

Appendix A
Baseline Human Health Risk Assessment

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 French Drain, 216-Z-9, and 216-Z-10 Injection/Reverse Well. 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) identified these soil sites as representative or unique of the 16 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 humans 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 concentrations are below maximum contaminant levels (MCLs). The unrestricted land use scenario (subsistence farmer) 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 subsistence farming population (adults and children) and a working population (well drillers) are hypothetically possible.

Note that the risk assessment assumes there will be no reduction in current contaminant levels but uses current concentrations to assess risks 150 years in the future. While this is consistent with the health-protective nature of risk assessment procedures, it is an overestimate of actual future risks because of the planned active groundwater treatment program and the natural degradation of the organic compounds.

Including an unrestricted land use scenario, this risk assessment meets the following obligations:

- 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)
- 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. The National Contingency Plan expectation for groundwater is that usable groundwater will be returned to the highest beneficial use (i.e., drinking water) “...wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site” (40 CFR 300.430[a][1][iii][F]).

Selection of Contaminants of Potential Concern

The first step in a HHRA 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 a risk assessment, contaminants are referred to as “final COPCs” until the feasibility study is complete. Contaminants that

exceed target health goals at the end of the risk assessment process are referred to as “final COPCs.” 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 (2001 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
- Chromium (total)
- 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.) Table ES-1 provides selected COPCs.

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

Contaminant	216-Z-1A	216-Z-8 French Drain	216-Z-9	216-A-8
Am-241	√	√	√	
Cadmium			√	
C-14				√
Carbon tetrachloride			√	
Cs-137				√
Eu-152			√	
Manganese			√	
Np-237			√	√
Nickel-63			√	
Pu-238		√	√	
Pu-239/240	√	√	√	√
Pa-231			√	
Ra-226			√	
Ra-228			√	√
Sr-90			√	
Tc-99			√	√
Thallium				√
Th-228			√	√
Th-230			√	

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 subsistence 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 (subsistence farmer use post-2150, if institutional controls fail in the future). The subsistence farmer land use scenario assumes that after the year 2150, potential exposures to a future subsistence 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 (RME) scenario for each pathway, which is a calculation that overestimates 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 range is 10^{-6} to 10^{-4} , with action usually required if risks exceed 10^{-4} ; target health goals for non-cancer contaminants are a hazard index (HI) of ≤ 1 .

Under current industrial land use and institutional controls, exposures to contaminants and radionuclides in groundwater and soil are less likely, but still possible. 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 encounter 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 the 216-Z-8 French Drain 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 the 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.

Table ES-2. Summary of Risks from Soil

Radionuclide or Contaminant	Current Construction Worker	Future Well Driller	Future Subsistence 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

Table ES-2. Summary of Risks from Soil

Radionuclide or Contaminant	Current Construction Worker	Future Well Driller	Future Subsistence Farmer		
	Soil	Soil	Soil	Produce ^a	
Total ^c	9E-07	2E-09	3E-06	1E-05	
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-12	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	

Table ES-2. Summary of Risks from Soil

Radionuclide or Contaminant	Current Construction Worker	Future Well Driller	Future Subsistence Farmer	
	Soil	Soil	Soil	Produce ^a
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

Notes:

- 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)

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. This is due to the fact that the half-lives of the plutonium isotopes are so long (or, in the case of the well driller and subsistence 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 subsistence farmer scenario was evaluated where humans could encounter 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 from current

concentrations. However, the third radionuclide COPC, tritium, will likely be at concentrations that are below a health concern within 150 years. Table ES-2 summarizes future soil risks for a driller and a subsistence farmer. Table ES-3 summarizes future groundwater risks and hazards for future regular workers and future subsistence farmers.

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
	Subsistence farmer	Child/adult	Nonradionuclides	316	55	1
Irrigation	Subsistence farmer	Adult	Nonradionuclides	2	0.3	0.006
Meat (beef)	Subsistence farmer	Child/adult	Nonradionuclides	0.3	0.02	0.01
Ingestion of produce	Subsistence farmer	Child/adult	Nonradionuclides	362	63	1
Dairy products (dairy)	Subsistence 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	6E-06
	Subsistence farmer	Child/adult	Radionuclides	1E-04	1E-05	4E-06
			Nonradionuclides	2E-02	3E-03	5E-05
Irrigation	Subsistence farmer	Adult	Radionuclides	2E-07	2E-08	3E-09
			Nonradionuclides	8E-05	1E-05	2E-07
Meat (beef)	Subsistence farmer	Child/adult	Radionuclides	3E-05	3E-06	8E-07
			Nonradionuclides	2E-06	3E-07	5E-09
Ingestion of produce	Subsistence farmer	Child/adult	Radionuclides	3E-03	4E-04	1E-04
			Nonradionuclides	1E-02	2E-03	3E-05
Dairy products (dairy)	Subsistence farmer	Child/adult	Radionuclides	2E-04	2E-05	6E-06
			Nonradionuclides	4E-06	6E-07	1E-08

Notes:

"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 2001 through 2005.

Totals are calculated using unrounded values.

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 subsistence farmers. Radionuclide risks from soil exposures at the 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 subsistence 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 subsistence farmer 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.

Subsistence 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.

Concerning 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 on the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling and likely overestimate the amount of COPC that could be in the plant. Ingestion rates were selected to represent a subsistence 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 as part of the baseline risk assessment. With some exceptions, Native American exposures are similar in type to the subsistence farmer, that is, both groups could be exposed via direct contact with contaminated materials and the food chain. However, exposures may be different in kind, that is, 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. Native American exposures are quantitatively addressed in Appendix G.

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 subsistence farmer soil concentrations, concentrations are dependent upon the size of garden over which drill cuttings would be spread. The risk calculations assumed a 100 m² (1,076 ft²) garden, based on an area that could likely supply approximately 25 percent 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 subsistence farmer 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. Table ES-4 summarizes the RBCs.

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

Risk Driver	RBC ($\mu\text{g/L}$ or pCi/g)
Regular Worker Exposure to Groundwater^a	
Carbon tetrachloride	62
Construction Worker Exposure to Soil^b	
Am-241	45,000
Pu-239	50,000
Pu-240	50,000
Cs-137	1,600
Notes:	
a. The RBC is based on a non-cancer endpoint because a target cancer goal of 10^{-4} results in a higher (i.e., less protective) RBC.	
b. The RBC is based on a target risk of 1×10^{-4} for a combined risk via the dust inhalation, soil ingestion, and external exposure pathways.	
NA	= not applicable
RBC	= risk-based concentration

The RBCs for each of the risk drivers were calculated to be protective of the target goal 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. 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 collocated 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.

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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	<i>Comprehensive Environmental Responses, Compensation, and Liability Act of 1980</i>
CFR	<i>Code of Federal Regulations</i>
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
DNAPL	dense nonaqueous phase liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objective
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
EFH	<i>Exposure Factors Handbook</i>
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FS	feasibility study
HEAST	<i>Health Effects Assessment Summary Tables (EPA 540/R-97-036)</i>
HHRA	human health risk assessment
HHSL	human health screening level
HI	hazard index
HQ	hazard quotient
HSRAM	<i>Hanford Site Risk Assessment Methodology</i>
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	<i>Model Toxics Control Act</i>
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
OEHHAt	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
RfD _i	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	<i>Washington Administrative Code</i>
WISHA	<i>Washington State Industrial Safety and Health Act</i>

A1 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 16 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 in the unlikely event that humans 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 subsistence farming population (adults and children) and a working population are evaluated. This risk assessment assumes there will be no reduction in current contaminant levels but uses current concentrations to assess risks 150 years in the future. While this is consistent with the health-protective nature of risk assessment procedures, it is an overestimate of actual future risks because of the planned active groundwater treatment program and the natural degradation of the organic compounds. The intent of including an unrestricted land use scenario is to meet the following needs:

- Fulfill National Contingency Plan (NCP) (40 *Code of Federal Regulations* [CFR] 300) requirements for a risk evaluation under a “no action” scenario.
- 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).
- Provide information to risk managers regarding the protectiveness of various remedies during the feasibility study (FS) process.

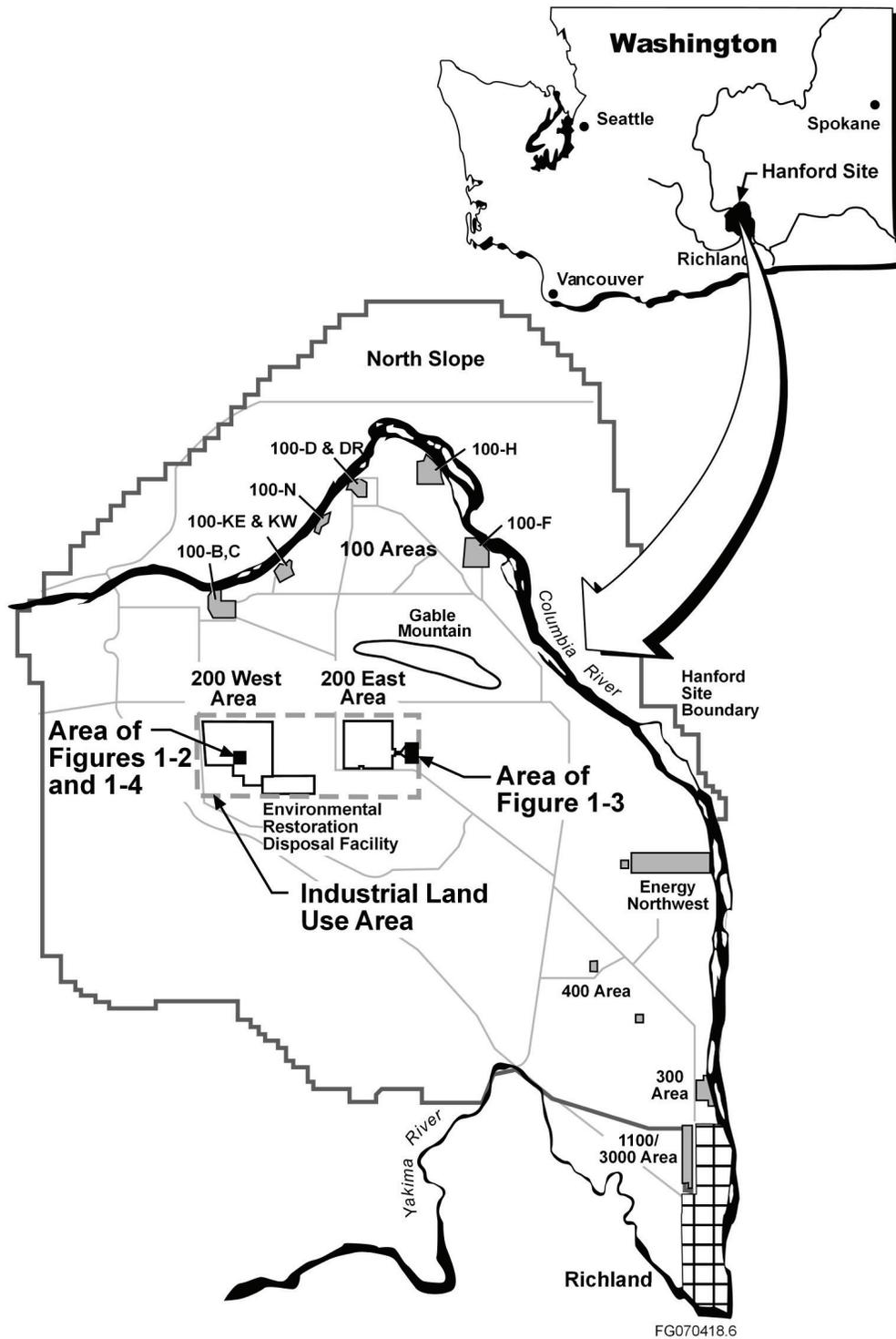


Figure A1-1. Site Vicinity and Location Map

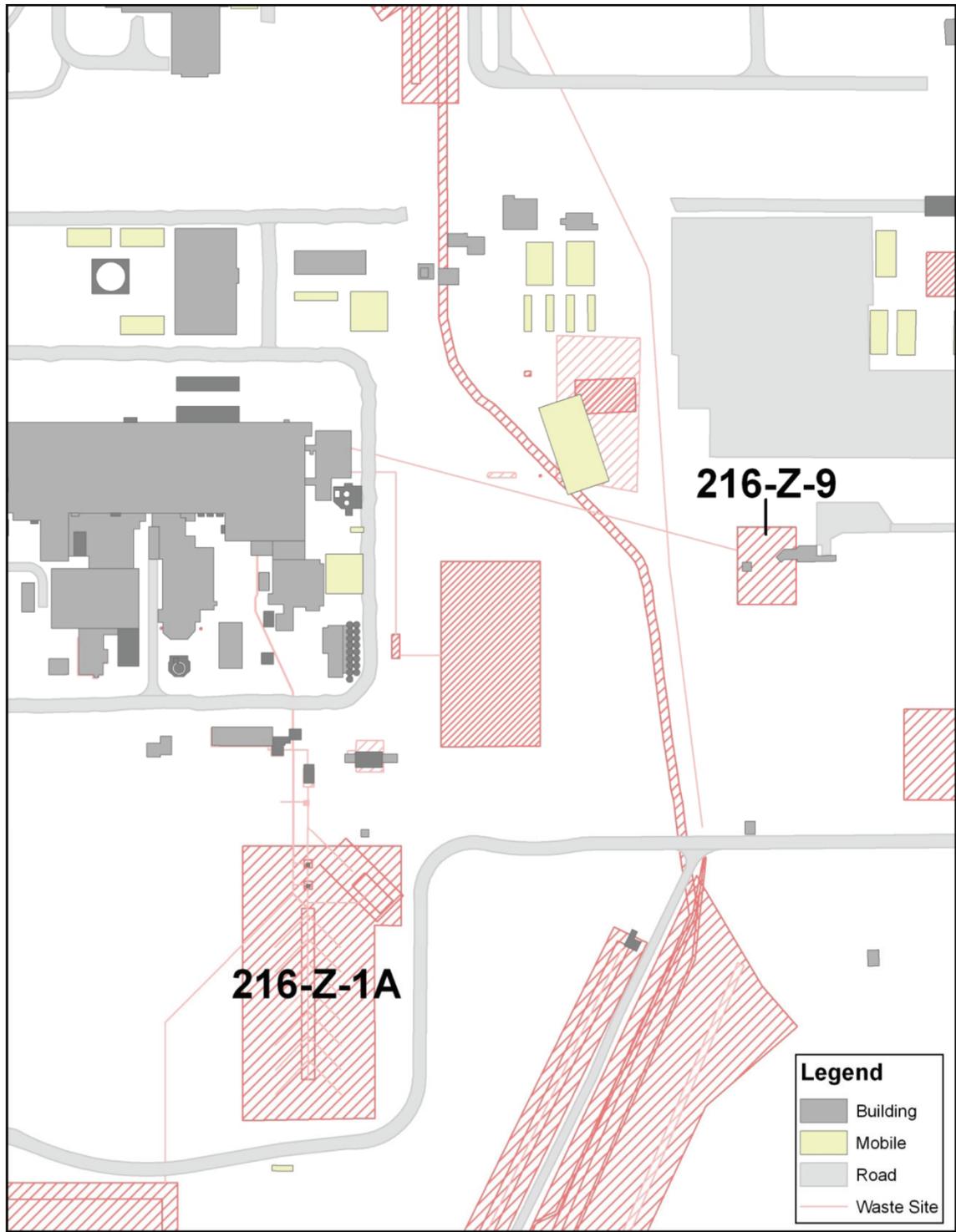


Figure A1-2. Locations of 216-Z-1A Tile Field and 216-Z-9 Trench in the 200 West Area

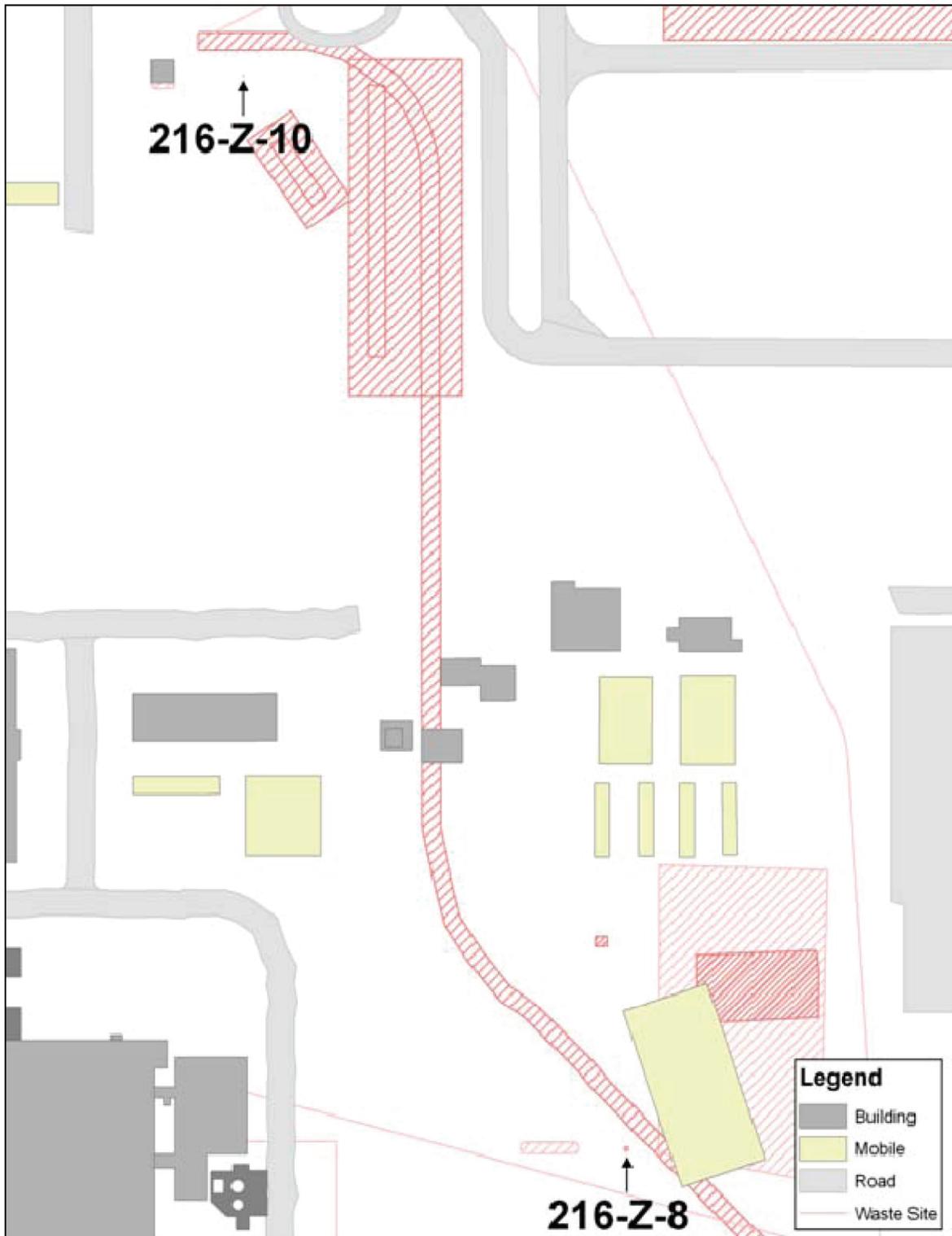
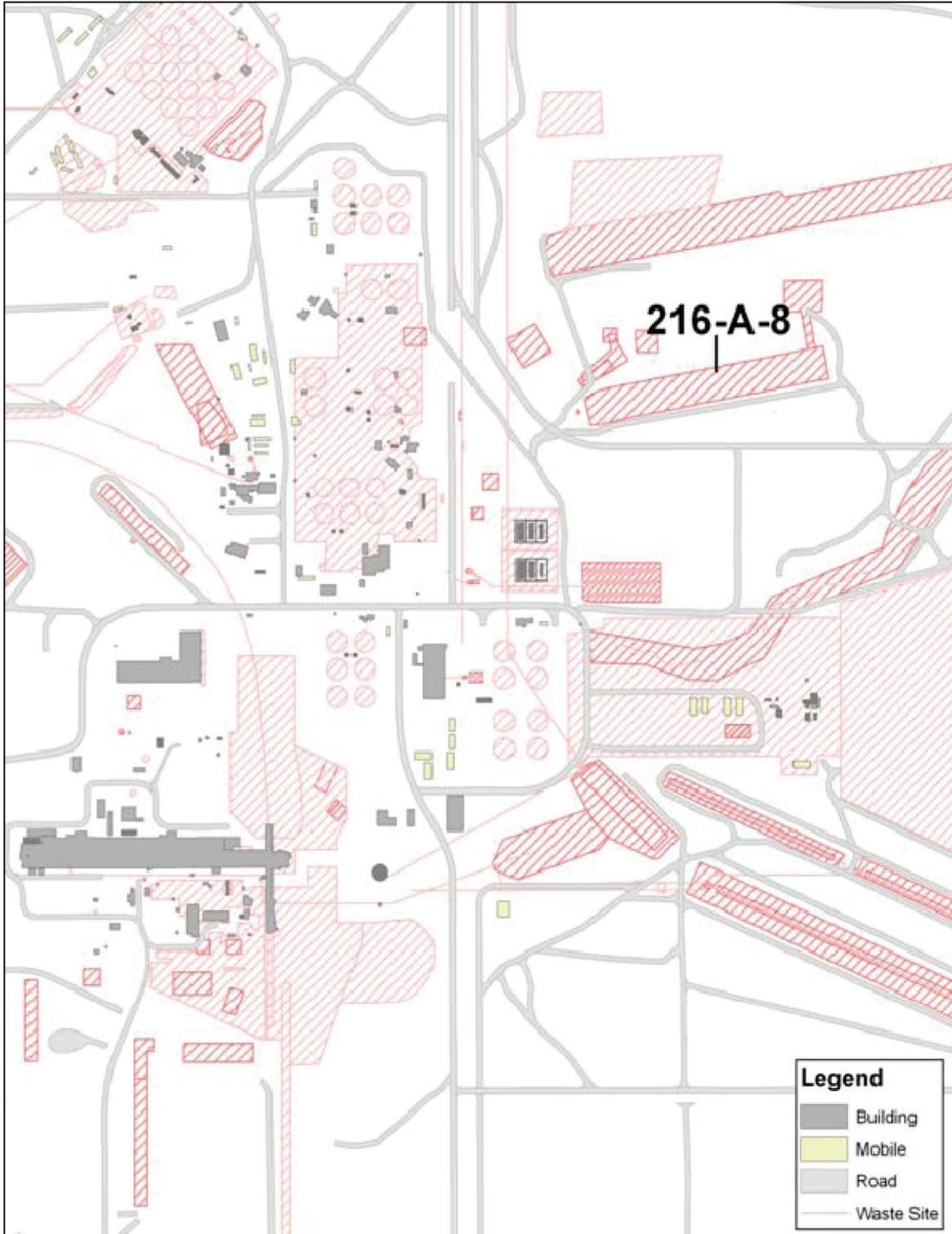


Figure A1-3. Locations of 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well in the 200 West Area



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

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. The NCP expectation for groundwater is that usable groundwater will be returned to the highest beneficial use (i.e., drinking water) “...wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site” (40 CFR 300.430[a][1][iii][F]).

