

0093674

DOE/RL-2007-27

DRAFT C

SECTION

2 OF 6

1

Appendix A

2

Baseline Human Health Risk Assessment

3

Executive Summary

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

18 Previous investigations identified chlorinated solvents, inorganics, and radionuclides
19 above regulatory criteria in groundwater and subsurface soil in the 200 West and
20 200 East Areas from past spills, leaks, and work practices associated with the processing
21 of uranium and plutonium to make nuclear weapons. This risk assessment evaluated
22 whether potential health risks are present if humans encounter these contaminants in
23 their environment.

24 The risk assessment evaluates risks under current conditions (industrial land use,
25 assuming the existing institutional controls with adult workers as the population
26 potentially exposed) and future conditions (unrestricted land use if institutional controls
27 fail in the future). Under current conditions, existing institutional controls prevent use of
28 groundwater until concentrations are below maximum contaminant levels (MCLs). The
29 unrestricted land use scenario (subsistence farmer) assumes that land use controls will
30 remain in place for 150 years; after that time there is assumed to be a failure of
31 institutional controls so potential exposures to a subsistence farming population
32 (adults and children) and a working population (well drillers) are hypothetically possible.

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

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

- 8 • Fulfills National Contingency Plan requirements (*40 Code of Federal Regulations*
9 [CFR] 300) for risk evaluation under a “no action” scenario
- 10 • Fulfills Federal U.S. Environmental Protection Agency (EPA) requirements to address
11 current and future conditions (*Risk Assessment Guidance for Superfund: Volume 1 - Human*
12 *Health Evaluation Manual* [EPA 540/1-89/002])
- 13 • Assesses food chain exposures consistent with EPA guidance (EPA 540/1-89/002) and the
14 *Hanford Site Risk Assessment Methodology* (DOE/RL-91-45)
- 15 • Provides information to risk managers regarding the protectiveness of various remedies
16 during the feasibility study (FS) process

17 However, cleanup concentration goals and decisions will be based on industrial land use
18 exposures as consistent with the current industrial nature of the site. The site is
19 anticipated to remain industrial with existing institutional controls for the foreseeable
20 future. The National Contingency Plan expectation for groundwater is that usable
21 groundwater will be returned to the highest beneficial use (i.e., drinking water)
22 “...wherever practicable, within a timeframe that is reasonable given the particular
23 circumstances of the site” (40 CFR 300.430[a][1][iii][F]).

24 **Selection of Contaminants of Potential Concern**

25 The first step in a HHRA is an evaluation of the data in order to select contaminants of
26 potential concern (COPCs) for human health. For groundwater, the *Remedial*
27 *Investigation Report for the 200-ZP-1 Groundwater Operable Unit* (DOE/RL-2006-24)
28 made a preliminary selection of likely contaminants of concern (COCs) after a rigorous
29 and thorough assessment of potential sources, quality of data, and a statistical evaluation
30 of the detected constituents in groundwater. Note that in a risk assessment, contaminants
31 are referred to as “final COPCs” until the feasibility study is complete. Contaminants that

1 exceed target health goals at the end of the risk assessment process are referred to as
2 “final COPCs.” In the 200-ZP-1 OU remedial investigation (RI) report, the term “COCs”
3 was used to identify contaminants that required further examination; therefore, the RI
4 term is retained when referring to RI findings.

5 The risk assessment refined the RI list using only the last 5 years of data (2001 through
6 2005) to represent current conditions. This data set was further evaluated using the target
7 action levels from the RI and additional health-based information. Of the RI list of
8 15 possible COCs, the groundwater data evaluation selected the following 12 COPCs to
9 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

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

16 Maximum detected concentrations in soil from each of the waste sites were compared to
17 EPA Region 6 human health screening levels for residential soil and EPA generic
18 residential screening levels for radionuclides to select COPCs in soil. (Note that EPA
19 Region 10 does not calculate their own screening levels but instead mandates the use of
20 Region 6 screening levels on EPA projects in Region 10.) Table ES-1 provides
21 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			√	

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

7 Concentrations of carbon tetrachloride and chloroform in air, collected from within the
8 covered 216-Z-9 Trench, are at concentrations below health concerns for workers;
9 however, if these concentrations were in a residential home basement in the future, the
10 indoor air pathway would be a health concern. Volatile organic compounds (VOCs) are
11 still being collected from the subsurface at the 216-Z-1A Tile Field, as well as

1 216-Z-9 Trench, even though VOCs are not COPCs in soil at the 216-Z-1A Tile Field.
2 Thus, carbon tetrachloride and chloroform are COPCs for indoor air for a future
3 subsistence farmer at both 216-Z-9 Trench and 216-Z-1A Tile Field.

4 **Exposure Assessment**

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

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

20 **Risk Assessment Results**

21 Risks (for cancer) and hazards (for non-cancer effects) are calculated for a reasonable
22 maximum exposure (RME) scenario for each pathway, which is a calculation that
23 overestimates risks for the majority of the population in order to ensure that public health
24 is protected. Cancer risk estimates represent the potential for cancer effects by estimating
25 the probability of developing cancer over a lifetime due to site exposures (e.g., a risk of
26 1×10^{-6} indicates a one in 1 million chance of developing cancer due to exposures at
27 the site). Non-cancer hazards assume there is a level of contaminant intake that is not
28 associated with an adverse health effect even in sensitive individuals. The EPA's target
29 cancer risk range is 10^{-6} to 10^{-4} , with action usually required if risks exceed 10^{-4} ; target
30 health goals for non-cancer contaminants are a hazard index (HI) of ≤ 1 .

31 Under current industrial land use and institutional controls, exposures to contaminants
32 and radionuclides in groundwater and soil are less likely, but still possible. Volatile or

1 radiological emissions from the subsurface are insignificant for workers. Institutional
 2 controls prevent the use of impacted groundwater, and impacted soil is covered by at
 3 least 1.8 m (6 ft) of non-impacted soil. However, if construction workers disturbed soil
 4 down to 4.6 m (15 ft) at the 216-Z-1A Tile Field, 216-Z-8 French Drain, or 216-A-8 Crib,
 5 they could encounter COPCs. Under that unlikely scenario (i.e., existing institutional
 6 control programs at Hanford are designed to prevent unprotected digging in
 7 impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A Tile Field and
 8 216-A-8 Crib, indicating that remedial action would be necessary. Risks from digging in
 9 soil at the 216-Z-8 French Drain were less than 1×10^{-6} . Risks from subsurface soil
 10 exposures at the 216-Z-1A Tile Field were driven by plutonium-239, followed by
 11 plutonium-240, then americium-241. Risks from subsurface soil at the 216-A-8 Crib are
 12 driven by cesium-137. There are no nonradionuclides in soil that are a health concern for
 13 construction workers. Construction workers were not evaluated for exposure to
 14 subsurface soil at the 216-Z-9 Trench, due to the depth to impacted soil and because the
 15 area is covered with a concrete cover; however, if construction workers were to disturb
 16 soil beneath the bottom of the trench, construction worker risks would likely exceed
 17 1×10^{-4} . Table ES-2 summarizes the cancer risks from exposure to COPCs in soil.
 18 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		--	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	Construction worker not evaluated at 216-Z-9	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
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)

1 Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to
 2 evaluate radioactive decay and in growth of daughter products. For the three Z Plant sites
 3 (216-Z-1A Tile Field, 216-Z-8 French Drain, and 216-Z-9 Trench) where risks are driven
 4 by plutonium-239, plutonium-240, and americium-241 (true for all soil scenarios),
 5 cumulative risks at future time horizons are not significantly different than current risks.
 6 This is due to the fact that the half-lives of the plutonium isotopes are so long (or, in the
 7 case of the well driller and subsistence farmer), risks at 150 years are not very different
 8 than risks at 500 and 1,000 years. Although at the 216-A-8 Crib where cesium-137 is the
 9 risk driver for all soil scenarios, risks are significantly lower at future time horizons due
 10 to the relatively short half-life (approximately 30 years) of cesium-137.

11 In the event that knowledge of the site is lost and institutional controls fail, a future
 12 subsistence farmer scenario was evaluated where humans could encounter groundwater
 13 and subsurface soil brought to the surface as drill cuttings from drilling a groundwater
 14 well. This scenario is assumed to occur 150 years in the future. Therefore, radiological
 15 concentrations in soil were modeled assuming 150 years of decay (although, as noted
 16 above, this assumption does not make a difference for the Z Plant sites). Two of the three
 17 radionuclides selected as COPCs in groundwater (technetium-99 and iodine-129) have
 18 very long half-lives and future concentrations would not be different from current

1 concentrations. However, the third radionuclide COPC, tritium, will likely be at
 2 concentrations that are below a health concern within 150 years. Table ES-2 summarizes
 3 future soil risks for a driller and a subsistence farmer. Table ES-3 summarizes future
 4 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.

1 In summary, risks from exposure to soils at the 216-Z-8 French Drain are below levels
2 that are a health concern. Risks from soil exposures at the 216-Z-1A Tile Field and
3 216-A-8 Crib are similar and exceed 1×10^{-4} for construction workers and subsistence
4 farmers. Radionuclide risks from soil exposures at the 216-Z-9 Trench were the highest
5 for the four waste sites evaluated, with risks of 2×10^{-5} for well drillers and 1×10^{-1} for
6 subsistence farmers. Plutonium-239 and americium-241, followed by plutonium-240,
7 were the risk drivers in soil for the Z Plant sites, and cesium-137 was the risk driver in
8 soil at the 216-A-8 Crib.

9 Risks from exposure to groundwater exceeded 1×10^{-4} at the 90th and 50th percentiles,
10 due primarily to carbon tetrachloride, followed by technetium-99, for both subsistence
11 farmer and industrial drinking water exposures. Carbon tetrachloride's non-cancer
12 hazards were also non-cancer risk drivers and exceeded target health goals at the 90th and
13 50th percentiles. Although reductions in future concentrations were not quantified for
14 carbon tetrachloride, the contaminant's concentrations will be decreasing relatively
15 rapidly over time in comparison to technetium-99 with a half-life of 213,000 years.
16 Therefore, while carbon tetrachloride concentrations represent the highest current risks,
17 in the future, technetium-99 will likely become the risk driver.

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

20 **Uncertainties**

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

25 Concerning produce ingestion, risks and hazards are significantly above target health
26 goals due to ingesting homegrown produce grown in impacted soil and watered with
27 impacted groundwater. Calculated risks and hazards from ingestion of homegrown
28 produce are dependent on the concentration in the plant tissue and the produce ingestion
29 rate. Plant tissue concentrations were estimated using health-protective modeling and
30 likely overestimate the amount of COPC that could be in the plant. Ingestion rates were
31 selected to represent a subsistence farming population that would be expected to receive
32 a significant portion of their produce from their own garden.

1 A Native American population was not quantitatively evaluated as part of the baseline
2 risk assessment. With some exceptions, Native American exposures are similar in type to
3 the subsistence farmer, that is, both groups could be exposed via direct contact with
4 contaminated materials and the food chain. However, exposures may be different in kind,
5 that is, more time spent outdoors and greater consumption of native plants and animals,
6 than the typical default exposures that EPA has developed for a residential population.
7 Native American exposures are quantitatively addressed in Appendix G.

8 For construction worker exposure-to-soil calculations at all three of the soil sites,
9 characterization of the top 4.6 m (15 ft) was limited, with few samples representing that
10 depth horizon because the shallower soil has not been impacted. Therefore, use of
11 exposure concentrations from the deepest soil depth that construction workers would
12 likely encounter has potentially resulted in risks that are biased as high because the
13 majority of a construction worker's exposure would be to the shallower,
14 uncontaminated soil.

15 For subsistence farmer soil concentrations, concentrations are dependent upon the size of
16 garden over which drill cuttings would be spread. The risk calculations assumed a 100 m²
17 (1,076 ft²) garden, based on an area that could likely supply approximately 25 percent of
18 vegetables and fruit for a family of four. Larger size gardens or other types of spreading
19 areas would result in a decrease in concentrations.

20 **Risk-Based Concentrations**

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

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

Risk Driver	RBC (µg/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

1 The RBCs for each of the risk drivers were calculated to be protective of the target goal
2 cancer risk level of 1×10^{-4} . However, combined exposures to each of the risk drivers at
3 the RBCs could result in an exceedance of the target health goals. The RBCs were not
4 adjusted downward to account for cumulative exposures because risk drivers may not all
5 be present at the same location, nor may the high concentrations of the risk drivers be
6 collocated with each other. Therefore, risk managers will consider potential cumulative
7 exposures to the COPCs when applying RBCs at specific locations in the evaluation of
8 the protectiveness of various remedies during the FS process. A downward adjustment to
9 account for cumulative exposures may or may not be necessary.

Contents

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37

- A1 Introduction..... A-1**
- A2 Data Evaluation and Selection of Contaminants of Potential Concern..... A-9**
 - A2.1 Selection of Data Applicable to Human Health A-9
 - A2.1.1 Soil A-9
 - A2.1.2 Soil Gas A-14
 - A2.1.3 Groundwater..... A-17
 - A2.1.4 Data Usability and Data Quality A-19
 - A2.2 Contaminant Selection Process for Contaminants in Soil A-25
 - A2.3 Results of Screening for Soil..... A-27
 - A2.3.1 216-Z-1A Tile Field..... A-27
 - A2.3.2 216-Z-8 French Drain A-27
 - A2.3.3 216-Z-9 Trench A-28
 - A2.3.4 216-A-8 Crib..... A-41
 - A2.4 Results of Screening for Soil Gas..... A-41
 - A2.5 Results of Screening for Groundwater A-42
 - A2.6 Summary of Contaminants of Potential Concern A-53
- A3 Exposure Assessment..... A-55**
 - A3.1 Conceptual Site Model A-55
 - A3.1.1 Affected Media and Land Use A-55
 - A3.1.2 Selected Populations A-56
 - A3.1.3 Identification of Exposure Pathways A-57
 - A3.2 Exposure Point Concentrations A-63
 - A3.2.1 Exposure Point Concentrations for Soil A-63
 - A3.2.2 Exposure Point Concentrations for Groundwater A-73
 - A3.2.3 Calculation of Tissue Concentrations from Groundwater and Soil Exposure Point Concentrations A-74
 - A3.3 Calculation of Contaminant Dose A-84
 - A3.3.1 Current Industrial Land Use Scenario A-85
 - A3.3.2 Post-2150 Unrestricted Land Use Scenario A-87
- A4 Toxicity Criteria..... A-103**
 - A4.1 Cancer Effects A-103
 - A4.2 Non-Cancer Effects A-106
 - A4.3 Oral Toxicity Criteria A-110
 - A4.4 Inhalation Toxicity Criteria A-110
 - A4.5 Dermal Toxicity Criteria A-110

1 A4.6 Hexavalent Chromium and Cadmium Exposure Route Toxicity Differences A-111

2 **A5 Risk Characterization** **A-113**

3 A5.1 Methodology for Evaluating Noncarcinogenic Hazards A-113

4 A5.2 Methodology for Evaluating Carcinogenic Risks A-113

5 A5.3 Summary of Risk Results A-114

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

7 Workers A-116

8 A5.3.2 Post-2150 Unrestricted Land Use: Worker Exposures A-118

9 A5.3.3 Post-2150 Unrestricted Land Use: Subsistence Farmer Exposures A-122

10 A5.3.4 Future Groundwater Risks for Subsistence Farmer A-134

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

12 A5.4 Summary of Dose Results A-135

13 A5.5 Risk Characterization Summary and Conclusions A-139

14 **A6 Uncertainties in Risk Assessment** **A-143**

15 A6.1 Uncertainties Related to Data Evaluation and the Selection of Contaminants of

16 Potential Concern A-143

17 A6.1.1 Soil Data and Contaminant of Potential Concern Selection A-143

18 A6.1.2 Groundwater Data and Contaminant of Potential Concern Selection A-146

19 A6.2 Uncertainties Related to Exposure A-150

20 A6.2.1 Tribal Subsistence Exposures A-150

21 A6.2.2 Other Exposure Pathways and Populations Not Quantified A-156

22 A6.2.3 Exposure Point Concentrations A-156

23 A6.2.4 Uncertainties in Food Chain Ingestion Rates A-159

24 A6.2.5 Uncertainties in Other Exposure Factors A-162

25 A6.3 Uncertainties in Assessment of Toxicity A-163

26 A6.3.1 Radionuclides Slope Factors A-163

27 A6.3.2 Radionuclide Dose Versus Risk Estimates A-164

28 A6.3.3 Trichloroethylene Slope Factors A-166

29 A6.4 Uncertainties in Risk Characterization A-167

30 A6.4.1 Uncertainties Associated with Large Estimates of Risk A-167

31 A6.4.2 Uncertainties in Radiation Risk Assessment A-168

32 A6.5 Summary of Uncertainty A-168

33 **A7 Potential Risk-Based Concentrations** **A-169**

34 A7.1 Calculation Methods 169

35 A7.1.1 Soil A-169

36 A7.1.2 Groundwater A-171

37 A7.2 Application of Cleanup Levels A-171

38 **A8 Summary and Conclusions** **A-173**

1	A8.1 Data Evaluation	A-173
2	A8.2 Exposure Assessment	A-175
3	A8.3 Toxicity Assessment.....	A-176
4	A8.4 Risk Characterization	A-176
5	A8.5 Uncertainties in Risk Assessment	A-179
6	A8.6 Risk-Based Concentrations	A-179
7	A9 References	A-181

8
9

Attachments

10	A-1	ProUCL Outputs for Contaminants of Potential Concern in Soil
11	A-2	Cwaste Details and Exposure Point Concentration Calculations for Well Driller and Subsistence Farmer
12		
13	A-3	RESRAD Input Summary
14	A-4	Default Exposure Factors
15	A-5	Toxicity Profiles for Each Contaminant of Potential Concern
16	A-6	Groundwater and Soil Risk Calculations
17	A-7	Soil RESRAD Risk Summary Tables
18	A-8	Risk-Based Concentrations for Groundwater and Soil RESRAD Summaries

19
20

Figures

21	Figure A1-1.	Site Vicinity and Location Map	A-2
22	Figure A1-2.	Locations of 216-Z-1A Tile Field and 216-Z-9 Trench in the 200 West Area	A-3
23	Figure A1-3.	Locations of 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well in the	
24		200 West Area	A-4
25	Figure A1-4.	Location of 216-A-8 Crib in the 200 East Area	A-5
26	Figure A2-1.	216-Z-1A Tile Field Sample Locations for Soil.....	A-11
27	Figure A2-2.	216-Z-8 French Drain Sample Location for Soil.....	A-12
28	Figure A2-3.	216-Z-9 Trench Sample Locations for Soil.....	A-15
29	Figure A2-4.	216-A-8 Crib Sample Location for Soil	A-16
30	Figure A2-5.	Section Views of the 216-Z-9 Trench	A-17
31	Figure A3-1.	Schematic Human Health Conceptual Site Model Current Industrial Land Use	A-60
32	Figure A3-2.	Schematic Human Health Conceptual Site Model Depicting the Populations and	
33		Exposure Pathways Evaluated in the Risk Assessment under Future Unrestricted	
34		Land Use.....	A-61
35	Figure A3-3.	Ingrowth of Americium-241 at 216-Z-1A Vadose Zone.....	A-72
36	Figure A3-4.	Ingrowth of Americium-241 at 216-Z-9 Vadose Zone.....	A-72

1 Figure A3-5. Ingrowth of Americium-241 at 216-Z-1A Shallow Soils (Construction Worker
2 Soil Contact Zone)..... A-73
3 Figure A5-1. Decreases in Cancer Risks Over Time – Future Subsistence Farmer at the
4 216-Z-9 Trench..... A-115
5 Figure A5-2. Decreases in Cancer Risks Over Time – Future Subsistence Farmer at the
6 216-A-8 Crib A-116
7 Figure A5-3. Cancer Risks from Tritium in Groundwater Over Time A-135
8 Figure A6-1. Filtered versus Unfiltered Chromium in Two ZP-1 Groundwater Wells A-149
9 Figure A6-2a. Carbon Tetrachloride Groundwater Concentration Frequencies A-158
10 Figure A6-2b. Technetium-99 Groundwater Concentration Frequencies..... A-158
11 Figure A6-3. Change in Plutonium-239 Concentration with Garden Size..... A-159
12

13 **Tables**

14 Table A1-1. Appendix A Sections Specific to Soil, Soil Gas, and Groundwater A-8
15 Table A2-1. Summary of Soil Data Locations Included in the Risk Assessment, 216-Z-1A Tile
16 Field A-9
17 Table A2-2. Summary of the Number of Samples by Constituent Group A-13
18 Table A2-3. Summary of Soil Data Locations Included in the Risk Assessment for the 216-Z-9
19 Trench..... A-14
20 Table A2-4. Summary of Groundwater Data Locations Included in the Risk Assessment for the
21 200-ZP-1 Operable Unit A-18
22 Table A2-5. Site Analysis of Soil Contamination Using the U.S. Environmental Protection
23 Agency’s Data Usability Guide A-20
24 Table A2-6. Detected Contaminants with Method Reporting Limits Exceeding Screening Values A-24
25 Table A2-7. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil
26 at the 216-Z-1A Tile Field..... A-29
27 Table A2-8. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil
28 at the 216-Z-8 French Drain A-31
29 Table A2-9. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil
30 at the 216-Z-9 Trench A-33
31 Table A2-10. Frequency and Magnitude of Exceedance for Contaminants in Soil With Detected
32 Concentrations Greater Than the Screening Values and Less Than Background at the
33 216-Z-9 Trench..... A-39
34 Table A2-11. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil
35 at the 216-A-8 Crib A-43
36 Table A2-12. Frequency and Magnitude of Exceedance for Contaminants in Soil with Detected
37 Concentrations Greater Than the Screening Values and Less Than Background at the
38 216-A-8 Crib..... A-47
39 Table A2-13. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in
40 Trench Air at the 216-Z-9 Trench A-49

