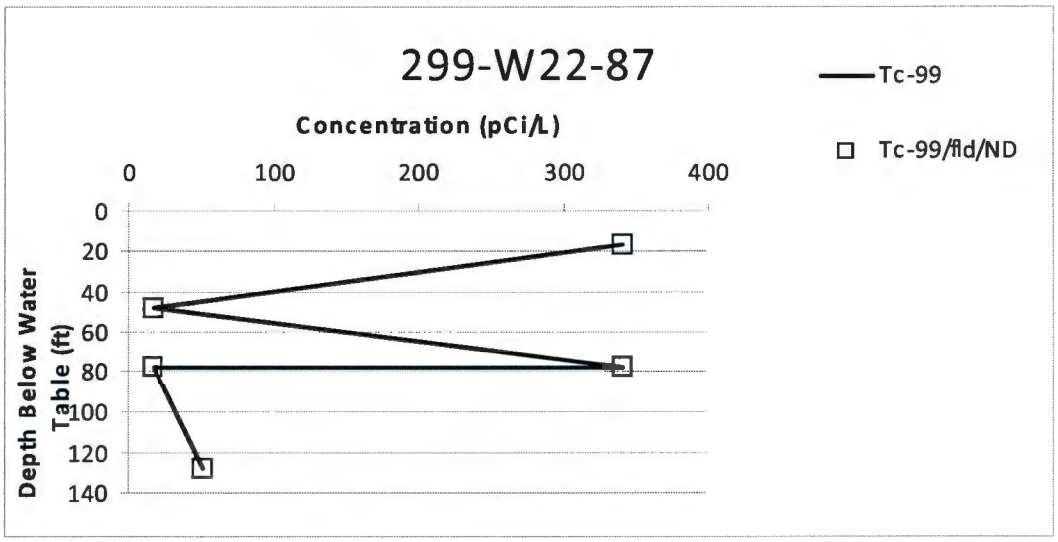
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-14. Depth Profile for Technetium-99 in Well 299-W22-86.



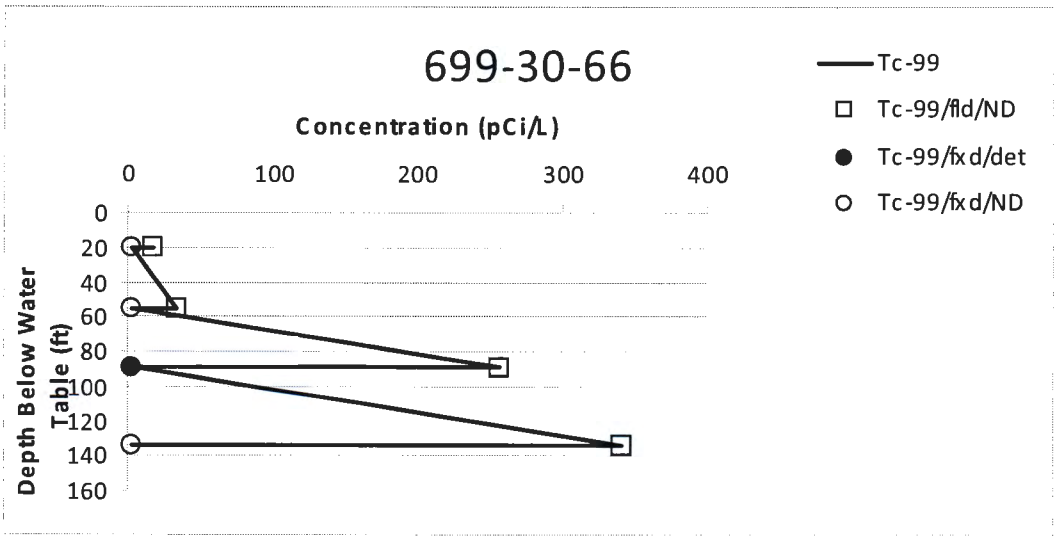
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-15. Depth Profile for Technetium-99 in Well 299-W22-87.



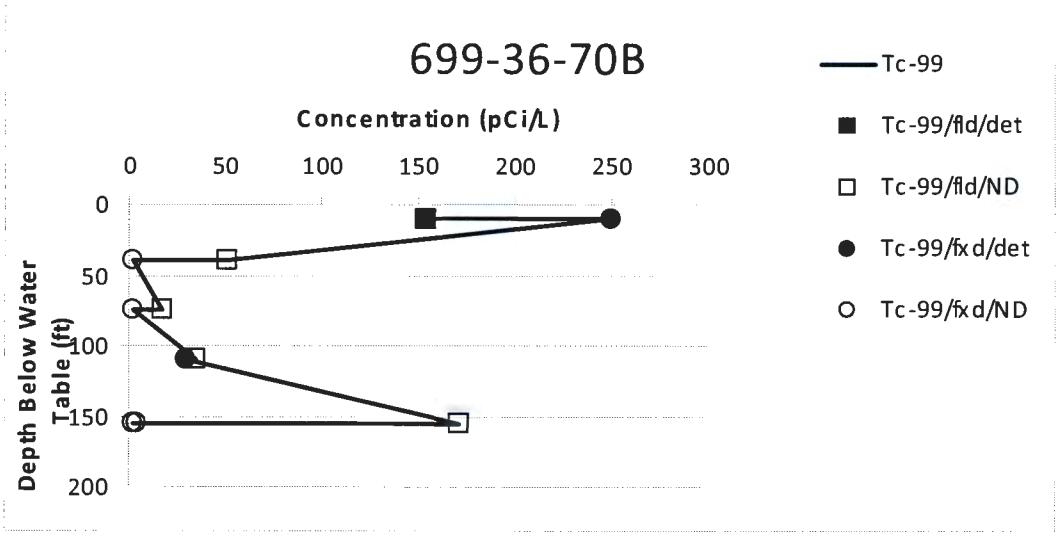
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-16. Depth Profile for Technetium-99 in Well 699-30-66.



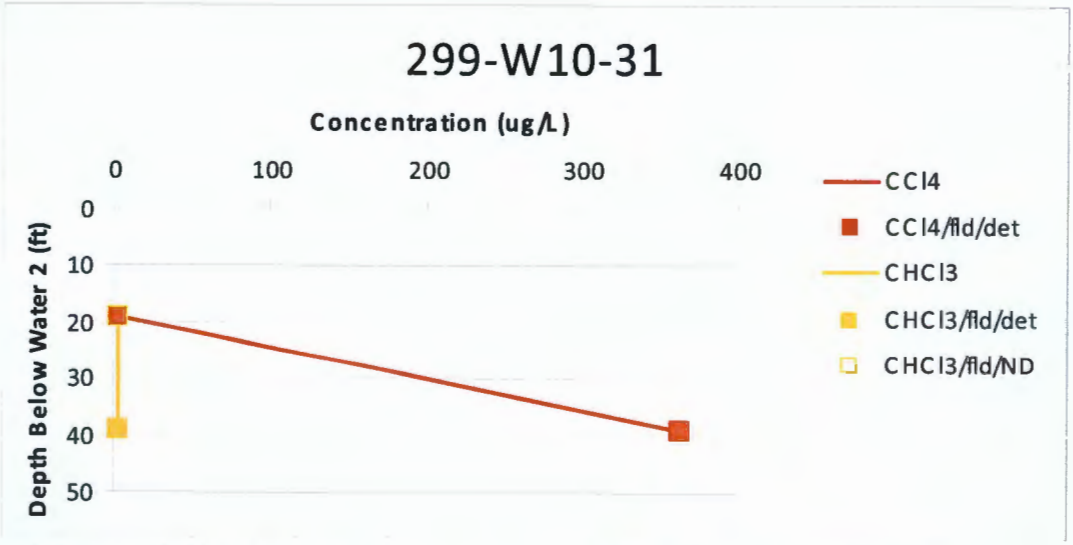
Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

Figure E-17. Depth Profile for Technetium-99 in Well 699-36-70B.



Tc-99 indicates technetium-99
Circles indicate fixed laboratory (fxd) results.
Squares indicate field screening (fld) results.
Filled symbols indicate detects (det).
Open symbols indicate nondetects (ND).

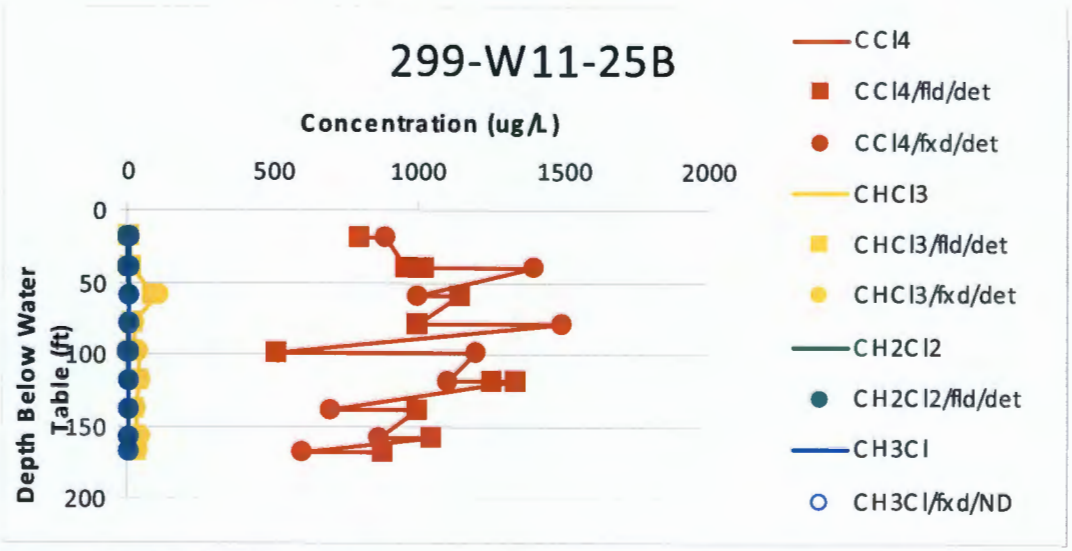
Figure E-18. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W10-31.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

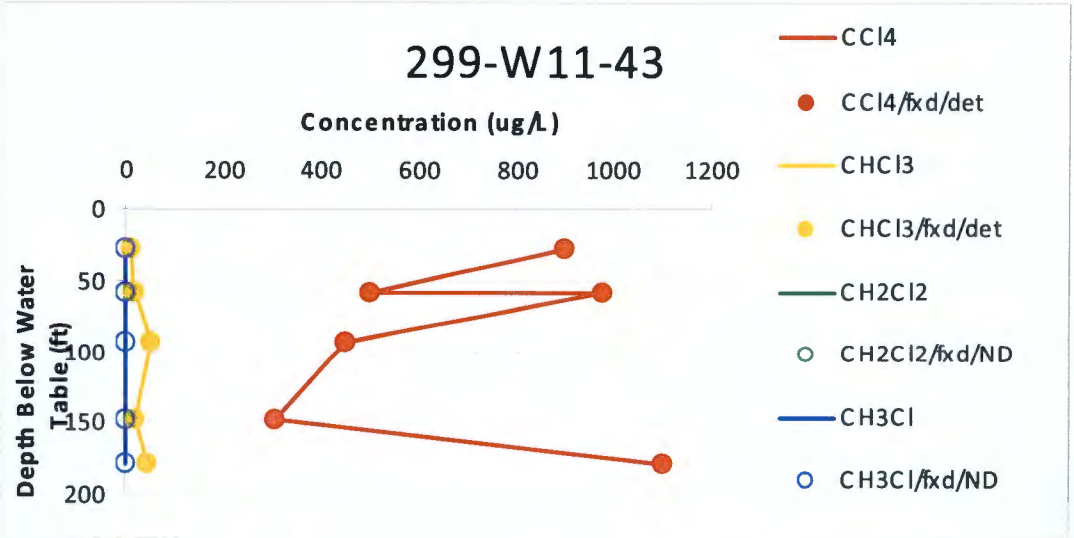
Figure E-19. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-25B.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

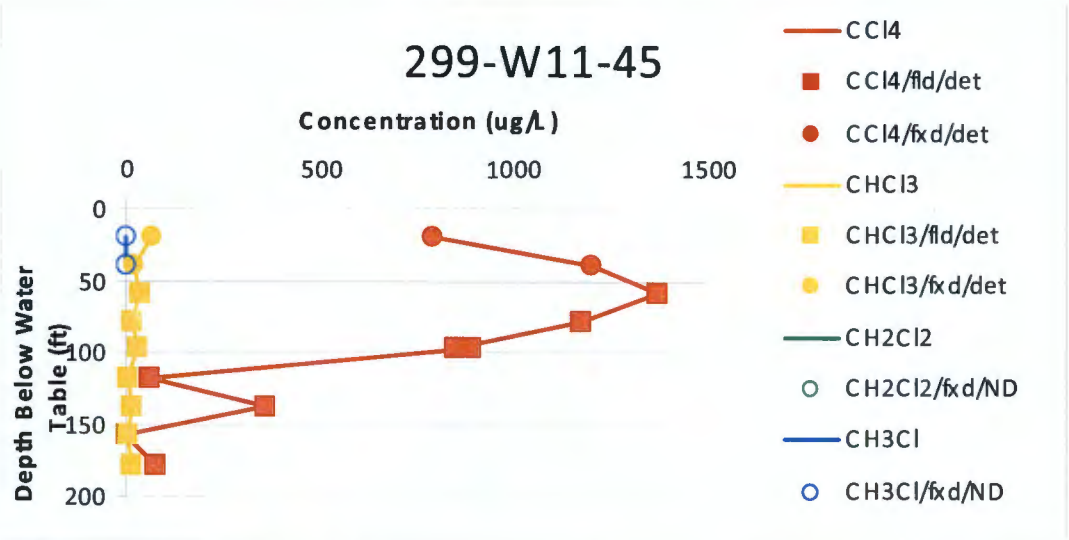
Figure E-20. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-43.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

Figure E-21. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-45.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

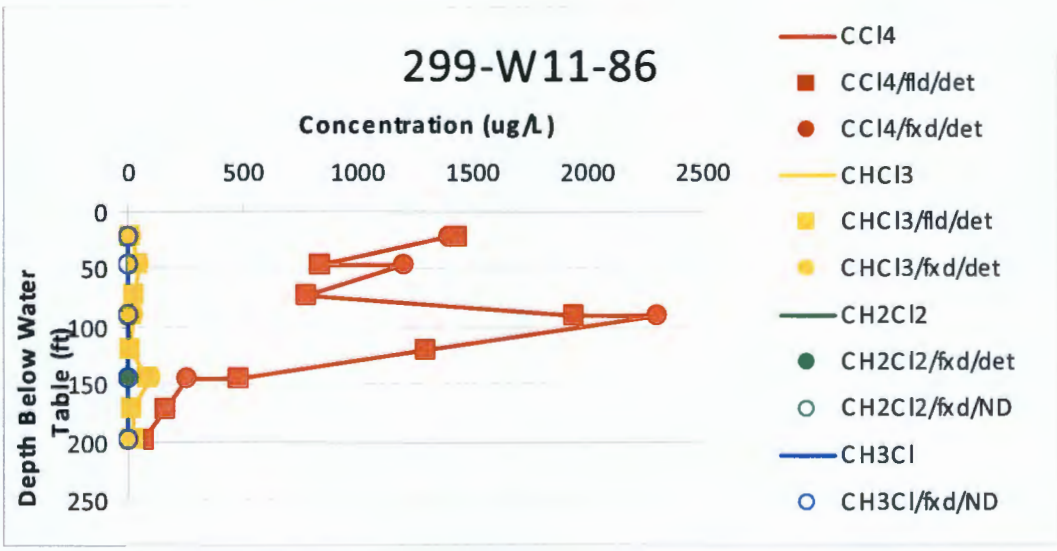
Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

Figure E-22. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-47.

Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

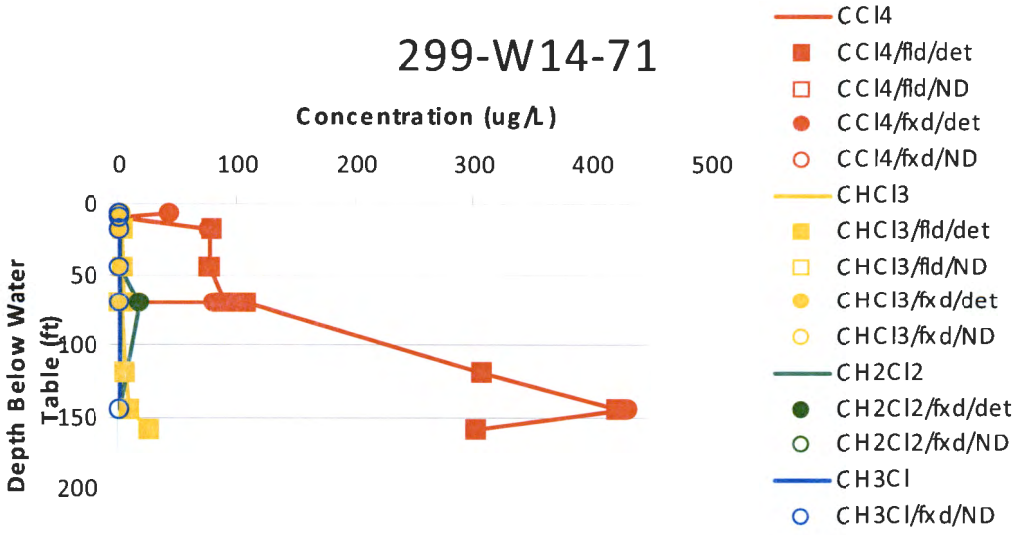
Figure E-23. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W11-86.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

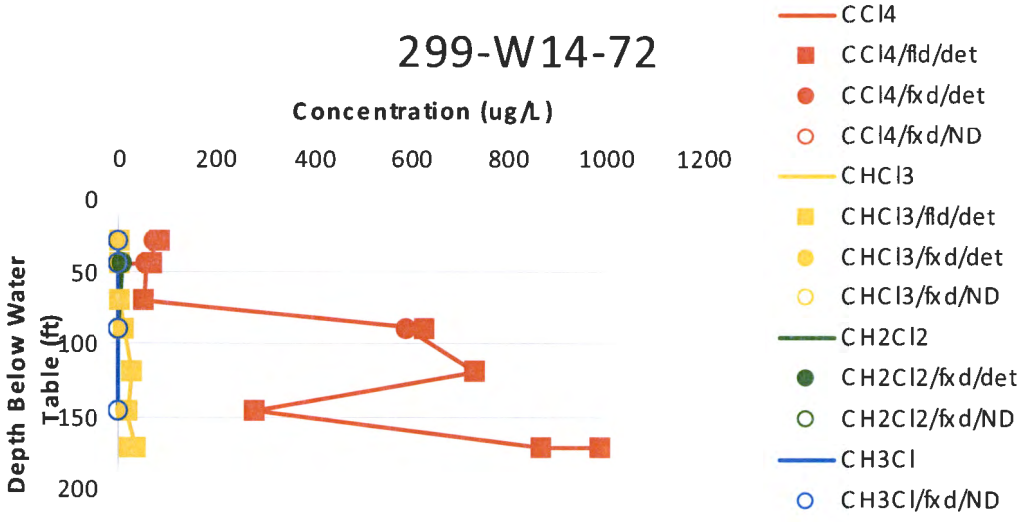
Figure E-24. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W14-71.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

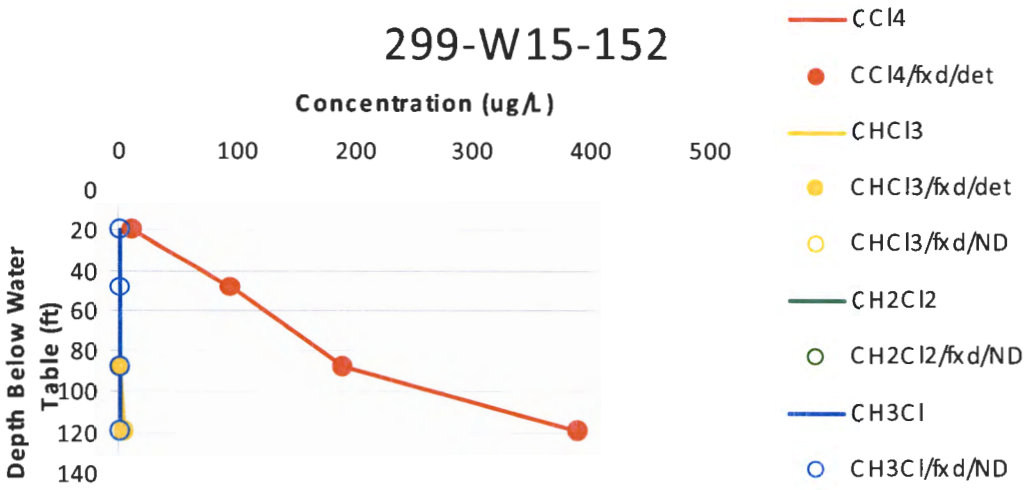
Figure E-25. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W14-72.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

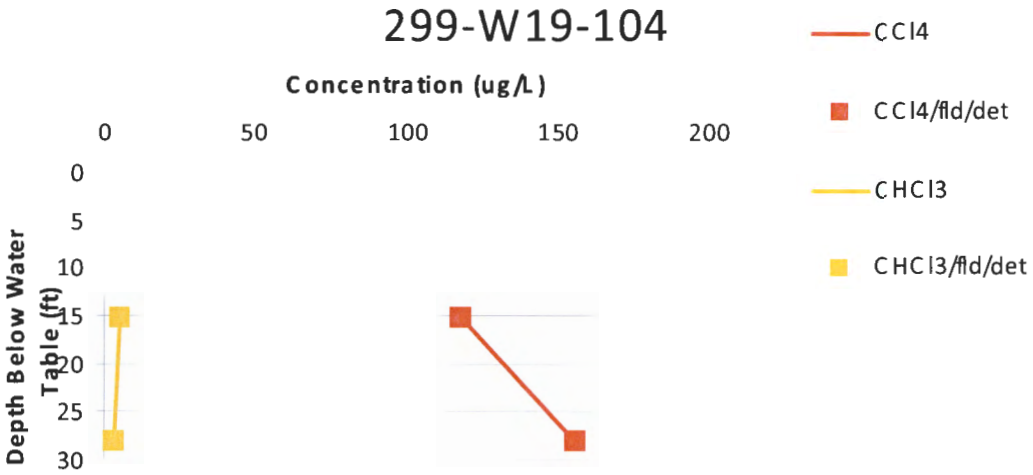
Figure E-26. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W15-152.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

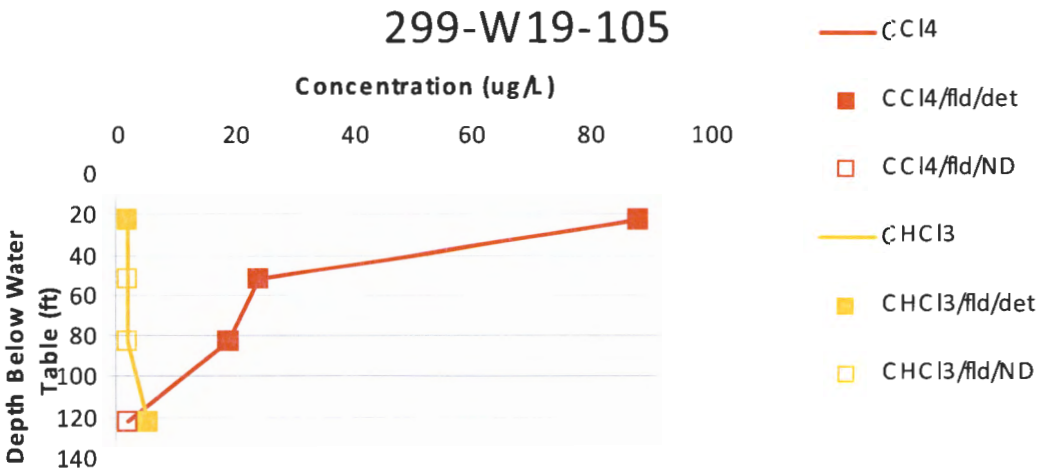
Figure E-27. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-104.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

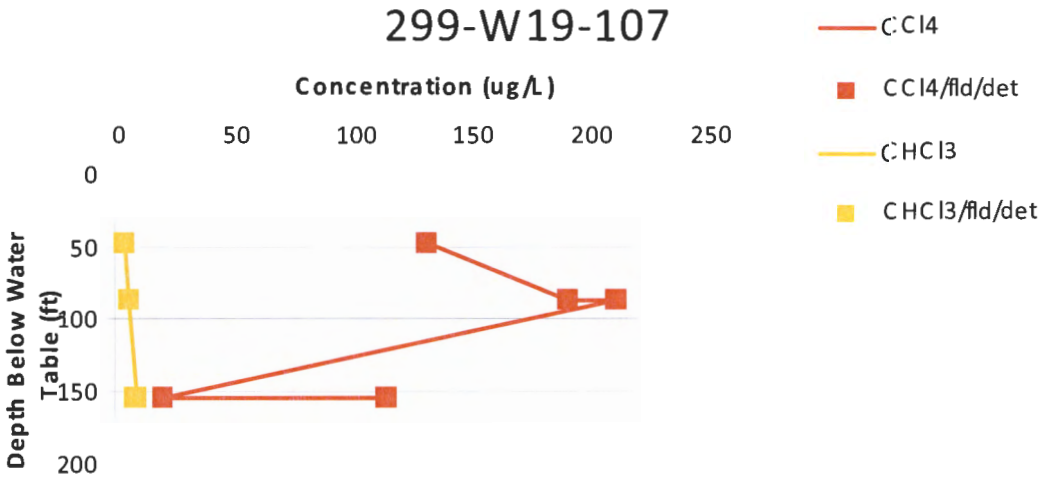
Figure E-28. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-105.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

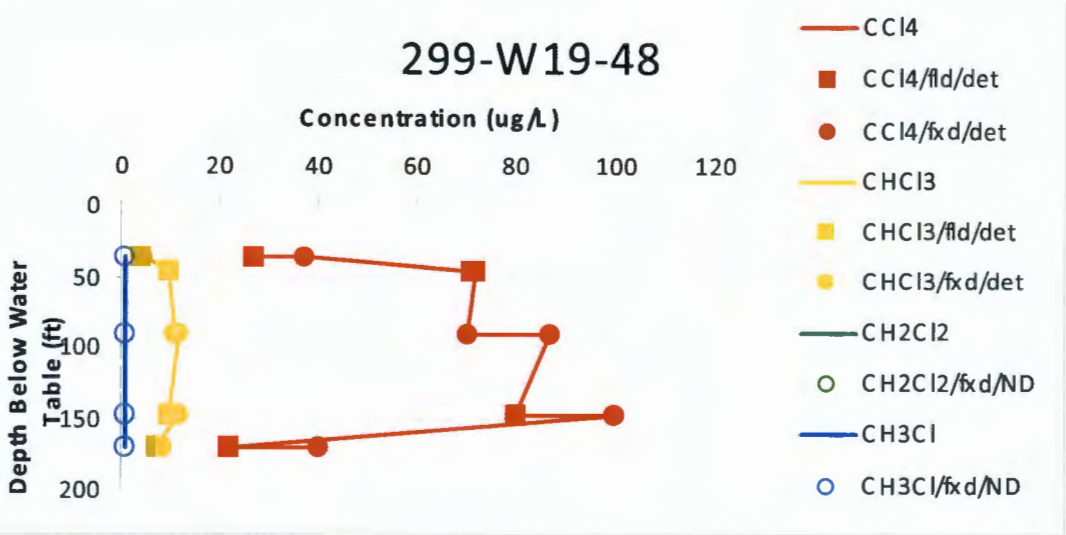
Figure E-29. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-107.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

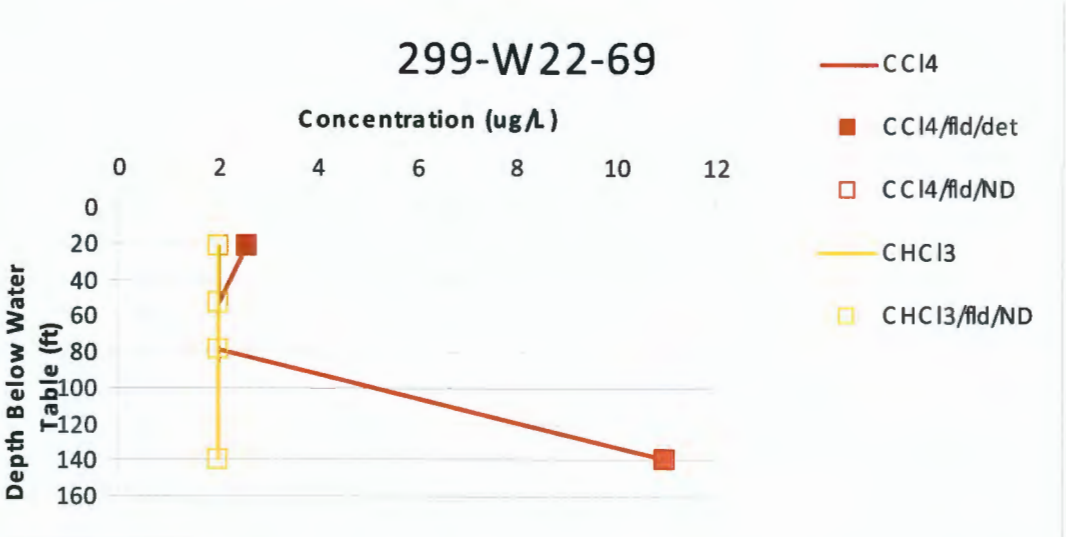
Figure E-30. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-48.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

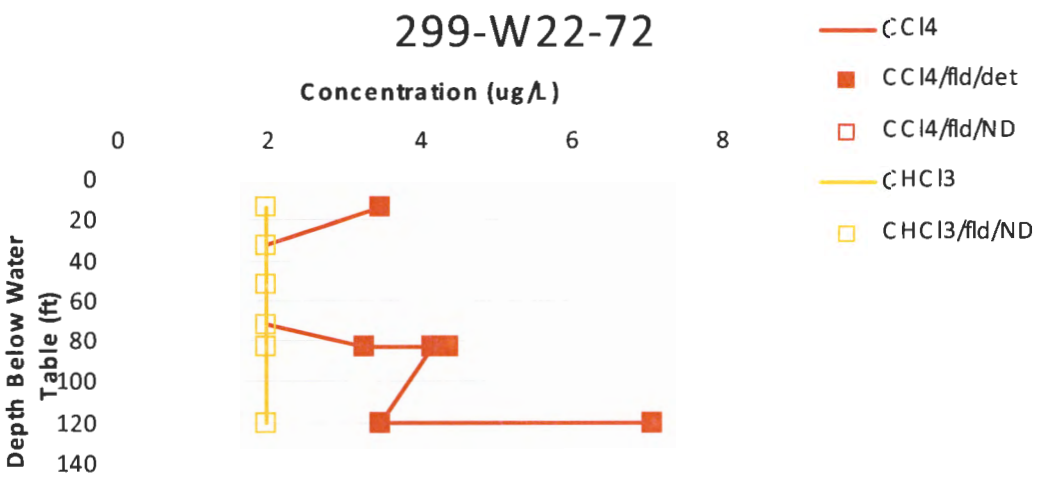
Figure E-31. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-69.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

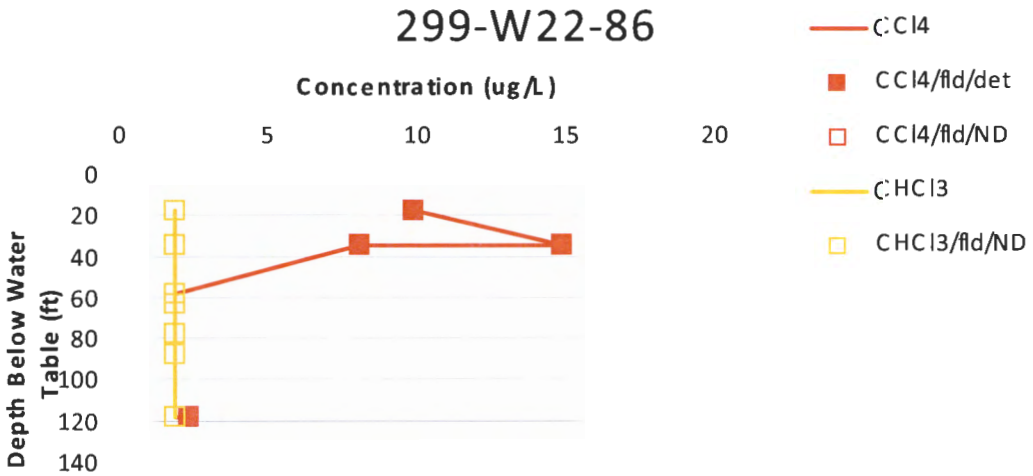
Figure E-32. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-72.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

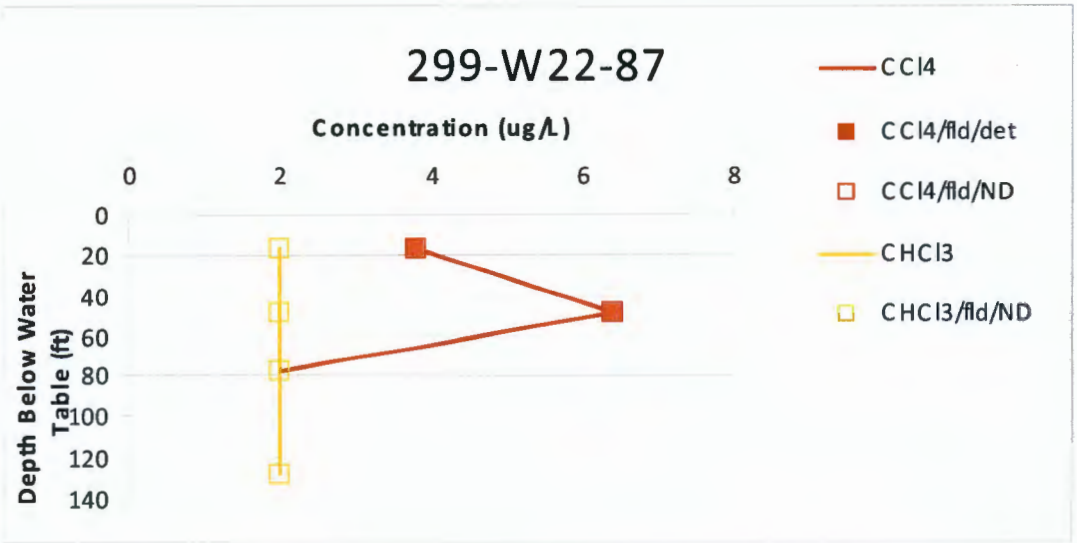
Figure E-33. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-86.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

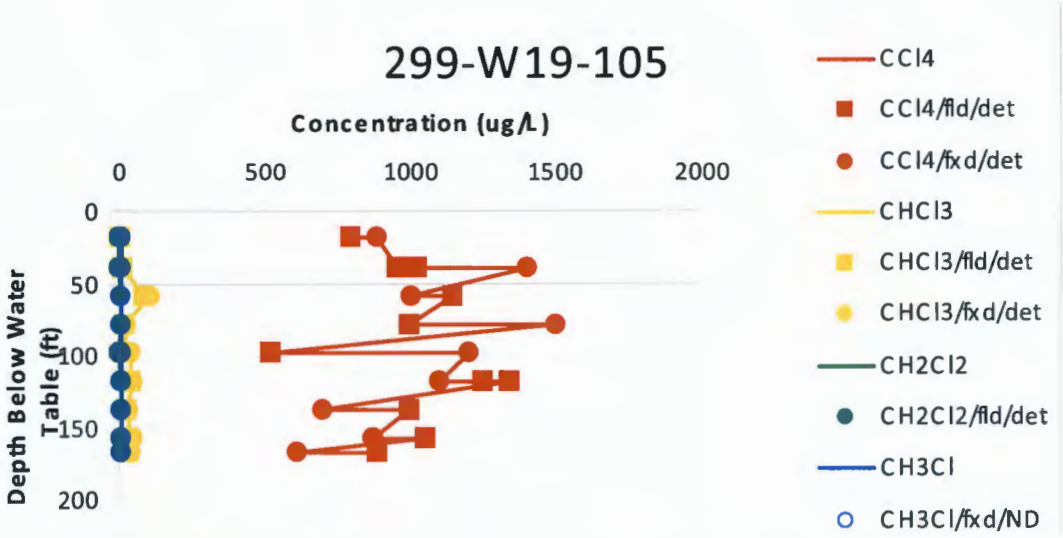
Figure E-34. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W22-87.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

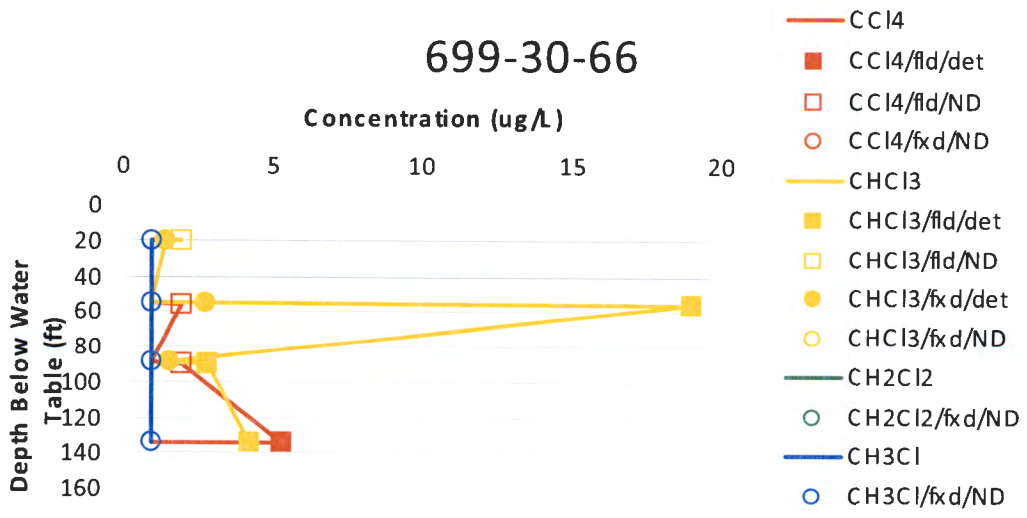
Figure E-35. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 299-W19-105.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

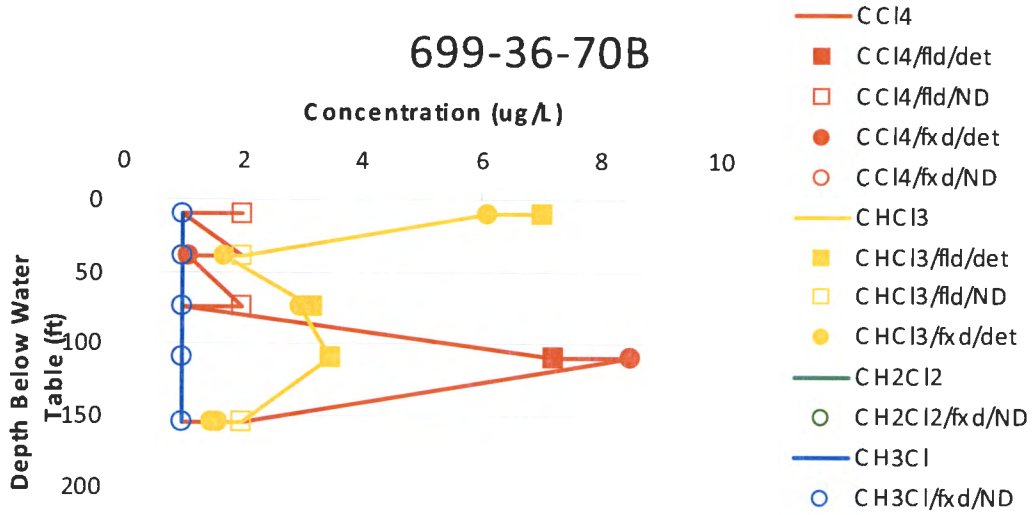
Figure E-36. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 699-30-66.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

Figure E-37. Depth Profile for Carbon Tetrachloride and Potential Degradation Products in Well 699-36-70B.



Carbon tetrachloride is shown in red.
Methylene chloride (CH2Cl2) in shown in green.
Circles indicate fixed laboratory (fxd) results.
Filled symbols indicate detects (det).

Chloroform (CHCl3) in shown in orange.
Chloromethane (CH3Cl) in shown in blue.
Squares indicate field screening (fld) results.
Open symbols indicate nondetects (ND).

Table E-1. Standards for Chemicals and Radionuclides in 200-ZP-1 Operable Unit Groundwater.

Contaminant	Federal Standard (MCL)
Carbon tetrachloride (ppb or µg/L)	5
Trichloroethylene (TCE) (ppb or µg/L)	5
Total chromium (ppb or µg/L)	100
Hexavalent chromium (ppb or µg/L)	[a]
Nitrate (ppb or µg/L), expressed as total nitrogen[b]	10,000[b]
Tc-99 (pCi/L)	900
I-129 (pCi/L)	1
Tritium (pCi/L)	20,000

[a] There is no MCL specific to hexavalent chromium

[b] Nitrate may be expressed as total nitrate (NO_3) or as total nitrogen (N). The limit of nitrate as NO_3 is 45,000 and the same concentration expressed as N is 10,000 µg/L. EPA drinking water regulations are published as 10,000 µg/L.

MCL = maximum contaminant level

ppb = parts per billion

Table E-2 . Well Names, Drill Dates, and Physical Parameters for 200-ZP-1 Operable Unit.

Well Name	Drill Date	Total Depth Drilled (ft)	Screened Interval (ft)	Screen Length (ft)	Diameter (in.)[a]	Depth to Water Table (ft)	Status[b]
299-W11-25B	2-Feb-05	409.5	N/A[c]	N/A[c]	N/A[c]	N/A[c]	Decommissioned[d]
299-W11-43	23-May-05	448	425 to 440	15	4	270	In use
299-W11-46	26-Jul-05	285.8	262 to 280	18	4	245.2	In use
299-W11-45	2-Sep-05	438	280 to 295	15	6	254.6	In use
299-W15-152	15-Sep-05	358.3	236 to 276	40	4	238.6	In use
299-W15-94	19-Sep-05	278	236 to 271	35	4	239	In use
299-W11-47	6-Jan-06	407	274 to 304	30	6	243.9	In use
299-W15-224	8-Feb-06	274.1	235 to 270	35	4	236	In use
299-W10-29	1-Mar-06	287.2	245 to 280	35	4	246.5	In use
299-W10-30	14-Mar-06	283	242 to 277	35	4	243.9	In use
299-W10-25	6-Apr-06	138	N/A[c]	N/A[c]	N/A[c]	N/A[c]	Decommissioned[d]
299-W10-31	20-Apr-06	278.9	240 to 275	35	4	241	In use
299-W11-86	1-Jun-06	491	N/A[c]	N/A[c]	N/A[c]	N/A[c]	Decommissioned[d]
299-W14-72	15-Aug-06	439.5	414 to 429	15	6	265	In use
299-W11-87	1-Mar-07	405.4	381 to 396	15	6	293.7	In use

[a] The diameters reflect the inner diameter of the well casing and is presented in inches.
[b] The status reflects whether the well is currently in use or has been decommissioned. Decommissioned wells are presented for completeness of data associated with the well.
[c] If the well was decommissioned the physical parameters are listed as not applicable (N/A).
[d] Wells 299-W11-25B, 299-W10-25, and 299-W11-86 were damaged during development, and were subsequently decommissioned.

Table E-3. Well Names, Drill Dates, and Physical Parameters for 200-UP-1 Operable Unit.

Well Name	Drill Date	Total Depth Drilled (ft)	Screened Interval (ft)	Screen Length (ft)	Diameter (in.) [a]	Depth to Water Table (ft)	Status[b]
699-36-70B	9-Jun-04	427	264 to 299	35	4	265.8	In use
299-W19-48	5-Oct-04	424	262 to 297	35	6	253.6	In use
699-30-66	13-Oct-04	406.5	380 to 395	15	4	255.7	In use
299-W19-105	13-Dec-05	379	255 to 290	35	4	257.6	In use
299-W22-87	14-Dec-05	379.5	250 to 285	35	4	251.8	In use
299-W22-69	27-Jan-06	376.6	238 to 273	35	4	237	In use
299-W22-72	22-Feb-06	357.8	237 to 272	35	4	237.6	In use
299-W22-86	10-Mar-06	350	231 to 266	35	4	232	In use
299-W19-104	27-Mar-06	315	N/A[c]	N/A[c]	N/A[c]	N/A[c]	Decommissioned[d]
299-W19-107	31-Mar-06	429	310 to 325	15	4	272	In use
299-W14-71	27-Jul-06	279.7	410 to 425	15	6	276.6	In use

[a] The diameters reflect the inner diameter of the well casing.
[b] The status reflects whether the well is currently in use or has been decommissioned. Decommissioned wells are presented for completeness of data associated with the well.
[c] If the well was decommissioned, the physical parameters are listed as not applicable (N/A).
[d] Well 299-W19-104 was damaged during development and was subsequently decommissioned.

Table E-4. Maximum Concentrations of Eleven Analytes in 200-ZP-1 and 200-UP-1 Wells. (2 sheets)

Well Name	Carbon Tetrachloride	Tc-99	Trichloroethylene	Tritium	I-129	Chromium (Total)	Hexavalent Chromium	Nitrogen n Nitrate	Methylene Chloride	Chloroform	Chloromethane
299-W11-25B	1,500	185,000	9.1	8,770	6.96	4.41	0	664,000	8	110	10[a]
299-W11-43	1,100	640	14	61,000	9.1[a]	150	43	102,000	1[a]	54	1[a]
299-W11-46	1,000	101,000	7.2	10,100	10.9	708	0	132,000	0.1[a]	15	ND
299-W11-45	1,500	23,500	12	36,300	3.65	143	0	619,000	1[a]	65	1[a]
299-W15-152	390	157	0.6	1,750	0.278[a]	8.8	0	33,700	1[a]	4.3	1[a]
299-W15-94	1,200	106	1.2	1,160	0.364 [a]	7.4	0	32,300	0.6[a]	15	ND
299-W11-47	1,400	4,670	13	24,800	0.41[a]	121	0	863,000	0.6[a]	144	ND
299-W15-224	140	140	0.2[a]	1,520	0.224	7.4	0	28,900	0.1[a]	1.1	ND
299-W10-29	91	10.4	0.38	328	0.429	3.1	0	4,000	0.6[a]	1.7	ND
299-W10-30	16	10	0.32	327	1.02	3.1	0	5,490	0.6[a]	0.97	ND
299-W10-25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
299-W10-31	363	10.1	0.61	367	0.295	3.1	0	8,111	0.6[a]	3.2	ND
299-W11-86	2,300	51.2	5.4	305	8.3[a]	0	27	24,400	2	100	1[a]
299-W14-72	988	65.9	5.52	958	4.6[a]	4[a]	2[a]	8,990	7.2	69	1[a]
299-W11-87	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
699-36-70B	14	358	N/A	N/A	N/A	N/A	N/A	N/A	1	7	1.2
299-W19-48	240	1,520	N/A	N/A	N/A	N/A	N/A	N/A	0.51	12	1.3
699-30-66	5.4	12.2	N/A	N/A	N/A	N/A	N/A	N/A	1	19	0.5
299-W19-105	88	205	N/A	N/A	N/A	N/A	N/A	N/A	1	5.4	ND
299-W22-87	6.4	12.8	N/A	N/A	N/A	N/A	N/A	N/A	ND	2[a]	ND
299-W22-69	11	1,080	N/A	N/A	N/A	N/A	N/A	N/A	0.429	0.4	ND
299-W22-72	7.8	140	N/A	N/A	N/A	N/A	N/A	N/A	0.1	0.87	ND

Table E-4. Maximum Concentrations of Eleven Analytes in 200-ZP-1 and 200-UP-1 Wells. (2 sheets)

Well Name	Carbon Tetrachloride	Tc-99	Trichloroethylene	Tritium	I-129	Chromium (Total)	Hexavalent Chromium	Nitrogen n Nitrate	Methylene Chloride	Chloroform	Chloromethane
299-W22-86	32	3,500	N/A	N/A	N/A	N/A	N/A	N/A	0.1	1.6	ND
299-W19-104	156	58.5	N/A	N/A	N/A	N/A	N/A	N/A	ND	5.5	ND
299-W19-107	220	62	N/A	N/A	N/A	N/A	N/A	N/A	1[a]	9.7	ND
299-W14-71	1,600	82.1	N/A	N/A	N/A	N/A	N/A	N/A	19	33	1[a]

[a] There were no detected results. These numbers are maximum nondetect values.

N/A = not applicable (the only contaminants for the 200-UP-1 Operable Unit wells are carbon tetrachloride, technetium-99, methylene chloride, chloroform, and chloromethane)

ND = no data available for the analyte

Table E-5. Minimum, Maximum, and Mean Values for Carbon Tetrachloride in the 200-ZP-1 and 200-UP-1 Operable Units.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	2	79	85	91
299-W10-30	0	N/A	N/A	N/A	2	16	16	16
299-W10-31	0	N/A	N/A	N/A	4	2.3	189	363
299-W11-25B	0	N/A	N/A	N/A	21	520	1,020	1,500
299-W11-43	0	N/A	N/A	N/A	11	310	790	1,100
299-W11-45	0	N/A	N/A	N/A	13	2.4	805	1,500
299-W11-46	0	N/A	N/A	N/A	1	1,000	1,000	1,000
299-W11-47	0	N/A	N/A	N/A	10	6.6	644	1,400
299-W11-86	0	N/A	N/A	N/A	15	58	823	2,300
299-W14-71	2	1	1.5	2	14	45	278	1,600
299-W14-72	1	1	1	1	13	52.8	434	988
299-W15-152	0	N/A	N/A	N/A	11	12	77.6	390
299-W15-224	0	N/A	N/A	N/A	2	120	130	140
299-W15-94	0	N/A	N/A	N/A	3	830	1,010	1,200
299-W19-104	0	N/A	N/A	N/A	2	118	137	156
299-W19-105	1	2	2	2	6	19	49.8	88
299-W19-107	0	N/A	N/A	N/A	6	20.6	148	220
299-W19-48	0	N/A	N/A	N/A	23	22	112	240
299-W22-69	4	1	1.75	2	3	2.6	5.87	11
299-W22-72	4	2	2	2	8	3.3	5.09	7.8
299-W22-86	6	2	2	2	5	2.5	13.5	32
299-W22-87	3	2	2	2	2	3.8	5.1	6.4
699-30-66	10	0.09	1.12	2	7	0.22	1.83	5.4
699-36-70B	9	1	1.56	2	13	1.1	8.8	14

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-6. Minimum, Maximum, and Mean Values for Technetium-99 in the 200-ZP-1 and 200-UP-1 Operable Units.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	2	9.64	10	10.4	0	N/A	N/A	N/A
299-W10-30	2	9.84	9.92	10	0	N/A	N/A	N/A
299-W10-31	2	9.92	10	10.1	0	N/A	N/A	N/A
299-W11-25B	0	N/A	N/A	N/A	51	243	35,600	185,000
299-W11-43	6	137	425	855	8	113	346	640
299-W11-45	0	N/A	N/A	N/A	6	14,700	20,000	23,500
299-W11-46	0	N/A	N/A	N/A	8	36000	66,800	101,000
299-W11-47	10	17.6	113	219	27	37.3	1,040	4670
299-W11-86	6	2.6	22.5	51.3	6	15	31.3	51.2
299-W14-71	9	2.4	41.6	171	4	17.1	46.1	82.1
299-W14-72	9	2.2	36.5	171	4	6.7	36.4	65.9
299-W15-152	0	N/A	N/A	N/A	4	129	148	157
299-W15-224	0	N/A	N/A	N/A	2	117	129	140
299-W15-94	0	N/A	N/A	N/A	3	73.6	84.6	106
299-W19-104	2	17.3	37.9	58.5	0	N/A	N/A	N/A
299-W19-105	0	N/A	N/A	N/A	7	34.2	136	205
299-W19-107	5	17.1	65.9	171	1	62	62	62
299-W19-48	0	N/A	N/A	N/A	32	33	340	1,520
299-W22-69	4	17.1	94.1	171	7	574	748	1,080
299-W22-72	7	17.1	100	342	6	119	128	140
299-W22-86	0	N/A	N/A	N/A	15	75.1	1,270	3,500
299-W22-87	7	6.3	112	342	3	10.2	11.2	12.8
699-30-66	11	2.5	62.4	342	2	3.4	7.8	12.2
699-36-70B	9	2.4	31.9	171	13	30	247	358

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-7. Minimum, Maximum, and Mean Values for Trichloroethylene in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	2	0.25	0.315	0.38
299-W10-30	0	N/A	N/A	N/A	2	0.22	0.27	0.32
299-W10-31	2	2	2	2	2	0.58	0.595	0.61
299-W11-25B	1	2	2	2	20	5	6.96	9.1
299-W11-43	0	N/A	N/A	N/A	11	1.6	7.46	14
299-W11-45	2	2	2	2	11	2.6	8.95	12
299-W11-46	0	N/A	N/A	N/A	1	7.2	7.2	7.2
299-W11-47	2	2	2	2	8	3.8	7.64	13
299-W11-86	6	1	1.5	2	9	1.9	3.08	5.4
299-W14-71	11	1	1.55	2	5	1.8	4.67	13
299-W14-72	8	1	1.5	2	6	2.78	3.82	5.52
299-W15-152	11	0.037	0.607	1	0	N/A	N/A	N/A
299-W15-224	2	0.2	0.2	0.2	0	N/A	N/A	N/A
299-W15-94	0	N/A	N/A	N/A	3	0.77	0.92	1.2

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-8. Minimum, Maximum, and Mean Values for Tritium in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	2	314	321	328	0	N/A	N/A	N/A
299-W10-30	2	313	320	327	0	N/A	N/A	N/A
299-W10-31	2	312	340	367	0	N/A	N/A	N/A
299-W11-25B	0	N/A	N/A	N/A	6	5,300	6,800	8,770
299-W11-43	0	N/A	N/A	N/A	10	22,600	40,500	61,000
299-W11-45	0	N/A	N/A	N/A	19	665	13,200	36,300
299-W11-46	0	N/A	N/A	N/A	8	4,450	6,520	10,100
299-W11-47	0	N/A	N/A	N/A	16	794	11,600	24,800
299-W11-86	5	150	164	180	1	305	305	305
299-W14-71	6	120	173	230	0	N/A	N/A	N/A
299-W14-72	2	170	170	170	2	434	696	958
299-W15-152	0	N/A	N/A	N/A	4	1,660	1,700	1,750
299-W15-224	0	N/A	N/A	N/A	2	1,360	1,440	1,520
299-W15-94	0	N/A	N/A	N/A	3	1,080	1,130	1,160

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-9. Minimum, Maximum, and Mean Values for Iodine-129 in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	2	0.255	0.342	0.429	0	N/A	N/A	N/A
299-W10-30	2	0.287	0.654	1.02	0	N/A	N/A	N/A
299-W10-31	2	0.258	0.277	0.295	0	N/A	N/A	N/A
299-W11-25B	3	4.75	5.68	6.96	0	N/A	N/A	N/A
299-W11-43	10	0.364	3.42	9.1	0	N/A	N/A	N/A
299-W11-45	0	N/A	N/A	N/A	3	3.03	3.24	3.65
299-W11-46	1	6.62	6.62	6.62	2	6.63	8.77	10.9
299-W11-47	14	0.247	0.347	0.41	0	N/A	N/A	N/A
299-W11-86	6	3.3	6.58	8.3	0	N/A	N/A	N/A
299-W14-71	5	0.309	2.7	5.5	0	N/A	N/A	N/A
299-W14-72	4	1.9	3.18	4.6	0	N/A	N/A	N/A
299-W15-152	4	0.221	0.259	0.278	0	N/A	N/A	N/A
299-W15-224	2	0.217	0.221	0.224	0	N/A	N/A	N/A
299-W15-94	3	0.185	0.275	0.364	0	N/A	N/A	N/A

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-10. Minimum, Maximum, and Mean Values for Total Chromium in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	2	3.1	3.1	3.1	0	N/A	N/A	N/A
299-W10-30	2	3.1	3.1	3.1	0	N/A	N/A	N/A
299-W10-31	2	3.1	3.1	3.1	0	N/A	N/A	N/A
299-W11-25B	4	1.02	1.93	4.41	0	N/A	N/A	N/A
299-W11-43	1	4	4	4	7	21.3	63.8	150
299-W11-45	14	0.728	1.74	3.21	21	6.12	70.5	143
299-W11-46	0	N/A	N/A	N/A	9	208	394	708
299-W11-47	11	0.831	1.9	3.1	20	1.11	56.9	121
299-W11-86	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W14-71	3	4	5	7	1	182	182	182
299-W14-72	2	4	4	4	0	N/A	N/A	N/A
299-W15-152	0	N/A	N/A	N/A	4	6.3	7.63	8.8
299-W15-224	0	N/A	N/A	N/A	2	5.9	6.65	7.4
299-W15-94	0	N/A	N/A	N/A	3	5.7	6.73	7.4

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-11. Minimum, Maximum, and Mean Values for Hexavalent Chromium in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W10-30	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W10-31	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-25B	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-43	1	3	3	3	5	10	22.2	43
299-W11-45	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-46	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-47	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-86	4	2	2	2	2	6	16.5	27
299-W14-71	4	2	2	2	0	N/A	N/A	N/A
299-W14-72	4	2	2	2	0	N/A	N/A	N/A
299-W15-152	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W15-224	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W15-94	0	N/A	N/A	N/A	0	N/A	N/A	N/A

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-12. Minimum, Maximum, and Mean Values for Nitrate in the 200-ZP-1 Operable Unit.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	2	3,500	3,750	4,000
299-W10-30	0	N/A	N/A	N/A	2	5,310	5,400	5,490
299-W10-31	0	N/A	N/A	N/A	4	7,230	7,600	8,110
299-W11-25B	0	N/A	N/A	N/A	33	242,000	399,000	664,000
299-W11-43	0	N/A	N/A	N/A	10	60,100	73,900	102,000
299-W11-45	0	N/A	N/A	N/A	46	139,000	394,000	619,000
299-W11-46	0	N/A	N/A	N/A	8	99,400	113,000	132,000
299-W11-47	0	N/A	N/A	N/A	38	6,030	378,000	863,000
299-W11-86	0	N/A	N/A	N/A	15	11,500	17,900	24,400
299-W14-71	0	N/A	N/A	N/A	13	919	2,050	2,940
299-W14-72	0	N/A	N/A	N/A	14	2,480	4,930	8,990
299-W15-152	0	N/A	N/A	N/A	6	27,100	30,200	33,700
299-W15-224	0	N/A	N/A	N/A	2	25,500	27,200	28,900
299-W15-94	0	N/A	N/A	N/A	3	27,600	29,400	32,300

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-13. Minimum, Maximum, and Mean Values for Methylene Chloride in the 200-ZP-1 and 200-UP-1 Operable Units.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	2	0.1	0.35	0.6	0	N/A	N/A	N/A
299-W10-30	2	0.1	0.35	0.6	0	N/A	N/A	N/A
299-W10-31	2	0.1	0.35	0.6	0	N/A	N/A	N/A
299-W11-25B	0	N/A	N/A	N/A	10	2	4.8	8
299-W11-43	11	0.1	0.764	1	0	N/A	N/A	N/A
299-W11-45	5	0.1	0.66	1	0	N/A	N/A	N/A
299-W11-46	1	0.1	0.1	0.1	0	N/A	N/A	N/A
299-W11-47	2	0.6	0.6	0.6	0	N/A	N/A	N/A
299-W11-86	5	1	1	1	1	2	2	2
299-W14-71	6	0.6	0.933	1	1	19	19	19
299-W14-72	5	0.6	0.92	1	1	7.2	7.2	7.2
299-W15-152	11	0.1	0.682	1	0	N/A	N/A	N/A
299-W15-224	2	0.1	0.1	0.1	0	N/A	N/A	N/A
299-W15-94	3	0.1	0.267	0.6	0	N/A	N/A	N/A
299-W19-104	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W19-105	2	0.1	0.55	1	0	N/A	N/A	N/A
299-W19-107	1	1	1	1	0	N/A	N/A	N/A
299-W19-48	17	0.1	0.429	1	1	0.51	0.51	0.51
299-W22-69	2	0.1	0.55	1	0	N/A	N/A	N/A
299-W22-72	2	0.1	0.1	0.1	0	N/A	N/A	N/A
299-W22-86	1	0.1	0.1	0.1	0	N/A	N/A	N/A
299-W22-87	0	N/A	N/A	N/A	0	N/A	N/A	N/A
699-30-66	12	0.1	0.522	1	0	N/A	N/A	N/A
699-36-70B	16	0.1	0.536	1	0	N/A	N/A	N/A

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-14. Minimum, Maximum, and Mean Values for Chloroform in the 200-ZP-1 and 200-UP-1 Operable Units.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	2	1.6	1.65	1.7
299-W10-30	0	N/A	N/A	N/A	2	0.95	0.96	0.97
299-W10-31	1	2	2	2	3	2.6	2.83	3.2
299-W11-25B	0	N/A	N/A	N/A	21	7.9	35.8	110
299-W11-43	0	N/A	N/A	N/A	11	6.7	19.2	54
299-W11-45	0	N/A	N/A	N/A	13	4.9	23.1	65
299-W11-46	0	N/A	N/A	N/A	1	15	15	15
299-W11-47	0	N/A	N/A	N/A	9	13	39.3	144
299-W11-86	0	N/A	N/A	N/A	15	8.4	32.4	100
299-W14-71	2	1	1.5	2	14	3	9.72	33
299-W14-72	1	1	1	1	13	4.7	18.8	69
299-W15-152	4	1	1	1	7	0.21	1.14	4.3
299-W15-224	0	N/A	N/A	N/A	2	1	1.05	1.1
299-W15-94	0	N/A	N/A	N/A	3	5.7	8.87	15
299-W19-104	0	N/A	N/A	N/A	2	3.5	4.5	5.5
299-W19-105	4	1	1.75	2	3	1.6	3.07	5.4
299-W19-107	0	N/A	N/A	N/A	6	3.2	6.18	9.7
299-W19-48	0	N/A	N/A	N/A	23	3.4	6.54	12
299-W22-69	6	1	1.83	2	1	0.4	0.4	0.4
299-W22-72	10	2	2	2	2	0.84	0.855	0.87
299-W22-86	10	2	2	2	1	1.6	1.6	1.6
299-W22-87	5	2	2	2	0	N/A	N/A	N/A
699-30-66	3	0.19	1.06	2	14	0.6	3.21	19
699-36-70B	3	2	2	2	19	1.5	3.09	7

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

Table E-15. Minimum, Maximum, and Mean Values for Chloromethane in the 200-ZP-1 and 200-UP-1 Operable Units.