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 encounter contaminants at the site.

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

- 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.
- 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).
- A toxicity assessment is performed to summarize the carcinogenic and noncarcinogenic effects associated with the COPCs and to provide toxicity values that are used to estimate the dose-response relationship.
- 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 underestimated. A discussion of uncertainties in the HHRA is presented in Section A6 in this appendix. This appendix was prepared in accordance with current EPA, Hanford-specific, and DOE guidelines for risk assessment from the following sources:

- *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* (EFH), 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)
- *Hanford Site Risk Assessment Methodology* (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; and 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 below:

- Section A1.0: Contains an introduction.
- Section A2.0: Selects the data for the risk assessment and the COPCs for workers and subsistence farming 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 appendix.

As discussed previously, this risk assessment evaluates both risks from soil at the 200-PW-1, 200-PW-3, and 200-PW-6 OUs and from groundwater at the 200-ZP-1 OU in an integrated manner. Both of these risk assessments were previously included in the FS for the 200-ZP-1 Groundwater OU (DOE/RL-2007-28, *Feasibility Study for the 200-ZP-1 Groundwater Operable Unit*). Because this risk assessment is written in an integrated manner, certain subsections of this appendix describe processes or provide results that pertain only to soil and soil gas from the 200-PW-1, 200-PW-3, and 200-PW-6 OUs and certain subsections of this appendix describe processes or provide results that pertain only to groundwater from the 200-ZP-1 OU. Table A1-1 lists the sections that are specific to soil, soil gas, and groundwater.

Table A1-1. Appendix A Sections Specific to Soil, Soil Gas, and Groundwater

Section Number	200-PW-1/3/6 OU (Soil)	200-PW-1/3/6 OU (Soil Gas)	200-ZP-1 OU (Groundwater)
A2.0 – Data Evaluation and Selection of Contaminants of Potential Concern	Section A2.1.1 Section A2.1.4.1 Section A2.1.4.2 Section A2.2 Section A2.3	Section A2.1.2 A2.4	Section A2.1.3 Section A2.1.4.2 Section A2.5
A3.0 - Exposure Assessment	Section A3.1 Section A3.2.1	Section A3.1	Section A3.1 Section A3.2.2
A4.0 – Risk Characterization	Section A5.3.1 Section A5.3.2.1 Section A5.3.3.1 A5.4	A5.3.3.4	Section A5.3.2.2 Section A5.3.3.2 A5.3.4
A6.0 - Uncertainties in Risk Assessment	A6.1.1	A6.2.3	

A2 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:

- The available sampling data and site information are reviewed to select data applicable to human health.
- 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 below:

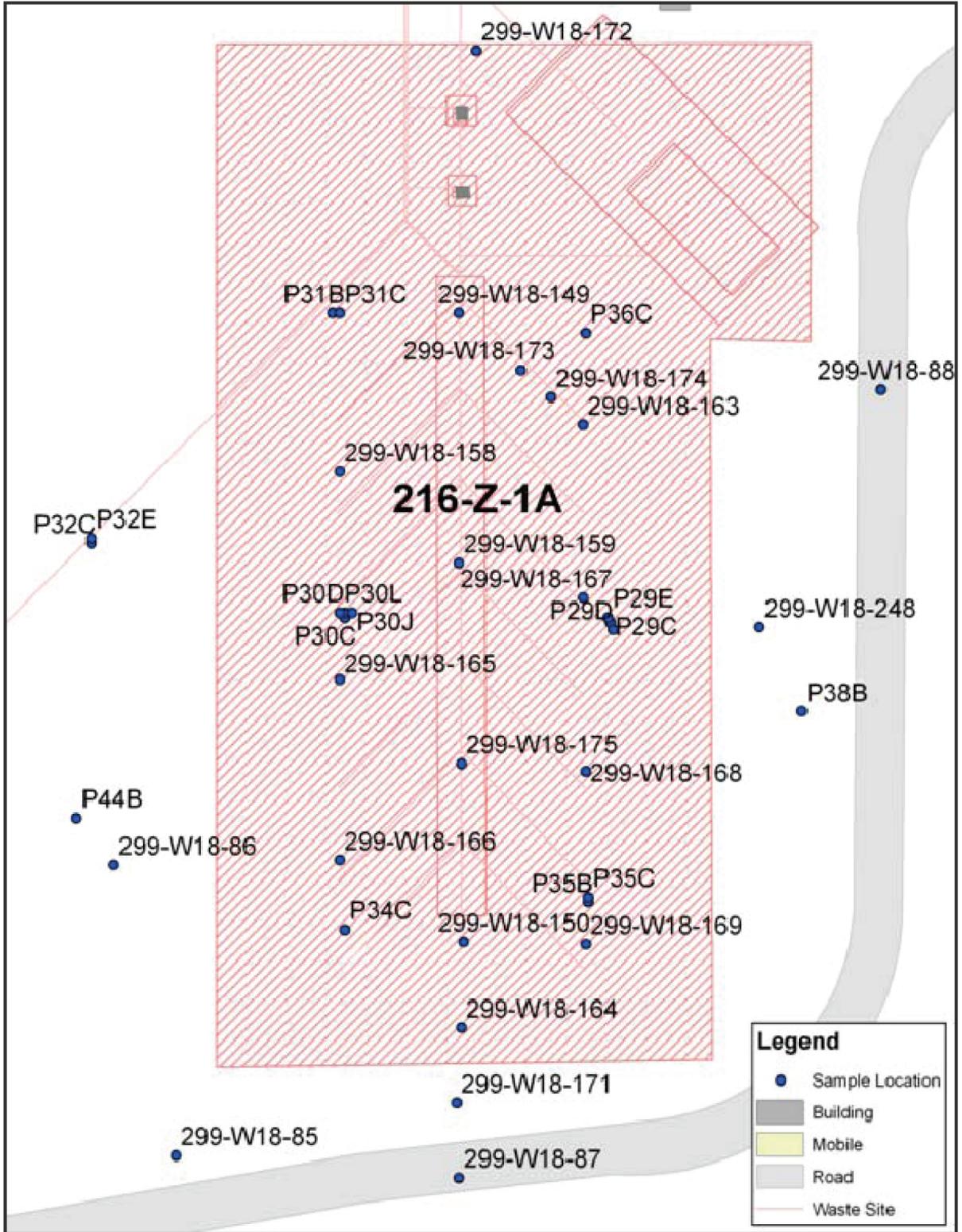
- At the 216-Z-1A Tile Field, the data used for screening are from the cone penetrometer rig locations in and around the 216-Z-1A Tile Field (Table 3-9 of the 200-PW-1/3/6 RI report [DOE/RL-2006-51]), Appendix C of the RI report (circa 1992-1993 sampling), and Appendix D of the RI report (circa 1979 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.

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

Wells	Cone Penetrometer Borings
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

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

Wells	Cone Penetrometer Borings
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	



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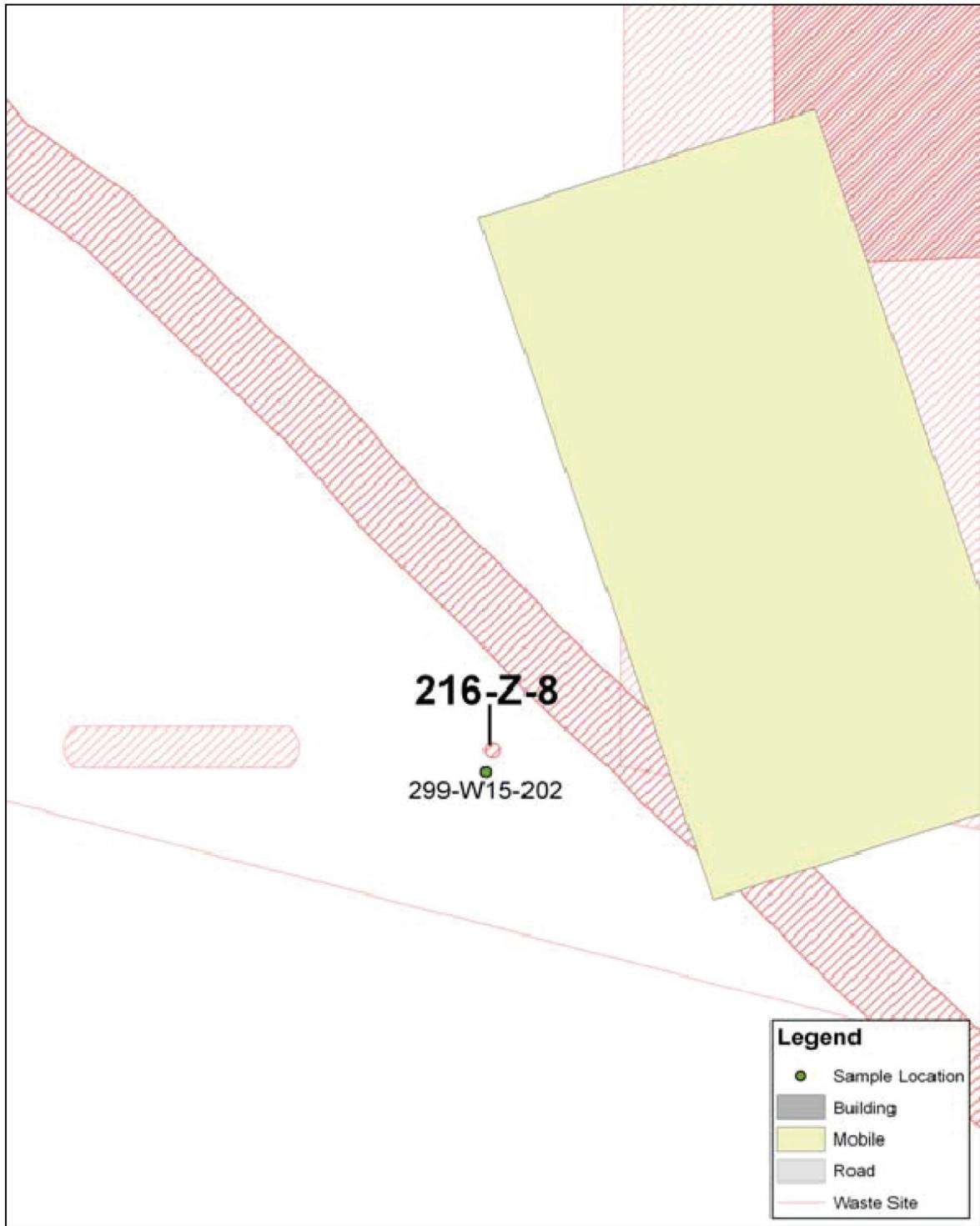
Figure A2-1. 216-Z-1A Tile Field Sample Locations for Soil

- 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. Figure A2-5 shows section views of the Trench.
- 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 near the 216-Z-9 Trench and the 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 Tile Field collected in 2006 were reviewed to evaluate 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).

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.



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

**Table A2-2. Summary of the Number of Samples
by Constituent 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)	835
Radionuclides	903
SVOCs	1
VOCs	581
Other	1,015

Notes:

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])

Hole A

Hole B

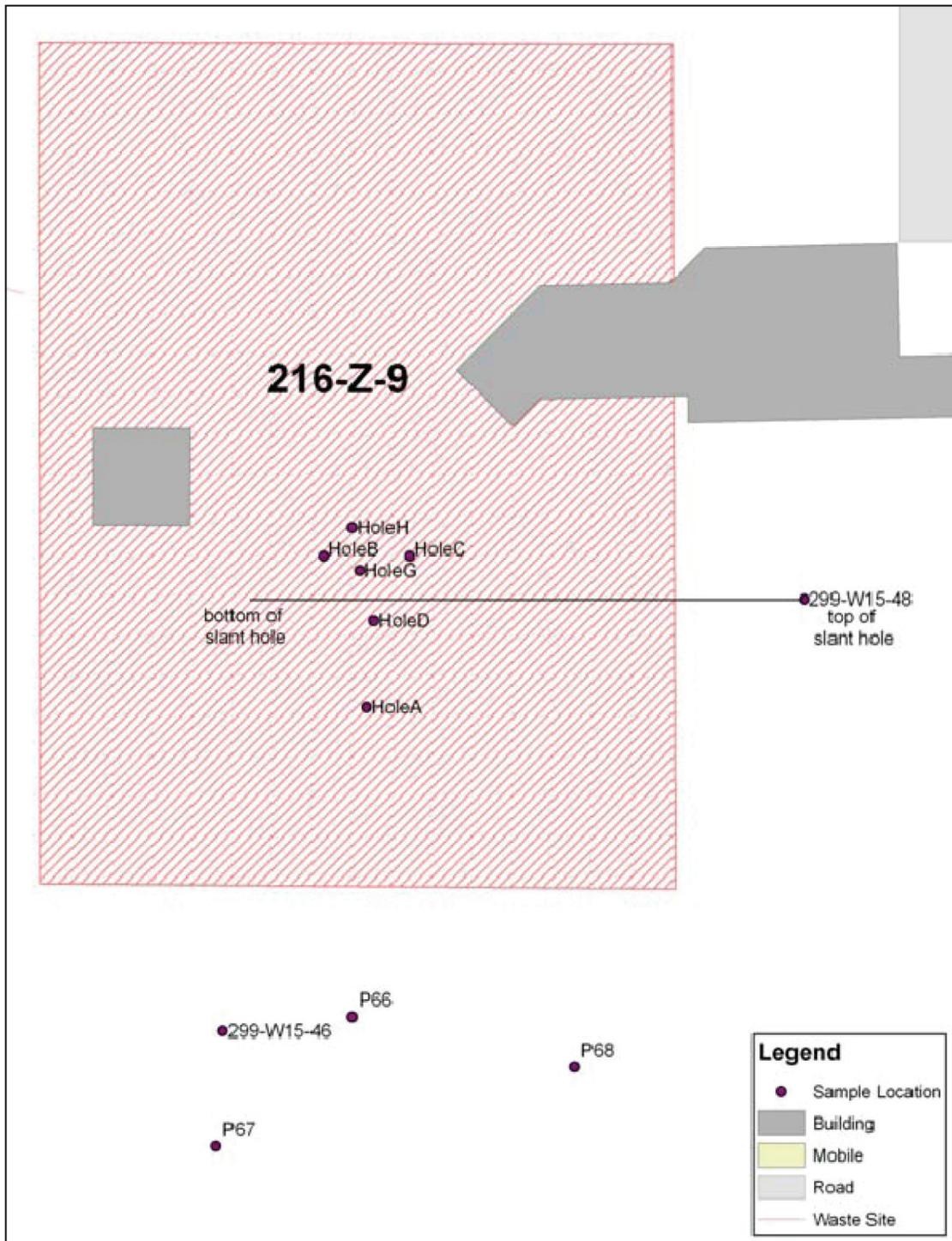
Hole C

Hole D

Hole G

Hole H

bgs = below ground surface



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

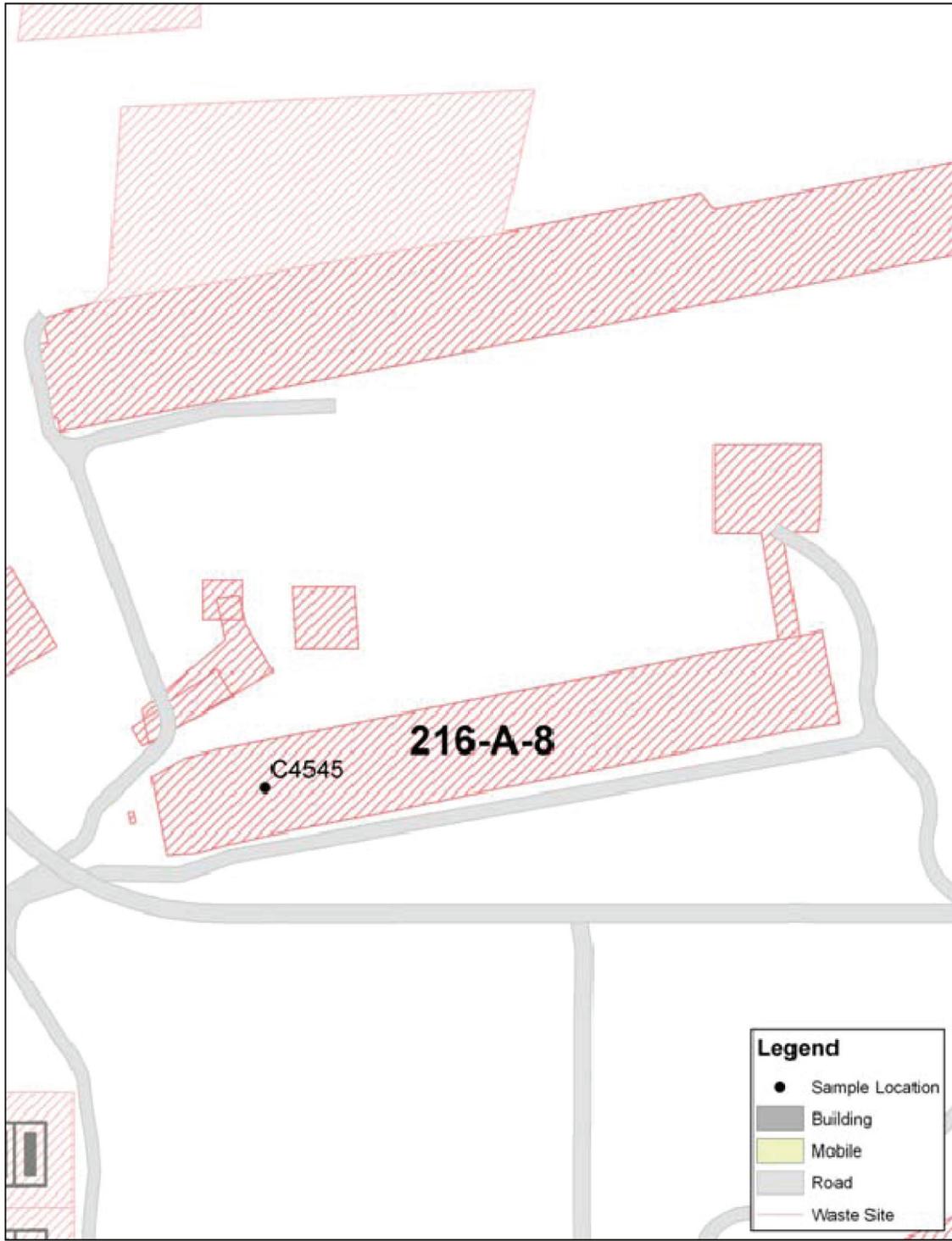
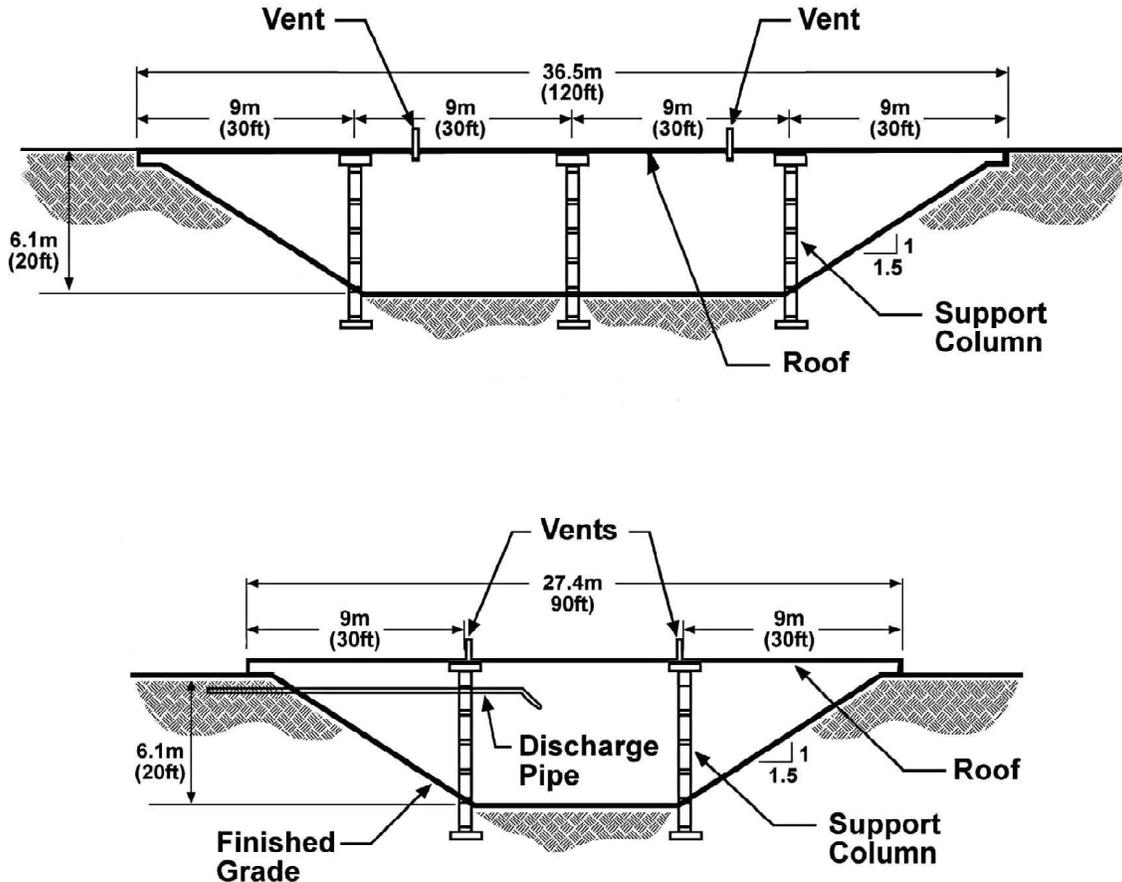


Figure A2-4. 216-A-8 Crib Sample Location for Soil



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

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 1988-2005. 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 2001-2005), and data prior to 2001 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. Table A2-2 shows the numbers of samples available per constituent or constituent group.