1 Table A2-14. Draft Occurrence, Distribution, and Selection of Contaminants of Potential Concern
 2 in Groundwater (Based on Target Action Levels) at the 200-ZP-1 Operable Unit A-51

3 Table A2-15. Contaminants Selected as Contaminants of Potential Concern in Soil..... A-53

4 Table A3-1. Summary of Exposure Point Concentrations for Soil Current Construction Worker A-64

5 Table A3-2. Summary of Exposure Point Concentrations for Soil Representative of Current
 6 Vadose Zone Concentrations (Cwaste)..... A-66

7 Table A3-3. Summary of Exposure Point Concentrations for Soil for Future Receptors..... A-68

8 Table A3-4. Summary of Exposure Point Concentrations for Groundwater for 200-ZP-1 Operable
 9 Unit Source Area A-74

10 Table A3-5. Summary of Food Chain Pathway Exposure Point Concentrations
 11 (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants
 12 (Nonradionuclides Only) A-75

13 Table A3-6. Summary of Homegrown Produce Exposure Point Concentrations Soil to Plant
 14 Pathway (RESRAD Methodology) 150 Years from Now A-77

15 Table A3-7. Plant Tissue Modeling Calculations Future Subsistence Farmer, 200-ZP-1
 16 Groundwater and Residential Soil (Nonradionuclides) A-78

17 Table A3-8. Summary of Transfer Coefficients Used in Tissue Modeling Calculations A-80

18 Table A3-9. Beef Tissue and Dairy Products Modeling Calculations, Subsistence Farmer,
 19 200-ZP-1 Operable Unit Groundwater A-83

20 Table A3-10. Construction Worker Exposures to Soil – Exposure Assumptions and Intake
 21 Equations A-85

22 Table A3-11. Summary of Volatilization Factor and Particulate Emission Factor Inputs and
 23 Equations (2 sheets)..... A-87

24 Table A3-12. Subsistence Farmer Exposures to Soil – Exposure Assumptions and Intake Equations
 25 (2 sheets)..... A-88

26 Table A3-13. Intake Assumptions Children (2 to 6 Years) and Adults – Subsistence Farming
 27 Exposures Ingestion, Dermal, and Inhalation Exposure to Tap Water (2 sheets)..... A-91

28 Table A3-14. Absorbed Dose per Event Dermal Exposure to Tap Water and Irrigation Water..... A-93

29 Table A3-15. Intake Assumptions Adults - Subsistence Farmer Dermal and Inhalation Exposure to
 30 Groundwater During Irrigation..... A-94

31 Table A3-16. Intake Assumptions Child and Adults – Subsistence Farmer Food Chain Pathways A-97

32 Table A3-17. Well Driller Exposures to Well Cuttings – Exposure Assumptions and Intake
 33 Equations A- A-99

34 Table A3-18. Intake Assumptions Adults – Industrial Exposures Ingestion and Inhalation
 35 Exposure to Tap Water A-101

36 Table A4-1. Carcinogenic Toxicity Criteria for the Nonradionuclide Contaminants of
 37 Potential Concern..... A-104

38 Table A4-2. Radionuclide Toxicity Criteria for Contaminants of Potential Concern..... A-105

39 Table A4-3. Noncarcinogenic Chronic and Subchronic Toxicity Criteria for Contaminants
 40 of Potential Concern (3 sheets)..... A-107

41 Table A5-1. Summary of Cancer Risks for the Current Construction Worker from Soil..... A-117

42 Table A5-2. Summary of Cancer Risks for the Future Well Driller from Soil..... A-119

1 Table A5-3. Future Well Driller – Summary of Non-Cancer Hazards from Soil at the 216-Z-9
2 Trench..... A-120

3 Table A5-4. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide
4 and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater
5 Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker..... A-121

6 Table A5-5. Summary of Non-Cancer Hazards for Contaminants of Potential Concern
7 (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater
8 Concentrations, Post-2150 Unrestricted Land Use – Future Regular Worker..... A-122

9 Table A5-6. Summary of Cancer Risks for the Future Subsistence Farmer from Soil (2 sheets)..... A-123

10 Table A5-7. Future Subsistence Farmer – Summary of Non-Cancer Hazards from Soil Exposures . A-125

11 Table A5-8. Summary of Cancer Risks for Contaminants of Concern (Radionuclide and
12 Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater
13 Concentrations, Post-2150 Unrestricted Land Use – Future Subsistence Farmer A-127

14 Table A5-9. Summary of Non-Cancer Hazards for Contaminants of Potential Concern
15 (Nonradionuclides Only) Based on the 90th, 50th, and 25th Percentile Groundwater
16 Concentrations, Post-2150 Unrestricted Land Use – Future Subsistence Farmer A-128

17 Table A5-10. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide
18 and Nonradionuclide) Based on the 90th, 50th, and 25th Percentile Groundwater
19 Concentrations, Post-2150 Unrestricted Land Use–Food Chain Pathways–Future
20 Subsistence Farmer A-130

21 Table A5-11. Summary of Non-Cancer Hazards for the Nonradionuclide Contaminants of
22 Concern Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations,
23 Post-2150 Unrestricted Land Use–Food Chain Pathways–Future
24 Subsistence Farmer A-131

25 Table A5-12. Cumulative Risks for the Subsistence Farmer from Soil and Groundwater A-136

26 Table A5-13. Summary of Dose (mrem/yr) for Future Well Driller from Soil A-137

27 Table A5-14. Summary of Dose (mrem/yr) for the Future Subsistence Farmer from Soil A-138

28 Table A6-1. Contaminants Analyzed in Soil but Never Detected with Method Detection Limits
29 Exceeding Screening Values A-147

30 Table A6-2. 200-ZP-1 Contaminants in Groundwater Detected Above EPA Region 6 Tap Water
31 Screening Levels..... A-153

32 Table A6-3. Comparison of Subsistence Farmer Exposure Factors with Tribal Subsistence
33 Exposure Factors A-155

34 Table A6-4. Groundwater Percentile Concentrations and Summary Statistics..... A-157

35 Table A6-5. Summary of Available Ingestion Rates for Homegrown Produce..... A-161

36 Table A6-6. Dose Conversion Factors and Risk Coefficients for Different Exposure Pathways..... A-165

37 Table A6-7. Risks at a 100 mrem/yr Dose Limit for 1-Year and 30-Year Exposure Durations
38 from Individual Pathways..... A-165

39 Table A7-1. Summary of Soil Risk-Based Concentrations for Current Construction
40 Worker Exposures A-170

41 Table A8-1. Selected COPCs in Soil Based on Maximum Detected Concentrations from
42 Waste Sites..... A-174

43
44

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

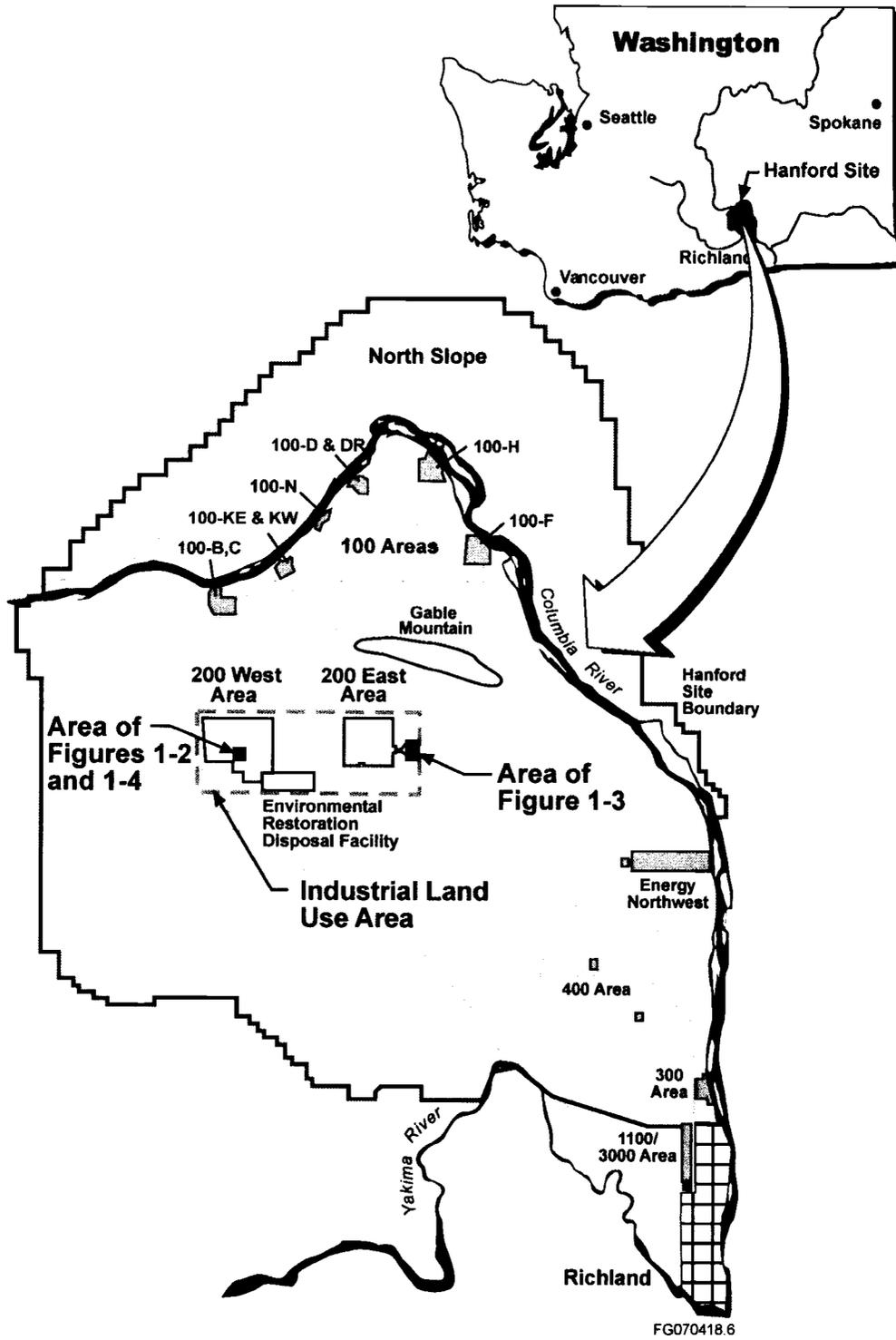
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44

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

Previous investigations have identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West Area from past spills, leaks, and work practices associated with the processing of uranium to make nuclear weapons and related activities (e.g., reprocessing of nuclear fuels and storing spent fuels). Industrial activities at Hanford have been ongoing since the 1940s and, while the nuclear processing activities are no longer occurring, much of the 200 West Area is still being used for industrial purposes (e.g., various storage and waste management activities). This appendix evaluates whether potential health risks are present in the unlikely event that humans encounter these solvent- and radionuclide-impacted materials in their environment.

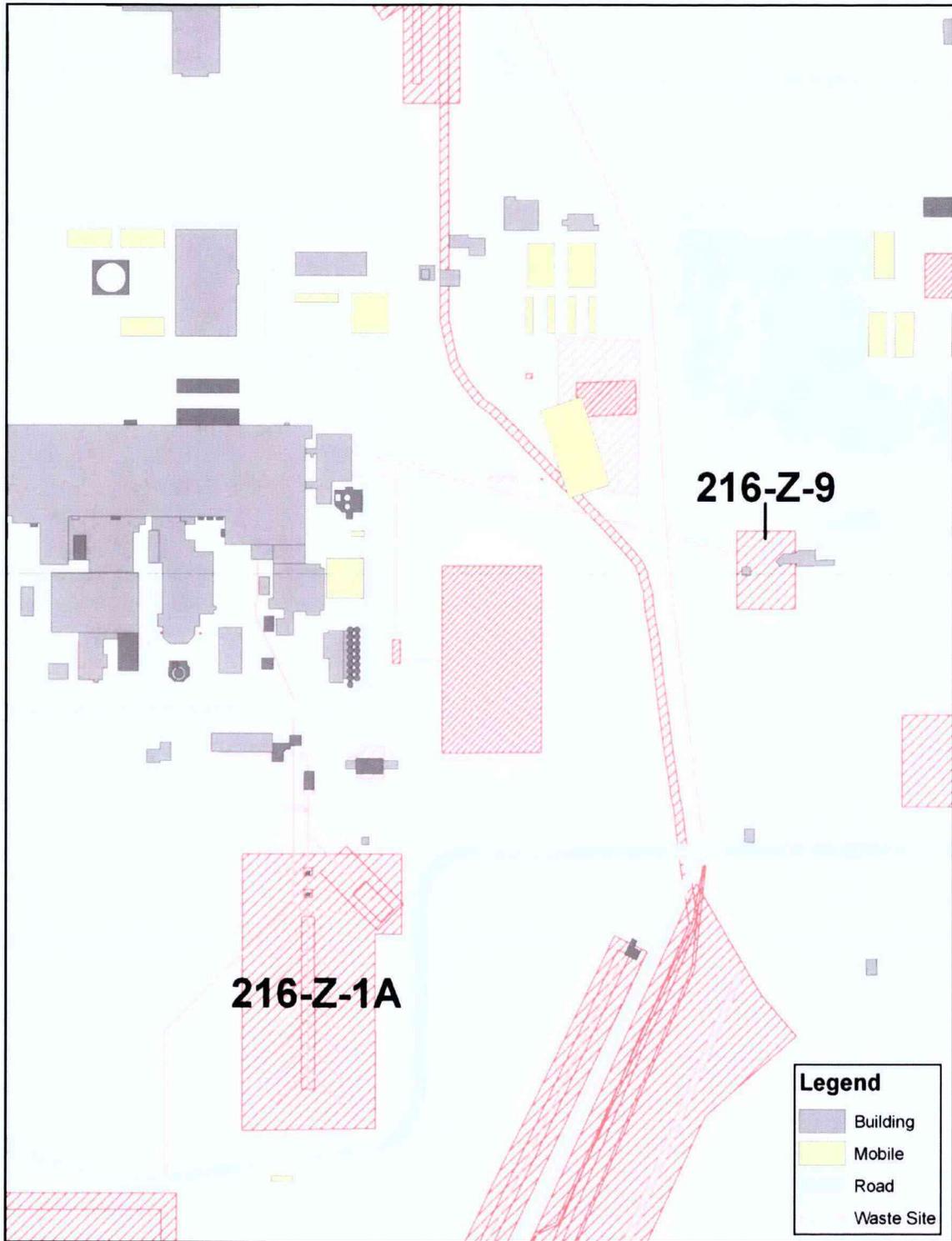
The risk assessment evaluates risks under current conditions (industrial land use, assuming the existing institutional controls with adult workers as the population potentially exposed) and future conditions (unrestricted land use if institutional controls fail in the future). The unrestricted land use 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.



1
2

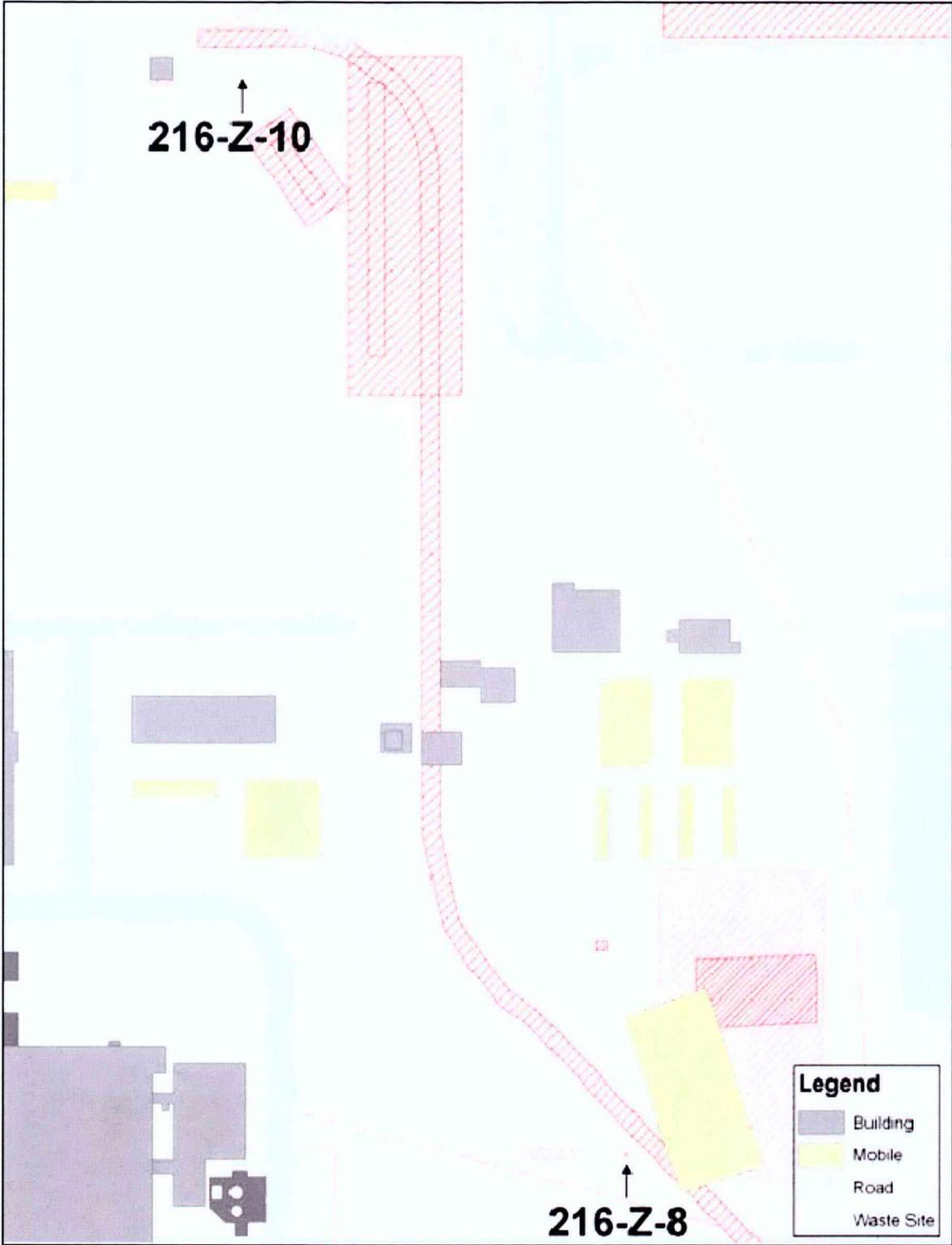
Figure A1-1. Site Vicinity and Location Map



CHPUBS1003-01 B

1
2

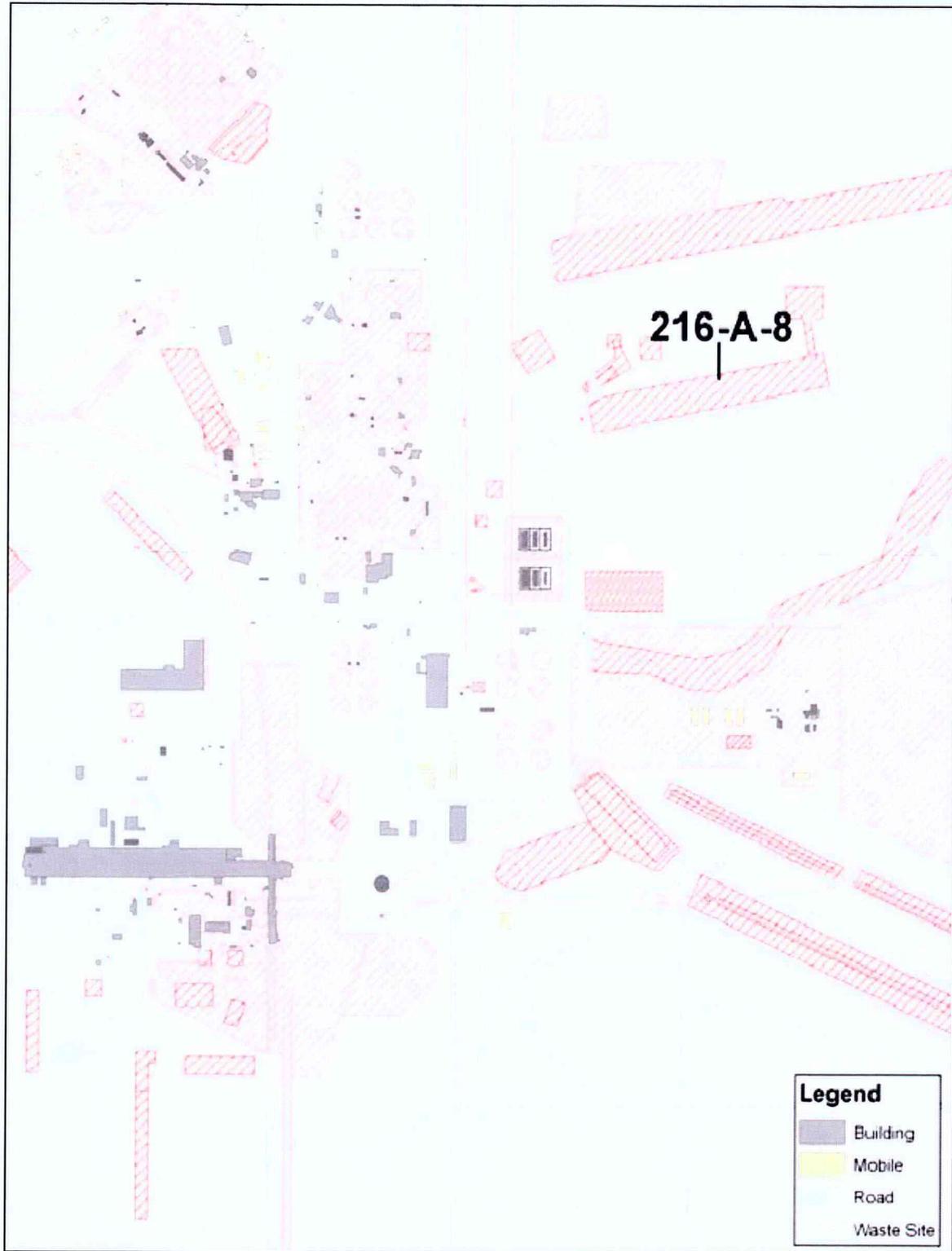
Figure A1-2. Locations of 216-Z-1A Tile Field and 216-Z-9 Trench in the 200 West Area



CHPUBS1003-01.9

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

1
2
3



CHPUBS1003-01.10

1
2

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

1 However, cleanup concentration goals and decisions will generally be based on industrial land use
2 exposures, as consistent with the current industrial nature of the site. The site is anticipated to remain
3 industrial with existing institutional controls for the foreseeable future. The NCP expectation for
4 groundwater is that usable groundwater will be returned to the highest beneficial use (i.e., drinking water)
5 "...wherever practicable, within a timeframe that is reasonable given the particular circumstances of the
6 site" (40 CFR 300.430[a][1][iii][F]).