Well Name	Nondetect				Detect			
	Num	Min	Mean	Max	Num	Min	Mean	Max
299-W10-29	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W10-30	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W10-31	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-25B	10	10	10	10	0	N/A	N/A	N/A
299-W11-43	6	1	1	1	0	N/A	N/A	N/A
299-W11-45	2	1	1	1	0	N/A	N/A	N/A
299-W11-46	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-47	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W11-86	6	1	1	1	0	N/A	N/A	N/A
299-W14-71	6	1	1	1	0	N/A	N/A	N/A
299-W14-72	5	1	1	1	0	N/A	N/A	N/A
299-W15-152	5	1	1	1	0	N/A	N/A	N/A
299-W15-224	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W15-94	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W19-104	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W19-105	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W19-107	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W19-48	17	0.048	0.414	1	1	1.3	1.3	1.3
299-W22-69	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W22-72	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W22-86	0	N/A	N/A	N/A	0	N/A	N/A	N/A
299-W22-87	0	N/A	N/A	N/A	0	N/A	N/A	N/A
699-30-66	9	0.048	0.626	1	3	0.22	0.357	0.5
699-36-70B	13	0.048	0.533	1	3	0.28	0.677	1.2

Max = maximum result
Mean = average of results
Min = minimum result
N/A = no analyses for this analyte
Num = number of results

APPENDIX F

SCREENING OF POTENTIAL REMEDIATION METHODS FOR THE 200-ZP-1 OPERABLE UNIT AT THE HANFORD SITE (PNNL-15954)

The document included in this appendix was published as PNNL-15954 and is included here as an appendix for the convenience of the reader.

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PNNL-15954

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Screening of Potential Remediation Methods for the 200-ZP-1 Operable Unit at the Hanford Site

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August 2006

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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PNNL-15954

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Summary

A screening-level evaluation of potential remediation methods for application to the contaminants of concern (COC) in the 200-ZP-1 Operable Unit at the Hanford Site was conducted based on the methods outlined in the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA Interim Final* (EPA 1988). The scope of this screening was to identify the most promising remediation methods for use in the more detailed analysis of remediation alternatives that will be conducted as part of the full feasibility study. The screening evaluation was conducted for the primary COC (potential major risk drivers) identified in the remedial investigation report (DOE-RL 2006). COC with similar properties were grouped for the screening evaluation.

The screening evaluation was conducted in two primary steps. The initial screening step evaluated potential remediation methods based on whether they can be effectively applied within the environmental setting of the 200-ZP-1 Operable Unit for the specified contaminants. In the second step, potential remediation methods were screened using scoping calculations to estimate the scale of infrastructure, overall quantities of reagents, and conceptual approach for applying the method for each defined grouping of COC. Based on these estimates, each method was screened with respect to effectiveness, implementability, and relative cost categories of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) feasibility study screening process defined in the U.S. Environmental Protection Agency (EPA) guidance (EPA 1988).

Based on the screening evaluation criteria, potential remediation methods were comparatively evaluated to identify those most promising for continued evaluation as part of the feasibility study. Only a few methods are applicable to all COC. Thus, identification of the most promising potential remediation methods was categorized by COC group. Multiple scales of application may be useful for the overall remediation efforts in the 200-ZP-1 Operable Unit. For this reason, identification of the most promising potential remediation methods was also categorized by the scales of application identified in the effectiveness evaluation criteria. This resulting matrix of most promising potential remediation methods is intended to provide information to support either use of a single remedy or a "treatment train" approach as part of the feasibility study for the 200-ZP-1 Operable Unit.

Contents

Summary iii
1.0 Introduction 1.1
2.0 Conceptual Model 2.1
2.1 Carbon Tetrachloride 2.3
2.2 Trichloroethene 2.5
2.3 Chromium 2.7
2.4 Technetium-99 ..... 2.9
2.5 Iodine-129 ..... 2.12
2.6 Uranium 2.14
2.7 Nitrate 2.16
2.8 Tritium 2.19
3.0 Remediation Objectives 3.1
4.0 Assumptions 4.1
5.0 Evaluation Criteria 5.1
6.0 Potential Remediation Methods 6.1
7.0 Screening 7.1
7.1 Initial Screening 7.1
7.2 Screening Based on Scoping Calculations 7.2
7.2.1 Physical Containment 7.4
7.2.2 Monitored Natural Attenuation 7.6
7.2.3 Pump-and-Treat 7.10
7.2.4 Chemical Oxidation 7.10
7.2.5 Injectable Apatite Solution 7.11
7.2.6 Stabilization by Polyphosphate 7.13
7.2.7 Injectable Zero-Valent Iron 7.15
7.2.8 Surfactant Flushing 7.17
7.2.9 In-Well Air Stripping (and Thermally Enhanced In-well Air Stripping) 7.18
7.2.10 Down-Well System 7.21
7.2.11 Air Sparging 7.22
7.2.12 Anaerobic Bioremediation 7.24
7.2.13 Aerobic Bioremediation (co-metabolism) 7.26

7.2.14 In Situ Thermal Treatment 7.28

7.2.15 Permeable Reactive Barriers 7.30

8.0 Results of Screening Evaluation 8.1

9.0 References 9.1

Figures

2.1 Extent of Major Constituents of Concern at Levels above Drinking Water Standards for the 200-ZP-1 Operable Unit 2.2

2.2 Average Carbon Tetrachloride Concentrations in 200 West Area, Top of Unconfined Aquifer 2.4

2.3 Average Trichloroethene Concentrations in 200 West Area, Top of Unconfined Aquifer 2.6

2.4 Average Chromium Concentrations in 200 West Area, Top of Unconfined Aquifer 2.8

2.5 Average Technetium-99 Concentrations in 200 West Area, Top of Unconfined Aquifer 2.10

2.6 Depth-Distribution of Technetium-99 in Well 299-W11-25B 2.11

2.7 Depth-Distribution of Technetium-99 in Well 299-W14-11 ..... 2.11

2.8 Average Iodine-129 Concentrations in 200 West Area, Top of Unconfined Aquifer 2.13

2.9 Depth-Distribution of Iodine-129 in Well 299-W14-11 ..... 2.14

2.10 Average Uranium Concentrations in 200 West Area, Top of Unconfined Aquifer 2.15

2.11 Average Nitrate Concentrations in 200 West Area, Top of Unconfined Aquifer 2.17

2.12 Depth-Distribution of Nitrate in Well 299-W11-25B 2.18

2.13 Depth-Distribution of Nitrate in Well 299-W18-16 ..... 2.18

2.14 Average Tritium Concentrations in 200 West Area, Top of Unconfined Aquifer 2.20

2.15 Depth-Distribution of Tritium in Well 299-W11-43 ..... 2.21

2.16 Depth-distribution of Tritium in Well 299-W14-11 ..... 2.21

Tables

1.1 COC Groupings Used in the Screening Evaluation 1.1

2.1 Areal Extent Considered in Screening for each Contaminant of Concern 2.3

2.2 Area and Volume of Carbon Tetrachloride Contamination for Remediation Technology Screening 2.5

2.3 Area and Volume of Trichloroethene Contamination for Remediation Technology Screening 2.5

2.4 Area and Volume of Chromium Contamination for Remediation Technology Screening 2.9

2.5 Area and Volume of Technetium-99 Contamination for Remediation Technology Screening 2.12

2.6 Area and Volume of Iodine-129 Contamination for Remediation Technology Screening 2.14

2.7 Area and Volume of Uranium Contamination for Remediation Technology Screening 2.16
2.8 Area and Volume of Nitrate Contamination for Remediation Technology Screening 2.19
2.9 Area and Volume of Tritium Contamination for Remediation Technology Screening 2.22
5.1 Screening Evaluation Criteria for the Second Step of Screening 5.2
6.1 Potential Remediation Methods for COC Group 1 ..... 6.2
6.2 Potential Remediation Methods for COC Group 2 ..... 6.3
6.3 Potential Remediation Methods for COC Group 3 ..... 6.4
6.4 Potential Remediation Methods for COC Group 4 ..... 6.4
7.1 COC Group 1 – Remediation Methods Screened Out in Initial Screening 7.1
7.2 COC Group 2 – Remediation Methods Screened Out in Initial Screening 7.1
7.3 COC Group 3 – Remediation Methods Screened Out in Initial Screening 7.2
7.4 COC Group 4 – Remediation Methods Screened Out in Initial Screening 7.2
7.5 Remediation Methods Considered in Second Stage of Screening 7.3
7.6 Zero-Valent Iron Required as a Function of Aquifer Volume 7.15
7.7 Estimated Radius of Influence and Treatment Volumes for an In-Well Air Stripping Well 7.19
7.8 Volume of Dithionite Solution as a Function of Treatment Depth 7.34
8.1 Summary of Potential Remediation Methods Recommended for Further Assessment for Each COC Grouping Based on the Results of the Screening Evaluation 8.2

1.0 Introduction

A screening-level evaluation of potential remediation methods for application to the contaminants of concern (COC) in the 200-ZP-1 Operable Unit at the Hanford Site was conducted based on the methods outlined in the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA Interim Final* (EPA 1988). The scope of this screening was to identify the most promising remediation methods for use in the more detailed analysis of remediation alternatives that will be conducted as part of the full feasibility study. The screening evaluation was conducted for the primary COC (potential major risk drivers) identified in the remedial investigation report (DOE-RL 2006). The primary COC were grouped, as shown in Table 1.1, based on similarity in chemical/physical properties such as mobility and/or, for the most part, the same remediation methods would apply to each contaminant in the group. Additional human health or ecological COC that are not also primary COC were identified in the remedial investigation report as Group B and include chloroform, tetrachloroethene, 1,2-dichloroethane, antimony, iron, hexavalent chromium, and cyanide. These compounds are termed secondary COC for the purpose of the screening evaluation. The screening evaluation includes assessment of whether the potential remediation methods identified for the primary COC have a positive or negative impact on these secondary COC.

Table 1.1. Primary COC Groupings Used in the Screening Evaluation

COC Group	Contaminants
Group 1 (selected VOC)	Carbon tetrachloride and trichloroethene
Group 2 (mobile metals and radionuclides)	Chromium, technetium-99 (Tc-99), iodine-129 (I-129), and uranium (uranium-234, uranium-235, uranium-238)
Group 3 (nitrate)	Nitrate
Group 4 (tritium)	Tritium

2.0 Conceptual Model

A generalized conceptual model of the volume, nature, and extent of contamination and the environmental setting for the 200-ZP-1 Operable Unit was developed for use in the screening evaluation. For the purposes of this analysis, the conceptual model addresses the eight primary COC. The plume boundaries were selected based on the following concentrations, which are consistent with the anticipated target action levels.

- Carbon tetrachloride (5 µg/L)
- Trichloroethene (5 µg/L)
- Chromium (100 µg/L)
- Technetium-99 (900 pCi/L)
- Iodine-129 (1 pCi/L)
- Uranium (30 µg/L)
- Nitrate (45 mg/L as NO_3)
- Tritium (20,000 pCi/L)

The overall extent of these contaminants at the top of the unconfined aquifer in the 200-ZP-1 Operable Unit for fiscal year (FY) 2005 is shown in Figure 2.1. The carbon tetrachloride plume extending into the 200-UP-1 Operable Unit is considered with the 200-ZP-1 contamination.

Both the area of aquifer with contaminant levels above target action levels and the volume of contaminated aquifer are important for screening of potential remediation methods. In addition, the area and volume containing higher levels of contamination (e.g., source areas) was considered in the screening evaluation.

The conceptual model and associated figures and tables were developed using data from the *Hanford Site Groundwater Monitoring for Fiscal Year 2005* (Hartman et al. 2006) except as noted. Specifically, the areal extent of contamination at levels above the target action level and higher levels of concern are calculated from the contamination contours included in Hartman et al. (2006). Average concentrations refer to the average of the data values in Hartman et al. (2006) over the indicated timeframe. There is greater uncertainty in depth of contamination than for the lateral extent at the water table. Some plumes are known to extend farther in some directions at depth than is shown on the concentration maps at the top of the aquifer (near the water table). In general, for most constituents data are insufficient to fully define the three-dimensional extent. However, the resulting uncertainty in contaminated area is not likely to have a significant impact on the screening calculations. Where thickness of contamination is poorly defined, the contaminant volume is generally calculated as being throughout the aquifer to the top of the Ringold lower mud unit, which is ~55 m below the water table in the 200 West Area. For the 200-ZP-1 Operable Unit, the water table is on the order of 100 m below ground surface. This thickness of vadose zone is an important factor in the cost and implementability of remediation. Specific impacts of the thick vadose zone are discussed in the review of individual technologies. The aquifer is heterogeneous with vertical and lateral variations in particle size distribution and cementation that impact the hydrogeologic characteristics of the aquifer. Implementation of any technology is impacted by this heterogeneity. In some cases, this heterogeneity renders a technology unsuitable as discussed in the review of individual technologies.

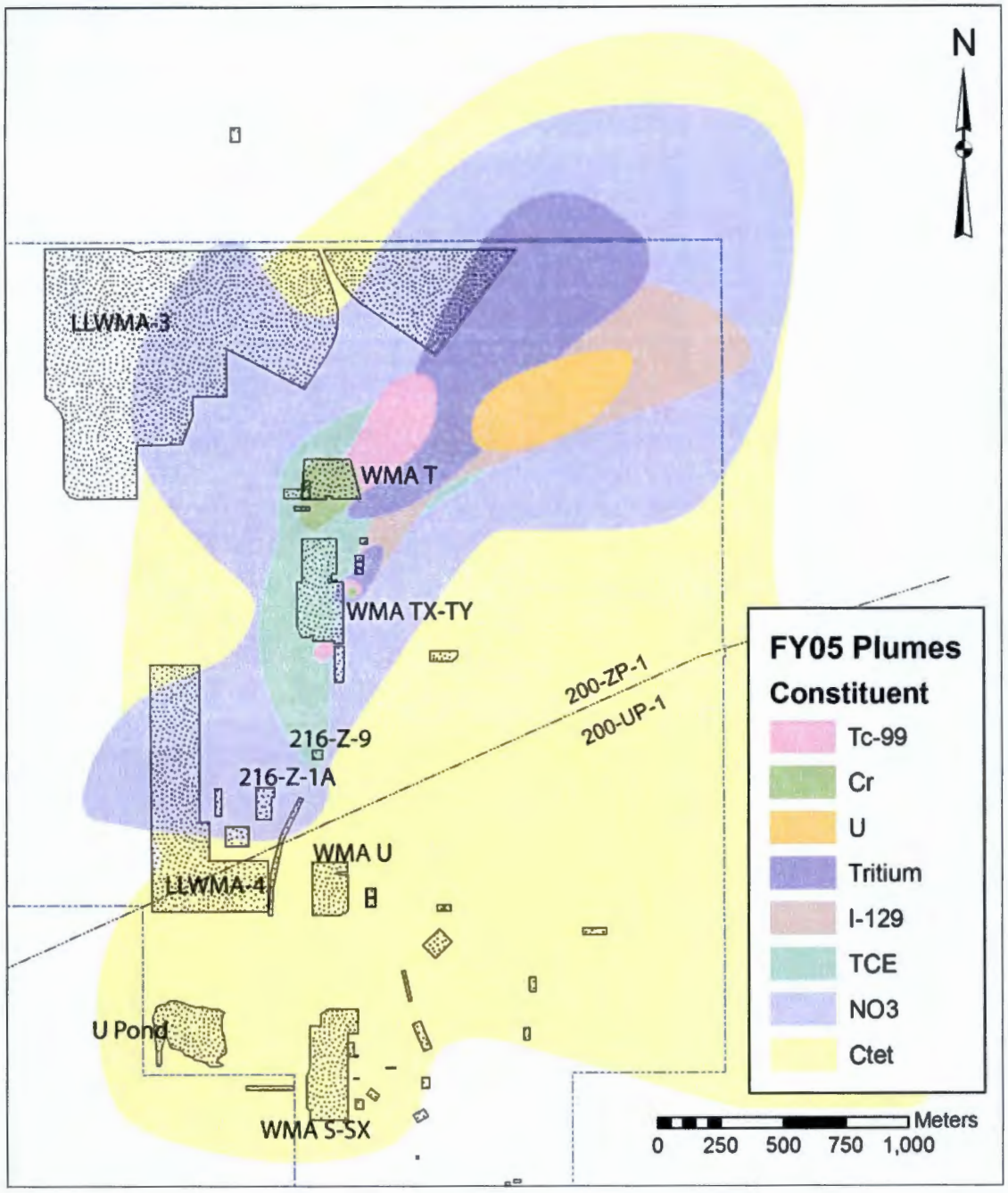

Figure 2.1. Extent of Major Constituents of Concern at Levels above Drinking Water Standards for the 200-ZP-1 Operable Unit (from Hartman et al. 2006)

The following sections define the conceptual model for each COC. Based on this information the areal extent of treatment for each COC is shown in Table 2.1. Note that these are not the exact areal extent shown for each COC, but are a selected set of areas for use in estimating the scale of treatment relevant to plume elements. The impact of treating a selected volume in terms of meeting the overall remediation goals was not assessed as part of the screening evaluation. The fate and transport evaluation necessary to assess the impact to the overall remediation goal will be conducted as part of the subsequent feasibility study.

Table 2.1. Areal Extent Considered in Screening for each Contaminant of Concern

COC	Areal Extent Considered in Screening (acre)
Carbon tetrachloride	1, 5, 25, 250, >250
Trichloroethene	1, 5, 25, 250
Chromium	1, 5, 25
Technetium-99	1, 5, 25
Iodine-129	1, 5, 25, 250
Uranium	1, 5, 25
Nitrate	1, 5, 25, 250, >250
Tritium	1, 5, 25, 250

2.1 Carbon Tetrachloride

Carbon tetrachloride forms the most extensive area of contamination in the 200-ZP-1 Operable Unit (Figure 2.2). The contamination extends into the 200-UP-1 Operable Unit. The entire area of contamination will be evaluated for the 200-ZP-1 Operable Unit because the major contaminant sources are believed to be located near the Plutonium Finishing Plant in 200-ZP-1. Other sources may also be present near the Waste Management Area (WMA) T Tank Farm; however, these have not been specifically identified. The areal extent for the plume was determined based on the near water-table concentration distribution. The thickness of the plume was determined based on the interpolated three-dimensional distribution of carbon tetrachloride in Murray et al. (2006). The thickness from the interpolated distribution was then multiplied by the corresponding areal extent from the near water-table distribution. This projection presumes that treatment would extend from the water table downward to the deepest contamination at a selected concentration level. Note that there are differences in the three-dimensional interpolation of the plume and the near water-table distribution. However, these differences were not considered for the screening evaluation.

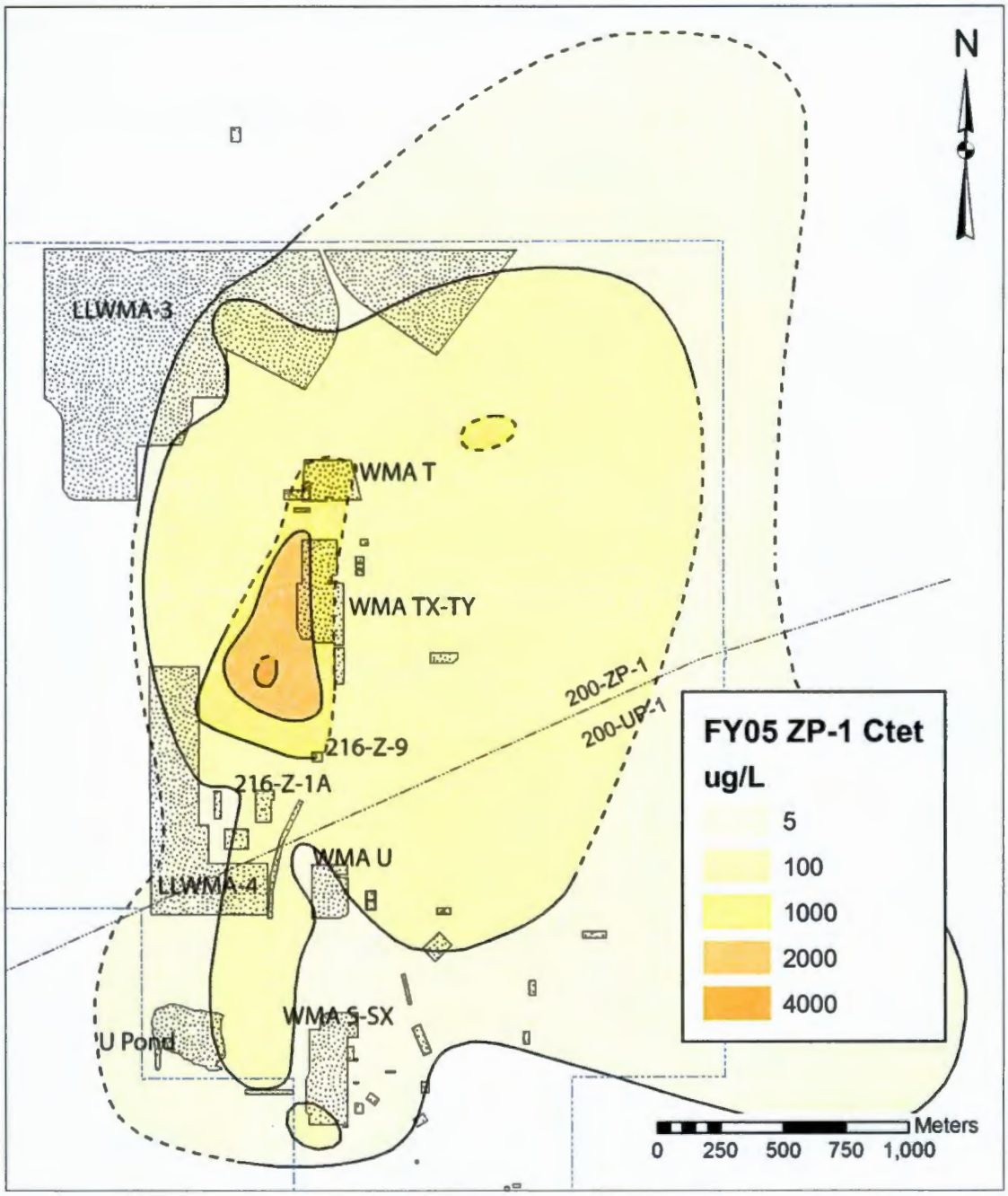

Figure 2.2. Average Carbon Tetrachloride Concentrations in 200 West Area, Top of Unconfined Aquifer

The area and volume calculations for the carbon tetrachloride contamination are summarized in Table 2.2.

Table 2.2. Area and Volume of Carbon Tetrachloride Contamination for Remediation Technology Screening

Concentration (µg/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
5	10,861,822 (2,700)	60	651,709,320
100	4,912,591 (1,220)	60	294,755,460
1,000	450,117 (112)	30	13,503,510
2,000	182,996 (45)	20	3,659,920
4,000	11,827 (2.9)	20	236,540

For the screening evaluation, potential continuing source areas (e.g., dense, non-aqueous phase liquid [DNAPL]) for the carbon tetrachloride plume were defined as having an areal extent of less than 1 acre and a thickness of 20 m.

2.2 Trichloroethene

The source of the trichloroethene plume (Figure 2.3) is believed to be from cribs that received waste from the Plutonium Finishing Plant. These sources are generally south of the WMA T and WMA TX-TY Tank Farms. The highest FY 2005 average concentration, 13 µg/L, was observed in extraction wells for the 200-ZP-1 interim action pump-and-treat system. The concentration and extent of trichloroethene deeper in the aquifer is poorly established. The trichloroethene plume is entirely contained within the carbon tetrachloride plume. The deepest trichloroethene detected at levels above the 5-µg/L drinking water standard was 8 µg/L at 66 m below the water table. Several other wells throughout the plume showed trichloroethene at levels above 5 µg/L at 50–60 m below the water table. A maximum contaminated thickness of 70 m was used for the screening calculations.

The area and volume calculations for the trichloroethene contamination are summarized in Table 2.3.

Table 2.3. Area and Volume of Trichloroethene Contamination for Remediation Technology Screening

Concentration (µg/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
5	733,218 (182)	70	51,325,260

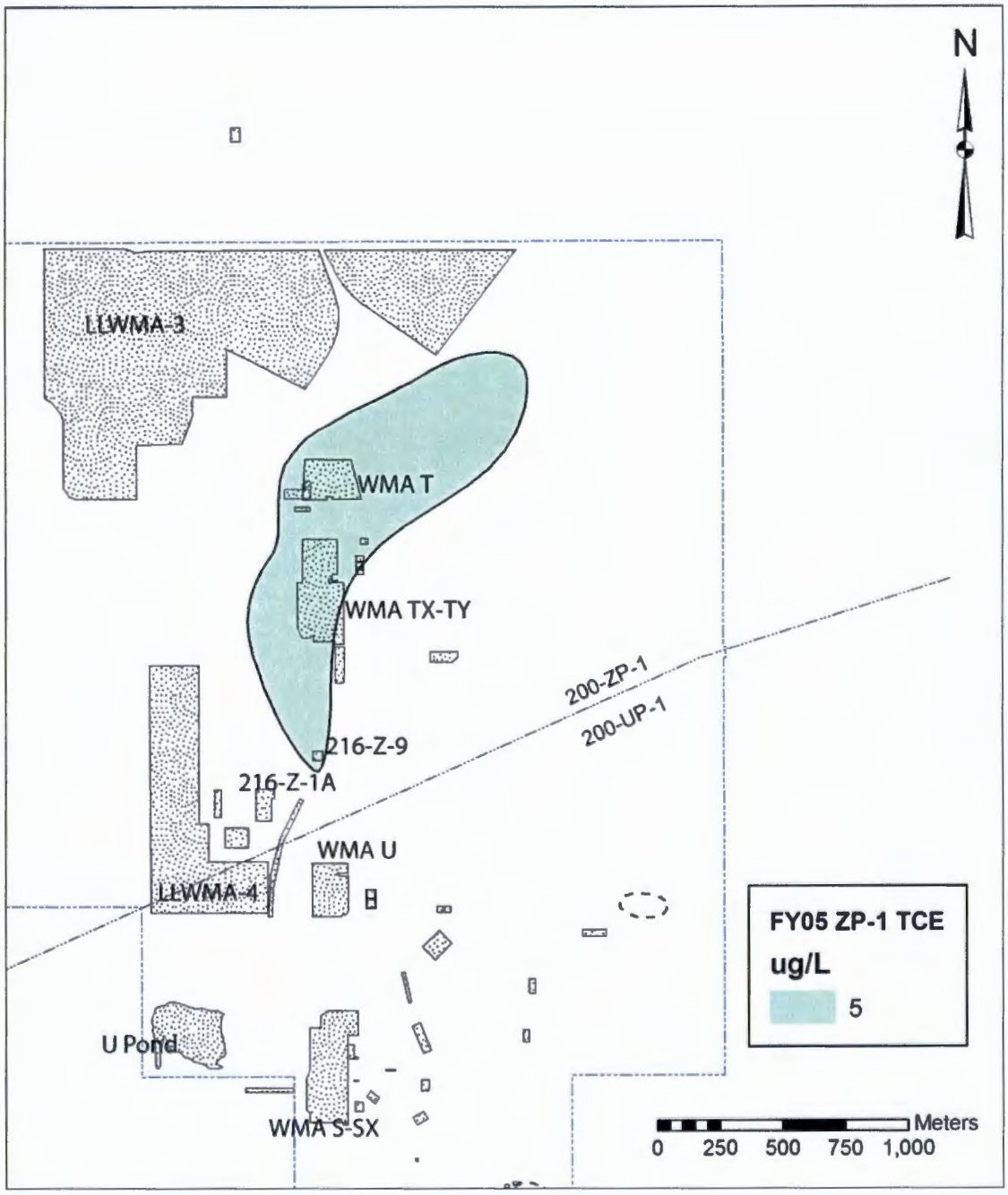

Figure 2.3. Average Trichloroethene Concentrations in 200 West Area, Top of Unconfined Aquifer

2.3 Chromium

Chromium forms two small plumes in the 200-ZP-1 Operable Unit at levels above the drinking water standard (Figure 2.4). The chromium interpretation is based on samples filtered through a 0.45-µm filter during collection. The northernmost plume is centered at the WMA T Tank Farm. The tank farm is believed to be a source of the contamination but liquid waste disposal facilities in the vicinity may also contribute. This plume has been traced downgradient (to the northeast/east) at levels less than the drinking water standard but the area mapped at levels greater than the 100 µg/L standard appears not to have grown very much in the past decade. However, south of WMA T concentrations have been increasing in well 299-W10-4 near the 216-T-36 crib. This well currently has the highest chromium concentration (670 µg/L average in FY 2005) in the operable unit.

Information on chromium distribution with depth near WMA T is available from samples collected during drilling of well 299-W11-25B. Only samples collected with a pump are considered representative of aquifer conditions. The deepest sample with concentrations greater than 500 µg/L was approximately 11 m, and the next sample at approximately 18 m contained 64 µg/L of chromium. For the purposes of this screening, the thickness greater than 500 µg/L was approximated as 15 m and the thickness greater than 100 µg/L was approximated as 20 m. This is the only location where chromium was detected at levels above 100 µg/L in samples collected at depths greater than 10 m below the water table.

Technetium-99 and nitrate are co-contaminants found with the chromium near WMA T. Carbon tetrachloride and trichloroethene are also found at levels above their drinking water standards in the area of the chromium plume.

The second plume at levels greater than the drinking water standard at the water table is restricted to a single well, 299-W14-13, east of WMA TX-TY tank farms. The FY 2005 average filtered chromium concentration in this well was 690 µg/L. Chromium concentrations are increasing in a well ~60 m to the south but still have not reached the drinking water standard. Because this plume is defined by only one well, the area mapped at the 500 µg/L level was assumed to be approximately the same as the area greater than 100 µg/L.

Little information on the depth-distribution of chromium near WMA TX-TY is available. A depth distribution similar to technetium-99 (see below) will be assumed. The depth to the 100 µg/L drinking water standard level is estimated from the depth used for technetium-99 above the drinking water standard, 30 m. The depth for 500 µg/L chromium is estimated from the technetium-99 at levels greater than five times the technetium-99 drinking water standard, conservatively at 10 m below the water table.

Tritium, iodine-129, and Technetium-99 are co-contaminants found at high concentrations centering in the same area as the chromium at WMA TX-TY. Carbon tetrachloride, trichloroethene, and nitrate are also found at levels above the drinking water standard in the area of the WMA TX-TY chromium.

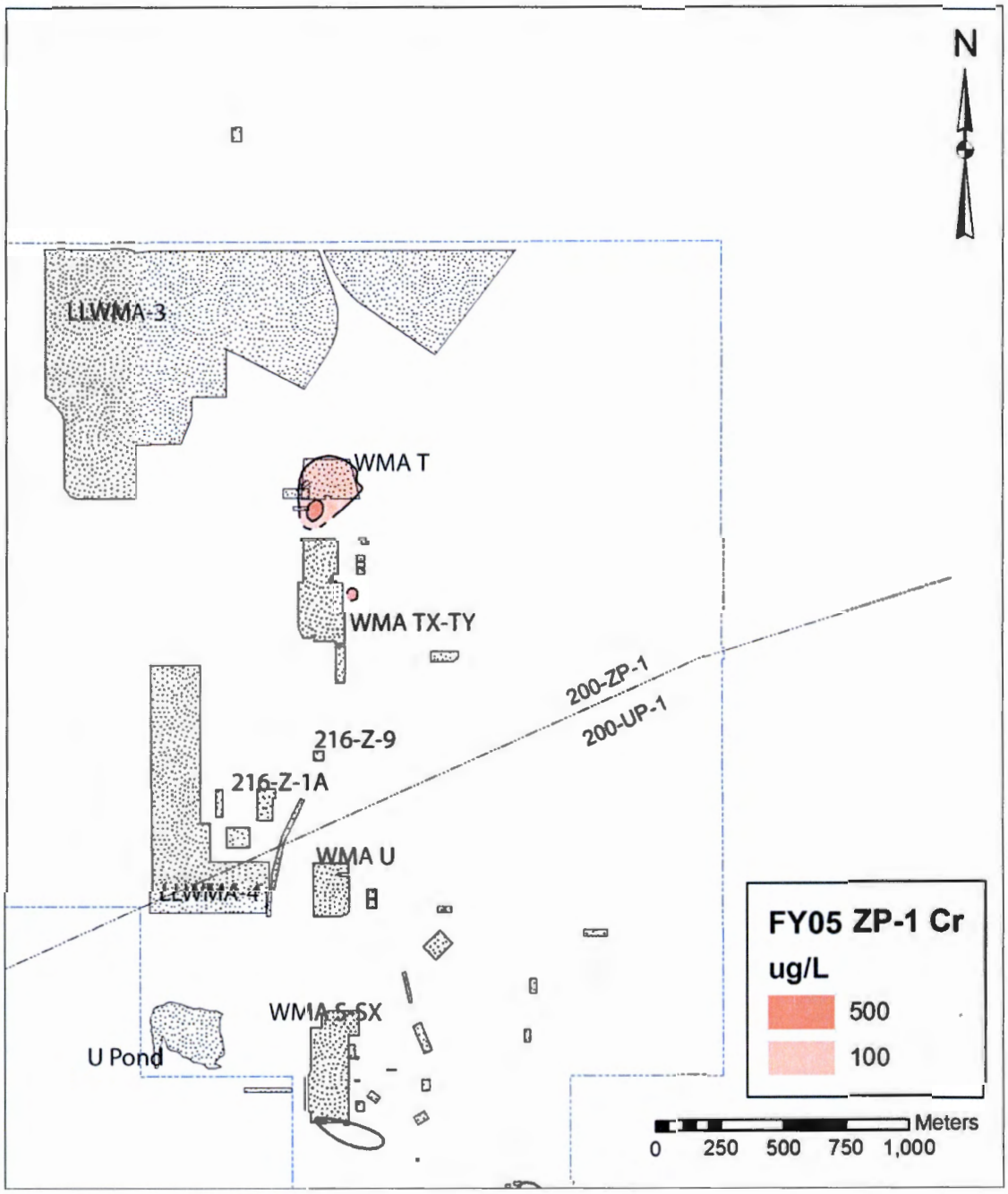

Figure 2.4. Average Chromium Concentrations in 200 West Area, Top of Unconfined Aquifer

The area and volume calculations for the chromium contamination are summarized in Table 2.4.

Table 2.4. Area and Volume of Chromium Contamination for Remediation Technology Screening

Area	Concentration (μg/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
WMA-T	100	52,179 (13)	20	1,043,580
	500	4,042 (1)	15	60,360
WMA-TX-TY	100	1,566 (0.4)	30	46,980
	500	1,566 (0.4)	10	15,660
Total	**100**	**53,745 (13)**	**--**	**1,090,560**
	500	**5,608 (1.4)**	**--**	**76,020**

2.4 Technetium-99

Technetium-99 is found at levels above the drinking water standard in three small plumes in the 200-ZP-1 Operable Unit (Figure 2.5).

The first plume is located in the vicinity of the WMA T Tank Farm. The tank farm is a probable source of much of the contamination but liquid waste disposal facilities appear to contribute some technetium-99, and characterization efforts are ongoing. This plume extends northeast from the source area. The highest concentration observed in wells completed at the water table was 17,000 pCi/L in well 299-W11-39. This plume, as mapped at the water table, overlaps the chromium and tritium plumes and is contained within the area of the carbon tetrachloride, trichloroethene, and nitrate plumes.

Data from drilling well 299-W11-25B indicate that the highest technetium-99 concentration, 182,000 pCi/L, was found at 10 m below the water table (Figure 2.6). However, the concentration remained above ten times the drinking water standard to the bottom of the boring at 51 m below the water table (depth of the Ringold lower mud unit, which is considered to be the bottom of the uppermost aquifer), where the result from the pumped sample was 21,200 pCi/L. For the purpose of the screening evaluation, a thickness of 55 m was used.

The second technetium-99 plume to be considered is located east of the WMA TX-TY Tank Farm in the area of the chromium, tritium, and iodine-129 plumes. Only one well, 299-W14-13, showed technetium-99 at levels above the drinking water standard. The FY 2005 average concentration was 2,200 pCi/L. The technetium-99 is also within the area of the carbon tetrachloride and nitrate plumes. The trichloroethene plume partially overlaps this technetium-99 contamination.

Some information on the depth-distribution of technetium-99 near WMA TX-TY is available from well 299-W14-11 that was drilled approximately 5 m from well 299-W14-13 (Figure 2.7). Technetium-99 concentrations were highest (75,000 pCi/L) at approximately 5 m below the water table and generally declined with depth. The deepest sample with concentrations greater than the drinking water standard

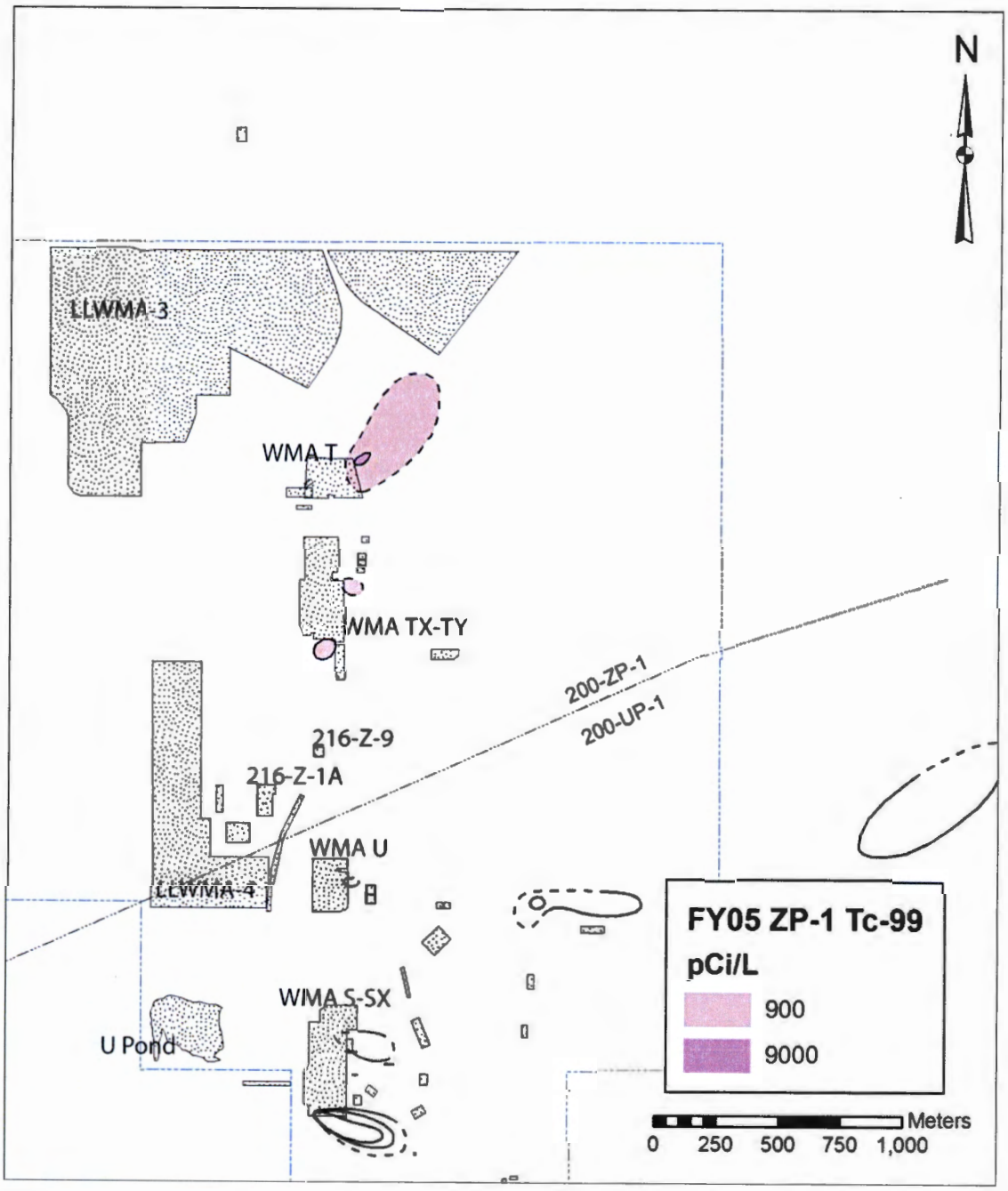

Figure 2.5. Average Technetium-99 Concentrations in 200 West Area, Top of Unconfined Aquifer

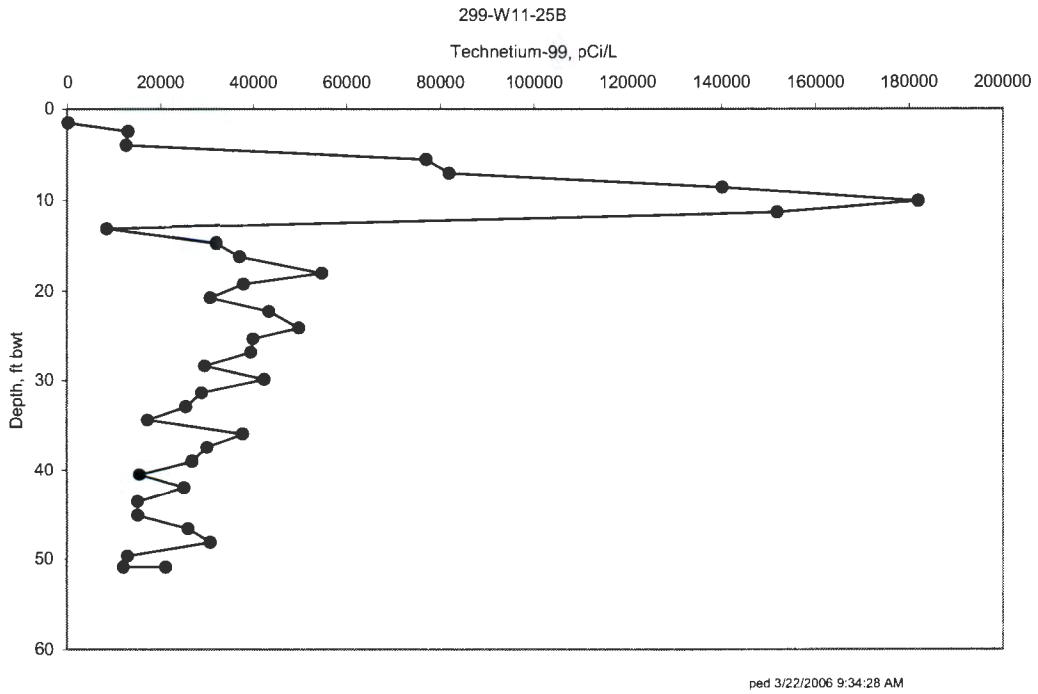

Figure 2.6. Depth-Distribution of Technetium-99 in Well 299-W11-25B

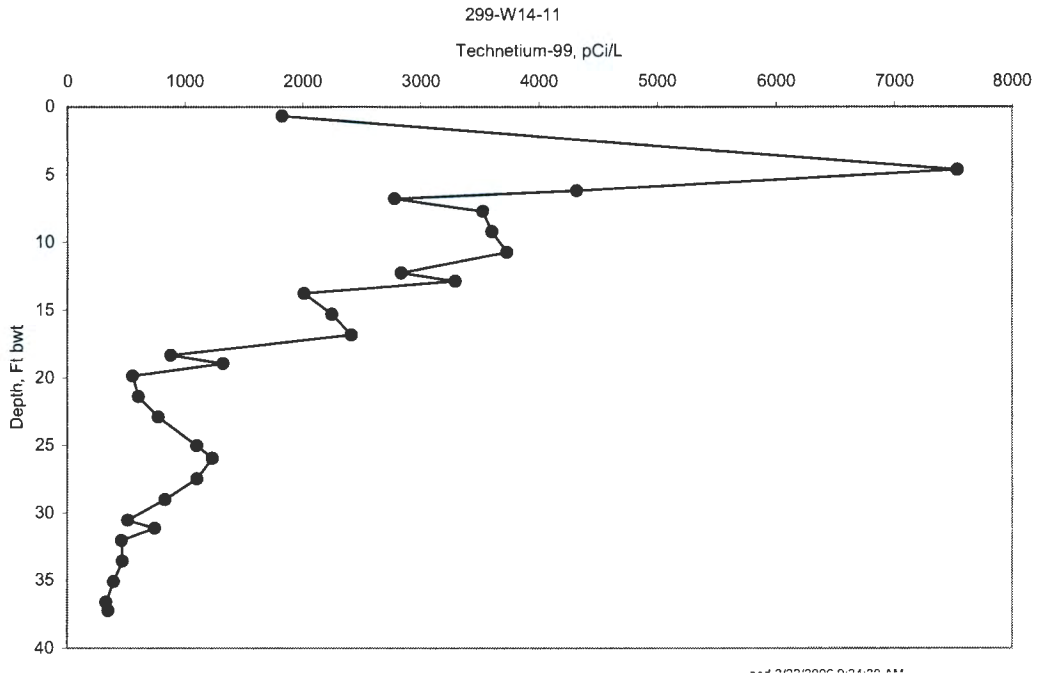

Figure 2.7. Depth-Distribution of Technetium-99 in Well 299-W14-11

was at approximately 27 m below the water table, and the subsequent sample, below the drinking water standard, was at approximately 29 m. The contamination thickness was approximated as 30 m for the screening calculations.

The third technetium-99 plume is located south of WMA TX-TY and appears to be drawn toward the south by the 200-ZP-1 interim action pump-and-treat system. The well with the highest FY 2005 average concentration contained 1,000 pCi/L of technetium-99. This plume is within the area of the carbon tetrachloride, trichloroethene, and nitrate plumes. There is no available information on the depth distribution of the technetium-99 in this plume. A thickness of 30 m was used to be consistent with the contamination on the east side of WMA TX-TY.

The area and volume calculations for the technetium-99 contamination are summarized in Table 2.5.

Table 2.5. Area and Volume of Technetium-99 Contamination for Remediation Technology Screening

Area	Concentration (pCi/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
WMA-T	900	106,285 (26)	55	5,845,675
	9,000	1,871 (0.5)	55	102,905
WMA-TX-TY				
East Side	900	4,284 (1)	30	128,520
South Side	900	5,274 (1.3)	30	158,220
Total	**900**	**115,843 (27)**	--	**6,132,415**
	9,000	**1,871 (0.5)**	--	**102,905**

2.5 Iodine-129

The extent of iodine-129 at levels above the drinking water standard at the water table in the 200-ZP-1 Operable Unit appears to form a single plume with the highest concentrations detected east of WMA TX-TY and extending to the northeast (Figure 2.8). It is possible that iodine-129 is present at levels very close to the drinking water standard in a single well south of WMA T, near the 216-T-36 crib, but analytical difficulties (possible technetium-99 interference, lack of confirmation at a second energy level for the detection) mean that this is uncertain. In depth, discrete samples from drilling well 299-W11-25B near the northeast corner of WMA T, iodine-129 was not detected but the detection limits were elevated above the drinking water standard.

The high-concentration part of the iodine-129 plume is coincident with high concentrations of tritium, chromium, and technetium-99. The plume is entirely contained within the carbon tetrachloride and nitrate plumes and contains the mapped extent of the uranium plume. The iodine-129 plume overlaps parts of the trichloroethene plume.

The specific sources of iodine-129 in the groundwater have not been completely defined. The high-concentration part of the plume is in the vicinity of the WMA TX-TY Tank Farms, the 216-T-26, 216-T-28, and other cribs. Although there are potentially other source areas, this vicinity is considered a continuing source of contamination.

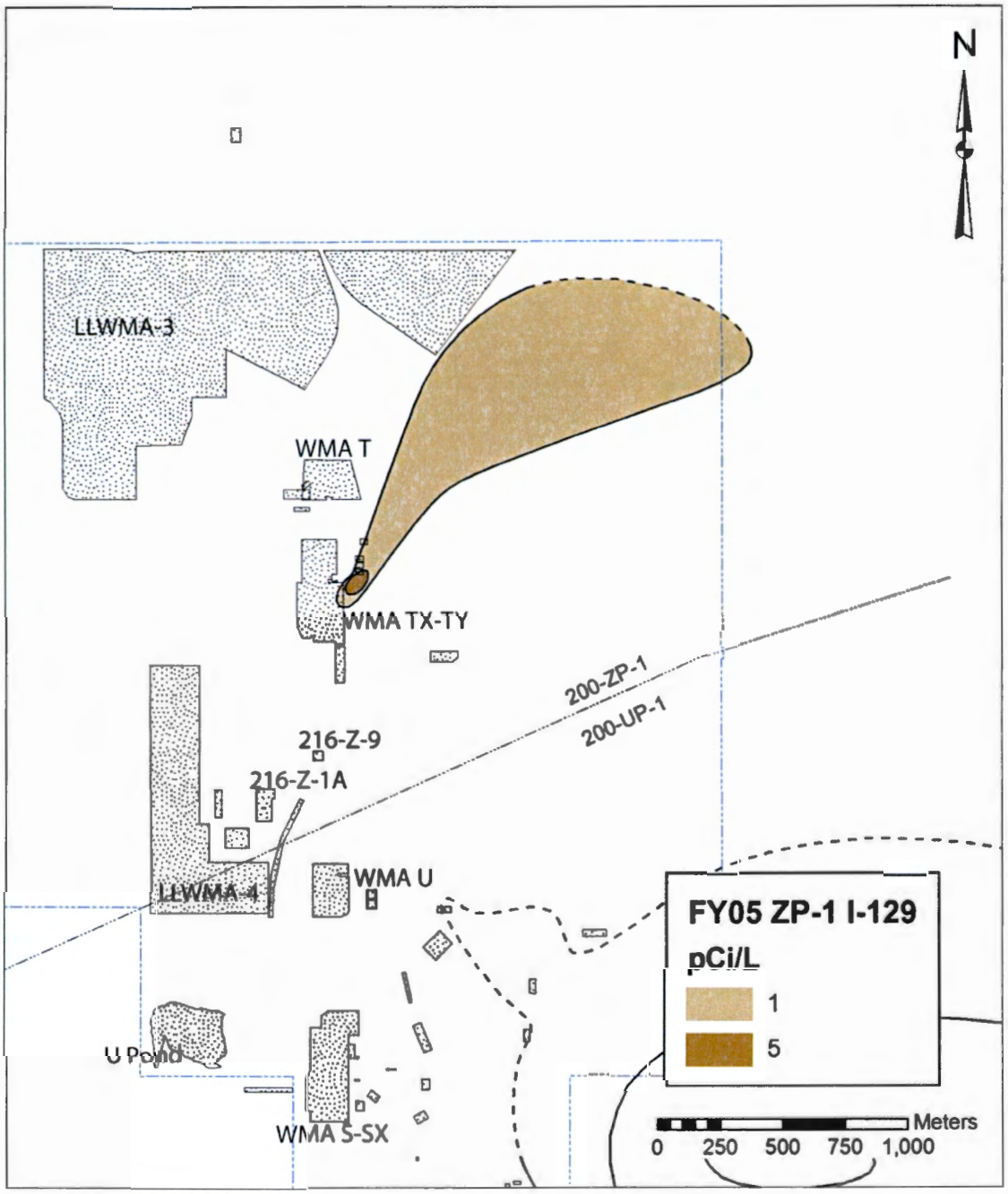

Figure 2.8. Average Iodine-129 Concentrations in 200 West Area, Top of Unconfined Aquifer

Contaminant depth for iodine-129 is not well defined throughout the plume. Characterization data from drilling well 299-W14-11 can be used to define the depth distribution near the source area. The data indicate that the iodine-129 concentration remains above the drinking water standard down to a depth between approximately 30–35 m below the water table and above 5 pCi/L to less than 20 m below the water table (Figure 2.9). For the technology screening, a thickness of 35 m was used for the contaminant thickness throughout the plume at the 1-pCi/L level and 20 m at the 5-pCi/L level.

The area and volume calculations for the iodine-129 contamination are summarized in Table 2.6.