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

Wells			
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 ^a
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 ^a
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	

Notes:

* Total uranium and technitium-99 data from these wells were excluded from the risk assessment because the presence of total uranium and technetium-99 in these wells is associated with another source area, unrelated to the 200-ZP-1 Operable Unit source area.

Risk assessment guidance (EPA 540/1-89/002) generally requires the use of unfiltered (total) data in the assessment of risks from metals and other inorganics in groundwater. Unfiltered samples are preferred because metals can be present in groundwater dissolved in the water and also attached to suspended particles. If humans swallowed unfiltered water, exposure would be to contaminants present in both the dissolved and the suspended particulate portions; therefore, use of filtered data may underestimate the amount of contaminant to which a person might be exposed. Differences in filtered versus unfiltered concentrations do not apply to most organic compounds, as they are present in groundwater primarily in the dissolved state.

Both filtered (dissolved) and unfiltered (total) analyses were performed for the groundwater data; however, the majority of the groundwater data for metals is based on filtered samples, with the exception of total uranium. The metals identified as COPCs in groundwater, according to the groundwater RI report (DOE/RL-2006-24), are antimony, iron, chromium, hexavalent chromium, and uranium. For total uranium, the majority of the results are based on unfiltered samples. Only 39 of 225 results for uranium are based on filtered samples. Therefore, these 39 filtered results were removed from the data, and only the unfiltered results were used in the evaluation of total uranium in groundwater.

For the remaining metals in groundwater, the majority of the groundwater data are based on filtered samples. Therefore, these filtered concentrations of antimony, iron, chromium, and hexavalent chromium potentially underestimate the total concentrations present in groundwater. Because antimony is present at background concentrations and iron concentrations were orders of magnitude below a health-based level, the exclusion of these chemicals from the in-depth risk analysis (see Section A2.3.2) will not affect the conclusions of the risk assessment. The uncertainty associated with the use of filtered results for chromium and hexavalent chromium is discussed in detail in the uncertainty section (Section A.6.1.2.1). Because the most toxic form of chromium (hexavalent) is expected to be present primarily in the dissolved form, the use of filtered data is not expected to impact the conclusions of the baseline risk assessment.

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 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.

A2.1.4.1 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. What contamination is present, and at what levels? 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 Injection/Reverse Well) and is discussed here. There are no analytical data for plutonium-241, which was produced as part of the plutonium-production process, 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; 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, potential increases in americium-241 concentrations are estimated 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 at Hanford 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 in the 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 underestimated. Table A2-5 presents details for each soil waste site.

Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection Agency’s Data Usability Guide

Waste Site	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

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

Waste Site	What contamination is present, and at what levels?	Are all exposure areas fully characterized?
		vapor out of the subsurface. Samples were 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 (<i>The 216-2-8 French Drain Study</i> [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 greater depths (RHO-RE-EV-46P).
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 are 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-8 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	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

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

Waste Site	What contamination is present, and at what levels?	Are all exposure areas fully characterized?
	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).	samples from location C4545 were collected at depths ranging from 3.2 to 80.62 m (19 to 264.5 ft) bgs. 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).
216-Z-10 Injection/Reverse Well	Historically, plutonium was discharged to 216-Z-10 Injection/Reverse Well (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-137, cobalt-137, cobalt-60, 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/Reverse 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		

A2.1.4.2 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, the 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.

As a result of 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, to assess potential sources, and to 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 of 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, exposure concentrations could be either over- or underestimated. 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, 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 percent 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. This should be taken into account especially if risks are near a decision point of either slightly above or below a target health goal used to establish the need for 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 percent or greater of the data set are in this uncertain category. Table A2-6 does not present the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well sites because only three constituents were reported for the 216-Z-8 French Drain or because no constituents were detected at the 216-Z-10 Injection/Reverse Well. Section A6.1.1 discusses further the uncertainties surrounding the inadequate MRLs for these compounds and the potential effect on the selection of COPCs and the risk assessment results.

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, Section A6.1.1.

¹Note 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.

Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values

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
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

Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values

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-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

Notes: The 216-Z-8 French Drain site did not have any nondetected contaminants.

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. 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 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 below.

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 nonradionuclides² (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 percent) of samples. Therefore, if the maximum concentration exceeded background but was within two times the background level and exceedances above background were <5 percent, the constituent was eliminated as a COPC because it was likely present at background levels.
4. Evaluation of the frequency of detection: The EPA generally allows constituents detected in <5 percent 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 percent of the risk, and those representing <1 percent 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 percent of the risk have been identified. Therefore, in addition to frequency of detection, a comparison of 95 percent 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 percent 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 percent 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

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.

as COPCs based on the rationale presented 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 three 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. Section A2.3.3 presents the COPCs for the 216-Z-9 Trench. However, only 24 constituents were detected in soil at the 216-Z-1A Tile Field, with only three 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-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 percent) 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 percent 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. Furthermore, if exposure point concentrations (EPCs) were calculated for the well driller and subsistence farmer, they would be lower than the 95 percent 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 percent. As shown in Table A2-10, the remaining two contaminants had exceedances above health screening levels at frequencies >5 percent (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. Section A6.1.1 discusses the impact of excluding these seven contaminants on the findings of the risk assessment.

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

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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

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	HHSL	NO	BSL
7440-48-4	Cobalt	3.8		10		mg/kg	299-W18-174	17/17	--	10	15.7	903	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	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	NO	BCK
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

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
Notes:															
Contaminants bolded exceeded their screening value. Shaded 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 <i>Soil Screening Guidance for Radionuclides: Technical Background Document</i> (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 percent 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 <i>Human Health Medium-Specific Screening Levels for Residential Soil</i>															
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

Notes:

Contaminants bolded exceeded their screening value. Shaded 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 percent detection frequency

c = cancer

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-00-006)

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

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	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	HHSL	NO	BSL
7440-48-4	Cobalt	5.19		20.6		mg/kg	299-W15-46/B17N60	21/21	-	20.6	15.7	903	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	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

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

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
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	HHSL	NO	BSL
110-82-7	Cyclohexane	2		2		mg/kg	299-W15-48/B1HK77	1/1	-	2	0	14	HHSL	NO	BSL
541-02-6	Decamethyl-cyclopentasiloxane	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
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	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	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	HHSL	NO	BSL

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

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
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	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	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	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	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	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	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	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	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	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	HHSL	NO	FREQ
109-99-9	Tetrahydrofuran	0.0096		0.49		mg/kg	299-W15-48/B1HK54	9/9	-	0.49	0	64	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	HHSL	NO	BSL
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	HHSL	NO	BSL

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

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
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	HHSL	NO	BSL
Radionuclides															
14596-10-2	Am-241	0.038		43,478,261		pCi/g	Hole C/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

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

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
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

Notes:

Chemicals bolded exceeded their screening toxicity value. Shaded 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:

Deletion reason: ASL = above screening level

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 percent)

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 percent 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

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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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A2.3.4 216-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 percent 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: bismuth, phosphorous, nitrite, phosphate
- SVOCs: decane, nondecane, tributyl phosphate
- VOCs: 2-ethyl-1-hexanol

The discussions regarding the constituents without health screening levels for the 216-Z-1A Tile Field and 216-Z-9 Trench also apply 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.

Table A2-13 presents the screening levels and a summary of the air concentration data. 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 subsistence farming 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 identified 55 compounds of possible concern in groundwater in the Data Quality Objectives Summary Report Supporting the 200-ZP-1 Operable Unit Remedial Investigation/Feasibility Study Process (CP-16151) and the 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 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:

- Analytes with fewer than 10 percent of detects above a TAL and the 95 percent UCL (calculated by "bootstrapping") of results were above the TAL.
- Analytes with >10 percent of detects above the TAL with 95 percent UCL also above the TAL.

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

CAS No.	Chemical	Minimum Concentration ^a	Minimum Qualifier	Maximum Concentration ^a	Maximum Qualifier	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		C4545-B1D7C8/C4545-B1D9Y4	3/3	--	1.9	NE	3.1	HHSL	NO	BSL
7440-38-2	Arsenic	0.65		2.45		C4545-B1D994	10/10	--	2.45	6.47	0.39	HHSL	NO	BCK
7440-39-3	Barium	25.5		88.6		C4545-B1D7C8	10/10	--	88.6	132	1,564	HHSL	NO	BSL
7440-69-9	Bismuth	94.3		102		C4545-B1D9Y4	3/10	1.08 to 1.1	102	NE	NE	NA	NA	NA
7440-43-9	Cadmium	0.118		0.24		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		C4545-B1D993	10/10	--	41.8	18.5	211	HHSL	NO	BSL
7440-50-8	Copper	5.01		14.7		C4545-B1D7C8	10/10	--	14.7	22	291	HHSL	NO	BSL
18540-29-9	Hexavalent chromium	0.27		0.278		C4545-B1D7C7	2/10	0.2 to 0.25	0.278	18.5	30.1	HHSL	NO	BSL
7439-92-1	Lead ^e	1.39		5.34		C4545-B1D7C7	10/10	--	5.34	10.2	400	HHSL	NO	BSL
7439-97-6	Mercury	0.119		0.3		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		C4545-B1D7D0	10/10	--	30.6	19.1	156	HHSL	NO	BSL
7723-14-0	Phosphorus	451		1430		C4545-B1D9Y4	10/10	--	1430	NE	NE	NA	NA	NA
7782-49-2	Selenium	0.583		1.8		C4545-B1D9Y4	5/10	0.408 to 0.42	1.8	NE	39	HHSL	NO	BSL
7440-22-4	Silver	0.135		0.135		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		C4545-B1D9Y4	3/3	--	2.5	NE	0.55	HHSL	YES	ASL
7440-61-1	Uranium	0.18		2.16		C4545-B1D9Y4	10/10	--	2.16	NE	1.6	PRG	NO	MAG
PCBs														
11097-69-1	Aroclor-1254	0.039		0.039		C4545-B1D994	1/10	0.0048 to 0.013	0.039	0	0.22	HHSL	NO	BSL
Semi-Volatile Compounds														
124-18-5	Decane	0.5	J	0.5	J	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	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	C4545-B1D992	1/1	--	1.6	0	NE	NA	NA	NA
126-73-8	Tributyl phosphate	0.59	J	0.59	J	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	C4545-B1D7C7	1/1	-	0.76	0	NE	NA	NA	NA
67-64-1	Acetone	0.0033	J	0.019	J	C4545-B1D9Y4	3/10	0.0017 to 0.0021	0.019	0	1,415	HHSL	NO	BSL

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

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
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
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	B	mg/kg	C4545-B1D7C7	5/10	4.9 to 5	107	237	NE	NA	NO	BCK

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

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
Notes:															
Chemicals bolded exceeded their screening value. Shaded 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 <i>Soil Screening Guidance for Radionuclides: Technical Background Document</i> (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 percent 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, <i>Human Health Medium-Specific Screening Levels for Residential Soil</i>													
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													

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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								

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 percent). 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 toxicity 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

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

Notes:

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 percent 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 (Washington Administrative Code 296-841-20025)

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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	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	46.2	B	299-W8-1	46/831	1.1 to 55.5	46.2	55.1	10	TAL	NO	BCK
7440-47-3	Chromium (total)	0.406		769		299-W14-13	688/835	0.73 to 7.4	769	2.4	100	TAL	YES	ASL
18540-29-9	Hexavalent chromium	3		730		299-W14-13	27/29	3 to 3	730	NE	48	TAL	YES	ASL
7439-89-6	Iron	7	B	2,080		299-W15-40	470/830	6.8 to 54.5	2,080	570	300	TAL	NO	FREQ
7440-61-1	Total uranium	0.0724		367		299-W11-37	182/186	0.1 to 1.02	367	9.85	30	TAL	YES	ASL
Radionuclides														
15046-84-1	I-129	0.765		36.7		299-W14-13	29/386	-1.22 to 35.7	36.7	0.9	1	TAL	YES	ASL
14133-76-7	Tc-99	3.4		27,400		299-W11-39	747/799	-5.9 to 15.4	27,400	0.83	900	TAL	YES	ASL
10028-17-8	Tritium	3.59		2,170,000		299-W14-13	722/903	-2.10 to 369	2,170,000	119	20,000	TAL	YES	ASL
Volatile Organic Compounds														
107-06-2	1,2-Dichloroethane	0.089	J	1	J	699-48-77D	8/462	0.08 to 8.5	1	0	5	TAL	NO	BSL
56-23-5	Carbon tetrachloride	0.15	J	5,200	D	299-W15-31A	468/574	0.09 to 1	5,200	0	3	TAL	YES	ASL
67-66-3	Chloroform	0.077	J	420		299-W15-46	452/581	0.07 to 120	420	0	7.17	TAL	YES	ASL
75-09-2	Methylene chloride	0.23	JB	740.52	B	299-W15-33	132/581	0.12 to 100	740.52	0	5	TAL	YES	ASL
127-18-4	Tetrachloroethylene	0.12	JN	5	N	299-W15-1	191/581	0.08 to 120	5	0	5	TAL	YES	ASL
79-01-6	Trichloroethylene	0.17	J	36	N	299-W15-50	353/581	0.09 to 120	36	0	5	TAL	YES	ASL
Other														
NO2-N	Nitrogen in nitrate	38		1,720,000	D	299-W10-4	1013/1015	22 to 220	1,720,000	28,063	1,000	TAL	YES	ASL

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
Notes:															
Chemicals bolded exceeded their screening value. Shaded chemicals were selected as COPCs.															
a. Minimum/maximum detected concentration.															
b. Background is assumed to be zero for volatile organic compounds. Background values were taken from <i>Hanford Site Background: Part 3, Groundwater Background (DOE/RL-96-61)</i> .															
c. Screening values are TALs from DOE/RL-2006-24, Table 1-5.															
d. Rationale codes:															
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 percent)															
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															
NE = not established															
TAL = target action level															

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.

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

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

COPC = contaminant of potential concern

A3 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 dose³ 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 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 summary report (CP-16151) and RI report (DOE/RL-2006-24) 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 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 RI for soil (DOE/RL-2006-51), the RI for groundwater (DOE/RL-2006-24), and numerous additional documents, the processing of ores to produce plutonium and for nuclear fuel reprocessing in the 200-PW-1/3/6 OUs led to contaminants being discharged to subsurface soils where they then 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 16 past-practice waste sites and unplanned release sites). An extensive soil vapor extraction (SVE) system is in place in the 200-PW-1 OU, particularly near the 216-Z-9 Trench and 216-Z-1A Tile Field, to provide ongoing removal of the chlorinated solvents still present in soil.

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.

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. As a result of 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 near 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 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 km² [586 mi²]) 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 and 200 East Areas of the Central Plateau are 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 and 200 East Areas are anticipated to remain industrial for the foreseeable future. These areas are 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 subsistence 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 control 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 is currently no significant exposure to impacted soil and groundwater by workers at the selected waste sites (see the 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 subsistence farming population is also selected for evaluation. This assumes exposure to contaminants in groundwater and soil if institutional controls fail at some point in the future and additional exposures via the food chain (i.e., plants, meat, and

dairy products). The future point selected for subsistence farmer 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 subsistence 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 the groundwater and subsurface soil in the 200 West Area under a future failure of institutional controls scenario, similar to a subsistence 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 subsistence farmer, that is, both groups could be exposed via direct contact with contaminated materials and the food chain. However, exposures may be different in kind, that is, 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 baseline assessment, the subsistence 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 subsistence farming population meets the following requirements:

- 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)
- Provides information to risk managers regarding the protectiveness of various remedies during the FS process

Section A6.2.1, the uncertainty section of this appendix, discusses potential under-estimation of future Native American exposures using EPA residential parameters further. Appendix G of this FS evaluates Native American exposures in-depth.

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 encounter impacted soil (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 subsistence 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. The following subsections discuss these current and future exposure pathways in more detail.

A3.1.3.1 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. The EPA defines surface soil as the top 2 cm (0.78 in.) (*Soil Screening Guidance: Technical Background Document* [EPA/540/R-95/128]). However, 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 than 1 m (3 ft) bgs and, in some cases, contamination is also below the 4.6 m (15 ft) 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 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, a concrete cap over the trench also covers the area (see Figure A2-5). For the other three sites, a construction worker could potentially encounter 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. The EPA guidance (EPA 540/R/99/05) recommends evaluating dermal soil exposures only for SVOCs and the two metals that have sufficient absorption information (i.e., 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

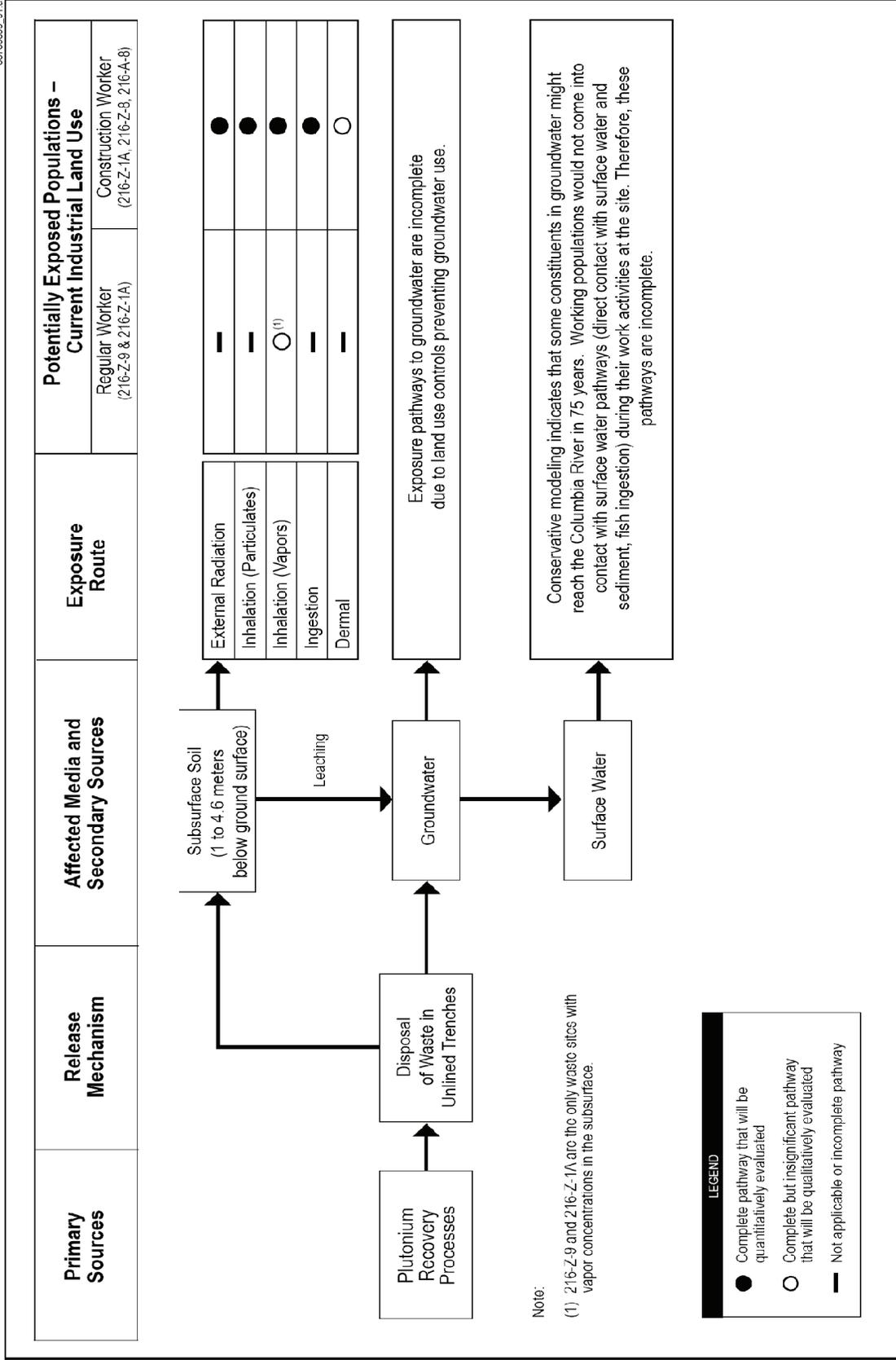


Figure A3-1. Schematic Human Health Conceptual Site Model Current Industrial Land Use

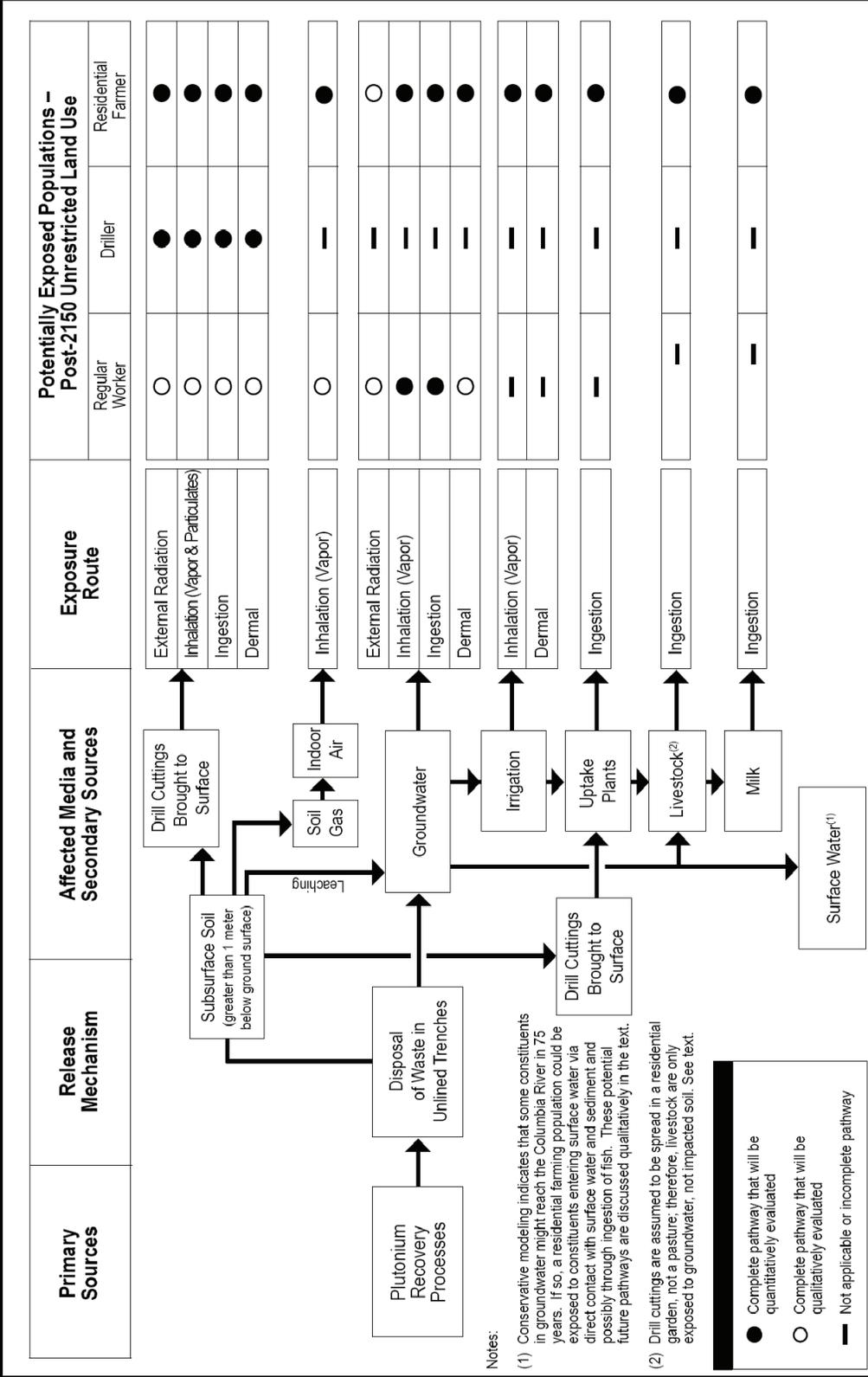


Figure A3-2. Schematic Human Health Conceptual Site Model Depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under Future Unrestricted Land Use

pathway for radionuclides was, at most, 3 percent 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).