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

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

- 14 • The sampling data are initially screened to select the applicable data set for humans and, within that
15 data set, to select contaminants that could be a health concern.
- 16 • Contaminant sources, pathways, receptors, exposure duration and frequency, and routes of exposure
17 are evaluated to quantitatively assess the amount of exposure to the contaminants of potential
18 concern (COPCs).
- 19 • A toxicity assessment is performed to summarize the carcinogenic and noncarcinogenic effects
20 associated with the COPCs and to provide toxicity values that are used to estimate the
21 dose-response relationship.
- 22 • Risk characterization is performed that integrates the quantitative and qualitative results of the data
23 evaluation, exposure, and toxicity assessment sections.

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

26 The accuracy of the information presented in this section depends, in part, on the quality and
27 representativeness of the available sample, exposure, and toxicological data. Where information is
28 incomplete, conservative assumptions were made so risk to human health was not underestimated.
29 A discussion of uncertainties in the HHRA is presented in Section A6 in this appendix. This appendix
30 was prepared in accordance with current EPA, Hanford-specific, and DOE guidelines for risk assessment
31 from the following sources:

- 32 • *Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual, Part A,*
33 *Interim Final* (EPA 540/1-89/002)
- 34 • *Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual,*
35 *Supplemental Guidance: Standard Default Exposure Factors, Interim Final* (OSWER
36 Directive 9285.6-03)
- 37 • *Exposure Factors Handbook* (EFH), Volumes I–III (EPA/600/P-95-002Fa)
- 38 • *EPA Region 10, Interim Final Guidance: Developing Risk-Based Cleanup Levels at Resource*
39 *Conservation and Recovery Act Sites in Region 10* (EPA 910/R-98-001)

- 1 • *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*
2 (OSWER Directive 9285.6-10)
- 3 • *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (OSWER Directive
4 9355.4-24)
- 5 • *Final Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E,*
6 *Supplemental Guidance for Dermal Risk Assessment)* (EPA 540/R/99/05)
- 7 • *Hanford Site Risk Assessment Methodology* (DOE/RL-91-45)

8 Risk assessment methodology primarily follows EPA guidelines (EPA 540/1-89/002; OSWER Directive
9 9285.7-01B; OSWER Directive 9285.6-03; EPA/600/P-95-002Fa; EPA/540-R-00-006; OSWER
10 Directive 9285.6-10; and OSWER Directive 9355.4-24), with consideration of DOE (DOE/RL-91-45;
11 *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*
12 [Rittman, 2004]) and Washington State’s “Model Toxic Control Act (MTCA) – Cleanup,” (*Washington*
13 *Administrative Code* [WAC] 173-340). In the absence of appropriate regulatory guidance (e.g., for
14 site-specific conditions), the evaluation followed the available science.

15 This appendix is organized below:

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

30 As discussed previously, this risk assessment evaluates both risks from soil at the 200-PW-1, 200-PW-3,
31 and 200-PW-6 OUs and from groundwater at the 200-ZP-1 OU in an integrated manner. Both of these
32 risk assessments were previously included in the FS for the 200-ZP-1 Groundwater OU
33 (DOE/RL-2007-28, *Feasibility Study for the 200-ZP-1 Groundwater Operable Unit*). Because this risk
34 assessment is written in an integrated manner, certain subsections of this appendix describe processes or
35 provide results that pertain only to soil and soil gas from the 200-PW-1, 200-PW-3, and 200-PW-6 OUs
36 and certain subsections of this appendix describe processes or provide results that pertain only to
37 groundwater from the 200-ZP-1 OU. Table A1-1 lists the sections that are specific to soil, soil gas, and
38 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	

1

1 **A2 Data Evaluation and Selection of Contaminants of Potential Concern**

2 The primary objective of the data collection and evaluation process in the HHRA is to develop a data set
3 of sufficient quality and quantity to adequately evaluate the potential constituent impacts to human
4 receptors. The initial step has two parts:

- 5 • The available sampling data and site information are reviewed to select data applicable to
6 human health.
- 7 • Constituent concentrations within the data set are evaluated to identify constituents and affected
8 environmental media (i.e., soil) that are potential human health concerns requiring a more
9 detailed assessment.

10 **A2.1 Selection of Data Applicable to Human Health**

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

17 **A2.1.1 Soil**

18 This risk assessment used the available data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for all
19 of the representative sites, except the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well, where
20 the sources of the data were earlier documents. The data sources are below:

- 21 • At the 216-Z-1A Tile Field, the data used for screening are from the cone penetrometer rig locations
22 in and around the 216-Z-1A Tile Field (Table 3-9 of the 200-PW-1/3/6 RI report
23 [DOE/RL-2006-51]), Appendix C of the RI report (circa 1992-1993 sampling), and Appendix D of
24 the RI report (circa 1979 sampling). Data are available from depth ranges of 1.5 to 46.6 m (5 to
25 153 ft) below ground surface (bgs). Sample locations used in the risk analysis are tabulated in
26 Table A2-1. Figure A2-1 shows the sample locations at the 216-Z-1A Tile Field.

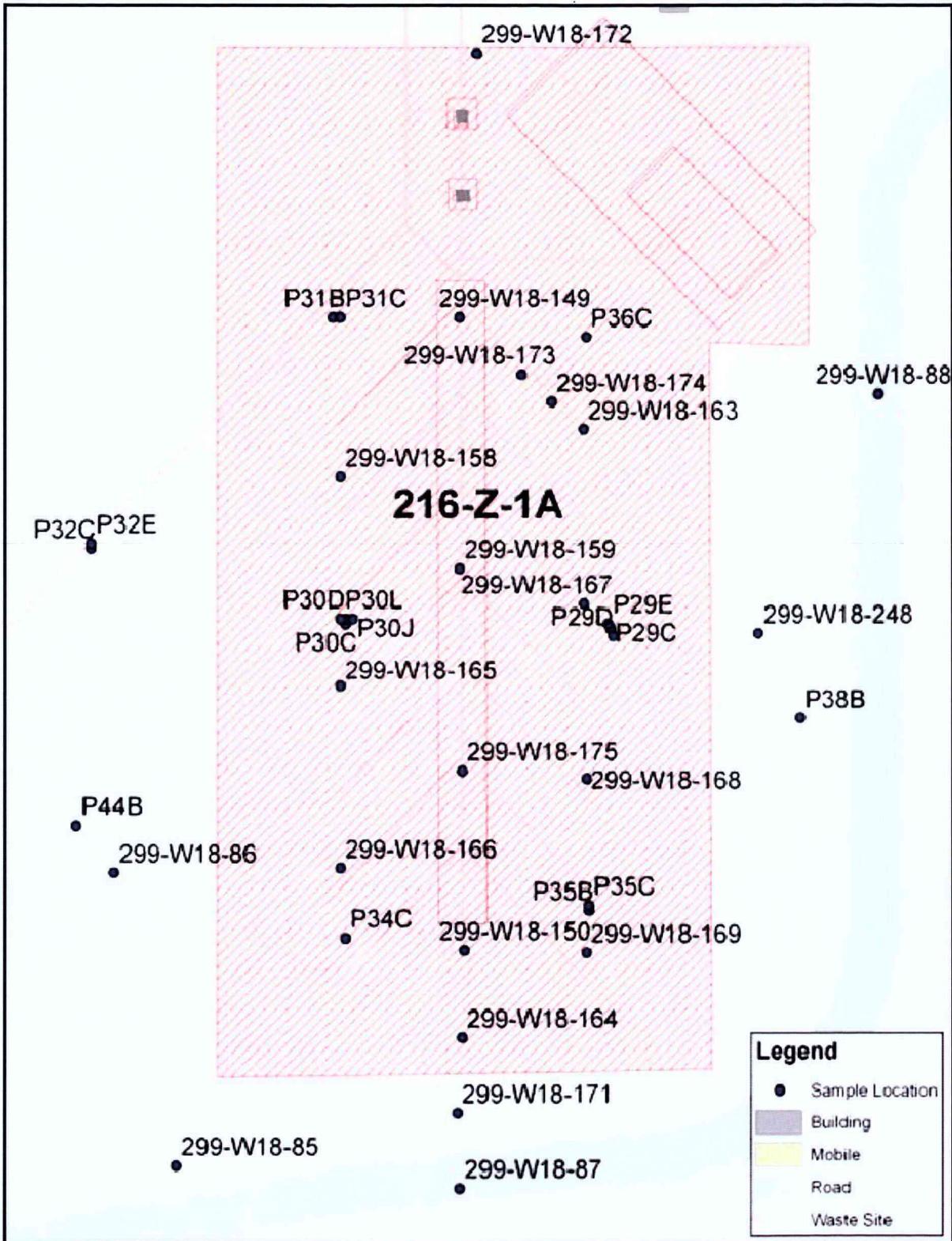
**Table A2-1. Summary of Soil Data Locations Included
in the Risk Assessment, 216-Z-1A Tile Field**

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	

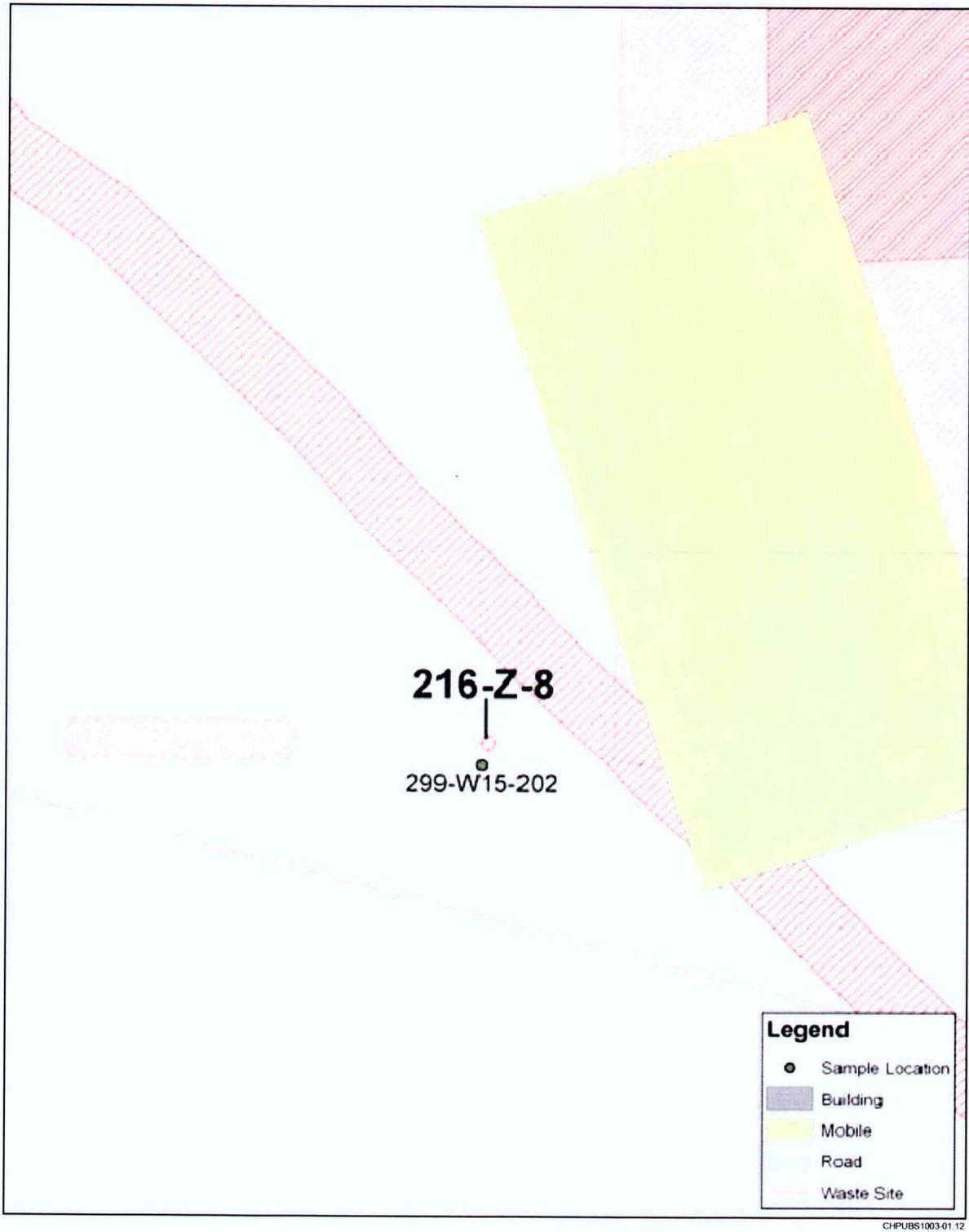
- 1
- 2 • At the 216-Z-8 French Drain, the data used for screening are from Table 3 of *The 216-Z-8 French*
 3 *Drain Characterization Study* (Marratt et al., 1984), which shows samples collected circa 1979, with
 4 sample depths from approximately 5 to 11 m (16 to 35 ft) bgs. Only one sample location,
 5 299-W15-202, is available and was used in the risk analysis. Figure A2-2 shows the location of the
 6 single boring, and Table A2-2 shows the numbers of samples by constituent group available for the
 7 risk assessment.
- 8 • At the 216-Z-9 Trench, the data used for screening are from Appendix B of the 200-PW-1/3/6 RI
 9 report (DOE/RL-2006-51) (circa 2003-2006 sampling), in addition to historical data from 1961, 1963,
 10 and 1973 (*Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench* [ARH-2915]). Sample depths
 11 ranged from 6.6 to 40 m (22 to 133 ft) bgs. Sample locations used in the risk analysis are tabulated in
 12 Table A2-3 and are shown spatially in Figure A2-3. Table A2-2 shows the numbers of samples by
 13 constituent group available for the risk assessment. Figure A2-5 shows section views of the Trench.
- 14 • At the 216-Z-10 Injection/Reverse Well, the source of the data used to evaluate the site was
 15 *Underground Waste Disposal at Hanford Works* (HW-9671). Three borings were sampled within
 16 4.6 m (15 ft) of the drain, from ground surface down to 45.7 m (150 ft) bgs. No contaminants
 17 were detected.
- 18 • At the 216-A-8 Crib, the data used for screening are from Appendix B of the 200-PW-1/3/6 RI report
 19 (DOE/RL-2006-51) (circa 2005 sampling). Data were available from a single location (C4545), with
 20 sample depths ranging from approximately 5.8 to 80 m (19 to 264.5 ft) bgs. Figure A2-4 shows the
 21 location of the boring. Table A2-2 shows the numbers of samples by constituent group available for
 22 the risk assessment.



CHPUBS1003-01.11

1
2
3

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



1
2
3

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

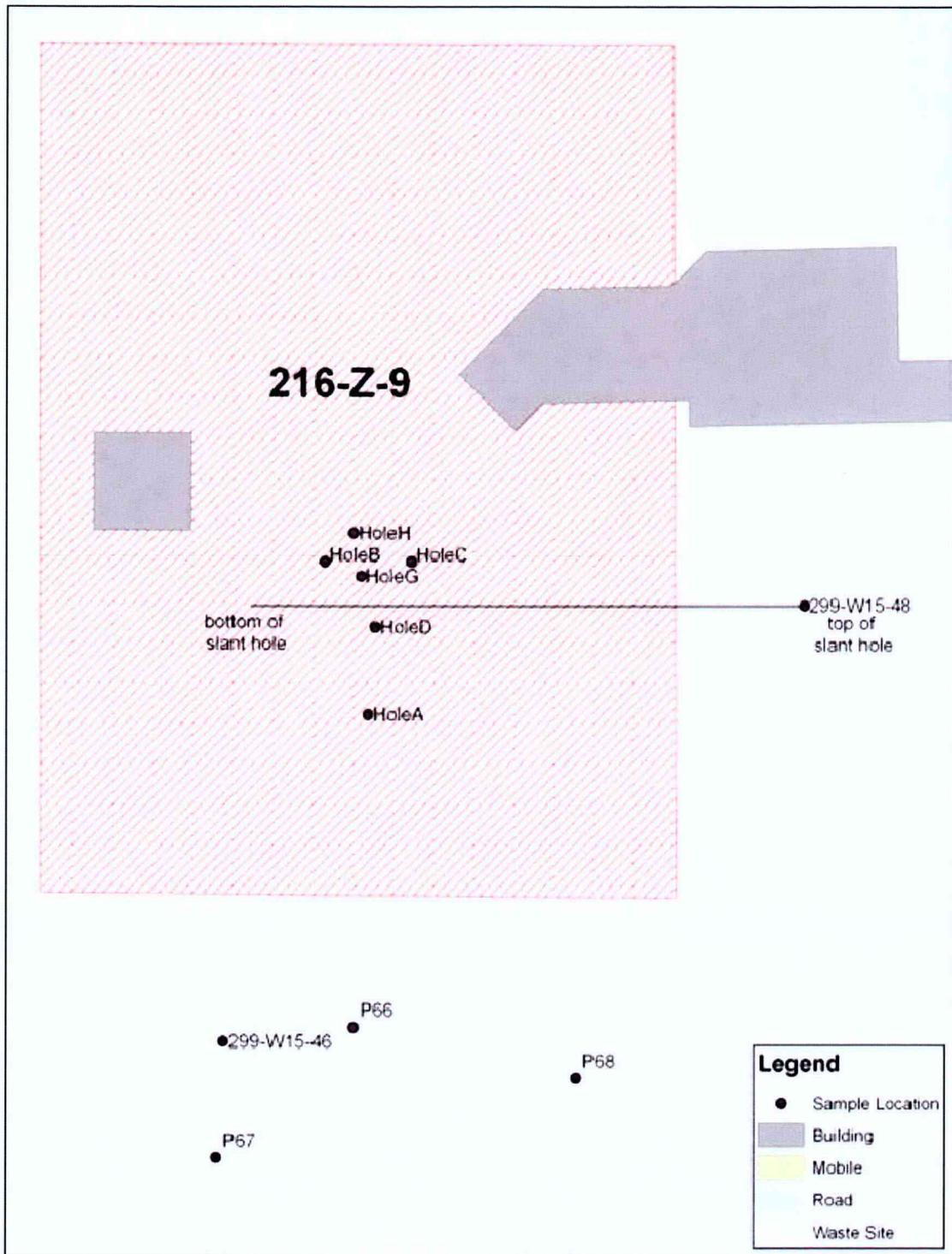
1 **A2.1.2 Soil Gas**

2 Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater
3 beneath the 200-PW-1 OU (particularly near the 216-Z-9 Trench and the 216-Z-1A Tile Field), soil gas
4 sampling has occurred over a number of years. Soil gas data from the vicinity of 216-Z-9 Tile Field
5 collected in 2006 were reviewed to evaluate suitability for inclusion in the risk assessment. Soil gas was
6 collected from three sample locations and analyzed for volatile organic compounds (VOCs)
7 (locations P66, P67, and P68 [see Figure A2-3]), approximately 3 m (10 ft) south of the 216-Z-9 Trench.
8 The depth of the screened interval during sample collection was 19.8 to 21.3 m (65 to 70 ft) bgs. These
9 sample locations are in the dense nonaqueous phase liquid (DNAPL) pool that was identified at this
10 location (DOE/RL-2006-51); therefore, these soil gas samples likely represent worst-case conditions for
11 subsurface vapors, and high concentrations of some VOCs were measured at these locations. Low
12 concentrations of soil gas are generally seen at most of the waste sites, with the exception of the
13 216-Z-9 Trench and 216-Z-1A Tile Field (DOE/RL-2006-51).