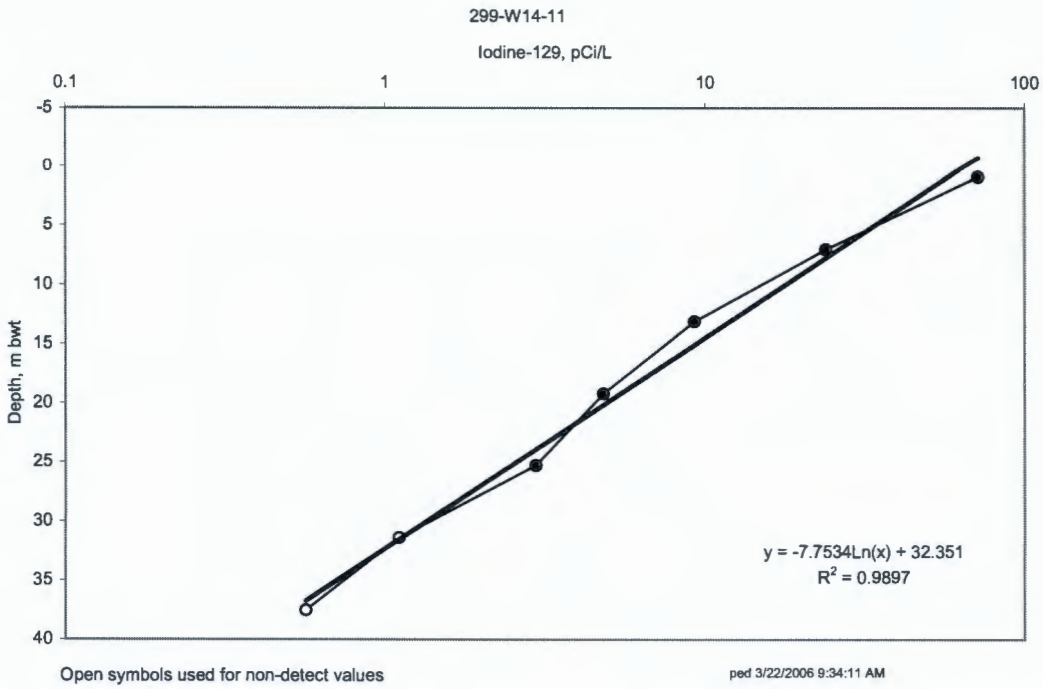

Figure 2.9. Depth-Distribution of Iodine-129 in Well 299-W14-11

Table 2.6. Area and Volume of Iodine-129 Contamination for Remediation Technology Screening

Concentration (pCi/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
1	783,629 (195)	35	27,427,015
5	5,624 (1.4)	20	112,480

2.6 Uranium

A uranium plume has been identified north of the T Plant Canyon building (Figure 2.10). Relatively little is known regarding the source of this plume, and the extent is not well defined; 183 µg/L of uranium was detected in well 299-W11-37 in FY 2005. No data on the depth distribution of uranium are available within this plume. For the purposes of the screening of alternatives, a thickness of 35 m was assumed.

The uranium plume is overlapped by the carbon tetrachloride, trichloroethene, iodine-129, tritium, and nitrate plumes.

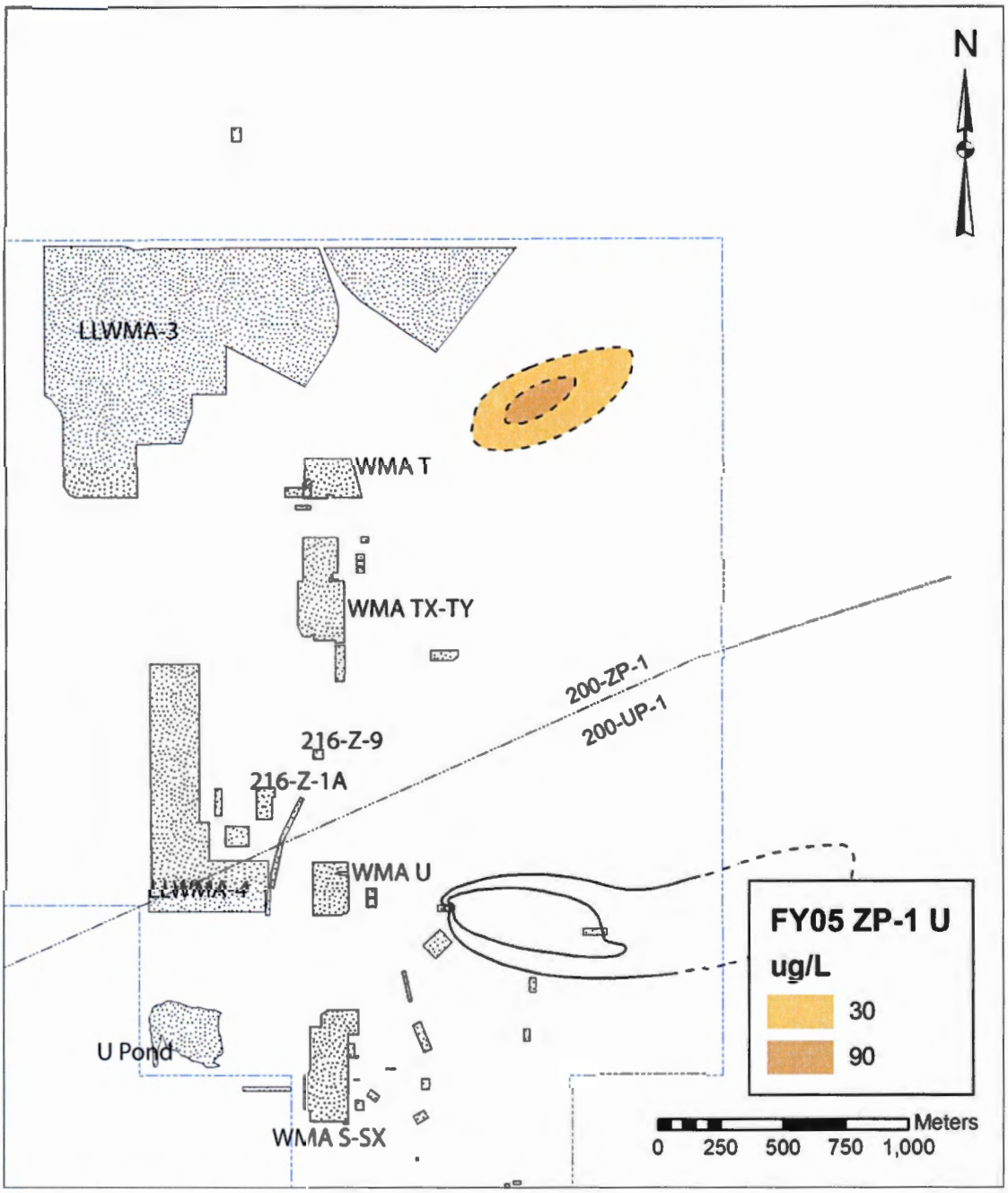

Figure 2.10. Average Uranium Concentrations in 200 West Area, Top of Unconfined Aquifer

The area and volume calculations for the uranium contamination are summarized in Table 2.7.

Table 2.7. Area and Volume of Uranium Contamination for Remediation Technology Screening

Concentration (μg/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
30	164,325 (41)	35	5,751,375
90	28,797 (7.2)	35	1,007,895

2.7 Nitrate

Nitrate contamination covers a large area of the 200-ZP-1 Operable Unit at levels above the drinking water standard (Figure 2.11). There are multiple sources of contamination. Some contamination originates in the vicinity of the Plutonium Finishing Plant. The highest contamination levels are associated with cribs near WMA T, although it appears the tank farm also contributed. The highest average nitrate concentration for FY 2005 near WMA T was 3,540 mg/L in well 299-W10-4 located south of the tank farm.

Nitrate was found at levels between 45 and 500 mg/L in several wells at depths between 30 and 60 m below the water table. However, no data show nitrate levels above 45 mg/L at depths greater than 60 m below the water table although fewer borings reached those depths. Thus, the assumption of contamination above 45 mg/L to the lower mud at ~55 m below the water table throughout the plume area was used for the screening calculations.

In the vicinity of WMA T, the highest nitrate concentrations are found in the upper part of the aquifer and drop below 500 mg/L at depths less than 20 m below the water table. The data for well 299-W11-25B, located east of WMA T are shown in Figure 2.12. None of the vertical-profile samples in the area show nitrate greater than 1,000 mg/L. For the screening calculations, a depth of 20 m below the water table was used to bound the 500 mg/L volume, and a depth of 10 m below the water table was used for the 1,000 mg/L volume in the vicinity of WMA-T.

A newly installed well, 299-W18-16, located near the 216-Z-1A crib and tile field has nitrate concentrations significantly higher than surrounding wells (766 mg/L). The tile field is a likely source for the higher level of contamination but the precise extent is somewhat uncertain. Concentrations of nitrate in this well were above 500 mg/L down to the maximum sampled depth (~28 m below the water table, Figure 2.13). Since the depth distribution of contamination is not well bounded, both the 500 and 45 mg/L concentrations are assumed to extend down to 55 m below the water table, approximately the top of the lower mud unit in the 200-ZP-1 Operable Unit.

One well northwest of the 200 West Area has reported nitrate at levels above the drinking water standard. The area associated with this contamination is uncertain because well coverage is sparse away from the operational areas. The thickness was assumed to be 55 m below the water table for screening purposes.

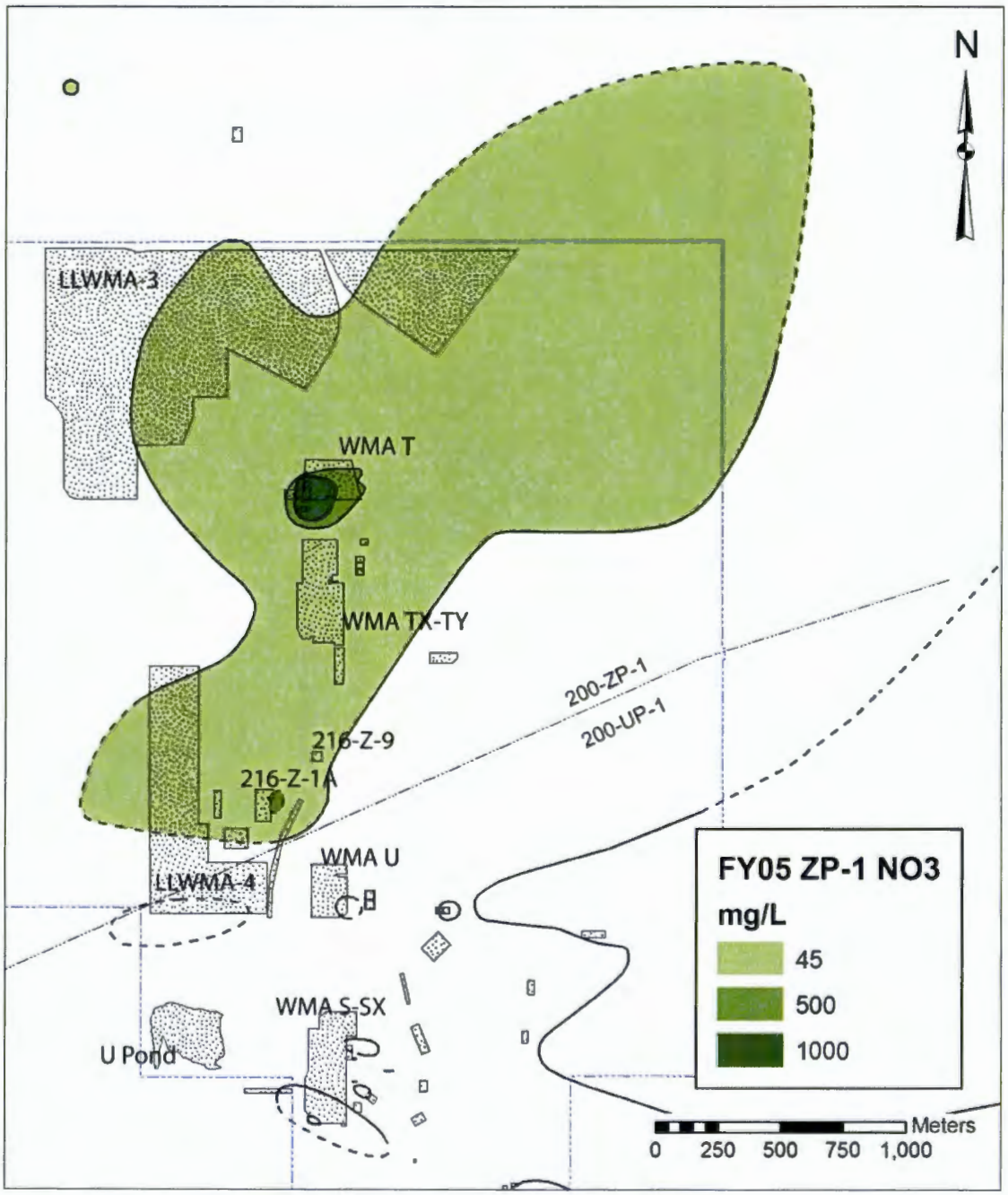

Figure 2.11. Average Nitrate Concentrations in 200 West Area, Top of Unconfined Aquifer

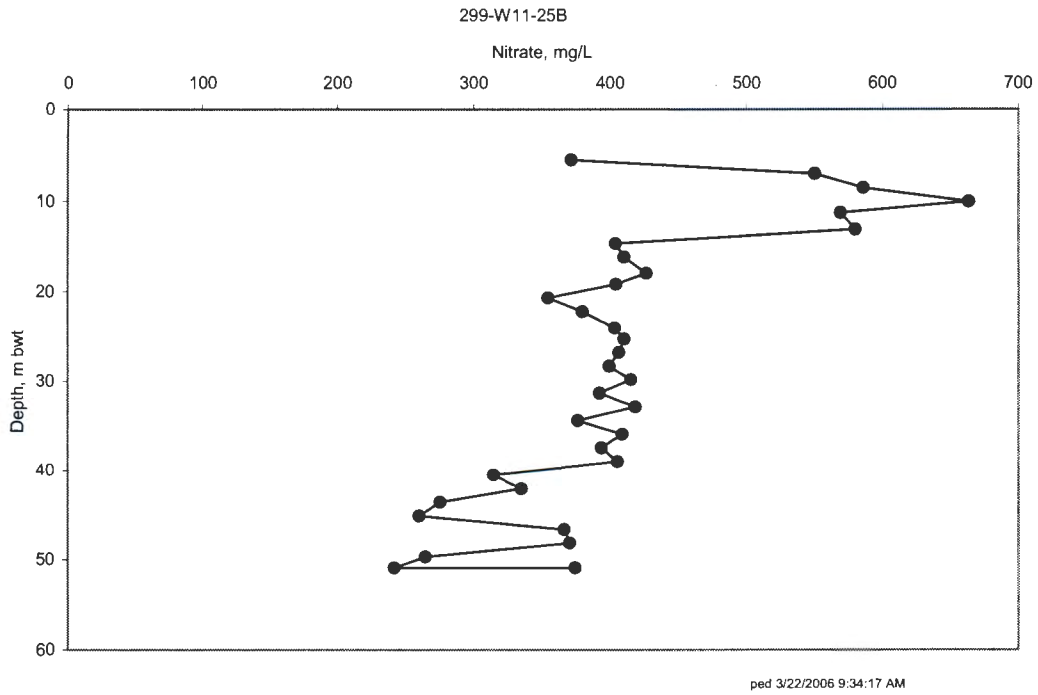

Figure 2.12. Depth-Distribution of Nitrate in Well 299-W11-25B

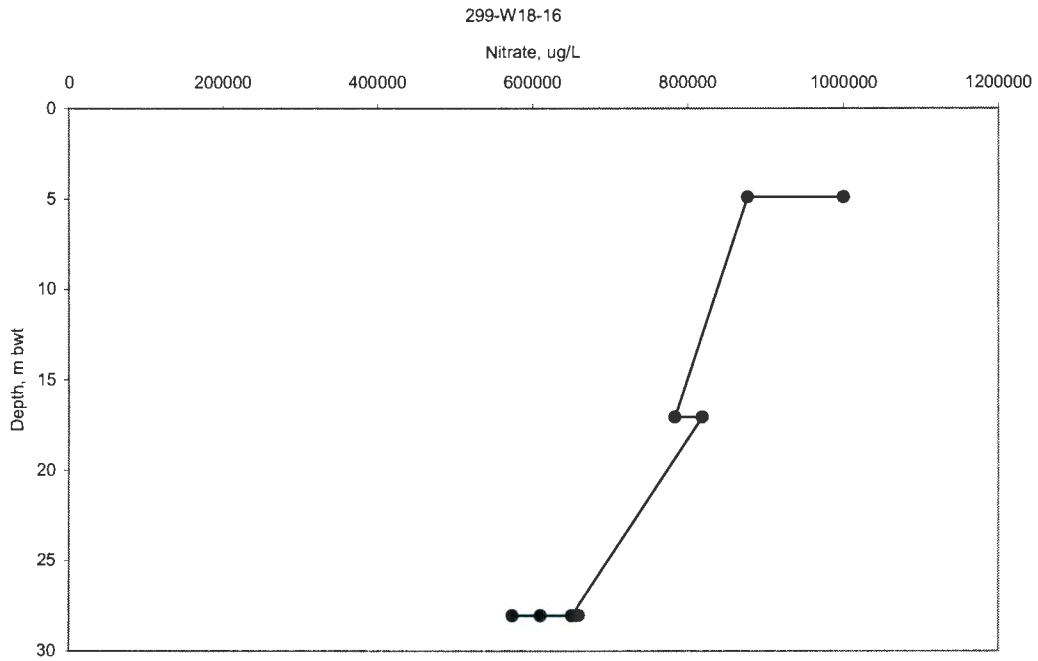

Figure 2.13. Depth-Distribution of Nitrate in Well 299-W18-16

The area and volume calculations for the nitrate contamination are summarized in Table 2.8.

Table 2.8. Area and Volume of Nitrate Contamination for Remediation Technology Screening

Area	Concentration (mg/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
WMA-T	500	56,453 (14)	20	1,129,060
	1,000	23,484 (5.8)	10	234,840
216-Z-1A	500	4,038 (1)	55	222,090
NW of Area	45	2,580 (0.6)	55	141,900
Major Plume	45	4,631,642 (1,150)	55	254,740,310
Total	**45**	**4,634,222 (1,151)**	**--**	**254,882,210**
	500	**60,491 (15)**	**--**	**1,351,150**
	1,000	**23,484 (5.8)**	**--**	**234,840**

2.8 Tritium

Tritium in the 200-ZP-1 Operable Unit is currently mapped as two plumes, although it is possible there is only one continuous plume at the 20,000 pCi/L level (Figure 2.14). The highest concentrations, >200,000 pCi/L, are found east of WMA TX-TY and are associated with iodine-129, chromium, technetium-99, and nitrate.

Tritium concentrations were measured during drilling of well 299-W11-43, located northeast of WMA T down to a depth of 55 m below the water table (Figure 2.15). The tritium concentration at the maximum depth was 48,000 pCi/L. This is at or near the top of the Ringold lower mud unit and was used for the assumed thickness of contamination above drinking water standards (20,000 pCi/L). However, contamination below the lower mud has not been characterized.

Tritium was detected at levels above 200,000 pCi/L in well 299-W14-11 down to 13 m below the water table (Figure 2.16). A logarithmic regression to the data provides an estimate of 200,000 pCi/L at 18 m below the water table. For screening calculations, a depth of 20 m below the water table was used to define the volume above 200,000 pCi/L. The deepest sample at this location, 37 m below the water table, was still above the 20,000-pCi/L drinking water standard.

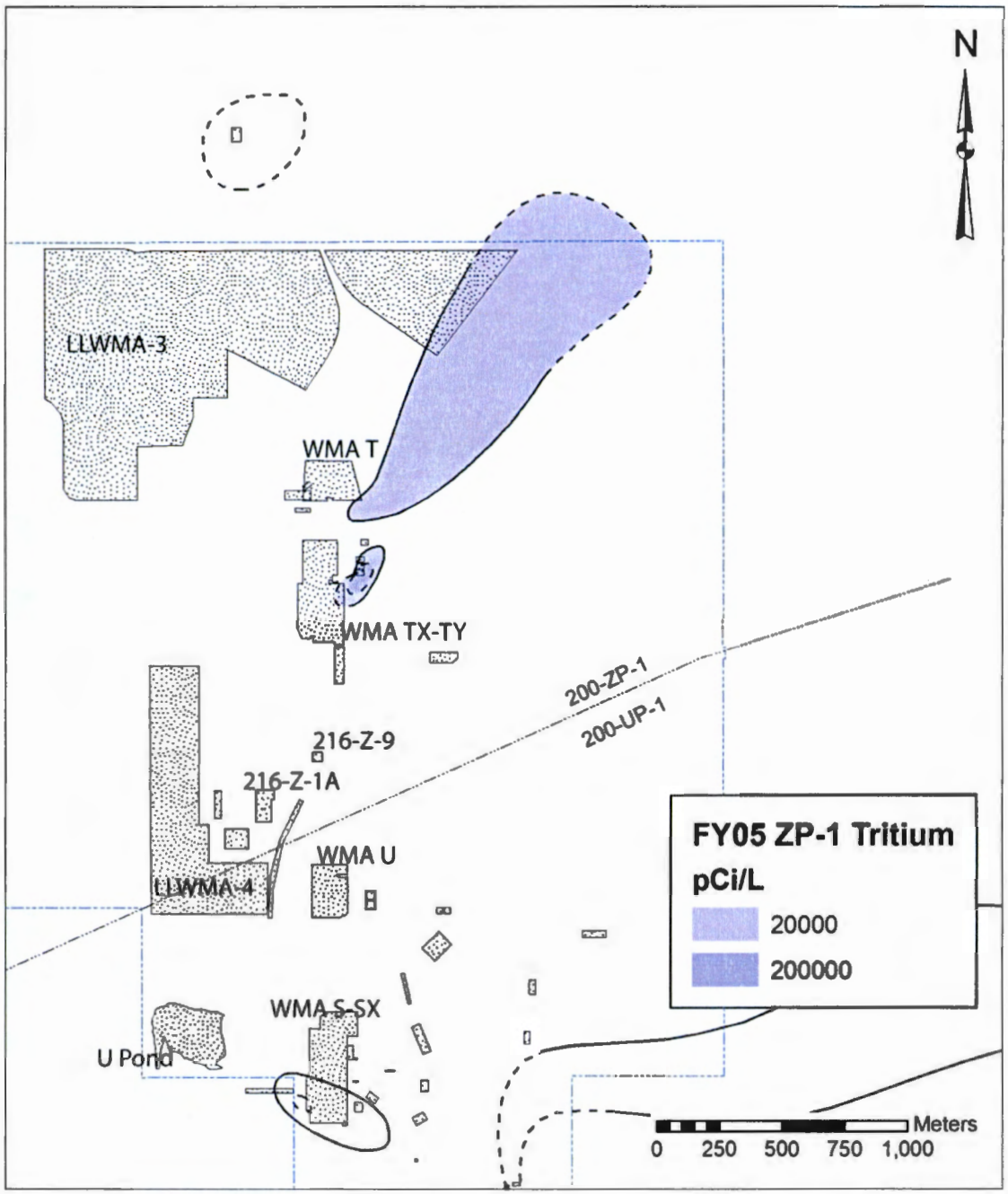

Figure 2.14. Average Tritium Concentrations in 200 West Area, Top of Unconfined Aquifer

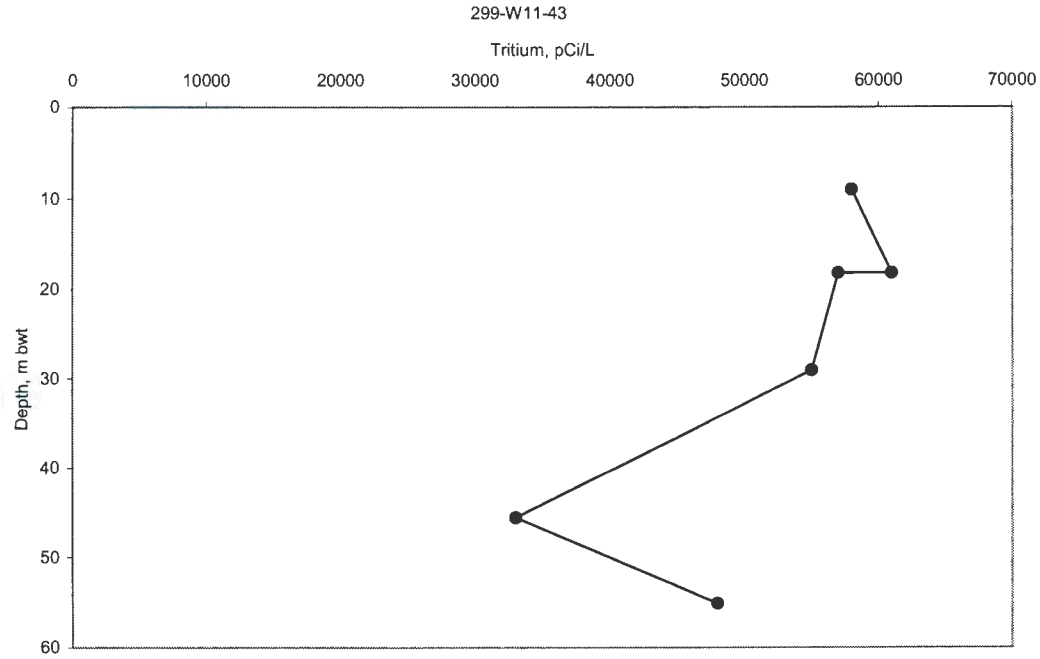

Figure 2.15. Depth-Distribution of Tritium in Well 299-W11-43

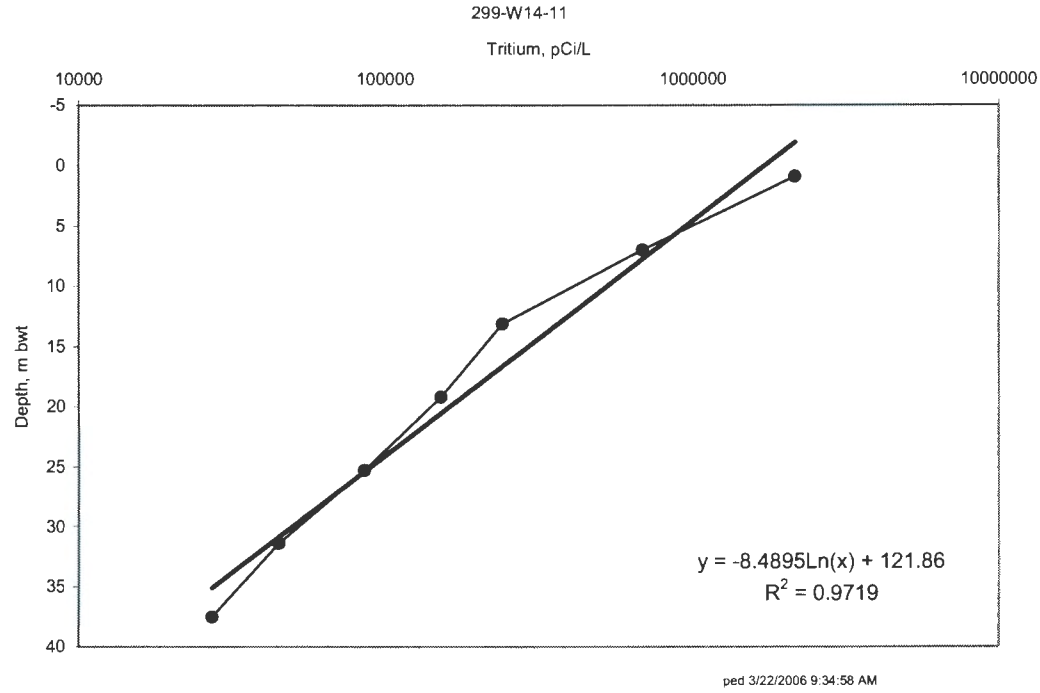

Figure 2.16. Depth-distribution of Tritium in Well 299-W14-11

The area and volume calculations for the tritium contamination are summarized in Table 2.9.

Table 2.9. Area and Volume of Tritium Contamination for Remediation Technology Screening

Area	Concentration (pCi/L)	Area m^2 (acre)	Thickness (m)	Aquifer Volume (m^3)
WMA-T	20,000	656,145 (163)	55	36,087,975
WMA-TX-TY	20,000	24,236 (6)	55	1,332,980
	200,000	7,480 (1.9)	20	149,600
Total	**20,000**	**680,381 (169)**	**--**	**374,20,995**
	200,000	**7,480 (1.9)**	**--**	**149,600**

3.0 Remediation Objectives

Target action levels identified in the *Remedial Investigation/Feasibility Study Work Plan for the 200-ZP-1 Groundwater Operable Unit* (DOE-RL 2004) were used as the remediation goal for the screening evaluation.

- Carbon tetrachloride (5 µg/L)
- Trichloroethene (5 µg/L)
- Chromium (100 µg/L)
- Technetium-99 (900 pCi/L)
- Iodine-129 (1 pCi/L)
- Uranium (30 µg/L)
- Nitrate (45 mg/L as NO_3)
- Tritium (20,000 pCi/L)

4.0 Assumptions

The following assumptions were used as part of conducting the screening evaluation:

- Contaminant distribution was based on current data for groundwater contamination. The potential for continuing contamination flux from the vadose zone was not explicitly considered. However, the screening included assessment of remediation methods potentially suitable for application to a small continuing source area in the groundwater.

- The screening evaluation considered application of remediation methods to specific treatment volumes, but did not estimate the time frame for treatment. Thus, the relative cost and effectiveness assessment were based on factors other than the treatment time frame.

- The screening evaluation was conducted using the data available and the general conceptual model presented in this report. Uncertainty in the data and conceptual model was not addressed. Instead, the evaluation assessed potential remediation methods based on application to a specified treatment volume.

- The general conceptual model used for the screening evaluation was intended to describe the volume and extent of the plume suitably for use in screening potential remediation methods. The conceptual model did not include all aspects important for defining the fate and transport of a contaminant. The evaluation assessed potential remediation methods based on application to a specified treatment volume.

5.0 Evaluation Criteria

The screening evaluation was conducted in two primary steps. The initial screening step evaluated potential remediation methods based on whether they can be effectively applied within the environmental setting of the 200-ZP-1 Operable Unit for the specified contaminants. In the second step, potential remediation methods were screened using scoping calculations to estimate the scale of infrastructure, overall quantities of reagents, and conceptual approach for applying the method for each defined grouping of COC. Based on these estimates, each method was screened with respect to effectiveness, implementability, and relative cost categories of the CERCLA feasibility study screening process defined in the U.S. Environmental Protection Agency (EPA) guidance (EPA 1988). In general, the effectiveness evaluation is related to (1) the estimated reliability of the process and whether it has been proven successful, (2) the expected ability of the method to treat the necessary volume of contaminated media, and (3) the ability to be constructed and operated without negative human or environmental impacts. Implementability is generally related to (1) the scale of effort and technical certainty that the method can be implemented at the site, (2) the availability of consumables, equipment, and services, and (3) ability to obtain permits and administratively manage the method. The relative cost is generally evaluated using a general conceptual design and relative cost estimates based on the relative capital and operation and maintenance required for each option.

The specific evaluation criteria for each of these screening categories are listed in Table 5.1. Remediation methods were eliminated from further consideration based on a comparative assessment of implementability, effectiveness, and relative cost, whereby those methods with significant uncertainty in effectiveness, significant difficulties for implementation, and relatively high costs compared to other more viable and less costly methods were identified and screened out. Innovative methods were assessed based on the available information in the literature. It may be necessary to conduct treatability studies as part of final assessment and implementation for some innovative methods. Presumptive remedies applicable within the environmental setting were retained for use in the more detailed analysis of remediation alternatives that will be conducted as part of the full feasibility study.

Table 5.1. Screening Evaluation Criteria for the Second Step of Screening

Effectiveness	Implementability	Relative Cost
• Is the method able to reliably decrease contaminant concentration, mass, or mobility to meet 1) the target concentration or 2) ten times the target concentration? • Does the method produce no hazardous products unless these are readily remediated or attenuated? • Does the method negatively impact the remediation of other COC to the extent that the remediation objectives could not be met for the other COC? • For the plume thicknesses identified in the conceptual model, is the method suitable for decreasing contaminant concentration, mass, or mobility of 1) continuing source in groundwater with an areal extent of less than 1 acre, 2) high concentrations within an areal extent of less than 5 acres, 3) high or low concentrations within an areal extent of up to 25 acres, and 4) low concentrations for an areal extent of 250 acres or greater than 250 acres? The volume of treatment for these targets will be defined based on the depth of the individual COC. • Does the method cause significant human or environmental risk during construction or operation?	• Can the method be reliably constructed and operated for the target volume (see effectiveness categories) within the Hanford aquifer (technical uncertainty at scale of application)? • Can the consumable or reagent usage be reasonably provided at the scale of application?	• Based on scoping calculations defining the scale of infrastructure and consumables, are the relative costs for capital and operation/maintenance expected to be grossly higher than for other options with similar effectiveness and implementability?

6.0 Potential Remediation Methods

The potential remediation methods for each COC grouping are shown in Tables 6.1 through 6.4. The potential remediation methods were identified from a review of EPA resources and technical literature including primarily the Hanford 200 West Area Carbon Tetrachloride Project Innovative Remediation Technology Review 1999-2000 (DOE-EM 2002: "Innovative Treatment and Remediation Demonstration [ITRD] report") and the http://www.epareachit.org and http://www.frtr.gov technology information websites. The screening focuses on categories of remediation method, not specific commercial products, unless there is only one commercial vendor for a remediation method category. Potential methods only demonstrated at the laboratory scale were not considered unless there are current efforts to obtain information from field treatability tests.

Table 6.1. Potential Remediation Methods for COC Group 1 (carbon tetrachloride and trichloroethene)

General Category	Remediation Method Category
No Action	No Action
Institutional Controls	Institutional Controls
Containment	Physical Containment • Slurry Walls • Grout Curtain • Sheet Piling Hydraulic Control
Removal, treatment, and disposal	Excavation
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump-and-Treat • Physical treatment • Chemical treatment • Biological treatment • Constructed Wetlands/Phyto-Irrigation
In Situ Treatment	Chemical Oxidation
	Air Sparging
	Zero-Valent Iron
	Surfactant Flushing
	In-Well Air Stripping
	Thermally Enhanced In-Well Stripping
	Phytoremediation
	Aerobic Bioremediation • Aerobic Co-metabolism
	Anaerobic Bioremediation • Soluble substrate • Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil)
	In Situ Thermal Treatment • Electrical Resistance Heating • Steam Heating • Conductive Heating
	Permeable Reactive Barriers • Zero-Valent Iron • Aerobic Biobarrier (e.g., injection of long-duration oxygen source as a barrier) • Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier) • In Situ Redox Manipulation

Table 6.2. Potential Remediation Methods for COC Group 2 (chromium, technetium-99, iodine-129, and uranium)

General Category	Remediation Method Category
No Action	No Action
Institutional Controls	Institutional Controls
Containment	Physical Containment • Slurry Walls • Grout Curtain • Sheet Piling Hydraulic Control
Removal, treatment, and disposal	Excavation
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump and Treat • Chemical treatment • Biological treatment (except I-129)
In Situ Treatment	Chemical Stabilization by Apatite (uranium)
	Chemical Stabilization by Polyphosphate (uranium)
	Nanoparticles (other than zero-valent iron)
	Down-Well Bio-Reactor/Adsorption Systems
	Reduction by Zero-Valent Iron (chromate, uranium isotopes, and Tc-99)
	Surfactant Flushing
	Phytoremediation
	Anaerobic Bioremediation • Soluble substrate – direct reduction (chromate, uranium isotopes and Tc-99) – Sulfate Reducing Bacteria (chromate, uranium isotopes and Tc-99) • Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil)
	Permeable Reactive Barriers • Zero-Valent Iron (chromate, uranium isotopes and Tc-99) • Apatite barrier (uranium) • Polyphosphate barrier (uranium) • Adsorbent barriers • Multi-Zone Biobarrier • Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier) • In Situ Redox Manipulation (chromate, uranium isotopes and Tc-99)

Table 6.3. Potential Remediation Methods for COC Group 3 (nitrate)

General Category	Remediation Method Category
No Action	No Action
Institutional Controls	Institutional Controls
Containment	Physical Containment • Slurry Walls • Grout Curtain • Sheet Piling Hydraulic Control
Removal, treatment, and disposal	Excavation
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump and Treat • Chemical treatment • Biological treatment • Constructed Wetlands/Phyto-Irrigation
In Situ Treatment	Phytoremediation
	Anaerobic Bioremediation • Soluble substrate • Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil)
	Permeable Reactive Barriers • Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier) • Zero-Valent Iron • In Situ Redox Manipulation

Table 6.4. Potential Remediation Methods for COC Group 4 (tritium)

General Category	Remediation Method Category
No Action	No Action
Institutional Controls	Institutional Controls
Containment	Physical Containment • Slurry Walls • Grout Curtain • Sheet Piling Hydraulic Control
Removal, treatment, and disposal	Excavation
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA)
Ex Situ Treatment	Pump and Treat • Isotopic separation

7.0 Screening

Potential remediation methods were screened in a two-step process. Section 7.1 presents the initial screening results. Screening based on scoping calculations is presented in Section 7.2.

7.1 Initial Screening

The first step of screening eliminated remediation methods that are infeasible because they are not appropriate for application in the environmental setting of the 200-ZP-1 Operable Unit. Tables 7.1 through 7.4 list the remediation method categories screened out in this first stage and the reason they were removed from further consideration.

Table 7.1. COC Group 1 – Remediation Methods Screened Out in Initial Screening

Remediation Method Category	Reason
Containment	Grout curtains and slurry walls emplaced by trenching and sheet piling are eliminated due to the depth of the aquifer. Hydraulic control is eliminated as not applicable for large plumes in transmissive aquifers. Containment by injectable materials is retained.
Removal, treatment, and disposal	Removal, treatment, and disposal technologies are targeted at shallow contamination only.
Phytoremediation	Not appropriate for deep aquifers.
Zero-Valent Iron	Emplacement by trenching is eliminated due to the depth of the aquifer. Injectable iron is retained as a potential remediation method.
Permeable Reactive Barriers • Zero-Valent Iron	Use of zero-valent iron with emplacement by trenching is eliminated due to the depth of the aquifer. Use of injectable iron is retained as a potential permeable reactive barrier remediation method.

Table 7.2. COC Group 2 – Remediation Methods Screened Out in Initial Screening

Remediation Method Category	Reason
Containment	Grout curtains and slurry walls emplaced by trenching and sheet piling are eliminated due to the depth of the aquifer. Hydraulic control is eliminated as not applicable for large plumes in transmissive aquifers. Containment by injectable materials is retained.
Removal, treatment, and disposal	Removal, treatment, and disposal technologies are targeted at shallow contamination only
Nanoparticles	Presently, there are no deployable nanotechnologies other than zero-valent iron for remediation of the COC. Ongoing studies may result in viable remediation technologies in the future.
Phytoremediation	Not appropriate for deep aquifers
Zero-Valent Iron	Emplacement by trenching is eliminated due to the depth of the aquifer. Injectable iron is retained as a potential remediation method.
Stabilization by Apatite (by trenching)	Use of solid apatite with emplacement by trenching is eliminated due to the depth of the aquifer. Use of injectable apatite is retained as a potential permeable reactive barrier remediation method.
Permeable Reactive Barriers • Zero-Valent Iron (by trenching) • Apatite (by trenching) • Adsorbent barriers • Multi-Zone Biobarrier	Use of zero-valent iron, adsorbants, solid apatite or the multi-zone barrier with emplacement by trenching is eliminated due to the depth of the aquifer. Use of injectable iron, apatite, or polyphosphate is retained as a potential permeable reactive barrier remediation method.

Table 7.3. COC Group 3 – Remediation Methods Screened Out in Initial Screening

Remediation Method Category	Reason
Containment	Grout curtains and slurry walls emplaced by trenching and sheet piling are eliminated due to the depth of the aquifer. Hydraulic control is eliminated as not applicable for large plumes in transmissive aquifers. Containment by injectable materials is retained.
Removal, treatment, and disposal	Removal, treatment, and disposal technologies are targeted at shallow contamination only
Phytoremediation	Not appropriate for deep aquifers

Table 7.4. COC Group 4 – Remediation Methods Screened Out in Initial Screening

Remediation Method Category	Reason
Containment	Grout curtains and slurry walls emplaced by trenching and sheet piling are eliminated due to the depth of the aquifer. Hydraulic control is eliminated as not applicable for large plumes in transmissive aquifers. Containment by injectable materials is retained.
Removal, treatment, and disposal	Removal, treatment, and disposal technologies are targeted at shallow contamination only

7.2 Screening Based on Scoping Calculations

Based on the initial screening results, the potential remediation methods retained for further screening evaluation were compiled (Table 7.5). Scoping-level calculations to define the general scale of infrastructure and equipment, amendments needs, and other method-specific parameters were conducted to support assessment of each method remaining after the initial screening in terms of the effectiveness, implementability, and relative cost categories of the evaluation criteria.

Table 7.5. Remediation Methods Considered in Second Stage of Screening

General Category	Remediation Method Category (applicable COC shown in parentheses)
No Action	No Action (all)
Institutional Controls	Institutional Controls (all)
Containment	Injectable materials for stabilizing source areas (all)
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA) (all)
Ex Situ Treatment	Pump and Treat • Physical treatment (air stripping/activated carbon) (carbon tetrachloride and trichloroethene only) • Chemical treatment (all) • Biological treatment (all except I-129 and tritium)
In Situ Treatment	Chemical Oxidation (carbon tetrachloride and trichloroethene only)
	Chemical Stabilization by Injectable Apatite (uranium isotopes)
	Chemical Stabilization by Polyphosphate (uranium isotopes)
	Injectable Zero-Valent Iron (carbon tetrachloride, trichloroethene, chromate, Tc-99, and uranium isotopes)
	Surfactant Flushing (all except tritium)
	In-Well Air Stripping (carbon tetrachloride and trichloroethene)
	Thermally Enhanced In-Well Stripping (carbon tetrachloride and trichloroethene)
	Down-well bioreactor/adsorption system (chromate, uranium isotopes, I-129 and Tc-99)
	Air Sparging (carbon tetrachloride and trichloroethene)
	Anaerobic Bioremediation • Soluble substrate (all except tritium) – Direct reduction (chromate, uranium isotopes and Tc-99) – Sulfate Reducing Bacteria • Injection of long-duration substrate (e.g., a non-aqueous substrate such as vegetable oil) (all except tritium)
	Aerobic Bioremediation (trichloroethene) • Aerobic Co-metabolism
	In Situ Thermal Treatment (carbon tetrachloride and trichloroethene) • Electrical Resistance Heating • Steam Heating • Conductive Heating
	Permeable Reactive Barriers • Injectable Zero-Valent Iron (carbon tetrachloride, trichloroethene, chromate, Tc-99, and uranium isotopes) • Anaerobic Biobarrier (e.g., injection of long-duration substrate as a barrier) (all except tritium) • In Situ Redox Manipulation (carbon tetrachloride, trichloroethene, chromate, Tc-99, and uranium isotopes) • Injectable Apatite Barriers (uranium isotopes) • Polyphosphate Barrier (uranium isotopes)

The following sections describe each potential remediation method and present scoping calculations to estimate the scale of infrastructure and equipment, amendments needs, and other method-specific parameters needed for evaluating the method against the criteria listed in Table 5.1 and for each COC group.

7.2.1 Physical Containment

Injection-based technologies for physical containment were examined. Injectable grout walls and freeze walls were identified as the two categories of injection technology potentially applicable to the 200-ZP-1 Operable Unit. Injectable grout barriers are installed by jet-grouting from an injection well. Grout walls or "curtains" have been used extensively in the past for civil engineering projects, but less frequently to contain hazardous waste. Jet-grouted walls are constructed by injecting grout at very high pressure (up to 6,000 psi) into the subsurface. In general, a small-diameter pilot hole is drilled to the total depth of the barrier. The hole is jet-grouted from the bottom up. Multiple, closely spaced holes are grouted to form a horizontally continuous barrier. Jet-grout barriers have been built to depths greater than 61 m, although below 30 m the vertical consistency, and thus continuity of jet-grouted barriers, are difficult to control or confirm. Typically, a Portland cement is used, although a variety of grout formulations may be used. Supersaturated solutions forming grouts in situ have been tested and applied for hydraulic control. However, this technique would have similar technical issues as for injection grouting and additional uncertainties related to its effectiveness. Thus, supersaturated grouts were not considered separately for the screening evaluation.

Frozen soil barrier technology (DOE 1999) consists of a series of subsurface heat transfer devices, known as thermoprobes, which are installed around a contaminant source and function to freeze the soil pore water. The barrier is maintained for a finite period of time, until remediation or removal of the contaminants is complete. The thermoprobes are installed with drilling techniques. The subsurface thermoprobes utilize liquid-to-gas phase change of a passive refrigerant (carbon dioxide) to remove heat from the surrounding sediment. Above-ground refrigeration units and interconnecting piping are installed and operated. Insulation and a waterproof membrane are installed at grade to prevent heat gain from the surface and minimize infiltration. Frozen soil barriers offer advantages by being "self-healing" and allowing immobilization within the frozen matrix or containment. However, unlike the grout or cement barriers, frozen barriers do require electric power for the life of the barrier. Therefore, use of these barriers is best restricted to short or medium durations of 20 years or less. Demonstration projects have been limited to shallow depths (10 m) and small areas (less than 0.15 acre).

Potentially, physical containment could be applied to all COC groups. However, the characteristics of physical containment are best suited to containing relatively small zones of contamination. For the screening evaluation, physical containment was only considered for application to small continuing source areas; in particular, application to containment of a carbon tetrachloride continuing source of less than 1 acre.

Based on the technical uncertainty and high costs, physical containment is rejected as a potential remediation technology (see Sections 7.2.1.1 through 7.2.1.3).

7.2.1.1 Effectiveness

Effectiveness Screening Criteria (see Table 2.1)	COC Group 1 (carbon tetrachloride continuing source)
Reliably meet goal?	Significant uncertainty is associated with the ability to physically contain the relatively large contaminated volume of a continuing source area at the depths of the 200-ZP-1 Operable Unit. Grout walls may be less effective for containing solvent over the long term due to diffusion of solvent through the grout wall. Freeze walls would require active operation over a very long time period.
Produce hazardous products?	No hazardous byproducts would be produced.
Negatively impact to other COC?	No negative impacts on other COC are expected.
Treat target volume?	Efficacy of physical containment placement depends on target volume depth. There is some uncertainty with placement of effective containment at the depth to groundwater plus an additional 20+ m needed to contain a continuing source area for carbon tetrachloride.
Cause risk during construction or operation?	Construction risk would be from necessary drilling.

7.2.1.2 Implementability

Implementability Screening Criteria (see Table 2.2)	COC Group 1 (carbon tetrachloride continuing source)
Reliably constructed and operated?	Grout walls effectiveness is impacted by stratigraphy and depth. Freeze walls are less sensitive to stratigraphy.
Reasonable consumable usage?	While a significant amount of grout would be needed for a 1 acre containment, consumables are not significant issue for physical containment technologies.

7.2.1.3 Relative Cost

Cost factors for physical containment are primarily associated with the large number of boreholes necessary due to the limited radius of injection for grout or for effective freezing for freeze walls. Even with an optimistic radius of influence of 3–5 m, a large number of boreholes are needed to contain a 1 acre volume. Using costs at the high end of the range for injection grouting technology ($20 per square foot of panel area), a barrier 3 m thick by 250 m long by 20 m deep would cost in the range of $1M. Costs for an application to the 200-ZP-1 Operable Unit are expected to be higher than this estimate due to higher Hanford drilling costs (due to the presence of radioactive contamination and geologic difficulties) and an overall depth of application that is deeper than existing applications. Freeze walls are expected to have a similar capital cost as for injected grout walls, but active operation to maintain cooling would be required over a very long time period.

7.2.2 Monitored Natural Attenuation

The EPA Office of Solid Waste and Emergency Response (OSWER) identifies the requirements for MNA in "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites" (OSWER Directive 9200.4-17P, EPA 1999), hereafter referred to as the "OSWER MNA Directive." Quotations from this directive are shown in italics font. The OSWER MNA Directive defines natural attenuation processes as follows. *The "natural attenuation processes" that are at work in such a remediation approach* [MNA] *include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.*

The OSWER MNA Directive provides some key considerations for determining whether MNA is an appropriate remedy for a site. These considerations and a discussion relative to each COC group are listed below.

1. *Whether the contaminants present in soil or groundwater can be effectively remediated by natural attenuation processes.*

   - COC Group 1 – Natural attenuation processes acting on carbon tetrachloride include abiotic degradation, sorption, dispersion, and dilution. Previous modeling analysis suggests that these mechanisms may significantly reduce concentrations within the plume and decrease the extent of carbon tetrachloride plume migration (Truex et al. 2001; Bergeron and Cole 2005). Natural attenuation processes acting on trichlorethene include sorption, dispersion, and dilution. These mechanisms have the potential to reduce trichlorethene concentrations and limit plume migration, but quantitative studies to define the extent of attenuation have not been conducted. Current data suggest that within the Group 1 plumes there are not significant zones with reducing conditions conducive to reductive dechlorination processes.

   - COC Group 2 – Natural attenuation processes acting on COC Group 2 include sorption, dispersion, and dilution. These mechanisms have the potential to reduce COC concentration and limit plume migration, but quantitative studies to define the extent of attenuation have not been conducted. Current data suggest that within the Group 2 plumes there are not significant zones with reducing conditions conducive to reductive dechlorination processes.

   - COC Group 3 – Natural attenuation processes acting on nitrate include dispersion and dilution. These mechanisms have the potential to reduce nitrate concentrations and limit plume migration, but quantitative studies to define the extent of attenuation have not been conducted. Current data suggest that within the Group 3 plumes there are not significant zones with reducing conditions conducive to reductive dechlorination processes.

   - COC Group 4 – Natural attenuation processes acting on tritium include radioactive decay, dispersion, and dilution. These mechanisms have the potential to significantly reduce tritium concentrations and limit plume migration.

2. *Whether or not the contaminant plume is stable and the potential for the environmental conditions that influence plume stability to change over time.*

   - COC Group 1 – Plume stability was not evaluated as part of the screening evaluation. Conditions over time will act to reduce the groundwater flow rate because surface water discharges have been significantly decreased. The degradation rate (carbon tetrachloride only), sorption, dispersion, and dilution are not expected to change over time.

   - COC Group 2 – Plume stability was not evaluated as part of the screening evaluation. Conditions over time will act to reduce the groundwater flow rate because surface water discharges have been significantly decreased. Sorption, dispersion, and dilution are not expected to change over time.

   - COC Group 3 – Plume stability was not evaluated as part of the screening evaluation. Conditions over time will act to reduce the groundwater flow rate because surface water discharges have been significantly decreased. Dispersion and dilution are not expected to change over time.

   - COC Group 4 – Plume stability was not evaluated as part of the screening evaluation. Conditions over time will act to reduce the groundwater flow rate because surface water discharges have been significantly decreased. The decay rate, dispersion, and dilution are not expected to change over time.

3. *Whether human health, drinking water supplies, other groundwaters, surface waters, ecosystems, sediments, air, or other environmental resources could be adversely impacted as a consequence of selecting MNA as the remediation options.*

   For all COC, direct use of groundwater is the only likely exposure pathway. Thus, adverse impacts depend on the controls on groundwater usage, the volume of aquifer impacted by the contaminant, and the time frame over which the groundwater remains contaminated above action levels. As such, this aspect of MNA is not directly considered in the screening evaluation.

4. *Current and projected demand for the affected resource over the time period that the remedy will remain in effect.*

   The groundwater demand is a function of administrative decisions, the volume of aquifer impacted by the contaminant, and the time frame over which the groundwater remains contaminated above action levels. As such, this aspect of MNA is not directly considered in the screening evaluation.

5. *Whether the contamination, either by itself or as an accumulation with other nearby sources (on-site or off-site), will exert a long-term detrimental impact on available water supplies or other environmental resources.*

   The groundwater availability is a function of administrative decisions, the volume of aquifer impacted by the contaminant, and the time frame over which the groundwater remains contaminated above action levels. As such, this aspect of MNA is not directly considered in the screening evaluation.

6. *Whether the estimated timeframe of remediation is reasonable compared to timeframes required for other more active methods (including anticipated effectiveness of various remedial approaches on different portions of the contaminated soil and/or groundwater).*

   The time frame for MNA is likely longer than the time frame for active remedies. The reasonableness of the time frame will be considered in the detailed analysis of the full feasibility study. As such, this aspect of MNA is not directly considered in the screening evaluation.

7. *The nature and distribution of sources of contamination and whether these sources have been, or can be, adequately controlled.*

   Due to the large vadose zone with uncertain contaminant distribution, there is some uncertainty in the long-term nature of the sources. However, efforts are underway to examine potential source control methods.

8. *Whether the resulting transformation products present a greater risk, due to increased toxicity and/or mobility, than do the parent contaminants.*

   None of the degradation or decay products for those COC that degrade or decay by natural processes under the Hanford aquifer conditions are hazardous except if there are areas with reduced geochemical conditions where carbon tetrachloride and trichlorethene can be reductively dechlorinated to other hazardous chlorinated solvents (e.g., chloroform, dichloroethene, and vinyl chloride.

9. *The impact of existing and proposed active remediation measures upon the MNA component of the remedy, or the impact of remediation measures or other operations/activities (e.g., pumping wells) in close proximity to the site.*

   Existing interim remedial actions (e.g., pump-and-treat) and most active remedies under consideration have a positive impact on natural attenuation by reducing contaminant mass/concentration and addressing source areas. Consideration of any negative impacts on MNA will be included in the assessment of potential future active remedies.

10. *Whether reliable site-specific mechanisms for implementing institutional controls (e.g., zoning ordinances) are available, and if an institution responsible for their monitoring and enforcement can be identified.*

    The Hanford Site has existing mechanisms for implementing institutional controls that are expected to remain viable for the foreseeable future.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, MNA is retained as a potential remediation method for all COC groups (see Sections 7.2.2.1 through 7.2.2.3).

7.2.2.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3	COC Group 4
Reliably meet goal?	MNA has the potential to significantly decrease contaminant concentration.	MNA will moderately decrease concentrations over time due to sorption, dispersion and dilution.	MNA will moderately decrease concentrations over time due to dispersion and dilution.	MNA has the potential to significantly decrease contaminant concentration.
Produce hazardous products?	MNA does not produce hazardous byproducts except if there are areas with reduced geochemical conditions.	MNA does not produce hazardous byproducts.	MNA does not produce hazardous byproducts.	MNA does not produce hazardous byproducts.
Negatively impact to other COC?	MNA of one COC does not negatively impact another.	MNA of one COC does not negatively impact another.	MNA of one COC does not negatively impact another.	MNA of one COC does not negatively impact another.
Treat target volume?	MNA is independent of volume.	MNA is independent of volume.	MNA is independent of volume.	MNA is independent of volume.
Cause risk during construction or operation?	MNA has no construction or operational risk.	MNA has no construction or operational risk.	MNA has no construction or operational risk.	MNA has no construction or operational risk.

7.2.2.2 Implementability

Implementability Screening Criteria (see Table 11)	COC Group 1	COC Group 2	COC Group 3	COC Group 4
Reliably constructed and operated?	MNA has no construction or operational problems, but the need to long-term monitoring and the potential need for a contingency remedy if natural attenuation does not limit plume migration are operational risks.	MNA has no construction or operational problems but the need to long-term monitoring and the potential need for a contingency remedy if natural attenuation does not limit plume migration are operational risks.	MNA has no construction or operational problems but the need to long-term monitoring and the potential need for a contingency remedy if natural attenuation does not limit plume migration are operational risks.	MNA has no construction or operational problems but the need to long-term monitoring and the potential need for a contingency remedy if natural attenuation does not limit plume migration are operational risks..
Reasonable consumable usage?	MNA has no significant consumable usage.	MNA has no significant consumable usage.	MNA has no significant consumable usage.	MNA has no significant consumable usage.

7.2.2.3 Relative Cost

MNA is expected to have a cost comparable to other options. The primary cost factors are costs for the initial MNA evaluation, monitoring well costs, and long-term monitoring costs.

7.2.3 Pump-and-Treat

Pump-and-treat is a baseline remedy for all COC groups and, as such, will be carried forward for the more detailed analysis in the feasibility study.

7.2.4 Chemical Oxidation

This category of remediation method includes use of strong oxidants such as hydrogen peroxide, Fenton's Reagent, permanganate, persulfate, and ozone. These oxidants can degrade organic contaminants and are therefore potentially applicable to COC Group 1. A primary factor in applying chemical oxidation is overcoming the oxygen demand within the aquifer during injection of the oxidant. As oxidant is injected, it quickly reacts with oxidizable materials in the aquifer (including the contaminant). With radial injection flow, the volume of aquifer, and therefore the mass of oxidizable materials associated with aquifer solids, increases with the square of the distance from the injection point. As a scoping calculation, therefore, the oxidant demand was estimated based on the mass of oxidizable material in the aquifer as a function of radial distance from a well and for target treatment volumes.