A3.1.3.2 Contact with Soil by a Subsistence Farming Population

In order for residents to encounter 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 most likely 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 subsistence farmer 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]).

A3.1.3.3 Inhalation of Vapors in Indoor Air by a Subsistence Farming Population Post-2150

Exposures to VOCs in subsurface soil might be possible for a future subsistence 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 subsistence farming 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 SVE system, and due to their natural decrease in environmental media because of volatilization 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).

A3.1.3.4 Contact with Groundwater Post-2150 (Subsistence Farmer and Worker)

If a well is drilled under an institutional controls failure scenario, the water could be used for drinking and for irrigation of crops and livestock. A future subsistence 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 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.

A3.1.3.5 Subsistence Farmer Food Chain Exposures

In order to estimate an upper-bound risk value for the subsistence 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 meat from cattle watered by groundwater, and eating or drinking dairy products made from dairy cattle. Quantification of food chain risks from eating beef and drinking dairy products assumes 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 percent UCL of the arithmetic mean as the appropriate estimate of the average site concentration for an RME scenario (OSWER Directive 9285.6-03, OSWER Directive 9285.6-10). At the 95 percent UCL, the probability of under-estimating the true mean is <5 percent. The 95 percent UCL can address the uncertainties surrounding a distribution average due to limited sampling data.

The formula used to calculate a 95 percent 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 percent 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 percent 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.

A3.2.1.1 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, contaminated soil at the 216-Z-9 Trench does not begin until below the bottom of the 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 were 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 percent 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 percent 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). Table A3-1 provides a summary of construction worker EPCs.

A3.2.1.2 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 percent UCL calculation to represent a high-end estimate of the average contaminant concentration that could be in the drill cuttings (C_{waste}). Table A3-2 presents the 95 percent UCLs calculated for current C_{waste} concentrations for each site. The future well driller would not be exposed to contaminants in soil until 150 years in the future; thus, current C_{waste} concentrations for radionuclides were entered into RESRAD, 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 subsistence 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 subsistence farmer EPCs at future time horizons. These future C_{waste} concentrations were the basis for estimating EPCs for the future driller (C_{cut}) using the methodology from Rittman (2004).

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*	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	
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)	Maximum concentration selected
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)	

Notes:

* 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)

Site Name	Contaminant Name	Cwaste (pCi/g or mg/kg)	Distribution	Rationale from ProUCL	Number of Samples
216-Z-1A Tile Field	Am-241 ^a	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
	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 ^b	4
216-Z-9 Trench	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 ^b	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 ^b	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 A3-1. Summary of Exposure Point Concentrations for Soil Current Construction Worker

COPC	EPC	Units	EPC Rationale		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 ^b	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 ^b	3
	Th-228	124.75	Non-parametric	95% Chebyshev (Mean, Sd) UCL	14

Notes:

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

b. Too few samples available to produce a meaningful 95 percent UCL using ProUCL.

NA = not applicable

ProUCL = U.S. Environmental Protection Agency's software for calculating the UCL (Version 3.00.02)

UCL = upper confidence limit

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 toward 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 point 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 percent 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 percent 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 percent UCLs are still likely overestimates of the concentrations in Cwaste.

Table A3-3 summarizes future soil concentrations for radionuclides. These concentrations were calculated with the following assumptions.

- 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 not impacted.

Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors

COPC	Cwaste 150 Years in the Future	Well Driller EPC Ccut 150 Years in the Future	Subsistence 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

Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors

COPC	Cwaste 150 Years in the Future	Well Driller EPC Ccut 150 Years in the Future	Subsistence Farmer EPC Cgarden 150 Years in the Future	Units
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
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

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). Attachment A-2 of this appendix presents details. 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.

A3.2.1.3 Future Subsistence Farmer

For the subsistence 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 percent 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 below:

- 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-m² (1,076-ft²) area.
- The depth of contaminated soil is 15 cm (6 in.) default shallowest tilling depth.

Consequently, the subsistence 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 m² (1,076 ft²) 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 subsistence farmer EPCs were calculated. Table A3-3 provides the soil EPCs for the subsistence farmer scenario.

A3.2.1.4 Calculation of Plutonium-239 and Plutonium-240 Concentrations

Plutonium-239 and plutonium-240 were analyzed together in the laboratory, and one 95 percent 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 below:

- In weapons-grade plutonium, 94.2 percent of the weight of plutonium-239/240 mixture is plutonium-239 and 5.8 percent 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.

A3.2.1.5 Estimation of Americium-241 Concentrations at 216-Z-1A Tile Field and 216-Z-9 Trench

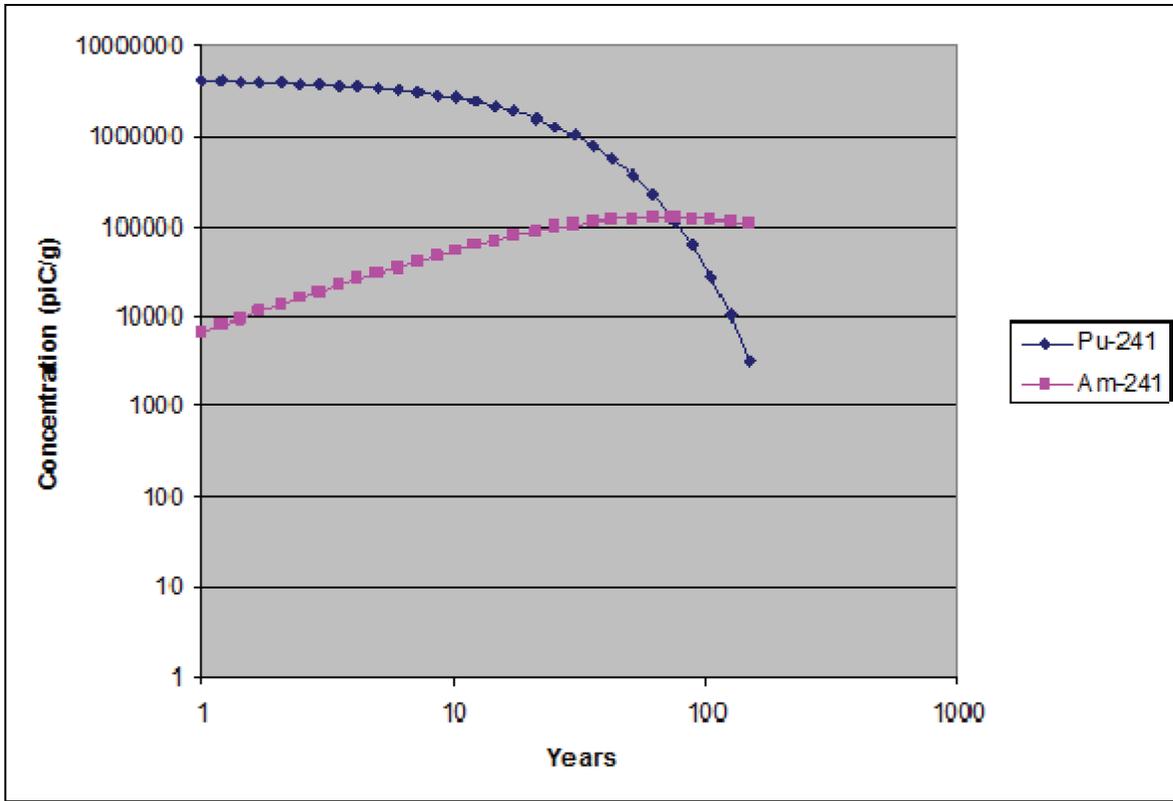
As noted in Section A2.1.4.1, there are no available soil data for plutonium-241, which is the parent compound for americium-241. Plutonium-241 has a relatively short half-life of 14.5 years. The production of plutonium (including plutonium-241) started in 1944 at the Hanford Site. The final waste disposals 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. Section A6.1.1 discusses uncertainties surrounding maximum americium concentrations at the 216-Z-8 French Drain. 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 (RESRAD) dose model, which can estimate radiological concentrations in the future taking into consideration radionuclide decay and ingrowth.

Maximum americium-241 concentrations were estimated below:

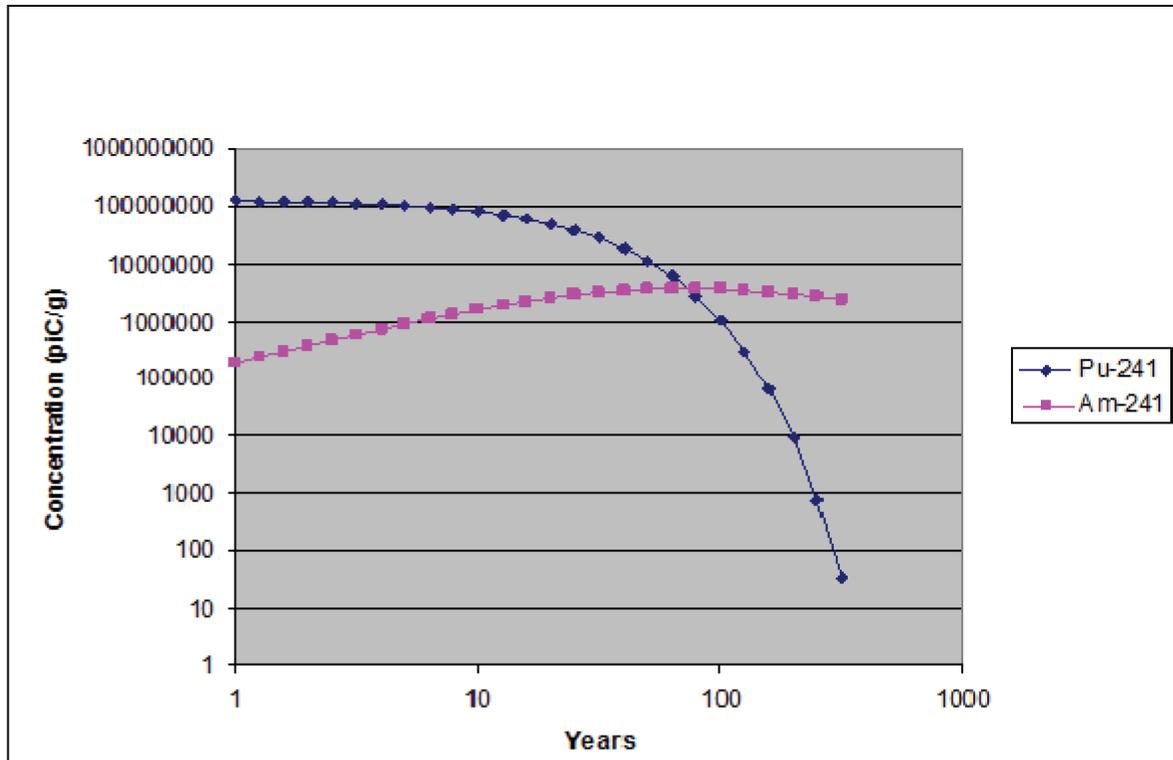
- Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969 and at 216-Z-9 Trench from 1955 to 1962. Therefore, the year 0 in RESRAD was estimated to be 1967 for the 216-Z-1A Tile Field and 1960 for the 216-Z-9 Trench.
- Site-specific information on the vadose zone and the contaminant distribution for each site was entered into RESRAD (see Section 3.0).
- The known americium-241 concentration for each site was the 95 percent 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 subsistence 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 subsistence farmers (the earliest vadose zone exposures [see Section A3.1]), use of the maximum americium-241 concentration as the current concentration slightly overestimates americium-241 concentrations in the year 2150. For the 216-Z-1A Tile Field, current (year 2005) concentrations are 93 percent 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 percent 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 protective of health, 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).



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



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

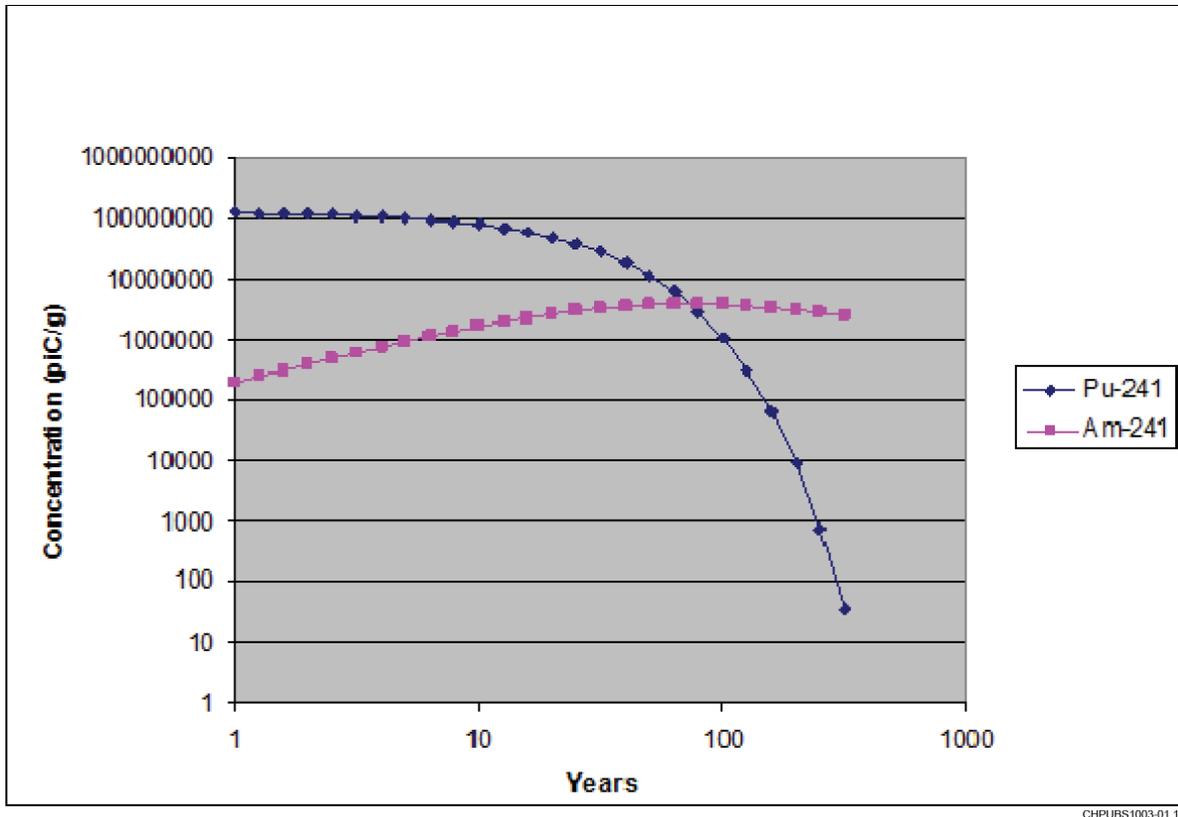


Figure A3-5. Ingrowth of Americium-241 at 216-Z-1A Shallow Soils (Construction Worker Soil Contact Zone)

At the 216-Z-9 Trench where there are 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.

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 of 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. Section A2.1.3 discusses the available groundwater data and the data selected for inclusion in the risk assessment. 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. As recommended by EPA, one-half of the MRL was used as a surrogate concentrate for nondetect results in

the percentile calculations (EPA 540/1-89/002). 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 percent UCL of the mean or possible increase in risks if water were consumed at the location of a maximum concentration) are discussed further in the uncertainty section of this appendix (Section A6.2).

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

Contaminant of Potential Concern	Percentiles			Units
	25 th	50 th	90 th	
Carbon tetrachloride	6.53	505.00	2,900	µg/L
Chloroform	0.58	6.40	24	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
Tetrachloroethylene (PCE)	0.18	0.36	2.5	µg/L
trichloroethylene (TCE)	0.155	1.7	10.9	µg/L
Uranium	0.808	1.18	8.295	µg/L
I-129	ND	0.030	1.170	pCi/L
Technetium-99	59	180	1,442	pCi/L
Tritium	513.75	3,605	36,200	pCi/L

ND = not detected

Risks were not calculated for future groundwater concentrations under baseline conditions. Future risks from groundwater are assumed to be at least “risky” at 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. Section A5.3.4 discusses the potential lowering of future groundwater concentrations further.

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 RESRAD 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.

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

COPC	Units	200-ZP-1 Groundwater Area			Soil Waste Sites	
		25 th a	50 th a	90 th a	216-Z-9 Trench	216-A-8 Crib
Homegrown Produce						
Cadmium	mg/kg	d	d	d	8.30E-01	d
Carbon tetrachloride	mg/kg	1.26E-01	9.78E+00	5.62E+01	5.52E+00	d
Chloroform	mg/kg	1.90E-02	2.10E-01	7.86E-01	d	d
Chromium (total)	mg/kg	4.66E-02	1.33E-01	1.68E+00	d	d
Chromium (VI)	mg/kg	9.06E-02	1.41E-01	2.63E+00	d	d
Manganese	mg/kg	d	d	d	2.96E+01	d
Methylene chloride	mg/kg	7.77E-03	1.20E-02	1.77E-01	d	d
Nitrate	mg/kg	b	b	b	d	d
PCE	mg/kg	2.86E-03	5.72E-03	3.97E-02	d	d
TCE	mg/kg	3.69E-03	4.05E-02	2.59E-01	d	d
Thallium	mg/kg	d	d	d	d	5.00E-02
Uranium	mg/kg	1.10E-02	1.52E-02	1.08E-01	d	d
I-129	pCi/g	ND	3.93E-04	1.53E-02	d	d
Tc-99	pCi/g	8.02E+00	2.45E+01	1.96E+02	e	e
Tritium	pCi/g	1.30E+01	9.50E+01	9.50E+02	d	d
Meat						
Carbon tetrachloride	mg/kg	3.1E-05	2.40E-03	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	6.65E-03	1.90E-02	2.40E-01		
Chromium (VI)	mg/kg	1.29E-02	2.01E-02	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		

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

COPC	Units	200-ZP-1 Groundwater Area			Soil Waste Sites	
		25 th ^a	50 th ^a	90 th ^a	216-Z-9 Trench	216-A-8 Crib
Uranium	mg/kg	5.0E-05	7.3E-05	5.13E-04		
I-129	pCi/g	ND	2.52E-04	9.82E-03		
Tc-99	pCi/g	9.94E-02	3.03E-01	2.43E+00		
Tritium	pCi/g	5.00E-01	3.60E+00	3.60E+01		
Dairy Products						
Carbon tetrachloride	mg/kg	1.46E-05	1.13E-03	6.49E-03		
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		
Methylene chloride	mg/kg	1.99E-08	3.07E-08	4.54E-07		
Nitrate	mg/kg	^b	^b	^b	Cattle are assumed to be directly exposed only to groundwater.	
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	1.0E-04	1.47E-04	1.03E-03		
I-129	pCi/g	ND	1.14E-04	4.45E-03		
Tc-99	pCi/g	2.0E-01	6.1E-01	4.89E+00		
Tritium	pCi/g	5.00E-01	3.60E+00	3.60E+01		

Notes:

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-227c	0.001
Np-237c	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-210c	0.007
Pu-239	0.03	Pu-238	0.04
Pu-240	0.007	Pu-239	311
		Pu-240	67
216-A-8 Crib		Ra-226	0.03
C-14	6E-37	Ra-228	0.0000000004
Cs-137	8	Sr-90	0.005
Np-237	0.002	Tc-99	0.0000008
Pu-239	0.0006	Th-228	0.0000000001
Pu-240	0.0001	Th-230	0.0008
Ra-228	0.00000001		
Tc-99	0.000000000002		
Th-228	0.0000000002		

Notes:

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

A3.2.3.1 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.

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

Calculation of Plant Concentration from Groundwater Used for Irrigation:

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

$$Irr_{rup} = \frac{I_r \times F \times Bv_{wet} \times (1 - \exp(-L_b \times t_b))}{P \times L_b} \quad \text{Equation 2}$$

$$Irr_{res} = \frac{I_r \times F \times MLF \times (1 - \exp(-L_b \times t_b))}{P \times L_b} \quad \text{Equation 3}$$

$$Irr_{dep} = \frac{I_r \times F \times I_f \times T \times (1 - \exp(-LE \times t_v))}{Y_v \times LE} \quad \text{Equation 4}$$

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

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

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*	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

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

Calculation of Plant Concentration from Groundwater Used for Irrigation:

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

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

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

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

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
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	10,950	Default value, ORNL RAIS
Tr	Half-life	day	Chemical-specific *	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

Notes:

* Radionuclides only

ORNL = Oak Ridge National Laboratory

RAIS = Risk Assessment Information System

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 radionuclides (except tritium), tritium, and nonradionuclides, respectively. Table A3-8 summarizes the transfer factors that were used in the plant tissue calculations.

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

COPC	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

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

COPC	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
-------------	---	--	-------------------------	-----------------------------------

Notes:

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 subsistence 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 ratio 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

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 percent, 46 percent, and 45 percent 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.

$$F_{\text{PLANTS}} = 7.7 (\text{KOW}) - 0.58.$$

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.

A3.2.3.2 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 product concentrations from cattle that are raised by the subsistence 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 that of 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 milk and other related dairy products. Dairy product consumption includes drinking milk, as well as eating dairy products made from the milk. Table A3-9 presents the equations and equation inputs 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 EPCs.