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

22

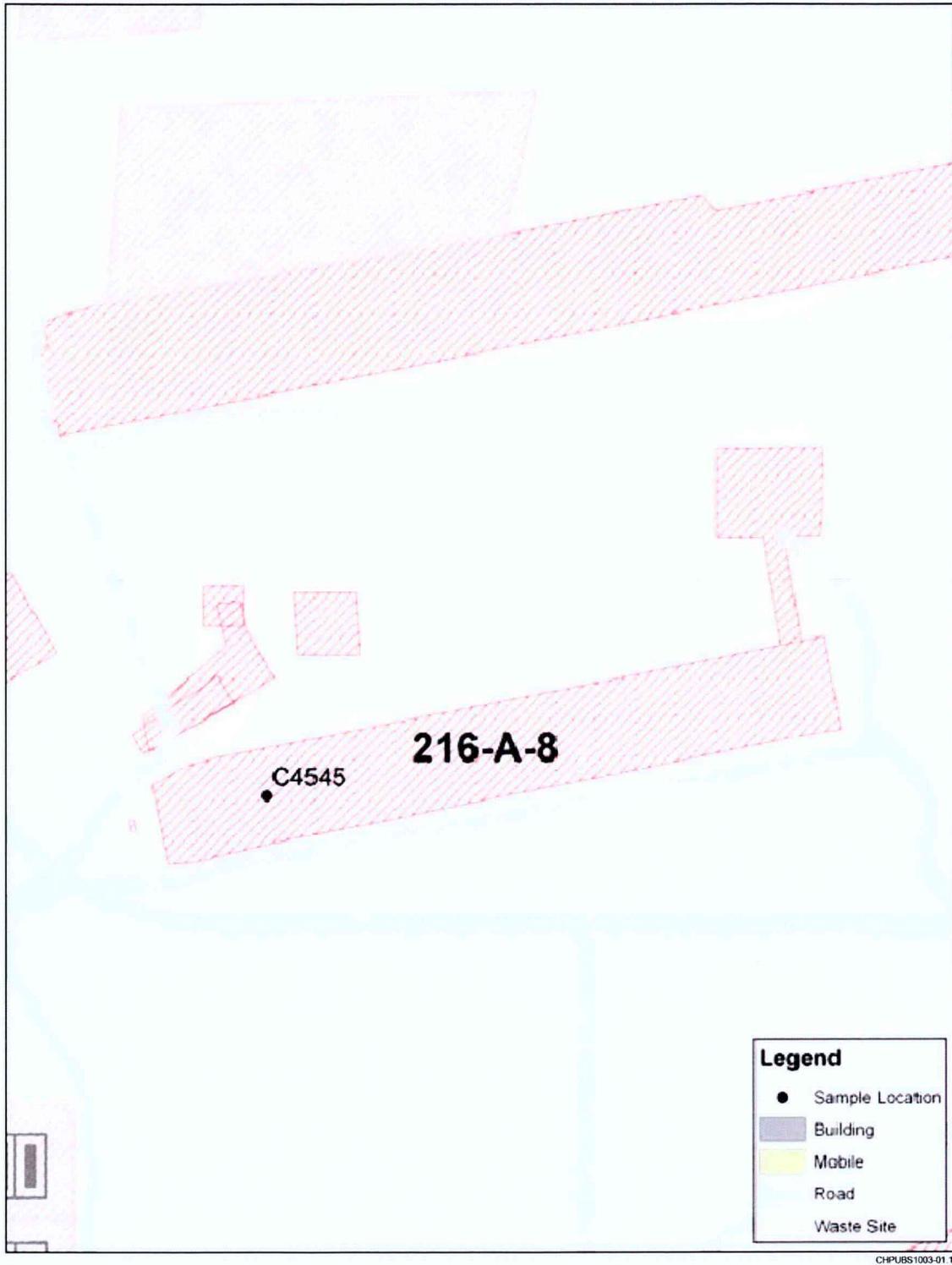
1



2

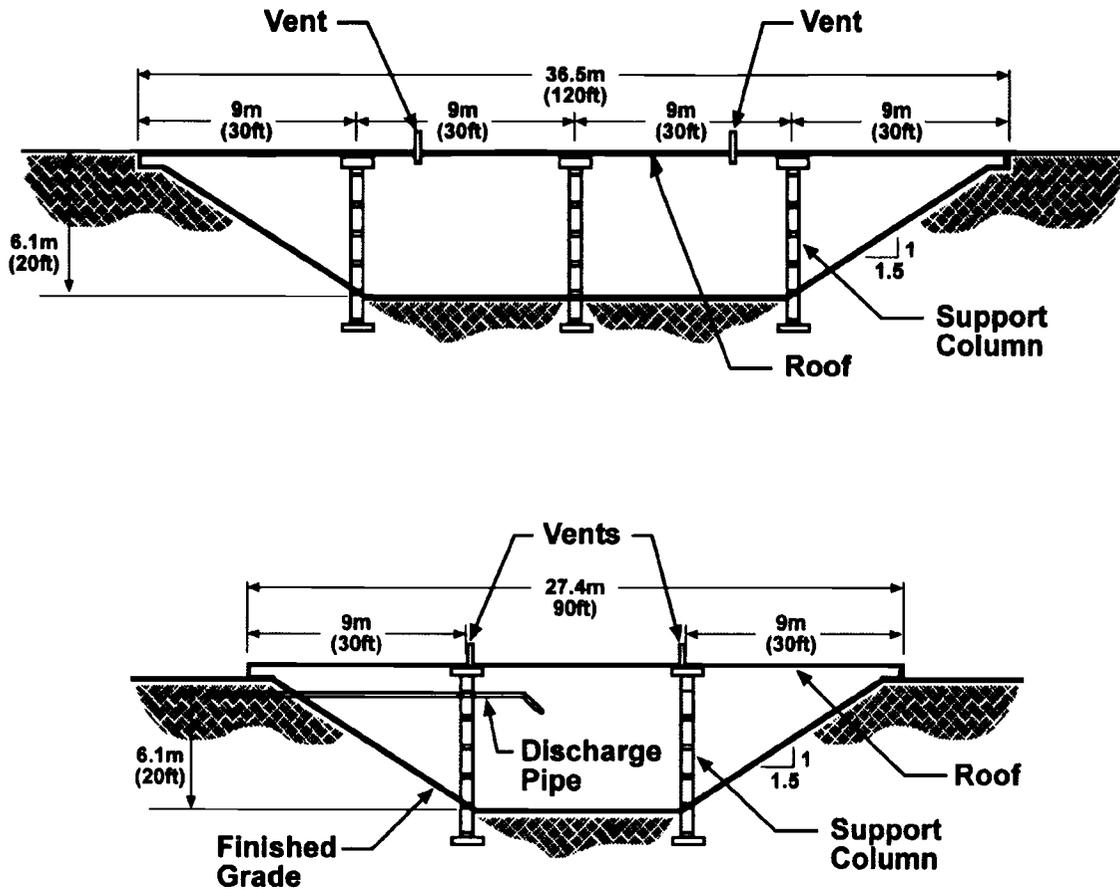
3

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



1
2
3

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



FG070418.1

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.

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

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

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

26 **A2.1.4 Data Usability and Data Quality**

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

37 **A2.1.4.1 Data Usability**

38 The following four data application questions from EPA’s data usability guidance (OSWER Directive
39 9285.7-09A) provide a very useful perspective for risk assessment:

- 40 1. What contamination is present, and at what levels? The quantity and location of samples were chosen
41 based on an understanding of the sources of contamination and the potential migratory pathways of
42 constituents. Details for each site are included in Table A2-5. However, one issue is common to the
43 four Z Plant sites (216-Z-1A Tile Field, 216-Z-9 Trench, 216-Z-8 Crib, and 216-Z-10 Injection/
44 Reverse Well) and is discussed here. There are no analytical data for plutonium-241, which was
45 produced as part of the plutonium-production process, because of the difficulties with analyzing for

- 1 this isotope of plutonium. Plutonium-241 is the parent compound of americium-241 for which there
 2 are analytical data. Plutonium-241 has a relatively short half-life of 14.5 years. The production of
 3 plutonium (including plutonium-241) started around 1944 at the Hanford Site. The final waste
 4 disposals to the major 200-PW-1/3/6 facilities varied; therefore, some sites are further along the
 5 americium-241 ingrowth curve than others. Therefore, there is uncertainty at the Z Plant sites whether
 6 the maximum concentrations of americium-241 have been adequately captured in the existing data. In
 7 Section A3.2.1.1, potential increases in americium-241 concentrations are estimated based on the
 8 known concentrations at specific dates and the specific disposal dates at each site. This issue is also
 9 further discussed in the uncertainty section of this appendix (Section A6.1.1).
- 10 2. Are site concentrations different from background? Concentrations of constituents that occur at
 11 Hanford in the absence of site activities are defined as “background concentrations” and include
 12 inorganic species and radionuclides. Comparison of site data to background concentrations allows for
 13 the determination of the degree of contamination caused by site-related activity. For this analysis,
 14 site-specific background concentrations are available for radionuclides and metals in soil and
 15 groundwater developed specifically for the Hanford Site (*Hanford Site Background: Part 1, Soil*
 16 *Background for Nonradioactive Analytes* [DOE/RL-92-24]; *Hanford Site Background: Part 2, Soil*
 17 *Background for Radionuclides* [DOE/RL-96-12]; *Hanford Site Background: Part 3, Groundwater*
 18 *Background* [DOE/RL-96-61]). Background soil concentrations are listed in the soil screening tables
 19 (Tables A2-7 through A2-11), and Table A2-14 presents background levels for groundwater.
 20 Section A2.3 discusses the detected constituents not selected as COPCs in the risk assessment
 21 (because they are present at background levels).
- 22 3. Are all exposure pathways and areas identified and examined? Sufficient site knowledge exists to
 23 understand potential current and future exposure pathways. Exposure pathways are identified and
 24 discussed in detail in Section A3.1 of this appendix. Exposure pathways also are presented pictorially
 25 and schematically in the CSM figures in Section A3.0.
- 26 4. Are all exposure areas fully characterized? Sufficient data exist to characterize exposures to
 27 constituents in soil and groundwater and to adequately perform the risk assessment. In some cases,
 28 data are limited, but health-protective assumptions will be made so health risks will not be
 29 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?
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]).	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). 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-37, 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

1 **A2.1.4.2 Data Quality**

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

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

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

10 An MRL evaluation is conducted because risk assessment typically assigns nondetected constituents with
11 a proxy concentration of half the MRL in the risk calculations for the COPCs. Therefore, for those
12 constituents with both a low detection frequency and a high percentage of the nondetected values with
13 MRLs above a health-based level, there is a greater degree of uncertainty as to whether their
14 concentrations are a health concern. If a constituent has both a low frequency of detection and a large
15 portion of the data set with MRLs above health-based levels, exposure concentrations could be either
16 over- or underestimated. Very high MRLs may bias an exposure concentration downward because the
17 constituents are actually present above half the MRL; or if the constituent is actually not present at all or
18 is present at a concentration less than half the MRL, the exposure concentration using half the MRL could
19 result in over-estimating concentration. While there is no specific guidance on this issue, if more than
20 50 percent of the data for a constituent are in this uncertain category (i.e., low frequency of detection and
21 high MRLs), this uncertainty should be taken into account when interpreting risk results. This should be
22 taken into account especially if risks are near a decision point of either slightly above or below a target
23 health goal used to establish the need for some type of action at the site.

24 Table A2-6 presents the results of the MRL analysis for each waste for all of the constituents that were
25 detected at least once. As shown in Table A2-6, there are compounds at both the 216-Z-9 Trench and
26 216-A-8 Crib where 50 percent or greater of the data set are in this uncertain category. Table A2-6 does
27 not present the 216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well sites because only three
28 constituents were reported for the 216-Z-8 French Drain or because no constituents were detected at the
29 216-Z-10 Injection/Reverse Well. Section A6.1.1 discusses further the uncertainties surrounding the
30 inadequate MRLs for these compounds and the potential effect on the selection of COPCs and the risk
31 assessment results.

32 Constituents that were never detected but with MRLs exceeding a screening level were not carried
33 through the risk assessment but were instead identified as an area of uncertainty. The impacts of these
34 never-detected constituents on the conclusions of the risk assessment are discussed qualitatively in the
35 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.

1 A2.2 Contaminant Selection Process for Contaminants in Soil

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

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

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

- 1 2. Comparison of maximum detected contaminant concentrations to health-protective screening levels:
2 Specifically, EPA's Region 6 human health screening levels (HHSLs) for residential soil were used as
3 the risk-based screening values for nonradionuclides² (OSWER Directive 9355.4-24), and EPA's
4 generic residential screening levels for radionuclides (EPA/540-R-00-006) were selected for the
5 radiological evaluation. If contaminant concentrations were above screening values, they were
6 considered for selection as COPCs. Contaminants with concentrations below screening values were
7 not selected because they are unlikely to present a health concern. EPA Region 10 guidance for
8 screening was followed in that non-cancer HHSLs were divided by 10 to account for additivity, but
9 the screening levels for carcinogens were not divided by 10 (EPA 910/R-98-001). If the maximum
10 concentration exceeded its screening level, then further evaluation was conducted as described in
11 steps 3, 4, and 5 below.
- 12 3. Comparison of maximum detected contaminant concentrations to background: The maximum
13 concentrations of inorganics and radionuclides were compared to the Hanford-specific background
14 values shown in the screening tables (Tables A2-7 through A2-11). Inorganics and radionuclides were
15 eliminated from selection as COPCs based on these background levels if their maximum
16 concentrations did not exceed background. Because of the heterogeneous nature of soil, isolated
17 concentrations of inorganic and radiological analytes above established background levels may
18 simply represent random members of the background population. Such values are expected to occur
19 in a small percentage (approximately 5 percent) of samples. Therefore, if the maximum concentration
20 exceeded background but was within two times the background level and exceedances above
21 background were <5 percent, the constituent was eliminated as a COPC because it was likely present
22 at background levels.
- 23 4. Evaluation of the frequency of detection: The EPA generally allows constituents detected in
24 <5 percent of the data to be eliminated from risk assessment even if a health-based screening level is
25 exceeded (EPA 540/1-89/002). Therefore, at least 20 samples are needed in order to evaluate
26 a constituent's frequency of detection. The goal of risk assessment is to identify the constituents
27 contributing 99 percent of the risk, and those representing <1 percent of the total risk are addressed in
28 the uncertainty section of the risk assessment.
- 29 5. Evaluation of evidence for eliminating a COPC not significantly contributing to overall site risks:
30 EPA guidance (EPA 540/1-89/002) allows further reduction in the number of constituents carried
31 through the risk assessment as long as the rationale is clearly documented and the constituents
32 contributing 99 percent of the risk have been identified. Therefore, in addition to frequency of
33 detection, a comparison of 95 percent upper confidence limit (UCL) with health-based values
34 (as opposed to screening values that are below health-based levels), the frequency of exceedance of
35 concentrations above the screening level, the magnitude of exceedance over the screening value, and
36 the target populations relative to the screening value were also evaluated. Estimates of risk are
37 calculated using 95 percent UCL of the mean concentration for each constituent/radionuclide because
38 the risk calculations are based on an estimate of average exposure concentration over time, not the
39 maximum concentration. Therefore, a constituent can be eliminated as a COPC if the 95 percent UCL
40 does not exceed a screening or health-based level. Likewise, if a constituent's magnitude of
41 exceedance is not large relative to other site constituents, its contribution to cumulative site risks is
42 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.

1 as COPCs based on the rationale presented in steps 4 and 5 are further discussed in the uncertainty
2 section of this appendix (Section A6.1.1) after the risk assessment calculations are complete, where
3 their concentrations are re-assessed in light of the results of the risk assessment and the identified
4 risk drivers.

5 **A2.3 Results of Screening for Soil**

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

10 **A2.3.1 216-Z-1A Tile Field**

11 Table A2-7 summarizes the screening processes of soil at this site. In the 216-Z-1A Tile Field area,
12 24 contaminants were detected in soil, and three radionuclides (americium-241 and plutonium-239/240)
13 had maximum concentrations greater than their respective screening values and were selected as COPCs.
14 Iron, manganese, and vanadium had maximum concentrations greater than their respective screening
15 values, but their maximum concentrations did not exceed background levels by two times; thus,
16 concentrations of these constituents are likely present due to their natural occurrence (i.e., background
17 levels) and were not selected as COPCs.

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

22 The data quality objectives (DQOs) for the 200-PW-1/3/6 OUs (DOE/RL-2006-51) required that all of the
23 COPCs for the 216-Z-9 Trench also be listed as COPCs for the 216-Z-1A Tile Field. Section A2.3.3
24 presents the COPCs for the 216-Z-9 Trench. However, only 24 constituents were detected in soil at the
25 216-Z-1A Tile Field, with only three above screening levels, compared to the 216-Z-9 Trench with
26 108 detected constituents and 31 with concentrations above screening levels. The additional constituents
27 selected as COPCs at the 216-Z-9 Trench were either not detected (all VOCs, except methylene chloride)
28 or were below either screening levels or background, or both; therefore, these additional contaminants are
29 not included as COPCs at the 216-Z-1A Tile Field. In particular, the data set for the 216-Z-1A Tile Field
30 included 23 soil samples analyzed for VOCs, 17 samples for metals, and over 400 samples for
31 radionuclides (Table A2-2); thus, it is unlikely that additional constituents present at the 216-Z-9 Trench
32 were mis-identified at the 216-Z-1A Tile Field. A possible exception is VOCs at depth. A soil gas
33 extraction system is in operation at the 216-Z-1A Tile Field and VOCs are being collected. The VOCs
34 were sampled in soil down to a depth of 26 m (85 ft); therefore, VOCs still present in soil at the 216-Z-1A
35 Tile Field appear to be located deeper than 26 m (85 ft). Consequently, VOCs are considered COPCs in
36 soil gas beneath the 216-Z-1A Tile Field, as well as the 216-Z-9 Trench (see Sections A2.4 and A2.6).

37 **A2.3.2 216-Z-8 French Drain**

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

1 **A2.3.3 216-Z-9 Trench**

2 Table A2-9 summarizes the screening process of soil at the 216-Z-9 Trench site. A total of
3 107 constituents and radionuclides were detected and, of these detected contaminants, 30 had maximum
4 concentrations greater than their respective screening values. These 30 contaminants were further
5 evaluated according to the steps outlined in Section A2.2. Of these 30 contaminants, 13 were eliminated
6 as COPCs because they are not present at levels that would be a health concern. Six constituents
7 (aluminum, arsenic, iron, cesium-137, potassium-40, and vanadium) were not selected as COPCs because
8 concentrations are likely due to background levels. One contaminant, europium-154, was only detected
9 once in 30 samples (see Table A2-9) and was eliminated as a COPC based on infrequent detection
10 (<5 percent) and a short half-life of 8.5 years. As shown in Table A2-10, the remaining seven
11 contaminants (antimony, chloroform, europium-155, lead, tetrachloroethylene [PCE], uranium, and
12 uranium-233/234) were not selected as COPCs because the calculated 95 percent UCLs were below or
13 near health-based values. These health-based values are the residential screening level adjusted to a target
14 goal of one and a cancer risk level of 1×10^{-5} , which is an acceptable risk level for this site and protective
15 of residents or construction workers. Furthermore, if exposure point concentrations (EPCs) were
16 calculated for the well driller and subsistence farmer, they would be lower than the 95 percent UCL
17 because of the dilution involved with the mixing of clean and contaminated soil, as described in
18 Section A3.2. Additional support for eliminating five of the seven contaminants is that their frequency of
19 exceedance was <5 percent. As shown in Table A2-10, the remaining two contaminants had exceedances
20 above health screening levels at frequencies >5 percent (uranium and uranium-234); however, the
21 magnitude of exceedance was only two in both cases. In addition, the extremely large exceedances
22 identified for americium-241 and the plutonium isotopes (Table A2-10) indicate that the risks from the
23 seven contaminants that were not selected would be insignificant relative to overall risk totals and would
24 not affect risk assessment conclusions. Section A6.1.1 discusses the impact of excluding these seven
25 contaminants on the findings of the risk assessment.