For many aquifers, the organic carbon content of the aquifer sediments is an important source of oxidizable material. There are limited site-specific data for the organic carbon content within the remediation study area. A value of 0.0007 (g-organic carbon/g-soil) for the fraction of organic carbon was used in the screening evaluation based on the average of reported values in Truex et al. (2001) and Riley et al. (2005). A unit oxidant demand of 0.033 mole-O_2/kg-soil for an f_{oc} of 0.0007 was estimated based on a bulk density of 1.8 and a generalized organic carbon formula of $C_{187}H_{186}O_{89}$ (Sposito 1989). For comparison, Schnarr et al. (1998) measured an oxidant demand of 0.025 mole-$KMnO_4$/kg-soil for an f_{oc} of 0.00027 in oxidation tests at a field test site in a sandy aquifer. Converting the oxidant demand from Schnarr et al. (1998) into moles of molecular oxygen and assuming a proportional relationship to the f_{oc}, the measured oxidant demand is equivalent to 0.05 mole-O_2/kg-soil for an f_{oc} of 0.0007. The unit oxidant demand for Schnarr et al. (1998) may be higher than estimated for the Hanford sediment because Schnarr's data include oxidant demand associated with minerals in addition to the demand from organic carbon. As an example, 1.5 million O_2-equivalent moles of a strong oxidant would be required to overcome the oxygen demand of sediment organic carbon for a treatment cylinder with a 20-m radius and a depth interval of 20 m using an oxygen demand of 0.033 mole-O_2/kg-soil. Additional oxidant would be required to support contaminant degradation. Because large quantities of strong oxidant are needed to overcome oxidant demand, even in low organic-content sediment, use of strong oxidants is typically limited to small volumes. For the screening evaluation, chemical oxidation was only considered for application to small continuing source areas.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, chemical oxidation is retained as a potential remediation method for carbon tetrachloride (part of COC Group 1) only for application to a small potential continuing source zone (see Sections 7.2.4.1 through 7.2.4.3).

7.2.4.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1
Reliably meet goal?	Likely reliable to reduce concentrations in a small volume. Potential issues with permanganate usage due to solids formation (Schroth et al. 2001). Fenton's reagent effectiveness demonstrated in the laboratory with an average of 42.8 mole of hydrogen peroxide consumed per mole of carbon tetrachloride degraded (Watts et al. 2005).
Produce hazardous products?	No hazardous byproducts are produced.
Negatively impact to other COC?	Likely no impact if applied in a small volume such as the core of a continuing source area for carbon tetrachloride or trichlorethene.
Treat target volume?	Only applicable for small volume such as with a continuing source area.
Cause risk during construction or operation?	Construction risk would be from necessary drilling. Operational risk is associated with handling of strong oxidants during injection time frame.

7.2.4.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1
Reliably constructed and operated?	Uniform distribution of oxidant with a long well screen may be problematic.
Reasonable consumable usage?	Large quantities of oxidant would be needed unless only a limited volume were treated.

7.2.4.3 Relative Cost

For an example application in a treatment cylinder of 20-m radius and depth interval of 20 m (e.g., a core of the potential carbon tetrachloride continuing source area), 1.5 million O_2-equivalent moles would be on the order of 51,000 kg of hydrogen peroxide and 300,000 kg of potassium permanganate. With Fenton's reagent, the subsurface may need to also be amended with Fe(III). Cost factors for chemical oxidation are associated with the relatively high reagent usage and handling of the reagent during injection. For application to a small volume such as the core of the potential carbon tetrachloride continuing source area, costs may be comparable to other potential active remedies. Costs are expected to be higher than other potential remedies for any larger volumes due to the high reagent usage.

7.2.5 Injectable Apatite Solution

Hydroxyapatite [$Ca_5(PO_4)_3OH$] has been found to be very effective in sequestration of many dissolved metals including strontium and uranium. Such divalent metal oxyanions do react with dissolved phosphate to precipitate and immobilize the heavy metal. Apatite sequestration is expected to

be minimally effective with chromium, technetium, and iodine groundwater contamination. Thus, for the screening evaluation, apatite was only considered for applicable to uranium as part of COC Group 2 (Fuller et al. 2002; Flury and Harsh 2000; Bostick et al. 2003). Because of the depth to groundwater, application of solid phase apatite is not feasible and will not be considered as a viable technology for the site. However, apatite minerals can be formed in situ from injection of soluble reagents (Moore et al. 2004). This method relies on injection of calcium citrate and phosphate solutions. The calcium is complexed with citrate during the injection and does not react with the phosphate until the citrate is degraded by microorganisms in the subsurface. Thus, the apatite formation can be distributed over a radial distance of meters to ~10 m away from the injection well depending on the subsurface hydrology and the microbial citrate degradation rate. This technique is currently being tested for application to strontium contamination at the Hanford 100 N Area. Injectable apatite would be considered an innovative treatment option.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, injectable apatite is retained as a potential remediation method for uranium (part of COC Group 2) over an areal extent of less than 5 acres. This is an innovative technology that would likely need treatability testing (see Sections 7.2.5.1 through 7.2.5.3).

7.2.5.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably meet goal?	Likely reliable to reduce concentrations in a small volume. Laboratory-scale studies show promise. Field-scale testing yet to be conducted.
Produce hazardous products?	No hazardous byproducts are produced.
Negatively impact to other COC?	Likely no impact if applied in a small volume such as the uranium plume. Residual phosphate could stimulate microbiological growth.
Treat target volume?	Distribution of the reagents meters to ~10 m from the injection point is expected. As such volumetric treatment of up to 5 acres could be achieved with a reasonable number of access wells.
Cause risk during construction or operation?	Construction risk would be from drilling necessary.

7.2.5.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably constructed and operated?	Uniform distribution of reagents possible with proper engineering and hydraulic control. Treatability testing is needed.
Reasonable consumable usage?	Treatability testing is needed to assess design of the remediation system.

7.2.5.3 Relative Cost

The injectable apatite remediation method is an innovative technology still under development. Cost factors are primarily related to the radius of influence that can be obtained. It is expected that a radius of influence similar to injection of a long-duration substrate for anaerobic bioremediation will be possible. As such, costs for injectable apatite could be comparable to other technologies at an areal extent of less than 5 acres where well costs would be similar to an anaerobic bioremediation application.

7.2.6 Stabilization by Polyphosphate

Another phosphate-based technology for stabilization of uranium using phosphate is presently in development. This technology uses injection of liquid polyphosphate to stabilize uranium. It is not applicable to the other COC. This technology stabilizes uranium by a different mechanism than apatite stabilization.

The process uses polymers of phosphate to release phosphate at a slow, controlled rate into groundwater downgradient of the application point. The presence of phosphate in groundwater, even in minor concentrations (10^{-8} M), promotes the formation of autunite–group minerals, $X_{3-n}^{(n)*}[(UO_2)(PO_4)]_2 \cdot xH_2O$, thereby limiting the mobility of the uranyl cation (UO_2^{2+}) in the subsurface environment. The use of soluble long-chain polyphosphate reagent delays precipitation of the autunite, thereby mitigating plugging of the formation near the application point. By tailoring the polyphosphate chain, the hydrolysis reaction that releases the phosphate into the water can be engineered and the uranium stabilization rate controlled. Because autunite sequesters uranium in the oxidized form, U^{6+}, rather than forcing reduction to U^{4+}, the possibility of re-oxidation and subsequent re-mobilization is negated. Extensive laboratory testing demonstrates the very low solubility of autunite. In addition to autunite, excess phosphorous may result in apatite mineral formation, providing a secondary, long-term source of treatment capacity.

Deployment polyphosphate may be designed to treat a horizontal extent as well as vertical zone of uranium in the groundwater and at the water-table interface. The liquid form of the reagent facilitates application to and transport within the contaminated groundwater plume. Uranium transport studies in columns packed with contaminated sediment from the Hanford 300 Area indicate that a polyphosphate solution reduces the concentration of uranium in water to near the drinking water standard (30 μg/L) (Wellman et al. 2006). Polyphosphate would be considered an innovative treatment option.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, polyphosphate is retained as a potential remediation method for uranium (part of COC Group 2) over an areal extent of less than 5 acres. This is an innovative technology that would likely need treatability testing (see Sections 7.2.6.1 through 7.2.6.3).

7.2.6.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably meet goal?	Likely reliable to reduce concentrations in a small volume. Laboratory-scale studies show promise. Field-scale testing yet to be conducted.
Produce hazardous products?	No hazardous byproducts are produced.
Negatively impact to other COC?	Likely no impact if applied in a small volume such as the uranium plume. Residual phosphate could stimulate microbiological growth.
Treat target volume?	Distribution of the polyphosphate meters to ~10 m from the injection point is expected. As such volumetric treatment of up to 5 acres could be achieved with a reasonable number of access wells.
Cause risk during construction or operation?	Construction risk would be from necessary drilling.

7.2.6.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably constructed and operated?	Uniform distribution of polyphosphate possible with proper engineering and hydraulic control. Treatability testing is needed.
Reasonable consumable usage?	Treatability testing is needed to assess design of the remediation system.

7.2.6.3 Relative Cost

The polyphosphate remediation method is an innovative technology still under development. Cost factors are primarily related to the radius of influence that can be obtained. It is expected that a radius of influence similar to injection of a long-duration substrate for anaerobic bioremediation will be possible. As such, costs for polyphosphate could be comparable to other technologies at an areal extent of less than 5 acres where well costs would be similar to an anaerobic bioremediation application.

7.2.7 Injectable Zero-Valent Iron

Emplacement of zero-valent iron particles in the subsurface provides an electron source for dechlorination of carbon tetrachloride and trichlorethene (COC Group 1) and reduction of chromium, technetium-99, uranium, and nitrate (COC Groups 2 and 3, except iodine-129). Typically, zero-valent iron is applied as a permeable reactive barrier. Potentially, it could be deployed in a manner more suitable for volumetric treatment (e.g., Quinn et al. 2005). However, for volumetric treatment, the extent to which the particles can be distributed is a key issue for consideration. Present technology permits placement of small-scale iron particles from wells to radial distances of about 3–7 m (GeoSierra 2005). Similarly, low radial influences are observed with current applications of emulsified zero-valent iron (Quinn et al. 2005 and personal communication J. Quinn). Because large quantities of zero-valent iron are needed for large volume treatment (see Table 7.6) and the small radius of influence, zero-valent iron is typically limited to small volumes application or for permeable reactive barrier applications (see Section 7.2.15).

Based on the evaluation of effectiveness, implementability, and relative cost presented below, zero-valent iron for volumetric treatment is eliminated as a potential remediation method for all COC groups (see Sections 7.2.7.1 through 7.2.7.3).

Table 7.6. Zero-Valent Iron Required as a Function of Aquifer Volume

Radius or Areal Extent	Volume of Aquifer (m^3)	Mass of Zero-Valent Iron[(a)] (kg)
Radius of 3 m at 20 m depth	565	8,300
Radius of 7 m at 20 m depth	3,079	45,000
Radius of 20 m (multiple wells needed)	25,133	370,000
4,000 m^2 (~1 acre) at 20 m depth (multiple wells needed)	80,000	1,170,000

(a) Calculated using a porosity of 0.3 and for a 10% zero-valent iron emulsion filling 20% of the pore space.

7.2.7.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably meet goal?	Likely reliable to reduce concentrations in a small area. However, may not be adequate for carbon tetrachloride DNAPL contamination in a continuing source area.	Likely reliable for chromium. Tc-99 and uranium likely reduced to meet goal, but can re-oxidize over time.	Likely reliable for nitrate.
Produce hazardous products?	Reductive dechlorination of carbon tetrachloride and trichlorethene may lead to hazardous byproducts.	No hazardous byproducts.	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.	No negative impacts expected.	No negative impacts expected.
Treat target volume?	Only applicable for small volume such as with a continuing source area.	Only applicable for small volume not likely relevant to overall COC Group 2 plume treatment.	Only applicable for small volume not likely relevant to overall nitrate plume treatment.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.

7.2.7.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably constructed and operated?	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.
Reasonable consumable usage?	Very large amounts of iron necessary for volumetric treatment.	Very large amounts of iron necessary for volumetric treatment.	Very large amounts of iron necessary for volumetric treatment.

7.2.7.3 Relative Cost

Cost factors for zero-valent iron are associated with the relatively high reagent usage and large number of wells needed due to the limited radius of injection. Nano-zero-valent iron in powder form costs over $16 per pound, and emulsified zero-valent iron costs more than $20 per gallon for a 10% iron solution (personal communication, J. Greg Booth, Applied Science & Advanced Technologies, Inc.). The cost of the emulsified zero-valent iron, even for a treatment cylinder volume represented by a 20-m radius and a depth interval of 20 m, would be on the order of $6M. Costs for zero-valent iron as a volumetric treatment are expected to be higher than other potential remedies due to the high reagent usage and large number of wells for the relatively large treatment volumes associated with 200-ZP-1 COC.

7.2.8 Surfactant Flushing

This technology employs surfactant mixtures (i.e., nonionic and anionic) in injection wells at levels generally around 1% to 3% with or without additional chemicals (cosolvents, alcohols, inorganic salts, etc.) to promote the mobilization and/or solubilization of nonaqueous phase liquid (NAPL). Solubilization of sorbed contaminants may also occur. The surfactants function by lowering the NAPL-water interfacial tension and decreasing capillary forces within the porous media, which creates a micro-emulsion system and solubilizes the contaminant. In most demonstrations, surfactants or cosolvents are pumped through the aquifer displacing at least one or more pore volumes of groundwater, followed by several pore volumes of water to remove the residual surfactant. Various well configurations are used including single vertical circulation wells and injection/extraction well networks. Recovered contaminant with recovered surfactant is processed ex-situ using a variety of treatment processes.

Applicability of surfactant flushing appears to be most relevant to carbon tetrachloride (COC Group 1) because DNAPL may be present in the aquifer. Surfactant flushing is not likely to be appropriate for treating other COC groups because of the difficulty in selecting and applying an effective yet selective surfactant to inorganic contaminants that would not also mobilize large quantities of non-target minerals in the formation. Thus, for the screening evaluation, surfactant flushing was only considered for application to small continuing source areas.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, surfactant flushing is retained as a potential remediation method for carbon tetrachloride (part of COC Group 1) for small continuing source areas (see Sections 7.2.8.1 through 7.2.8.3).

7.2.8.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1 (carbon tetrachloride only)
Reliably meet goal?	Likely able to reduce concentrations in a known area of DNAPL. Significant uncertainty related to ability to mobilize and then capture the contamination and to effectively treat DNAPL in low permeability zones.
Produce hazardous products?	Residual surfactant could promote reductive dechlorination of carbon tetrachloride and trichlorethene, which may lead to hazardous byproducts. Otherwise, hazardous products are not expected.
Negatively impact to other COC?	Surfactant flushing could disperse other contaminants.
Treat target volume?	Only applicable for a NAPL area.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling.

7.2.8.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1
Reliably constructed and operated?	Ex-situ separation and recovery of halogenated solvent could be problematic. Re-cycling or accumulation of surfactant may be difficult.
Reasonable consumable usage?	Surfactant consumption could be uneconomic based upon recycle rates and efficiency of COC recovery.

7.2.8.3 Relative Cost

Cost factors for surfactant flushing are associated with the wells and groundwater recirculation infrastructure needed to inject the surfactant and then ensure capture of the mobilized contaminants. Another cost factor is the above-ground equipment needed to treat, or separate and treat, the extracted contaminants. As such, costs for surfactant flushing are expected to be somewhat higher than for other technologies such as bioremediation because of the importance of hydraulic control. Costs may be comparable to other source area treatment technologies such as chemical oxidation and thermal treatment.

7.2.9 In-Well Air Stripping (and Thermally Enhanced In-well Air Stripping)

In-well air stripping (vapor stripping) is the process of injecting air into a well below the water table to cause air-lift pumping of water from a bottom well screen to an upper well screen, where the groundwater and air are separated. This process induces a recirculation pattern in the aquifer where contaminated water is drawn into the lower well screen and flows back into the formation at the upper well screen. At the same time, the air contacting the groundwater in the well causes mass transfer of volatile contaminants from the groundwater to the gas phase, which is typically captured by a vacuum extraction blower. Contaminant concentrations eventually decline as groundwater circulates through the aquifer

around the treatment well. Variants of the technology use in-well reactors, submersible pumps, ozone injection, soil vapor extraction, and/or vadose zone biodegradation. There are four patented commercial variations of this technology (DOE 2002): NoVOCs (MACTEC, Inc.), UVB (IEG-Technologies Corp.), Density Driven Convection (Wasatch Environmental, Inc.), and C-Sparger (K-V Associates, Inc.). A variety of applications have been documented (EPA 1998). In-well air stripping is applicable to volatile organic compounds and is therefore relevant to COC Group 1.

Key properties that determine the effectiveness/implementability of this technology are: contaminant properties (i.e., Henry's Law constant), hydraulic conductivity of the aquifer, anisotropy of the aquifer, distance between upper and lower well screens (i.e., thickness of contaminated saturated zone), recirculation flow rate, thickness of vadose zone, and the natural groundwater flow gradient. The volatility of the chemical and the contact (distance/duration of contact, surface area/size of bubbles) between the groundwater and the air phase will determine the effectiveness of the mass transfer and removal of contaminant. Aquifer properties and physical geometry of the system impact the radius of influence for the well. In situations of low anisotropy (ratio of horizontal to vertical hydraulic conductivity), the radius of influence is lower as the recirculation gets more "short circuited." At high anisotropy, recirculation will be harder to develop, and there is potential for the plume to spread. Technology reports (DOE 2002; EPA 1995) indicate that a typical radius of influence is two to three times the distance between the upper and lower well screens. The hydraulic conductivity of the aquifer, induced pumping rate, and natural gradient for groundwater flow will all impact the radius of influence and the treatment effectiveness. In-well air stripping has been demonstrated both in the laboratory (e.g., Katz and Gvirtzman 2000) and at actual sites (e.g., DOE 2002).

Potentially, in-well air stripping could be configured to treat a specified volume or serve as a treatment barrier. Using an estimate for the radius of influence of two times the distance between upper and lower screens and a nominal screen length of 5 m, a radius of influence and associated per-well treatment volume can be calculated (Table 7.7). Treatment depth intervals greater than 30 m for calculating the radius of influence were not considered because the largest depth interval in the references reviewed was about 30 m. For treating thicker contaminated intervals, a separate shallow and deep treatment system would be needed (e.g., two 30-m intervals versus one 60-m interval).

Table 7.7. Estimated Radius of Influence and Treatment Volumes for an In-Well Air Stripping Well

Depth Interval (m)	Estimated Radius of Influence (m)	Areal Extent of Treatment Zone m^2 (acre)	Estimated Treatment Volume (m^3)
15	10	314 (0.08)	4,700
20	20	1,256 (0.31)	25,000
25	30	2,827 (0.7)	71,000
30	40	5,026 (1.2)	151,000

While it is possible to thermally enhance the effectiveness of in-well air stripping, this type of enhancement is not necessary for carbon tetrachloride or trichlorethene because they are sufficiently volatile for effective extraction at the ambient groundwater temperature. Thus, thermally enhanced in-well air stripping is eliminated as a potential remediation method for COC Group 1.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, in-well air stripping is retained as a potential remediation method for COC Group 1 for application to treat an areal extent of up to 25 acres or as a barrier technology (see Sections 7.2.9.1 through 7.2.9.3). Treatability testing would likely be required for the in-well air stripping technology.

7.2.9.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1
Reliably meet goal?	Effective extraction depends on the ability to recirculate contamination into the air stripping well. Testing would be needed to verify performance at Hanford. Performance as a barrier is less certain than performance as a volumetric treatment. Treatment is for dissolved-phase contaminants, not DNAPL.
Produce hazardous products?	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.
Treat target volume?	In-well air stripping may be suitable over an areal extent of up to 25 acres using the estimated radius of influence shown in Table 7.7. For treatment volumes above 25 acres, a large number of wells would be needed because COC Group 1 contaminants are present over a thick interval at larger areal extent.
Cause risk during construction or operation?	Construction risk would be from a significant amount of necessary drilling. Because contamination is extracted to the surface, the operation risk is similar to that of a pump-and-treat system.

7.2.9.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1
Reliably constructed and operated?	Construction and operation of the system is straightforward.
Reasonable consumable usage?	Consumable usage is similar to that of a pump-and-treat system.

7.2.9.3 Relative Cost

Cost factors for in-well air stripping include well drilling and above-ground vapor treatment. The number of wells is highly dependent on the effective radius of influence for contaminant extraction that is obtained. A site-specific treatability test would likely be needed to determine the radius of influence. Based on the estimated radii of influence and associated treatment volumes listed in Table 7.7, the

number of wells per treatment volume can be estimated. For an areal treatment extent above about 25 acres, the number of wells required to apply in-well air stripping will likely increase cost significantly compared to the cost for other viable options.

Applied as a treatment barrier, well spacing can be determined from information in Table 7.7. Costs are directly related to the radius of influence by determining the number of wells needed for a barrier application.

7.2.10 Down-Well System

Down-well treatment systems place a bioreactor or adsorption media within the well bore. Such technology is presently developmental and has not been deployed at a large scale. The technology requires treating groundwater within the relatively limited volume of the well bore. Biological treatment systems require a definite control volume to contain the biological process for a specific detention or reaction time. Down-well sorption systems are limited by the media-holding capacity of the well bore. Consequently, frequent media replacement may be needed. For the screening evaluation, down-well systems were considered as potentially applicable to COC Group 2.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, down-well treatment is eliminated as a potential remediation method (see Sections 7.2.10.1 through 7.2.10.3).

7.2.10.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 2
Reliably meet goal?	Significant uncertainty in the ability to reduce contaminant concentration.
Produce hazardous products?	No hazardous by products.
Negatively impact to other COC?	No negative impacts expected.
Treat target volume?	Potentially applicable to the same aquifer volume as for in-well air stripping based on expected recirculation patterns.
Cause risk during construction or operation?	Primary risk would be from significant amount of drilling necessary.

7.2.10.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1
Reliably constructed and operated?	Complex construction and maintenance concerns due to small volume available for the treatment system within the well.
Reasonable consumable usage?	Reagent or consumable costs could be uneconomic based upon limited operating efficiencies.

7.2.10.3 Relative Cost

Cost factors for down-well treatment include well drilling and maintenance of the treatment process. The number of wells is highly dependent on the effective radius of influence for contaminant extraction that is obtained. A site-specific treatability test would likely be needed to determine the radius of influence. Based on the estimated radii of influence and associated treatment volumes listed in Table 7.7, the number of wells per treatment volume can be estimated. For an areal treatment extent above about 25 acres, the number of wells required for application of down-well treatment will likely increase cost significantly compared to the cost for other viable options.

Applied as a treatment barrier, well spacing can be determined from information in Table 7.7. Costs are directly related to the radius of influence by determining the number of wells needed for a barrier application.

7.2.11 Air Sparging

Air sparging involves injecting a gas (usually air/oxygen) under pressure into the saturated subsurface to volatilize organic groundwater contaminants. Volatilized vapors migrate into the vadose zone where they are extracted via vacuum, generally by a soil vapor extraction system installed into the vadose zone. Air sparging is applicable to the COC Group 1 volatile organic contaminants. Sites with relatively permeable, homogeneous soil conditions favor the use of air sparging due to greater effective contact between sparged air and the media being treated and effective extraction of volatilized vapors. Other appropriate site variables include relatively large saturated thicknesses and depths to groundwater. Saturated thicknesses and depths to groundwater control the area of influence of a sparging well and the number of wells needed. Because air transport through an aquifer is more difficult than water transport, compared to the sensitivity of technologies that recirculate water, air sparging tends to be more sensitive to heterogeneities.

Site conditions that preclude effective air sparging include:

- Fine-grained, low-permeability soils that decrease air flow
- Lithology that includes a low-permeability layer overlying the aquifer, which would inhibit effectively capturing volatilized vapor in the vapor recovery wells
- Heterogeneous soils, which foster channeling of sparge air or vapor flow.

The nominal thickness of the COC Group 1 is 70 m with a similar depth to the water table. This thickness/depth is approximately two times greater than is typical for deeper applications of air sparging.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, air sparging is retained as a potential remediation method for COC Group 1 for application to treat small, focused areas of groundwater contamination up to 5 acres in area and for thicknesses of less than 30 m (see Sections 7.2.11.1 through 7.2.11.3). Treatability testing is likely needed before implementation to assess the ability to effectively sparge and collect the contamination.

7.2.11.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1
Reliably meet goal?	Effective extraction depends on whether heterogeneous layers within the aquifer will be conducive to effective sparging and the ability to collect sparged vapors in the vadose zone. Testing would be needed to verify performance at Hanford.
Produce hazardous products?	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.
Treat target volume?	The suitability of air sparging is a function of the permeability and vertical stratigraphy of the aquifer and vadose zone. Air sparging may be suitable over smaller areas with higher target concentrations. For treatment over large plume size areas, a large number of wells would be needed because nominally sparging and vapor recovery is limited to the radii of influence not exceeding 30 m.
Cause risk during construction or operation?	Construction risk would be from a significant amount of necessary drilling. Because contamination is extracted to the surface, the operation risk is similar to that of a pump-and-treat system.

7.2.11.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1
Reliably constructed and operated?	Construction and operation of the system is straightforward.
Reasonable consumable usage?	Consumable usage is similar to that of a pump-and-treat system for treatment of extracted vapors.

7.2.11.3 Relative Cost

Cost factors for air sparging include well drilling and above-ground vapor treatment. The number of wells is highly dependent on the effective radius of influence for contaminant extraction that is obtained. A site-specific treatability test would likely be needed to determine the radius of influence. For an areal treatment extent above about 25 acres, the number of wells required for application of air sparging will likely increase cost significantly compared to the cost for other viable options. Applied as a treatment barrier, costs are directly related to the radius of influence.

7.2.12 Anaerobic Bioremediation

Carbon tetrachloride can be dechlorinated under anaerobic conditions to either CF or non-hazardous compounds depending on the subsurface conditions (Truex et al. 2001). Trichlorethene can be directly reduced to ethene by some bacteria as part of anaerobic reductive dechlorination reactions (e.g., DeBruin et al. 1992; Freedman and Gossett 1989), though reductive dechlorination or trichlorethene may also result in DCE and VC as persistent dechlorination products. Anaerobic dechlorination reactions require that an appropriate substrate is present and the dechlorinating bacteria can effectively compete for the substrate against other microorganisms that can also use the substrate with other electron acceptors. Nitrate, chromium technetium-99, and uranium can also be reduced under anaerobic conditions and converted to non-hazardous products (for nitrate) or to insoluble chemical forms (for chromium, technetium-99, and uranium). The biomass that grows during anaerobic bioremediation may also increase the adsorption of other contaminants such as iodine-129, potentially enhanced through reduction of the iodine (Muramatsu et al. 2004). Thus, anaerobic bioremediation is potentially applicable to COC Groups 1, 2, and 3.

In situ anaerobic bioremediation relies on effective distribution of substrate and activity of appropriate bacteria. A groundwater recirculation system could be used to distribute a soluble substrate (e.g., molasses) over large distances to attempt enhancing reductive dechlorination of carbon tetrachloride or trichlorethene and reduction of chromium, technetium-99, and uranium. However, the success in stimulating dechlorination without producing hazardous byproducts, and contaminant reduction versus other types of anaerobic activity, is dependent on the microbial ecology and groundwater geochemistry (e.g., presence of other electron acceptors). The ability to stimulate appropriate microbial activity would need to be evaluated to confirm whether remediation goals will likely be met.

In situ anaerobic bioremediation could also be implemented by distributing a long-duration substrate such as vegetable oil into the aquifer. Because the substrate is less accessible to the bacteria, it is not consumed as it is distributed and can provide a long-term food supply once in place. The key property with this technology is the hydraulic conductivity of the aquifer. The radius of the treatment zone depends on how well the substrate can be injected into and distributed through the aquifer formation. A secondary property of interest is the length of time that the substrate lasts, which impacts the frequency of "regenerating" the treatment zone. The radius of influence for long-duration substrate injection will be less than that for a soluble substrate. Functionally, a radius of about 7 m for oil distribution is similar to what has been achieved for other applications of this technology.

Based on the evaluation of effectiveness, implementability, and relative cost (presented below), in situ anaerobic bioremediation is retained as a potential remediation method for COC Groups 1, 2, and 3 for application to treat an areal extent of up to 5 acres (see Sections 7.2.12.1 through 7.2.12.3). For thick contaminated intervals such as for COC Group 1, multiple injection well intervals would likely be needed.

7.2.12.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably meet goal?	There is moderate uncertainty in meeting the goals because complete dechlorination to non-hazardous compounds may not be obtained.	There is moderate uncertainty in meeting the goals for Tc-99 and uranium because these compounds can reoxidize readily and become mobile again after being microbially reduced and temporarily immobilized. It is likely that goals for chromium could be met because it remains stable and immobile after microbial reduction. Increased adsoption of I-129 and reduction may also occur.	It is likely that goals for nitrate could be met because it will likely be reduced to nitrogen gas.
Produce hazardous products?	Reductive dechlorination of carbon tetrachloride and trichlorethene may lead to hazardous byproducts.	No hazardous byproducts.	Likely no hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.	No negative impacts expected.	No negative impacts expected.
Treat target volume?	Bioremediation can treat large or small volumes, but will require numerous wells for larger volumes due to a limited radius of influence for substrate distribution.	Bioremediation can treat large or small volumes, but will require numerous wells for larger volumes due to a limited radius of influence for substrate distribution.	Bioremediation can treat large or small volumes, but will require numerous wells for larger volumes due to a limited radius of influence for substrate distribution.
Cause risk during construction or operation?	Primary risk would be from a significant amount of necessary drilling.	Primary risk would be from a significant amount of necessary drilling.	Primary risk would be from a significant amount of necessary drilling.

7.2.12.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably constructed and operated?	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.
Reasonable consumable usage?	Very large amounts of substrate necessary for large treatment volumes.	Very large amounts of substrate necessary for large treatment volumes.	Very large amounts of substrate necessary for large treatment volumes.

7.2.12.3 Relative Cost

Cost factors for anaerobic bioremediation are a function of well costs, the amount of substrate required to maintain appropriate conditions over the desired treatment volume, and the longevity of the substrate. Long-duration substrates can only be distributed a short distance from injection wells. Thus, use of vegetable oil or similar long-duration substrates would be limited to small volumes because the cost for injection wells would render bioremediation much more expensive than other potential options at larger volumes. For instance, assuming a 7-m effective radius for vegetable oil injection stimulating bioremediation within a radius of influence of 14 m, 9 wells per acre are necessary. Soluble substrates can be distributed over larger volumes but are not long lasting and would require frequent injection. Thus, use of soluble substrates would also be limited to relatively small volumes because the cost of substrate injection via groundwater recirculation wells at large volumes would render bioremediation much more expensive than other potential options.

7.2.13 Aerobic Bioremediation (co-metabolism)

Trichlorethene can be co-metabolically oxidized by some bacteria in the presence of molecular oxygen and substrates such as methane, toluene, and phenol (e.g., Chang and Alvarez-Cohen 1995). This method is only applicable to trichlorethene (part of COC Group 1). In situ aerobic bioremediation relies on effective distribution of reagents and activity of appropriate bacteria. In addition to using air, pure oxygen or dilute concentrations of hydrogen peroxide are other methods for oxygenating the injected water. This technology requires that bacteria that utilize monooxygenase enzymes (e.g., methanotrophs – bacteria that use methane as a substrate) are present in the aquifer to support co-metabolic trichlorethene degradation. The ability to stimulate appropriate microbial activity would need to be evaluated to confirm whether remediation goals will likely be met. Biological degradation processes would not produce hazardous products (trichlorethene is destroyed, not transformed).

Treatment would be stimulated through either injection of methane and oxygen as gases directly into the target zone or through groundwater recirculation, where methane and oxygen would be dissolved into the water at the surface and then injected into the aquifer. In situ aerobic bioremediation requires a significant design effort. Not only must the ability to stimulate appropriate microbial activity be assessed, but also a number of design issues for the substrate and oxygen system must be addressed.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, in situ aerobic bioremediation is retained as a potential remediation method for trichlorethene (part of COC Groups 1) for application to treat an areal extent of up to 5 acres (see Sections 7.2.13.1 through 7.2.13.3). However, treatment of the full contaminated thickness may require multiple substrate distributions systems (e.g., one shallow and one deep).

7.2.13.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1 (trichlorethene only)
Reliably meet goal?	Effective treatment depends on the ability to distribute the substrate and oxygen with the contamination and the presence of appropriate bacteria. Testing would be needed to verify performance at Hanford.
Produce hazardous products?	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.
Treat target volume?	Bioremediation can treat large or small volumes, but will require numerous wells for larger volumes due to a limited radius of influence for substrate and oxygen distribution.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling. Small operational risks may be associated with handling methane and oxygen

7.2.13.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1 (trichlorethene only)
Reliably constructed and operated?	Uniform distribution of substrate and oxygen with a long well screen may be problematic. Large number of wells necessary for large volumes.
Reasonable consumable usage?	Large amounts of substrate necessary for large treatment volumes.

7.2.13.3 Relative Cost

Cost factors are primarily associated with the ability to distribute oxygen and methane in the aquifer and therefore the number of wells required. Relatively large-scale application of aerobic bioremediation has been demonstrated at the DOE Savannah River Site. This type of application at Hanford may be viable over similar treatment volumes and have costs similar to other potential options.

7.2.14 In Situ Thermal Treatment

In situ thermal treatment is applicable to volatile and semi-volatile compounds and is primarily applied for treatment of NAPL contaminant rather than dissolved-phase contaminant. As such, in situ thermal treatment is considered for carbon tetrachloride only because it is the only COC potentially present as a NAPL in the groundwater (part of COC Group 1).

In situ thermal treatment increases the temperature of the subsurface to enhance the extraction of liquid-, dissolved-, or vapor-phase contamination. For instance, liquid-phase extraction can be enhanced if the viscosity of NAPL contamination decreases sufficiently with increased temperature. Dissolved-phase extraction can be enhanced if the solubility of the contaminant increases with temperature or if NAPL is volatilized and it dissolves in an aqueous phase at higher concentrations than before heating. While it is not clear that this mechanism plays a strong role in removing large amounts of contaminant mass, it is important to consider for containment of the contamination and may be relevant near the end of the treatment period. Vapor-phase extraction is typically a key component of in situ thermal treatment. Raising the temperature volatilizes NAPL so that it can be extracted in the soil gas. In addition, raising the subsurface temperature can boil groundwater, enhancing pathways for vapor transport to the surface. Multi-phase extraction can also be used to more aggressively remove contaminant mass, but this increases the treatment burden for above-ground equipment.

Through the above mechanisms, in situ thermal treatment can effectively enhance extraction of NAPL contaminant from the subsurface. Several techniques for in situ thermal treatment have been applied for site remediation. This screening evaluation primarily focuses on electrical resistance heating and steam injection. Electrical resistance heating (e.g., six-phase soil heating) has been applied to enhance extraction of chlorinated solvents from the saturated and unsaturated subsurface zones (Fain et al. 2002; Hudson et al. 2002; Pope et al. 2002; Smith et al. 2000; Beyke et al. 2000a). Hydrocarbon contamination has also been treated using electrical resistance heating (e.g., Beyke et al. 2000b). Similarly, steam injection has been applied recently to enhance removal of chlorinated solvents (Jepsen et al. 2002), chlorinated solvents mixed with hydrocarbons (Larson et al. 2002; Adams and Smith 1998), PCBs mixed with hydrocarbons (Cote et al. 2002), and hydrocarbons (Dablow and Balshaw-Biddle 1998). For carbon tetrachloride, the homogeneous hydrolysis rate (abiotic degradation) is significantly increased at higher temperatures (Jeffers et al. 1989, 1996; Truex et al. 2001) and may be an important component of the overall carbon tetrachloride mass removal during thermal treatment.

Both site and contaminant properties can limit the effectiveness of in situ thermal treatment in reaching remediation goals, especially if the goal is source removal (versus source reduction). Heterogeneous subsurface hydrologic conditions can impact the distribution of heat and the pathways for contaminant extraction. For each site remediation, the combination of remediation goals, subsurface complexities, and contaminant properties will impose operational constraints and determine the remediation cost for use of in situ thermal treatment as a means to enhance contaminant extraction. Specific remediation goals for NAPL may vary between sites. In some cases, source reduction or containment is sufficient. In other cases, source removal is needed. The remediation goal affects the treatment cost because more heating time and energy are needed to reach lower residual concentrations in the subsurface. Other cost drivers for in situ thermal treatment include 1) stratigraphic layering that impacts the heating or extraction efficiency, 2) thickness of the vadose zone column through which contaminant must be extracted, 3) groundwater flux rate (heat losses), 4) overall size/depth/thickness of contaminated zone, and 5) presence of non- or semi-volatile contaminants.

Because of the characteristics and cost drivers for thermal treatment technologies, only application to small, continuing source areas for carbon tetrachloride was considered.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, thermal treatment is retained as a potential remediation method for carbon tetrachloride (part of COC Group 1) for small, continuing source areas for the portion of the aquifer (see Sections 7.2.14.1 through 7.2.14.3). There would be increasing costs and uncertainty in treatment for increasing treatment depth into the aquifer.

7.2.14.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1 (carbon tetrachloride only)
Reliably meet goal?	Likely reliable to reduce concentrations in a small volume. Potential issues with thermal treatment are associated with effective extraction of the vapor-phase contaminants in a heterogeneous subsurface without spreading of the contamination.
Produce hazardous products?	No hazardous products are produced.
Negatively impact to other COC?	No negative impacts to other COC.
Treat target volume?	Only applicable for small volume such as with a continuing source area.
Cause risk during construction or operation?	Construction risk would be from necessary drilling. Operational risk is associated with vapor-phase treatment processes and electrical/steam equipment.

7.2.14.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1 (carbon tetrachloride only)
Reliably constructed and operated?	Electrodes and/or other system components are deeper than previous applications. Operation is similar to previous applications.
Reasonable consumable usage?	Electricity use will be large for a finite period of time, but this consumption has been effectively addressed for other applications.

7.2.14.3 Relative Cost

Cost factors are primarily associated with installation of the wells and/or electrodes necessary for treatment. Costs are expected to be similar to other potential active remedy options for source area treatment. Thus, thermal treatment is retained as potential remediation method for small continuing source areas.

7.2.15 Permeable Reactive Barriers

Permeable reactive barrier (PRB) technology is an interception technology designed to treat contaminant as it passes through the treatment zone. This technology relies on having sufficient knowledge of the contaminant plume location and the groundwater flow paths. In general, PRB may act on the contaminants flowing through by destroying the contaminant in a reaction (biological or abiotic), by adsorption of the contaminant onto the PRB media, or by precipitation resulting from a chemical reaction. The PRB technology may be implemented as a funnel-and-gate system or an interception wall. The funnel-and-gate system uses physical barriers (e.g., sheet piling or a low-permeability material such as a clay or grout) on two sides to direct groundwater (and contaminant plume) flow through a smaller permeable treatment zone. An interception wall is a continuous treatment zone wide enough to intersect with the expected span of the contaminant plume. The groundwater flow velocity controls the duration of the remediation effort and the design of the PRB. The PRB must be designed with a suitable thickness (or multiple walls in series) to provide enough residence time for reaction (destruction), adsorption, or precipitation of the contaminant to, at, or below the desired downgradient concentration. A funnel-and-gate system is impractical to install for the depth and extent of the contamination and will not be considered further. Treatment variants that are applicable to the COC Group 1, 2 (except iodine-129), and 3 include zero-valent iron, in situ redox manipulation, and biodegradation. Phosphate-based barriers such as injectable apatite and polyphosphate are potential innovative methods applicable to the uranium plume. A PRB is not considered applicable to iodine-129 or tritium COC. The specific PRB variants are discussed in more detail below.

7.2.15.1 Zero-Valent Iron PRB

Zero-valent iron is most often installed in a trench-and-fill system, but can be installed by injection of material into the aquifer through wells. Present technology permits placement of small-scale iron particles from wells to radial distances of about 3–7 m (GeoSierra 2005). Similarly, low radial influences are observed with current applications of emulsified zero-valent iron (Quinn et al. 2005 and personal communication, J. Quinn). Emplacement of zero-valent iron particles in the subsurface provides an electron source for dechlorination of carbon tetrachloride and trichlorethene (COC Group 1) and reduction of chromium, technetium-99, uranium, and nitrate (COC Groups 2 and 3, except iodine-129).

Based on the evaluation of effectiveness, implementability, and relative cost presented below, zero-valent iron as a PRB is eliminated as a potential remediation method for all COC Groups (see Sections 7.2.15.1.1 through 7.2.15.1.3).

7.2.15.1.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably meet goal?	Likely reliable to reduce concentrations in a barrier application.	Likely reliable for chromium. Tc-99 and uranium likely reduced to meet goal, but can re-oxidize over time.	Likely reliable for nitrate.
Produce hazardous products?	Reductive dechlorination of carbon tetrachloride and trichlorethene may lead to hazardous byproducts.	No hazardous byproducts.	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.	No negative impacts expected.	No negative impacts expected.
Treat target volume?	A PRB could be emplaced at the downgradient edge of a selected treatment volume.	A PRB could be emplaced at the downgradient edge of a selected treatment volume.	A PRB could be emplaced at the downgradient edge of a selected treatment volume.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.

7.2.15.1.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably constructed and operated?	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of iron with a long well screen may be problematic. Very large number of wells necessary.
Reasonable consumable usage?	Very large amounts of iron necessary for even moderate barrier lengths.	Very large amounts of iron necessary for even moderate barrier lengths.	Very large amounts of iron necessary for even moderate barrier lengths.

7.2.15.1.3 Relative Cost

Cost factors for zero-valent iron are associated with the relatively high reagent usage and large number of wells needed due to the limited radius of injection. Nano-zero-valent iron in powder form costs over $16 per pound, and emulsified zero-valent iron costs more than $20 per gallon for a 10% iron solution.[1] The cost of the emulsified zero-valent iron for a PRB of 300 m over a depth interval of 20 m, assuming a radial influence of 7 m per well and only one line of injection wells (total of about 22 wells), would be on the order of $15M.

7.2.15.2 In Situ Redox Manipulation PRB

In Situ Redox Manipulation (ISRM) involves the injection of a reducing solution (e.g., sodium dithionite) and the creation of a zone of ferrous iron that can facilitate the chemical reduction of the contaminants. After the reducing solution has been injected and allowed to react with the aquifer sediments, the solution is extracted from the aquifer to remove unreacted reagent, sulfate, etc. The ferrous iron created by reaction with the reagent remains in place and reacts to reduce contaminants and oxygen or oxidized solutes carried into the barrier. In addition to the general PRB design issues of groundwater flow path and barrier thickness, key properties that determine the effectiveness/ implementability of ISRM are the hydraulic conductivity of the aquifer and the natural iron content of the aquifer sediments. The hydraulic conductivity of the aquifer affects the ability and rate of distribution of the reagent. The amount of natural iron in the aquifer sediments affects the distribution of the reagent and the resulting reactivity of the barrier. Too little iron will result in an ineffective reducing barrier, and too much iron will result in fast consumption of the reagent and a correspondingly small radius of influence. A proof-of-principle test at the Hanford Site had an apparent radius of influence of about 8 m (DOE 2000). An ISRM PRB in the subsurface provides an electron source for dechlorination of carbon tetrachloride and trichlorethene (COC Group 1) and reduction of chromium, technetium-99, uranium, and nitrate (COC Groups 2 and 3, except for iodine-129).

Based on the evaluation of effectiveness, implementability, and relative cost presented below, ISRM as a PRB is retained as a potential remediation method for COC groups 1, 2, and 3 (except for iodine-129) (see Sections 7.2.15.2.1 through 7.2.15.2.3).

[1] Personal communication to the authors from J. Greg Booth, Applied Science & Advanced Technologies, Inc., Baton Rouge, Louisiana, July 25, 2005.

7.2.15.2.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably meet goal?	Likely reliable to reduce concentrations in a barrier application.	Likely reliable for chromium. Tc-99 and uranium likely reduced to meet goal, but can re-oxidize over time.	Likely reliable for nitrate.
Produce hazardous products?	Reductive dechlorination of carbon tetrachloride and trichlorethene may lead to hazardous byproducts.	No hazardous byproducts.	No hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.	No negative impacts expected.	No negative impacts expected.
Treat target volume?	A PRB could be emplaced at the downgradient edge of a selected treatment volume.	A PRB could be emplaced at the downgradient edge of a selected treatment volume.	A PRB could be emplaced at the downgradient edge of a selected treatment volume.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.

7.2.15.2.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably constructed and operated?	Uniform distribution of reagent (e.g., dithionite) with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of reagent (e.g., dithionite) with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of reagent (e.g., dithionite) with a long well screen may be problematic. Very large number of wells necessary.
Reasonable consumable usage?	Very large amounts of reagent (e.g., dithionite) necessary for even moderate barrier lengths.	Very large amounts of reagent (e.g., dithionite) necessary for even moderate barrier lengths.	Very large amounts of reagent (e.g., dithionite) necessary for even moderate barrier lengths.

7.2.15.2.3 Relative Cost

The cost factors for ISRM are the drilling costs, reagent costs, and the frequency of re-injection. Using a presumed radius of influence of 8 m per well, the total reducing solution volume as a function of depth is shown in Table 7.8. At a cost of $0.625/gal for this solution (Envirochem Technology Services), the cost of the dithionite for a PRB of 300 m over a depth interval of 20 m, assuming a radial influence of 8 m per well and two lines of injection wells (total of about 36 wells), would be on the order of $3.2M.

Table 7.8. Volume of Dithionite Solution as a Function of Treatment Depth

Treatment Depth	Volume of Aquifer[(a)] (m^3)	Volume of Dithionite[(b)] (gal)
15 m	3,016	239,000
20 m	4,021	319,000
30 m	6,032	478,000

(a) Calculated with an 8-m radius of influence.
(b) Calculated using a porosity of 0.3 and for dithionite filling 100% of the pore space.

7.2.15.3 In Situ Anaerobic Bioremediation PRB

Carbon tetrachloride can be dechlorinated under anaerobic conditions to either CF or non-hazardous compounds depending on the subsurface conditions (Truex et al. 2001). trichlorethene can be directly reduced to ethene by some bacteria as part of anaerobic reductive dechlorination reactions (e.g., DeBruin et al. 1992; Freedman and Gossett 1989), though reductive dechlorination or trichlorethene may also result in DCE and VC as persistent dechlorination products. The anaerobic dechlorination reactions require that an appropriate substrate is present and that the dechlorinating bacteria can effectively compete for the substrate against other microorganisms that can also use the substrate with other electron acceptors. Nitrate, chromium, technetium-99, and uranium can also be reduced under anaerobic conditions and converted to non-hazardous products (for nitrate) or to insoluble chemical forms (for chromium, technetium-99, and uranium). The biomass that grows during anaerobic bioremediation may also increase the adsorption of other contaminants such as iodine-129, potentially enhanced through reduction of the iodine. Thus, anaerobic bioremediation is potentially applicable to COC Groups 1, 2, and 3.

The success in stimulating dechlorination without producing hazardous byproducts and contaminant reduction versus other types of anaerobic activity is dependent on the microbial ecology and groundwater geochemistry (e.g., presence of other electron acceptors). The ability to stimulate appropriate microbial activity would need to be evaluated to confirm whether remediation goals will likely be met.

An in situ anaerobic bioremediation PRB would be implemented by distributing a long-duration substrate such as vegetable oil into the aquifer. Because the substrate is less accessible to the bacteria, it is not consumed as it is distributed and can provide a long-term food supply once in place. The key property with this technology is the hydraulic conductivity of the aquifer. The radius of the treatment zone depends on how well the substrate can be injected into and distributed through the aquifer formation. A secondary property of interest is the length of time that the substrate lasts, which impacts the frequency of "regenerating" the treatment zone. The radius of influence for long-duration substrate injection used for the screening evaluation is about 7 m for oil distribution, similar to what has been achieved for other applications of this technology.

Based on the evaluation of effectiveness, implementability, and relative cost (presented below), Anaerobic Bioremediation as a PRB is retained as a potential remediation method for COC groups 1, 2, and 3 (see Sections 7.2.15.3.1 through 7.2.15.3.3).

7.2.15.3.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably meet goal?	There is moderate uncertainty in meeting the goals because complete dechlorination to non-hazardous compounds may not be obtained.	There is moderate uncertainty in meeting the goals for Tc-99 and uranium because these compounds can reoxidize readily and become mobile again after being microbially reduced and temporarily immobilized. It is likely that goals for chromium could be met because it remains stable and immobile after microbial reduction. Increased adsoption of I-129 and reduction may also occur.	It is likely that goals for nitrate could be met because it will likely be reduced to nitrogen gas.
Produce hazardous products?	Reductive dechlorination of carbon tetrachloride and trichlorethene may lead to hazardous byproducts.	No hazardous byproducts.	Likely no hazardous byproducts.
Negatively impact to other COC?	No negative impacts expected.	No negative impacts expected.	No negative impacts expected.
Treat target volume?	Bioremediation can be applied as a treatment barrier, but will require numerous wells for long barriers due to a limited radius of influence for substrate distribution. The rate of biological reactions would need to be sufficient to treat the contaminants within the residence item of the barrier. Thus the design must consider the necessary barrier thickness.	Bioremediation can be applied as a treatment barrier, but will require numerous wells for long barriers due to a limited radius of influence for substrate distribution. The rate of biological reactions would need to be sufficient to treat the contaminants within the residence item of the barrier. Thus, the design must consider the necessary barrier thickness.	Bioremediation can be applied as a treatment barrier, but will require numerous wells for long barriers due to a limited radius of influence for substrate distribution. The rate of biological reactions would need to be sufficient to treat the contaminants within the residence item of the barrier. Thus, the design must consider the necessary barrier thickness.
Cause risk during construction or operation?	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.	Primary risk would be from significant amount of necessary drilling.

7.2.15.3.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 1	COC Group 2	COC Group 3
Reliably constructed and operated?	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.	Uniform distribution of substrate with a long well screen may be problematic. Very large number of wells necessary.
Reasonable consumable usage?	Very large amounts of substrate necessary for long barriers.	Very large amounts of substrate necessary for long barriers.	Very large amounts of substrate necessary for long barriers.

7.2.15.3.3 Relative Cost

Cost factors for anaerobic bioremediation are a function of well costs, the amount of substrate required to maintain appropriate conditions within the barrier, and the longevity of the substrate. Long-duration substrates can only be distributed a short distance from injection wells. However, substrate volume and costs are likely similar or lower than those for other PRB reagents (e.g., ISRM).

7.2.15.4 Injectable Apatite Barrier

Hydroxyapatite [$Ca_5(PO_4)_3OH$] has been found to be very effective in sequestration of many dissolved metals including strontium and uranium. Such divalent metal oxyanions do react with dissolved phosphate to precipitate and immobilize the heavy metal. Apatite sequestration is expected to be minimally effective with chromium, technetium, and iodine groundwater contamination. Thus, for the screening evaluation, apatite was only considered for applicable to uranium as part of COC Group 2 (Fuller et al. 2002; Flury and Harsh 2000; Bostick et al. 2003). Because of the depth to groundwater, application of solid phase apatite is not feasible and will not be considered as a viable technology for the site. However, apatite minerals can be formed in situ from injection of soluble reagents (Moore et al. 2004). This method relies on injection of calcium citrate and phosphate solutions. The calcium is complexed with citrate during the injection and does not reaction with the phosphate until the citrate is degraded by microorganisms in the subsurface. Thus, the apatite formation can be distributed over a radial distance of meters to ~10 m away from the injection well depending on the subsurface hydrology and the microbial citrate degradation rate. This technique is currently being tested for application to strontium contamination at the Hanford 100-N Area. Injectable apatite would be considered an innovative treatment option.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, injectable apatite is retained as a potential remediation method for uranium (part of COC Group 2) as a barrier (see Sections 7.2.15.4.1 through 7.2.15.4.3). This is an innovative technology that would likely need treatability testing.

7.2.15.4.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably meet goal?	Likely reliable to reduce concentrations as a barrier. Laboratory-scale studies show promise. Field-scale testing yet to be conducted.
Produce hazardous products?	No hazardous byproducts are produced.
Negatively impact to other COC?	Likely no impact if applied as a barrier for the uranium plume. Residual phosphate could stimulate microbiological growth.
Treat target volume?	Distribution of the reagents meters to ~10 m from the injection point is expected. As such a barrier application similar to an anaerobic biobarrier is likely possible.
Cause risk during construction or operation?	Construction risk would be from drilling necessary.

7.2.15.4.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably constructed and operated?	Uniform distribution of reagents possible with proper engineering and hydraulic control. Treatability testing is needed.
Reasonable consumable usage?	Treatability testing is needed to assess design of the remediation system.

7.2.15.4.3 Relative Cost

The injectable apatite remediation method is an innovative technology still under development. Cost factors are primarily related to the radius of influence that can be obtained. It is expected that a radius of influence similar to injection of a long-duration substrate for anaerobic bioremediation will be possible. As such, costs for injectable apatite could be comparable to other technologies for a barrier where well costs would be similar to an anaerobic bioremediation biobarrier.

7.2.15.5 Polyphosphate Barrier

Another phosphate-based technology for stabilization of uranium using phosphate is presently in development. This technology uses injection of liquid polyphosphate to stabilize uranium. It is not applicable to the other COC. This technology stabilizes uranium by a different mechanism than apatite stabilization.

The process uses polymers of phosphate to release phosphate at a slow, controlled rate into groundwater downgradient of the application point. The presence of phosphate in groundwater, even in minor concentrations (10^{-8} M), promotes the formation of autunite–group minerals, $X_{3-n}^{(n)*}[(UO_2)(PO_4)]_2 \cdot xH_2O$, thereby limiting the mobility of the uranyl cation (UO_2^{2+}) in the subsurface environment. The use of soluble long-chain polyphosphate reagent delays precipitation of the autunite, thereby mitigating plugging of the formation near the application point. By adjusting the length of the polyphosphate chain, the hydrolysis reaction that releases the phosphate into the water can be engineered and the uranium stabilization rate controlled. Because autunite sequesters uranium in the oxidized form, U^{6+}, rather than forcing reduction to U^{4+}, the possibility of re-oxidation and subsequent re-mobilization is negated. Extensive laboratory testing demonstrates the very low solubility of autunite. In addition to autunite, excess phosphorous may result in apatite mineral formation, providing a secondary, long-term source of treatment capacity.

Deployment polyphosphate may be designed to treat a horizontal extent as well as vertical zone of uranium in the groundwater and at the water-table interface. The liquid form of the reagent facilitates application to and transport within the contaminated groundwater plume. Uranium transport studies in columns packed with contaminated sediment from the Hanford 300 Area indicate that a polyphosphate solution reduces the concentration of uranium in water to near the drinking water standard (30 µg/L) (Wellman et al. 2006). Polyphosphate would be considered an innovative treatment option.

Based on the evaluation of effectiveness, implementability, and relative cost presented below, polyphosphate is retained as a potential remediation method for uranium (part of COC Group 2) as a barrier (see Sections 7.2.15.5.1 through 7.2.15.5.3). This is an innovative technology that would likely need treatability testing.

7.2.15.5.1 Effectiveness

Effectiveness Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably meet goal?	Likely reliable to reduce concentrations as a barrier. Laboratory-scale studies show promise. Field-scale testing yet to be conducted.
Produce hazardous products?	No hazardous byproducts are produced.
Negatively impact to other COC?	Likely no impact if applied as a barrier for the uranium plume. Residual phosphate could stimulate microbiological growth.
Treat target volume?	Distribution of the polyphosphate meters to ~10 m from the injection point is expected. As such a barrier application similar to an anaerobic biobarrier is likely possible.
Cause risk during construction or operation?	Construction risk would be from drilling necessary.

7.2.15.5.2 Implementability

Implementability Screening Criteria (see Table 5.1)	COC Group 2 (uranium only)
Reliably constructed and operated?	Uniform distribution of polyphosphate possible with proper engineering and hydraulic control. Treatability testing is needed.
Reasonable consumable usage?	Treatability testing is needed to assess design of the remediation system.

7.2.15.5.3 Relative Cost

The polyphosphate remediation method is an innovative technology still under development. Cost factors are primarily related to the radius of influence that can be obtained. It is expected that a radius of influence similar to injection of a long-duration substrate for anaerobic bioremediation will be possible. As such, costs for polyphosphate could be comparable to other technologies as a barrier where well costs would be similar to an anaerobic bioremediation biobarrier.

8.0 Results of Screening Evaluation

Based on the screening evaluation criteria, potential remediation methods were comparatively evaluated to identify those most promising for continued evaluation as part of the feasibility study. Only a few methods are applicable to all COC. Thus, identification of the most promising potential remediation methods is categorized by COC group. Multiple scales of application may be useful for the overall remediation efforts in the 200-ZP-1 Operable Unit. For this reason, identification of the most promising potential remediation methods is also categorized by the scales of application identified in the effectiveness evaluation criteria (Table 5.1). Using this matrix of most promising potential remediation methods provides information to support either use of a single remedy or a "treatment train" approach as part of the feasibility study. Table 8.1 lists the potential remediation methods recommended for further assessment in the subsequent feasibility study as a function of both COC group and scale of application.