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

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*	Not applicable
Cw	Contaminant concentration in water	mg/L	Site-specific	Analytical data
fp	Fraction of year animal is at Hanford	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

Notes:

*Radionuclides only

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

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

ORNL = Oak Ridge National Laboratory

RAIS = Risk Assessment Information System

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 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 product EPC calculations were calculated below:

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

where:

$H-3_{m,d}$ = tritium concentration in meat and dairy products

$H-3_w$ = 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 RME is, thus, an estimate of the highest exposure that reasonably can be expected to occur at the site; it may overestimate 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 subsistence 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 radionuclides in soil, RESRAD was used to calculate doses for construction workers, drillers, and subsistence 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 subsistence 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.

A3.3.1.1 Exposure Duration and Frequency

The EPA default value for construction workers (OSWER Directive 9355.4-24) assumes exposure duration of 1 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.

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

<i>Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):</i>				
	Ingestion =	$CS \times IR \times EF \times ED \times CF / AT_{nc} \times BW$		
	Inhalation =	$CS \times InhR \times EF \times ED \times (1/PEF \text{ or } VF) / AT_{nc} \times BW$		
<i>Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):</i>				
	Ingestion =	$CS \times IR \times EF \times ED \times CF / AT_{ca} \times BW$		
	Dermal absorption =	$CS \times SA \times AF \times ABS \times EF \times ED \times CF / AT_{ca} \times BW$		
	Inhalation =	$CS \times InhR \times EF \times ED \times (1/PEF \text{ or } VF) / AT_{ca} \times BW$		
<i>Soil Intake Factors - Radioactive COPCs (pCi):</i>				
	Ingestion =	$CS \times IR \times EF \times ED \times CF_2$		
	Inhalation =	$CS \times InhR \times EF \times ED \times (1/PEF) \times CF_3$		
Intake Parameter				
		Value	Unit	Source
ABS	Absorption factor	Contaminant-specific	unit-less	EPA 540/R/99/05
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/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

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

<i>Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):</i>				
Ingestion =			$CS \times IR \times EF \times ED \times CF / AT_{nc} \times BW$	
Inhalation =			$CS \times InhR \times EF \times ED \times (1/PEF \text{ or } VF) / AT_{nc} \times BW$	
<i>Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):</i>				
Ingestion =			$CS \times IR \times EF \times ED \times CF / AT_{ca} \times BW$	
Dermal absorption =			$CS \times SA \times AF \times ABS \times EF \times ED \times CF / AT_{ca} \times BW$	
Inhalation =			$CS \times InhR \times EF \times ED \times (1/PEF \text{ or } VF) / AT_{ca} \times BW$	
<i>Soil Intake Factors - Radioactive COPCs (pCi):</i>				
Ingestion =			$CS \times IR \times EF \times ED \times CF_2$	
Inhalation =			$CS \times InhR \times EF \times ED \times (1/PEF) \times CF_3$	
Intake Parameter				
		Value	Unit	Source
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
	Exposure frequency:			
	216-Z-1A Tile Field	30	days/yr	Site-specific, OSWER Directive 9355.4-24
EF	216-Z-8 French Drain	30	days/yr	Site-specific, OSWER Directive 9355.4-24
	216-A-8 Crib	30	days/yr	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	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		
EPA	=	U.S. Environmental Protection Agency		
OSWER	=	EPA Office of Solid Waste and Emergency Response		

A3.3.1.2 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 m³/kg.

A3.3.2 Post-2150 Unrestricted Land Use Scenario

In the post-2150 unrestricted land use scenario, a future subsistence 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 location of employment. The following subsections discuss the exposure factors used to quantify exposures for each of these populations.

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

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

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

$$D_A = \{[(q_a^{10/3} \times D_i \times H^7) + (q_w^{10/3} \times D_w)]/\eta^2\} / \{p_b k_{oc} f_{oc} + q_w + q_a H^7\}$$

Parameter	Definition (Units)	Value	Source
T (subsistence 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

A3.3.2.1 Subsistence Farmer

Future subsistence 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 subsistence farming exposures and default exposure parameters (see Attachment A-4). Exposure factors and formulas for the subsistence 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.

Table A3-12. Subsistence Farmer Exposures to Soil – Exposure Assumptions and Intake Equations (2 sheets)*Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):*

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

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

Ingestion child/adult =	$(CS \times EF \times CF / ATca) \times (IRc \times EDc / BWc + IRa \times EDa / Bwa)$
Dermal absorption child/adult =	$(CS \times EF \times AB / ATca) \times (SAc \times AFc \times EDc / BWc + SAa \times AFa \times EDa / Bwa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF \text{ or } VF) / ATca) \times (InhRc \times EDc / BWc + InhRa \times EDa / Bwa)$

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	$(CS \times EF \times CF2) \times (IRc \times EDc + IRa \times EDa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF) \times CF3) \times (InhRc \times EDc + InhRa \times EDa)$

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, EPA 540/R/99/05

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

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

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

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

Ingestion child/adult =	$(CS \times EF \times CF / ATca) \times (IRc \times EDc / BWc + IRa \times EDa / Bwa)$
Dermal absorption child/adult =	$(CS \times EF \times AB / ATca) \times (SAc \times AFc \times EDc / BWc + SAa \times AFa \times EDa / Bwa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF \text{ or } VF) / ATca) \times (InhRc \times EDc / BWc + InhRa \times EDa / Bwa)$

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	$(CS \times EF \times CF^2) \times (IRc \times EDc + IRa \times EDa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF) \times CF^3) \times (InhRc \times EDc + InhRa \times EDa)$

Intake Parameter		Value	Unit	Source
AT	AFc: Child	0.2		
	Averaging time:	(ED × 365 days)		
	Noncarcinogenic			
	ATnc-a: Adult	8,760	days	Default value, OSWER Directive 9285.7-01B
	ATnc-c: Child	2,190		
BW	Carcinogenic			
	Atca: Lifetime (adult/child)	25,550	days	Default value, OSWER Directive 9285.7-01B
	Body weight:			
CF	BWa: Adult	70	kg	Default value, OSWER Directive 9285.7-01B
	BWc: Child	15		
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 9285.7-01B
ED	Exposure duration:			
	EDa: Adult	24	years	Default value, OSWER Directive 9285.7-01B

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

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

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

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

Ingestion child/adult =	$(CS \times EF \times CF / ATca) \times (IRc \times EDc / BWc + IRa \times EDa / Bwa)$
Dermal absorption child/adult =	$(CS \times EF \times AB / ATca) \times (SAc \times AFc \times EDc / BWc + SAa \times AFa \times EDa / Bwa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF \text{ or } VF) / ATca) \times (InhRc \times EDc / BWc + InhRa \times EDa / Bwa)$

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	$(CS \times EF \times CF^2) \times (IRc \times EDc + IRa \times EDa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF) \times CF^3) \times (InhRc \times EDc + InhRa \times EDa)$

Intake Parameter		Value	Unit	Source
InhR	EDc: Child	6		
	Inhalation rate (adult/child):			
	InhRa: Adult	20	m ³ /day	Default value, OSWER Directive 9285.6-03
IR	InhRc: Child	10		
	Ingestion rate, soil:			
	IRa: Adult	100	mg/day	Default value, OSWER Directive 9285.7-01B
PEF	IRc: Child	200		
	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		
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 – Subsistence Farming Exposures
Ingestion, Dermal, and Inhalation Exposure to Tap Water (2 sheets)**

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

Ingestion child =	$C_w \times IR_c \times EF \times ED_c \times CF / AT_c \times BW_c$
Dermal absorption child =	$DA_{ev-c} \times SA_c \times EV_w \times EF \times ED_c \times / AT_c \times BW_c$
Inhalation child =	$C_w \times InhR_c \times EF \times ED_c \times VF_w \times CF / AT_c \times BW_c$
Ingestion adult =	$C_w \times IR_a \times EF \times ED_a \times CF / AT_a \times BW_a$
Dermal absorption adult =	$DA_{ev-a} \times SA_a \times EV_w \times EF \times ED_a \times / AT_a \times BW_a$
Inhalation adult =	$C_w \times InhR_a \times EF \times ED_a \times VF_w \times CF_w / AT_a \times BW_a$
Ingestion child/adult =	$(C_w \times EF \times CF / AT_c) \times (IR_c \times ED_c / BW_c + IR_a \times ED_a / B_wa)$
Dermal absorption child/adult =	$(DA_{ev-a} \times EF \times EV_w / AT_c) \times (SA_c \times ED_c / BW_c + SA_a \times ED_a / B_wa)$
Inhalation child/adult =	$(C_w \times EF \times VF_w \times CF_w / AT_c) \times (InhR_c \times ED_c / BW_c + InhR_a \times ED_a / B_wa)$

Water Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	$C_w \times IR_a \times EF \times ED$
Inhalation child/adult =	$C_w \times InhR_a \times EF \times ED \times VF_{rad}$

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	Subsistence Farming exposure frequency	350	days/yr	Default value, EPA 540/1-89/002
ED	Subsistence Farming exposure duration	30	years	Default value, EPA 540/1-89/002
ED _a	Subsistence Farming exposure duration—adult	24	years	Default value, EPA 540/1-89/002
ED _c	Subsistence Farming exposure duration—child	6	years	Default value, EPA 540/1-89/002
IR _a	Ingestion rate—adult	2	L/day	Default value, EPA 540/1-89/002
IR _c	Ingestion rate—child	1	L/day	Default value, EPA 540/1-89/002
SA _a	Skin surface area—adult	18,000	cm ²	Default value, EPA 540/R/99/05
SA _c	Skin surface area—child	6,600	cm ²	Default value, EPA 540/R/99/05
EV _w	Event frequency—water contact	1	events/day	Default value, EPA 540/R/99/05
DA _{ev}	Absorbed dose per event	Contaminant-specific	mg/cm ² -event	Calculated value (see Table A3-14)
InhR _a	Inhalation rate—adult	20	m ³ /day	Default value, EPA/600/P-95-002Fa
InhR _c	Inhalation rate—child	10	m ³ /day	Default value, EPA/600/P-95-002Fa

**Table A3-13. Intake Assumptions Children (2 to 6 Years) and Adults – Subsistence Farming Exposures
Ingestion, Dermal, and Inhalation Exposure to Tap Water (2 sheets)***Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)*

Ingestion child =	$C_w \times IR_c \times EF \times ED_c \times CF / AT_c \times BW_c$
Dermal absorption child =	$DA_{ev-c} \times SA_c \times EV_w \times EF \times ED_c \times / AT_c \times BW_c$
Inhalation child =	$C_w \times InhR_c \times EF \times ED_c \times VF_w \times CF / AT_c \times BW_c$
Ingestion adult =	$C_w \times IR_a \times EF \times ED_a \times CF / AT_a \times BW_a$
Dermal absorption adult =	$DA_{ev-a} \times SA_a \times EV_w \times EF \times ED_a \times / AT_a \times BW_a$
Inhalation adult =	$C_w \times InhR_a \times EF \times ED_a \times VF_w \times CF_w / AT_a \times BW_a$
Ingestion child/adult =	$(C_w \times EF \times CF / AT_c) \times (IR_c \times ED_c / BW_c + IR_a \times ED_a / B_wa)$
Dermal absorption child/adult =	$(DA_{ev-a} \times EF \times EV_w / AT_c) \times (SA_c \times ED_c / BW_c + SA_a \times ED_a / B_wa)$
Inhalation child/adult =	$(C_w \times EF \times VF_w \times CF_w / AT_c) \times (InhR_c \times ED_c / BW_c + InhR_a \times ED_a / B_wa)$

Water Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult =	$C_w \times IR_a \times EF \times ED$
Inhalation child/adult =	$C_w \times InhR_a \times EF \times ED \times VF_{rad}$

Intake Parameter		Value	Unit	Source
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
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:

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

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

Inorganic Contaminants:

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

	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 τ_{event}	Contaminant-specific	Exhibit B-3 of EPA Region 9 preliminary remediation goal
τ_{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

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 m³/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 subsistence farmer 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 subsistence farmers are assumed to use the groundwater as an irrigation source for their crops and livestock. Therefore, adult subsistence 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.

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

<i>Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)</i>				
	Dermal Absorption adult =	$DA_{ev-a} \times SA_a \times EV_w \times EF \times ED \times / AT_{nc} \times BW_a$		
	Inhalation adult =	$C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{nc} \times BW_a$		
<i>Water Intake Factors - Nonradioactive COPCs, Cancer (mg/kg BW-day)</i>				
	Dermal Absorption adult =	$DA_{ev-a} \times SA_a \times EV_w \times EF \times ED \times / AT_{ca} \times BW_a$		
	Inhalation adult =	$C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{ca} \times BW_a$		
<i>Water Intake Factors - Radioactive COPCs (pCi)</i>				
	Inhalation adult =	$C_w \times InhRa \times EF \times ED \times ET \times VF_{rad}$		
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	Subsistence 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)

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

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

Dermal Absorption adult = $DA_{ev-a} \times SA_a \times EV_w \times EF \times ED \times / AT_{nc} \times BW_a$

Inhalation adult = $C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{nc} \times BW_a$

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

Dermal Absorption adult = $DA_{ev-a} \times SA_a \times EV_w \times EF \times ED \times / AT_{ca} \times BW_a$

Inhalation adult = $C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{ca} \times BW_a$

Water Intake Factors - Radioactive COPCs (pCi)

Inhalation adult = $C_w \times InhRa \times EF \times ED \times ET \times VF_{rad}$

Intake Parameter		Value	Unit	Source
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

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 subsistence 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 cm² (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 one event/day was assumed for this pathway. This value was obtained from the ORNL RAIS Website (<http://rais.ornl.gov/>). The value 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 m³/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 m³/hr, 1.5 m³/hr for those engaged in moderate outdoor activities, and a rate 2.5 m³/hr for those engaged in heavy activities outdoors. The inhalation rate of 1.5 m³/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 VF 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:

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

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 percent.

The resulting VF_w for the irrigation scenario of 0.02 L/m³ was used in the risk calculations.

Future Subsistence Farmer Exposures Through Ingestion of Garden Produce, Beef, and Dairy Products

Subsistence 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 products 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 affect risk results are discussed in Section A6.2.4.

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

<i>Tissue Intake Factors - Nonradioactive COCs, Non-Cancer (mg/kg BW-day):</i>				
Ingestion child/adult =		$C_{ti} \times IR_{ti} \times EF \times ED \times CF / AT_{nc}$		
<i>Tissue Intake Factors - Nonradioactive COCs, Cancer (mg/kg BW-day):</i>				
Ingestion child/adult =		$C_{ti} \times IR_{ti} \times EF \times ED \times CF / AT_{ca}$		
<i>Tissue Intake Factors - Radioactive COCs (pCi):</i>				
Ingestion adult =		$C_{ti} \times IR_{ti} \times EF \times ED$		
Intake Parameter		Value	Unit	Source
C _{ti}	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
IR _{pa}	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	Subsistence Farmer exposure frequency	350	days/yr	ORNL RAIS
ED	Subsistence Farmer exposure duration	30	years	Default value, EPA 540/1-89/002
AT _{nc}	Averaging time (noncarcinogen)	10,950	days	Default value, EPA 540/1-89/002 (ED x 365)
AT _{ca}	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			

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 be constant over a lifetime and was used to evaluate child and adult combined exposures.

Beef Ingestion Rate

Chapter 13 of EPA's 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 be constant over a lifetime and was used to evaluate child and adult combined exposures.

Dairy Ingestion Rate

Chapter 13 of EPA's 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 be constant over a lifetime and was used to evaluate child and adult combined exposures.

A3.3.2.2 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 time that it would take to install a well.

Particulate Emission Factor

The PEF described above for construction workers and subsistence 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 m³/kg.

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

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

$$\begin{aligned} \text{Ingestion} &= \text{CS} \times \text{IR} \times \text{ED} \times \text{CF} / \text{ATnc} \times \text{BW} \\ \text{Dermal absorption} &= \text{CS} \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{ED} \times \text{CF} / \text{ATnc} \times \text{BW} \\ \text{Inhalation} &= \text{InhR} \times \text{ED} \times (1/\text{PEF or VF}) / \text{ATnc} \times \text{BW} \end{aligned}$$

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

$$\begin{aligned} \text{Ingestion} &= \text{CS} \times \text{IR} \times \text{ED} \times \text{CF} / \text{ATca} \times \text{BW} \\ \text{Dermal absorption} &= \text{CS} \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{ED} \times \text{CF} / \text{ATca} \times \text{BW} \\ \text{Inhalation} &= \text{InhR} \times \text{ED} \times (1/\text{PEF or VF}) / \text{ATca} \times \text{BW} \end{aligned}$$

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

$$\begin{aligned} \text{Ingestion} &= \text{CS} \times \text{IR} \times \text{ED} \times \text{CF}_2 \\ \text{Inhalation} &= \text{CS} \times \text{InhR} \times \text{ED} \times (1/\text{PEF or VF}) \times \text{CF}_3 \end{aligned}$$

	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

Volatilization Factor for Soil

As described above for subsistence 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.

A3.3.2.3 Industrial Worker Drinking Water Exposures

For this scenario, it was assumed that a Hanford 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 vapor 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 subsistence farmer 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 of this appendix. The following site-specific exposure parameters were used in the evaluation of industrial exposures to groundwater.

Inhalation Rate for Irrigation

An inhalation rate of $1.5 \text{ m}^3/\text{hr}$ 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 $1 \text{ m}^3/\text{hr}$, $1.5 \text{ m}^3/\text{hr}$ for those engaged in moderate outdoor activities, and $2.5 \text{ m}^3/\text{hr}$ for those engaged in heavy activities outdoors. The inhalation rate of $1.5 \text{ m}^3/\text{hr}$ 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.

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

<i>Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)</i>				
	Ingestion adult =	$C_w \times IR_a \times EF \times ED_a \times CF / AT_{nc} \times B_{Wa}$		
	Inhalation adult =	$C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{nc} \times B_{Wa}$		
<i>Water Intake Factors - Nonradioactive COPCs, Cancer (mg/kg BW-day)</i>				
	Ingestion adult =	$C_w \times IR_a \times EF \times ED \times CF / AT_{ca} \times B_{Wa}$		
	Inhalation adult =	$C_w \times InhRa \times EF \times ED \times ET \times VF_w \times CF_w / AT_{ca} \times B_{Wa}$		
<i>Water Intake Factors - Radioactive COPCs (pCi)</i>				
	Ingestion adult =	$C_w \times IR_a \times EF \times ED$		
	Inhalation adult =	$C_w \times InhRa \times EF \times ET \times ED \times VF_{rad}$		
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

A4 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 to 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 for non-radionuclides:

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 $[\text{mg}/\text{kg}\cdot\text{day}]^{-1}$) expresses excess cancer risk as a function of dose. The dose-response model is based on high- to low-dose extrapolation and assumes 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. Table A4-1 presents the cancer SFs for each of the nonradionuclide COPCs.

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

Contaminant	Oral Cancer: Slope Factor (mg/kg-day) ⁻¹	Inhalation Cancer: Slope Factor (mg/kg-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 (total)	—	—	—	D	IRIS
Chromium (VI) (hexavalent)	—	290 ^b	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	0.007	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

b. The inhalation pathway for hexavalent chromium is considered incomplete/insignificant in groundwater, and hexavalent chromium is not a COPC in soil (see Appendix A, Attachment 5 for toxicity profile information of hexavalent chromium).

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

The SFs for radionuclides are incremental cancer risks resulting from exposure to radionuclides through 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. Table A4-2 presents the cancer SFs for the radionuclide COPCs. 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.

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

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, which 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. Table A4-3 presents the non-cancer toxicity criteria for nonradionuclide COPCs.

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 EPA calculates the RfDs 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 Hanford 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 1-year duration. A 1-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, EPA has calculated subchronic criteria 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 five) 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.

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 (total)	None ^b	--	--	--	--	--	--
Chromium (VI) (hexavalent)-inhaled and particulate dust	2.90E-05 ^c	Respiratory toxicity	Subchronic rat	300	IRIS	NC	NC
Chromium (VI) (hexavalent)-mists and aerosols	2.3E-06 ^c	Nasal septum atrophy	Subchronic human occupational	90	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. ^d	1.0E-02
Chloroform	1.0E-02	Liver, kidney, and central nervous system toxicity	Chronic dog study	100	IRIS	NC	NC
Chromium (total) (trivalent toxicity criteria used)	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 ^e	6.6E-05	None reported	Rat oral subchronic study	3,000	IRIS	Remove UF of 10 for subchronic to chronic.	0.0007

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)
TCE	3.0E-04	Central nervous system, liver, and endocrine toxicity	Subchronic mouse	3,000	EPA 2001	NC	NC
Uranium	3.0E-03	Weight loss, nephrotoxicity	30-day rat bioassay	1,000	IRIS	NC	NC

a. EPA indicates 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. The inhalation pathways for CrVI are incomplete; therefore these toxicity criteria were not used in this assessment.

d. 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.

e. 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 (online 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

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.

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/m³) for noncarcinogens and unit risk factors (URFs) expressed in cubic meters of air per microgram of contaminant (m³/μg) 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 m³ 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 below:

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

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

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 percent 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 percent 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.

A4.6 Hexavalent Chromium and Cadmium Exposure Route Toxicity Differences

Many chemicals can have a different toxic response depending on the exposure route taken into the body (e.g., ingestion versus inhalation). Route-specific toxicity criteria take those different responses into account. For most chemicals, while there may be differences in toxicity, there are not differences in whether the toxic response is cancer versus non-cancer. For example, arsenic is associated with lung cancer when inhaled and skin/bladder cancer when ingested. Different cancer sites, but a carcinogenic response occurs via both exposure routes.

A handful of chemicals are associated with a cancer response via one route of exposure but not another. This is true for two of the COPCs in this assessment, hexavalent chromium and cadmium. Both these chemicals are carcinogenic when they are inhaled (as dust or vapor) but do not exhibit a carcinogenic response when they are swallowed (EPA, 2007). Cadmium is a COPC in soil at the 216-Z-9 Trench. It is evaluated as a carcinogen for the dust inhalation exposure route and is evaluated for its non-cancer toxicity by the soil ingestion route. Hexavalent chromium is a COPC in groundwater. During regular domestic water use (i.e., drinking water pathway), nonvolatile compounds are not sufficiently airborne to represent a significant inhalation exposure. Therefore, hexavalent chromium is not evaluated as a carcinogen for the drinking water pathway because the inhalation pathway is not significant and is therefore not quantified in the risk calculations. Neither of the inhalation RfCs for hexavalent chromium (listed in Table A4-3) or the inhalation slope factor (listed in Table A4-2) were used in this baseline risk assessment. Additional information on exposure route toxicity differences is included in the toxicity profiles for each contaminant in Attachment A-5 of this appendix.