26 The 17 contaminants (counting plutonium-239 and plutonium-240 as individual compounds, even though
27 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

28

29

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		259,000		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 *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-R-00-006).

d. Rationale codes:

Selection reason:

ASL = above screening level

Deletion reason:

BSL = below screening level

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

NUT = essential nutrient

NA = not applicable

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

-- = contaminant has 100 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 *Human Health Medium-Specific Screening Levels for Residential Soil*

EPA = U.S. Environmental Protection Agency

NA = not applicable

na = not available

NE = not established

SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)

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

CAS No.	Chemical	Minimum Concentration ^a	Minimum Qualifier	Maximum Concentration ^a	Maximum Qualifier	Units	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value ^b	Screening Value ^c	Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection ^d	
Radionuclides																
14596-10-2	Am-241	0.0901		457		pCi/g	299-W15-202-20.008	8/8	--	457	NE	3.7	c	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	c	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	c	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)

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	c	HHSL	NO	BCK
7440-39-3	Barium	36		112		mg/kg	299-W15-46/B17N65	24/24	-	112	132	1,564		HHSL	NO	BSL
7440-41-7	Beryllium	0.13		0.68		mg/kg	299-W15-48/B1HL26	22/24	0.27 to 1.43	0.68	1.51	15		HHSL	NO	BSL
7440-69-9	Bismuth	53.6		156		mg/kg	299-W15-48/B1HL26	8/24	0.24 to 10.4	156	NE	NE		NA	NA	NA
7440-43-9	Cadmium	0.145		118		mg/kg	299-W15-48/B1HK57	18/24	0.07 to 0.14	118	NE	3.9		HHSL	YES	ASL
7440-70-2	Calcium	2,240		209,000		mg/kg	299-W15-48/B1HK67	21/21	-	209,000	17,200	NE		NA	NO	NUT
7440-47-3	Chromium	6.65		162		mg/kg	299-W15-46/B17N63	24/24	-	162	18.5	211	c	HHSL	NO	BSL
7440-48-4	Cobalt	5.19		20.6		mg/kg	299-W15-46/B17N60	21/21	-	20.6	15.7	903	c	HHSL	NO	BSL
7440-50-8	Copper	7		26.3		mg/kg	299-W15-46/B17N65	24/24	-	26.3	22	291		HHSL	NO	BSL
18540-29-9	Hexavalent chromium	0.22		0.75		mg/kg	299-W15-46/B17TM6-B	3/20	0.15 to 0.4	0.75	18.5	30	c	HHSL	NO	BSL
7439-89-6	Iron	9,230		49,400		mg/kg	299-W15-46/B17N60	21/21	-	49,400	32,600	5,475		HHSL	NO	BCK
7439-92-1	Lead^e	2.39		620		mg/kg	299-W15-46/B191Y7	20/24	0.063	620	10.2	400		HHSL	NO	MAG
7439-93-2	Lithium	5.06		16.1		mg/kg	299-W15-48/B1HK57	24/24	-	16.1	33.5	156		HHSL	NO	BSL
7439-95-4	Magnesium	3,120		7,900		mg/kg	299-W15-48/B1HK67	21/21	-	7,900	7,060	NE		NA	NO	NUT
7439-96-5	Manganese	157		2,240		mg/kg	299-W15-46/B17N70	24/24	-	2,240	512	324		HHSL	YES	ASL
7439-97-6	Mercury	0.0405		1.02		mg/kg	299-W15-46/B17N67	22/24	0.01 to 0.987	1.02	2.3	NE		NA	NA	NA
7440-02-0	Nickel	5.67		72.9		mg/kg	299-W15-46/B17N63	24/24	-	72.9	19.1	156		HHSL	NO	BSL
7723-14-0	Phosphorus	426		1,470		mg/kg	299-W15-46/B17N60	24/24	-	1,470	NE	NE		NA	NA	NA
7440-09-7	Potassium	89.8		1,990		mg/kg	299-W15-48/B1HK57	21/21	-	1,990	2,150	NE		NA	NO	NUT
7782-49-2	Selenium	0.28		3.76		mg/kg	299-W15-46/B17N63	10/24	0.18 to 10.5	3.76	NE	39		HHSL	NO	BSL
7440-22-4	Silver	0.565		2.88		mg/kg	299-W15-46/B17N67	9/24	0.06 to 1.11	2.88	0.73	39		HHSL	NO	BSL
7440-23-5	Sodium	144		2,660		mg/kg	299-W15-46/B17N63	20/21	1,950	2,660	690	NE		NA	NO	NUT
7440-24-6	Strontium	11.7		264		mg/kg	299-W15-48/B1HK67	24/24	-	264	NE	4,693		HHSL	NO	BSL
7440-61-1	Uranium	0.382		3.14		mg/kg	299-W15-46/B191Y7	8/11	0.158 to 0.995	3.14	NE	1.6		PRG	NO	MAG
7440-62-2	Vanadium	22.2		137		mg/kg	299-W15-46/B17N60	21/21	-	137	85.1	39		HHSL	NO	BCK
7440-66-6	Zinc	31.9		84		mg/kg	299-W15-48/B1HK77	24/24	-	84	67.8	2,346		HHSL	NO	BSL

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	c	HHSL	NO	BSL
110-82-7	Cyclohexane	2		2		mg/kg	299-W15-48/B1HK77	1/1	-	2	0	14	sat	HHSL	NO	BSL
541-02-6	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	c	HHSL	NO	BSL
75-35-4	1,1-Dichloroethene	0.0011		0.0011		mg/kg	299-W15-46/B191Y4	1/42	0.00064 to 0.19	0.0011	0	28		HHSL	NO	BSL
71-36-3	1-Butanol	0.075		5.7		mg/kg	299-W15-48/B1HK34	1/1	-	5.7	0	611		HHSL	NO	BSL
78-93-3	2-Butanone	0.0021		1.7		mg/kg	299-W15-48/B1HK54	25/42	0.0008 to 0.16	1.7	0	3,209		HHSL	NO	BSL
104-76-7	2-Ethyl-1-hexanol	0.0085		0.024		mg/kg	299-W15-46/B18XW3	2/2	-	0.024	0	NE	NA	NA	NA	
591-78-6	2-Hexanone	0.0013		0.0076		mg/kg	299-W15-46/B17N64-A	6/36	0.0011 to 0.37	0.0076	0	NE	NA	NA	NA	
75-65-0	2-Methyl-2-Propanol	0.0043		0.0043		mg/kg	299-W15-46/B17N61	1/1	-	0.0043	0	NE	NA	NA	NA	
107-87-9	2-Pentanone	0.006		0.0066		mg/kg	299-W15-46/B17N64	2/2	-	0.0066	0	NE	NA	NA	NA	
108-10-1	2-Pentanone, 4-Methyl	0.0012		0.0012		mg/kg	299-W15-46/B17N64	1/42	0.00062 to 0.37	0.0012	0	580		HHSL	NO	BSL
67-63-0	2-Propanol	0.01		0.01		mg/kg	299-W15-46/B191Y4	1/1	-	0.01	0	NE	NA	NA	NA	
79-20-9	Acetic acid, methyl ester	0.2		12		mg/kg	299-W15-48/B1HK54	2/2	-	12	0	2,212		HHSL	NO	BSL
67-64-1	Acetone	0.0061		2.9		mg/kg	299-W15-48/B1HK64	30/42	0.0019 to 0.18	2.9	0	1,415		HHSL	NO	BSL
75-05-8	Acetonitrile	0.0066		1.3		mg/kg	299-W15-48/B1HK29	7/32	0.0026 to 0.75	1.3	0	62		HHSL	NO	BSL
71-43-2	Benzene	0.00072		0.0037		mg/kg	299-W15-48/B1HK30	6/42	0.00024 to 0.19	0.0037	0	0.66	c	HHSL	NO	BSL

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	sat	HHSL	NO	BSL
56-23-5	Carbon tetrachloride	0.00083		380		mg/kg	299-W15-46/B17TM6	20/42	0.00016 to 0.24	380	0	0.24	c	HHSL	YES	ASL
108-90-7	Chlorobenzene	0.00098		0.00098		mg/kg	299-W15-46/B191Y4	1/42	0.00013 - 0.19	0.00098	0	27	HHSL	NO	BSL	
67-66-3	Chloroform	0.00096		4.9		mg/kg	299-W15-46/B17TM6	16/42	0.00024 to 0.19	4.9	0	0.25	c	HHSL	NO	FREQ
74-87-3	Chloromethane	0.11		0.11		mg/kg	299-W15-46/B18XT1	1/42	0.00025 to 0.62	0.11	0	1	c	HHSL	NO	BSL
124-18-5	Decane	0.75		0.88		mg/kg	299-W15-48/B1HK59	2/2	-	0.88	0	NE	NA	NA	NA	
100-41-4	Ethylbenzene	0.0008		0.0008		mg/kg	299-W15-48/B1HK35	1/42	0.00017 to 0.19	0.0008	0	23	sat	HHSL	NO	BSL
67-72-1	Hexachloroethane	0.0052		20		mg/kg	299-W15-48/B1HK29	9/28	0.035 to 0.53	20	0	35	c	HHSL	NO	BSL
66-25-1	Hexanal	0.013		0.013		mg/kg	299-W15-46/B17N64-A	1/1	-	0.013	0	NE	NA	NA	NA	
110-54-3	Hexane	0.002		0.0034		mg/kg	299-W15-48/B1HK30	2/32	0.00032 to 0.19	0.0034	0	11	sat	HHSL	NO	BSL
554-12-1	Methyl propionate	0.084		0.084		mg/kg	299-W15-48/B1HK59	1/1	-	0.084	0	NE	NA	NA	NA	
75-09-2	Methylene chloride	0.0056		0.14		mg/kg	299-W15-48/B1HK49	7/42	0.0011 to 0.25	0.14	0	8.9	c	HHSL	NO	BSL
75-52-5	Nitromethane	0.0055		0.0055		mg/kg	299-W15-46/B18XW3	1/1	-	0.0055	0	NE	NA	NA	NA	
110-62-3	n-Valeraldehyde	0.0089		0.0089		mg/kg	299-W15-46/B17N64-A	1/1	-	0.0089	0	NE	NA	NA	NA	
100-42-5	Styrene	0.00048		0.0034		mg/kg	299-W15-46/B17N70	3/33	0.00026 to 0.19	0.0034	0	173	sat	HHSL	NO	BSL
127-18-4	Tetrachloroethylene	0.00094		17		mg/kg	299-W15-46/B17TM6	12/42	0.00041 to 0.19	17	0	0.55	c	HHSL	NO	FREQ
109-99-9	Tetrahydrofuran	0.0096		0.49		mg/kg	299-W15-48/B1HK54	9/9	-	0.49	0	64	c	HHSL	NO	BSL
108-88-3	Toluene	0.00065		0.0038		mg/kg	299-W15-48/B1HK65	7/42	0.00047 to 0.19	0.0038	0	52	sat	HHSL	NO	BSL
598-16-3	Tribromoethylene	0.0057		0.0057		mg/kg	299-W15-46/B17N64-A	1/1	-	0.0057	0	NE	NA	NA	NA	
79-01-6	Trichloroethylene	0.0011		0.0013		mg/kg	299-W15-48/B1HK35	2/42	0.00026 to 0.19	0.0013	0	0.043	c	HHSL	NO	BSL

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	sat	HHSL	NO	BSL
Radionuclides																
14596-10-2	Am-241	0.038		43,478,261		pCi/g	HoleC/4-13 (1973 Smith data)	160/165	0.009 to 300,000	43,478,261	NE	3.7	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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	c	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

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

1 **A2.3.4 216-A-8 Crib**

2 Table A2-11 summarizes the screening processes for soil at the 216-A-8 Crib, where 46 constituents were
3 detected. Thirteen constituents had maximum concentrations greater than their respective residential
4 screening values, and eight were selected as COPCs. Arsenic, potassium-40, and radium-226 had
5 maximum concentrations below natural background levels; therefore, they were not selected as COPCs.
6 Tritium and uranium were eliminated as COPCs because they are not present at levels that would be
7 a health concern. As shown in Table A2-12, the calculated 95 percent UCLs for these constituents are
8 below or near the screening value. Because the screening value is based on a hazard of 0.1 or a risk of
9 1×10^{-6} , the risks from these constituents would not exceed target health goals. Additional support for
10 eliminating these two constituents is a low magnitude of exceedance over the screening value.
11 Section A6.1.1 addresses the impacts to the risk assessment regarding the exclusion of these constituents.
12 The following COPCs were identified for soil at this site:

- 13 • Carbon-14 (does not exceed an HHSL protective of workers and will not be evaluated as a COPC for
14 worker populations)
- 15 • Cesium-137
- 16 • Neptunium-237
- 17 • Plutonium-239/240
- 18 • Radium-228
- 19 • Technetium-99 (does not exceed an HHSL protective of workers and will not be evaluated as a COPC
20 for worker populations)
- 21 • Thallium (does not exceed an HHSL protective of workers and will not be evaluated as a COPC for
22 worker populations)
- 23 • Thorium-228

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

- 26 • Inorganics: bismuth, phosphorous, nitrite, phosphate
- 27 • SVOCs: decane, nondecane, tributyl phosphate
- 28 • VOCs: 2-ethyl-1-hexanol

29 The discussions regarding the constituents without health screening levels for the 216-Z-1A Tile Field
30 and 216-Z-9 Trench also apply to the 216-A-8 Crib (i.e., inorganics naturally present and few detections
31 at very low concentrations for the SVOCs and VOCs). There were three detections of phosphate out of
32 10 samples, and the maximum concentration did exceed background levels by a factor of 3.

33 **A2.4 Results of Screening for Soil Gas**

34 The air samples collected from within the 216-Z-9 Trench were compared to both residential screening
35 levels (EPA Region 6 HHSLs) in air (*Integrated Risk Information System [IRIS] Online Database*
36 [EPA 2007]) and worker permissible exposure limits (PELs) established through the *Washington State*
37 *Industrial Safety and Health Act (WISHA)* (“Airborne Contaminants” [WAC 296-841-20025]). As noted
38 in Section A2.2, HHSLs are health-protective levels established for the general public. In contrast, PELs

1 are air concentrations established as safe for healthy adult workers to breathe 8 hours/day, 5 days/week
2 over a working lifetime.

3 Table A2-13 presents the screening levels and a summary of the air concentration data. Carbon
4 tetrachloride and chloroform both exceeded EPA Region 6 HHSLs by many orders of magnitude and are
5 selected as COPCs in indoor air for a future subsistence farming population (see Section A3.1.1). Because
6 the trench air concentrations did not exceed PELs and were collected from an area with the highest carbon
7 tetrachloride concentrations still present in soil, these air concentrations are likely worst-case scenarios
8 (i.e., equivalent to a basement with limited ventilation, there are two 4-in. vent pipes that pierce the
9 concrete cover at 216-Z-9) (see Figure A2-5) (DOE/RL-2006-24). Therefore, neither indoor nor outdoor
10 air concentrations of VOCs are considered health hazards for a working population. Outdoor air
11 concentrations would be lower than any concentrations collected from within the trench.

12 **A2.5 Results of Screening for Groundwater**

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

26 In the 200-ZP-1 RI report, the COCs selected after an initial screening of maximum concentrations
27 against TALs were grouped into two groups: Group A and Group B. Group A included the analytes of
28 groundwater plumes (presented in Table 1-9 of the 200-ZP-1 RI report [DOE/RL-2006-24]), and Group B
29 included analytes not part of a known plume. Group A, or the potential major risk drivers, had a least one
30 result greater than two times the TAL. The other analytes of Group B were separated into two subgroups:

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

34

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	
Metals																
7440-36-0	Antimony	1.7		1.9		mg/kg	C4545-B1D7C8/C4545-B1D9Y4	3/3	--	1.9	NE	3.1		HHSL	NO	BSL
7440-38-2	Arsenic	0.65		2.45		mg/kg	C4545-B1D994	10/10	--	2.45	6.47	0.39	c	HHSL	NO	BCK
7440-39-3	Barium	25.5		88.6		mg/kg	C4545-B1D7C8	10/10	--	88.6	132	1,564		HHSL	NO	BSL
7440-69-9	Bismuth	94.3		102		mg/kg	C4545-B1D9Y4	3/10	1.08 to 1.1	102	NE	NE		NA	NA	NA
7440-43-9	Cadmium	0.118		0.24		mg/kg	C4545-B1D992	5/10	0.104 to 0.14	0.24	NE	3.9		HHSL	NO	BSL
7440-47-3	Chromium	3.3		41.8		mg/kg	C4545-B1D993	10/10	--	41.8	18.5	211	c	HHSL	NO	BSL
7440-50-8	Copper	5.01		14.7		mg/kg	C4545-B1D7C8	10/10	--	14.7	22	291		HHSL	NO	BSL
18540-29-9	Hexavalent chromium	0.27		0.278		mg/kg	C4545-B1D7C7	2/10	0.2 to 0.25	0.278	18.5	30.1	c	HHSL	NO	BSL
7439-92-1	Lead ^e	1.39		5.34		mg/kg	C4545-B1D7C7	10/10	--	5.34	10.2	400		HHSL	NO	BSL
7439-97-6	Mercury	0.119		0.3		mg/kg	C4545-B1D9Y4	2/10	0.007 to 0.106	0.3	0.33	2.3		HHSL	NO	BSL
7440-02-0	Nickel	3.89		30.6		mg/kg	C4545-B1D7D0	10/10	--	30.6	19.1	156		HHSL	NO	BSL
7723-14-0	Phosphorus	451		1430		mg/kg	C4545-B1D9Y4	10/10	--	1430	NE	NE		NA	NA	NA
7782-49-2	Selenium	0.583		1.8		mg/kg	C4545-B1D9Y4	5/10	0.408 to 0.42	1.8	NE	39		HHSL	NO	BSL
7440-22-4	Silver	0.135		0.135		mg/kg	C4545-B1D7C9	1/10	0.102 to 0.27	0.135	0.73	39		HHSL	NO	BSL
7440-28-0	Thallium	0.84	B	2.5		mg/kg	C4545-B1D9Y4	3/3	--	2.5	NE	0.55		HHSL	YES	ASL
7440-61-1	Uranium	0.18		2.16		mg/kg	C4545-B1D9Y4	10/10	--	2.16	NE	1.6		PRG	NO	MAG
PCBs																
11097-69-1	Aroclor-1254	0.039		0.039		mg/kg	C4545-B1D994	1/10	0.0048 to 0.013	0.039	0	0.22	c	HHSL	NO	BSL
Semi-Volatile Compounds																
124-18-5	Decane	0.5	J	0.5	J	mg/kg	C4545-B1D992	1/7	0.18 to 0.34	0.5	0	NE		NA	NA	NA
84-74-2	Di-n-butylphthalate	0.18	J	0.73	J	mg/kg	C4545-B1D7C7	5/10	0.028 to 0.16	0.73	0	611		HHSL	NO	BSL
629-92-5	Nonadecane	1.6	J	1.6	J	mg/kg	C4545-B1D992	1/1	--	1.6	0	NE		NA	NA	NA
126-73-8	Tributyl phosphate	0.59	J	0.59	J	mg/kg	C4545-B1D7C7	1/10	0.072 to 0.35	0.59	0	NE		NA	NA	NA
Volatile Compounds																
104-76-7	2-Ethyl-1-hexanol	0.76	J	0.76	J	mg/kg	C4545-B1D7C7	1/1	-	0.76	0	NE		NA	NA	NA
67-64-1	Acetone	0.0033	J	0.019	J	mg/kg	C4545-B1D9Y4	3/10	0.0017 to 0.0021	0.019	0	1,415		HHSL	NO	BSL

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		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 *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-R-00-006).

d. Rationale codes:

Selection reason:

ASL = above screening levels

ABCK = above background (magnitude of exceedance more than two times)

TXT = see text for qualitative discussion of these chemicals

Deletion reason:

BSL = below screening level

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

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

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

-- = compound has 100 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, *Human Health Medium-Specific Screening Levels for Residential Soil*

J = estimated concentration for compounds quantified to be less than required quantitation limit but greater than zero

NA = not applicable

NE = not established

PCB = polychlorinated biphenyl

PRG = EPA Region 9 preliminary remediation goal for residential soil (EPA Region 9, 2004)

SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)

SVOC = semi-volatile organic compound

VOC = volatile organic compound

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

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

1 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

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

- 6 • 1,2-dichloroethane: Maximum contaminant concentration did not exceed the TAL in the last 5 years
7 of data.
- 8 • Antimony: Maximum concentration in the last 5 years does not exceed background levels.
- 9 • Iron: The TAL is a secondary MCL, and very little of the data over the last 5 years exceeded the TAL
10 (<5 percent). Secondary MCLs are not health-based, and the maximum concentration of iron in the
11 last 5 years of data did not exceed the EPA Region 6 HHSR for tap water. Thus, this contaminant is
12 not present at levels that are a health concern.

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

18 Table A2-14 presents a summary of the last 5 years of data for the 15 contaminants identified in the RI as
19 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

20

21

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?
<i>Trench Air Data</i>														
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/m³	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/m³	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, simple 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)

1
2

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	
<i>Metals</i>																
7440-36-0	Antimony	2.4	B	46.2	B	µg/L	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		µg/L	299-W14-13	688/835	0.73 to 7.4	769	2.4	100	TAL	YES	ASL	
18540-29-9	Hexavalent chromium	3		730		µg/L	299-W14-13	27/29	3 to 3	730	NE	48	TAL	YES	ASL	
7439-89-6	Iron	7	B	2,080		µg/L	299-W15-40	470/830	6.8 to 54.5	2,080	570	300	TAL	NO	FREQ	
7440-61-1	Total uranium	0.0724		367		µg/L	299-W11-37	182/186	0.1 to 1.02	367	9.85	30	TAL	YES	ASL	
<i>Radionuclides</i>																
15046-84-1	I-129	0.765		36.7		pCi/L	299-W14-13	29/386	-1.22 to 35.7	36.7	0.9	1	c	TAL	YES	ASL
14133-76-7	Tc-99	3.4		27,400		pCi/L	299-W11-39	747/799	-5.9 to 15.4	27,400	0.83	900	c	TAL	YES	ASL
10028-17-8	Tritium	3.59		2,170,000		pCi/L	299-W14-13	722/903	-210 to 369	2,170,000	119	20,000	c	TAL	YES	ASL
<i>Volatile Organic Compounds</i>																
107-06-2	1,2-Dichloroethane	0.089	J	1	J	µg/L	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	µg/L	299-W15-31A	468/574	0.09 to 1	5,200	0	3	c	TAL	YES	ASL
67-66-3	Chloroform	0.077	J	420		µg/L	299-W15-46	452/581	0.07 to 120	420	0	7.17	c	TAL	YES	ASL
75-09-2	Methylene chloride	0.23	JB	740.52	B	µg/L	299-W15-33	132/581	0.12 to 100	740.52	0	5	c	TAL	YES	ASL
127-18-4	Tetrachloroethylene	0.12	JN	5	N	µg/L	299-W15-1	191/581	0.08 to 120	5	0	5	c	TAL	YES	ASL
79-01-6	Trichloroethylene	0.17	J	36	N	µg/L	299-W15-50	353/581	0.09 to 120	36	0	5	c	TAL	YES	ASL
<i>Other</i>																
NO2-N	Nitrogen in nitrate	38		1,720,000	D	µg/L	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 *Hanford Site Background: Part 3, Groundwater Background* (DOE/RL-96-61).

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

d. Rationale codes:

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

1 **A2.6 Summary of Contaminants of Potential Concern**

2 Table A2-15 summarizes the contaminants selected as COPCs in soil by site. A total of 21 contaminants
3 were selected as soil COPCs for quantitative analysis. Plutonium-239 and plutonium-240 were the only
4 contaminants selected at every site. The COPCs selected for the sites around the former Z Plant (those
5 sites labeled "Z" in the middle) are all similar. Site 216-A-8, located in the 200 East Area rather than the
6 200 West Area, shows a different pattern of COPCs (e.g., cesium-137).

7 Of the 15 constituents selected as COCs in the 200-ZP-1 RI report, 12 COPCs were selected for inclusion
8 in the risk assessment for quantitative analysis (DOE-/RL-2006-24). Carbon tetrachloride and chloroform
9 were selected as COPCs in soil gas beneath the 216-Z-9 Trench and 216-Z-1A Tile Field and are
10 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 17 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.

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

16 Current land use at the site is industrial and public access to the site is restricted (PNNL-15892). The
17 large overall size of the Hanford Site (1,524 km² [586 mi²]) also provides a buffer around the Central
18 Plateau area that contributes to access control. As noted earlier, the Central Plateau contains the
19 200-PW-1/3/6 OU waste sites and overlies the groundwater plumes that are evaluated in this report. The
20 200 West and 200 East Areas of the Central Plateau are approximately 8 km (5 mi) from both the nearest
21 boundary of the Site to the west and the nearest section of the Columbia River to the north (Figure A1-1).