Table 8.1. Summary of Potential Remediation Methods Recommended for Further Assessment for Each COC Grouping Based on the Results of the Screening Evaluation

Target	COC Group 1	COC Group 2	COC Group 3	COC Group 4
Continuing Source (<1 acre) (areal extent over thickness of plume defined in Section 2)	• Pump-and-Treat • MNA • Chemical Oxidation (carbon tetrachloride) • Surfactant Flushing (carbon tetrachloride) • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • Aerobic Bioremediation (trichlorethene) • Thermal Treatment (carbon tetrachloride) • In-Well Air Stripping • ISRM as a PRB • Air Sparging	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • ISRM as a PRB (except I-129) • Injectable Apatite (U) • Polyphosphate (U) • Injectable Apatite Barrier (U) • Polyphosphate Barrier (U)	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • ISRM as a PRB	• P&T • MNA
High Concentrations (<5 acres) (areal extent over thickness of plume defined in Section 2)	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • Aerobic Bioremediation (trichlorethene) • In-Well Air Stripping • ISRM as a PRB • Air Sparging	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • ISRM as a PRB (except I-129) • Injectable Apatite (U) • Polyphosphate (U) • Injectable Apatite Barrier (U) • Polyphosphate Barrier (uranium)	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • ISRM as a PRB	• P&T • MNA
Low or High Concentrations (25 acres) (areal extent over thickness of plume defined in Section 2)	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • Aerobic Bioremediation (trichlorethene) • In-Well Air Stripping • ISRM as a PRB	• Pump-and-Treat • MNA • Anaerobic Bioremediation • Anaerobic Bioremediation as a PRB • ISRM as a PRB (except I-129)	• Pump-and-Treat • MNA • Anaerobic Bioremediation as a PRB • ISRM as a PRB	• P&T • MNA
Low Concentrations (250 acres or greater) (areal extent over thickness of plume defined in Section 2)	• Pump-and-Treat • MNA • Anaerobic Bioremediation as a PRB • ISRM as a PRB	• Pump-and-Treat • MNA • Anaerobic Bioremediation as a PRB • ISRM as a PRB (except I-129)	• Pump-and-Treat • MNA • Anaerobic Bioremediation as a PRB • ISRM as a PRB	• P&T • MNA

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APPENDIX G

ALTERNATIVES TO USING GRANULAR ACTIVATED CARBON TO TREAT 200-ZP-1 GROUNDWATER AND 200-PW-1 SOIL VAPOR (SGW-34467)

The document included in this appendix was published as SGW-34467 and is included here as an appendix for the convenience of the reader.

NOTE: The title on the cover page of the document erroneously states "100-ZP-1," where it should read "200-ZP-1."

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Revision 0

Alternatives to Using Granular Activated Carbon to Treat 200-ZP-1 Groundwater and 200-PW-1 Soil Vapor

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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TABLE OF CONTENTS

1.0 INTRODUCTION 1-1
1.1 BACKGROUND INFORMATION 1-1
1.2 RADIOLOGICAL CONTAMINANTS 1-4
2.0 IDENTIFICATION OF ALTERNATIVE TREATMENT OPTIONS 2-1
2.1 TREATMENT ALTERNATIVES THAT CONTINUE TO USE GRANULATED ACTIVATED CARBON 2-1
2.2 TREATMENT ALTERNATIVES THAT REPLACE GRANULAR ACTIVATED CARBON 2-3
2.3 ALTERNATIVES THAT REPLACE AIR STRIPPING 2-3
2.4 TREATMENT TECHNOLOGIES SCREENED OUT FROM EVALUATION 2-3
3.0 EVALUATION OF ALTERNATIVE TREATMENT OPTIONS 3-1
3.1 TREATMENT ALTERNATIVES THAT CONTINUE TO USE GRANULAR ACTIVATED CARBON 3-1
3.1.1 Installation of a Secondary Chiller Prior to Granular Activated Carbon 3-1
3.1.2 Installation of a High-Efficiency Particulate Air Filter Prior to Granular Activated Carbon 3-9
3.1.3 Using a Different Offsite Granular Activated Carbon Regeneration Facility 3-9
3.1.4 Disposal of Spent Granular Activated Carbon 3-9
3.1.5 Onsite Regeneration of Spent Granular Activated Carbon Using Steam 3-10
3.1.6 Onsite Regeneration of Spent Granular Activated Carbon Using Microwave Energy 3-10
3.2 TREATMENT ALTERNATIVES THAT REPLACE GRANULAR ACTIVATED CARBON 3-11
3.2.1 Sorbeum® Adsorbent 3-11
3.2.2 Rotary Concentrator with Thermal Oxidation 3-11
3.2.3 Catalytic (or Thermal) Oxidizer 3-11
3.3 ALTERNATIVES THAT REPLACE AIR STRIPPING 3-12
3.3.1 Liquid-Phase Granular Activated Carbon 3-12
3.3.2 Zero-Valent Iron 3-13
4.0 ALTERNATIVE TREATMENT OPTIONS RECOMMENDED FOR FURTHER EVALUATION 4-1
5.0 REFERENCES 5-1

FIGURES

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit. 1-2
Figure 1-2. External View of 200-ZP-1 Facility..... 1-3
Figure 1-3. 200-ZP-1 Granular Activated Carbon Canisters (Six Total Canisters)..... 1-3
Figure 1-4. 200-PW-1 Soil Vapor Extraction System. 1-5
Figure 1-5. 200-PW-1 Granular Activated Carbon Canisters (Two Used in Series)..... 1-5
Figure 2-1. 200-ZP-1 Pump-and-Treat Design Process Flow Diagram. 2-2

TABLES

Table 1-1. Radiological Contaminants of Concern, Maximum Granular Activated Carbon Sample Results, and Background Granular Activated Carbon Radioactivity. 1-6
Table 3-1. Alternative Treatment Technologies to Using Granular Activated Carbon – Pump-and-Treat System for Carbon Tetrachloride, 200-ZP-1 Operable Unit. (3 sheets) 3-3

LIST OF TERMS

COC	contaminant of concern
cfm	cubic feet per minute
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
ERDF	Environmental Restoration Disposal Facility
FH	Fluor Hanford, Inc.
GAC	granular activated carbon
gpm	gallons per minute
HEPA	high-efficiency particulate air
LDR	land-disposal restriction
MCL	maximum contaminant level
OU	operable unit
ppm	parts per million
SVE	soil vapor extraction
UTS	universal treatment standard
VOC	volatile organic compound
ZVI	zero-valent iron

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METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	millibecquerels	0.027	picocuries

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1.0 INTRODUCTION

This document presents an evaluation of alternative treatment options to granular activated carbon (GAC) for removing carbon tetrachloride generated from the groundwater pump-and-treat system at the 200-ZP-1 Operable Unit (OU) in the 200 West Area of the Hanford Site. This evaluation of alternative treatment options to GAC is also applicable to the vadose zone soil vapor extraction (SVE) system at the 200-PW-1 OU, which is also located in the 200 West Area of the Hanford Site.

1.1 BACKGROUND INFORMATION

The 200-ZP-1 OU is one of two groundwater OUs located within the 200 West groundwater aggregate area of the Hanford Site. The location of the 200-ZP-1 OU is shown in Figure 1-1. The 200-ZP-1 OU groundwater underlies Z Plant, T Plant, Low-Level Waste Management Areas 3 and 4, T Tank Farm, TX-TY Tank Farms, the State-Approved Land Disposal Site, and various cribs and trenches that formerly received liquid and solid waste as part of past waste disposal practices.

A pump-and-treat system for the 200-ZP-1 OU was implemented in 1995 in accordance with the *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit* (EPA et al. 1995). The groundwater pump-and-treat system is used to control the high-concentration portion of a carbon tetrachloride plume near the Plutonium Finishing Plant. This interim remedy is being implemented while groundwater characterization in support of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* remedial investigation/ feasibility study process is being completed within the OU. Other volatile organic contaminants of concern (COCs) within the 200-ZP-1 OU being remediated using this pump-and-treat system (other than carbon tetrachloride) include chloroform and trichloroethene.

Carbon tetrachloride and other volatile organic compounds (VOCs) are currently removed from groundwater through evaporative treatment (air stripping) and then removed from the vapor stream using GAC (DOE-RL 2006a). The photograph in Figure 1-2 shows a view of the 200-ZP-1 pump-and-treat facility, and the photograph in Figure 1-3 shows the GAC canisters inside the treatment building.

The 200-PW-1 OU waste sites, which overlie the 200-ZP-1 groundwater, received plutonium/ organic-rich liquid waste from Z Plant. Carbon tetrachloride was discharged primarily to three waste sites from 1955 through 1973: the 216-Z-9 Trench, the 216-Z-1A Tile Field, and the 216-Z-18 Crib. The SVE systems began operation in 1992 as an expedited response action (ERA) to extract carbon tetrachloride from the vadose zone in the 200-PW-1 OU (formerly designated as the 200-ZP-2 OU). The objective of the ERA, as stated in the *Action Memorandum: Expedited Response Action Proposal for 200 West Area Carbon Tetrachloride Plume* issued in January 1992 by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) is to mitigate the threat to site workers, public health, and the environment caused by the migration of carbon tetrachloride vapors through the soil column and into the groundwater (EPA and Ecology 1992). The ERA is an interim action taken to reduce the mass of carbon tetrachloride in the soil column beneath the 200 West Area pending final cleanup activities.

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit.

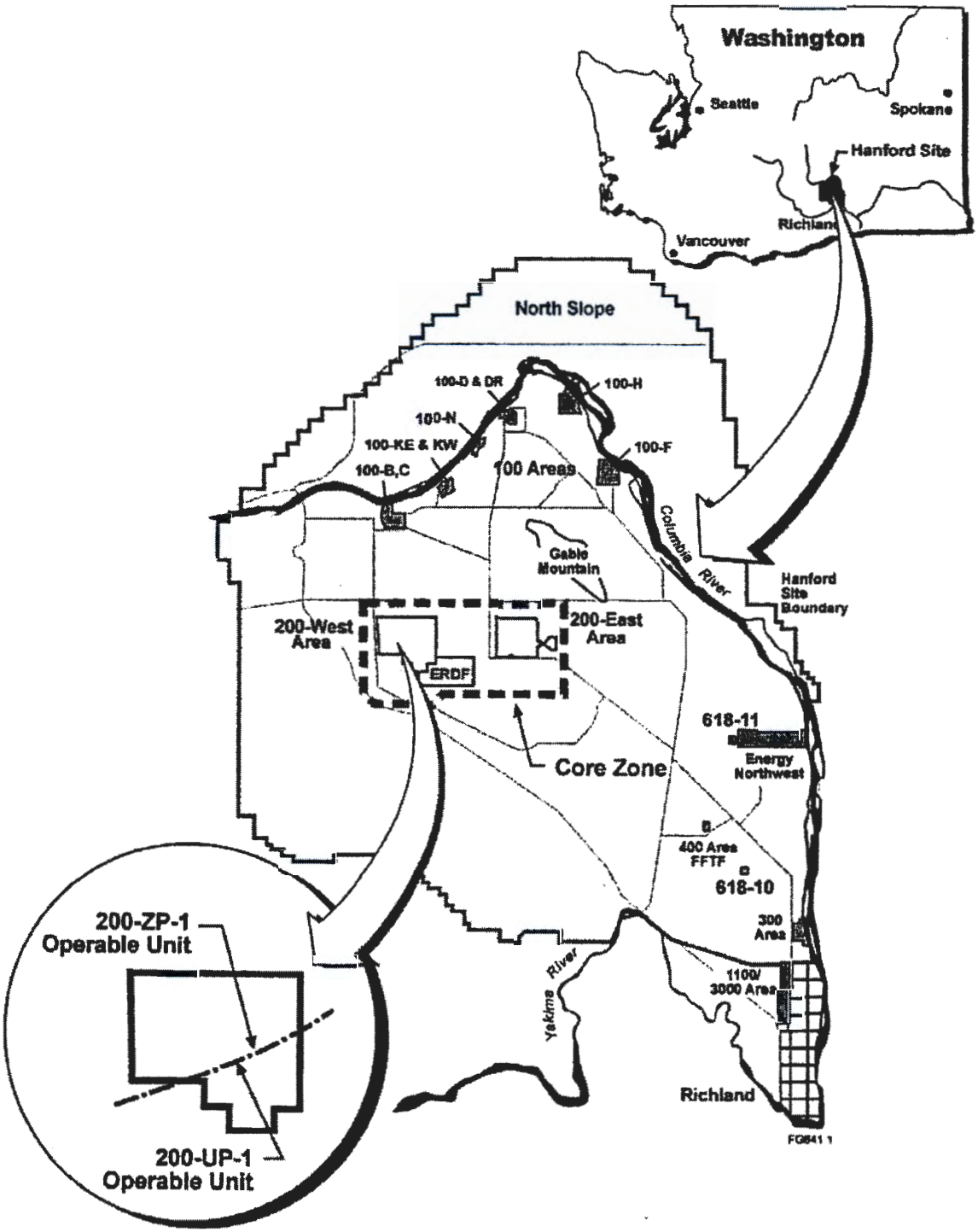


Figure 1-2. External View of 200-ZP-1 Facility.

Figure 1-3. 200-ZP-1 Granular Activated Carbon Canisters (Six Total Canisters).

The 200-PW-1 SVE system includes GAC canisters to remove carbon tetrachloride from the extracted vapors prior to discharge (FH 2006). The photograph in Figure 1-4 shows the 200-PW-1 SVE system, and the photograph in Figure 1-5 shows the GAC canisters.

The scope of this evaluation of alternative treatment options to GAC was limited to the 200-ZP-1 OU, but the alternative treatment options evaluated here (with the exception of the groundwater treatment alternatives) would also be applicable for use at the 200-PW-1 OU.

Until recently, the GAC canisters for the 200-ZP-1 and 200-PW-1 systems were shipped offsite to be regenerated when they became loaded with carbon tetrachloride. The GAC had been sent to a regeneration facility located in Parker, Arizona, which is operated by U.S. Filter Corporation, a subsidiary of Siemens Water Technologies Corporation. Fluor Hanford, Inc. (FH) had been sending spent GAC vessels for offsite regeneration at the rate of approximately 26 vessels per year. However, at this time FH is no longer able to ship these canisters offsite for regeneration due to the detection of trace levels of radiation in the GAC canisters. As a result, other options needed to be evaluated for removing carbon tetrachloride from air coming from the 200-ZP-1 OU stripping tower and the 200-PW-1 OU SVE system.

1.2 RADIOLOGICAL CONTAMINANTS

The radiological contaminants were previously described in *Authorized Limit Request for the Regeneration of Granular Activated Carbon at 200-ZP-1 and 200-PW-1 Pump-and-Treat Operations* (FH 2007). A summary of the radiological contaminants discussed in that document is provided in this section.

Prior to construction of the carbon tetrachloride SVE system, a study was performed to determine the potential for the GAC to become radiologically contaminated. It concluded that there is little chance of outside transport, via vapor extraction, of plutonium-239, plutonium-240, and americium-241 in the volatile state or associated with particulates (IM 81223-91-003). This has been the basis for the design and operation of the 200-PW-1 and 200-ZP-1 OU facilities (DOE-RL 1991).

In addition to the potential radiological contaminants introduced to the GAC from SVE and pump-and-treat operations, the background contamination of the GAC (either as new or regenerated GAC) is also a consideration. Analysis results from a few samples of new and regenerated GAC indicated detectable levels of uranium and thorium.

The radiological contaminants, the maximum results from samples of loaded GAC, and the background (i.e., baseline) GAC radiological testing results are presented in Table 1-1 (which was taken from FH [2007]). As indicated in Table 1-1, the detected uranium and thorium-232 in background (unused) GAC samples were 60% to 80% of the maximum sample results from the used GAC samples.

Figure 1-4. 200-PW-1 Soil Vapor Extraction System.

Figure 1-5. 200-PW-1 Granular Activated Carbon Canisters (Two Used in Series).

Table 1-1. Radiological Contaminants of Concern, Maximum Granular Activated Carbon Sample Results, and Background Granular Activated Carbon Radioactivity.

200-ZP-1[a]	200-PW-1[a]	Maximum Sample Results (pCi/g)	Background Activity (pCi/g)
	Am-241	ND (1)[e]	---
C-14	C-14	ND (50)[e]	---
Cs-137	Cs-137	ND (1)[e]	ND (0.02)[e]
	Co-60	ND (1)[e]	---
	Europium isotopes (Eu-152, -154, -155)	ND (1)[e]	---
I-129	I-129	ND (2)[e]	---
Np-237	Np-237	**0.065**	---
	Plutonium isotopes (Pu-238, -239, -240)	**0.003 (Pu-238), 0.081 (Pu-239/240)**	---
Pa-231		**0.356**	---
Se-79[b]		ND (10)[e]	---
Sr-90	Sr-90	ND (10)[e]	---
Tc-99	Tc-99	ND (15)[e]	---
	Th-232[c]	**0.372**	**0.239**[f]
	Th-230	—	ND (0.2)[e]
	Th-228	—	**0.219**
	Pb-210	—	ND (0.4)[e]
H-3	H-3	**127.0**	---
Uranium, total (U-238, U-235, and U-234[d])	Uranium, total (U-238, U-235, and U-234[d])	**0.641 mg/kg**[g]	**0.504 mg/kg**[g]
Gross alpha		---	ND (2.4)[e]
Gross beta		---	ND (4)[e]

[a] Obtained from DOE/RL-2006-54, *Sampling and Analysis Instruction for Characterization of 200-ZP-1 and 200-ZP-2 Spent Granulated Activated Carbon And Filter Elements*, Table 1-2 for 200-ZP-1 and Table 1-4 for 200-PW-1 (DOE-RL 2006b).
[b] Se-79 is difficult to analyze. If Cs-137 is detected, Se-79 concentrations will conservatively be assumed to be the same.
[c] Progeny included in the analysis.
[d] Short-lived progeny included in the analysis.
[e] Parameter not detected; value listed is the reporting limit value from DOE/RL-2006-54 (DOE-RL 2006b).
[f] Average of three samples.
[g] To convert mg/kg to pCi/g, multiply mg/kg by 0.7.
ND = parameter not detected
--- = not tested or data not available

2.0 IDENTIFICATION OF ALTERNATIVE TREATMENT OPTIONS

A wide variety of alternative treatment options to GAC were evaluated for use at the 200-ZP-1 pump-and-treat system. The main categories of treatment alternatives that were considered for evaluation included (1) treatment alternatives that continue to use vapor-phase GAC, (2) treatment alternatives that eliminate the use of vapor-phase GAC and treat the vapor stream from the air stripper in another manner, and (3) treatment alternatives that replace both the air stripper and the vapor-phase GAC and treat the groundwater in another manner. As previously stated, with the exception of the treatment alternatives that replace the air stripper, these treatment alternatives also apply to SVE operations at the 200-PW-1 OU.

Specific treatment alternatives that were selected for evaluation are discussed in the following subsections. Discussion is also provided regarding some of the treatment technologies that were screened out from further consideration.

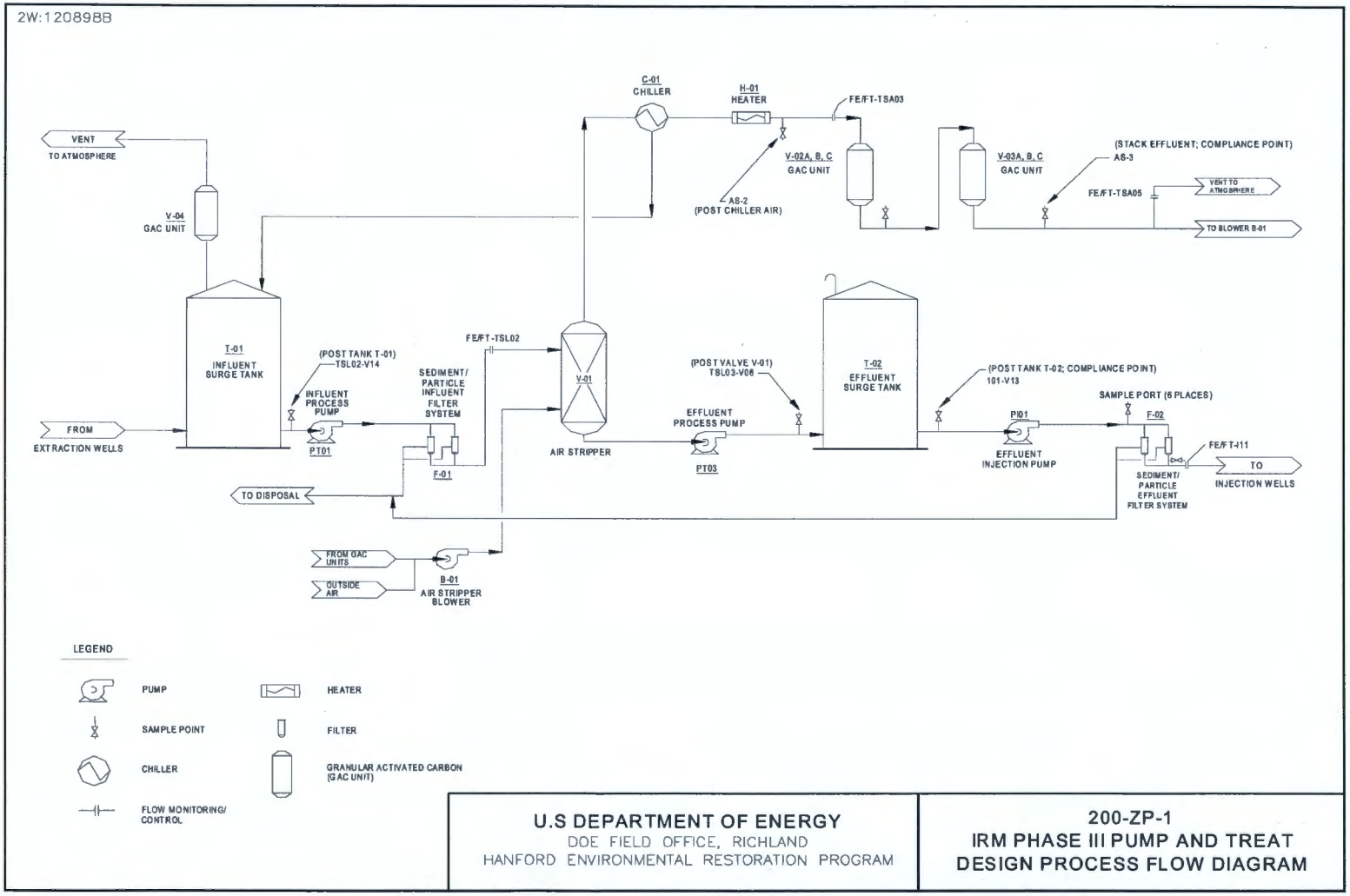
2.1 TREATMENT ALTERNATIVES THAT CONTINUE TO USE GRANULATED ACTIVATED CARBON

Treatment alternatives were identified that could continue to use GAC, and these alternatives would have the advantage of minimizing the amount of alteration to the existing groundwater treatment system. The alternative treatment options that were identified for evaluation that continue to use GAC include the following:

- Adding a second chiller/condenser: The addition of a second chiller/condenser after the air stripper and prior to GAC (see Figure 2-1) could further remove entrained water droplets and reduce relative humidity that may be carrying radioactivity to the GAC.
- Installing a high-efficiency particulate air (HEPA) filter: The installation of a HEPA filter on the vapor stream prior to GAC could, similar to the second chiller, also act to prevent radioactive material from collecting on the GAC. The HEPA filter would act to remove particles that may carry radioactive nuclides.
- Using a different GAC regeneration facility: Investigate the existence of a facility other than the Parker facility in Arizona for reactivating the spent GAC that has acceptance criteria for (or does not have the same restrictions from) accepting trace levels of radioactivity.
- Disposing spent GAC: Investigate the viability of removing GAC from service prior to accumulation of carbon tetrachloride at a concentration greater than the land disposal restriction (LDR) and then disposing the spent GAC at the Hanford Site's Environmental Restoration Disposal Facility (ERDF).
- Regenerating spent GAC onsite using steam: The regeneration of spent GAC onsite using steam would eliminate the need to ship the material offsite.
- Regenerating spent GAC onsite using microwave energy: The regeneration of spent GAC onsite using microwave technology would be similar to onsite regeneration using steam and would eliminate the need to ship the material offsite.

These alternative treatment options are described in more detail and evaluated in Section 3.0.

Figure 2-1. 200-ZP-1 Pump-and-Treat Design Process Flow Diagram.



2.2 TREATMENT ALTERNATIVES THAT REPLACE GRANULAR ACTIVATED CARBON

Treatment alternatives were identified that would continue to use the air stripper to transfer VOCs from the groundwater into a vapor stream but would replace GAC with another treatment technology to remove or destroy the VOCs from the vapor stream. These alternatives are listed below.

- Sorbeum® adsorbent: This proprietary adsorbent has been developed and tested at bench scale to have a higher adsorption capacity for VOCs compared to GAC. The Sorbeum can be regenerated onsite using pressurized steam.
- Rotary concentrator: Vapors pass through an adsorption rotor that collects and concentrates the VOCs. The concentrated contaminants are destroyed through a subsequent regenerative thermal oxidizer.
- Catalytic (or thermal) oxidizer: With this treatment alternative, the VOCs are destroyed by reaction with oxygen at a high temperature. Catalytic oxidizers use a catalyst for the oxidation reaction to occur at a lower temperature.

There would be no waste solid material that would need to be routinely managed or disposed with these three identified treatment alternatives. The use of the Sorbeum adsorbent would generate a liquid carbon tetrachloride waste stream, and the used adsorbent at the end of the project would need to be disposed.

2.3 ALTERNATIVES THAT REPLACE AIR STRIPPING

With the consideration of potentially making major changes to current operation of the pump-and-treat system, treatment alternatives were also identified that would eliminate the use of both the air stripper and the vapor-phase GAC. Elimination of the air stripper would save the cost of operating the blower, chiller, and air stream heater. These treatment alternatives are listed below:

- Treatment of groundwater by liquid-phase GAC: This alternative would involve processing the groundwater directly through liquid-phase GAC to remove VOCs. Process options would be similar to vapor-phase GAC and include offsite regeneration, onsite steam regeneration, and onsite disposal to ERDF.
- Treatment of groundwater by zero-valent iron (ZVI): The treatment of groundwater using granular ZVI would cause reductive dechlorination of chlorinated VOCs and would be performed using aboveground reaction vessels.

2.4 TREATMENT TECHNOLOGIES SCREENED OUT FROM EVALUATION

Other potential treatment technologies may be applicable to some of the COCs at the Hanford Site but were screened out from further evaluation due to readily apparent deficiencies. Those technologies and their deficiencies for this particular application are listed below:

Sorbeum® is a registered trademark in Bratislava, Slovak Republic.

- Ion exchange: Ion exchange would be applicable to the removal of technetium-99 or other ionic COCs but is not applicable to carbon tetrachloride.
- Absorptive resin: This technology was previously developed for adsorption of VOCs from groundwater or soil vapor. However, vendors of this technology no longer appear to be in the marketplace, likely due to the high costs relative to GAC. No documented full-scale applications for chlorinated VOCs were identified within the last 10 years in a literature search on this technology.
- Reverse osmosis: This technology results in high capital and operations and maintenance costs compared to other available treatment alternatives. Also, a high-concentration liquid waste stream is generated with this technology, which would require further treatment/disposal.
- Anaerobic bioreactor: This technology would be considered experimental for the treatment of carbon tetrachloride due to the lack of available pilot- or full-scale studies. The technology could not be quickly implemented because a pilot study and custom equipment would be required.
- Advanced oxidation: Oxidation of carbon tetrachloride, even by strong oxidants, has relatively slow-reaction kinetics and would require excessive energy use.

These technologies have been screened out from further evaluation and are not discussed in Section 3.0.

3.0 EVALUATION OF ALTERNATIVE TREATMENT OPTIONS

The alternative treatment options to using GAC identified in Section 2.0 were evaluated with respect to the criteria of effectiveness, technical implementability, administrative implementability, potential exposure of workers to radioactivity, estimated capital cost, and estimated operating costs. The evaluation matrix of the treatment alternatives versus these criteria is presented in Table 3-1.

As a basis for comparing all of the alternative treatment options, the pump-and-treat system operational conditions were used based on recent system operation. The assumed operational parameters are as follows:

- Average groundwater extraction flow rate = 270 gallons per minute (gpm)
- Average influent carbon tetrachloride concentration in groundwater = 1,600 µg/L
- Air (vapor) flow rate through the air stripper = 800 cubic feet per minute (cfm).

Summary descriptions of the evaluations of the identified treatment alternatives versus the evaluation criteria are provided in the following subsections.

3.1 TREATMENT ALTERNATIVES THAT CONTINUE TO USE GRANULAR ACTIVATED CARBON

The evaluations of the treatment alternatives that would continue to use the air stripper and vapor-phase GAC for groundwater treatment are discussed below.

3.1.1 Installation of a Secondary Chiller Prior to Granular Activated Carbon

With the exception of tritium, the radioactive elements listed in Table 1-1 are not considered to be volatile compounds that would transfer from groundwater into the vapor phase; thus, it was not expected that the GAC would be impacted by radioactivity. However, it may be that particles or small water droplets are being entrained in the air stripper vapor stream, are not being removed in the existing chiller/condenser, and are, thus, depositing onto the GAC. Within the past year, there have been problems with operation of the chiller.

Adding a secondary or backup in-line chiller would improve separation of water from the vapor stream exiting the air stripper. Enhanced removal of water droplets and reduction of humidity that potentially contain radioactive material would help to prevent radioactivity from passing through to the GAC vessels. Implementing a secondary chiller would be a viable option, as sufficient space within the treatment system building is expected to be available and costs are expected to be relatively low to moderate. This alternative may have greater administrative implementability relative to the other alternatives because it does not alter the general design basis of the initial treatment system. However, it cannot be determined with available information whether this alternative would be capable of eliminating sources of radioactivity to the GAC to below detection limits, which is what would be required currently to allow offsite transport and regeneration. A second chiller/condenser could be added to the system and run on a trial basis for relatively low capital cost. If successful, the added electrical power and maintenance cost of running the second chiller is also expected to be relatively low.

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Table 3-1. Alternative Treatment Technologies to Using Granular Activated Carbon – Pump-and-Treat System for Carbon Tetrachloride, 200-ZP-1 Operable Unit. (3 sheets)

Primary Treatment Technology	Process Option	Secondary Process Option	Description	Evaluation Criteria						Continue Evaluation ?
				Effectiveness[b]	Implementability		Exposure to Workers	Estimated Cost[c]		
					Technical	Administrative		Capital Costs	Operating Costs	
Air Stripping	**Vapor-phase GAC**	Use of a **secondary chiller** (and/or possibly a desiccant) to improve liquid separation from the vapor stream exiting the air stripper and to minimize or prevent radioactivity from passing through to the GAC.	This option could involve installation of a secondary or backup in-line chiller (and/or possible additional controls/alarms) to be more certain of removal of 100% entrained water droplets and a majority of the water vapor to minimize or eliminate pass through of radioactivity to the GAC.	**HIGH** (excluding tritium), **MODERATE** (tritium). Removal of entrained water droplets should be effective at removing all radioactivity, except that from tritium. To the degree that relative humidity can be reduced to near zero, tritium would also be removed from the vapor stream.	**MODERATE TO HIGH.** It is expected that there is adequate space within the treatment system building to add a larger or second chiller or to add a desiccant system.	**MODERATE.** No significant change to treatment system design basis, therefore easier to obtain regulatory acceptance. However, given historical detection of radioactivity, more extensive sampling of spent carbon for radioactive materials may be required.	No net change to worker exposure, with the exception of possible more frequent sampling of spent GAC.	**LOW TO MODERATE.** Depends on the temperature drop desired (the size of the chiller) and the ability to fit the chiller within existing ducting and the building.	**LOW TO MODERATE.** Depends on the temperature drop desired (the size of the chiller).	**Yes**
		Use of a **HEPA filter** to improve particulate separation from the vapor stream exiting the air stripper and to minimize or prevent radioactivity from passing through to the GAC.	Install a HEPA filter after the air stream chiller for enhanced removal of particles from vapor stream to minimize or prevent radioactivity from passing through to the GAC. HEPA filters are specifically designed for the collection of submicron particulates at high collection efficiencies and are commonly used for removal of radioactive particulates.	**MODERATE TO HIGH.** HEPA filters can theoretically remove up to 99.97% of 0.3 micron airborne particles, with even higher removal efficiency (99.999%) for </= 0.1 micron particles at higher flow rates (Note 1). However, has not been demonstrated for this specific type of application.	**HIGH.** The HEPA filters are available in various sizes that could fit within the treatment building. Standard units can handle flow rates up to 2,000 cfm (Note 1).	**MODERATE.** No significant change to treatment system design basis, therefore easier regulatory acceptance. Spent filters would need to be disposed as radioactive waste to ERDF. More extensive sampling of spent GAC for radioactivity may be required.	Increased exposure to radioactive material on spent filters during filter maintenance and changeout activities.	**LOW.** HEPA filters are readily available at low cost (Note 1).	**LOW TO MODERATE.** Depends on life of filter used in system operating conditions. Replacement frequency may be high and result in added costs for filters, maintenance labor, and disposal of spent filters.	**Yes**
		Regeneration of spent GAC at a different offsite facility, or offsite incineration.	Use another offsite regeneration facility (e.g., Calgon in Pennsylvania or Kentucky).	**HIGH.** Facility would utilize similar thermal regeneration process as the Siemens facility in Parker, Arizona.	**HIGH.** Handling and transport of GAC would be as previously performed.	**LOW.** Facility representatives indicated failure of acceptance criteria or did not confirm (Note 2).	No net change.	**LOW.** No new equipment.	No net change.	**No**
		Removal and land disposal of GAC before carbon tetrachloride concentration reaches the LDR.	This option would involve removing spent GAC well prior to saturation of carbon tetrachloride and disposing spent GAC to ERDF. The LDR for carbon tetrachloride is the UTS and is 6.0 mg/kg.	**LOW.** The large mass of GAC that would be required to be changed out daily and the frequency of changeout would not be practical.	**LOW.** Preliminary evaluation of GAC loading rate indicates disposal frequency of approximately one vessel (2,000 lb) every 5 minutes (Note 3).	**MODERATE.** If blending of high- and low-concentration GAC is acceptable to the regulators than implementable. But if blending is not allowed, then there would be a problem with disposal of GAC that inadvertently becomes greater than LDR.	Greatly increased onsite handling of GAC.	**HIGH.** High capital cost due to the large number and size of GAC vessels that would be required to prevent daily breakthrough.	**HIGH.** Estimated disposal frequency would require approximately 576,000 lb of fresh GAC per day (Note 3).	**No**
		Onsite steam regeneration of the vapor-phase GAC	A manually activated batch process would be employed using a new boiler to produce steam. Regenerative carbon adsorption systems use multiple vessels for switching between adsorption and regeneration modes. One system vendor indicates that two main skids would each be approx. 8 ft wide by 12 ft long by 12 ft high, plus additional space necessary for boiler.	**HIGH.** Onsite regeneration of GAC not typical due to higher cost than offsite regeneration, but full-scale projects have demonstrated effectiveness in removing VOCs similar to carbon tetrachloride from carbon and allowing reuse. GAC can be regenerated for many years, but GAC at the end of the project would need to be put through a kiln before it would meet the LDR (UTS = 6 mg/kg).	**HIGH.** Pre-packaged carbon regeneration systems do not appear to be available. However, a steam-regeneration system could be custom designed and constructed in 4 months (Note 4). Expected to meet applicable numeric air emission limitations. A previous preliminary estimate for time for design and construction was approximately 24 months (FH 2007).	**MODERATE.** Radioactive constituents are not expected in the concentrated carbon tetrachloride liquid because those constituents should remain in the aqueous phase and be removed from the liquid carbon tetrachloride. Estimated that three 55-gal drums could be shipped offsite for incineration each year. Modification to vapor treatment process requires regulatory review/approval.	Typically no exposure to spent carbon because steam regeneration takes place inside adsorption unit. Limited handling of concentrated carbon tetrachloride liquid from the regeneration process.	**MODERATE TO HIGH.** Equipment cost for a four-vessel GAC steam-regeneration system is estimated at $900,000 (Note 4).	**MODERATE.** Batch steam regeneration three times per week, requiring low amounts of steam (1,600 lb/hr) (Note 4). Transportation and incineration of generated liquid carbon tetrachloride estimated to cost approximately $2,000/yr (Note 5).	**Yes**

Table 3-1. Alternative Treatment Technologies to Using Granular Activated Carbon – Pump-and-Treat System for Carbon Tetrachloride, 200-ZP-1 Operable Unit. (3 sheets)

Primary Treatment Technology	Process Option	Secondary Process Option	Description	Evaluation Criteria						Continue Evaluation ?
				Effectiveness[b]	Implementability		Exposure to Workers	Estimated Cost[c]		
					Technical	Administrative		Capital Costs	Operating Costs	
Air Stripping (continued)	**Vapor-phase GAC** (continued)	**Onsite regeneration** of the vapor-phase GAC using **microwave technology.**	Microwave regeneration technology is designed to capture and recover chlorinated and non-chlorinated VOCs from spent GAC. A fully automated system, including an adsorber vessel, microwave reactor, and recovered solvents condenser, would replace the GAC vessels currently being used. Saturated carbon from the vapor treatment system would be automatically conveyed from the adsorption vessel to a microwave reactor for reactivation. The reactivated carbon would then be automatically returned to the adsorption vessel for continued use. Solvent vapors would be recovered in a two-stage condenser using nitrogen as a total recycle sweep gas.	**MODERATE to HIGH.** A pilot study performed at McClellan Air Force Base using microwave regeneration technology indicated removal efficiencies for adsorbed solvents of 96% to 99.5%, varying with applied microwave power (Note 6). The microwave reactivating unit used at McClellan included two 25-kg/hr microwave generators to regenerate carbon at an overall rate of 50 kg/hr. This technology has only been used in pilot studies, but full-scale applications are underway.	**MODERATE to HIGH.** The system is compact enough to mount onto a trailer, but there may not be enough clearance inside the treatment system building to accommodate the height of the top feed hopper for the microwave reactor. If there is not enough vertical clearance, then the microwave GAC reactivation system would have to be implemented outside the treatment building. Unknown if spare electrical power is available for the 3 kW microwave unit.	**LOW TO MODERATE.** Concentrated liquid carbon tetrachloride from the microwave reactivation system condenser would need to be shipped offsite for incineration, assuming the concentrated carbon tetrachloride liquid would be adequately free of radioactivity.	Typically no exposure to spent GAC because reactivation system is fully automated with pneumatic conveyor to transport spent GAC to the top feed hopper. Limited handling of carbon tetrachloride liquid from the regeneration process.	**MODERATE.** Estimated capital cost of an installed 50-kg/hr microwave onsite reactivation system is $300,000 (Note 6).	**LOW.** Total carbon reactivation cost is $0.60/kg for the CHA Corporation's integrated 50-kg/hr system (Note 6). Transportation and disposal (incineration) of liquid carbon tetrachloride from the system is estimated to be $1,500 to $2,000/yr (Note 5).	**No** (Note 7)
	Use of **Sorbeum® adsorbent** in place of vapor-phase GAC	Onsite steam regeneration of the Sorbeum®, with offsite treatment/ disposal of concentrated carbon tetrachloride liquid waste.	Sorbeum, an adsorptive medium that contains a combination of carbon and other elements, could be placed in treatment vessels similar to granular activated carbon. Sorbeum weighs 100 times less than carbon and can adsorb approximately 2,000% by weight of carbon tetrachloride (20 g carbon tetrachloride per gram of Sorbeum). Can be regenerated using pressurized steam to recover adsorbed contaminants.	**LOW to HIGH.** Has 2,000% (by weight) adsorption capacity for carbon tetrachloride based on vendor's laboratory testing (Note 8). However, no documentation of previous full-scale similar application. Pilot testing would be required to verify effectiveness.	**LOW TO MODERATE.** Media is shipped from Slovakia. Vessels can be manufactured locally. Regeneration requires hot steam generator, cooling water source, and storage barrels for recovered carbon tetrachloride. Pilot testing would be required to verify performance because only bench-scale testing data are available.	**LOW TO MODERATE.** The concentrated liquid carbon tetrachloride waste stream would need to be shipped offsite for incineration, assuming that the concentrated carbon tetrachloride liquid would be adequately free of radioactivity.	Possible onsite handling of Sorbeum when disposal is necessary.	**MODERATE to HIGH.** Estimated $5,000 for Sorbeum media shipped from Slovakia. The major cost is for vessels, steam boiler, and controls. System may be smaller than for onsite GAC regeneration but still likely >$400,000 (Note 8).	**MODERATE?.** Regeneration frequency estimated to be only once per year by vendor (Note 8). Operational costs would primarily be for steam generation; however, no documentation of O&M costs available. Transportation and incineration of generated liquid carbon tetrachloride is approximately $2,000/yr (Note 5).	**No**
	Rotary concentrator	Regenerative thermal oxidizer for destruction of concentrated carbon tetrachloride, with acid gas scrubber.	Vapors pass through an adsorption rotor that collects and concentrates contaminants. The concentrated contaminants are destroyed through a subsequent regenerative oxidizer (see Thermal Treatment of Vapor Stream description below).	**LOW.** There is limited information available regarding the removal efficiency of carbon tetrachloride to low or nondetect concentrations using this technology.	**LOW.** Concentrator systems are not readily available for the current system's flow rate and VOC vapor concentrations. Systems are designed for higher flow rates (>>1,000 cfm) and higher solvent concentrations (Note 9).	**MODERATE.** No increase in air emissions expected; but because of the treatment system design change, regulatory review and approval would be required.	No increase in exposure expected. Eliminates handling of GAC. Scrubber would prevent discharge of radioactive material to air.	**HIGH.** Would require engineering, design, custom fabrication, and high equipment costs (Note 9).	**HIGH.** Regenerative thermal oxidizer would require high energy use.	**No**
	Thermal treatment of vapor stream	**Thermal or catalytic oxidation**, with acid gas scrubber.	VOCs are destroyed by reaction with oxygen at high temperature. Catalytic oxidizers use a catalyst for the oxidation reaction to occur at a lower temperature (900°F). A scrubber using treated groundwater would remove acid gas generated.	**HIGH.** >99% destruction efficiency of carbon tetrachloride can be achieved. Acid gas created can be removed by scrubber. Catalyst life is 3 to 5 years.	**MODERATE TO HIGH.** Catalytic oxidizer and scrubber system can be produced in approximately 2 months. Would require installation of propane tank(s) and weekly trucked delivery, if natural gas is not available (Note 10).	**MODERATE.** Would maintain the same carbon tetrachloride removal effectiveness, but modification of the vapor treatment process would require regulatory review and approval.	No increase in exposure expected. Eliminates handling of GAC. Scrubber would prevent discharge of radioactive material to air.	**MODERATE.** Estimated capital cost for 800 scfm CatOx system with scrubber and propane storage tank(s) is approximately $250,000 (Note 10).	**MODERATE.** Estimated $100,000/yr for propane and electricity (Note 10), plus replace catalyst bed every 3 to 5 years. Eliminates need for GAC.	**Yes**

Table 3-1. Alternative Treatment Technologies to Using Granular Activated Carbon – Pump-and-Treat System for Carbon Tetrachloride, 200-ZP-1 Operable Unit. (3 sheets)

Primary Treatment Technology	Process Option	Secondary Process Option	Description	Evaluation Criteria						Continue Evaluation ?
				Effectiveness[b]	Implementability		Exposure to Workers	Estimated Cost[c]		
					Technical	Administrative		Capital Costs	Operating Costs	
Liquid - Phase GAC	Offsite regeneration	N/A	*(Screened out because expected to collect even more radioactive material than vapor-phase GAC.)*	**LOW.** Same expected issue with radioactivity.						**No**
	Onsite steam regeneration		*(Screened out as having no better effectiveness that onsite regeneration of vapor-phase carbon and requiring more effort to redesign the treatment system.)*							**No**
	Onsite disposal to ERDF	Remove lead liquid-phase carbon vessel from service before carbon tetrachloride concentration reaches the LDR (UTS = 6.0 mg/kg).	Removal of liquid-phase GAC prior to reaching the LDR value is the same as described above for vapor-phase GAC, but there is added benefit in reduction of power costs (i.e., no blower, chiller, or heater needed).	Liquid-phase GAC is typically less efficient (i.e., fewer grams contaminant adsorbed per gram of GAC) than vapor phase. The early removal of GAC would require higher usage of GAC.	**LOW.** Required disposal frequency (within every hour) would pose difficulties with implementing this option (Note 3).	**MODERATE to HIGH.** If blending of high-concentration and low-concentration GAC is acceptable to the regulators, then readily implementable. But if blending is not allowed, then there would be a problem with disposal of GAC that inadvertently becomes > LDR.	Increased onsite handling of GAC.	**HIGH.** High capital cost due to the large number and size of GAC vessels that would be required to prevent daily breakthrough.	**HIGH.** Estimated disposal frequency would require high daily volume of fresh GAC (approximately 576,000 lb) (Note 3).	**No**
Ex Situ Use of Zero-Valent Iron (ZVI)	Use of liquid-phase reaction vessels, similar to GAC	Long-term use followed by disposal at ERDF.	Iron filings could be placed in treatment vessels similar to GAC. ZVI provides electrons and can reduce and dechlorinate contaminants by direct electron transfer from the metal Fe(0) --> Fe(II) or by transfer from corroded (dissolved) iron Fe(II) --> Fe(III); or reaction with water from the anaerobic corrosion of Fe(II) if an effective catalyst is present.	**LOW.** Slow reaction time. A large amount of iron filings is required for a small flow rate (144 tons per 5 gpm). Process generates dichloromethane. Longevity of iron filings prior to complete surface oxidation is not fully known.	**LOW.** Current system flow of 270 gpm would require 8,000 tons of iron filings for the system. ZVI also generates 180 µg/L residual dichloromethane, which is above the 5 µg/L MCL and would require secondary treatment system (Note 11). Assume disposal of spent iron with low radioactivity to ERDF.	**MODERATE.** Does not absorb carbon tetrachloride, so land disposal would not be an issue.	Infrequent removal and disposal of spent iron filings.	**HIGH.** To meet current system operating parameters, estimated cost is >$5.5 million (Note 11).	**HIGH.** High cost to replace spent iron filings (approximately $700/ton), although changeout frequency is unknown. Additional operating costs for treatment of dichloromethane (Note 11).	**No**

Notes:

1. Technical effectiveness and cost data include the following sources: www.filt-air.com/Resources/Articles/hepa/hepa_filters.aspx; www.hss.energy.gov/csa/csp/hepa; www.wynnenv.com/hepa_filters.htm.
2. Information for alternative offsite regeneration or incineration facilities included communications with Troy York of Calgon Corporation, Jim Beck of Clean Harbors, and John Hagan of Perma-Fix Environmental Services.
3. Evaluation of GAC-loading rate and required disposal frequency based system information provided by Kent Hodgson of Fluor Hanford, Inc. (via e-mail communication). Loading rate estimated using groundwater carbon tetrachloride concentration of 1,600 µg/l, groundwater flow rate of 270 gpm to air stripper, vapor flow rate of 800 cfm through air stripper, and current carbon usage rate of approximately 20 GAC vessels (2,000 lb each) per year (from *Authorized Limit Request for the Regeneration of Granular Activated Carbon at 200-ZP-1 and 200-PW-1 Pump-and-Treat Operations*, FH-0602994.1 [FH 2007]). Required disposal frequency for this option estimated based on estimated carbon tetrachloride loading rate, weight of GAC per vessel, and LDR of 6 mg/kg (FH 2007).
4. Information for onsite steam-regeneration technology was obtained through communications with Joe Enders of Enders Process Equipment Corporation. Costs estimated based on Quotation E-2268-1 from Enders. It was previously estimated that the start-up cost for onsite regeneration would be $2 to $5 million, and the annual operational cost for regeneration of 54 canisters/yr would be $500,000 to $1 million (FH 2007).
5. Costs for offsite incineration of concentrated liquid carbon tetrachloride based on Clean Harbors Quote #460366.
6. Technical information and costs for microwave reactivation technology are from SBRP Research Brief 149, "Microwave Technology for Granular Activated Carbon Regeneration," documenting the technology developed and tested by Dr. Chang Yul Cha of CHA Corporation.
7. Even though cost data from the vendor indicate that microwave regeneration technology may have potential cost savings over steam regeneration, the lack of independently published effectiveness and cost data indicates that consideration of the technology on a full-scale site is premature.
8. Sorbeum® information was obtained through communications with Richard Weiss of Weiss Associates and included documentation of laboratory research performed by the Slovakian manufacturing company.
9. Rotary concentrator information was obtained through communications with Jim Stone of Durr Environmental.
10. Technical information and costs for catalytic oxidation system were provided by Keith Herbert of Catalytic Combustion Corporation. Operating costs were estimated based on power and fuel requirements for operating a halogenated destruction catalytic oxidizer (HD-CAT, Model SRCO 500G).
11. Technical information and costs for zero-valent iron technology was obtained through communications with Andrzej Przepiora, M.Sc. of EnviroMetal Technologies, Inc.

cfm = cubic feet per meter
ERDF = Environmental Restoration Disposal Facility
GAC = granular activated carbon
gpm = gallons per minute
HEPA = high-efficiency particulate air
LDR = land disposal restriction
MCL = maximum contaminant level
N/A = not applicable
O&M = operations and maintenance
UTS = universal treatment standard
VOC = volatile organic compound

3.1.2 Installation of a High-Efficiency Particulate Air Filter Prior to Granular Activated Carbon

Adding a HEPA filter to the air stream from the air stripper after the chiller would remove small particulates, including submicron particles from vapors exiting the air stripper. This filtration would be expected to enhance the removal of radioactive material from the vapor stream and may prevent radioactivity from passing through to the GAC vessels. The existing chiller and heater units would still be employed to reduce the relative humidity of the vapor stream for VOC removal efficiency by the GAC and to prevent the HEPA filters from getting wet, which could negatively affect the filtration effectiveness. The HEPA filters are commonly used in the nuclear power industry for removing radioactive particulates. They are highly effective at removing particles less than 0.3 microns in size (see Table 3-1 for details) and can accommodate flows up to 2,000 cfm. It cannot be determined from available information whether this alternative would be capable of eliminating all sources of radioactivity to the GAC to below detection limits, which is what would be required currently to allow offsite transport and regeneration. There is concern, especially for tritium (with a small radius of less than a nanometer), that unless it is complexed with a much larger molecule or sorbed onto particulates, it would not be removed with a HEPA filter, and that the HEPA filter would not prevent loading onto the GAC to below detection limits.

Implementing a HEPA filter can be readily achieved due to ease of availability and relatively low cost. As with installation of a second chiller, this alternative has good administrative implementability relative to the other alternatives because it does not alter the general design basis of the initial treatment system. The filters would need to be periodically replaced, so there would be some increase in exposure to system operation and maintenance personnel. The need to dispose the spent filter units would add to the system operation costs, but the filters would not be expected to retain detectable levels of VOCs and could be disposed at ERDF without concern of exceeding the LDR for carbon tetrachloride.

3.1.3 Using a Different Offsite Granular Activated Carbon Regeneration Facility

It is of interest to investigate the possible existence of another offsite facility, other than the Parker facility in Arizona, for reactivating the spent GAC. The offsite facility would need to have acceptance criteria for (or not have the same restrictions from) accepting GAC with trace levels of radioactivity. There are other carbon regeneration facilities in other states (e.g., Calgon Carbon facilities in Kentucky and Pennsylvania), and representatives from these other facilities were contacted to discuss regeneration of the GAC from the Hanford Site. In addition, representatives from facilities that perform incineration were contacted to discuss the possibility of incinerating the GAC and then disposing the incinerated GAC, even though this option would be a significantly higher cost than regenerating the GAC.

Unfortunately, the various facilities either had explicit restrictions on accepting material with higher-than-background radiation, or they could not provide confirmation of their ability to accept the waste profile of the GAC from the Hanford Site.

3.1.4 Disposal of Spent Granular Activated Carbon

One spent GAC management option that was investigated was the viability of removing the GAC from service prior to accumulation of carbon tetrachloride at a concentration greater than the LDR. The spent GAC could then be disposed at ERDF. However, using the carbon

tetrachloride loading rate calculated from the operating parameters of the treatment system (previously provided) and using the results of spent GAC analysis, it was determined that the GAC saturation carbon tetrachloride concentration is so much higher than the LDR (the universal treatment standard [UTS] is 6.0 mg/kg) that removal of GAC prior to exceeding the LDR would be too frequent to be practical. For example, preliminary evaluation of premature removal of GAC vessels from service to limit carbon tetrachloride concentration to below the 6.0 mg/kg LDR indicates that one 2,000-lb vessel would have to be taken off-line approximately every 5 minutes. The high frequency of removal/disposal for this option would not only be extremely costly, but it would also greatly increase exposure to workers due to significantly increased handling of spent GAC.

3.1.5 Onsite Regeneration of Spent Granular Activated Carbon Using Steam

The regeneration of spent GAC onsite using steam would eliminate the need to ship the material offsite. For this treatment option, a manually activated batch process would be employed using a new boiler to produce steam. Regenerative carbon adsorption systems use multiple vessels for switching between adsorption and regeneration modes. Steam regeneration of the GAC would produce concentrated carbon tetrachloride liquid, as well as waste water containing some dissolved constituents. The wastewater would be pumped back to the air stripper for treatment, and the liquid carbon tetrachloride would be collected and stored in drums prior to offsite disposal, recycling, or incineration. The estimated space required to implement this alternative would need to accommodate at least two equipment skids (approximately 8 ft wide by 12 ft long by 12 ft high) for the adsorption/regeneration carbon vessels and would require enough space for the boiler and liquid collection tanks.

Steam regeneration is expected to be effective in removing carbon tetrachloride and other VOCs from the spent GAC to allow for continued re-use in the system for many years. There is fairly high confidence in the performance of this technology because it has been implemented at other full-scale groundwater pump-and-treat systems. A steam-regeneration system could be installed at the site in less than 6 months. The use of steam-regenerated GAC would still be expected to achieve nondetect concentrations of VOCs in the air emissions, but because this process would be a change in the treatment system design, it is expected that lead regulatory agency approval would be needed prior to implementation. This alternative would not increase the exposure of workers to the GAC because the steam-regeneration process occurs within the GAC vessels without the need for physical transfer; however, there would be occasional handling of drums containing the concentrated carbon tetrachloride liquid. The capital cost of this alternative is estimated to be relatively moderate to high, and the operating cost is estimated to be moderate.

3.1.6 Onsite Regeneration of Spent Granular Activated Carbon Using Microwave Energy

The regeneration of spent GAC onsite using microwave radiation would be similar to onsite regeneration using steam and would eliminate the need to ship spent GAC offsite. The main differences between the two regeneration technologies include the level of development of the technology and the estimated cost. There is considered to be a higher level of risk in implementing microwave regeneration compared to steam regeneration. The higher risk is due, in part, to the fact that only one pilot-scale test of the technology has been performed at the former McClellan Air Force Base (CHA Corporation 2006). The lower degree of certainty in this technology is also due to the fact that the only estimated cost data are provided by the vendor

of the technology. There does not appear to be any independently published data on performance, reliability, and cost of this technology.

3.2 TREATMENT ALTERNATIVES THAT REPLACE GRANULAR ACTIVATED CARBON

The treatment alternatives that were identified for evaluation that would continue to use the air stripper but would replace the GAC with another vapor treatment process included the use of a proprietary adsorbent (e.g., Sorbeum), the use of a rotary concentrator with thermal oxidation, or the direct thermal destruction of the VOCs in the vapor stream using a catalytic or thermal oxidizer. The evaluation matrix of these treatment alternatives versus these criteria is presented in Table 3-1, and a summary of the evaluation is provided below.

3.2.1 Sorbeum® Adsorbent

This proprietary adsorbent has been developed and bench-scale tested to have a higher adsorption capacity for VOCs compared to GAC. The Sorbeum can be regenerated onsite using a new boiler and pressurized steam. The vendor of this adsorbent claims a 2,000% by weight adsorption capacity for carbon tetrachloride based on their laboratory testing, which is a significantly higher adsorption capacity compared to GAC. The higher adsorption capacity would reduce the frequency of steam regeneration and/or the size of the steam boiler required. However, the capital cost for the steam-regeneration system is still estimated to be moderate to high compared to other treatment alternatives. In addition, due to the lack of available independently published performance data for the Sorbeum adsorbent, there is a significantly lower degree of confidence in this treatment alternative versus the demonstrated technology of onsite steam regeneration of GAC.

3.2.2 Rotary Concentrator with Thermal Oxidation

A rotary concentrator system would involve passing the air stripper effluent vapor through an adsorption rotor that collects and concentrates VOCs. The concentrated contaminants are then destroyed through a subsequent thermal oxidizer, which is typically a regenerative-type thermal oxidizer. Because thermal destruction of the contaminants would produce an acid gas (HCl), a scrubber would need to be used to remove the acid gas.

There is limited information regarding the removal efficiency of carbon tetrachloride using this technology. The information available for this type of system suggests that it is typically used for much higher air flow rates than the 800 cfm air stripper flow rate, and it is used for much higher VOC concentrations than the roughly 10 parts per million (ppm) concentration of carbon tetrachloride in the air stripper vapor. Standard pre-packaged systems of this type are not commercially available, and the need for custom system engineering design and fabrication contributes to the high estimated relative cost for a rotary concentrator system for this application.

3.2.3 Catalytic (or Thermal) Oxidizer

With this treatment alternative, the VOCs in the vapor from the air stripper would be destroyed by reaction with oxygen at high temperature. Catalytic oxidizers use a catalyst for the oxidation reaction to occur at a lower temperature (approximately 900°F) versus thermal oxidation. Due to the significant savings in fuel costs, it is assumed that a catalytic oxidizer would be selected over

a thermal oxidizer. The destruction efficiency for carbon tetrachloride and other VOCs is typically very high (>99%) with the selection of the correct-size unit for the application. Oxidation of chlorinated VOCs (e.g., carbon tetrachloride) generates acid gases (HCl), so the oxidation system would need to be provided with a gas scrubber system. The scrubber would consist of spraying a water stream (in this case, treated groundwater) through the oxidized vapor stream to absorb the acid gas. The water used for scrubbing may then need to be pH-adjusted using a small amount of caustic prior to discharge. The oxidizer would require a fuel source, and because natural gas is not available at this location, the fuel would likely be provided by a propane tank(s) with routine propane delivery by truck.