A5 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 below:

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

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 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 3×10^{-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, below:

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

$$\text{Cancer risk (radionuclides)} = \text{radiological dose (pCi)} \times \text{SF (risk/pCi)}$$

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]):

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

The risk from exposure to multiple carcinogens is assumed to be additive but is bounded by 1, corresponding to a 100 percent 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 percent 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. In addition to the three radionuclides that are COPCs in groundwater, there are a number of nonradiological carcinogens.

The EPA's target cancer risk range is 10^{-6} to 10^{-4} , and EPA considers risk levels as high as 4×10^{-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). Tables A5-1 through A5-11 summarize the risk and hazard results, presented to one significant figure. 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, and 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) decrease significantly over the 1,000-year period; however, cumulative risks do not change significantly within 1,000 years.⁴ Figure A5-1 illustrates the decline in risk over 1,000 years for the future subsistence 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 of this appendix.

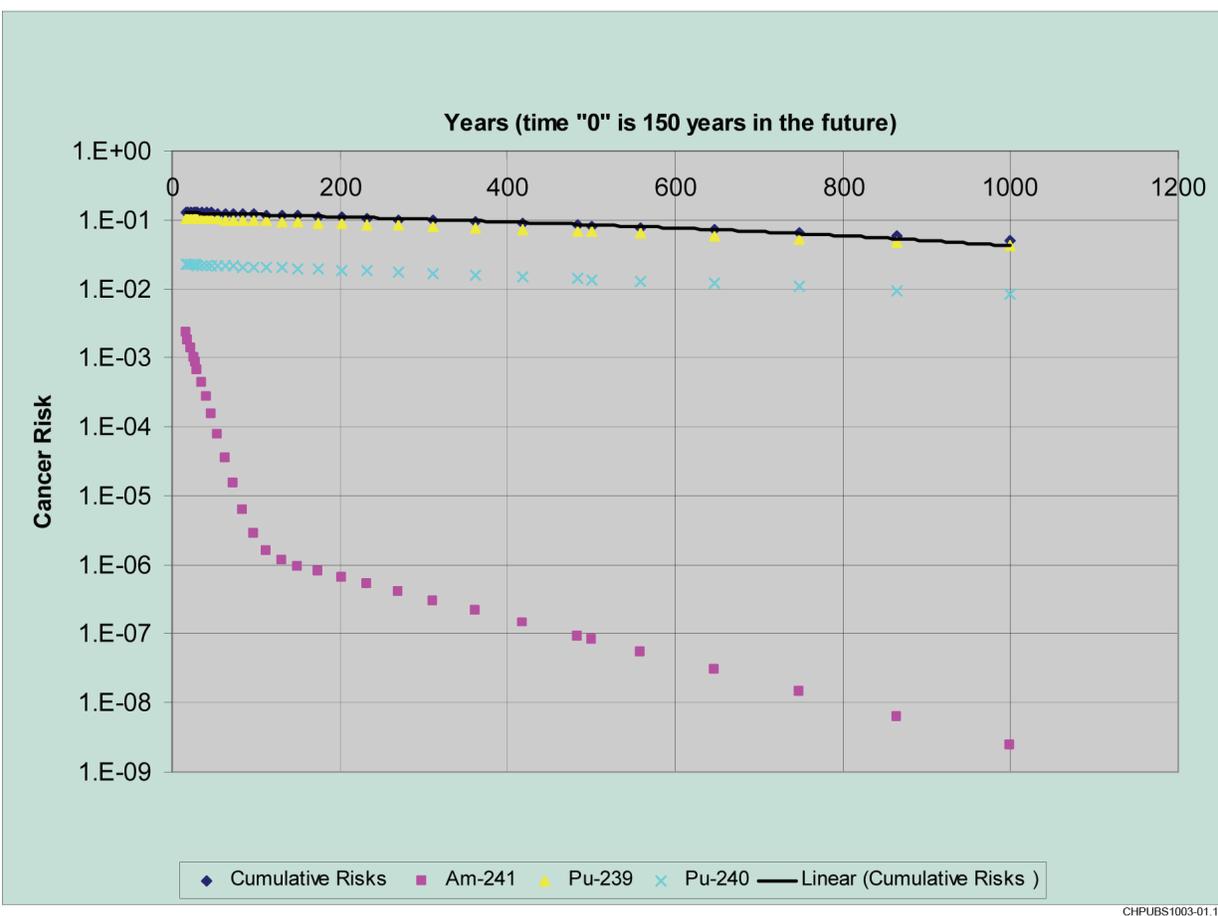


Figure A5-1. Decreases in Cancer Risks Over Time – Future Subsistence Farmer at the 216-Z-9 Trench

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,

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

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 subsistence farmer for the 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 periods evaluated for 216-A-8 Crib, so daughter risks are included in Attachment A-7 of this appendix, but individual radionuclides for future time horizons are not presented in the risk summary tables in this section.

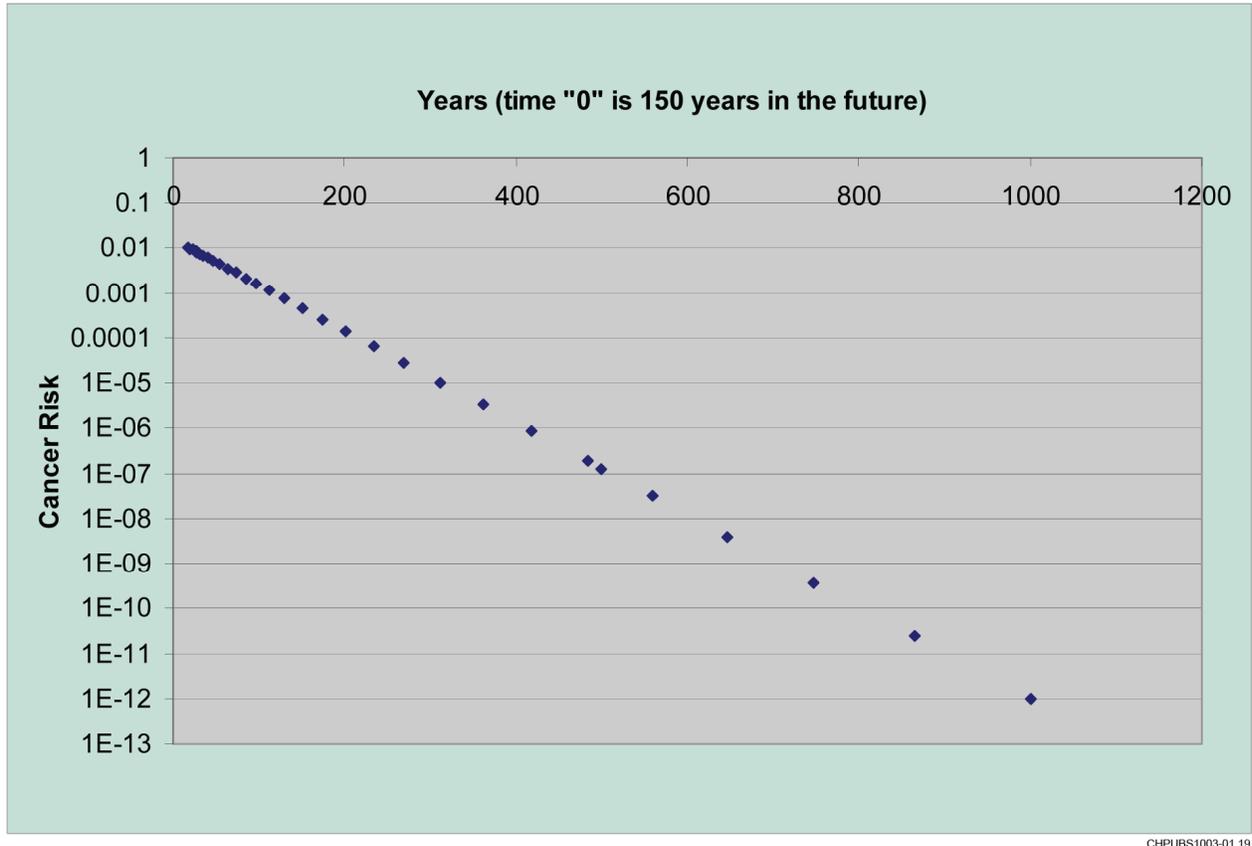


Figure A5-2. Decreases in Cancer Risks Over Time – Future Subsistence Farmer at the 216-A-8 Crib

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 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 below:

- 216-Z-1A Tile Field:** Risks from exposure to all three COPCs exceed 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 percent 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 10^{-4} , but the external radiation risk for americium-241 exceeded 10^{-4} .

- **216-Z-8 French Drain:** Risks were below 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 percent of the risks due to cesium-137. No other contaminants exceeded 10^{-6} . Somewhere between 150 and 500 years in the future, cesium-137 decays to the point where risks fall below 10^{-6} (cumulative risks at 500 years are 7×10^{-7}).

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

Radionuclide (Parent and Decay)	Total*	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	1E-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

Notes:

Shaded values exceed 10^{-4}

*Totals are calculated using unrounded values.

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 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:

- A well driller exposed to contaminants in soil via drill cuttings while engaged in installing a water supply well.
- 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.

A5.3.2.1 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. Table A5-2 presents risks for well drillers and Table A5-3 presents non-cancer hazards for the 216-Z-9 Trench. Well driller risks were much less than those for construction workers and did not exceed 10^{-4} at any site, but did exceed 10^{-6} at all sites except 216-Z-8 French Drain. The results are below:

- **216-Z-1A Tile Field:** Cumulative risks were 2×10^{-6} , due to americium-241 (80 percent of total risks), followed by plutonium-239 (18 percent of total). Risks are driven by the external radiation pathway for americium-241.
- **216-Z-8 French Drain:** Risks were below 10^{-6} for all COPCs and exposure pathways evaluated.
- **216-Z-9 Trench:** Cumulative risks were 2×10^{-5} for the radionuclides, with plutonium-239 (46 percent of total), americium-241 (43 percent of total risks), and plutonium-240 having risks in excess of 10^{-6} . Carbon tetrachloride had the highest risks of the two nonradionuclide carcinogens, with a risk of 2×10^{-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 7×10^{-6} due almost entirely to cesium-137 via the external radiation pathway.

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

Radionuclide (Parent and Decay) or Contaminant	Total*	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	--

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

Radionuclide (Parent and Decay) or Contaminant	Total*	Inhalation	Ingestion	External Radiation	Radon
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

* 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* HI	Ingestion HI	Dermal HI	Inhalation HI
Cadmium	0.002	0.0002	0.00004	--
Carbon tetrachloride	0.00007	0.00007	--	--
Manganese	0.0001	0.00007	--	--
Total	0.0004	0.0003	0.00004	0.00003

* Totals are calculated using unrounded values.

HI = hazard index

A5.3.2.2 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 4×10^{-5} , within EPA's acceptable risk range of 10^{-6} to 10^{-4} . Technetium-99 contributes the most to the total cancer risk with a risk of 2×10^{-5} , followed by tritium and iodine-129 with cancer risks of 1×10^{-5} and 1×10^{-6} , respectively. Under the medium-exposure scenario (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower, at 4×10^{-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 10^{-6} .
- Cancer risks from nonradionuclides:** As shown in Table A5-4, total nonradionuclide cancer risks exceed 10^{-4} under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios, at 3×10^{-3} and 4×10^{-4} , respectively. Total cancer risks under the low-exposure

(25th percentile) scenario are 7×10^{-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 percent of the total nonradionuclide cancer risks under both the high- and medium-exposure scenario but for only 88 percent of the total cancer risks under the low-exposure scenario. Approximately 50 percent of the cancer risks for carbon tetrachloride result from ingestion exposures, while the other 50 percent 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 percent of the total non-cancer hazard under both the high- and medium-exposure scenario but for only 44 percent of the total cancer risks under the low-exposure scenario.

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

COPC	Tap Water ^a		
	90 th	50 th	25 th
Radionuclide			
I-129	1E-06	3E-08	^b
Tc-99	3E-05	3E-06	1E-06
Tritium	1E-05	1E-06	2E-07
Total	4E-05	4E-06	1E-06
Nonradionuclide			
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	1E-06	2E-07	2E-08
Total	3E-03	5E-04	6E-06

Notes:

Shaded values exceed 10^{-4} .

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

contaminant of potential concern COPC	Tap Water*		
	90 th	50 th	25 th
Carbon tetrachloride	41	7	0.1
Chloroform	0.07	0.02	0.002
Chromium	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
Tetrachloroethylene (PCE)	0.003	0.0004	0.0002
Trichloroethylene (TCE)	0.4	0.06	0.005
Uranium	0.03	0.004	0.003
Total	42	7	0.2

Notes:

Shaded values exceed target goal of an HI < or equal to 1.

* Totals are calculated using unrounded values.

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

In an institutional control failure scenario, a subsistence 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 evaluate 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.

A5.3.3.1 Soil Exposures

Subsistence 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 subsistence farmers exposed to drill cuttings were evaluated at all four waste sites. Table A5-6 presents risks for subsistence farmer soil exposures and Table A5-7 presents non-cancer hazards for the 216-Z-9 Trench. Subsistence 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 and include children's exposures. The results are below:

- **216-Z-1A Tile Field:** Risks from exposure to all COPCs are above 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 10^{-6} .
- **216-Z-9 Trench:** Cumulative risks are 2×10^{-2} for the radionuclides, with plutonium-239 (63 percent of total risks), americium-241 (20 percent of total), plutonium-240 (16 percent of total), neptunium-237, radium-226, and radon (including entire radon decay chain) all having risks in excess of 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 overall risks; however, inhalation risks were also greater than 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 10^{-4} , with risks of 2×10^{-2} due to external radiation. No other radionuclides exceed 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 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 subsistence farming adults.

Table A5-6. Summary of Cancer Risks for the Future Subsistence 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 ^c	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 ^c	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
Np-237	2E-04	1E-09	1E-07	2E-04	--	1E-05
Pa-231 ^c	2E-06	2E-10	2E-08	2E-06	--	1E-06
Pb-210 ^c	6E-07	2E-10	5E-07	1E-07	--	3E-05
Pu-238	2E-06	2E-08	1E-06	1E-07	--	1E-05

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

Radionuclide or Contaminant	Direct-Exposure Pathways					Food Chain Pathway
	Total ^a	Inhalation	Ingestion	External Radiation	Radon	Produce ^b
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 ^c	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^d						
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

Notes:

Shaded values exceed 10^{-4} .

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.

c. This radionuclide was not selected as a COPC, but is a daughter product with risks greater than $1E-7$.

d. Carbon-14 is a COPC at this site; however, at 150 years, risks are insignificant.

-- = indicated incomplete pathway or not applicable (i.e., radon column)

COPC = contaminant of potential concern

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

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

Notes:

Shaded values exceed target goal of an HI < or equal to 1.

*Totals are calculated using unrounded values.

HI = hazard index

A5.3.3.2 Groundwater Exposures

Future child and adult subsistence farmers were evaluated for future exposures to groundwater used as 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 subsistence farmers are assumed to use the groundwater as an irrigation source for their crops and livestock. Therefore, adult subsistence 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 subsistence 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 subsistence 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 10^{-4} , equal to the target risk goal. 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 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 percent of the total nonradionuclide cancer risks under both the high- and medium-exposure scenario but only for 87 percent 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 percent to the total cancer risk, followed by the ingestion pathway (32 percent), and the dermal pathway (4 percent).
- 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 percent 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.

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 Subsistence Farmer

COPC	Tap Water			Irrigation		
	90 th	50 th	25 th	90 th	50 th	25 th
Radionuclide						
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						
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	8E-06	1E-06	1E-07	2E-08	4E-09	3E-10
Total^c	2E-02	3E-03	5E-05	8E-05	1E-05	2E-07

Notes:

Shaded values exceed 10^{-4} .

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 Subsistence Farmer

COPC	Tap Water						Irrigation		
	90 th		50 th		25 th		90 th	50 th	25 th
	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	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	0.2	0.08	0.03	0.01	0.02	0.007	0.00008	0.00001	0.000007
Total^b	316	135	55	23	1	0.6	2	0.28	0.006

Notes:

Shaded values exceed target goal of and HI < or equal to 1.

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

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 subsistence 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 10^{-4} , although carbon tetrachloride risks exceed 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.

A5.3.3.3 Food Chain Exposures

Subsistence 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 10^{-4} under both the high and medium groundwater concentrations (Table A5-10) and 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 the 216-Z-9 Trench soil where risks are 1×10^{-1} ; however, risks due to ingestion of produce grown in impacted soil also exceeded 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 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 10^{-4} under the high-exposure scenario, as shown in Table 5A-10. However, 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 the 216-Z-1A Tile Field and the 216-Z-9 Trench 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 the 216-A-8 Crib.
- Cancer risk from nonradionuclides:** As shown in Table A5-10 for groundwater, the total nonradionuclide cancer risk from ingestion of homegrown produce also exceeds 10^{-4} under both the high- and medium-exposure scenarios. Total cancer risks under the high-exposure scenario are 1×10^{-2} , and total cancer risks under the medium-exposure scenario are 2×10^{-3} . Total cancer risks under the low-exposure scenario are 3×10^{-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 1×10^{-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 provide 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 percent 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.

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 Subsistence Farmer

COPC	Homegrown Produce			Beef			Dairy Products		
	90 th	50 th	25 th	90 th	50 th	25 th	90 th	50 th	25 th
Radionuclide									
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	3E-05	2E-06	7E-07	2E-04	2E-05	6E-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									
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

Notes:

Shaded values exceed 10⁻⁴.

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

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 the 216-Z-9 Trench but were primarily due to carbon tetrachloride. However, carbon tetrachloride at the 216-Z-9 Trench 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 subsistence farmer). Hazards due to ingesting thallium at the 216-A-8 Crib (the only nonradionuclide COPC at this site) also exceeded one with an HQ of 3.

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 Subsistence Farmer

COPC	Homegrown Produce			Beef			Dairy Products		
	90 th	50 th	25 th	90 th	50 th	25 th	90 th	50 th	25 th
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	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	0.000001
Uranium	0.2	0.02	0.02	0.0004	0.00006	0.00004	0.003	0.0005	0.0003
Total^a	362	63	1	0.3	0.02	0.01	0.09	0.02	0.0006

Notes:

Shaded values exceed target goal of an HI < or equal to 1.

a. Totals are calculated using unrounded values.

COPC = contaminant of potential concern

PCE = tetrachloroethylene

TCE = trichloroethylene

Ingestion of Beef

- Cancer risk from radionuclides:** As shown in Table A5-10, the total radionuclide cancer risk from ingestion of beef is below 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 percent, 68 percent, and 83 percent 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 percent, 30 percent, and 17 percent 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 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 10^{-6} , with a cancer risk of 2×10^{-6} in the high-exposure scenario. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under the high- and medium- exposure scenarios and for 73 percent of 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 percent, 66 percent, and 99 percent 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 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 6×10^{-6} , respectively. Technetium-99 is responsible for approximately 75 percent, 80 percent, and 90 percent 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 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 10^{-6} , with a cancer risk of 3×10^{-6} under the high-exposure scenario. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under the high- and medium-exposure scenarios and for 73 percent of 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 percent and 96 percent of the total hazards of each scenario, respectively.

Total Subsistence Farmer Exposures through the Food Chain Pathways

It is possible for subsistence 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 of 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 contributions from the ingestion of beef and dairy products pathways to cumulative food chain exposures for the subsistence farmer are insignificant relative to the ingestion through the 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.

A5.3.3.4 Vapor Intrusion Exposures

Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater beneath the 200-PW-1 OU (particularly near 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. The 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 subsistence farming 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 subsistence farming 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 subsistence farming 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, 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 target cancer risk level of 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 volatilization 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 Subsistence 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 for 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 overestimated for the subsistence 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 overestimate 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}
- Subsistence farmer drinking water: 1×10^{-8}
- Subsistence farmer irrigation exposures: 5×10^{-11}
- Subsistence farmer plant ingestion: 1×10^{-7}

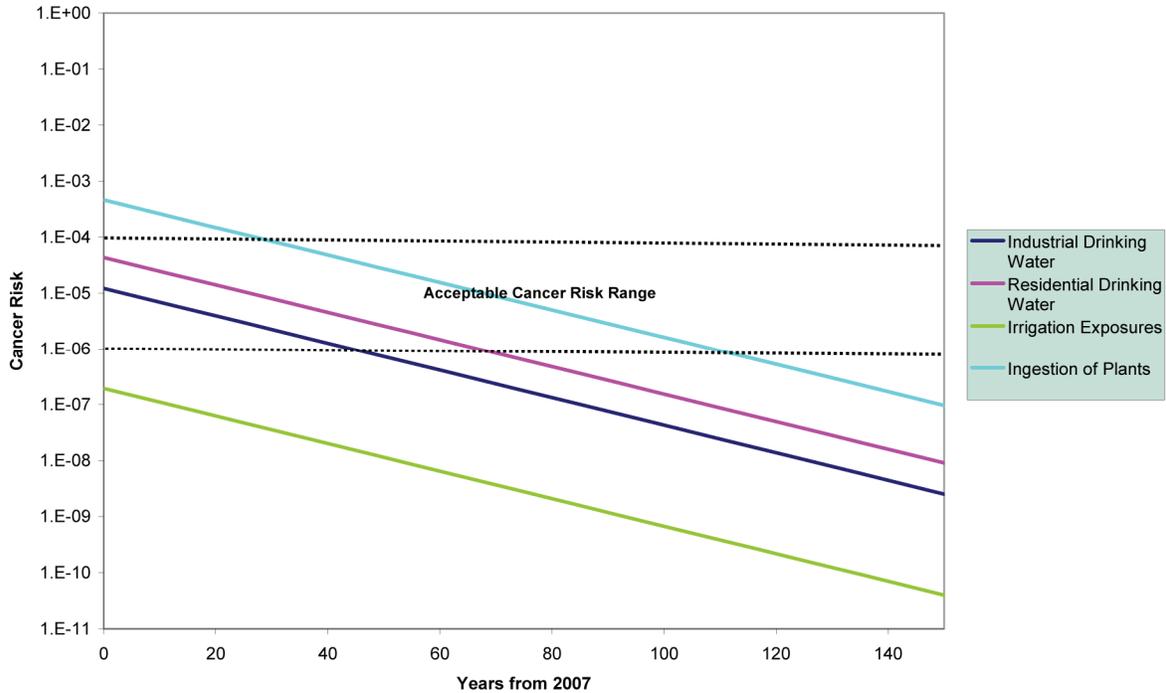


Figure A5-3. Cancer Risks from Tritium in Groundwater Over Time

A5.3.5 Cumulative Risks from Multiple Media Exposures

A subsistence farmer could potentially build a house at the 216-Z-9 Trench site (or another waste site) then could be exposed to contaminants in soil, groundwater, and the food chain at the same time. Table A5-12 presents an example of potential cumulative risks if a future subsistence 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 subsistence 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 subsistence 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, radiological dose estimates are provided for the intruder scenario— subsistence farmer and the future well driller—consistent with U.S. Nuclear Regulatory Commission (NRC) guidance (10 CFR, Subpart E). Tables A5-13 and A5-14 present radiation dose levels for carcinogens in soil for the well driller and subsistence farmer, respectively. 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 French Drain are many times greater than 15 mrem/yr for subsistence farmers. For well drillers, dose levels exceed 15 mrem/yr only at the 216-Z-1A Tile Field. Although radiation dose levels are not presented for radionuclides in groundwater, dose levels for those exposures for the subsistence farmer would also exceed 15 mrem/yr, primarily due to exposure to technetium-99 in the food chain pathways.