22 Land use at the 200 West and 200 East Areas are anticipated to remain industrial for the foreseeable
23 future. These areas are part of the Central Plateau core zone, which is designated as an industrial
24 exclusion zone that will be used for ongoing waste disposal operations and infrastructure services
25 (DOE/RL-2006-51).

26 **A3.1.2 Selected Populations**

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

- 29 • Current and future worker exposures (adults)
- 30 • Future subsistence farmers (adults and children)
- 31 • Future Native American populations (adults and children)

32 Under the current industrial land use conditions, two worker populations (regular worker [i.e., no active
33 soil disturbance] and construction worker) could theoretically come into contact with contaminants in
34 impacted soil and groundwater in the 200 West Area. Because soil impacts at the four selected sites are to
35 subsurface soil, contact with impacted soil by current regular workers is not occurring. In addition, the
36 existing institutional control programs at the Hanford Site preclude unprotected worker contact (e.g., by
37 current construction workers) with any of the impacted soils at the 200-PW-1/3/6 OUs and would also
38 prevent contact with groundwater (PNNL-15892). Therefore, there is currently no significant exposure to
39 impacted soil and groundwater by workers at the selected waste sites (see the discussion in
40 Section A3.1.3).

41 While land use is anticipated to remain industrial for the foreseeable future, because the radionuclides
42 present in soil and groundwater have very long half-lives, a subsistence farming population is also
43 selected for evaluation. This assumes exposure to contaminants in groundwater and soil if institutional
44 controls fail at some point in the future and additional exposures via the food chain (i.e., plants, meat, and

1 dairy products). The future point selected for subsistence farmer exposures to begin is the year 2150. At
2 this time, it is assumed that someone could drill a well and bring drill cuttings to the surface where they
3 would be available for direct exposure by future subsistence farmers. Under this post-2150 scenario, the
4 groundwater from this well could be used by residents or at a business. Thus, a working population could
5 be exposed to soil during drilling (future well drillers), and a separate working population would be
6 exposed to groundwater via drinking it at their place of work (future regular workers).

7 Native Americans currently live near the Hanford Site and could potentially be exposed to contaminants
8 in the groundwater and subsurface soil in the 200 West Area under a future failure of institutional controls
9 scenario, similar to a subsistence farming population. Native Americans also have treaty fishing rights on
10 portions of the Columbia River and have reserved the right to fish, hunt, gather roots and berries, and
11 pasture horses and cattle on open unclaimed land (PNNL-15892). With some exceptions, Native
12 American exposures are similar in type to the subsistence farmer, that is, both groups could be exposed
13 via direct contact with contaminated materials and the food chain. However, exposures may be different
14 in kind, that is, more time spent outdoors and greater consumption of native plants and animals, than the
15 typical default exposures that the EPA has developed for a residential population (OSWER Directive
16 9285.6-03; EPA/600/P-95-002Fa; *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*
17 [Harris and Harper, 2004]).

18 For this baseline assessment, the subsistence farming population has been selected to represent the future
19 highly exposed population under the institutional controls failure scenario. Because soil contamination is
20 at depth and groundwater is very deep, technology (i.e., drilling a well) would have to be employed to
21 access the impacted materials. Native plants and animals would be expected to be minimally exposed, as
22 contamination would be centered around a residence and groundwater would be used to grow crops and
23 water domestic livestock. Evaluating risks for a subsistence farming population meets the
24 following requirements:

- 25 • Fulfills the NCP requirements for a risk evaluation under a “no action” scenario
- 26 • Fulfills Federal EPA requirements to address current and future conditions (EPA 540/1-89/002)
- 27 • Assesses food chain exposures consistent with EPA (EPA 540/1-89/002) and Hanford Site risk
28 assessment guidance (DOE/RL-91-45)
- 29 • Provides information to risk managers regarding the protectiveness of various remedies during the
30 FS process

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

34 **A3.1.3 Identification of Exposure Pathways**

35 Several possible pathways of exposure may exist at this site. An exposure pathway is the mechanism by
36 which a receptor (human) is exposed to contaminants from a source.

37 The following four elements constitute a complete exposure pathway:

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

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

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

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

15 Under current industrial land use and institutional control conditions, only a construction worker has the
16 potential to encounter impacted soil (as described above, actual exposures to an unprotected worker are
17 extremely unlikely). There are no complete and significant pathways for current regular workers. Under
18 a failure of institutional controls scenario (post-2150), soil and groundwater exposures are possible for
19 a subsistence farmer, soil exposures are possible for a well driller, and groundwater exposures are
20 possible to a future regular worker population drinking groundwater at their place of business. The
21 following subsections discuss these current and future exposure pathways in more detail.

22 **A3.1.3.1 Contact with Soil by Workers**

23 For risk assessment purposes, human exposures to soil can occur to “surface” and/or “subsurface” soil,
24 depending on the particular population exposed. For workers, EPA has three general categories:
25 (1) outdoor workers not involved in active soil disturbance (e.g., groundskeepers), (2) indoor workers,
26 and (3) construction workers who would have intensive soil contact through active digging (OSWER
27 Directive 9355.4-24). In this risk assessment, regular workers include both outdoor and indoor workers.
28 Outdoor workers would be exposed primarily only to surface soil over the long-exposure durations (25 to
29 70 years) assumed in the risk assessment equations. Construction workers involved in active soil
30 disturbance (e.g., putting in an underground utility line or constructing a building) could be exposed to
31 soils at depth for much shorter durations. The EPA defines surface soil as the top 2 cm (0.78 in.)
32 (*Soil Screening Guidance: Technical Background Document* [EPA/540/R-95/128]). However, depths of
33 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
34 a protective measure (*Final Guidance for Conduct of Deterministic Human Health Risk Assessments*
35 [ODEQ, 2000]; *Draft Risk Assessment Procedures Manual* [ADEC, 2005]). The depth horizon for direct
36 contact with subsurface soil in risk assessment is limited to depths up to 4.6 m (15 ft) bgs because there
37 would be very few instances of construction projects with deeper soil disturbance requirements
38 (OSWER Directive 9355.4-24; WAC 173-340).

39 Under the existing land use controls, outdoor or indoor regular worker exposures would only occur via
40 the vapor intrusion pathway. At all four of the quantitatively evaluated soil sites, impacts to soil do not
41 begin until more than 1 m (3 ft) bgs and, in some cases, contamination is also below the 4.6 m (15 ft)
42 depth interval for construction workers.

1 Specific depth intervals of soil contamination as established by the 200-PW-1/3/6 RI report
2 (DOE/RL-2006-51) and *the 216-2-8 French Drain Study* (RHO-RE-EV-46P) are as follows:

- 3 • 216-Z-1A Tile Field: 1.8 to 30.5 m (6 to 100 ft)
- 4 • 216-Z-8 French Drain: 5 to 11 m (16 to 35 ft)
- 5 • 216-Z-9 Trench: 6.4 to 36.6 m (21 to 120 ft)
- 6 • 216-A-8 Crib: 3.2 to 20 m (10.5 to 70 ft)

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

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

23 A current construction worker is evaluated at all sites except the 216-Z-9 Trench, where, in addition to the
24 depth to contamination, a concrete cap over the trench also covers the area (see Figure A2-5). For the
25 other three sites, a construction worker could potentially encounter the shallowest of the impacted
26 materials. Post-2150, well drillers could have exposure to concentrations throughout the entire impacted
27 depth interval, as a well would be drilled to the water table. The deeper contamination limit for each of
28 the waste sites generally represents the point where contamination is below health-based screening levels
29 and where well gamma logs indicate little to no radiological activity. Current construction workers and
30 future well drillers would have potentially significant exposures to all the direct-contact soil pathways
31 (i.e., ingestion, inhalation, dermal contact, and external radiation), as depicted in Figures A3-1 and A3-2
32 for construction workers and well drillers, respectively. The direct soil pathways for future regular
33 workers are identified as potentially complete but insignificant in Figure A3-2, under the assumption that
34 the drill cuttings would be spread around a home and not a place of business. Thus, any drill cutting
35 materials tracked into the workplace would likely be diluted to the point where concentrations would be
36 too low to be a health concern. If drill cuttings happened to end up around a business rather than a home,
37 significant exposures to regular workers might be possible and are discussed in the uncertainty section of
38 this appendix (Section A6.2).

39 While both current construction workers and future well drillers would be expected to get soil on their
40 skin where contaminants could be absorbed into the body, the dermal pathway for soil is not both
41 complete and significant for all contaminants. The EPA guidance (EPA 540/R/99/05) recommends
42 evaluating dermal soil exposures only for SVOCs and the two metals that have sufficient absorption
43 information (i.e., arsenic and cadmium). The HSRAM (DOE/RL-91-45) does not recommend quantitative
44 evaluation of dermal exposures for radionuclides in soil because the dermal pathway is insignificant in
45 comparison to the soil ingestion pathway. Sample calculations in Rittman (2004) found that the dermal

3375695_01.d

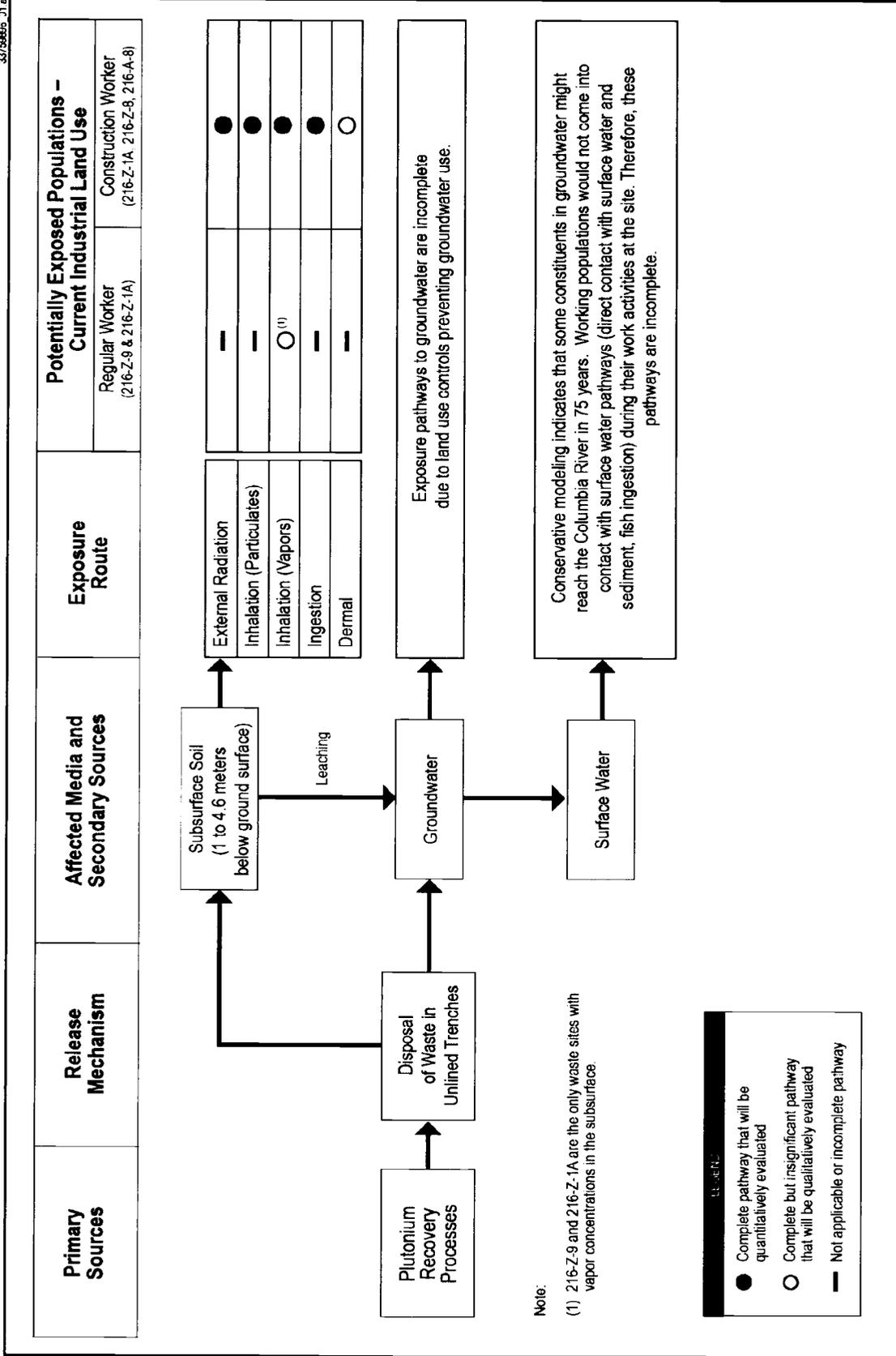


Figure A3-1. Schematic Human Health Conceptual Site Model Current Industrial Land Use

32759586 02.a

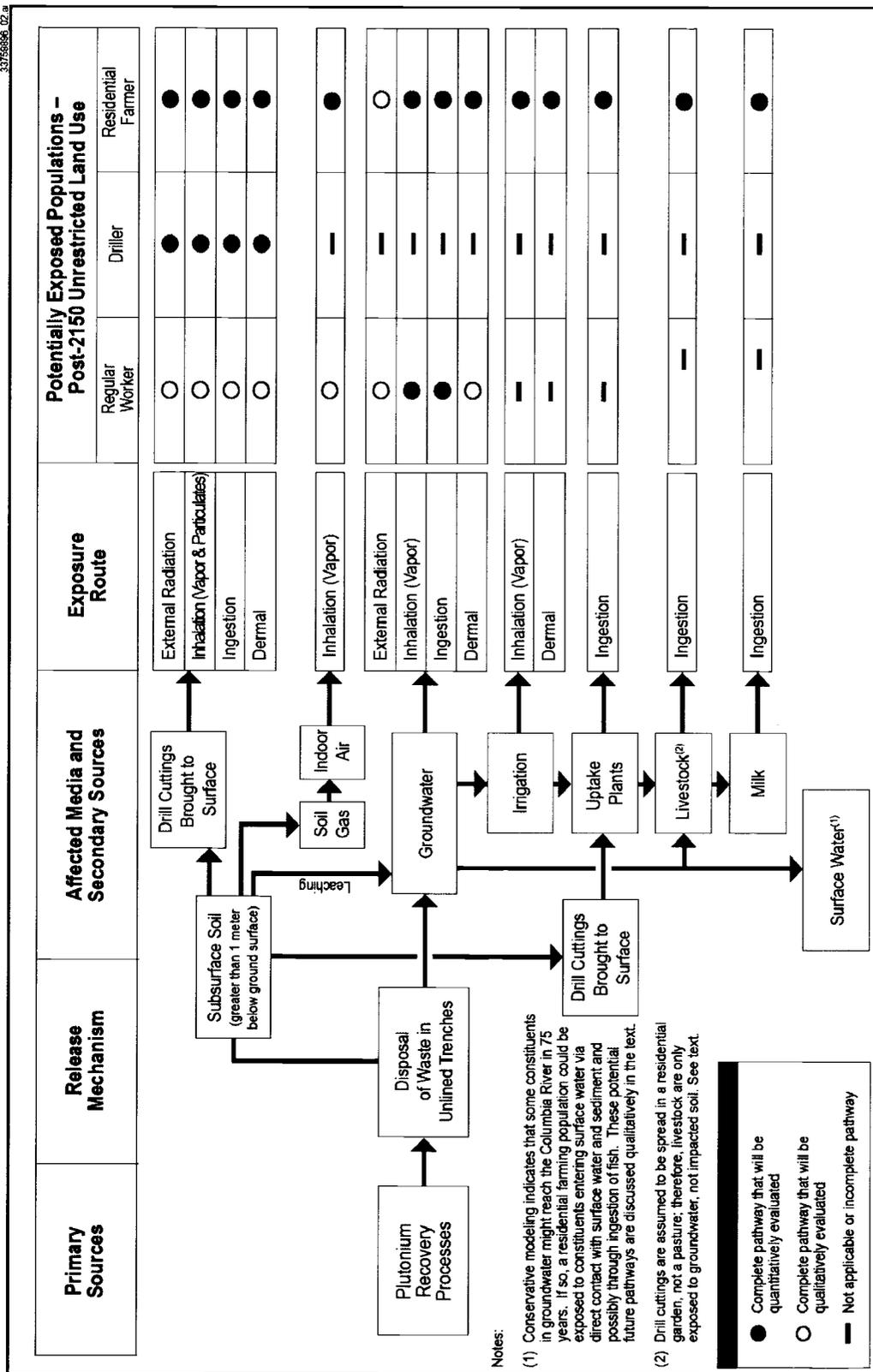


Figure A3-2. Schematic Human Health Conceptual Site Model Depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under Future Unrestricted Land Use

1 pathway for radionuclides was, at most, 3 percent of the ingestion dose. Of the contaminants
2 recommended by EPA for dermal soil exposures, only one COPC at one site (cadmium at the 216-Z-9
3 Trench) requires dermal evaluation. No SVOCs were selected as COPCs at any waste site. Therefore, the
4 dermal pathway is complete, but insignificant, for current construction workers (Figure A3-1) and is
5 complete and significant only for future well drillers exposed to cadmium in soils at the 216-Z-9 Trench
6 (Figure A3-2).

7 **A3.1.3.2 Contact with Soil by a Subsistence Farming Population**

8 In order for residents to encounter contamination in soil, the impacted materials at depth at the
9 200-PW-1/3/6 OU waste sites must be brought to the surface. This scenario would only occur if all
10 knowledge of the site is lost, as well as any markers or indicators that could be placed on the site; thus,
11 this is not considered to be possible in this assessment until at least the year 2150. At this time, it is
12 assumed that the most likely way for subsurface material to be brought to the surface would be through
13 drilling a well and spreading the drill cuttings in the area of a subsistence farmer home and vegetable
14 garden. Then, through daily activities, residents could potentially be exposed to surface soil through
15 ingestion, dermal contact (only cadmium at the 216-Z-9 Trench), inhalation of fugitive dust and vapors,
16 and external radiation.

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

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

22 Exposures to VOCs in subsurface soil might be possible for a future subsistence farming population
23 through inhalation of vapors emanating from the subsurface into the ambient air. Section A2.4 identified
24 vapor concentrations in the 216-Z-9 Trench as a possible health concern for a subsistence farming
25 population if a home were built above the impacted soil at this site, or possibly near the 216-Z-1A Tile
26 Field (i.e., the waste areas with chlorinated solvents). The concentrations of VOCs that are a possible
27 health concern via this pathway based on the 2006 data are declining over time due to their removal via
28 the active SVE system, and due to their natural decrease in environmental media because of volatilization
29 and breakdown in the environment. Thus, it is not known whether the indoor air pathway would still be
30 a concern 150 years in the future, if institutional controls were to fail. In addition, indoor vapor
31 concentrations are affected by the size of the building, ventilation, and type of building construction, and
32 there are many uncertainties in predicting what those parameters might be at a distant future date.
33 Therefore, while this pathway is shown as potentially complete and significant in Figure A3-2, possible
34 risks will only be semi-quantitatively discussed in the risk characterization section of this appendix
35 (Section A5.0).

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

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

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

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

14 **A3.1.3.5 Subsistence Farmer Food Chain Exposures**

15 In order to estimate an upper-bound risk value for the subsistence farming population, the risk assessment
16 assumes that the farming family will be consuming a portion of their diet from vegetables and fruit grown
17 in soil mixed with drill cuttings, eating meat from cattle watered by groundwater, and eating or drinking
18 dairy products made from dairy cattle. Quantification of food chain risks from eating beef and drinking
19 dairy products assumes that the cattle are not pastured on impacted soil but do eat fodder that has been
20 watered with the groundwater.

21 **A3.2 Exposure Point Concentrations**

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

30 **A3.2.1 Exposure Point Concentrations for Soil**

31 Because of the uncertainty associated with estimating the true average concentration at a site, the EPA
32 generally recommends the use of the 95 percent UCL of the arithmetic mean as the appropriate estimate
33 of the average site concentration for an RME scenario (OSWER Directive 9285.6-03, OSWER Directive
34 9285.6-10). At the 95 percent UCL, the probability of under-estimating the true mean is <5 percent. The
35 95 percent UCL can address the uncertainties surrounding a distribution average due to limited
36 sampling data.

37 The formula used to calculate a 95 percent UCL depends on the distribution of the data (i.e., the “shape”
38 of the curve) (OSWER Directive 9285.7-081). A statistical test is performed for each COPC data set to
39 determine the best distribution assumption for the data set. The 95 percent UCL is then calculated using
40 EPA’s ProUCL software (EPA/600/R04/079). The EPA recommends using half of the MRL as
41 a surrogate concentration if the contaminant is selected as a COPC for nondetected samples
42 (EPA 540/1-89/002). This methodology described for calculating the 95 percent UCL was employed for
43 estimation of the RME EPCs whenever there were sufficient data. For data sets with fewer than seven

1 samples, statistical analysis is generally not meaningful and the maximum concentration was used as the
2 RME EPC. Attachment A-1 to this appendix contains the ProUCL outputs for the COPCs.

3 **A3.2.1.1 Construction Worker**

4 Construction worker exposure from contact with soil was evaluated for each waste site with COPCs,
5 except the 216-Z-9 Trench. As shown in Figure A2-5, contaminated soil at the 216-Z-9 Trench does not
6 begin until below the bottom of the trench (more than 6.1 m [20 ft] bgs), and the trench area is currently
7 capped with a concrete cover. Therefore, no construction worker exposures are expected at the
8 216-Z-9 Trench.