Catalytic oxidation has been well demonstrated at the full-scale level, multiple vendors of the technology are available, and standard pre-packaged systems are available of the size that would be necessary for the 200-ZP-1 system. The capital and operating costs are considered to be moderate relative to other alternatives, with the cost of a catalytic oxidation system estimated at approximately $250,000 and the annual propane and electricity cost estimated at $100,000. In addition, it is expected that the catalyst bed of the oxidizer would need to be replaced approximately every 3 to 5 years due to the exposure to acid gasses.

3.3 ALTERNATIVES THAT REPLACE AIR STRIPPING

Two treatment alternatives were evaluated that would replace air stripping and treat the groundwater directly. These two alternatives are liquid-phase GAC and zero-valent iron (ZVI). An evaluation of these two treatment alternatives is presented in Table 3-1 and is summarized below.

3.3.1 Liquid-Phase Granular Activated Carbon

Liquid-phase GAC would be used to treat the groundwater directly to remove the VOCs rather than transferring the VOCs to a vapor stream for removal. For the option of offsite regeneration of the spent liquid-phase GAC, it was determined that the spent liquid-phase GAC was not likely to have a lower level of radioactivity than the vapor-phase GAC. Even though the vapor-phase GAC has a higher adsorptive capacity for VOCs and is, therefore, left on-line longer than liquid-phase GAC, the level of radioactivity in the groundwater is significantly higher than in the air stripper vapor stream. Therefore, the use of liquid-phase GAC would not eliminate the problem of trace-level radioactivity. In fact, the level of radioactivity would be expected to be higher on the spent liquid-phase GAC, which would only add to the current problem regarding offsite regeneration.

The use of liquid-phase GAC with onsite steam regeneration would eliminate the operating costs of the air stripper blower, chiller, and heater. However, that cost savings is not estimated to be large enough to offset the cost of the more significant system redesign and the increased steam requirements for carbon regeneration.

Using liquid-phase carbon with onsite disposal to the ERDF was also considered. However, similar to the conclusions of disposal to ERDF for the vapor-phase carbon, an unreasonable frequency of vessel replacements and the large volume and cost of GAC that would be required to avoid exceeding the LDR concentration of 6.0 mg/kg cause this option to be an unreasonable treatment alternative.

3.3.2 Zero-Valent Iron

The use of ZVI would involve the placement of iron filings into vessels similar to the way GAC is employed for treatment of impacted groundwater. However, rather than adsorbing the VOCs, the ZVI process dechlorinates the contaminants by electron transfer. The ZVI technology would require a significantly large amount of iron filings to treat even a low-flow rate. For example, an estimated approximate 144 tons of granular iron would be required for each 5 gpm of flow (see Table 3-1). Therefore, for the current system flow rate, ZVI treatment would require at least 8,000 tons of iron at an estimated capital cost of more than $5.5 million. The ZVI process would also result in generation of dichloromethane at a concentration that would require a secondary treatment system. Another potential problem with this technology is that the surface of the iron filings may become oxidized over time and require either regeneration or replacement, and adequate data are not available for ex situ ZVI case studies to accurately quantify the regeneration or replacement frequency.

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4.0 ALTERNATIVE TREATMENT OPTIONS RECOMMENDED FOR FURTHER EVALUATION

Based on the results of the evaluation presented in Section 3.0 and in Table 3-1, a number of the initially identified alternative treatment options were deemed to be unsuitable for continued evaluation, as is indicated in the final column of Table 3-1. The alternative treatment options that are recommended to be evaluated in greater detail for potential use at the 200-ZP-1 pump-and-treat system, and also for the 200-PW-1 SVE system, are as follows:

- Use of a second or larger chiller/condenser on the vapor stream prior to GAC
- Use of a HEPA filter on the vapor stream prior to GAC
- Onsite steam regeneration of vapor-phase GAC
- Replacement of the GAC vessels with a catalytic oxidizer.

The detailed evaluation should better define the effectiveness, implementability, capital cost, and operating costs of these treatment alternatives.

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APPENDIX H

DETAILED ANALYSIS OF THE MOST PROMISING ALTERNATIVES TO USING GRANULAR ACTIVATED CARBON TO TREAT 200-ZP-1 GROUNDWATER AND 200-PW-1 SOIL VAPOR (SGW-35663)

The document included in this appendix was published as SGW-35663 and is included here as an appendix for the convenience of the reader.

SGW-35663
Revision 0

Detailed Analysis of the Most Promising Alternatives to Using Granular Activated Carbon to Treat 200-ZP-1 Groundwater and 200-PW-1 Soil Vapor

Prepared for the U.S. Department of Energy
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Revision 0

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TABLE OF CONTENTS

1.0 INTRODUCTION 1-1

1.1 BACKGROUND INFORMATION 1-1

1.2 RADIOLOGICAL CONTAMINANTS 1-2

2.0 IDENTIFICATION OF ALTERNATIVE TREATMENT OPTIONS 2-1

3.0 EVALUATION OF ALTERNATIVE TREATMENT OPTIONS 3-1

3.1 INSTALLATION OF A HIGH-EFFICIENCY PARTICULATE AIR FILTER PRIOR TO GRANULAR ACTIVATED CARBON 3-1

3.1.1 General Technology Evaluation 3-2
3.1.2 Required Modifications to the Existing Treatment System 3-2
3.1.3 Required Modifications to Existing System Controls 3-3
3.1.4 Required Modifications to System Operation and Maintenance 3-3
3.1.5 Wastes Generated 3-3
3.1.6 Potential Releases to Air 3-3
3.1.7 Life Expectancy of Technology 3-4
3.1.8 Estimated Capital and Annual Operating Costs 3-4

3.2 INSTALLATION OF A LARGER CHILLER/CONDENSER PRIOR TO GRANULAR ACTIVATED CARBON 3-4

3.2.1 General Technology Evaluation 3-5
3.2.2 Required Modifications to Existing Treatment System 3-5
3.2.3 Required Modifications to Existing System Controls 3-5
3.2.4 Required Modifications to System Operation and Maintenance 3-5
3.2.5 Wastes Generated 3-5
3.2.6 Potential Releases to Air 3-6
3.2.7 Life Expectancy of Technology 3-6
3.2.8 Estimated Capital and Annual Operating Costs 3-6

3.3 ONSITE REGENERATION OF SPENT GRANULAR ACTIVATED CARBON USING STEAM 3-6

3.3.1 General Technology Evaluation 3-6
3.3.2 Required Modifications to Existing Treatment System 3-7
3.3.3 Required Modifications to Existing System Controls 3-8
3.3.4 Required Modifications to System Operation and Maintenance 3-8
3.3.5 Wastes Generated 3-8
3.3.6 Potential Releases to Air 3-9
3.3.7 Life Expectancy of Technology 3-9
3.3.8 Estimated Capital and Annual Operating Costs 3-9

3.4 CATALYTIC OXIDATION 3-9

3.4.1 General Technology Evaluation 3-10
3.4.2 Required Modifications to Existing Treatment System 3-10
3.4.3 Required Modifications to Existing System Controls 3-11

3.4.4 Required Modifications to System Operation and Maintenance 3-11
3.4.5 Wastes Generated 3-11
3.4.6 Potential Releases to Air 3-12
3.4.7 Life Expectancy of Technology 3-12
3.4.8 Estimated Capital and Annual Operating Costs 3-12

4.0 CONCLUSIONS AND RECOMMENDATIONS 4-1

5.0 REFERENCES 5-1

FIGURES

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit. 1-4
Figure 1-2. External View of 200-ZP-1 Facility 1-5
Figure 1-3. 200-ZP-1 Granular Activated Carbon Canisters (Total of Six Canisters). 1-5
Figure 1-4. Existing Pump-and-Treat system, 200-ZP-1 Site Plan. 1-6
Figure 1-5. Existing Pump-and-Treat System, 200-ZP-1 Process Flow Diagram. 1-7
Figure 1-6. 200-PW-1 Soil Vapor Extraction System. 1-8
Figure 1-7. 200-PW-1 Granular Activated Carbon Canisters (Two Used in Series) 1-8
Figure 3-1. Pump-and-Treat System with Larger Chiller/Condenser, 200-ZP-1 Site Plan. 3-13
Figure 3-2. Pump-and-Treat System with Larger Chiller/Condenser, 200-ZP-1 Process Flow Diagram. 3-14
Figure 3-3. Pump-and-Treat System with High-Efficiency Particulate Air Filters, 200-ZP-1 Site Plan. 3-15
Figure 3-4. Pump-and-Treat system with High-Efficiency Particulate Air Filters, 200-ZP-1 Process Flow Diagram. 3-16
Figure 3-5. Pump-and-Treat System with Regenerative Carbon, 200-ZP-1 Site Plan. 3-17
Figure 3-6. Pump-and-Treat System with Regenerative Carbon, 200-ZP-1 Process Flow Diagram 3-18
Figure 3-7. Pump-and-Treat System with Catalytic Oxidizer, 200-ZP-1 Site Plan 3-19
Figure 3-8. Pump-and-Treat System with Catalytic Oxidizer, 200-ZP-1 Process Flow Diagram 3-20

TABLES

Table 1-1. Radiological Contaminants of Concern, Maximum Granular Activated Carbon Sample Results, and Background Granular Activated Carbon Radioactivity. 1-9
Table 3-1. Estimated Cost for High-Efficiency Particulate Air Filtration at 200-ZP-1. (2 sheets) 3-21
Table 3-2. Estimated Cost for Larger Chiller/Condenser at 200-ZP-1. (2 sheets) 3-23
Table 3-3. Estimated Cost for Onsite Steam Regeneration of Granular Activated Carbon at 200-ZP-1. (2 sheets) 3-25
Table 3-4. Estimated Cost for Catalytic Oxidization at 200-ZP-1. (2 sheets) 3-27

LIST OF TERMS

COC	contaminant of concern
cfm	cubic feet per minute
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
FH	Fluor Hanford, Inc.
GAC	granular activated carbon
gpm	gallons per minute
HEPA	high-efficiency particulate air
NRC	U.S. Nuclear Regulatory Commission
O&M	operations and maintenance
OU	operable unit
ppm	parts per million
SVE	soil vapor extraction
VOC	volatile organic compound

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METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	millibecquerels	0.027	picocuries

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1.0 INTRODUCTION

This document presents a detailed evaluation of selected alternative treatment options to granular activated carbon (GAC) for removing carbon tetrachloride generated from the groundwater pump-and-treat system at the 200-ZP-1 Operable Unit (OU) in the 200 West Area of the Hanford Site. This evaluation of alternative treatment options to GAC is also applicable to the vadose zone soil vapor extraction (SVE) system at the 200-PW-1 OU, which is also located in the Hanford Site's 200 West Area.

1.1 BACKGROUND INFORMATION

The 200-ZP-1 OU is one of two groundwater OUs located within the 200 West groundwater aggregate area of the Hanford Site. The location of the 200-ZP-1 OU is shown in Figure 1-1. The 200-ZP-1 OU groundwater underlies Z Plant, T Plant, Low-Level Waste Management Areas 3 and 4, 241-T Tank Farm, 241-TX/TY Tank Farms, the State-Approved Land Disposal Site, and various cribs and trenches that formerly received liquid and solid waste as part of past waste disposal practices.

A pump-and-treat system for the 200-ZP-1 OU was implemented in 1995 in accordance with the *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit* (EPA et al. 1995). The groundwater pump-and-treat system is used to control the high-concentration portion of a carbon tetrachloride plume near the Plutonium Finishing Plant. This interim remedy is being implemented while groundwater characterization in support of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* remedial investigation/ feasibility study process is being completed within the OU. Other volatile organic contaminants of concern (COCs) within the 200-ZP-1 OU being remediated using the pump-and-treat system (besides carbon tetrachloride) are chloroform and trichloroethylene.

Carbon tetrachloride and other volatile organic compounds (VOCs) are removed from groundwater through evaporative treatment (air stripping) and are then removed from the vapor stream using GAC (*Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit* [DOE/RL-2006-24]). A view of the 200-ZP-1 pump-and-treat facility is shown in Figure 1-2, and the GAC canisters inside the treatment building are shown in Figure 1-3. Figure 1-4 shows a facility plan of the 200-ZP-1 treatment building and equipment, and Figure 1-5 is a process flow diagram of the 200-ZP-1 pump-and-treat system.

The 200-PW-1 OU waste sites that overlie the 200-ZP-1 groundwater received plutonium/ organic-rich liquid waste from Z Plant. Carbon tetrachloride was discharged primarily to three waste sites from 1955 through 1973: the 216-Z-9 Trench, the 216-Z-1A tile field, and the 216-Z-18 Crib. The SVE systems began operation in 1992 as an expedited response action (ERA) to extract carbon tetrachloride from the vadose zone in the 200-PW-1 OU (formerly designated as the 200-ZP-2 OU). The objective of the ERA, as stated in the *Action Memorandum: Expedited Response Action Proposal for 200 West Area Carbon Tetrachloride Plume* issued in January 1992 by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) (EPA and Ecology 1992) is to mitigate the threat to site workers, public health, and the environment caused by the migration of carbon tetrachloride vapors through the soil column and into the groundwater. The ERA is an interim

action taken to reduce the mass of carbon tetrachloride in the soil column beneath the 200 West Area pending final cleanup activities.

The 200-PW-1 SVE system includes GAC canisters to remove carbon tetrachloride from the extracted vapors prior to discharge (*Performance Evaluation Report for Soil Vapor Extraction Operations at 200-PW-1 Carbon Tetrachloride Site FY2005* [WMP-30426]). Figures 1-6 and 1-7, respectively, show the 200-PW-1 SVE system and the GAC canisters.

The scope of this evaluation of alternative treatment options to GAC was limited to the 200-ZP-1 OU, but the alternative treatment options evaluated here (with the exception of the groundwater treatment alternatives) would also be applicable for use at the 200-PW-1 OU.

Until recently, the GAC canisters for the 200-ZP-1 and 200-PW-1 systems were shipped offsite for regeneration when they became loaded with carbon tetrachloride. The GAC was sent to a regeneration facility located in Parker, Arizona, which is operated by U.S. Filter Corporation, a subsidiary of Siemens Water Technologies Corporation. Fluor Hanford, Inc. (FH) had been sending spent GAC vessels for offsite regeneration at the rate of approximately 26 vessels/year. However, recent detections of trace levels of radiation in the GAC canisters prompted the regeneration facility to temporarily stop accepting the canisters from FH for regeneration. As a result, other options needed to be evaluated for removing carbon tetrachloride from air coming from the 200-ZP-1 OU stripping tower and the 200-PW-1 OU SVE system. A preliminary evaluation of several treatment alternatives was conducted from which four alternatives were recommended for further assessment to determine effectiveness, implementability, cost, and other relevant factors.

In August 2007, during the final evaluation of recommended alternatives, the U.S. Department of Energy (DOE) received authorization from the U.S. Nuclear Regulatory Commission (NRC) to once again transport spent GAC from the 200-ZP-1 and 200-PW-1 systems for offsite regeneration at the facility in Parker, Arizona. Nevertheless, this evaluation of alternative treatment options to GAC was completed and may be useful for future reference if shipping the GAC to an offsite regeneration facility were again prohibited for some reason or for consideration of potential treatment technologies to be incorporated into the final site remedial action.

1.2 RADIOLOGICAL CONTAMINANTS

The radiological contaminants were described in a document that evaluated the potential levels of exposure, which was submitted to the NRC to seek approval for continued offsite regeneration of the GAC (*Authorized Limit Request for the Regeneration of Granular Activated Carbon at the 200-ZP-1 and 200-PW-2 Pump-and-Treat Operations* [FH-0602994.1]). A summary of the discussion of radiological contaminants in that document is provided in this section.

Prior to construction of the carbon tetrachloride SVE system, a study was performed to determine the potential for the GAC to become radiologically contaminated. The study concluded the following: "There is little chance of outside transport, via vapor extraction, of Pu-239, Pu-240, and Am-241 in the volatile state or associated with particulates" (IM 81223-91-003). This has been the basis for the design and operation of the 200-PW-1 and 200-ZP-1 OU facilities (*Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume* [DOE/RL-91-32]).

In addition to the potential radiological contaminants introduced to the GAC from the SVE and pump-and-treat operations, the background contamination of the GAC (either as new or regenerated GAC) is also a consideration. Analysis results from a few samples of new and regenerated GAC indicate detectable levels of uranium and thorium.

The radiological contaminants, the maximum results from samples of loaded GAC, and background (i.e., baseline) GAC radiological testing results are presented in Table 1-1. As indicated in Table 1-1, the detected uranium and thorium-232 in background (i.e., unused) GAC samples were 60% to 80% of the maximum sample results from the used GAC samples.

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit.

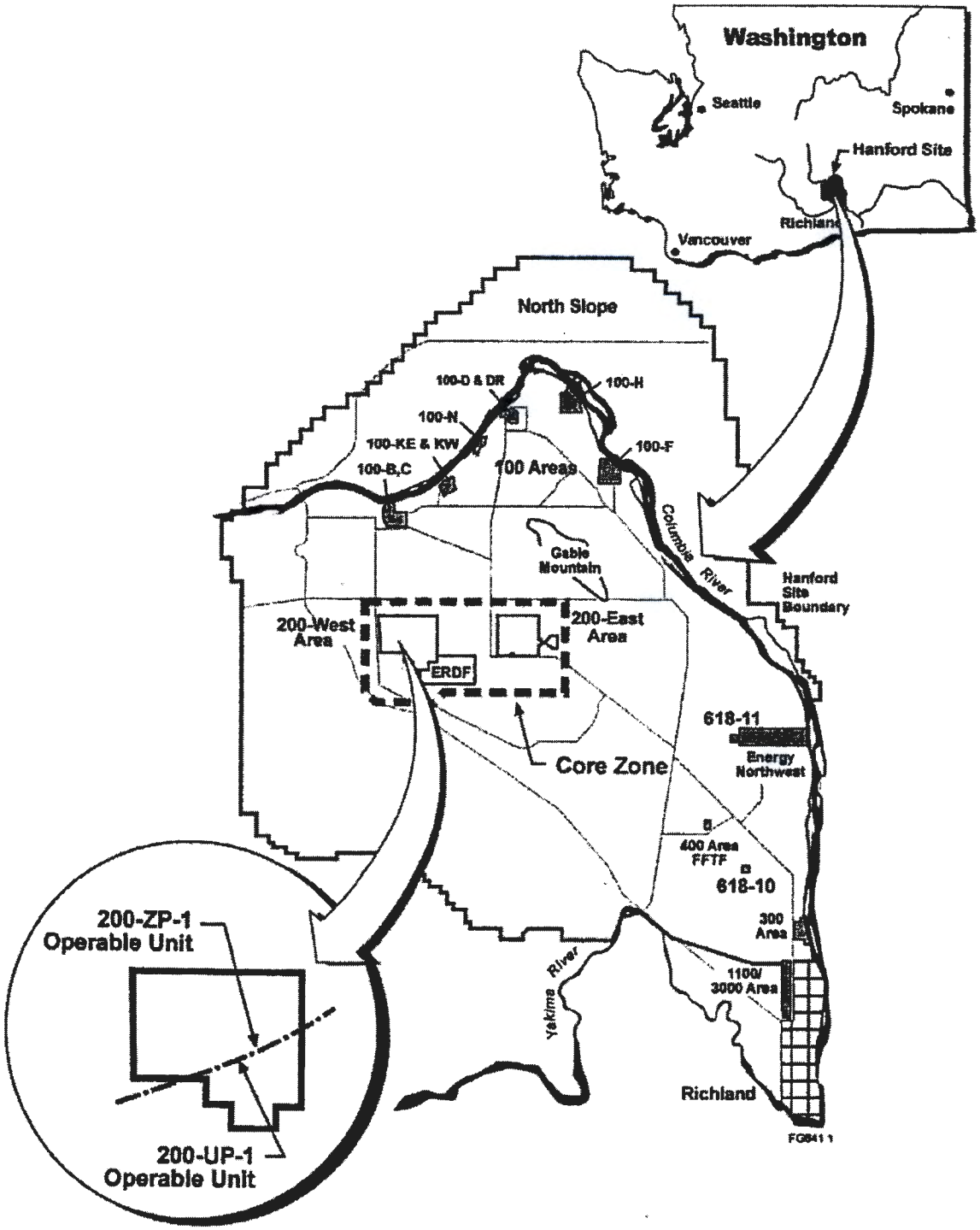

Figure 1-2. External View of 200-ZP-1 Facility.

Figure 1-3. 200-ZP-1 Granular Activated Carbon Canisters (Total of Six Canisters).

Figure 1-2. External View of 200-ZP-1 Facility.

Figure 1-3. 200-ZP-1 Granular Activated Carbon Canisters (Total of Six Canisters).

Figure 1-4. Existing Pump-and-Treat system, 200-ZP-1 Site Plan.

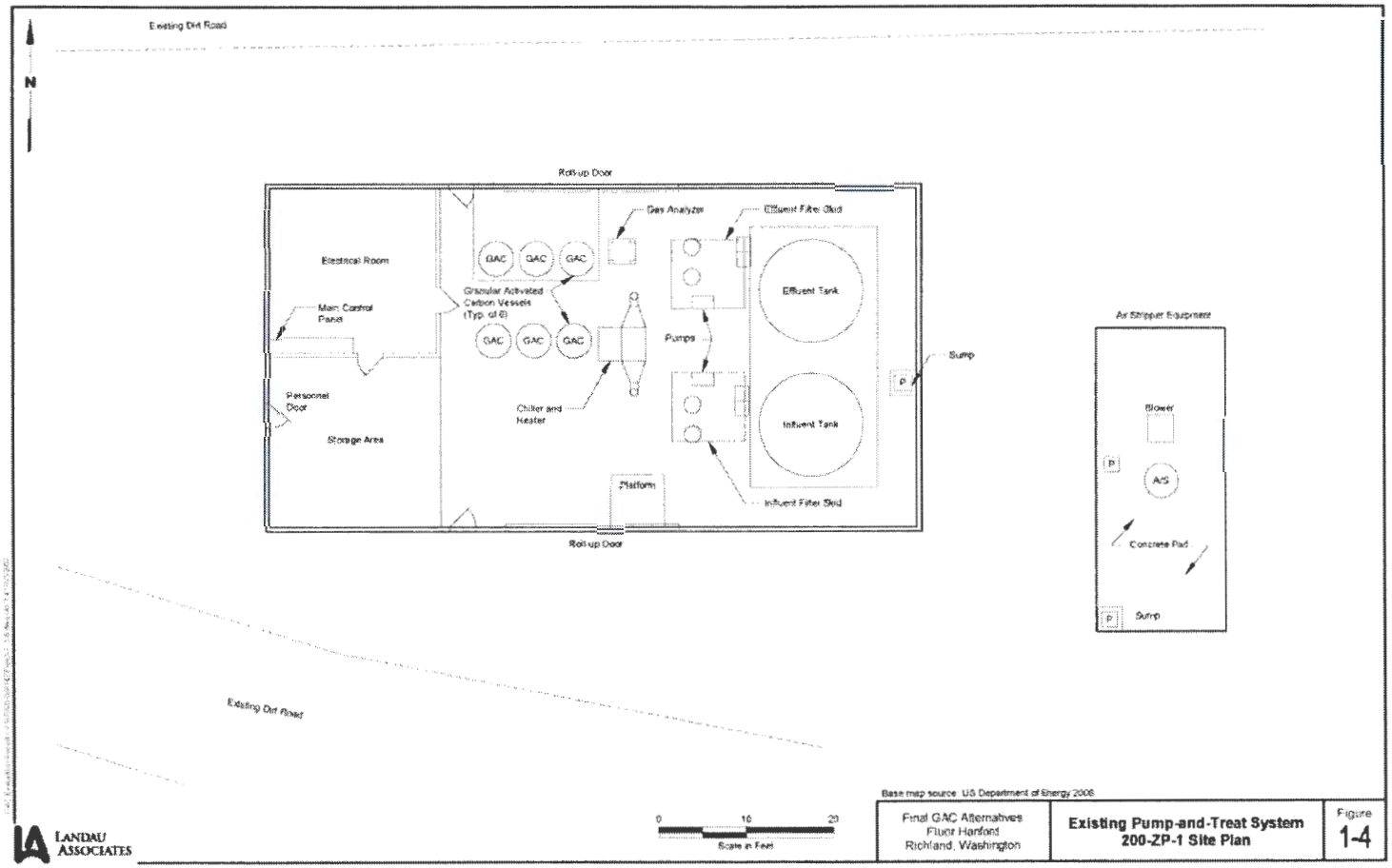

Figure 1-5. Existing Pump-and-Treat System, 200-ZP-1 Process Flow Diagram.

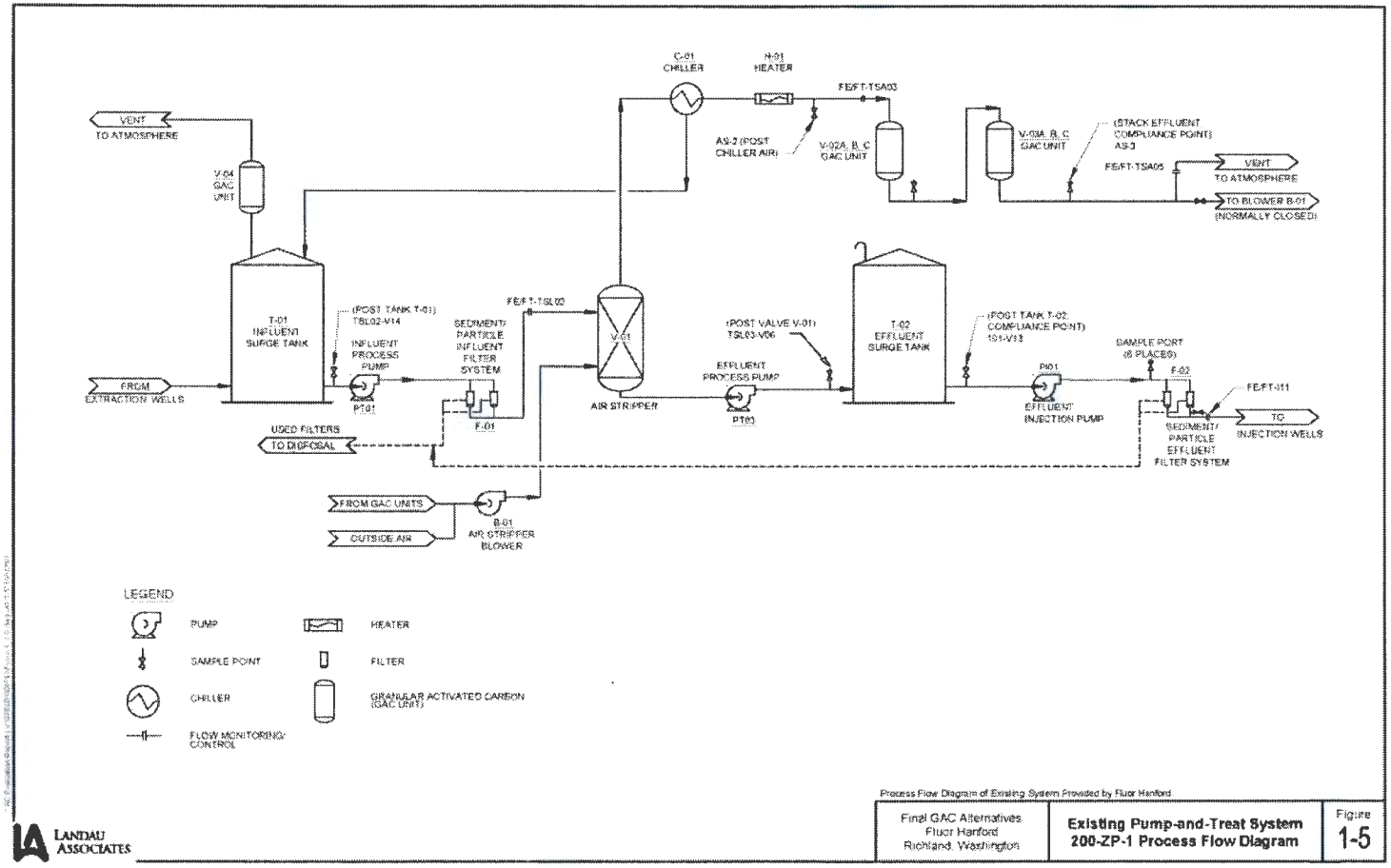

Figure 1-6. 200-PW-1 Soil Vapor Extraction System.

Figure 1-7. 200-PW-1 Granular Activated Carbon Canisters (Two Used in Series).

Table 1-1. Radiological Contaminants of Concern, Maximum Granular Activated Carbon Sample Results, and Background Granular Activated Carbon Radioactivity.

200-ZP-1[a]	200-PW-1[a]	Maximum Sample Results (pCi/g)	Background Activity (pCi/g)
	Am-241	ND (1)[e]	---
C-14	C-14	ND (50)[e]	---
Cs-137	Cs-137	ND (1)[e]	ND (0.02)[e]
	Co-60	ND (1)[e]	---
	Europium isotopes (Eu-152, -154, -155)	ND (1)[e]	---
I-129	I-129	ND (2)[e]	---
Np-237	Np-237	**0.065**	---
	Plutonium isotopes (Pu-238, -239, -240)	**0.003 (Pu-238), 0.081 (Pu-239/240)**	---
Pa-231		**0.356**	---
Se-79[b]		ND (10)[e]	---
Sr-90	Sr-90	ND (10)[e]	---
Tc-99	Tc-99	ND (15)[e]	---
	Th-232[c]	**0.372**	**0.239**[f]
	Th-230	---	ND (0.2)[e]
	Th-228	---	**0.219**
	Pb-210	---	ND (0.4)[e]
H-3	H-3	**127.0**	---
Uranium, total (U-238, -235, and -234)[d]	Uranium, total (U-238, -235, and -234)[d]	**0.641 mg/kg**	**0.504 mg/kg**
Gross alpha		---	ND (2.4)[e]
Gross beta		---	ND (4)[e]

[a] Obtained from *Sampling and Analysis Instruction for Characterization of 200-ZP-1 and 200-ZP-1 Spent Granulated Activated Carbon and Filter Elements* (DOE/RL-2006-54), Table 1-2 for 200-ZP-1 and Table 1-4 for 200-PW-1.
[b] Se-79 is difficult to analyze. If Cs-137 is detected, Se-79 concentrations will conservatively be assumed to be the same.
[c] Progeny included in the analysis.
[d] Short-lived progeny included in the analysis.
[e] Parameter not detected, value listed is the Reporting Limit value from DOE/RL-2006-54.
[f] Average of three samples.
ND = parameter not detected
--- = not tested or data not available

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2.0 IDENTIFICATION OF ALTERNATIVE TREATMENT OPTIONS

A preliminary evaluation of alternative treatment options to GAC was previously prepared for use at the 200-ZP-1 pump-and-treat system (SGW-34467). The treatment alternatives that were considered also generally applied to the SVE operations at the 200-PW-1 OU.

Based on the results of the preliminary evaluation, a number of the initially identified alternative treatment options were deemed to be unsuitable for continued evaluation on the basis of effectiveness, implementability, and/or cost. The alternative treatment options that were recommended to be evaluated in greater detail for potential use at the 200-ZP-1 pump-and-treat system and the 200-PW-1 SVE system are listed below:

- Use of a high-efficiency particulate air (HEPA) filter on the vapor stream prior to GAC
- Use of a second or larger chiller/condenser on the vapor stream prior to GAC
- Onsite steam regeneration of vapor-phase GAC
- Replacement of the GAC vessels with a catalytic oxidizer.

Detailed evaluations of each of these selected alternative treatment options are discussed in the Section 3.0.

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3.0 EVALUATION OF ALTERNATIVE TREATMENT OPTIONS

The alternative treatment options to using GAC identified in Section 2.0 were previously evaluated with respect to the criteria of effectiveness, technical implementability, administrative implementability, potential exposure of workers to radioactivity, estimated capital cost, and estimated operating costs. In addition to the preliminary evaluation criteria, the alternative treatment options discussed here are further evaluated in more detail with respect to those evaluation criteria and are also evaluated to determine modifications that may be required to the current system and controls, modifications to operation and maintenance procedures, wastes generated and potential releases to air, and technical life expectancy.

As a basis for comparing the alternative treatment options, the pump-and-treat system operational conditions were used based on recent system operation. The assumed operational parameters are as follows:

- Average groundwater extraction flow rate = 270 gallons per minute (gpm)
- Average influent carbon tetrachloride concentration in groundwater = 1,600 micrograms per liter (μg/L)
- Air (vapor) flow rate through the air stripper = 800 cubic feet per minute (cfm).

Descriptions of the identified recommended treatment alternatives with respect to the evaluation criteria are provided in the following subsections. All four alternatives would continue to use the air stripper for groundwater treatment. The first three alternatives summarized below (use of a HEPA filter, use of a second or larger chiller, and onsite steam regeneration of GAC) would also continue to use vapor-phase GAC for adsorption of VOCs. The fourth alternative would replace GAC with a catalytic oxidizer for thermal destruction of the VOCs.

For ease of discussion, these four alternative technologies are described as being implemented for the 200-ZP-1 groundwater treatment system; however, these four alternatives are equally implementable on the 200-PW-1 SVE operations. The specific estimated costs for implementing these technologies will be different for 200-PW-1 versus 200-ZP-1, but the relative costs of the four technologies are expected to be roughly the same.

3.1 INSTALLATION OF A HIGH-EFFICIENCY PARTICULATE AIR FILTER PRIOR TO GRANULAR ACTIVATED CARBON

Adding a HEPA filter to the air stream from the air stripper would be employed to remove small particulates, including submicron particles from vapors exiting the air stripper. This filtration would be expected to enhance the removal of radioactive material from the vapor stream and may prevent radioactivity from passing through to the GAC vessels. It should be noted that the term "HEPA" is used in this document to imply general particulate removal from an air stream, and the term, as used here, should not be taken to imply a specific set of regulatory performance standards that may be associated with certain industrial applications or for personal health and safety equipment applications.

A site facility plan showing the proposed layout of equipment for this alternative is shown in Figure 3-1. A process flow diagram of this alternative is shown in Figure 3-2.

3.1.1 General Technology Evaluation

The existing chiller and heater units (or new chiller and heater units) would still be employed to reduce the relative humidity of the vapor stream for enhanced VOC removal efficiency by the GAC and to prevent the HEPA filters from getting wet, which could negatively affect the filtration effectiveness. HEPA filters are commonly used in the nuclear power industry for removing radioactive particulates. The nuclear-grade HEPA filters meet various specifications, including the *Code on Nuclear Air and Gas Treatment* (ANSI/ASME AG-1), IEST-RP-CC001.4 Type B (*Handbook of Air Filtration* [IEST 1997]), MIL-STD-282 (*Military Standard Filter Units, Protective Clothing, Gas Mask Components, and Related Products: Performance Test Method*), and the DOE standard *Specification for HEPA Filters Used by DOE Contractors* (DOE-STD-3020-2005). HEPA filters are highly effective at removing particles less than 0.3 microns in size, and commercially available sizes can accommodate flows up to 2,000 cfm. Because testing data on the concentration of particulates and radioactivity in the vapor stream have not been collected, it cannot be determined whether this alternative would be capable of eliminating all sources of radioactivity to the GAC to below detection limits or to below background levels in GAC. There is concern, especially for tritium with its small radius of less than a nanometer, that unless it is complexed with a much larger molecule or sorbed onto particulates, it would not be removed with HEPA filtration and that the HEPA filter would not prevent loading onto the GAC to below detection limits.

Implementing HEPA filtration can be readily achieved due to ease of availability and relatively low cost. As with installation of a larger chiller, this alternative is expected to have favorable administrative implementability relative to other alternatives because it does not alter the general design basis of the existing treatment system. The filters would need to be replaced periodically, so to the degree at which the HEPA filter elements remove radioactive particulates there would be some increase in exposure to system operation and maintenance personnel.

The following subsections provide additional detail related to other evaluation criteria.

3.1.2 Required Modifications to the Existing Treatment System

Two HEPA filter housings would be installed on the vapor conveyance line downstream from the existing chiller and heater equipment. Piping between the heater and the existing GAC vessels would be modified to accommodate the filter housings. The two filters would be installed in parallel, so the conveyance piping would be installed with a tee so the air flow is split between the two filters.

Based on information supplied by a HEPA filter manufacturer, a filter housing that would accommodate an airflow rate of approximately 1,000 cfm would have dimensions of approximately 27 in. wide by 30 in. high by 38 in. deep. The HEPA filter elements would have approximate dimensions of 24 in. by 24 in. by 12 in. deep. Isolation dampers or valves would be installed in the ducting upstream and downstream of the filters to allow for filter maintenance or replacement while the system continues to operate. The overall length of the filter housings with the ductwork transitions and isolation valves at each end is estimated to be approximately 60 in. The housings could be placed near the existing GAC vessels in the available area within the treatment building.

The filter housings would have side access doors for accessing the filters for replacement or maintenance and can be equipped with differential pressure gauges, as well as static pressure taps for installation of pressure gauges. At least 3 ft of space should be available next to the side access doors to allow enough room for accessing the filters.

3.1.3 Required Modifications to Existing System Controls

Modifications to the control system and the addition of an alarm for high differential pressure would be optional. A high differential pressure alarm would alert the operator that the HEPA filter elements need to be replaced with new filters. However, control system modification is not considered to be necessary for implementing the HEPA filters. Specific data has not been collected for the concentration of particulates in the vapor stream exiting the air stripper, but the concentration is expected to be relatively low. Based on similar types of applications, it is estimated that the HEPA filters may only need to be replaced on an annual frequency. However, for cost-estimating purposes, the replacement frequency is estimated to be once per month. Inlet and outlet pressure or differential pressure at the filter housings can be monitored manually on a daily or weekly basis to determine when filter replacement is required, without the need for an automatic system alarm.

3.1.4 Required Modifications to System Operation and Maintenance

Replacement of HEPA filters may be required as often as once per month and would require a few hours of an operator's time to replace both filters and to coordinate disposal. Examination of differential pressure across the filters would need to be added to the system's routine daily or weekly monitoring program.

With the August 2007 acceptance by NRC of continued offsite regeneration of GAC, there is no longer immediate concern or need to test the spent GAC for radioactivity. However, it is assumed that if there would be enough concern about the spent GAC in the future where HEPA filtration would be required, then there would also be some level of testing the effectiveness of the air filtration. For purposes of a cost estimate and technology comparison, it is assumed that there would be quarterly HEPA effluent air testing (or possible testing of the spent GAC) to perform a limited analysis of radioactive indicator compounds.

3.1.5 Wastes Generated

The spent HEPA filter elements would require disposal, but the filters would not be expected to retain detectable levels of VOCs and could be disposed at the Environmental Restoration Disposal Facility at the Hanford Site without concern of exceeding the 6 mg/kg land disposal restriction for carbon tetrachloride.

3.1.6 Potential Releases to Air

The only expected change to air emissions is the small volume of air from the air-stripper effluent stream that would be released during each HEPA filter replacement event. The isolation valves on the filter housing would limit the volume of untreated air that is released to no more than a few liters per filter replacement.

3.1.7 Life Expectancy of Technology

The HEPA filter housings would be expected to have a service life of at least 10 years before requiring replacement. A high-humidity environment could reduce the life of the housing, but it is estimated that the HEPA filters would be placed downstream of the chiller/condenser and the heater and would, therefore, be in a low-humidity environment.

3.1.8 Estimated Capital and Annual Operating Costs

The capital cost of implementing HEPA filtration at the 200-ZP-1 OU is estimated to be approximately $68,000, and the annual operating cost is estimated to be approximately $40,000. The present-value cost of this alternative for 10 years of system operation is estimated to be approximately $460,000. A 4% discount factor was used in the evaluation to estimate the present value of future costs, and a 20% contingency was added to the total estimated costs. The details of this cost estimate are provided in Table 3-1.

3.2 INSTALLATION OF A LARGER CHILLER/CONDENSER PRIOR TO GRANULAR ACTIVATED CARBON

The existing chiller/condenser and heater for the vapor stream exiting the air stripper are designed to cool the vapor stream, condense and remove entrained water droplets and water vapor, and then reheat the vapor to a low relative humidity. A plan view of this equipment layout and a process flow diagram are shown in Figures 1-4 and 1-5, respectively. The existing system typically reduces the relative humidity to below approximately 30%. The purpose of achieving a low relative humidity in the air stream is because GAC is significantly more effective in the removal of VOCs at low relative humidity compared to high relative humidity. This reduced adsorption efficiency at higher relative humidity is caused by the collection of moisture in the pores of the activated carbon.

With the exception of tritium, the radioactive elements listed in Table 1-1 are not considered to be volatile compounds that would transfer from groundwater into the vapor phase, thus it was not expected during initial treatment system design that the GAC would be impacted by radioactivity. However, it may be that particles in small water droplets or water vapor are carrying radioactivity and are being entrained in the air-stripper vapor stream, are not being removed in the existing chiller/condenser, and are depositing onto the GAC. Within the past year, problems were observed with the operation of the existing chiller. When the existing chiller is not functioning properly, water droplets and water vapors from the air stripper may pass through the chiller and become deposited onto the GAC.

A desiccant system would be a possible option for reducing the relative humidity. However, the chlorinated VOCs would also potentially adsorb to the desiccant and would complicate the heating and atmospheric venting of the collected water vapor. Therefore, use of a desiccant at the Hanford Site is not considered further.

Installation of a second chiller/condenser in series with the existing chiller would be a possible option. However, based on discussions with site operators regarding the reliability of this unit and because the chiller and heater are inside one packaged unit, replacement of the existing chiller and heater unit with a larger, more efficient chiller and a new heater appears to be a preferable option and is, therefore, the focus of assessment for this alternative. A site facility plan showing the proposed layout of equipment for this alternative is shown in Figure 3-3. A process flow diagram of this alternative is provided in Figure 3-4.

3.2.1 General Technology Evaluation

Replacing the existing chiller with a larger, more efficient chiller would improve separation of water from the vapor stream exiting the air stripper. Enhanced removal of water droplets and reduction of humidity that potentially contain radioactive material would help to prevent radioactivity from passing through to the GAC vessels. Implementing a larger chiller would be a viable option, as sufficient space within the treatment system building is expected to be available and costs are expected to be relatively low to moderate. This alternative may have greater administrative implementability relative to other alternatives because it does not alter the general design basis of the initial treatment system. However, it cannot be determined with available information whether this alternative would be capable of eliminating sources of radioactivity to the GAC to below detection limits, or to below background concentrations. A chiller/condenser system cannot practically remove 100% of the water vapor.

The following subsections provide more detail related to other evaluation criteria.

3.2.2 Required Modifications to Existing Treatment System

A larger chiller/condenser and new heater would likely require a slightly larger floor space and would require minor modification to the ducting. The larger chiller/condenser would have a larger electrical power draw and, thereby, would require some electrical supply modifications.

3.2.3 Required Modifications to Existing System Controls

Because this alternative would be an improvement of an existing set of equipment, extensive control system modifications would not be required. To minimize the need for modifications to the existing main control system, the new chiller and heater system could be provided with its own control panel to allow monitoring of the operation and to provide warning alarms. It would be recommended to add a control interlock from the new chiller and heater system control panel to the main treatment system control panel to activate an alarm and shut the treatment system down in the unlikely event of a failure of the chiller/condenser system.

3.2.4 Required Modifications to System Operation and Maintenance

No significant modifications to system operation and maintenance would be required with the installation of a larger chiller/condenser unit.

Similar to HEPA filtration described above, it is assumed that if there would again be heightened concern in the future about radioactivity on the spent GAC, then sampling would be performed to periodically test the effectiveness of the larger chiller/condenser unit in removing those COCs. For purposes of a cost estimate and technology comparison, it is assumed that there would be quarterly chiller/condenser effluent air testing (or possible testing of the spent GAC) to perform a limited analysis of radioactive indicator compounds.

3.2.5 Wastes Generated

An increased volume of condensed water would be generated by the larger chiller/condenser. However, the condensed water would be pumped to the influent groundwater stream for treatment through the air stripper, as is the current process for handling the condensed water. No new waste stream would be generated.

3.2.6 Potential Releases to Air

The larger chiller/condenser system would still be part of the same closed ducting system for vapor treatment and would continue to use vapor-phase GAC for removal of VOCs. No increase in air emissions would be expected. The larger chiller/condenser would be installed with the objective to eliminate entrained water droplets and significantly reduce water vapor in order to reduce or eliminate traces of radioactive compounds from passing through from the air stripper to the GAC.

3.2.7 Life Expectancy of Technology

The warranty provided for the larger chiller/condenser unit would depend on which equipment manufacturer is selected, but the warranty would cover at least 1 year of operation. With continuous operation, the equipment life is estimated to be approximately 10 years.

3.2.8 Estimated Capital and Annual Operating Costs

The capital cost of installing a larger chiller/condenser system at the 200-ZP-1 OU is estimated to be approximately $150,000, and the annual operating cost is estimated to be approximately $42,000. The present-value cost of this alternative for 10 years of system operation is estimated to be approximately $560,000. The details of this cost estimate are provided in Table 3-2.

3.3 ONSITE REGENERATION OF SPENT GRANULAR ACTIVATED CARBON USING STEAM

The regeneration of spent GAC onsite using steam would eliminate the need to ship the material offsite for regeneration. For this treatment option, an automatic batch process would be employed to isolate a spent GAC vessel and desorb the accumulated VOCs using steam. A new boiler would need to be installed onsite to produce the steam. Regenerative carbon adsorption systems use multiple vessels for switching between adsorption and regeneration modes. A site facility plan showing the proposed layout of equipment for this alternative is shown in Figure 3-5, and a process flow diagram of this alternative is shown in Figure 3-6.

3.3.1 General Technology Evaluation

Steam regeneration is expected to be effective in removing carbon tetrachloride and other VOCs from the spent GAC to allow for continued reuse in the system for many years. There is a fairly high confidence in the performance of this technology because it has been implemented at other full-scale groundwater pump-and-treat systems. A steam regeneration system could be installed at the site in less than 6 months from the time that a system was ordered from a supplier. The use of steam-regenerated GAC would still be expected to achieve nondetect concentrations of VOCs in the air emissions, but because this process would be a change in the treatment system design, it is expected that lead agency and lead regulatory agency approval would be needed prior to implementation. This alternative would not increase the exposure of workers to the GAC because the steam regeneration process occurs within the GAC vessels without the need for physical transfer. However, occasional handling of drums containing the concentrated carbon tetrachloride liquid would be necessary.

It was previously estimated that the space required to implement this alternative would need to accommodate four GAC adsorption/regeneration vessels on two equipment skids approximately 8-ft wide by 12-ft long by 12-ft high and include enough space for the boiler and liquid

collection tanks. However, evaluation of the current VOC loading rate and communication with vendors of steam regeneration equipment regarding time necessary for steam regeneration cycles indicate that only two vessels with approximately 2,000 lb each of GAC would be necessary for this alternative. These two GAC vessels could be provided on one 8-ft by 12-ft skid.

As shown in Figures 3-5 and 3-6, the two GAC vessels could be placed in parallel operation, with one GAC vessel operating while the other is off-line. Operation with one GAC vessel versus the current six GAC vessels appears at first examination to offer less of a safety factor for breakthrough of VOCs. However, with onsite steam regeneration of a GAC vessel performed each day, there is a built-in safety factor of regenerating the GAC well before the time at which breakthrough of VOCs would occur.

If an added level of conservatism related to GAC breakthrough is still desired, then the two GAC vessels could also be placed in series operation. Considering that a steam regeneration cycle would only require a 2- to 3-hour period, the GAC vessels could be operated in series for 21 to 22 hours/day. There would be a modest added cost for additional automated valves to control the alternation of lead and lag GAC vessels.

3.3.2 Required Modifications to Existing Treatment System

To implement a regenerative carbon adsorption system, the six existing GAC vessels would need to be disconnected and removed from the treatment building. An 8-ft by 12-ft skid containing two regenerative GAC vessels and associated equipment would be placed within the treatment building in the area that the six existing GAC vessels currently occupy. The regenerative GAC vessels would be approximately 42 in. in diameter and 72 in. in height. Other equipment on the skid would include a drying cycle blower, a condenser, a condensate cooler, a decanter for separating solvent from water, and all associated control valves, sensors, and switches. These components would require appropriate plumbing, mechanical, and electrical connections per the vendor-supplied installation manual.

Vapor influent piping to the GAC vessels is currently split into three parallel vapor streams and would need to be modified down to two parallel vapor streams, one each connected to a regenerative GAC vessel. Control valves at each GAC vessel would be set so one of the GAC vessels operates in adsorption mode while the other is off-line for regeneration mode. Influent and effluent sensors and pressure gauges installed at each GAC vessel would continuously monitor vapor flows and concentrations, as well as pressure drop through each vessel, during operation. When breakthrough is detected at the adsorbing GAC vessel, the system will automatically switch the control valves between operational modes, thereby activating regeneration mode for the spent GAC and activating adsorption mode for the other GAC vessel.

An electric boiler capable of delivering approximately 120 lb/hour of steam for the regeneration process would be installed separately, either inside the treatment building or outside (*Ballpark Study for 800 SCFM Steam Regenerable Carbon Bed System AMCEC A3081* [AMCEC 2007]). The space required to accommodate an appropriately sized boiler is estimated to be at least 8 ft by 10 ft. The boiler would require three-phase, 480V, 650 amp electrical service to operate. A clean source of feed water should also be available for providing 4 gpm makeup water for steam generation. Piping would be installed from the boiler to each of the GAC vessels for conveyance of pressurized steam.

A solvent collection drum (over-packed 55-gal steel) would be installed near the main equipment skid and plumbed for gravity feed of solvent from the decanter. Wastewater conveyance piping would also be installed from the decanter to the treatment system's influent surge tank for reprocessing of the water from the regeneration process (i.e., treatment through the existing air stripper).

3.3.3 Required Modifications to Existing System Controls

Existing controls would not require significant modification since the regenerative GAC system would include a separate control panel with all associated controls necessary for automatic operation. The panel could be installed in a nonhazardous location within the treatment building or outside. A communication line would be installed from the new control panel to the system control room to activate shutdown of the treatment system in the unlikely event of a failure alarm condition associated with the regenerative carbon equipment (i.e., detection of VOCs in the effluent stream of one GAC vessel when the other GAC vessel has not yet completed its steam regeneration cycle and is not available for use).

3.3.4 Required Modifications to System Operation and Maintenance

Implementation of a regenerative carbon system will eliminate the need to replace the GAC vessels (at a current rate of approximately 26 per year). Because the system would operate continuously through use of automatic controls, very little hands-on operation would be required for handling the equipment or the GAC. Standard monitoring of system operational conditions (i.e., pressures, temperatures, flows, concentrations, etc.) would still be required to monitor overall operation.

Handling of drums containing condensed solvents recovered from the GAC regeneration process would be added to normal system operation and maintenance procedures. Because there would not be the need for offsite regeneration of the GAC with this alternative, it is assumed that periodic testing of air samples or spent GAC for radioactivity would not be needed.

3.3.5 Wastes Generated

Steam regeneration of the GAC would produce concentrated carbon tetrachloride liquid and also wastewater containing some dissolved constituents. The wastewater would be pumped back to the air stripper for treatment, and the liquid carbon tetrachloride would be collected and stored in drums prior to offsite recycling or incineration.

Based on influent flow rate and VOC concentrations, it is expected that the GAC regeneration and VOC recovery process would produce approximately one 55-gal drum of condensed VOCs (primarily carbon tetrachloride) every 3 to 4 months. As such, procedures would include measuring product level in the collection drum at least once per month and coordinating periodic offsite transport of the recovered carbon tetrachloride liquid a few times per year. The drums containing recovered carbon tetrachloride would be transported offsite either for solvent recycling (if an appropriate user could be identified), or more likely for incineration. It is expected, although no data are available for confirmation, that there would not be levels of radioactivity in the recovered carbon tetrachloride that would prevent offsite recycling or incineration. Furthermore, it is expected that the recovered carbon tetrachloride could be pumped through a submicron filter, if necessary, to remove any particulates that are the source of the radioactivity.

It would be recommended, prior to selection and implementation of onsite GAC regeneration, to perform VOC recovery testing and to test for radioactivity in the recovered VOCs. That testing could help to confirm whether the recovered liquid VOCs meet all necessary criteria for offsite transport and incineration.

3.3.6 Potential Releases to Air

Use of regenerative GAC would effectively adsorb the VOCs in the vapor stream, and data from previous similar full-scale applications have shown that this type of system is capable of achieving nondetectable concentrations in air emissions. Additionally, through the use of automatic sensors and controls, the GAC vessels will switch between adsorption and regeneration modes at the instant that breakthrough would be detected. Secondary sensors could also be installed for added safety if the primary sensors were to malfunction. Installing secondary sensors would be more cost effective than installing a second skid with additional GAC vessels.

3.3.7 Life Expectancy of Technology

Regenerative GAC used in systems at other sites for similar applications has proven to work effectively for periods of over 10 years. It is expected that this technology could be used at the site for as many as 20 years before the GAC would reach a level of inefficient adsorption capacity. However, the overall lifespan could be less and can vary depending on several factors. For instance, fouling of the GAC caused by scale buildup from the steam water supply could potentially occur, which would result in a shorter life span. Therefore, it is recommended that the feed water source for the boiler be of good quality with low solids concentration and relatively free of calcium and magnesium (i.e., minerals that are the source of water hardness).

3.3.8 Estimated Capital and Annual Operating Costs

Multiple companies will design and produce onsite steam GAC regeneration systems. A facility using a system produced by AMCEC, Inc. was recently visited, and for the 50-gpm system, the cost of the air stripper, two GAC canisters, and steam regeneration equipment was estimated at approximately $700,000 (*Onsite Regeneration Site Visit Report: Portsmouth, Ohio Enrichment Plant, Piketon, Ohio* [FH 2007b]). The system that would be required for the 200-ZP-1 OU would be larger but would not require a new air stripper. The capital cost of implementing onsite steam regeneration at the 200-ZP-1 OU is estimated to be approximately $800,000, and the annual operating cost is estimated to be approximately $48,000. The present-value cost of this alternative for 10 years of system operation is estimated to be approximately $1,300,000. The details of this cost estimate are provided in Table 3-3.

3.4 CATALYTIC OXIDATION

With the catalytic oxidation treatment alternative, the VOCs in the vapor from the air stripper would be destroyed by reaction with oxygen at high temperature. Catalytic oxidizers use a catalyst for the oxidation reaction to occur at a lower temperature (approximately 900°F for carbon tetrachloride or other chlorinated VOCs) versus thermal oxidation. Due to the significant savings in fuel or electrical power costs, a catalytic oxidizer would be preferable to a thermal oxidizer. A site facility plan showing the proposed layout of equipment for this alternative is shown in Figure 3-7 and a process flow diagram of this alternative is shown in Figure 3-8.

3.4.1 General Technology Evaluation

The destruction efficiency for carbon tetrachloride and other VOCs is typically very high (greater than 98% or 99%) with the selection of the correct-size unit for the application. Oxidation of chlorinated VOCs (e.g., carbon tetrachloride) generates acid gases (HCl), so the oxidation system would need to be provided with a gas scrubber system. The scrubber would consist of spraying a water stream (in this case, treated groundwater) through the oxidized vapor stream to absorb the acid gas. The water used for scrubbing then may need to be pH-adjusted using a small amount of caustic prior to discharge. For most applications, the oxidizer would use a fuel source such as natural gas or propane to heat the catalyst beds; however, natural gas is not available in the vicinity of the 200-ZP-1 treatment building and the use of propane tanks at this location is prohibited due to its proximity to the former Plutonium Finishing Plant and explosion risk. Therefore, the catalytic oxidizer would need to be heated through the use of electric-powered heating elements.

Catalytic oxidation has been well demonstrated at the full-scale level, multiple vendors of the technology are available, and standard pre-packaged systems are available of the size that would be necessary for the 200-ZP-1 system.

3.4.2 Required Modifications to Existing Treatment System

To implement a catalytic oxidizer system for vapor treatment, the six existing GAC vessels would be disconnected and removed from the treatment building. All catalytic oxidizer and scrubber equipment could be installed within the treatment building in the area that currently contains the existing GAC units. The catalytic oxidizer equipment and associated piping, sensors, and control panel would be mounted on a skid approximately 5-ft wide by 13-ft long. The skid-mounted oxidizer equipment would be approximately 7-ft high. The scrubber equipment would include a sump, a quench tube, a scrubber stack, and all associated piping, sensors, and control valves and would be mounted on a skid approximately 5-ft wide and 7-ft long. The top of the quench tube would be approximately 8 ft above the floor, and the top of the scrubber stack would be approximately 10 ft above the floor. Effluent piping would extend from the scrubber stack and would need to transition through the building roof to discharge treated air to the outside.

Ducting would be installed for transfer of effluent vapors from the discharge port of the catalytic oxidizer to the influent port of the quench tube. A makeup water feed line would be connected to the quench tube with a control valve to adjust the flow to approximately 33 gpm.[1] The makeup water for the scrubber system could either be piped from the treated system effluent tank or from a potable water source. Water from the quench tube would collect in the scrubber sump, which would then be recycled back to the quench tube through recirculation piping via a recycle pump.