Table A5-12. Cumulative Risks for the Subsistence 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 subsistence farmer at 216-Z-9 Trench =			2E-01

Notes:

Shaded values exceed 10⁻⁴.

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.

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

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

Radionuclide	Direct Contact with Soil				
	Total	Inhalation	Ingestion	External Radiation	Produce Ingestion
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

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

Radionuclide	Direct Contact with Soil				
	Total	Inhalation	Ingestion	External Radiation	Produce Ingestion
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

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 well digger exposure to soil as drill cuttings; a regular worker drinking groundwater at their place of employment; and a subsistence 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, exposures to contaminants and radionuclides in groundwater and soil are less likely, but still possible. 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 encounter 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 the 216-Z-8 French Drain 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 the 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 subsistence 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 humans could encounter 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 from 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 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 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 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 10^{-4} , whereas risks from eating beef was below 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 10^{-4} for construction workers and subsistence 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 subsistence farmers. Risks for future well drillers at all four soil sites were below 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 10^{-4} at the 90th and 50th percentiles due primarily to carbon tetrachloride, followed by technetium-99, for both subsistence farming 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.

Subsistence 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.

A6 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 humans 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. In general, the sampling strategies for contaminants in this assessment were designed to prevent under-estimation of media concentrations, thus avoiding an under-estimation of the risks to public health.

Uncertainties exist 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 overestimate 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 the 216-Z-1A Tile Field (hundreds of samples from 36 locations over an area of 2,416 m² [26,000 ft²]) and, to a lesser extent, also at the 216-Z-9 Trench (30 samples at nine locations over an area of 1,000 m² [10,800 ft²]) to select COPCs and identify the range of potential concentrations of contaminants. For the two sites where data were more limited (216-Z-8 French Drain and 216-A-8 Cribs), sample locations were selected in the area expected to have the highest concentrations. At the 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 underestimated. 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 French Drain are unlikely to have underestimated 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 overestimates rather than underestimates 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 ($1,580 \text{ m}^2$ [$17,000 \text{ ft}^2$] 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 overestimated risk unless the concentrations at the single sample location (C4545) are similar throughout the area. Risk estimates for the well driller and the subsistence farmer at this location used data from the multiple depth samples, three 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 remainder of the soil beneath this site is as impacted.

At two sites, the 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 percent 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 target risk goal is 1×10^{-4}). Because risks and hazards for soil were calculated using the 95 percent 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 subsistence farmers, above 1×10^{-2} ; 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 underestimated by screening procedures.

A6.1.1.1 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, the maximum risks for a subsistence farmer were 2×10^{-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 increase 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 percent of the known concentration instead of double the known concentration. Therefore, maximum americium-241 concentrations would only be underestimated 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 year 0 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 (i.e., 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 the 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 1×10^{-4} ; therefore, an increase in americium-241 risks would not affect the conclusions of the risk assessment.

A6.1.1.2 216-Z-10 Injection/Reverse Well

Data were available for the 216-Z-10 Injection/Reverse Well site from an old report, indicating 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’s (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, and 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, and DOE-EM/GJ920-2005). These include the following:

- Cesium-137 was found at 1 pCi/g at ground surface at one well and near the 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 the 216-Z-10 Injection/Reverse Well, even if analysis confirmed the above concentrations. This is due to the fact that 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 recent at levels that are a health

concern (although the data are only screening level), there are unlikely to be significant radionuclide hazards present at the 216-Z-10 Injection/Reverse 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 the 216-Z-10 Injection/Reverse 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/Reverse Well, the site was appropriately screened out of the risk assessment.

A6.1.1.3 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 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 these contaminants 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, these nondetected constituents remain an area of uncertainty in the risk assessment. However, risks already exceed target health goals.

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 107 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 29 valid results available for the risk assessment compared to 835 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 in 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

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

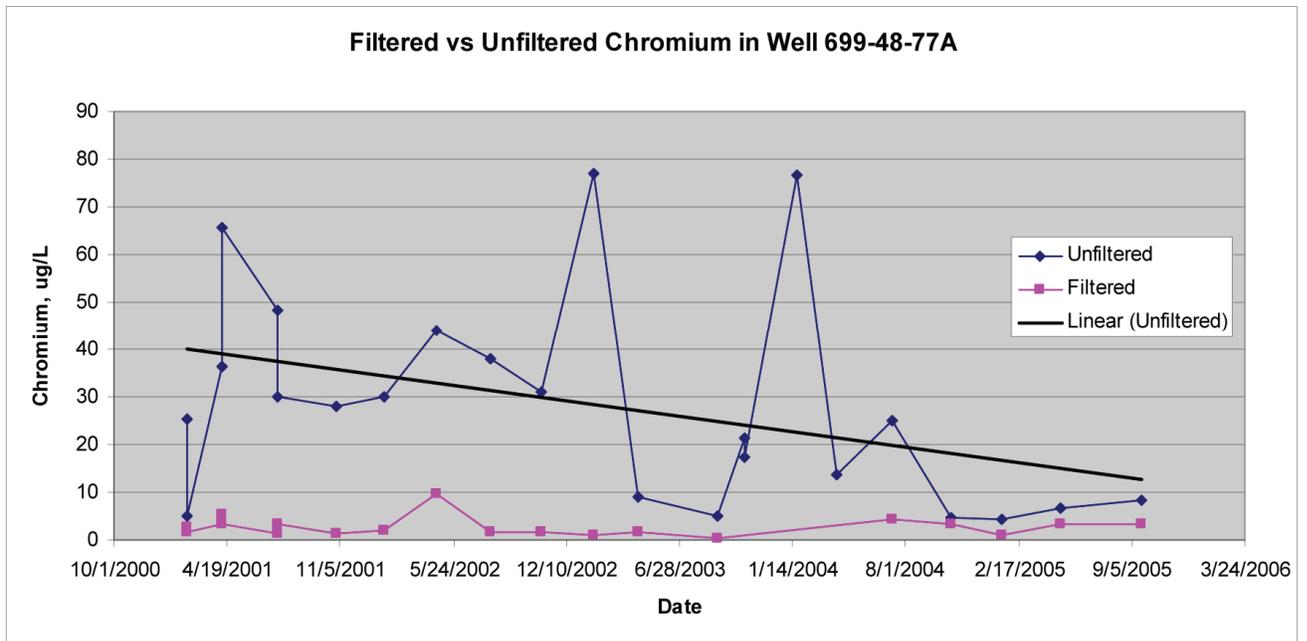
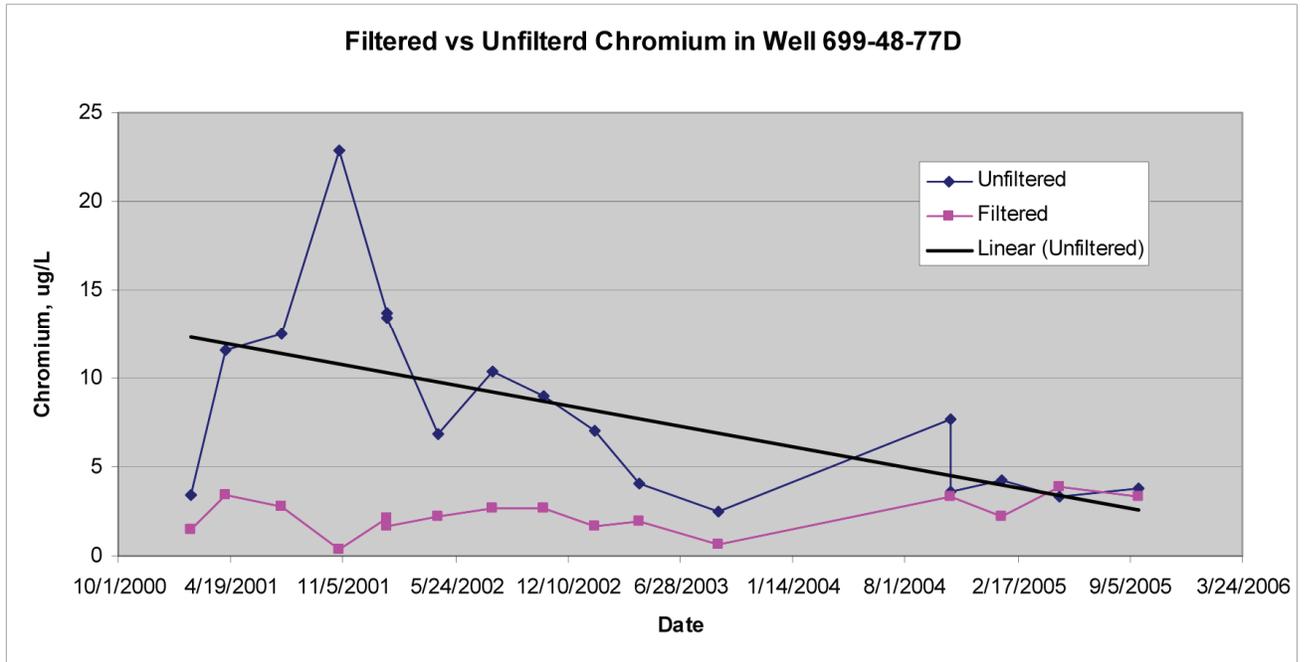
change the extent of the plume. Hexavalent chromium in drinking water exceeded an HI of 1 (HI = 5 for children) only at the 90th percentile concentration, a very minor contaminant when compared to a child HI of 304 for carbon tetrachloride at the 90th percentile concentration (Table A5-9).

A6.1.2.1 Use of Filtered versus Unfiltered Data

As discussed in Section A2, unfiltered sample data are not available for metals; therefore, the use of filtered data for metals potentially underestimates the concentrations present in groundwater. Of the 15 contaminants identified in the groundwater RI as potentially a health concern (DOE/RL-2006-24), six of them are metals/inorganics: antimony, chromium (total), hexavalent chromium, lead, uranium, and nitrate. For uranium and nitrate, the unfiltered data sets were sufficient for risk assessment and non-cancer hazards were calculated based on unfiltered data. Antimony was excluded as a COPC because concentrations in groundwater do not exceed background and the background level was also a dissolved value. Iron's maximum concentration was several orders of magnitude below a health-based screening value so even if iron concentrations are underestimated (i.e., iron concentrations would probably be higher if unfiltered data were available), concentrations are unlikely to be orders of magnitude higher and the contaminant was thus appropriately excluded as a health concern.

Although unfiltered data are available only for two or three samples for hexavalent chromium, research conducted on this issue has identified that dissolved data are more representative of the concentrations actually present in groundwater. Analyses for chromium and other metals in unfiltered samples are believed to be biased due to the stainless steel casing, screen, and pump materials. Filtered samples best indicate the chromium levels in the groundwater (likely dominantly hexavalent chromium). Stainless-steel well screens have been shown to significantly affect metal concentrations in laboratory studies (e.g., "Dynamic Study of Common Well Screen Materials" [Hewitt, 1994]). The latest groundwater monitoring report for Hanford (Hanford Site Groundwater Monitoring for Fiscal Year 2007 [DOE/RL-2008-01]) states the following:

- Erratic, high levels of chromium are seen in unfiltered samples. This is consistent with relatively coarse (>0.45 μm) particulate matter from the well construction. Unfiltered samples are highly variable and do not show a consistent trend. See Figure A6-1 for filtered versus unfiltered total chromium data for two of the 200-ZP-1 wells used in the risk assessment data set.
- Hexavalent chromium (the species of concern from a risk perspective) is highly soluble in groundwater but trivalent chromium is not. Hexavalent chromium will pass through the filters. Trivalent chromium will be immobile in groundwater but may be present in particles in unfiltered samples. For the majority of the data set there is a strong 1:1 correlation between filtered chromium measurements and hexavalent chromium showing that the hexavalent chromium contamination is effectively detected by measuring filtered chromium.
- The 90th percentile concentration for hexavalent chromium used in the risk calculations of 203 $\mu\text{g/L}$ is higher than the total chromium 90th percentile value of 130 $\mu\text{g/L}$. If all of the filtered total chromium data were assumed to be hexavalent chromium, the concentrations of hexavalent chromium used in the risk calculations would be lower. Therefore, health risks for hexavalent chromium have not been underestimated. Non-cancer hazards from chromium (total) have probably been underestimated by the use of the filtered data; however, chromium (total) health hazards (see Tables A5-5 and A5-9 in Section A5.0) are several orders of magnitude below an HI of 1. Consequently, an increase in chromium (total) concentrations due to use of unfiltered samples would probably not impact the risk assessment conclusions. For the limited paired data available, total chromium (total) appears to be about 30 percent higher in unfiltered versus filtered samples.



CHPUBS1003-01.21

Figure A6-1. Filtered Versus Unfiltered Chromium in Two ZP-1 Groundwater Wells

The 90th percentile concentration for hexavalent chromium used in the risk calculations of 203 µg/L is higher than the total chromium 90th percentile value of 130 µg/L. If all of the filtered total chromium data were assumed to be hexavalent chromium, the concentrations of hexavalent chromium used in the risk calculations would be lower. Therefore, health risks for hexavalent chromium have not been underestimated. Non-cancer hazards from chromium (total) have probably been underestimated by the use of the filtered data; however, chromium (total) health hazards (see Tables A5-5 and A5-9 in Section A5.0) are several orders of magnitude below an HI of 1. Consequently, an increase in chromium (total) concentrations due to use of unfiltered samples would probably not impact the risk assessment conclusions. For the limited paired data available, total chromium (total) appears to be about 30 percent higher in unfiltered versus filtered samples.

A6.1.2.2 Additional COPCs

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 percent 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, overestimate risk for most of a hypothetical population, even though not all assumptions may 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 underestimated.

A6.2.1 Tribal Subsistence Exposures

As discussed in Section A3.1.2, 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 subsistence farming population. A subsistence 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. In addition, the range of exposure factors for residential populations has been estimated providing information on population distributions, average values, and RME values. These data are generally not available for Native American populations.

However, based on the ongoing work evaluating the differences between a Tribal scenario and a subsistence farmer scenario, Native Americans likely have increased exposure to many environmental media, although with few exceptions, Native American exposure pathways are the same as the subsistence farmer (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 the Umatilla (Harris and Harper, 2004) and Yakama Nation (Ridolfi, 2007), with the subsistence farmer for the exposure pathways that are the same. The subsistence farmer results for soil listed in Table A6-3 are based on the methodology described in Appendix G (i.e., basement excavation) rather than the intruder scenario; therefore, the soil risk results listed in this table are not directly comparable to the risk results listed in Table A5-6. As shown in Table A6-3, because the multimedia cumulative cancer risks for the subsistence farmer already approach the maximum risk possible (i.e., approaching 100 percent), increased exposures for a Native American population do not necessarily result in an increase in risks. Because soil risks are at their maximum, differences in risk in this assessment between subsistence farmer and the Native American scenario quantified in Appendix G are not dramatic.

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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 (SV)	Detection Frequency	No. of Samples Exceeding Screening Value	Percent Exceedance (Based on SV)	Magnitude of Exceedance Ratio (Based on SV)	Background Value	No. of Samples Exceeding Background Value	Percent Exceedance (Based on Background)	Magnitude of Exceedance Ratio (Based on Background)	COPC Flag	Rationale Contaminant Deletion or Selection ^a
Inorganics														
7440-36-0	Antimony	µg/L	46.2	1.46	46/831	46	6	32	55.1	0	0	0	NO	BCK
7440-38-2	Arsenic	µg/L	14	0.045 c	86/105	86	82	312	7.85	3	3	2	NO	BCK
7440-43-9	Cadmium	µg/L	4.7	1.825	15/835	10	1	3	0.916	11	1	5	NO	FRQ
7440-47-3	Chromium^b	µg/L	769	10.95	688/835	399	48	70	2.4	649	78	320	YES	EVAL
18540-29-9	Hexavalent chromium	µg/L	730	10.95	27/29	13	45	67	NE	NA	NA	NA	YES	EVAL
7439-96-5	Manganese	µg/L	2030	170.3	626/829	22	3	12	38.5	46	6	53	NO	FRQ
7439-97-6	Mercury ^b	µg/L	0.12	0.06	2/216	1	1	2	0.003	2	1	40	NO	FRQ
7440-02-0	Nickel	µg/L	328	73	239/829	19	2	4	1.56	235	28	210	NO	FRQ
7440-22-4	Silver	µg/L	85	18.25	52/831	2	<1	5	5.28	12	1	16	NO	FRQ
7440-28-0	Thallium	µg/L	57.7	0.26	9/38	9	24	226	9.85	8	21	6	YES	ASL
7440-61-1	Total uranium^c	µg/L	367	11	182/186	14	8	33	11.5	12	7	32	YES	EVAL
7440-62-2	Vanadium	µg/L	92.9	18	821/829	711	86	5	1.67	821	99	56	YES	ASL
Organics														
107-06-2	1,2-Dichloroethane	µg/L	1	0.123 c	8/462	6	1	8	0	8	2	NA	NO	FRQ
56-23-5	Carbon tetrachloride	µg/L	5,200	0.171 c	468/574	466	81	30,356	0	468	82	NA	YES	EVAL
67-66-3	Chloroform	µg/L	420	0.167 c	452/581	443	76	2,514	0	452	78	NA	YES	EVAL
75-09-2	Methylene chloride	µg/L	740.52	4.276 c	132/581	41	7	173	0	132	23	NA	YES	EVAL
127-18-4	Tetrachloroethylene	µg/L	5	0.105 c	191/581	191	33	48	0	191	33	NA	YES	EVAL
79-01-6	Trichloroethylene	µg/L	36	0.028 c	353/581	353	61	1,285	0	353	61	NA	YES	EVAL
16984-48-8	Fluoride	µg/L	10,500	219	908/911	889	98	48	1,047	236	26	10	YES	ASL
NO3-N	Nitrogen in nitrate^c	µg/L	1,720,000	5,800	1,013/1,015	901	89	297	28,063	373	37	61	YES	EVAL
NO2-N	Nitrogen in nitrite ^c	µg/L	8,100	370	54/911	12	1	22	629	7	1	13	NO	FRQ

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 (SV)	Detection Frequency	No. of Samples Exceeding Screening Value	Percent Exceedance (Based on SV)	Magnitude of Exceedance Ratio (Based on SV)	Background Value	No. of Samples Exceeding Background Value	Percent Exceedance (Based on Background)	Magnitude of Exceedance Ratio (Based on Background)	COPC Flag	Rationale Contaminant Deletion or Selection ^a
Notes:														
Shaded chemicals were not selected as COPCs and may represent an under-estimation of health risks. Bold chemicals were evaluated as COPCs in the risk assessment.														
a. COPC rationale for selection/deletion:														
ASL = above screening levels and would be selected as a COPC using SVs shown on this table, but were not selected using target action levels (TALs). See Section A.2 for description of TALs.														
BCK = Near or below background levels (magnitude of exceedance over background less than two times).														
EVAL = selected as a COPC and evaluated in the risk assessment														
FRQ = low frequency of samples exceeding the screening value (<5 percent).														
b. Hexavalent chromium screening value is used for the chromium screening value and elemental mercury is used for the mercury screening value.														
c. Screening values are from EPA Region 3 Risk-Based Concentrations (EPA 2005).														
c = cancer endpoint														
COPC = contaminant of potential concern														
NA = not applicable														
NE = not established														
SV = screening value (1/10th of non-cancer or full value of cancer from EPA Region 6 [2006] Tap Water)														

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

Exposure Pathway	Umatilla (Intake Rates from Harris and Harper 2004)		Yakama Nation (Intake Rates from Ridolfi 2007)		Subsistence Farmer (Soil at 216-Z-1A; 90 th Percentile Groundwater)	
	Intake Rate	Risk	Intake Rate	Risk	Intake Rate	Risk
Groundwater exposure (radionuclides and non-radionuclides)						
Drinking water	4 L/day, 70 years	6E-02	4 L/day, 70 years	6E-02	2 L/day, 30 years	2E-02
Produce ingestion (fruit, vegetable, and grain)	247 kg/year ^a , 70 years	8E-02	309 kg/year ^a , 70 years	9E-02	116.5/kg/year ^b , 30 years	2E-02
Meat ingestion	75 g/day ^a , 70 years	3E-05	422.4 g/day ^a , 70 years	2E-04	168.7 g/day, 30 years	3E-06
Milk ingestion	Not available	--	1.2 L/day, 70 years	8E-04	0.68 L/day, 30 years	6E-06
Sweat lodge (inhalation of vapor)	30 m ³ /day, 70 years	3E-03	26 m ³ /day, 70 years	3E-03	Not evaluated for subsistence farmer	
Total groundwater cancer risk		1E-01		1E-01		4E-02
Soil exposure (RESRAD inputs for radionuclides only)						
Incidental ingestion	400 mg/day (adult – 70 years)	1E+00	400 mg/day (adult – 70 yrs)	1E+00	100 mg/day (adult – 30 yrs)	1E+00
Inhalation	30 m ³ /day, 70 years	7E-03	26 m ³ /day, 70 years	6E-03	23 m ³ /day, 30 years	2E-03
External radiation	70 yrs	5E-01	70 yrs	5E-01	30 yrs	3E-01
Produce ingestion (fruit, vegetable, and grain)	247 kg/year ^a , 70 years	1E+00	309 kg/year ^a , 70 years	1E+00	116.5 kg/year ^b , 30 years	1E+00
Total soil cancer risk		1E+00		1E+00		1E+00

a. The meat ingestion rate is 60 percent of the wild game/fowl value and the plant ingestion rate is 50 percent of the wild roots/greens and fruit values in the respective reports as described in detail in Section J3 of Appendix J.

b. Produce (fruits and vegetables) ingestion rates used in the risk assessment calculation are 16 percent of total per capita consumption rates for high-end consumers (95th percentile), and are 49 percent 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).