9 For the construction worker, exposure is typically to a depth of 4.6 m (15 ft) bgs. However, all of the data
10 were used for 216-Z-8 French Drain because only eight samples are available and the contamination is
11 spread in a relatively small area over the 5- to 11-m [16- to 35-ft]-bgs depth interval of contamination
12 present at this site. In some cases, the ProUCL output recommends use of the maximum concentration
13 rather than a 95 percent UCL where the data sets are small, as was the case with 216-Z-8 French Drain
14 (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
15 because the maximum concentration was found at the shallowest sample where a construction worker
16 would be most likely to come into contact with the material, providing an upper-bound estimate of EPCs
17 at the 216-A-8 Crib. A 95 percent UCL was calculated for the 216-Z-1A Tile Field because there were
18 sufficient samples (17 samples) collected at depths shallower than 5 m (16.4 ft). Table A3-1 provides
19 a summary of construction worker EPCs.

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)	--

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				
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

1 **A3.2.1.2 Future Well Driller**

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

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 A3-2. 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-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

1 At the 216-Z-9 Trench, there is a preponderance of data in the shallowest layer (ARH-2915), and the data
2 also represent the highest concentrations. Therefore, in order to reasonably estimate drill-cutting
3 concentrations, the following additional steps were used in the Cwaste EPC calculations at the
4 216-Z-9 Trench:

- 5 • Because the sampling was biased toward the shallower depth in holes A, B, C, D, G, and H, whereas
6 in locations 299-W15-46 and 299-W15-48 samples were collected in relatively even depth intervals at
7 deeper depths, less "weight" must be given to each individual data point collected from the "holes"
8 (see Figure A2-3).
- 9 • In order to reduce the effect of data points collected from the holes, the average of data collected in
10 each "hole" must first be taken into account and then use this average value as a single data point in
11 calculating the 95 percent UCL.
- 12 • No averaging is needed for locations 299-W15-46 and 299-W15-48 because the depths are evenly
13 spread out.

- 1 • Accordingly, the number of data points entered into the 95 percent UCL calculation is reduced, but
2 the sample size is still adequate. The biased high concentrations from the holes are reduced in
3 their importance.
- 4 • Because more weight is not given to the data collected from deeper depths (>36.6 m [<120 ft]) where
5 the concentrations are much lower even though there is a larger volume of cuttings from deeper
6 depths, 95 percent UCLs are still likely overestimates of the concentrations in Cwaste.
- 7 Table A3-3 summarizes future soil concentrations for radionuclides. These concentrations were calculated
8 with the following assumptions.
- 9 • It was assumed that the average density in the soil was the same as the density in the waste
10 (a reasonable assumption for contamination mixed into soil via leaching).
- 11 • It was assumed that the concentration of contaminant in the impacted soil (future Cwaste) would be
12 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

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
Pa-231	12.5	4.54	1.59	pCi/g
Ra-226	17.0	6.17	2.17	pCi/g
Ra-228	1.93E-07	6.98E-08	2.45E-08	pCi/g
Sr-90	0.4	0.13	0.05	pCi/g
Tc-99	3.67E-06	1.33E-06	4.68E-07	pCi/g
Th-228	2.76E-07	1.00E-07	3.52E-08	pCi/g
Th-230	19.2	6.95	2.44	pCi/g
216-A-8 Crib				
C-14	2.63E-35	5.02E-36	2.02E-36	pCi/g
Cs-137	8,167	1,557.87	625.32	pCi/g
Np-237	3.5	0.67	0.27	pCi/g
Pu-239	24.2	4.62	1.85	pCi/g
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

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

7 **A3.2.1.3 Future Subsistence Farmer**

8 For the subsistence farmer, it was assumed that the drill cuttings soil (Cwaste) exhumed during well
9 construction would be spread over a certain area of a residential yard that would include a vegetable
10 garden. The Ccut 95 percent UCL concentrations (Table A3-3) were thus modified to reflect dilution and
11 mixing of cuttings in the area of a home and garden, including the volume of soil excavated during
12 drilling, the area over which the cuttings are spread, and assumed tilling depth (i.e., mixing with
13 unimpacted soil before planting a garden).

1 These assumptions for size of garden and mixing depths are taken from Rittman (2004) and are below:

- 2 • A 26.7-cm (10.5-in.) diameter well is drilled (small-scale irrigation well, larger than a well used only
3 for drinking water 16.5 cm [6.5 in.] and smaller than a commercial irrigation well 40.6 cm [16 in.]).
- 4 • Drill cuttings will be spread over a 100-m² (1,076-ft²) area.
- 5 • The depth of contaminated soil is 15 cm (6 in.) default shallowest tilling depth.

6 Consequently, the subsistence farmer EPCs in Table A3-3 are lower than those for the driller because
7 they are spread over a garden area mixed with unimpacted soil. The selection of the size of the area to
8 spread drill cuttings has a direct impact on the concentration of contaminant in the soil. The selection of
9 100 m² (1,076 ft²) from Rittman (2004) was considered the smallest reasonable area that could still
10 produce a significant portion of a family's food and was selected after taking into consideration
11 information on garden sizes from various sources such as the Washington Department of Agriculture and
12 the Washington State University Cooperative Extension (Rittman, 2004). There is an obvious trade-off
13 between selecting too large a garden (diluting concentrations below a RME) and too small a garden
14 (insufficient size to produce a significant portion of a family's food).

15 Attachment A-2 of this appendix provides the equations and details of how subsistence farmer EPCs were
16 calculated. Table A3-3 provides the soil EPCs for the subsistence farmer scenario.

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

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

- 22 • In weapons-grade plutonium, 94.2 percent of the weight of plutonium-239/240 mixture is
23 plutonium-239 and 5.8 percent of the weight is plutonium-240. Therefore, 1 g of weapons-grade
24 plutonium-239/240 contains 0.942 g of plutonium-239 and 0.058 g of plutonium-240.
- 25 • The specific activity of plutonium-239 is 61.5 mCi/g and the specific activity of plutonium-240 is
26 227 mCi/g.
- 27 • Therefore, the activity of plutonium-239 in 1 g of weapons-grade plutonium-239/240 is 61.5 mCi/g x
28 0.942 g = 57.9 mCi.
- 29 • The activity of plutonium-240 in 1 g of weapons-grade plutonium-239/240 is 227 mCi/g x 0.058 g =
30 13.2 mCi.

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

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

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

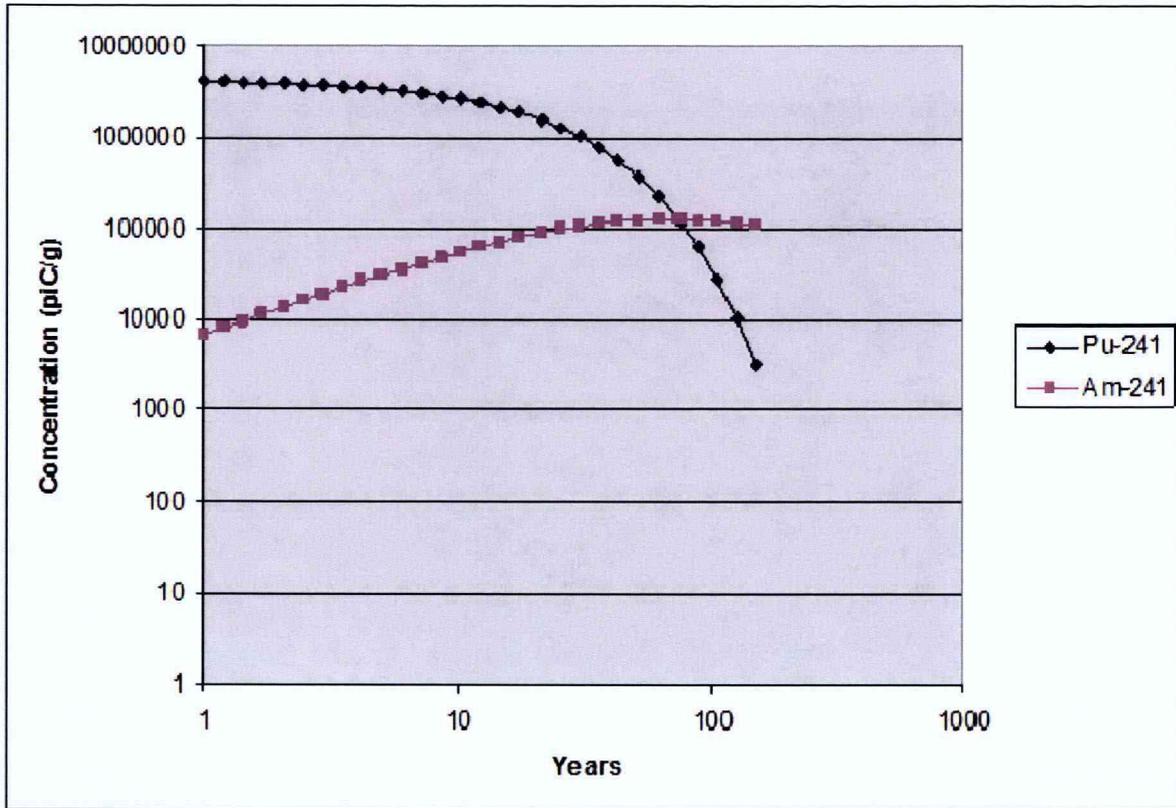
38 As noted in Section A2.1.4.1, there are no available soil data for plutonium-241, which is the parent
39 compound for americium-241. Plutonium-241 has a relatively short half-life of 14.5 years. The
40 production of plutonium (including plutonium-241) started in 1944 at the Hanford Site. The final waste

1 disposals to the major 200-PW-1/3/6 facilities varied and, therefore, some sites are further along the
2 americium-241 ingrowth curve than others. Because the americium-241 data at the 216-Z-1A Tile Field
3 and 216-Z-9 Trench are relatively old (1979 and 1963 through 1973, respectively), americium-241
4 concentrations in the available data sets likely do not represent the maximum ingrowth concentrations of
5 this radionuclide at these two sites. Section A6.1.1 discusses uncertainties surrounding maximum
6 americium concentrations at the 216-Z-8 French Drain. Americium-241 is not a COPC at the 216-A-8
7 Crib. Therefore, maximum concentrations of americium-241 were estimated using the disposal date
8 information from the waste sites, the date of the available americium-241 data, and the RESidual
9 RADioactivity (RESRAD) dose model, which can estimate radiological concentrations in the future
10 taking into consideration radionuclide decay and ingrowth.

11 Maximum americium-241 concentrations were estimated below:

- 12 • Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969 and at 216-Z-9 Trench
13 from 1955 to 1962. Therefore, the year 0 in RESRAD was estimated to be 1967 for the 216-Z-1A
14 Tile Field and 1960 for the 216-Z-9 Trench.
- 15 • Site-specific information on the vadose zone and the contaminant distribution for each site was
16 entered into RESRAD (see Section 3.0).
- 17 • The known americium-241 concentration for each site was the 95 percent UCL of the available
18 historical data. This was 1979 for the 216-Z-1A Tile Field (year 12 in RESRAD) and 1973 for the
19 216-Z-9 Trench (year 13 in RESRAD).
- 20 • Plutonium-241 concentrations at year 0 were entered into RESRAD until the americium-241
21 concentrations at the applicable year matched the existing data.

22 The resulting americium-241 ingrowth curves were graphed for each site and are presented in
23 Figures A3-3 and A3-4 for vadose zone soils at the 216-Z-1A Tile Field and 216-Z-9 Trench,
24 respectively. Figure A3-5 is a graph of the americium-241 and plutonium-241 concentrations in the
25 shallow soils at the 216-Z-1A Tile Field. Vadose zone concentrations are used to estimate EPCs for the
26 future driller and subsistence farmer; shallow soil concentrations are used to estimate an EPC for the
27 current construction worker. At both sites, it appears that the maximum americium-241 concentration
28 would occur around 60+ years from year 0. Therefore, current americium-241 concentrations are likely
29 20 to 25 years from their maximum values. Because current concentrations are aged to represent
30 150 years in the future for drillers and subsistence farmers (the earliest vadose zone exposures
31 [see Section A3.1]), use of the maximum americium-241 concentration as the current concentration
32 slightly overestimates americium-241 concentrations in the year 2150. For the 216-Z-1A Tile Field,
33 current (year 2005) concentrations are 93 percent of their maximum concentration (occurring
34 approximately 73 years from time 0, or year 2040 if time 0 is 1967). For the 216-Z-9 Trench, current-year
35 concentrations are 96 percent of their maximum concentration, which occurs around 63 years from time
36 0, or year 2023 if time 0 is 1960. Because this analysis is meant to be a reasonable approximation of
37 a maximum americium concentration, an exhaustive analysis has not been performed over exactly what
38 year should be year 0, and the possible differing amounts of plutonium-241 that might have been disposed
39 each year of operation. The maximum concentrations estimated (as described above) were used as
40 reasonably protective of health, given the lack of plutonium-241 data and the uncertainties in the
41 estimation process. This slight potential over-estimation does not have a significant effect on estimates of
42 health risk (see also Section 6.1.1.1).

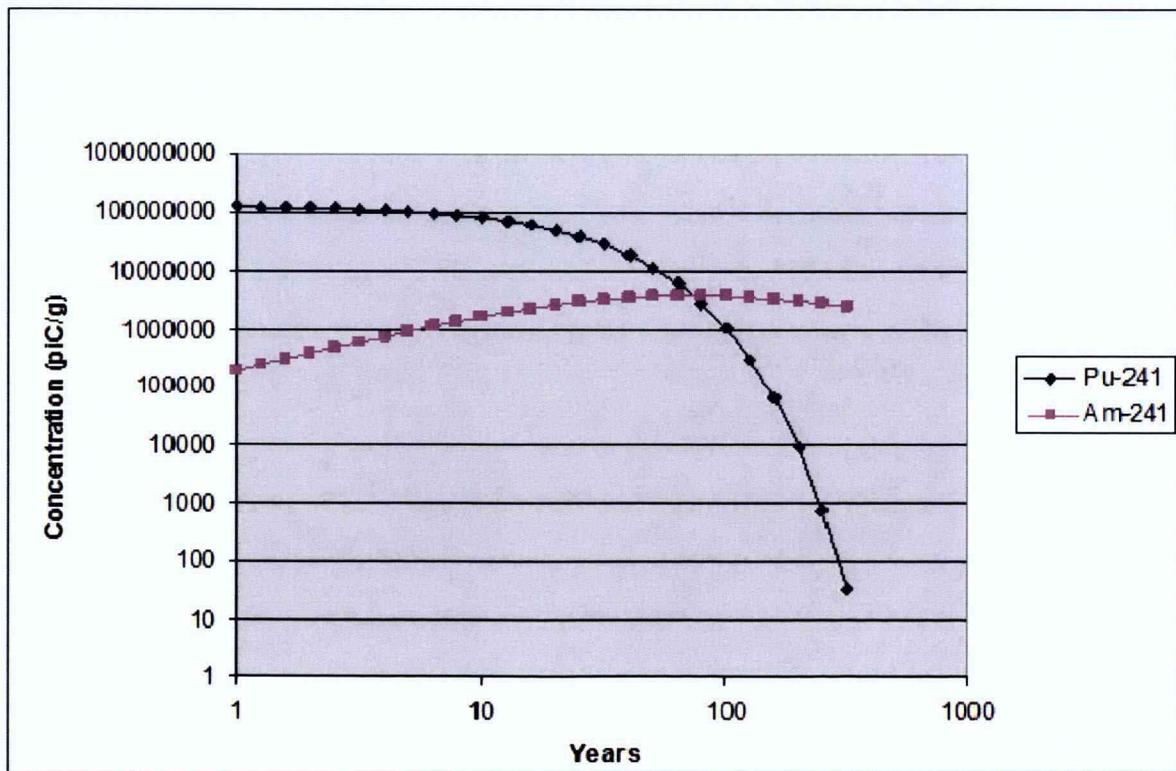


CHPUBS1003-01.15

1

2

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



CHPUBS1003-01.16

3

4

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

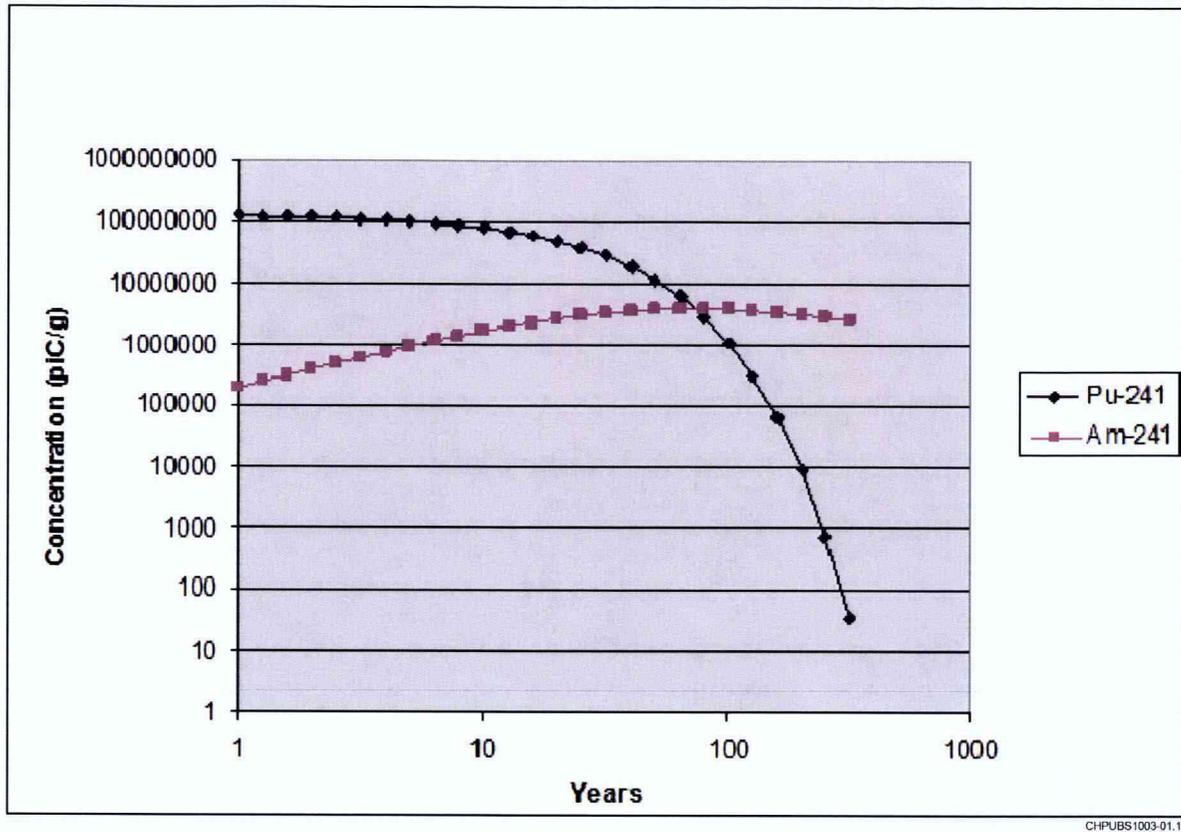


Figure A3-5. Ingrowth of Americium-241 at 216-Z-1A Shallow Soils
 (Construction Worker Soil Contact Zone)

CHPUBS1003-01.17

1
 2
 3

4 At the 216-Z-9 Trench where there are current (2005 to 2006), as well as historical, data for
 5 americium-241, the current americium-241 data were not adjusted, as it is sufficiently close to its
 6 maximum concentration. The maximum predicted values for the 216-Z-1A Tile Field and the maximum
 7 predicted values from 1973 combined with the 2005-2006 data at the 216-Z-9 Trench were used to
 8 estimate soil concentrations and subsequent health risks in the following subsections.

9 **A3.2.2 Exposure Point Concentrations for Groundwater**

10 Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater
 11 plumes (i.e., all of the highest concentrations or the lowest concentrations do not occur at the same
 12 location). In addition, a large amount of groundwater data has been collected at the site and includes
 13 samples collected at the water table, as well as samples collected from deeper in the aquifer, from over
 14 100 wells. Section A2.1.3 discusses the available groundwater data and the data selected for inclusion in
 15 the risk assessment. Using a well-by-well approach to estimate EPCs would generate a large amount of
 16 data of concentrations and health risks per well (i.e., risks at the concentrations found in well X, X1, X2,
 17 etc.), many of which would be similar. Because the purpose of the risk assessment is to provide risk
 18 managers with the information necessary to make remedial decisions, contaminants in groundwater were
 19 evaluated for a range of concentrations for each COPC, with the high-end of the range sufficient to cover
 20 the RME to groundwater, rather than on a well-by-well basis.

21 The range of concentrations selected for EPCs are the 25th, 50th, and 90th percentile values for each COPC
 22 from the existing groundwater data set (i.e., from the last 5 years). These EPCs were used to evaluate
 23 “low,” “medium,” and “high” groundwater concentrations for the groundwater exposure routes. As
 24 recommended by EPA, one-half of the MRL was used as a surrogate concentrate for nondetect results in

1 the percentile calculations (EPA 540/1-89/002). Table A3-4 summarizes the range of groundwater EPCs
 2 for each COPC used in the risk calculations. This methodology does not provide risks at a specific
 3 location, but instead results in information on the range of possible risks for each COPC at the current
 4 concentrations. In addition, the cumulative risks from the 90th percentile evaluation represent a bounding
 5 exposure condition, or RME, because not all COPCs are at the 90th percentile concentration at the same
 6 location. Implications for the risk assessment results on using different groundwater concentrations
 7 (e.g., the more typical risk assessment methodology of the 95 percent UCL of the mean or possible
 8 increase in risks if water were consumed at the location of a maximum concentration) are discussed
 9 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

10 Risks were not calculated for future groundwater concentrations under baseline conditions. Future risks
 11 from groundwater are assumed to be at least “risky” at current conditions. This approach is standard for
 12 nonradiological contaminants where concentrations are assumed to be either staying the same (many
 13 inorganics) or reducing over time (mostly organic compounds). For the three radionuclides that are
 14 COPCs in groundwater, decay curves are provided to support the assumption that risks will not be worse
 15 in the future due to changes in contaminant composition or concentration. Section A5.3.4 discusses the
 16 potential lowering of future groundwater concentrations further.