A caustic supply tank (30- to 50-gal capacity) would be installed near the scrubber skid. A small feed pump and tubing would be installed between the caustic supply tank and the scrubber stack to supply an estimated 0.07 gal/hour of 25% sodium hydroxide solution to the scrubber to neutralize acidic vapors from the catalytic oxidizer. Approximately 5% to 10% of the chloride will convert to chlorine gas. Scrubbing the chlorine gas requires that a reducing agent, such as

[1] This information was obtained via personal communication between Keith Herbert of Catalytic Combustion Corporation and Tena Seeds of Landau Associates, dated September 27, 2007.

sodium thiosulfate, be added to the caustic. The concentration of the reducing agent should be approximately 10% by weight (AMCEC 2007).

Implementation of the catalytic oxidizer and scrubber equipment would require three-phase, 480V electrical service to operate. The total electrical current requirement to run all of the equipment and to heat the catalyst beds to the minimum 900°F is estimated to be approximately 330 amps. The electrical power that would be required for the pre-heater and oxidizer is estimated to be approximately 260 kW.

The catalytic oxidizer unit would be insulated, but the system would still likely be a source of heat to the building. It is possible that a new or larger air conditioner would be required to maintain a comfortable temperature in the building in summer months.

3.4.3 Required Modifications to Existing System Controls

Existing controls would not require significant modification since the catalytic oxidizer and scrubber equipment would include a separate control panel with all associated controls necessary for automatic operation. The panel would be mounted on the catalytic oxidizer equipment skid. A communication line would be installed from the catalytic oxidizer control panel to the system control room to activate shutdown of the treatment system in the unlikely event of a failure alarm condition associated with the catalytic oxidizer and/or scrubber equipment.

3.4.4 Required Modifications to System Operation and Maintenance

Implementation of a catalytic oxidation system will eliminate handling of GAC vessels because they would no longer be used. Routine operation and maintenance procedures would include continued monitoring of influent and effluent vapor concentrations and flow rates, as well as new monitoring requirements such as the observation of catalytic oxidizer temperatures and caustic supply levels. Sampling and analysis of water being discharged from the scrubber system to the effluent tank would be performed to assure that pH is being properly controlled. The caustic supply tank would require replenishment with 25% sodium hydroxide solution once or twice per month, depending on the size of the tank. Maintenance activities would likely include an acid wash of the scrubber equipment once every 2 to 3 months.

Maintenance personnel should also use caution during any scrubber system maintenance, as the caustic spray in the scrubber can pose a safety hazard to the workers.

3.4.5 Wastes Generated

Operation of the catalytic oxidizer system would generate blowdown wastewater from the scrubber at a rate of 1 to 2 gal/hour. The blowdown water would contain approximately 25% sodium chloride (salt). However, it is expected that the blowdown could be discharged to the effluent tank and that the discharged groundwater would still have an acceptable salinity level for continued underground injection. There would be significant added cost if it would be necessary to store and transport the blowdown water for treatment.

Waste would also be generated from the acid wash of the scrubber every 2 to 3 months. One wash would generate less than one-half of a drum (55-gal) of waste, which would need to be neutralized onsite with caustic solution or treated as hazardous waste with appropriate offsite treatment and disposal.

3.4.6 Potential Releases to Air

The catalytic oxidation converts chlorinated VOCs into carbon dioxide and water (and chloride which is removed by the scrubber). Catalytic oxidizers for destruction of chlorinated hydrocarbons are typically designed to achieve a destruction efficiency of at least 98%. Operation of a similar system recently observed in Michigan achieves between 98% and 99% destruction efficiency of system vapors. However, based on prior experience with other catalytic oxidation systems, it is possible to achieve effluent VOC concentrations below laboratory detection limits. At 98% destruction efficiency, the system would emit less than 0.2 parts per million (ppm) of carbon tetrachloride into the atmosphere (based on a 9 ppm influent concentration). At that effluent concentration, and at the airflow rate from the 200-ZP-1 system, the carbon tetrachloride emission rate is calculated to be just above the acceptable source impact level of 0.067 $\mu g/m^3$ and would typically require air dispersion modeling to verify no anticipated unacceptable health risk. In order to stay within the current 10 lb/year discharge for carbon tetrachloride (which is the design basis of the current 200-ZP-1 system), destruction efficiency by the catalytic oxidation system would need to average greater than 99%, which may be difficult to achieve.

3.4.7 Life Expectancy of Technology

Because the catalyst bed of the oxidizer would be exposed to acid gases during operation, the catalyst may need to be replaced approximately every 3 to 5 years. However, information gathered from review of other catalytic oxidation systems being used for treatment of chlorinated vapors indicates that a longer operational lifespan is possible. One system operating at a paint manufacturing facility in Michigan for destruction of trichloroethylene has been operating since 2001 and the catalyst has not yet needed to be replaced in that 6-year period (*Catalytic Oxidation Site Visit Report: Paint Manufacturing Facility, 201 Woodword Height Blvd., Ferndale, Michigan* [FH 2007a]). Similar chlorinated catalytic oxidation systems have been operating for more than 10 years without needing to replace the catalyst.

3.4.8 Estimated Capital and Annual Operating Costs

Multiple vendors produce chlorinated VOC catalytic oxidizer and scrubber packages. Both Catalytic Combustion Corporation and Global Technologies, Inc. provided assistance with technical requirements and cost quotations. The capital cost of implementing catalytic oxidation at the 200-ZP-1 is estimated to be approximately $594,000, and the annual operating cost is estimated to be approximately $196,000. The present-value cost of this alternative for 10 years of system operation is estimated to be approximately $2,500,000. The details of this cost estimate are provided in Table 3-4.

Figure 3-1. Pump-and-Treat System with Larger Chiller/Condenser, 200-ZP-1 Site Plan.

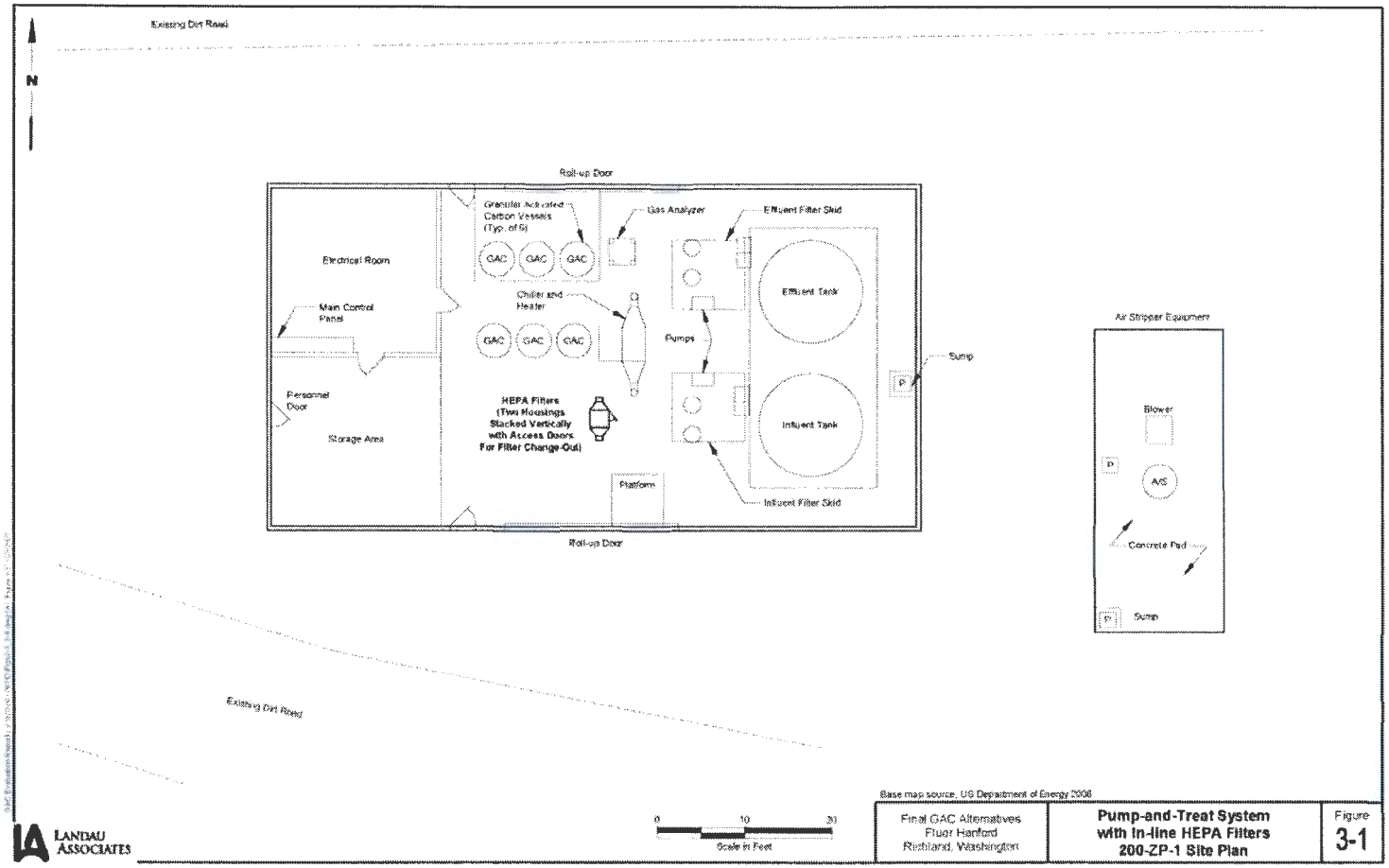

Figure 3-2. Pump-and-Treat System with Larger Chiller/Condenser, 200-ZP-1 Process Flow Diagram.

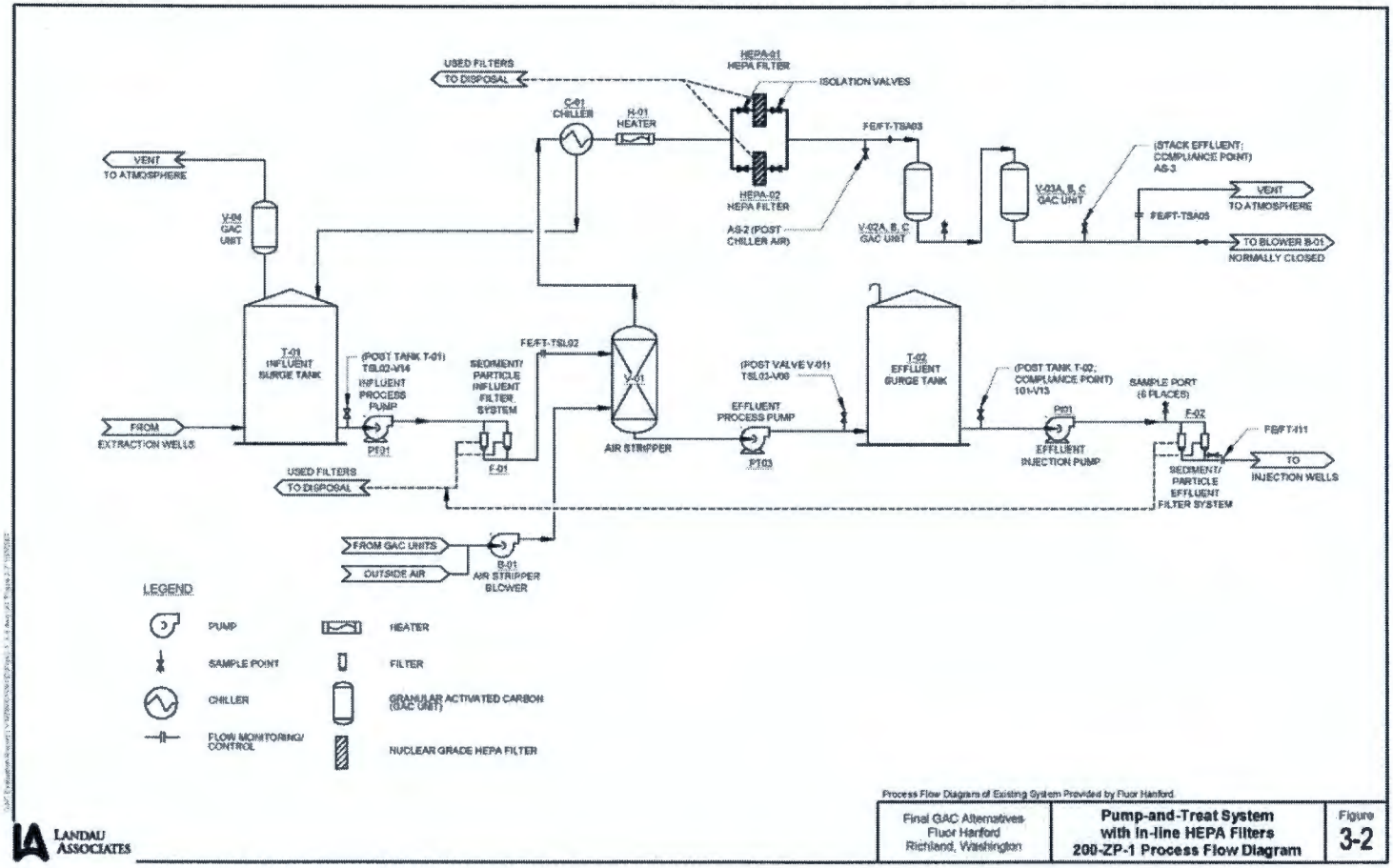

Figure 3-3. Pump-and-Treat System with High-Efficiency Particulate Air Filters, 200-ZP-1 Site Plan.

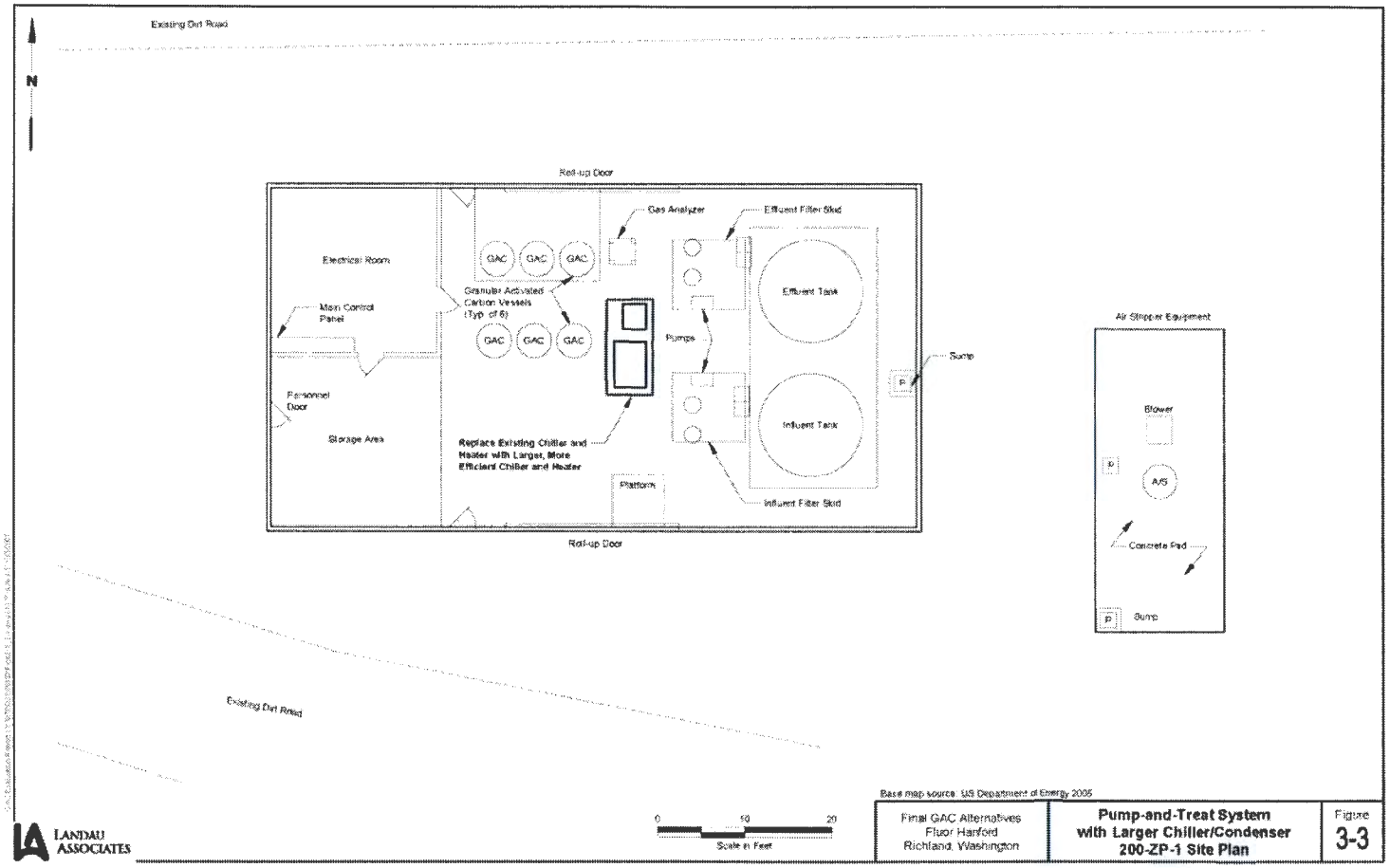

Figure 3-4. Pump-and-Treat system with High-Efficiency Particulate Air Filters, 200-ZP-1 Process Flow Diagram.

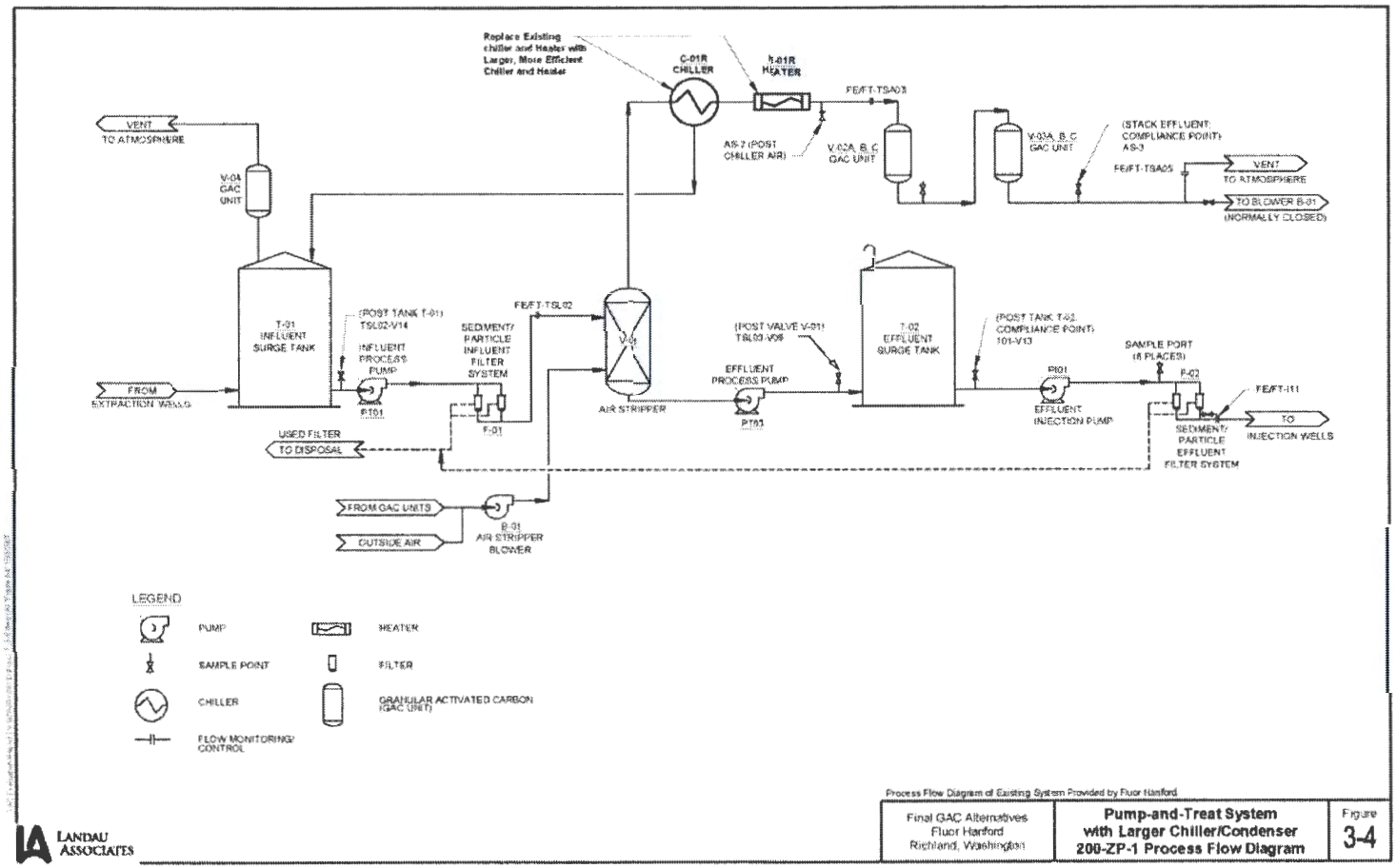

Figure 3-5. Pump-and-Treat System with Regenerative Carbon, 200-ZP-1 Site Plan.

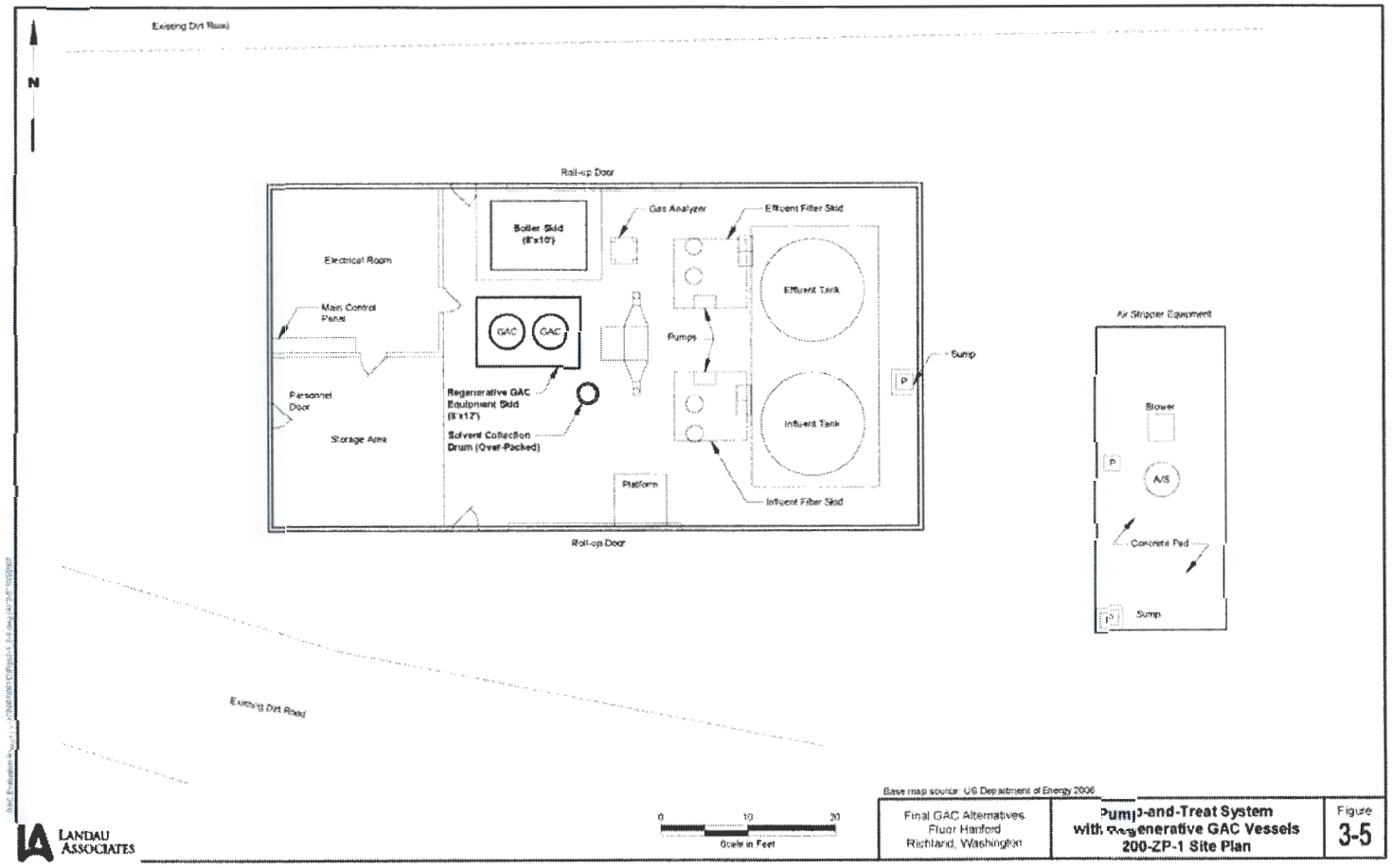

Figure 3-6. Pump-and-Treat System with Regenerative Carbon, 200-ZP-1 Process Flow Diagram.

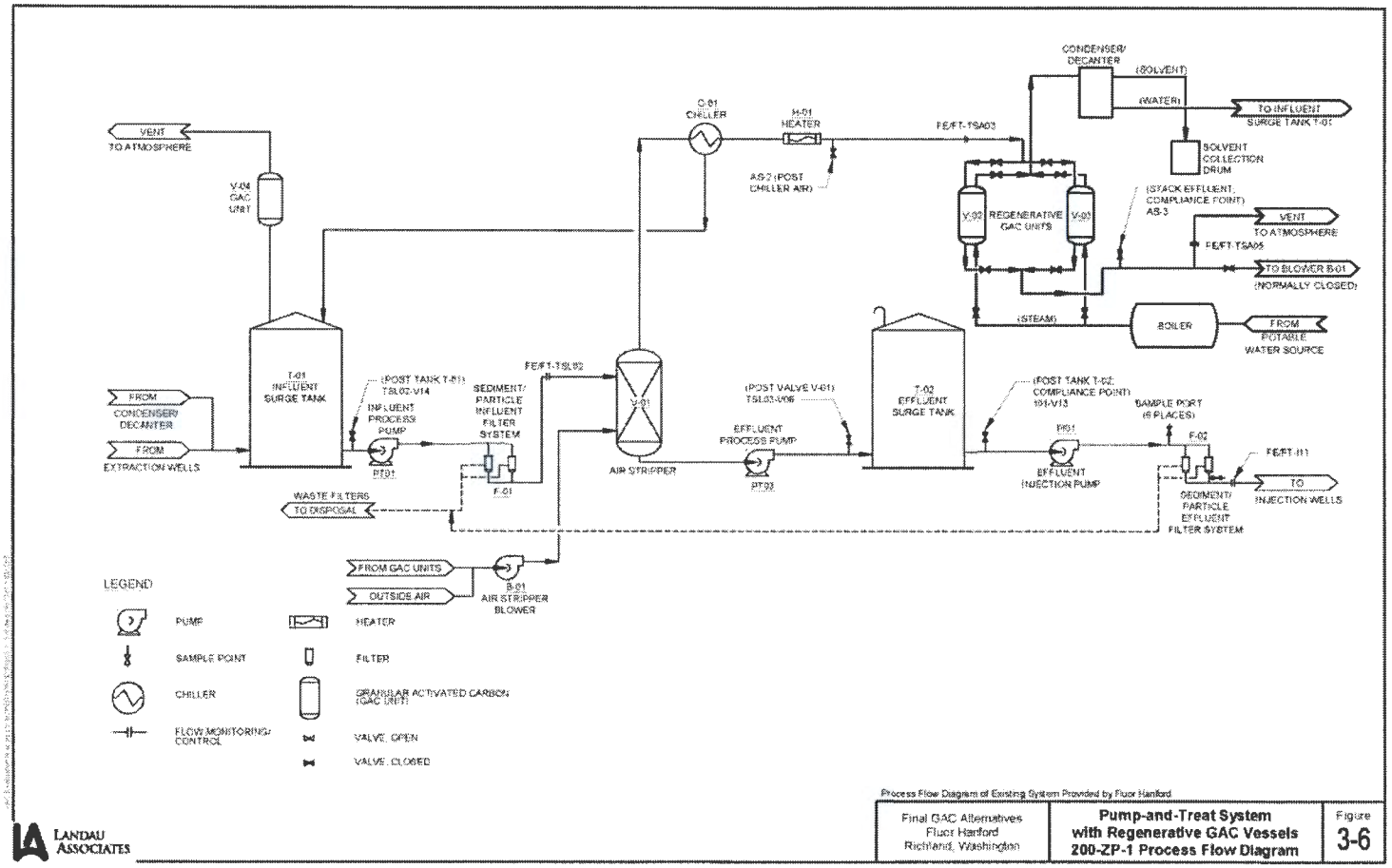

Figure 3-7. Pump-and-Treat System with Catalytic Oxidizer, 200-ZP-1 Site Plan.

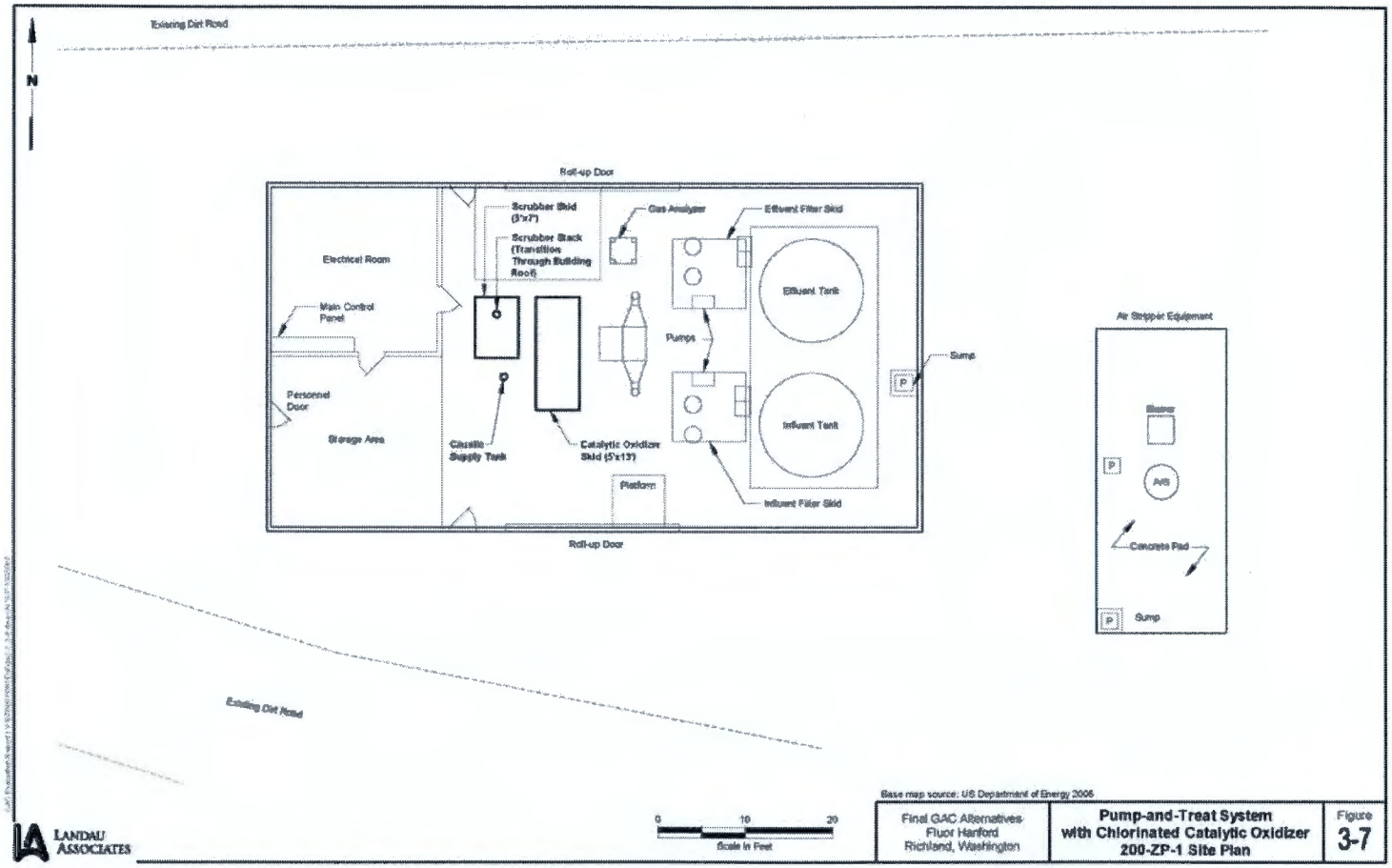

Figure 3-8. Pump-and-Treat System with Catalytic Oxidizer, 200-ZP-1 Process Flow Diagram.

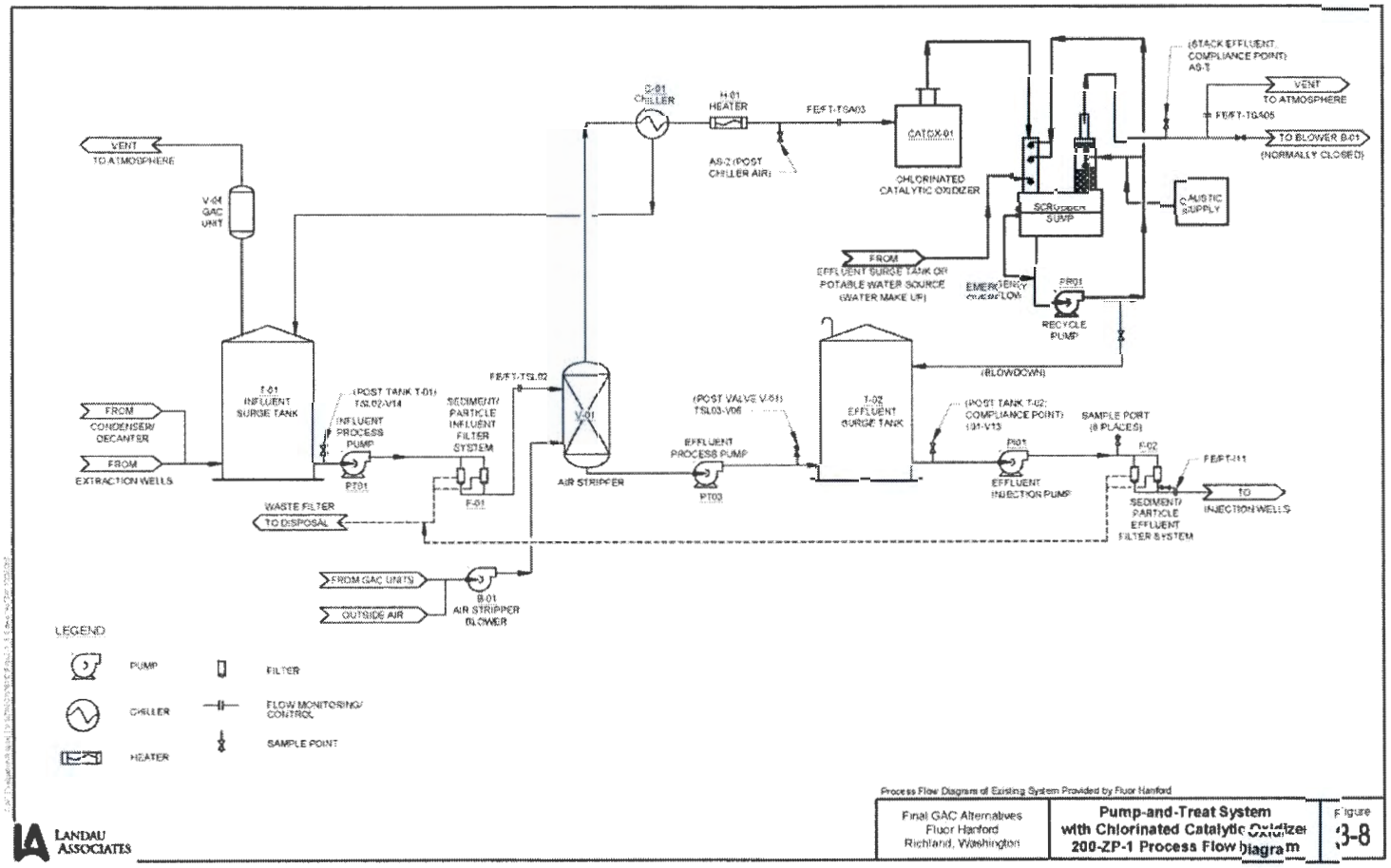

Table 3-1. Estimated Cost for High-Efficiency Particulate Air Filtration at 200-ZP-1. (2 sheets)

HEPA Filtration	Qty.	Unit	Unit Cost	Total	Comments
System Design and Capital Costs					
System design plans	1	LS	$10,000	$10,000	
HEPA filter housing	2	EA	$14,000	$28,000	To DOE specifications; including delivery.
Installation and ducting modifications	1	LS	$6,000	$6,000	
Differential pressure gauge	1	LS	$2,000	$2,000	Including installation.
Electrical and control system integration	1	LS	$0	$0	None required.
Update treatment system record drawings	2	EA	$3,000	$6,000	Update process and piping drawings.
Inspection and startup testing	1	LS	$10,000	$10,000	With influent and effluent samples.
Project management and coordination	10%			$6,000	
Total Estimated Capital Cost				**$68,000**	
Annual HEPA Filtration O&M Costs					
Operation and monitoring labor	52	hours	$70	$4,000	Estimated 1 extra hr/week.
Replacement HEPA filter elements	24	EA	$700	$17,000	Assume replace two filters/month.
Filter housing replacement	0	EA	$14,000	$0	Estimated 10-year housing life.
Effluent air sampling events, quarterly	4	EA	$3,000	$12,000	Air or GAC sample testing.
Annual equipment maintenance and repair	1	year	$3,000	$3,000	Estimated at 5% of capital cost.
Project management and coordination	10%			$4,000	
Estimated Annual O&M Cost				**$40,000**	

Table 3-1. Estimated Cost for High-Efficiency Particulate Air Filtration at 200-ZP-1. (2 sheets)

HEPA Filtration	Qty.	Unit	Unit Cost	Total	Comments
Present-Worth O&M (Years 1 to 10, Discount Rate = 4%)				**$324,000**	
Contingency	20%		$390,000	$65,000	
Total Estimated 10-Year Present-Value Cost				**$460,000**	Total rounded to nearest $10,000.

NOTES:

1. Costs, where totaled are rounded to the nearest $1,000 unless otherwise noted.
2. Estimated costs are for comparison purposes only. Costs shown do not include project costs that are common to all of the alternatives.

DOE = U.S. Department of Energy
GAC = granular activated carbon
HEPA = high-efficiency particulate air
O&M = operations and maintenance

Table 3-2. Estimated Cost for Larger Chiller/Condenser at 200-ZP-1. (2 sheets)

Improved Condenser System	Qty.	Unit	Unit Cost	Total	Comments
System Design and Capital Costs					
System design plans	1	LS	$10,000	$10,000	
New chiller/condenser system	1	EA	$50,000	$50,000	1,000 cfm capacity.
New heater unit	1	EA	$10,000	$10,000	
Installation and ducting modifications	1	LS	$15,000	$15,000	
Instrumentation	1	LS	$5,000	$5,000	Temperature gauges/transmitters.
Electrical and control system	1	LS	$30,000	$30,000	Including higher amp electrical panel.
Update treatment system record drawings	2	EA	$3,000	$6,000	Update process and piping drawings.
Inspection and startup testing	1	LS	$10,000	$10,000	With influent and effluent samples.
Project management and coordination	10%			$14,000	
			Total Estimated Capital Cost	**$150,000**	
Annual Chiller/Condenser O&M					
Operation and monitoring labor	104	hours	$70	$7,000	Estimated 2 extra hrs/week.
Added electrical power for larger condenser/heater	12	months	$900	$11,000	Estimated extra 20 kW.
Chiller/condenser replacement	0	EA	$50,000	$0	Estimated 10-year lifetime.
Effluent air sampling events, quarterly	4	EA	$3,000	$12,000	Air or GAC sample testing.
Annual equipment maintenance and repair	1	year	$8,000	$8,000	Estimated at 5% of capital cost.
Project management and coordination	10%			$4,000	
			Estimated Annual O&M Cost	**$42,000**	

Table 3-2. Estimated Cost for Larger Chiller/Condenser at 200-ZP-1. (2 sheets)

Improved Condenser System	Qty.	Unit	Unit Cost	Total	Comments
Present-Worth O&M (Years 1 to 10, Discount Rate = 4%)				**$341,000**	
Contingency	20%		$490,000	$68,000	
Total Estimated 10-Year Present-Value Cost				**$560,000**	Total rounded to nearest $10,000.

NOTES:

1. Costs, where totaled are rounded to the nearest $1,000 unless otherwise noted.
2. Estimated costs are for comparison purposes only. Costs shown do not include project costs that are common to all of the alternatives.

cfm = cubic feet per minute
GAC = granular activated carbon
O&M = operations and maintenance

Table 3-3. Estimated Cost for Onsite Steam Regeneration of Granular Activated Carbon at 200-ZP-1. (2 sheets)

Onsite Steam Regeneration of GAC	Qty.	Unit	Unit Cost	Total	Comments
System Design and Capital Costs					
System design plans	1	LS	$50,000	$50,000	
GAC steam regeneration system	1	LS	$500,000	$500,000	Quote from AMCEC, Inc., August 24, 2007.
Steam boiler	1	EA	$50,000	$50,000	Capacity of 120 lb/hr steam.
Boiler feed water pretreatment system	1	LS	$100,000	$100,000	Using treated groundwater.
Installation; piping and ducting modifications	1	LS	$40,000	$40,000	
Expanded electrical power feed to building	1	LS	$100,000	$100,000	New feed cable and transformer.
Electrical and control system	1	LS	$60,000	$60,000	Includes 480V, 700-amp electrical panel.
Installation completion report and record drawings	1	LS	$20,000	$20,000	
Inspection and startup testing	1	LS	$20,000	$20,000	
Project management and coordination	10%			$94,000	
Total Estimated Capital Cost				**$1,034,000**	
Annual Onsite GAC Regeneration O&M					
Operation and monitoring labor	200	hours	$70	$14,000	Estimated extra 4 hrs/week.
Equipment replacement	0	LS	$550,000	$0	Estimated 10-year lifetime.
Electrical power, 547 kW, 10% duty cycle	12	months	$2,400	$29,000	Assuming $0.06/kW-hr.
System sampling/analysis	0	EA	$0	$0	Assuming no extra sampling required.
Offsite incineration of recovered VOCs	3	drum	$5,000	$15,000	Including coordination labor.
Annual equipment maintenance and repair	1	year	$52,000	$52,000	Estimated at 5% of capital cost.
Project management and coordination	10%			$11,000	
Estimated Annual O&M Cost				**$78,000**	

Table 3-3. Estimated Cost for Onsite Steam Regeneration of Granular Activated Carbon at 200-ZP-1. (2 sheets)

Onsite Steam Regeneration of GAC	Qty.	Unit	Unit Cost	Total	Comments
Present-Worth O&M (Years 1 to 10, Discount Rate = 4%)				**$633,000**	
Contingency	20%		$1,670,000	$127,000	
Total Estimated 10-Year Present-Value Cost				**$1,800,000**	Total rounded to nearest $100,000.

NOTES:
1. Costs, where totaled are rounded to the nearest $1,000 unless otherwise noted.
2. Estimated costs are for comparison purposes only. Costs shown do not include project costs that are common to all of the alternatives.

GAC = granular activated carbon
O&M = operations and maintenance
VOC = volatile organic carbon

Table 3-4. Estimated Cost for Catalytic Oxidization at 200-ZP-1. (2 sheets)

Catalytic Oxidation	Qty.	Unit	Unit Cost	Total	Comments
System Design and Capital Costs					
System design plans	1	LS	$50,000	$50,000	
Catalytic oxidizer system	1	LS	$370,000	$370,000	Catalytic Combustion quote, September 4, 2007.
Installation; piping and ducting modifications	1	LS	$40,000	$40,000	
Expanded electrical power feed to building	1	LS	$75,000	$75,000	New feed cable and transformer.
Electrical and control system	1	LS	$40,000	$40,000	Includes 480V, 330-amp electrical panel.
Installation completion report and record drawings	1	LS	$20,000	$20,000	
Inspection and startup testing	1	LS	$20,000	$20,000	
Project management and coordination	10%			$62,000	
Total Estimated Capital Cost				**$677,000**	
Annual Catox System O&M					
Operation and monitoring labor	200	hours	$70	$14,000	Estimated extra 4 hrs/week.
Equipment replacement	0	LS	$370,000	$0	Estimated 10-year lifetime.
Electrical power, 260 kW for catox and scrubber	12	months	$11,200	$134,000	Assuming $0.06/kW-hr.
System sampling/analysis	0	EA	$0	$0	Assuming no extra sampling required.
Equipment repair including new catalyst every 3 years	1	year	$34,000	$34,000	Estimated at 5% of capital cost.
Project management and coordination	10%			$18,000	
Estimated Annual O&M Cost				**$200,000**	

Table 3-4. Estimated Cost for Catalytic Oxidization at 200-ZP-1. (2 sheets)

Catalytic Oxidation	Qty.	Unit	Unit Cost	Total	Comments
Present-Worth O&M (Years 1 to 10, Discount Rate = 4%)				**$1,620,000**	
Contingency	20%		$2,300,000	**$320,000**	
Total Estimated 10-Year Present-Value Cost				$2,600,000	Total rounded to nearest $100,000.

NOTES:
1. Costs, where totaled are rounded to the nearest $1,000 unless otherwise noted.
2. Estimated costs are for comparison purposes only. Costs shown do not include project costs that are common to all of the alternatives.

O&M = operations and maintenance

4.0 CONCLUSIONS AND RECOMMENDATIONS

Given that FH has received authorization from NRC to resume the offsite shipment and regeneration of GAC from the 200-ZP-1 and 200-PW-1 OUs and given that the four alternative technologies evaluated here would require significant additional cost and are uncertain as to their full effectiveness, proceeding with implementation of any of these alternatives would not be recommended at this time.

However, if there were to be again a halt on offsite regeneration of GAC due to low-level radioactivity, then it would be worth testing the lowest-cost alternative that was identified in this evaluation. The lowest-cost alternative was estimated to be HEPA filtration of the vapor stream prior to contact with the GAC.

Alternatively, in the event that detected low-level radioactivity has made offsite GAC regeneration no longer permissible, and HEPA filtration by itself has been found to be ineffective in adequately reducing the level of radioactivity on the GAC, then increasing the size of the chiller/condenser would be the next least-expensive alternative to test.

If these two alternatives together were still found to be ineffective in removing radioactivity to the level necessary, or if it was otherwise determined that offsite regeneration of GAC could not continue, then onsite steam regeneration of GAC would be the preferred technology for implementation due to its significantly lower operational cost compared to catalytic oxidation. However, remaining concerns that would need to be further examined prior to implementing onsite steam regeneration of GAC include (1) confirming that a small split stream of treated groundwater could be used for boiler feed water, (2) confirming the cost for bringing in a significantly larger electrical power supply to run the boiler, and (3)confirming that the recovered liquid carbon tetrachloride waste stream would not contain levels of radioactivity that would prevent it from being sent offsite for incineration.

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APPENDIX I

TREATABILITY TEST PLAN FOR USING PUROLITE RESIN TO REMOVE TECHNETIUM-99 FROM 200-ZP-1 GROUNDWATER (DOE/RL-2006-64)

The document included in this appendix was published as DOE/RL-2006-64 and is included here as an appendix for the convenience of the reader.

DOE/RL-2006-64
Revision 0
REISSUE

Treatability Test Plan for Using Purolite Resin to Remove Technetium-99 from 200-ZP-1 Groundwater

Prepared for the U.S. Department of Energy
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Approved for Public Release;
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REISSUE

Treatability Test Plan for Using Purolite Resin to Remove Technetium-99 from 200-ZP-1 Groundwater

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TABLE OF CONTENTS

1.0 INTRODUCTION 1-1

1.1 BACKGROUND INFORMATION 1-1

1.2 TECHNOLOGY SELECTION FOR TECHNETIUM-99 REMOVAL 1-3

1.2.1 Screening of Treatment Technologies 1-3

1.2.2 Ion Exchange Using Purolite A530 Resin 1-4

2.0 TEST OBJECTIVES 2-1

3.0 TEST IMPLEMENTATION 3-1

3.1 BENCH-SCALE TESTING 3-1

3.2 ONSITE PILOT-SCALE TREATABILITY TESTING 3-1

3.2.1 Testing at Extraction Well 299-W15-765 3-2

3.2.2 Testing at Extraction Well 299-W15-44 3-2

3.2.3 Piping, Valves, and Instrumentation 3-2

3.3 TEST SYSTEM MONITORING AND OPERATION 3-3

3.4 SAMPLING AND ANALYSIS 3-4

3.5 CRITERIA FOR TERMINATION OF TESTING 3-4

4.0 DATA ANALYSIS AND INTERPRETATION 4-1

4.1 ASSESSMENT OF DATA QUALITY 4-1

4.2 ASSESSMENT OF RESIN PERFORMANCE 4-1

4.3 EQUIPMENT EVALUATION AT END OF TESTING 4-1

4.4 DESIGN AND IMPLEMENTATION OF A FULL-SCALE REMEDY 4-1

5.0 HEALTH AND SAFETY 5-1

6.0 RESIDUALS MANAGEMENT 6-1

7.0 REFERENCES 7-1

APPENDICES

A ION-EXCHANGE VESSEL SIZING CALCULATIONS ..... A-i

B ION-EXCHANGE TREATABILITY TEST – PIPING AND INSTRUMENTATION DIAGRAMS ..... B-i

C TREATABILITY TEST OPERATION LOG ..... C-i

D SAMPLING AND ANALYSIS INSTRUCTION TO SUPPORT TREATABILITY TESTING OF PUROLITE RESIN A530E FOR REMOVING TECHNETIUM-99 FROM 200-ZP-1 GROUNDWATER ..... D-i

FIGURE

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit. 1-2

TABLE

Table 3-1. Preliminary Sampling Parameters and Frequency. 3-5

LIST OF TERMS

COC	contaminant of concern
COTS	commercial off-the-shelf
EPA	U.S. Environmental Protection Agency
FH	Fluor Hanford, Inc.
GAC	granular activated carbon
gpm	gallons per minute
ICP/MS	inductively coupled plasma/mass spectrometry
IX	ion exchange
MCL	maximum contaminant level
OU	operable unit
P&ID	piping and instrumentation diagram
PNNL	Pacific Northwest National Laboratory
psi	pounds per square inch
SAI	sampling and analysis instruction

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METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	millibecquerels	0.027	picocuries

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1.0 INTRODUCTION

This document presents the plan for conducting a treatability test for the removal of technetium-99 from groundwater extracted by the pump-and-treat system at the 200-ZP-1 Operable Unit (OU) at the Hanford Site. The testing will involve the use of an ion-exchange (IX) resin for selective removal of technetium-99. This test plan follows the U.S. Environmental Protection Agency's (EPA's) guidance and recommended outline for conducting treatability tests provided in *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988).

1.1 BACKGROUND INFORMATION

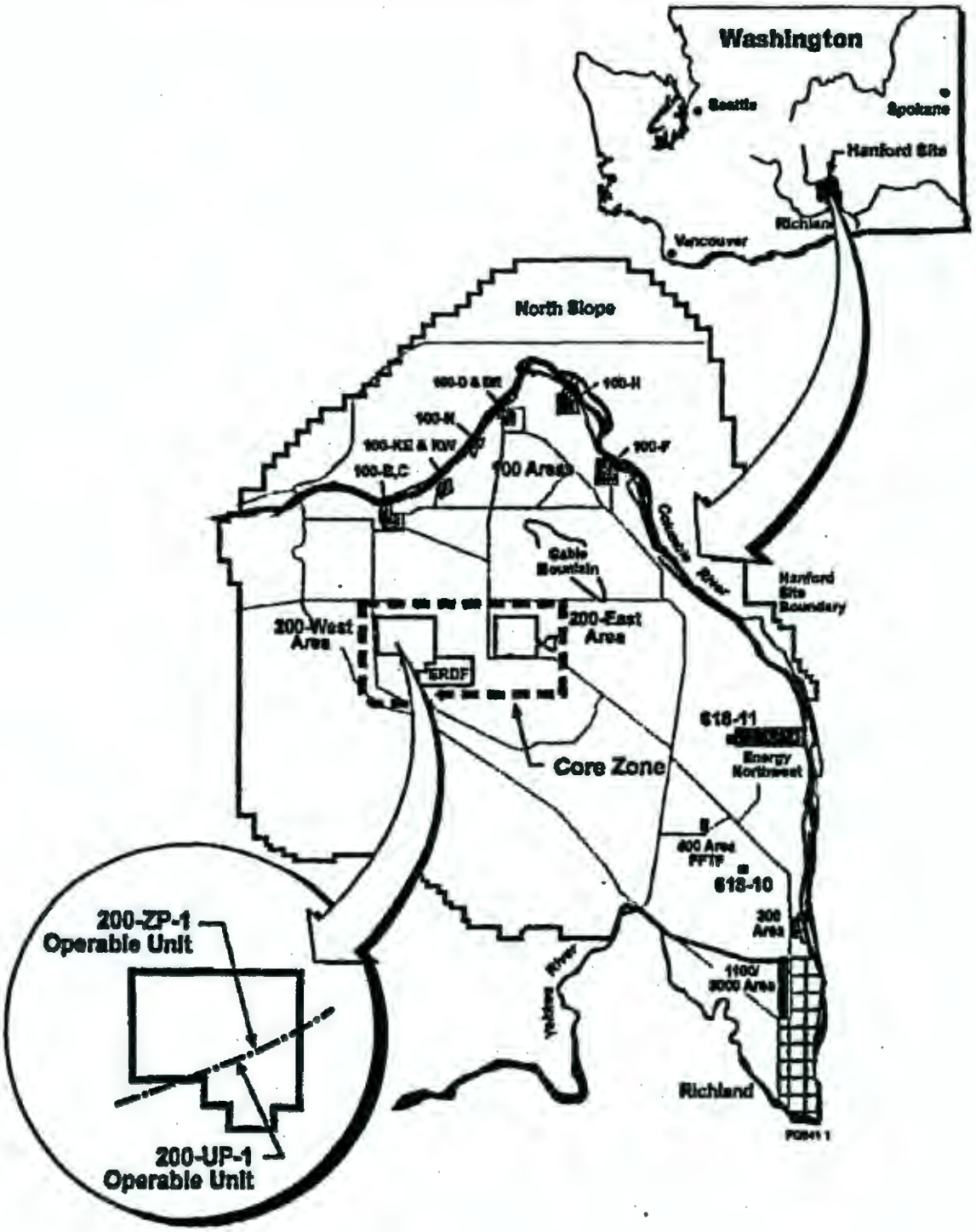
The 200-ZP-1 Groundwater OU is one of two groundwater OUs located within the 200 West groundwater aggregate areas of the Hanford Site. The location of the 200-ZP-1 OU is shown in Figure 1-1. A pump-and-treat system for the 200-ZP-1 OU was implemented in 1995 in accordance with the *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit* (EPA et al. 1995).

The primary contaminant of concern (COC) within the 200-ZP-1 OU is carbon tetrachloride. Additional COCs within the 200-ZP-1 OU include trichloroethene, technetium-99, nitrate, hexavalent chromium, uranium, and tritium. Carbon tetrachloride is removed from groundwater by the current pump-and-treat system, which processes water through evaporative treatment (air stripping) and polishes it by granular activated carbon (GAC) (DOE-RL 2006).

The pump-and-treat system at the 200-ZP-1 OU was implemented in three phases. Between August 1994 and July 1996, one extraction well and one injection well were operated at a rate of 40 gallons per minute (gpm) during Phase I of operation. In August 1996, the Phase II of operations commenced in accordance with the interim Record of Decision for the 200-ZP-1 OU (EPA et al. 1995). During Phase II, a total of three extraction wells pumping at a combined rate of approximately 150 gpm were operated, along with the single injection well.

In August 1997, Phase III of operations expanded the system to bring on-line three additional extraction wells and four additional injection wells. In January 2001, one of the extraction wells in this configuration was converted to a monitoring well, with five extraction wells and five injections wells remaining in operation. In July 2005, four groundwater monitoring wells were converted to extraction wells to address a newly discovered lobe of the carbon tetrachloride plume (DOE-RL 2006). In October 2006, one additional monitoring well was converted to an extraction well, bringing the current operating total to 10 extraction wells and 5 injection wells, operating at a combined rate of approximately 300 gpm.

Figure 1-1. Location of 200 West Area and the 200-ZP-1 Operable Unit.



Groundwater from two of the newest extraction wells, 299-W15-44 and 299-W15-765 (located near the TX-TY Tank Farms and the 216-T-19 Crib), began showing increasing concentrations of technetium-99 almost immediately after groundwater extraction began. Historically, the 216-T-19 Crib received more than 120 million gal of process condensate from the 242-T evaporator between 1965 and 1980. Wastes from 221/224-T Plant were disposed to the crib between 1951 and 1956. One or more waste tanks in the TX-TY Tank Farms may have leaked, creating another potential source of contamination. Each of these waste streams contained significant amounts of technetium-99, presumably as high as 8,000 pCi/L based on an average concentration of technetium-99 detected in a monitoring well (299-W14-13) located near the 242-T evaporator.