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 subsistence 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 subsistence farmer and would not include the food chain pathways; therefore, risks and hazards have not been underestimated. 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. As a result of 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 percent 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 percent 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 percent UCL values because the data set is robust. Generally the larger the data set, the closer the 95 percent UCL is to the mean concentration. For example, carbon tetrachloride’s 95 percent 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 underestimated for the COPCs where the maximum concentration is considerably larger than the 90th percentile value (true for eight of the 12 COPCs where the maximum concentration is more than an order of magnitude larger than the 90th percentile). Because only 10 percent of the data exceed the 90th percentile values, these very high concentrations are few and represent a very limited areal extent. Figures A6-2a and A6-2b 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.

Table A6-4. Groundwater Percentile Concentrations and Summary Statistics

COPC	Units	Percentile Concentrations					Summary Statistics		
		5 th	25 th	50 th	90 th	95 th	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	0.6	0.81	1.18	8.3	33.1	367	10.14	29.5
I-129	pCi/L	-0.05	-0.004	0.030	1.170	11.298	36.7	1.3	2.4
Tc-99	pCi/L	4.96	59	180	1,442	3,913	27,400	793	1160
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

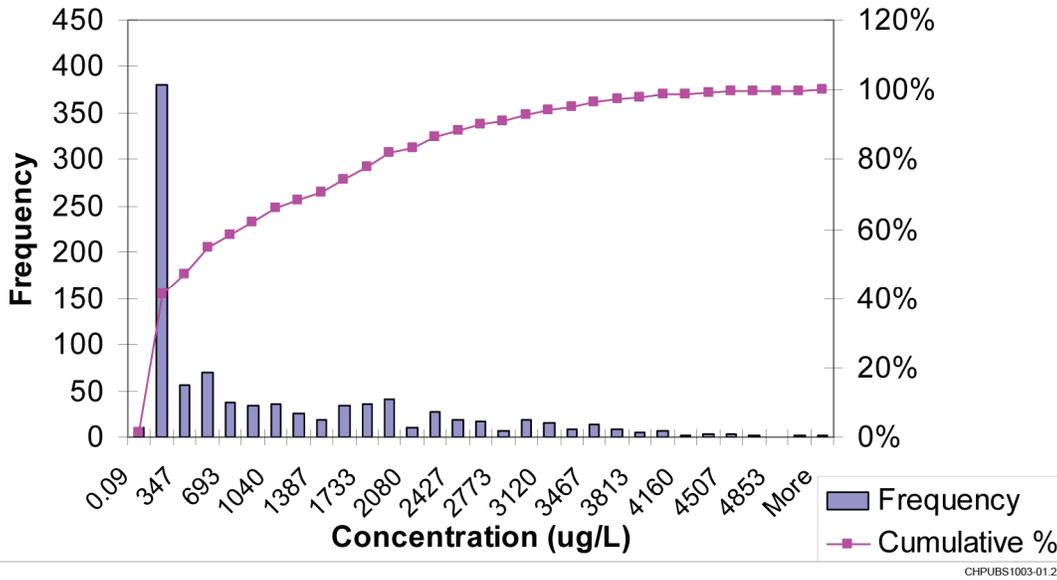


Figure A6-2a. Carbon Tetrachloride Groundwater Concentration Frequencies

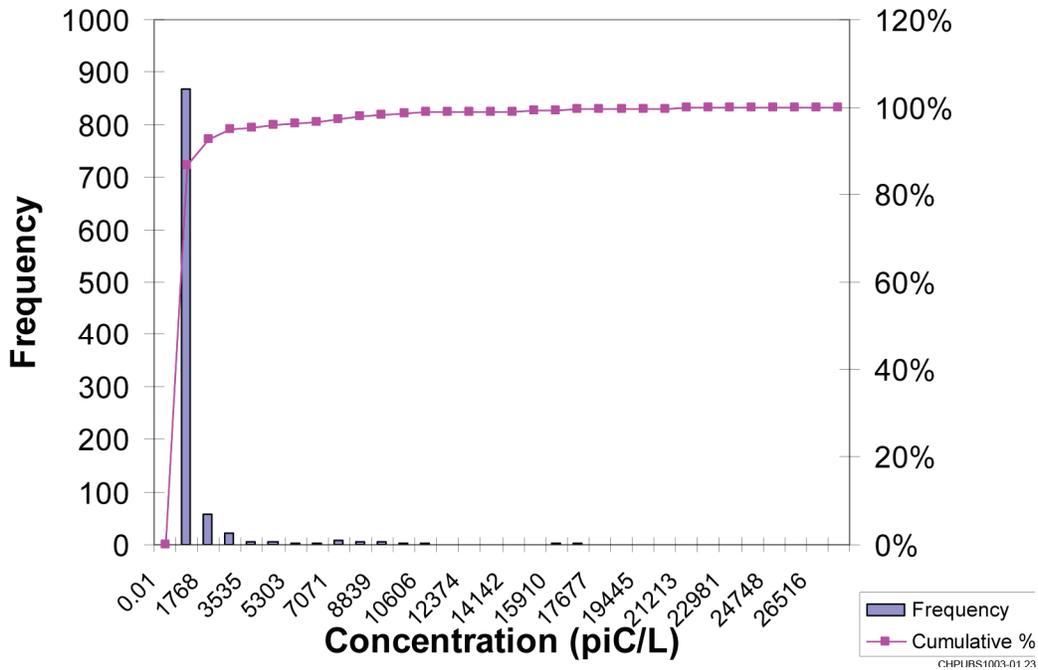


Figure A6-2b. Technetium-99 Groundwater Concentration Frequencies

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 percent 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 percent 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 subsistence 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-m² (1,076-ft²) garden from the analysis performed for the tank waste performance assessment (Rittman 2004). The value of 100 m² (1,076 ft²) is based on an area that could likely supply at 25 percent 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 Tile Field and 216-Z-9 sites for a subsistence farmer, assuming garden sizes of 100 m², 500 m², 1,000 m², 1,500 m², and 2,000 m² (1,076 ft², 5,382 ft², 10,764 ft², 16,146 ft², and 21,528 ft²). At 1,500 m² (16,146 ft²), 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 waste sites, concentration reductions by an order of magnitude would still result in risks well above 1×10^{-4} for the soil pathways.

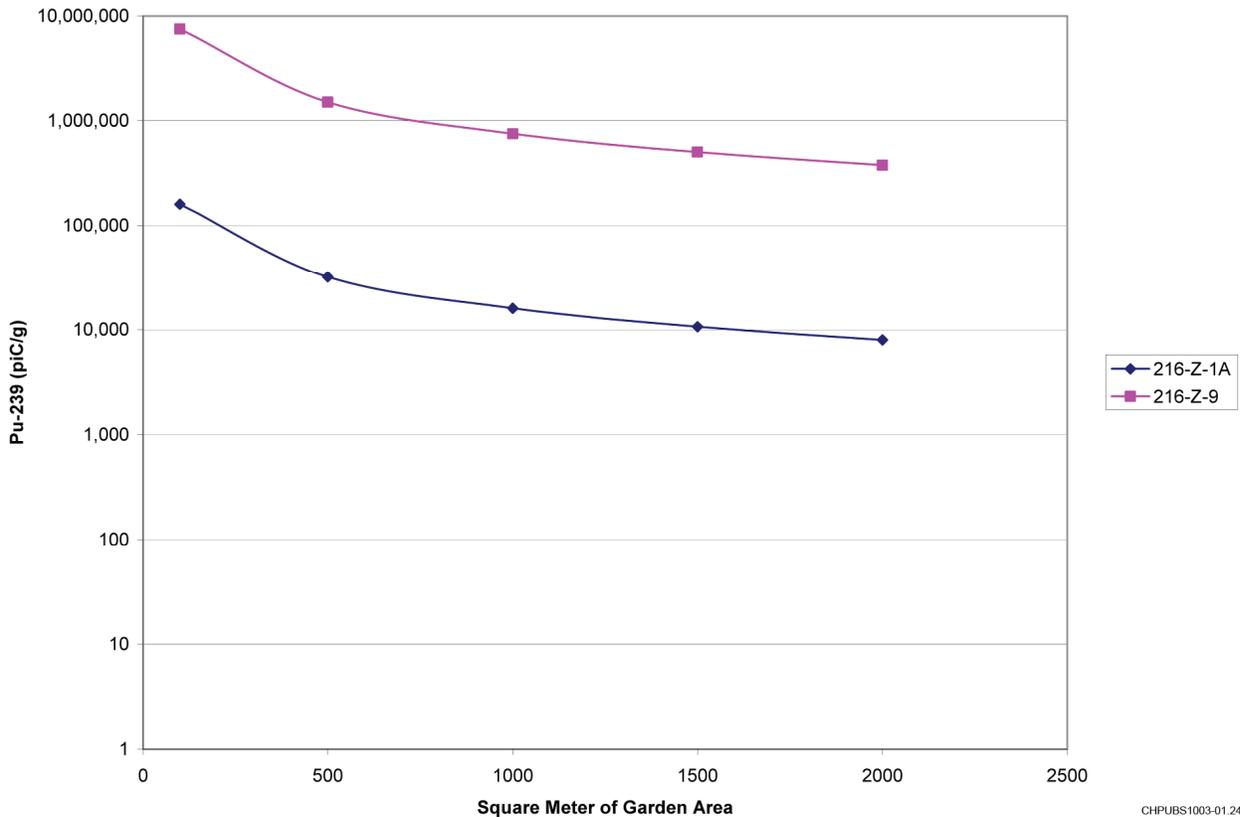


Figure A6-3. Change in Plutonium-239 Concentration with Garden Size

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 in risks and hazards that are equal to or greater than direct ingestion of groundwater used as a drinking water source. The two main factors that drive the calculated risks and hazards from ingestion of homegrown produce are: (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 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 overestimate, rather than underestimate, 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 grown 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 this modeling process overestimates the amount of COPC estimated to be in plant tissue. 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, through either 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 that farm in the west of 1.85 g/kg-day and the mean (average) total homegrown vegetable intake for households that 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 that 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 around, and because of uncertainties in intake rates between humans who live in the west (but may not be farmers) and specifically those who engage in farming activities, the unadjusted intake rates for households that 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.

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

EPA Recommended Intakes for Homegrown Produce (EPA/600/P-95-002Fa)	Units	Fruits	Vegetables	Total Produce
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)

Summing fruit and vegetable rates for households that farm together results in a total mean homegrown fruit and vegetable intake rate for households that 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 percent of a person's total fruit and vegetable intake using USDA average consumption rates (521 g/day, as cited in Rittman [2004]) or 49 percent 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 percent of total consumption rates (EPA/600/R-05/062F). While the ingestion rates used in this assessment may be an overestimate of the amount of vegetables and fruit (grains are excluded) that could be produced from a 100-m² (1,076-ft²) garden for a family of four or more humans (Rittman [2004] assumed that a 100-m² [1,076-ft²] garden could produce 25 percent of total fruit and vegetables for a family of four) (see Table A6-5), 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 m² (2,153 ft²) 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 A6-5). 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 percent to 40 percent 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 overestimate the amount of produce that could be grown in a 100-m² (1,076-ft²) 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 subsistence 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 subsistence farmer risks. The RESRAD default assumptions differ from EPA residential defaults below:

- 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 subsistence farmer equations, for 365 days/yr). Of the total, RESRAD assumes only 10 percent would come from the impacted garden area of 100 m² (1,076 ft²). This means that the RESRAD soil risks are significantly lower than the EPA defaults.
- RESRAD assumes that only 75 percent of a person's time will be spent at Hanford; EPA residential defaults assume that 96 percent of a person's time will be spent at home.
- RESRAD assumes an annual inhalation rate of 8,400 m³/yr, corrected to account for time spent offsite, time indoors (50 percent), and an indoor dust reduction factor (0.4), to 3,780 m³/yr (45 percent reduction of annual inhalation rate due to site exposures). This is equivalent to a daily on Hanford property inhalation rate for 350 days/yr of 10.8 m³/day, approximately one-half the EPA residential default of 20 m³/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 overall 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 percent 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 humans typically do not spend 96 percent of their time at home, and other risk assessments at Hanford have assumed a 60/20/20 factor (i.e., 60 percent inside, 20 percent outside, and 20 percent offsite), assuming less time outdoors and less time at Hanford lowers risk estimates.

A6.3 Uncertainties in Assessment of Toxicity

EPA has developed toxicity values 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 overestimate 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 U.S. will, in the 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 that 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.

A6.3.1 Radionuclides Slope Factors

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 used 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. Evidence indicates the response per unit dose at low doses and dose rates from low linear-energy transfer radiation (primarily gamma rays) may be overestimated if extrapolations are made from high doses acutely delivered. The degree of overestimation is often expressed in terms of a dose. A dose-rate effectiveness factor is used to adjust risks observed from high doses and dose rates for 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.

A6.3.2 Radionuclide Dose Versus Risk Estimates

EPA's OSWER Directive No. 9200.4-18 (*Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*) states that, at CERCLA sites, cleanup levels should be based on the CERCLA target risk range of 10^{-6} to 10^{-4} and not on radiological dose. Risk was therefore used as the basis for cleanup levels in Section A7 of this assessment. For the majority of common radionuclides, cleanup levels based on risk will be lower (i.e., more health protective), than those based on dose. However, this is not true for the transuranic contaminants that are the risk drivers at all waste sites evaluated in this assessment, except for Site 216-A-8. The differences between dose-based cleanup levels and risk-based cleanup levels depend on the individual radionuclide dose and risk conversion factors and the assumptions of exposure duration. There are two major reasons for differences in dose and risk cleanup level values:

- 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 1-year cancer risk of 5×10^{-5} , less than the target health goal of 1×10^{-4} . 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, a 100 mrem/yr RBC and the 1×10^{-4} cancer risk cleanup level would be similar for cesium-137 but are very different for americium-241 and the plutonium isotopes (dose-based cleanup levels are approximately two orders of magnitude lower).
- 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 A6-6). Table A6-7 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 1-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.

Table A6-6. 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 A6-7. 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
Radionuclide	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

The risks in Table A6-7 show an interesting relationship between 1-year exposure and chronic exposures. For a 1-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 1-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 1-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 (1 year or less exposure), the difference between the risk and dose criteria appears greater than if the exposure was for long term.

A6.3.3 Trichloroethylene Slope Factors

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 $0.007 \text{ (mg/kg-day)}^{-1}$ (as presented in *Technical Support Document for Describing Available Cancer Potency Factors* [OEHHA, 2002]) and an oral SF of $0.013 \text{ (mg/kg-day)}^{-1}$ (as presented in *Public Health Goal for Trichloroethylene in Drinking Water* [OEHHA, 1999]).

The OEHHA values are considerably lower than EPA's selection of $0.4 \text{ (mg/kg-day)}^{-1}$ 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 U.S. are recommending use of the California values; however, Ecology is currently recommending use of the $0.4 \text{ (mg/kg-day)}^{-1}$ 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, $0.4 \text{ (mg/kg-day)}^{-1}$, 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 associated non-Hodgkins lymphoma 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 (8×10^{-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 upward and/or the higher EPA SFs are validated, cancer risks due to TCE might have been underestimated. 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 significant difference in the overall cumulative cancer risks from groundwater.

A6.4 Uncertainties in Risk Characterization

Radiation is naturally present in the environment. The radionuclide risks estimated in this assessment have not been corrected to account for natural background radiation. The impacts of background are typically described in terms of radiation dose (millirem, or mrem). For the U.S. as a whole, the average radiation dose from background sources is approximately 300 mrem/yr, and 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 of the waste sites evaluated in this assessment were insignificant [see Attachment A-7 of this appendix]). The remaining 100 mrem of radiation from background sources is primarily from 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 U.S. 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. 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. The dose levels at 216-Z-8 French Drain are below 15 mrem/yr for the construction worker and well driller and were only 49 mrem/yr for the subsistence 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 that equal or 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 and 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 overestimate 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 (EPA 540/1-89/002) does not provide specific quantitative uncertainty estimates of the cancer SFs. *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 percent 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 overestimate rather than underestimate probable risk. The results of this assessment, therefore, are likely to be protective of health despite the inherent uncertainties in the process.

A7 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, and groundwater will not be used as a drinking water source as long as institutional controls are functioning and concentrations remain above cleanup levels, therefore, the RBCs presented in this section have been calculated based only on industrial land use. The NCP expectation for groundwater is that usable groundwater will be returned to the highest beneficial use (i.e., drinking water) "...wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" (40 CFR 300.430[a][1][iii][F]). The RBCs have been calculated based on a hypothetical future working population drinking the water at their place of employment. 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, 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 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 six constituents exceed 1×10^{-6} (technetium-99, tritium, carbon tetrachloride, chloroform, PCE, and TCE). Only carbon tetrachloride exceeds 1×10^{-4} and is the only contaminant with a non-cancer HI >1 (see Table A5-5). Therefore, the future regular worker RBC is calculated only for carbon tetrachloride.

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, 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} . 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 10^{-6} to 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 calculated and are presented in Table A7-1.

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

Risk Driver	Risk-Based Concentration * Based on a Target Annual Risk of 1E-4 (pCi/g)
Am-241	45,000
Pu-239	50,000
Pu-240	50,000
Cs-137	1,600
Notes: * The RBC is based on a combined risk via the dust inhalation, soil ingestion, and external exposure pathways. RBC = risk-based concentration	

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 3-2 and 3-5 of this appendix) that 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. The process to calculate the risk-based RBCs for the radionuclides in soil considered combined exposures through the soil ingestion, dust inhalation, and external radiation pathways, so the RBC is protective of a 1×10^{-4} cancer risk level across all pathways combined. 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 Tile Field and 216-A-8 French Drain 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 at these sites are provided in Attachment A-8, Table 8-5, in this appendix. The RBCs for each contaminant are presented in Table A7-1.

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 below:

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

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

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

The results of these equations for carbon tetrachloride are an RBC based on a cancer risk level of 1×10^{-4} of 111 $\mu\text{g/L}$ and an RBC based on HI of 1 of 62 $\mu\text{g/L}$. Because the non-cancer toxicity results in a lower RBC than the cancer RBC, the RBC for carbon tetrachloride is 62 $\mu\text{g/L}$. If 1×10^{-6} is selected as the target risk goal, the cancer RBC would be 1.1 $\mu\text{g/L}$, lower than the RBC based on non-cancer.

A7.2 Application of Cleanup Levels

The RBCs for each of the risk drivers were calculated to be protective of the target 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

collocated 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 using 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. There were no significant differences between these risks and the median calculated risks that were performed in this risk assessment. In addition, the site area size was increased and decreased by five times. 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.

A8 Summary and Conclusions

This section provides a summary of the HHRA that was 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 humans 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 subsistence farming population (adults and children) and a working population (future well drillers and future regular workers) are hypothetically possible. This risk assessment assumes there will be no reduction in current contaminant levels but uses current concentrations to assess risks 150 years in the future. While this is consistent with the health-protective nature of risk assessment procedures, it is an overestimate of actual future risks because of the planned active groundwater treatment program and the natural degradation of the organic compounds. 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 NCP expectation for groundwater is that usable groundwater will be returned to the highest beneficial use (i.e., drinking water) "...wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" (40 CFR 300.430[a][1][iii][F]).

The results and conclusions of risk assessment are summarized in the following sections.

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 (2001 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 COCs, the groundwater data evaluation selected 12 COPCs to carry through the risk assessment process:

- Carbon tetrachloride
- Chloroform
- Chromium (total)
- PCE
- TCE
- Uranium (contaminant toxicity only)

- Hexavalent chromium
- Methylene chloride
- Nitrate
- 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 near the 216-Z-1A Tile Field 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 listed in Table A8-1. No contaminants were identified as COPCs in soil at 216-Z-10 Injection/Reverse Well.

Table A8-1. Selected COPCs in Soil Based on Maximum Detected Concentrations from Waste Sites

COPC	216-Z-1A	216-Z-8 French Drain	216-Z-9	216-A-8
Am-241	√	√	√	
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			√	

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 subsistence farming population. COPCs are present in soil gas at both the 216-Z-9 Crib and 216-Z-1A Tile Field; no VOCs were detected in soil at the 216-Z-1A Tile Field 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; thus, are not a concern for a working population.

A8.2 Exposure Assessment

After the COPCs have been selected, the second step in risk assessment is an evaluation of the exposure pathways by which humans 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
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 the 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 (i.e., outdoor and indoor workers not engaged in active soil disturbance) will not be exposed to subsurface soil because impacted material is too deep, that is, below the 1-m (3.3 ft)-bgs limit considered as surface soil in most risk assessments. They will not 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 subsistence farming population was also selected for evaluation. This assumes exposure to contaminants in groundwater and soil if institutional controls fail at some point in the future and additional exposures via the food chain (i.e., fruits and vegetables, meat, and dairy products). The future point selected for subsistence farming 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 subsistence farmers. Child and adult future subsistence farming populations were evaluated for the following:
 - Direct contact with impacted soil brought to the surface as drill cuttings
 - Exposures to groundwater as drinking water
 - Ingestion of homegrown produce cultivated in contaminated soil and irrigated with groundwater
 - Ingestion of beef and dairy products from cattle watered with groundwater and grazing in pastures irrigated with groundwater
- Adult subsistence 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 percent UCL or maximum concentrations were used as reasonable maximum EPCs. Impacted groundwater beneath the site is widely dispersed, consisting 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 overestimates 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. It was not considered in this risk assessment, as discussed in Section A3.1.3.1. For radionuclide exposures in soil, the 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, exposures to contaminants and radionuclides in groundwater or soil are less likely, but still possible. 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 encounter COPCs. Under that unlikely scenario (existing institutional control programs at Hanford are designed to prevent digging in impacted soil), health risks would exceed 10^{-4} at the 216-Z-1A Tile Field and 216-A-8, Crib, indicating remedial action would be necessary (risks from digging in soil at the 216-Z-8 French Drain were less than 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 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. This is due to the fact that the half-lives of the plutonium contaminants are long (or, in the case of the future well driller and future subsistence 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 10^{-4} .

Because future subsistence 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 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 (213,000 years and 16 million years, respectively) and future concentrations would not be different from 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 below:

- Future well driller risks were much less than those for construction workers and did not exceed 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 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 10^{-4} 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 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 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 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 10^{-4} , and the risks from eating beef are below 10^{-4} .
- Carbon tetrachloride is currently the risk driver 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 subsistence 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 subsistence farmers. Risks for future well drillers at all four soil sites were below 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 10^{-4} at the 90th and 50th percentiles, due primarily to carbon tetrachloride and 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.

Subsistence 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 humans 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 overestimate 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 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 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 cancer risk level of 1×10^{-4} , or an HI of 1, whichever was lower. 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 collocated 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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