The current groundwater treatment system does not remove technetium-99, and the increasing technetium-99 concentrations from wells 299-W15-44 and 299-W15-765 currently exceed the EPA's maximum contaminant level (MCL) for technetium-99 (900 pCi/L). The technetium-99 concentration of the mixed groundwater from all 10 of the current extraction wells is just greater than one-half of the MCL for technetium-99 but is increasing rapidly. If the water remains untreated for technetium-99, there is concern that the water reinjected into the aquifer could exceed EPA standards, technetium-99 could plate onto metal components of the current system, and/or technetium-99 could be adsorbed by the existing GAC canisters. These issues could potentially expose site employees and operators to elevated levels of beta radiation.

This test plan discusses the steps necessary to implement a treatability test to address the rising technetium-99 concentrations within the 200-ZP-1 OU, thereby ensuring that discharges to the groundwater meet EPA standards and reduce potential employee exposure.

1.2 TECHNOLOGY SELECTION FOR TECHNETIUM-99 REMOVAL

Technetium-99 exists in groundwater at the Hanford Site in a fully oxidized form (Tc^{+7}), which exists as the pertechnetate anion (TcO_4^-). Pertechnetate is highly soluble, is kinetically inert in dilute aqueous solutions, and has a low charge and hydration energy. This anion cannot be removed using the existing treatment system at the Hanford Site, as it will not adequately be removed by adsorption or filtration by GAC. In order to prevent the discharge of unacceptable levels of technetium-99 to the groundwater after carbon tetrachloride treatment, several technologies were evaluated by Fluor Hanford, Inc. (FH) for selective removal of pertechnetate prior to carbon tetrachloride treatment.

1.2.1 Screening of Treatment Technologies

Several treatment technologies for selective treatment of technetium-99 in groundwater were reviewed, including the following: membrane separation, electrocoagulation, selective adsorbents, zero-valent iron, and IX. The review compared (1) the technologies' selectivity for technetium-99, (2) whether the technology was commercially available, and (3) the relative cost. Of the technologies evaluated, only IX was highly selective for technetium-99 and is commercially available. In addition, IX has a relatively low cost of implementation compared to the other technologies evaluated. Therefore, IX was selected for further evaluation and use in this treatability test.

The IX resins tend to indiscriminately absorb most anions, including nitrate, sulfate, bicarbonate, and chloride. Therefore, a nonselective resin would be ineffective at adsorbing technetium-99, as high concentrations of these other anions are also present in groundwater at the 200-ZP-1 OU. However, strong-base, anion-specific resins have been shown to be effective in selectively removing pertechnetate. Through research funded by the U.S. Department of Energy, newly developed resins have been shown to concentrate technetium-99 in the presence of competing anions at concentrations 4 to 6 orders of magnitude higher than technetium-99 concentrations in the groundwater. The resin selected for this treatability test is commercially available from Purolite® under the designation of "A530E" as a macroporous, strong-base, anion-exchange resin for the selective removal of perchlorate and pertechnetate oxy anions. The subsection below discusses the properties that make this the preferred resin for the treatability test and summarizes the proposed testing process.

1.2.2 Ion Exchange Using Purolite A530 Resin

Purolite A530E is a specially designed, macroporous, strong-base anion resin that has been cross-linked with divinylbenzene, allowing the resin to selectively remove hydrophobic anions. The resin is recommended for removal of perchlorate and pertechnetate oxy anions, even in the presence of higher concentrations of competing anions (as described above). At the Hanford Site, elevated concentrations of nitrate and sulfate are present in the groundwater. The primary reason for choosing the Purolite A530E resin for this treatability test is the resin's selective nature to absorb technetium-99 in the presence of these anions.

The treatability test will be conducted at the well heads of extraction wells 299-W15-44 and 299-W15-765. The reason for conducting the treatability study at these two locations is to assess the resin's effectiveness for groundwater with both relatively high and low concentrations of technetium-99 and nitrates. Well 299-W15-765 contains groundwater with concentrations of technetium-99 (measured at 3,400 pCi/L in October 2006) and nitrate (previously measured in the range of 202 to 439 mg/L), while lower concentrations of technetium-99 (1,500 pCi/L measured in October 2006) and nitrate (previously measured in the range of 113 to 185 mg/L) are present at well 299-W15-44. Performing the treatability test with these two conditions will allow confirmation of vendor-supplied data for treatment bed volumes, which are highly dependent upon anion concentrations.

A small IX column will be installed at both of the well heads for evaluation. The columns will be sized to achieve 50% breakthrough in approximately 60 days. The data collected from the study will be used to evaluate the effectiveness of the Purolite A530E resin for selective removal of technetium-99 and to assess operational costs and design considerations for full-scale application.

Purolite® is a registered trademark of The Purolite Company, Bala Cynwood, Pennsylvania.

2.0 TEST OBJECTIVES

The objectives of the treatability test for the 200-ZP-1 OU are as follows:

- Verify that Purolite A530E resin adequately removes technetium-99 from Hanford Site groundwater and determine the site-specific Purolite A530E resin usage rate (i.e., verify other treatment studies and vendor-provided data indicating treatment of 55,000 bed volumes at a concentration of up to 10,000 pCi/L for low competing anion concentrations and 15,000 bed volumes for elevated anions).
- Verify that Purolite A530E IX resin is selective for technetium-99 and does not adsorb other contaminants (e.g., carbon tetrachloride) present in Hanford Site groundwater.
- Verify that competing anions present in high concentrations (e.g., nitrate, sulfate, chloride, and bicarbonate) do not adversely reduce the resin's efficiency to the point that the technology is no longer viable.
- Verify that the resin is not adversely impacted by scaling or precipitates due to groundwater geochemistry.
- Determine operational parameters (e.g., pressure drop through the resin bed over time, need for backwashing, formation of scale on test equipment materials, plating of pertechnetate on metal components, and breakthrough times) to allow full-scale design of an IX system for technetium-99 removal.

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3.0 TEST IMPLEMENTATION

Treatability testing of the IX resin will consist of both bench-scale and pilot-scale testing. The bench-scale testing will be performed using a surrogate for technetium-99 and a range of concentrations of anions to test the influence of competing anion concentration on the ability of the resin to remove technetium-99.

The pilot-scale treatability tests will be conducted onsite using groundwater from operating extraction wells. Technetium-99 is currently only present at levels of concern in two extraction wells (299-W15-44 and 299-W15-765) and is not expected to be of concern at the majority of the 200-ZP-1 extraction wells. Therefore, it is desirable to minimize the size and cost of a technetium-99 pre-treatment system by employing the system only at the impacted wells rather than treating the full combined and diluted technetium-99 concentration at the air-stripper influent. Even though the conveyance pipes from extraction wells 299-W15-44 and 299-W15-765 are routed independently to the treatment system building, the IX treatability test will be employed directly at the well heads (i.e., still ex situ). This decision was made to avoid possible space constraints within the treatment system building, to take advantage of better accessibility of existing piping at the well heads, and to minimize pressure differentials and potential impacts to the current treatment system.

The following sections describe the details of the treatability testing equipment, equipment operation during the test, data to be collected during the test, and procedures for sample collection and analysis.

3.1 BENCH-SCALE TESTING

Bench-scale testing of the IX resin will be performed using a surrogate for technetium-99 (either rhenium in the perrhenate form [ReO4-] or perchlorate [ClO4-]). The characteristics of the resin will be examined as they pertain to the groundwater composition in wells 299-W15-44 and 299-W15-765. The resin is commercially made by Purolite (product name A530E), which was originally developed at Oak Ridge National Laboratory for technetium removal and is now marketed as a perchlorate removal resin. The bench-scale testing will determine the impact of varying concentrations of competing anions on technetium-99 loading. Currently, nitrate concentrations are rapidly climbing in well 299-W15-765, which may have future impact on a technetium-99 removal system design. Additionally, technetium-99 concentrations are rising in both of the extraction wells, and the impact of this on loading needs to be determined to accurately predict future system behavior or to port the design to future wells (should they begin to show increasing technetium-99 levels).

3.2 ONSITE PILOT-SCALE TREATABILITY TESTING

Two treatability test systems will be designed and built for treatment of water from wells 299-W15-765 and 299-W15-44. The systems will be able to process at least 10 gpm at existing concentrations of technetium-99 for approximately 60 days. The units will be intended to discern the real-world loading capacity of technetium-99 (in the presence of competing ions) associated with the existing flow from the groundwater wells. The systems will be designed to achieve 50% breakthrough in 60 days. Test systems will be manufactured with simplicity in mind using commercial off-the-shelf (COTS) material (i.e., polyvinyl chloride materials,

hand-valving, etc.). It is not intended that these systems provide long-term solutions, and they will be constructed as such; instead, the systems will be designed as short-term treatability systems to achieve rapid schedule and low-cost requirements using COTS material. Descriptions of the IX test columns and related equipment to be used for the tests at extraction wells 299-W15-765 and 299-W15-44 are provided in the following subsections.

3.2.1 Testing at Extraction Well 299-W15-765

Based on the expected water quality at well 299-W15-765, the resin manufacturer's testing data suggest that 50% breakthrough will occur after processing 20,000 resin bed volumes of groundwater. The column is designed to achieve 50% breakthrough in approximately 60 days.

It was determined that an IX test flow rate of 30 gpm from this well and a resin bed volume of 17.3 cu ft would achieve the 50% breakthrough in the desired 60-day timeframe. These calculations are provided in Appendix A.

A 30-in.-diameter, fiberglass-reinforced plastic test vessel will be used. The vessel will have a length (i.e., height) of approximately 72 in. to accommodate the 17.3 cu ft of resin, plus an additional 40% excess volume to allow for resin expansion.

Piping and instrumentation diagrams (P&IDs) have been prepared for the testing equipment (see Appendix B). The IX test vessel can be piped in at the well head as a parallel slipstream, as shown in the P&IDs in Appendix B. Alternatively, if the technetium-99 concentration is high enough that untreated bypass is to be avoided, then the IX test vessel can be piped directly in-line with the existing well head piping to have all extracted groundwater from this well flow through the IX resin. A particulate filter (either bag or cartridge type) will be installed upstream to help prevent clogging of the resin bed. A nominal 20-micron filter bag or cartridge (or smaller particle capture size) will be used in the filter, based on the resin manufacturer's recommendation.

3.2.2 Testing at Extraction Well 299-W15-44

Based on the expected water quality at well 299-W15-44, the resin manufacturer's testing data suggest that 50% breakthrough will occur after processing 71,000 resin bed volumes of groundwater. The recently observed flow capacity of extraction well 299-W15-44 is approximately 8 gpm. In addition, it is desired to perform the IX test at hydraulic flow conditions that are within the range of typical full-scale conditions.

At well 299-W15-44's current operating flow rate of 8 gpm, it was determined that a resin bed volume of 1.3 cu ft would achieve the 50% breakthrough in the desired 60-day timeframe. A 10-in.-diameter, fiberglass-reinforced plastic test vessel will be used for the test column for well 299-W15-44. The vessel will have a length (i.e., height) of approximately 54 in. to accommodate the 1.3 cu ft of resin, plus an additional 40% excess volume to allow for resin expansion. The test column would be designed to be capable of processing a flow rate of up to 10 gpm.

3.2.3 Piping, Valves, and Instrumentation

As identified in the P&IDs (Appendix B), adequate valves will be installed to control the flow rate through the test vessel. The valves can be installed in a manner to allow continued flow of groundwater from the well to the air-stripper treatment system in the event that the testing equipment needs to be isolated and repaired.

Insulation or heat tracing of the testing equipment and piping may be required to protect the system from extreme heat and cold conditions. During active groundwater pumping through the testing equipment, the water will act to moderate extreme temperatures. However, there would be special concern if the testing system was idle during periods when ambient temperature was below freezing due to possible pipe bursting. Necessary safeguards to protect against extreme temperatures or other potential causes of leaks will be considered if necessary and incorporated into the test system during final test system design. Containment will be installed to capture minor leaks and drips.

Sample ports will be installed to allow for the collection of influent and effluent samples from the resin column. One pressure-indicating gauge and approximately three differential pressure gauges will be installed within the testing equipment to monitor system pressure and to help identify possible issues (e.g., plugging of the filter or the IX resin bed). A turbine flow meter and totalizer (or alternate type of meter that is rated over the flow range of 2 to 50 gpm) will be used, and the manufacturer's recommendation will be followed for the minimum distance of straight-run pipe into and out of the meter. A thermo well and temperature gauge will be installed at the influent of the test system to allow for temperature monitoring during the test.

Based on discussions with Purolite, it does not appear likely that the beads of IX resin would become clogged and require backflushing, particularly because the testing is planned over a period of only 2 months. Therefore, no mechanism for backflushing the vessels is incorporated into the design.

If the technetium-99 concentration increases to such a degree that it is desirable to prevent untreated groundwater (i.e., post-breakthrough groundwater) from being pumped to the carbon tetrachloride air-stripper treatment system, then a secondary IX column can be added in series behind the primary test column. The secondary resin column can be used solely for technetium-99 containment and treatment purposes, and the effluent of the secondary column would not necessarily need to be analyzed at the same frequency as the primary test column.

3.3 TEST SYSTEM MONITORING AND OPERATION

Normal operation and maintenance procedures for the existing pump-and-treat system include daily examination of the groundwater extraction well field and piping. As part of this daily routine, the operator will examine the test systems and record relevant operational data during the testing period. Operational parameters to be recorded during the treatability test include pressure, temperature, and flow rate. An example test operation log form has been prepared for recording relevant data (see Appendix C).

The frequency of test system observation by an operator is expected to be once each normal workday throughout the duration of the test to identify potential leaks or malfunctioning equipment. An operation log form is anticipated to be completed once each workday for the first week of testing. If no significant potential concerns are identified during the first week of testing, it is anticipated that the frequency of completing the operation log can then be reduced to three times per week for the remainder of the testing period. The frequency of data collection may need to be adjusted based upon conditions encountered during testing.

Operational parameters that will be evaluated during the course of the testing include pressure drop across the particle filter and across the IX resin bed. For the particle filter, the manufacturer's recommendations will be followed, but filter cartridges or bags should typically be replaced before the pressure drop across the filter exceeds 15 pounds per square inch (psi).

For the IX column, the manufacturer's literature suggests that for the column size and flow rate to be used during this test, the pressure drop should be slightly under 10 psi. If the pressure drop increases to above 20 psi, the manufacturer suggests that backflushing the resin bed may be necessary because plugging of the resin is occurring.

3.4 SAMPLING AND ANALYSIS

A preliminary list of the sampling locations, sample collection frequency, and parameters for laboratory analysis is provided in Table 3-1. This section also refers to the sampling and analysis instruction (SAI), which is included as Appendix D. The SAI discusses sampling methods, containers, preservative, labeling, handling, holding times, etc. A laboratory of FH's preference will be used for sample analysis.

3.5 CRITERIA FOR TERMINATION OF TESTING

The IX treatability testing will continue until 50% breakthrough of technetium-99 has been measured at the effluent of the resin bed and the analytical result of a second sample confirms the breakthrough. The 50% breakthrough is defined as the point at which the effluent concentration equals one-half of the influent concentration:

$$C_{Eff} / C_{In} = 0.5$$

If, for some reason, 50% breakthrough is found to occur well in advance of the time expected (i.e., 20,000 bed volumes for well 299-W15-765 and 71,000 bed volumes for well 299-W15-44), then the test should be extended for the full 60 days. If 50% breakthrough does not occur by the end of 60 days, then the test duration should be extended until the 50% breakthrough is achieved.

Table 3-1. Preliminary Sampling Parameters and Frequency.

	Anions (EPA Method 300.0)[c]				Alkalinity (EPA Method 310.1)[c]	Technetium-99 (ICP/MS)[c,d]	Carbon Tetrachloride (SW-846 Method 8260B)[c]	pH (Water Quality Meter)
	Nitrate	Sulfate	Chloride	Phosphate				
Baseline								
299-W15-765	X	X	X	X	X	X	X	X[a]
299-W15-44	X	X	X	X	X	X	X	X[a]
299-W15-765								
Influent (two times per week)[b]	X					X		
Effluent (two times per week)[b]	X					X		
Influent (weekly)		X	X	X	X			X
Effluent (weekly)		X	X	X	X			X
A530E resin post-study samples[e]	X	X	X	X	X	X	X	
299-W15-44								
Influent (two times per week)[b]	X					X		
Effluent (two times per week)[b]	X					X		
Influent (weekly)		X	X	X	X		X	X
Effluent (weekly)		X	X	X	X		X	X
A530E resin post-study samples[e]	X	X	X	X	X	X	X	

NOTE: PNNL will act as the primary laboratory for analyses.

[a] For baseline pH conditions, analysis should be performed both in the field using a dedicated water quality instrument and by an analytical laboratory using EPA Method 150.1.

[b] It is initially estimated that collection of samples two times per week will be adequate. Of these two samples, one sample can be analyzed using field screening on a 48-hour turnaround time for nitrate and technetium-99. If the effluent sample is detected with technetium-99, then the second samples collected during that week can be analyzed by field screening as well, holding times permitting. If technetium-99 is not detected in the effluent sample by field screening, only one of the samples collected each week should be run by the fixed laboratory (using a standard 45-day turnaround time) using the ICP/MS methods and EPA Method 300.0. Otherwise, both samples collected each week could be run by the fixed laboratory (using a standard 45-day turnaround time).

[c] All fixed laboratory analyses should be run using a standard 45-day turnaround time.

[d] Technetium-99 analysis for groundwater samples is conducted in accordance with Procedure PNNL-AGG-415, *Inductively Coupled Plasma Mass Spectrometric (ICP-MS) Analysis* (PNNL 1998).

[e] If premature breakthrough of the IX resin is found to occur during testing, it may be advisable to perform a post-test analysis of the resin to determine the mass adsorption of technetium-99, other competing anions, and possible fouling agents (e.g., carbon tetrachloride) in order to determine possible causes for the poor IX resin performance. Resin may also need to be sampled for waste-designation purposes.

EPA = U.S. Environmental Protection Agency
ICP/MS = inductively coupled plasma/mass spectrometry
IX = ion exchange
PNNL = Pacific Northwest National Laboratory

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4.0 DATA ANALYSIS AND INTERPRETATION

4.1 ASSESSMENT OF DATA QUALITY

Data collected during the test (as described in Section 3.3) will be validated and evaluated as discussed in the SAI (Appendix D). Adequacy of the data will be evaluated in the treatability test report.

4.2 ASSESSMENT OF RESIN PERFORMANCE

If the data quality evaluation concludes that the testing data were of adequate quality, then an assessment of the effectiveness of the resin in removal of technetium-99 will be performed.

If premature breakthrough of the IX resin (relative to the expected number of bed volumes estimated by the resin supplier) is found to have occurred during testing, it may be advisable to perform laboratory analysis of the spent resin. The laboratory analysis of the spent test resin could be performed to determine the mass of technetium-99, other competing anions, and possible fouling agents (e.g., carbon tetrachloride) that were absorbed in order to determine possible causes for the poor IX resin performance. One reason that this post-test analysis may be helpful in determining whether competing anions or carbon tetrachloride caused premature exhaustion of the IX resin is that with the relatively high concentration of these other potentially competing parameters, it may be that there is a high degree of uncertainty in the adsorption rate onto the resin based solely on the influent and effluent concentrations. For example, if a nitrate inlet sample is measured by the laboratory to be 400 mg/L and the effluent to be 395 mg/L, the question remains if the resin actually absorbed 5 mg/L of nitrate, or rather that the 5 mg/L difference is simply a function of inherent laboratory accuracy.

If it is determined that it may be useful, Oak Ridge National Laboratory has developed a method by which the spent column may be "stripped," and an average of the accumulated concentration of technetium-99 within the resin measured. This data would be useful for future disposal of spent media.

4.3 EQUIPMENT EVALUATION AT END OF TESTING

To evaluate whether there is concern with scaling (i.e., the formation of precipitate) in the IX resin, the pressure data recorded during testing may be evaluated. A physical examination of the resin may also be conducted at the conclusion of testing to examine for the presence of scale or whether the resin beads have become cemented together.

Inspection of the IX column will be performed to assess radioactivity and to determine if the use of metal within a technetium-99 environment becomes significantly radioactive.

4.4 DESIGN AND IMPLEMENTATION OF A FULL-SCALE REMEDY

After the test results are analyzed, and if the test was successful, a decision may be made to proceed with full-scale application. Design considerations for a full-scale system may include the following:

- Location of the full-scale treatment system(s) at the well head versus at the carbon tetrachloride treatment plant

- Construction of mobile versus fixed-base treatment systems
- The need to provide for backflushing of resin beds
- Methods for disposal of spent IX media.

Following submittal of the treatability test summary report, a test plan will be developed for full-scale operations, and test procedures will be developed to implement the plan. The test procedures document will serve as the operations and maintenance manual for full-scale operations.

5.0 HEALTH AND SAFETY

All field operations will be performed in accordance with FH's, or its approved subcontractor's, health and safety plan (or equivalent) and the requirements of the most recent Waste Management Project radiological control procedures (or equivalent). Where necessary, a work-planning package will include a job hazard analysis and/or site-specific health and safety plan, as well as applicable radiological work permits, when appropriate.

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6.0 RESIDUALS MANAGEMENT

The nature of pertechnetate is such that it would be difficult to handle the regeneration effluent. Therefore, it is Purolite's recommendation that the used resin be disposed rather than regenerated. The spent IX column will be tested to determine its chemical and radiological characteristics. The spent column should be turned over to FH's Waste Management group for waste designation and disposal. Waste generated during this treatability test will be managed in accordance with the 200-ZP-1 Waste Management Plan (DOE/RL-2005). It is anticipated that the spent column will be able to be disposed of in the Environmental Restoration Disposal Facility.

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7.0 REFERENCES

DOE-RL, 2005, *Waste Management Plan for the Expedited Response Action for 200 West Area Carbon Tetrachloride Plume and the 200-ZP-1 and 200-PW-1 Operable Units*, DOE/RL-2000-40, Rev. 6, REISSUE, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL, 2006, *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit*, DOE/RL-2006-24, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, EPA/540/G-89/004, U.S. Environmental Protection Agency, Washington, D.C.

EPA, Ecology, and DOE, 1995, *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit*, #016085, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

PNNL, 1998, *Inductively Coupled Plasma Mass Spectrometric (ICP-MS) Analysis*, Procedure PNNL-AGG-415, Pacific Northwest National Laboratory, Richland, Washington

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APPENDIX A

ION-EXCHANGE VESSEL SIZING CALCULATIONS

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TABLE A-1
ION EXCHANGE VESSEL SIZING CALCULATIONS FOR TEST AT EXTRACTION WELL 299-W15-765
FLUOR HANFORD
RICHLAND, WASHINGTON

Extraction Well 299-W15-765

User Entered Values for the Calculations:

12,000	Treatment Bed Volumes (estimated by Purolite based on influent concentrations below)
<5,000	Tc-99 Concentration (pCi/L)
400	Nitrate (mg/L)
<50	Sulfate (mg/L)
11	Flow Rate (gpm)
2.5	Media Efficiency (1-5 gpm/cf) = 3.0 minutes empty bed contact time
40%	Percent Expansion for Backwashing (Recommended 40-60%)

1) Calculate Media Capacity
12,000 Bed Volumes x 7.48 gal/cf = **89,760 gal/cf**

2) Calculate Volume of Media
11 gpm x $\frac{1}{2.5 \text{ gpm/cf}}$ = **4.4 cf of media**

3) Calculate Time for Breakthrough
89,760 gal/cf x $\frac{1}{2.5 \text{ gpm/cf}}$ = **35,904 min**
598.4 hr
25 days

4) Calculate Column Dimensions
Note: Minimum resin depth = 30"
Therefore, minimum column height based on **40%** expansion = **3.5 ft**

Using an 8" Diameter Column

4.40 cf x 40% expansion = 6.16 cf

Height of column = $\frac{6.16 \text{ cf}}{0.349 \text{ sf}}$ = **17.6 ft**

Flux (8 to 12 gpm/sf typical design)
32 gpm/sf

Using a 10" Diameter Column

4.40 cf x 40% expansion = 6.16 cf

Height of column = $\frac{6.16 \text{ cf}}{0.545 \text{ sf}}$ = **11.3 ft**

20 gpm/sf

Using a 12" Diameter Column

4.40 cf x 40% expansion = 6.16 cf

Height of column = $\frac{6.16 \text{ cf}}{0.785 \text{ sf}}$ = **7.8 ft**

14 gpm/sf

Using a 14" Diameter Column (16" Sch. 80 PVC = 14.3" I.D.)

4.40 cf x 40% expansion = 6.16 cf

Height of column = $\frac{6.16 \text{ cf}}{1.115 \text{ sf}}$ = **5.5 ft**

10 gpm/sf

TABLE A-2
ION EXCHANGE VESSEL SIZING CALCULATIONS FOR TEST AT EXTRACTION WELL 299-W15-44
FLUOR HANFORD
RICHLAND, WASHINGTON

Extraction Well 299-W15-44

User Entered Values for the Calculations:

55,000	Treatment Bed Volumes (estimated by Purolite based on influent concentrations below)
<5,000	Tc-99 Concentration (pCi/L)
110	Nitrate (mg/L)
<50	Sulfate (mg/L)
8.5	Flow rate (gpm)
2.5	Media Efficiency (1-5 gpm/cf) = 3.0 minutes empty bed contact time
40%	Percent Expansion for Backwashing (Recommended 40-60%)

1) Calculate Media Capacity

55,000 Bed Volumes x 7.48 gal/cf = **411,400 gal/cf**

2) Calculate Volume of Media

8.5 gpm x $\frac{1}{2.5 \text{ gpm/cf}}$ = **3.4 cf of media**

3) Calculate Time for Breakthrough

411,400 gal/cf x $\frac{1}{2.5 \text{ gpm/cf}}$ = **164,560 min**
2743 hr
114 days

4) Calculate Column Dimensions

Note: Minimum resin depth = 30"
Therefore, minimum column height based on **40%** expansion = **3.6 ft**

Using an 8" Diameter Column

3.40 cf x 40% expansion = 4.76 cf

Height of column = $\frac{4.76 \text{ cf}}{0.349 \text{ sf}}$ = **13.6 ft**

Flux (8 to 12 gpm/sf typical design)
24 gpm/sf

Using a 10" Diameter Column

3.40 cf x 40% expansion = 4.76 cf

Height of column = $\frac{4.76 \text{ cf}}{0.545 \text{ sf}}$ = **8.7 ft**

16 gpm/sf

Using a 12" Diameter Column

3.40 cf x 40% expansion = 4.76 cf

Height of column = $\frac{4.76 \text{ cf}}{0.785 \text{ sf}}$ = **6.1 ft**

11 gpm/sf

Using a 14" Diameter Column (16" Sch. 80 PVC = 14.3" I.D.)

3.40 cf x 40% expansion = 4.76 cf

Height of column = $\frac{4.76 \text{ cf}}{1.115 \text{ sf}}$ = **4.3 ft**

8 gpm/sf

APPENDIX B

ION-EXCHANGE TREATABILITY TEST -- PIPING AND INSTRUMENTATION DIAGRAMS

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Figure B-1. Piping and Instrumentation Diagram for Well 299-W15-765.

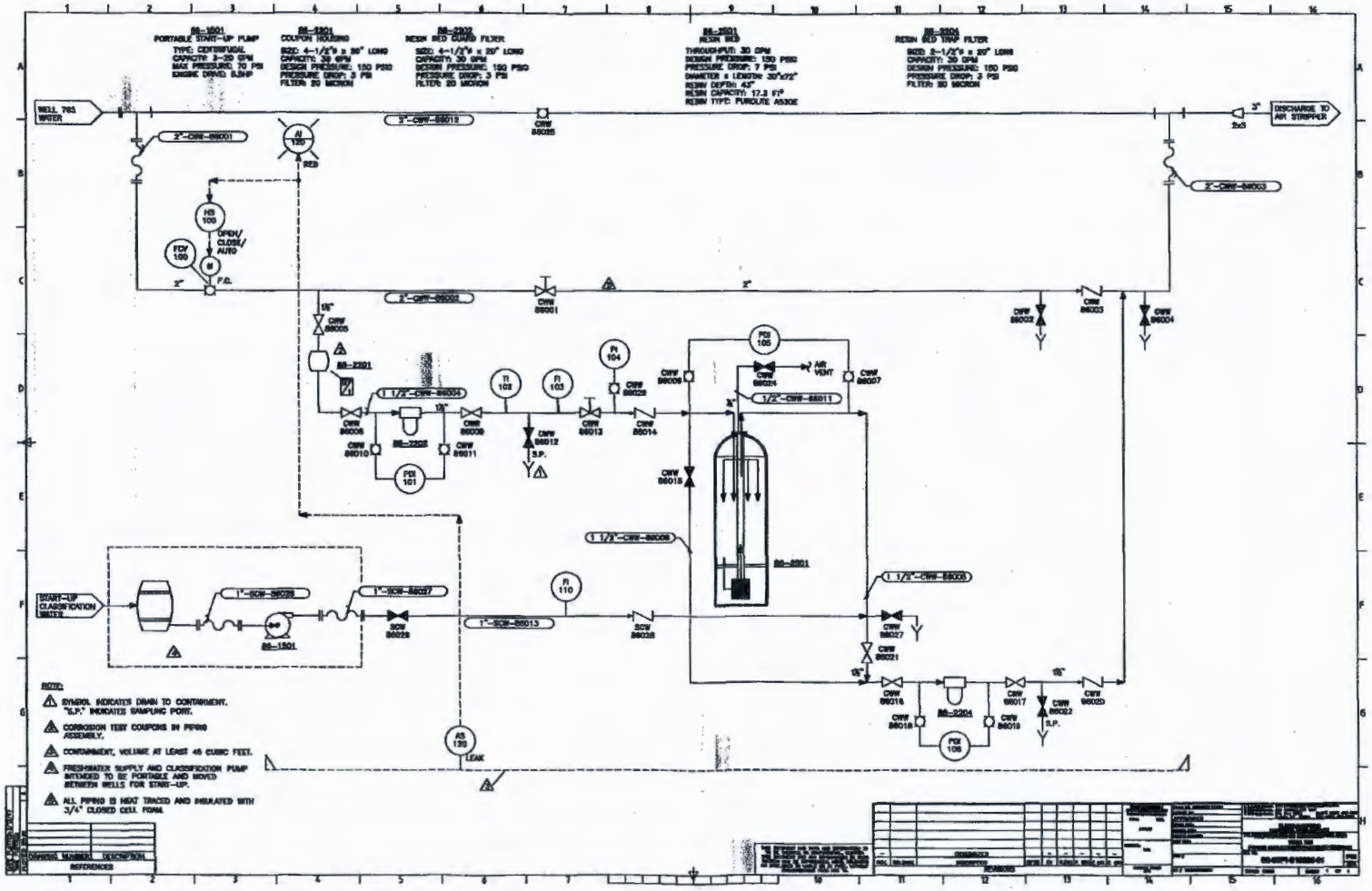
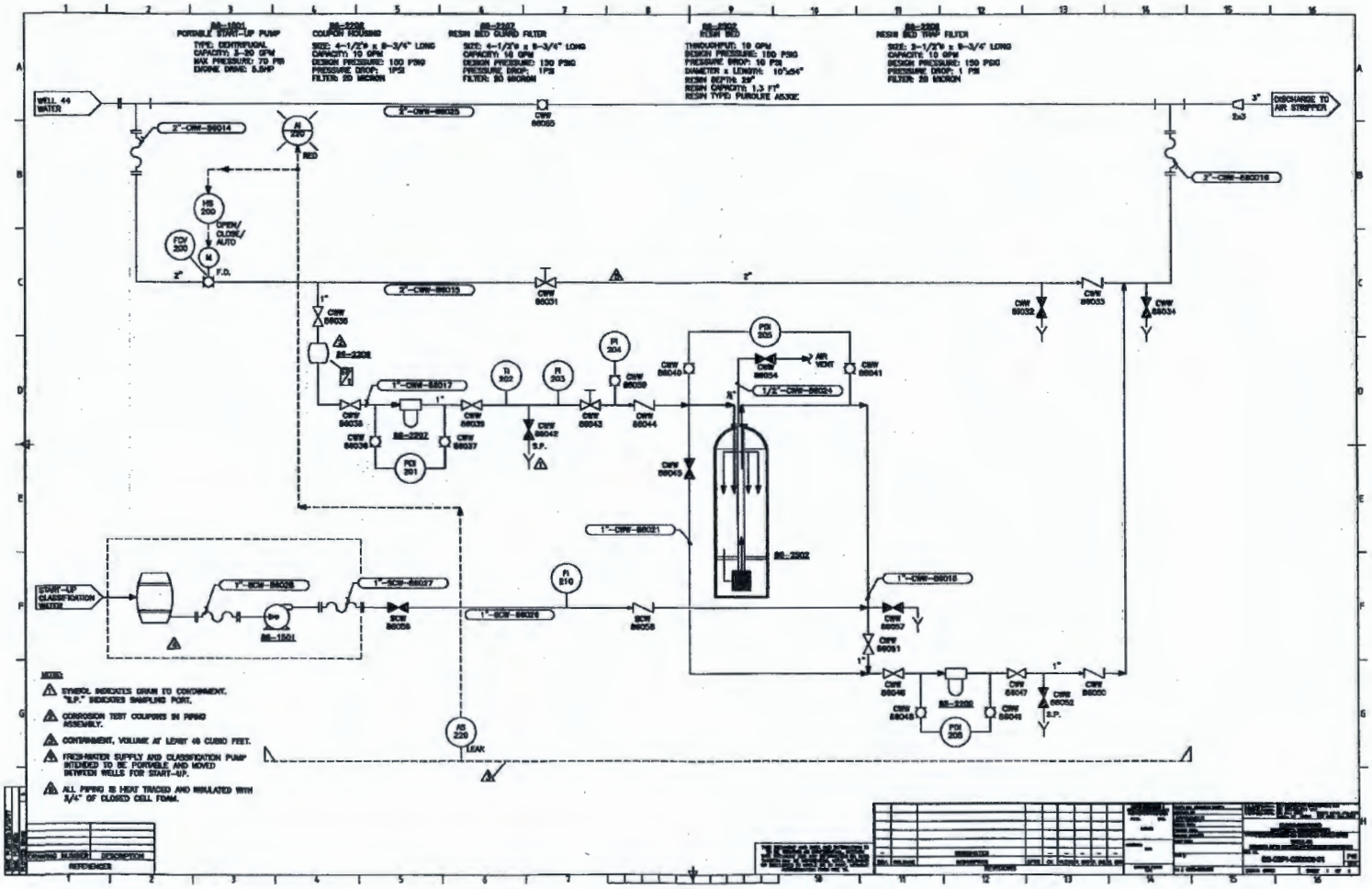


Figure B-2. Piping and Instrumentation Diagram for Well 299-W15-44.



APPENDIX C

TREATABILITY TEST OPERATION LOG

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TREATABILITY TEST OPERATION LOG
FLUOR HANFORD
RICHLAND, WASHINGTON

Operator Name: _____ **Date:** _____

299-W15-765

Time of Reading	
System Influent Pressure Gauge, PI-101 (psi)	
Inlet Temperature, TI-101 (°F)	
Particulate Filter Inlet Pressure Gauge, PI-102 (psi)	
Particulate Filter Outlet/Resin Column Inlet Pressure Gauge, PI-103 (psi)	
Treatment System Flow Rate (gpm)	
Totalized Discharge Volume (gal)	
Resin Column Outlet Pressure Gauge, PI-104 (psi)	
Water Leaks from system?	Yes / No

Water Quality Samples Collected Today? Yes / No
If yes, sample locations: _____
Samples were submitted for: _____
Immediate Analysis (48 hr TAT)
Hold for Analysis

Comments: _____

299-W15-44

Time of Reading	
System Influent Pressure Gauge, PI-101 (psi)	
Inlet Temperature, TI-101 (°F)	
Particulate Filter Inlet Pressure Gauge, PI-102 (psi)	
Particulate Filter Outlet/Resin Column Inlet Pressure Gauge, PI-103 (psi)	
Treatment System Flow Rate (gpm)	
Totalized Discharge Volume (gal)	
Resin Column Outlet Pressure Gauge, PI-104 (psi)	
Water Leaks from system?	Yes / No

Water Quality Samples Collected Today? Yes / No
If yes, sample locations: _____
Samples were submitted for: _____
Immediate Analysis (48 hr TAT)
Hold for Analysis

Comments: _____

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APPENDIX D

SAMPLING AND ANALYSIS INSTRUCTION TO SUPPORT TREATABILITY TESTING OF PUROLITE RESIN A530E FOR REMOVING TECHNETIUM-99 FROM 200-ZP-1 GROUNDWATER

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CONTENTS

D1.0 INTRODUCTION D-1
D1.1 CONTAMINANTS OF CONCERN D-1
D1.2 SAMPLING AND ANALYSES TO SUPPORT TREATABILITY TESTING D-1
D2.0 QUALITY ASSURANCE PROJECT PLAN D-2
D2.1 PROJECT MANAGEMENT D-2
D2.1.1 Project/Task Organization D-2
D2.1.2 Quality Objectives and Criteria for Measurement Data D-2
D2.1.3 Special Training Requirements and Certification D-2
D2.1.4 Documentation and Records D-3
D2.2 DATA/MEASUREMENT ACQUISITION D-3
D2.2.1 Sampling Methods Requirements D-4
D2.2.2 Sampling Identification D-4
D2.2.3 Sample Handling, Shipping, and Custody Requirements D-4
D2.2.4 Analytical Methods Requirements D-4
D2.2.5 Quality Control Requirements D-4
D2.2.6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements D-5
D2.2.7 Instrument Calibration and Frequency D-5
D2.2.8 Inspection/Acceptance Requirements for Supplies and Consumables D-5
D2.2.9 Data Management D-5
D2.2.10 Sample Preservation, Containers, and Holding Times D-6
D2.2.11 Field Documentation D-6
D2.3 ASSESSMENT/OVERSIGHT D-6
D2.3.1 Assessments and Response Action D-6
D2.3.2 Reports to Management D-6
D2.4 DATA REVIEW, VERIFICATION, VALIDATION, AND USABILITY REQUIREMENTS D-6
D2.4.1 Data Verification and Usability Methods D-6
D2.4.2 Data Validation D-6
D2.4.3 Data Quality Assessment D-7
D3.0 FIELD SAMPLING PLAN D-7
D3.1 SAMPLING OBJECTIVES D-7
D3.2 SAMPLING LOCATIONS AND FREQUENCY D-7
D3.3 WELL DRILLING PROCEDURES D-7
D3.4 SAMPLING PROCEDURES D-7

D3.5 SAMPLE MANAGEMENT D-8
D3.5.1 Sample Custody D-8
D3.5.2 Sample Packaging and Shipping D-8
D3.5.3 Field Documentation D-8
D3.6 MANAGEMENT OF WASTE D-8
D4.0 HEALTH AND SAFETY D-9
D5.0 REFERENCES D-9

TABLES

Table D2-1. Analytical Performance Requirements for Contaminant of Concern Analysis D-3
Table D2-2. Field Quality Control Requirements D-5

APPENDIX D

SAMPLING AND ANALYSIS INSTRUCTION TO SUPPORT TREATABILITY TESTING OF PUROLITE RESIN A530E FOR REMOVING TECHNETIUM-99 FROM 200-ZP-1 GROUNDWATER

D1.0 INTRODUCTION

This sampling and analysis instruction (SAI) was prepared to support treatability testing of the Purolite® A530E resin for removing technetium-99 from groundwater at the 200-ZP-1 Operable Unit (OU). The current 200-ZP-1 groundwater treatment system does not remove technetium-99, and the increasing technetium-99 concentrations from wells 299-W15-44 and 299-W15-765 currently exceed the U.S. Environmental Protection Agency's (EPA's) maximum contaminant level (MCL) for technetium-99 (900 pCi/L). The technetium-99 concentration of the mixed groundwater from all 10 of the current extraction wells is just greater than one-half of the MCL for technetium-99 but is increasing rapidly. If the water continues to remain untreated for technetium-99, there is a concern that the water reinjected into the aquifer could exceed EPA standards, technetium-99 could plate onto metal components of the current system, and/or technetium-99 could be adsorbed by the existing granular activated carbon canisters. These issues could potentially expose site employees and operators to elevated levels of beta radiation.

This SAI presents details on the sampling and analyses that will be performed to support this treatability testing.

D1.1 CONTAMINANTS OF CONCERN

The contaminants of concern (COCs) related to this study include technetium-99, carbon tetrachloride, nitrate, sulfate, chloride, phosphate. Other parameters of interest for testing include alkalinity and pH.

D1.2 SAMPLING AND ANALYSES TO SUPPORT TREATABILITY TESTING

Groundwater samples shall be collected from the influent and effluent of treatability test filters placed in line with the extraction water from wells 299-W15-44 and 299-W15-765. The samples shall be collected at the frequency and analyzed for the parameters that are specified in Table 3-1 in the main text of the treatability test plan. The purpose of this sampling is to evaluate the effectiveness of Purolite A530E resin in removing technetium-99 from 200-ZP-1 groundwater and the affect that various anions (e.g., nitrate), alkalinity, and carbon tetrachloride have on the performance of the resin.

A post-study sample of the A530E resin may also be collected and analyzed for the parameters specified in Table 3-1 (see main text of treatability test plan) if premature breakthrough of the ion-exchange (IX) resin occurs during the test. It may be advisable to perform a post-test analysis of the resin to determine the mass adsorption of technetium-99 and the presence of other

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competing anions or possible fouling agents (e.g., carbon tetrachloride) in order to determine possible causes for the poor IX resin performance.

D2.0 QUALITY ASSURANCE PROJECT PLAN

This section identifies the individuals or organizations participating in the project and discusses specific roles and responsibilities. The quality objectives for measurement data and the special training requirements for staff performing the work are also discussed.

D2.1 PROJECT MANAGEMENT

The following subsections address the basic areas of project management and will ensure that the project has a defined goal, the participants understand the goal and the approach to be used, and the planned outputs have been appropriately documented.

D2.1.1 Project/Task Organization

Fluor Hanford, Inc. (FH), or its approved subcontractor, will be responsible for collecting, packaging, and shipping groundwater samples to the laboratory. FH will select a laboratory to perform the analyses; the laboratory selected must conform to Hanford Site laboratory procedures (or their equivalent), as approved by the U.S. Department of Energy, Richland Operations Office; EPA; and the Washington State Department of Ecology. FH is responsible for managing all interfaces among subcontractors involved in executing the work described in the treatability test plan and SAI.

D2.1.2 Quality Objectives and Criteria for Measurement Data

The detection limits and the precision and accuracy requirements for each analysis to be performed are summarized Table D2-1.

Procedures from either FH or its approved subcontractor will be used. This applies to all FH or approved subcontractor procedures identified in this SAI.

D2.1.3 Special Training Requirements and Certification

Training or certification requirements for sampling personnel shall be in accordance with the requirements specified in the *Hanford Analytical Services Quality Assurance Requirements Document* (HASQARD), Vol. 1, "Administrative Requirements" (DOE-RL 1998).

Field personnel will typically have completed the following training before starting work:

- Occupational Safety and Health Administration 40-Hour Hazardous Waste Worker Training
- 8-Hour Hazardous Waste Worker Refresher Training (as required)
- Radiation Worker II Training
- Hanford General Employee Training.

Table D2-1. Analytical Performance Requirements for Contaminant of Concern Analysis.

Type of COC	COCs	Survey or Analytical Method[a]	CRDL[b] µg/L	Precision Required	Accuracy Required
Nonradiological COCs					
Volatile organics	Carbon tetrachloride	SW-846, Method 8260[b]	5	±20%[d]	80%-120%[d]
Non-metals	Nitrate	300.0[c]	250	±20%[e]	80%-120%[e]
	Sulfate	300.0[c]	500	±20%[e]	80%-120%[e]
	Chloride	300.0[c]	200	±20%[e]	80%-120%[e]
	Phosphorus and phosphate (must digest to include organo-phosphates)	365.1, 365.2, or 365.3	100	±20%[e]	80%-120%[e]
	Alkalinity	310.1	5,000	±20%[e]	80%-120%[e]
Radiological COCs					
Beta emitters	Tc-99	Liquid scintillation	15 pCi/L	±30%[f]	70-130%[f]

[a] Analytical method selection is based on available methods by laboratories currently contracted to the Hanford Site. Equivalent methods may be substituted in future sampling and analysis instructions or other documents. Four-digit methods are from EPA's SW-846 (EPA 1997); other methods referenced to source.

[b] Typical CRDL or minimum detectable concentrations are based on current Hanford laboratory contracts. Detection limits in subsequent documents may differ depending on method selection and the contract laboratory. Units are "µg/L" for nonradiological COCs and "pCi/L" for radiological COCs (unless otherwise noted).

[c] Method from *Standard Methods for Examination of Water and Wastewater* (Eaton et al. 1995).

[d] Accuracy criteria are the minimum for associated batch laboratory control sample percent recoveries. Laboratories must meet statistically based control, if more stringent. Additional analyte-specific evaluations also performed for matrix spikes and surrogates as appropriate to the method. Precision criteria for batch laboratory replicate matrix spike sample analyses.

[e] Accuracy criteria for associated batch matrix spike percent recoveries. Evaluation based on statistical control of laboratory control samples also performed. Precision criteria for batch laboratory replicate matrix spike sample analyses or replicate sample analyses.

[f] Accuracy criteria for associated batch laboratory control sample percent recoveries. With the exception of gamma energy analysis, additional analysis-specific evaluations are also performed for matrix spikes, tracers, and carriers, as appropriate to the method. Precision criteria for batch laboratory replicate sample and analyses.

COC = contaminant of concern
CRDL = contract-required detection limit

D2.1.4 Documentation and Records

Field sampling and laboratory analytical documentation will be in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D2.2 DATA/MEASUREMENT ACQUISITION

The following subsections present the requirements for sampling methods, sample handling and custody, analytical methods, and field and laboratory quality control (QC). The requirements for instrument calibration and maintenance, supply inspections, and data management are also addressed.

D2.2.1 Sampling Methods Requirements

The sampling procedures to be implemented in the field should be in accordance with those outlined in FH internal work processes and requirements (or flow-down requirements to FH subcontractors). When any problems are encountered during the sampling, the task lead should be contacted for direction.

D2.2.2 Sampling Identification

A sample and data-tracking database will be used to track samples from the point of collection through the laboratory analysis process. The Hanford Environmental Information System (HEIS) database is the repository for laboratory analytical results. The HEIS sample numbers will be issued to the sampling organization for this project. The HEIS numbers are to be carried through the laboratory data-tracking system.

D2.2.3 Sample Handling, Shipping, and Custody Requirements

All sample handling, shipping, and custody requirements will be in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D2.2.4 Analytical Methods Requirements

Analytical parameters and methods are listed in Table D2-1. Laboratory-specific standard operating procedures for analytical methods are described in FH internal work processes and requirements (or flow-down requirements to FH subcontractors). If problems are encountered when running analytical methods, the laboratory shall contact Sample and Data Management, who will in turn contact the task lead and issue a sample disposition record.

D2.2.5 Quality Control Requirements

The QC procedures described in FH internal work processes and requirements (or flow-down requirements to FH subcontractors) will be followed in the field and laboratory to ensure that reliable data are obtained. When performing this field sampling effort, care should be taken to prevent the cross-contamination of sampling equipment, sample bottles, and other equipment that could compromise sample integrity.

Table D2-2 lists the field QC requirements for sampling. If only disposable equipment is used or equipment is dedicated to a particular well, then an equipment rinsate blank is not required. If volatile organic compound samples are not collected, then a field transfer blank is not required.

Laboratory QC sample requirements are specified in FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

Table D2-2. Field Quality Control Requirements.

Sample Type	Frequency	Purpose
Duplicate	5% (1 sample in 20)	To check the precision of the laboratory analyses.
Equipment rinsate[a]	One per 10 well trips	To check the effectiveness of the decontamination process.
Field transfer blank	One per day when volatile organics are sampled	To check for contamination during transport.

[a] Only required if reusable sample tool is required to collect samples.

D2.2.6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements

All onsite environmental instruments shall be tested, inspected, and maintained in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors). The results from all testing, inspection, and maintenance activities shall be recorded in a bound logbook in accordance with procedures outlined in FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D2.2.7 Instrument Calibration and Frequency

If onsite instrumentation is used, it shall be calibrated in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors). The results from all instrument calibration activities shall be recorded in a bound logbook in accordance with procedures outlined in FH internal work processes and requirements (or flow-down requirements to FH subcontractors). Tags will be attached to all field screening and onsite analytical instruments, noting the date when the instrument was last calibrated and the calibration expiration date.

D2.2.8 Inspection/Acceptance Requirements for Supplies and Consumables

All subject activities shall meet the requirements of FH internal work processes and requirements (or flow-down requirements to FH subcontractors). The lot number from the manufacturer-certified, pre-cleaned sample containers shall be recorded in the sampler's logbook.

D2.2.9 Data Management

Data resulting from the implementation of this SAI will be stored in the HEIS database. All reports and supporting analytical data packages will be subject to final technical review by qualified reviewers before submittal to the regulatory agencies or inclusion in reports or technical memoranda. Electronic data access, when appropriate, shall be through computerized databases (e.g., HEIS). Where electronic data are not available, hard copies will be provided in accordance with Section 9.6 of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et. al. 2003).

D2.2.10 Sample Preservation, Containers, and Holding Times

Sample preservation, container, and holding time requirements will be prepared for specific sample events as specified on sampling authorization forms and chain-of-custody forms in accordance with the requirements specified in FH internal work processes and requirements (or flow-down requirements to FH subcontractors) and the specific analytical method.

D2.2.11 Field Documentation

Field documentation shall be kept in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D2.3 ASSESSMENT/OVERSIGHT

D2.3.1 Assessments and Response Action

The FH Compliance and Quality Programs group may conduct random surveillance and assessments to verify compliance with the requirements outlined in this SAI, project work packages, the project quality management plan, procedures, and regulatory requirements.

Deficiencies identified during these assessments shall be reported to FH's 200-ZP-1 task lead. When appropriate, corrective actions will be taken by the task lead in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors) to minimize recurrence.

D2.3.2 Reports to Management

Management shall be made aware of all deficiencies identified by self-assessments. Identified deficiencies shall be reported to FH's 200 Area task lead.

D2.4 DATA REVIEW, VERIFICATION, VALIDATION, AND USABILITY REQUIREMENTS

D2.4.1 Data Verification and Usability Methods

Data review and verification are performed by the laboratory to confirm that sampling and chain-of-custody documentation are complete. Documentation includes tying sample numbers to specific sampling location, reviewing sample collection, indicating the preparation and analysis dates to assess meeting required holding times, and reviewing QC to determine whether analyses met the data quality requirements specified in this SAI.

All data verification and usability assessments shall be performed in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D2.4.2 Data Validation

Data validation is performed either by an independent third party not involved in sampling, analysis, or assessment; or by the Waste Disposal/Groundwater Remediation Projects; or by Pacific Northwest National Laboratory using FH internal work processes and requirements (or flow-down requirements to FH subcontractors). Five percent of the results will undergo validation.

D2.4.3 Data Quality Assessment

Data quality may be assessed based on the trends of concentration in wells over time. As appropriate, the data quality assessment may include the statistical approaches identified in EPA's *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA 2000).

D3.0 FIELD SAMPLING PLAN

D3.1 SAMPLING OBJECTIVES

The objective of the field sampling plan is to clearly identify project sampling and analysis activities. The field sampling plan uses figures and tables whenever possible to identify sampling locations, the total number of samples to be collected, sampling procedures to be implemented, analyses to be performed, and sample bottle requirements.

D3.2 SAMPLING LOCATIONS AND FREQUENCY

Groundwater samples shall be collected from the influent and effluent of treatability test filters placed in line with the extraction water from wells 299-W15-44 and 299-W15-765. These samples shall be collected at the frequency and analyzed for the parameters specified in Table 3-1 in the main text of this treatability test plan. The purpose of this sampling is to evaluate the effectiveness of the A530E resin in removing technetium-99 from 200-ZP-1 groundwater and the affects that various anions (e.g., nitrate), alkalinity, and carbon tetrachloride have on the performance of the resin.

A post-study sample of the A530E resin may also be collected and analyzed for the parameters specified in Table 3-1 (main text of this treatability test plan) if premature breakthrough of the IX resin is occurs during testing. It may be advisable to perform a post-test analysis of the resin to determine the mass adsorption of technetium-99 and the presence of other competing anions or possible fouling agents (e.g., carbon tetrachloride) in order to determine possible causes for the poor IX resin performance.

D3.3 WELL DRILLING PROCEDURES

Well drilling will be performed in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors) and *Washington Administrative Code* (WAC) 173-160, "Minimum Standards for Construction and Maintenance of Wells."

D3.4 SAMPLING PROCEDURES

The procedures to be implemented in the field for sampling and purgewater management should be in accordance with those outlined in FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D3.5 SAMPLE MANAGEMENT

Sample and data management activities will be performed in accordance with FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

Sample preservation, container, and holding-time requirements will be specified on sampling authorization forms and chain-of-custody forms in accordance with the requirements specified in FH internal work processes and requirements (or flow-down requirements to FH subcontractors) and the specific analytical method.

D3.5.1 Sample Custody

All samples obtained during the project will be controlled from the point of origin to the analytical laboratory, as required by FH internal work processes and requirements (or flow-down requirements to FH subcontractors).

D3.5.2 Sample Packaging and Shipping

Sample custody during laboratory analysis will be addressed in the applicable laboratory's standard operating procedures.

D3.5.3 Field Documentation

Sample preservation and container details will be addressed on the sampling authorization form and chain-of-custody form in accordance with the requirements specified in FH internal work processes and requirements (or flow-down requirements to FH subcontractors); and analytical method requirements.

D3.6 MANAGEMENT OF WASTE

FH internal work processes and requirements (or flow-down requirements to FH subcontractors) will be used to address the management of waste.

Waste generated by sampling activities will be managed in accordance with an established waste management plan and the requirements of FH internal work processes and requirements (or flow-down requirements to FH subcontractors). Investigation-derived wasted from sampling activities will be handled as *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* waste. Unused samples and associated laboratory waste for the analysis will be dispositioned in accordance with the laboratory contract and agreements for return to the Hanford Site. In accordance with 40 *Code of Federal Regulations* (CFR) 300.440, Remedial Project Manager approval is required before returning unused samples or waste from offsite laboratories.

A waste management plan (DOE-RL 2000) has been prepared for the 200-ZP-1 OU. The waste management plan establishes the requirements for management and disposal of waste generated from groundwater wells that are used to monitor the 200-ZP-1 OU, as required by the *Declaration of the Interim Record of Decision for the 200-ZP-1 Operable Unit* (EPA et. al. 1995).

D4.0 HEALTH AND SAFETY

All field operations will be performed in accordance with FH's, or its approved subcontractor's, health and safety plan (or equivalent) and the requirements of the most recent Waste Management Project radiological control procedures (or equivalent). Where necessary, a work planning package will include a job hazard analysis and/or site-specific health and safety plan, and applicable radiological work permits, as appropriate. The job hazard analysis has been and may continue to be used for ongoing sampling activities that are already underway. However, with more extensive work performed (e.g., drilling), a site-specific plan is currently being written.

D5.0 REFERENCES

40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of Federal Regulations*, as amended.

BHI, 2001, *Remedial Investigation Data Quality Objectives Summary Report for the 200-PW-1 Operable Unit Phase I Representative Waste Sites,* BHI-01477, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601, et seq.

CP-GPP-EE-01-1.11, "Purgewater Management," Fluor Hanford, Inc., Richland, Washington.

CP-GPP-EE-02-14.0, "Drilling, Maintaining, Remediating, and Decommissioning Resource Protection Wells, Geoprobe, and Geotechnical Soil Borings," Fluor Hanford, Inc., Richland, Washington.

DOE-RL, 2000, *Waste Management Plan for the Expedited Response Action for 200 West Area Carbon Tetrachloride Plume and the 200-ZP-1 and 200-PW-1 Operable Units*, DOE/RL-2000-40, Rev.-4, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Eaton, A. D., L. S. Clesceri, and A. E. Greenberg, 1995, *Standard Methods for Examination of Water and Wastewater*, 19th edition, American Public Health Association, Washington, D.C.

Ecology, EPA, and DOE, 2003, *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement), 2 vols., as amended, 89-10, Rev. 6, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

EPA, 1997, *Test Methods for Evaluation Solid Waste, Physical/Chemical Methods,* SW-846, 3rd edition (as amended by Update I [July 1992], Update IIA [August, 1993], Update IIB [January 1995], and Update III), U.S. Environmental Protection Agency, Washington, D.C.

EPA, 2000, *Guidance for Data Quality Assessment: Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, U.S. Environmental Protection Agency, Environmental Protection Office of Environmental Information, Washington, D.C.

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HNF-MP-599, *Project Hanford Quality Assurance Program Description*, Fluor Hanford, Inc., Richland, Washington.

HNF-PRO-455, *Solid Waste Management*, Fluor Hanford, Inc., Richland, Washington.

RFS, 1999, *Statement of Work for Environmental and Waste Characterization Analytical Services*, RFSH-SOW-0003, Rev. 6, Rust Federal Services, Richland, Washington.

WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," *Washington Administrative Code*, as amended.

WAC 173-340, "Model Toxics Control Act – Cleanup," *Washington Administrative Code*, as amended.

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APPENDIX J

NATIVE AMERICAN TRADITIONAL LIFEWAYS SCENARIO RISK ASSESSMENT

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The Native American scenario risk assessment will be included in the next revision of this document.

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