17 **A3.2.3 Calculation of Tissue Concentrations from Groundwater and Soil Exposure Point** 18 **Concentrations**

19 The methodology recommended on Oak Ridge National Laboratory’s (ORNL’s) Risk Assessment
 20 Information System (RAIS) Website (<http://rais.ornl.gov/>) was applied to estimate concentrations in
 21 homegrown produce and farm-raised beef and dairy products for all COPCs in groundwater and for
 22 nonradionuclides in soil. The ORNL online database is part of the Toxicology and Risk Analysis section

1 in the Life Sciences Division at ORNL. ORNL is a DOE multi-program laboratory, and its risk
 2 information database is routinely used on a wide variety of public- and private-sector risk assessment
 3 projects. The equations presented in RAIS use site-specific soil and groundwater concentrations and
 4 bio-uptake factors to estimate concentrations in plants, beef, and dairy products, as described below. For
 5 the radionuclides in soil, RESRAD Version 6.3 was used to determine risks from eating produce grown in
 6 soil impacted with radionuclides. RESRAD is a computer model designed to estimate radiation doses and
 7 risks from residual radioactive materials (*User's Manual for RESRAD Version 6* [ANL/EAD-4]). Because
 8 only soil concentrations can be used in the RESRAD model, the radionuclides in groundwater were
 9 calculated based on the ORNL methodology. Tables A3-5 and A3-6 summarize the EPCs for the food
 10 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	Am-241	9
Pu-239	23	Eu-152	0.000003
Pu-240	5	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
216-A-8 Crib		Pu-240	67
C-14	6E-37	Ra-226	0.03
Cs-137	8	Ra-228	0.0000000004
Np-237	0.002	Sr-90	0.005
Pu-239	0.0006	Tc-99	0.0000008
Pu-240	0.0001	Th-228	0.00000000001
Ra-228	0.00000001	Th-230	0.0008
Tc-99	0.000000000002		
Th-228	0.0000000002		

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

1 **A3.2.3.1 Plant Tissue Exposure Point Concentrations**

2 Homegrown produce could potentially accumulate concentrations of the COPCs because it is assumed
3 that crops are irrigated with contaminated groundwater and are grown in contaminated post-intrusion
4 soils. Table A3-7 summarizes the equations and input parameters used to estimate plant tissue
5 concentrations from groundwater EPCs and the nonradionuclide soil EPCs. The end result of the

1 calculations is an estimate of the concentrations in plant tissues consumed by humans. This methodology
 2 was used to estimate plant tissue EPCs for the radionuclide and nonradionuclide COPCs in groundwater
 3 for each of the percentiles and for the nonradionuclide EPCs calculated for residential soil. Of the four
 4 representative soil waste sites evaluated, only the 216-Z-9 Trench area and the 216-A-8 Crib area had
 5 nonradionuclide COPCs. As noted above, plant concentrations for the radionuclides in soil were
 6 estimated using the RESRAD model.

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

<i>Calculation of Plant Concentration from Groundwater Used for Irrigation:</i>				
C =	$(C_w \times Irr_{rup} \times CF^*) + (C_w \times Irr_{res} \times CF^*) + (C_w \times Irr_{dep} \times CF^*)$			Equation 1
$Irr_{rup} =$	$\frac{I_r \times F \times Bv_{wet} \times (1 - \exp(-L_b \times t_b))}{P \times L_b}$			Equation 2
$Irr_{res} =$	$\frac{I_r \times F \times MLF \times (1 - \exp(-L_b \times t_b))}{P \times L_b}$			Equation 3
$Irr_{dep} =$	$\frac{I_r \times F \times I_f \times T \times (1 - \exp(-LE \times t_v))}{Y_v \times LE}$			Equation 4
<i>Calculation of Plant Concentration Grown in Post-2150 Residential Soil:</i>				
C =	$(C_s \times Rupv) + (C_s \times Res)$			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:

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

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

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

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

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

$$C = (C_s \times R_{upv}) + (C_s \times R_{es}) \quad \text{Equation 5}$$

Variable	Variable Definition	Units	Value	Source
I _r	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
t _b	Long-term deposition and buildup	day	10,950	Default value, ORNL RAIS
T _r	Half-life	day	Chemical-specific *	Rittman (2004)
t _v	Aboveground exposure time	day	60	Default value, ORNL RAIS
t _w	Weathering half-life	day	14	Default value, ORNL RAIS
Y _v	Plant yield (wet)	kg/m ²	2	Default value, ORNL RAIS
L _b	Effective rate for removal	1/day	Li + Lhl	Default value, ORNL RAIS
LE	Decay for removal on produce	1/day	Li + (0.693/t _w)	Default value, ORNL RAIS
Lhl	Soil leaching rate	1/day	0.000027	Default value, ORNL RAIS
Li	Decay	1/day	0.693/T _r *	Default value, ORNL RAIS

Notes:

* Radionuclides only

ORNL = Oak Ridge National Laboratory

RAIS = Risk Assessment Information System

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

14 The model for root uptake of a contaminant into terrestrial plants assumes that the concentration in the
 15 edible portion is proportional to the concentration in the soil at the time of harvest. The soil-to-plant
 16 transfer factor is used to quantify this pathway. The soil-to-plant transfer factors presented in Rittman
 17 (2004) were used in the plant modeling equations. The following discussions detail the derivation of the
 18 transfer factors for radionuclides (except tritium), tritium, and nonradionuclides, respectively. Table A3-8
 19 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 <i>Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment</i> (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			

1 Soil-to-Plant Transfer Factors for Radionuclides (Except Tritium)

2 For radionuclides, transfer factors are available for leafy vegetables, root vegetables, and fruits.
 3 A weighted average, based on the ratio of human consumptions for each of these types of plants, was
 4 calculated to derive a single transfer factor that could be applied to consumption of all types of fruits and
 5 vegetables. (Note that transfer factors are also available for grains; however, grains are not typically
 6 irrigated or grown in gardens. Therefore, grains are not included in the total vegetable consumption
 7 equations.) As presented in Rittman (2004), based on the U.S. Department of Agriculture's (USDA's)
 8 consumption rates, an individual's typical fruit and vegetable diet consists of 16 kg, 55 kg, and 38 kg per
 9 year of leafy vegetables, root vegetables, and fruits, respectively. This corresponds to 9 percent,
 10 46 percent, and 45 percent for leafy vegetables, root vegetables, and fruits, respectively. These
 11 percentages were applied to the transfer factors presented in Rittman (2004) for the radionuclides to
 12 derive a weighted average transfer factor. The equations presented in RAIS require transfer factors in wet
 13 weight. Therefore, these transfer factors were converted to wet weight by applying the dry-to-wet ratio of
 14 0.2, also described in Rittman (2004).

15 Soil-to-Plant Transfer Factor for Tritium

16 Uptake of tritium by organisms is evaluated differently than other radionuclides. Tritium (which is
 17 ubiquitous, mobile, and is equivalent to stable hydrogen isotopes in the environment) requires special
 18 consideration in radiological analysis to more accurately assess its potential hazard. In general, it is
 19 assumed that tritium is transferred in environmental media through its association with water as tritiated
 20 water (ANL/EAD-4). Transfer factors for tritium are not typically used because the animal concentration
 21 is calculated using an equilibrium model based on the mass fraction of hydrogen in water and mass

1 fraction of hydrogen in plant tissue. However, because the tissue and pathway analysis models are
2 inherently complex, to avoid additional complexity, the basic strategy employed for the other
3 radionuclides was applied in the evaluation of tritium in the environment.

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

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

17 ***Soil-to-Plant Transfer Factors for Nonradionuclides***

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

$$23 \text{ FPLANTS} = 7.7 (\text{KOW}) - 0.58.$$

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

27 ***A3.2.3.2 Beef Tissue and Dairy Product Exposure Point Concentrations***

28 Beef and dairy cattle could potentially accumulate concentrations of the COPCs if the livestock were
29 watered with contaminated groundwater and if the fodder was irrigated with contaminated groundwater.
30 Unlike the plant tissue calculations described above, groundwater is the only source of COPCs to cattle
31 because the soil from drill cuttings is assumed to be dispersed in a relatively small area of a residential
32 garden and is not expected to be dispersed throughout an entire grazing pasture. Therefore, the
33 soil-to-cattle food chain pathways are considered incomplete. This section summarizes the methodology
34 used to model beef tissue and dairy product concentrations from cattle that are raised by the
35 subsistence farmer.

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

1 As shown in Table A3-9, the equations used to estimate beef tissue and dairy product concentrations in
 2 cattle are very similar. In general, the ORNL RAIS default values were used for the beef parameters. The
 3 default values were developed for use in DOE PRGs and represent health-protective estimates of the
 4 amount of contaminant that would end up in beef tissue and dairy products. The transfer factors for
 5 estimating the uptake into tissue and the concentration in fodder were obtained from Rittman (2004).
 6 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

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

1 Therefore, the meat and dairy product EPC calculations were calculated below:

$$2 \quad H-3_{m,d} \text{ (pCi/g)} = H-3_w \text{ (pCi/L)} \times 1 \text{ (L/kg)} \times 10^{-3} \text{ (kg/g)}$$

3 where:

4 $H-3_{m,d}$ = tritium concentration in meat and dairy products

5 $H-3_w$ = tritium concentration in irrigation water.

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

7 **A3.3 Calculation of Contaminant Dose**

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

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

34 The formulas and exposure factors that were used together with the EPCs to quantify doses for the
35 complete pathways are presented in Tables A3-11 through 3-18. The tables also indicate the sources of
36 the factors. In general, EPA default exposure factors (OSWER Directive 9355.4-24) were assumed for
37 construction worker exposures; EPA/600/P-95-002Fa and OSWER Directive 9285.6-03 default exposure
38 factors were used for subsistence and industrial exposures. No default exposure factors are available to
39 quantify exposures to the well driller. Default exposure factors are discussed in Attachment A-4 of this
40 appendix. Where site-specific factors rather than accepted defaults are proposed, the rationale for their
41 selection is provided in the following discussions for each land use scenario. Note that for radionuclides
42 in soil, RESRAD was used to calculate doses for construction workers, drillers, and subsistence farmers.
43 For some residential parameters, RESRAD exposure estimates are less conservative than EPA defaults,

1 but the defaults in RESRAD were not changed in order to be consistent with past risk assessments at the
2 Hanford Site. Differences between RESRAD and EPA defaults for the subsistence farmer and potential
3 impacts on the risk results are discussed in Section A6.2.5, and RESRAD input parameters are included in
4 Attachment A-3 of this appendix.

5 **A3.3.1 Current Industrial Land Use Scenario**

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

11 **A3.3.1.1 Exposure Duration and Frequency**

12 The EPA default value for construction workers (OSWER Directive 9355.4-24) assumes exposure
13 duration of 1 year, during which workers are at a job site in a contaminated area for 250 days (exposure
14 frequency). However, construction activities are not expected to occur throughout an entire year because
15 of the size of these sites. Therefore, an exposure frequency of 30 days/yr was selected as a more
16 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

1 **A3.3.1.2 Particulate Emission Factor**

2 The particulate emission factor (PEF) relates the concentration of contaminants in soil with the
3 concentration of dust particles in the air, or “fugitive dust” (EPA/540/R-95/128). A site-specific PEF was
4 calculated for the site using the equation from EPA’s soil screening-level guidance (OSWER Directive
5 9355.4-24). The emissions part of the equation is based on the “unlimited reservoir” model from *Rapid*
6 *Assessment of Exposure to Particulate Emissions from Surface Contamination* (EPA/600/8-85/002)
7 developed to estimate particulate emissions owing to wind erosion (as cited in EPA/540/R-95/128). The

1 dispersion part of the equation includes a dispersion coefficient (Q/C_{wind}). The variable, Q/C_{wind} , is
 2 dependent on the climatic zone and meteorology conditions at a site. Therefore, site-specific dispersion
 3 factors can be calculated that reflect the site location and climate, as well as the site size. Table A3-11
 4 summarizes the inputs for the PEF equation. The PEF calculated for the Hanford Site is $2.72 \times 10^9 \text{ m}^3/\text{kg}$.

5 **A3.3.2 Post-2150 Unrestricted Land Use Scenario**

6 In the post-2150 unrestricted land use scenario, a future subsistence farming population was evaluated
 7 assuming exposure to contaminants in soil and groundwater if institutional controls fail at some point in
 8 the future. In addition, the post-2150 scenario also evaluated worker risks for two populations: future
 9 drillers exposed to drill cuttings from the subsurface and future regular workers drinking groundwater
 10 from the 200-ZP-1 OU at their location of employment. The following subsections discuss the exposure
 11 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)**

$D_A = \{[(q_a^{10/3} \times D_i \times H') + (q_w^{10/3} \times D_w)]/n^2\} / \{p_b k_{oc} f_{oc} + q_w + q_a H'\}$			
Parameter	Definition (Units)	Value	Source
q_a	Air-filled soil porosity (L_{air}/L_{soil})	0.28	Default value, OSWER Directive 9355.4-24
D_i	Diffusivity in air (cm^2/s)	Contaminant-specific	Table 37, page 137 of EPA/540/R-95/128
H'	Henry's Law constant (unit-less)	Contaminant-specific	Table 36, page 134 of EPA/540/R-95/128
q_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15	Default value, OSWER Directive 9355.4-24
D_w	Diffusivity in water (cm^2/s)	Contaminant-specific	Table 37, page 137 of EPA/540/R-95/128
n	Total soil porosity (L_{pore}/L_{soil})	0.43	$1-(p_b/p_s)$
p_b	Dry soil bulk density (g/cm^3)	1.5	Default value, OSWER Directive 9355.4-24
p_s	Soil particle density (g/cm^3)	2.65	Default value, OSWER Directive 9355.4-24
k_{oc}	Soil organic carbon-water partition coefficient (cm^3/g)	Contaminant-specific	Table 39, page 143 of EPA/540/R-95/128. The larger of the calculated K_{oc} or measured K_{oc} was used.
f_{oc}	Organic carbon content (g/g)	0.006	Default value, OSWER Directive 9355.4-24
$VF = Q/C \times (1/F_D)^* \times [(3.14 \times D_A \times T)^{1/2} / (2 \times p_b \times D_A)] \times 10^{-4}$			
(Note: The F_D factor is only used with the Q/C_{sa} dispersion coefficient.)			
$Q/C_{vol} [Q/C_{sa}]$	Dispersion coefficient for volatiles (subchronic dispersion coefficient) ($\text{g}/\text{m}^2\text{-s}$ 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)

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

Parameter	Definition (Units)	Value	Source
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 × IR_c × EF × ED_c × CF / AT_{nc-c} × BW_c
Dermal absorption child = CS × SA_c × AF_c × AB × EF × ED_c × CF / AT_{nc-c} × BW_c
Inhalation child = InhR_c × EF × ED_c × (1/PEF or VF) / AT_{nc-c} × BW_c
Ingestion adult = CS × IR_s × EF × ED_a × CF / AT_{nc-a} × BW_a
Dermal absorption adult = CS × SA_a × AF_a × AB × EF × ED_a × CF / AT_{nc-a} × BW_a
Inhalation adult = InhR_a × EF × ED_a × (1/PEF or VF) / AT_{nc-a} × BW_a

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

Ingestion child/adult = (CS × EF × CF / AT_{ca}) × (IR_c × ED_c / BW_c + IR_a × ED_a / BW_a)
Dermal absorption child/adult = (CS × EF × AB / AT_{ca}) × (SA_c × AF_c × ED_c / BW_c + SA_a × AF_a × ED_a / BW_a)
Inhalation child/adult = (CS × EF × (1/PEF or VF) / AT_{ca}) × (InhR_c × ED_c / BW_c + InhR_a × ED_a / BW_a)

Soil Intake Factors - Radioactive COPCs (pCi):

Ingestion child/adult = (CS × EF × CF²) × (IR_c × ED_c + IR_a × ED_a)
Inhalation child/adult = (CS × EF × (1/PEF) × CF³) × (InhR_c × ED_c + InhR_a × ED_a)

Intake Parameter	Value	Unit	Source	
AB	Absorption factor	Contaminant-specific	unit-less	EPA 540/R/99/05
AF	Adherence factor, soil:			
	AF _a : 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 =	$(CS \times EF \times CF2) \times (IRc \times EDc + IRa \times EDa)$
Inhalation child/adult =	$(CS \times EF \times (1/PEF) \times CF3) \times (InhRc \times EDc + InhRa \times EDa)$

	Intake Parameter		Value	Unit	Source
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)**

<i>Water Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg BW-day)</i>	
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 =	$(C_w \times EF \times CF / AT_c) \times (IR_c \times ED_c / BW_c + IR_a \times ED_a / B_w)$
Dermal absorption child/adult =	$(DA_{ev-a} \times EF \times EV_w / AT_c) \times (SA_c \times ED_c / BW_c + SA_a \times ED_a / B_w)$
Inhalation child/adult =	$(C_w \times EF \times VF_w \times CF_w / AT_c) \times (InhR_c \times ED_c / BW_c + InhR_a \times ED_a / B_w)$
<i>Water Intake Factors - Radioactive COPCs (pCi):</i>	
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-95-002F a
InhR _c	Inhalation rate—child	10	m ³ /day	Default value, EPA/600/P-95-002F a

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

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-95-002F a
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:

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

Equation 2: 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:

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

1

2 **Site-Specific Exposures to Surface Soil**

3 **Particulate Emission Factor**

4 The PEF described above for construction workers was also used to evaluate residential exposures to
5 COPCs in fugitive dust. Table A3-11 summarizes the inputs for the PEF equation. The PEF calculated for
6 the Hanford Site is 2.72×10^9 m³/kg.

7 **Volatilization Factor for Soil**

8 The soil-to-air volatilization factor (VF) is used to define the relationship between the concentration of
9 the volatile contaminant in soil and the flux of the volatilized contaminant to air. The VF only applies to
10 volatile contaminants in soil, while the PEF (described above) only applies to nonvolatile contaminants.

1 OSWER Directive 9355.4-24 provides a method for deriving contaminant-specific VFs that are
2 appropriate for evaluating exposures for outdoor inhalation of volatiles by residential populations. The
3 equation used to derive the VFs for the subsistence farmer scenario is Equation B-11 of the supplemental
4 guidance and is shown in Table A3-11. The VF equation combines contaminant-specific properties with
5 dispersion assumptions. As described above for the PEF, the dispersion part of the equation also includes
6 a dispersion coefficient (Q/C_{vol}). The variable, Q/C_{vol} , is dependent upon the climatic zone and
7 meteorology conditions at a site. Therefore, site-specific dispersion factors can be calculated that reflect
8 the site location and climate, as well as the site size. The site-specific Q/C_{vol} is calculated to be the same
9 as the Q/C_{wind} described above.

10 **Exposures to Groundwater during Irrigation**

11 Future subsistence farmers are assumed to use the groundwater as an irrigation source for their crops and
12 livestock. Therefore, adult subsistence farmers were evaluated for dermal and inhalation exposures to
13 COPCs in groundwater during irrigation activities. Default exposure factors are not available to quantify
14 exposures through this pathway. The exposure factors used to quantify exposures through this pathway
15 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)

$$\text{Dermal Absorption adult} = \text{DAev-a} \times \text{SAa} \times \text{EVw} \times \text{EF} \times \text{ED} \times / \text{ATnc} \times \text{BWa}$$

$$\text{Inhalation adult} = \text{Cw} \times \text{InhRa} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{VFW} \times \text{CFw} / \text{ATnc} \times \text{BWa}$$

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

$$\text{Dermal Absorption adult} = \text{DAev-a} \times \text{SAa} \times \text{EVw} \times \text{EF} \times \text{ED} \times / \text{ATca} \times \text{BWa}$$

$$\text{Inhalation adult} = \text{Cw} \times \text{InhRa} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{VFW} \times \text{CFw} / \text{ATca} \times \text{BWa}$$

Water Intake Factors - Radioactive COPCs (pCi)

$$\text{Inhalation adult} = \text{Cw} \times \text{InhRa} \times \text{EF} \times \text{ED} \times \text{ET} \times \text{VFRad}$$

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

1 **Exposure Frequency**

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

5 **Exposure Time**

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

9 **Skin Surface Area**

10 For this pathway, an exposed skin surface area of 1,933 cm² (299.6 in.²) was selected. The mean surface
11 area of forearms and hands (average for men and women) from Table 6-4 of EPA/600/8-89/043 was used
12 to calculate this value. This value corresponds to exposure to forearms and hands during irrigation.

13 **Event Frequency for Irrigation**

14 An event frequency of one event/day was assumed for this pathway. This value was obtained from the
15 ORNL RAIS Website (<http://rais.ornl.gov/>). The value assumes that irrigation will occur once every day
16 for the entire 3-month irrigation period.

1 **Inhalation Rate for Irrigation**

2 An inhalation rate of 1.5 m³/hr was assumed for irrigation activities. According to the EPA’s EFH
3 (EPA/600/P-95-002Fa), an inhalation rate for adults engaged in light outdoor activities is 1 m³/hr,
4 1.5 m³/hr for those engaged in moderate outdoor activities, and a rate 2.5 m³/hr for those engaged in
5 heavy activities outdoors. The inhalation rate of 1.5 m³/hr for moderate activities was considered
6 appropriate for evaluating inhalation exposures during irrigation. While the definitions of heavy activities
7 are somewhat subjective, *Lognormal Distribution in Environmental Applications* (EPA/600/R-97/006)
8 states that representative “moderate” activities include slow running, yard work, heavy indoor cleanup,
9 and climbing stairs.

10 **Volatilization Factor for Water for Irrigation**

11 The inhalation pathway during irrigation of groundwater is considered to be complete and significant only
12 for volatile contaminants. The VF for water (VF_w) is used to estimate the concentration in air of a volatile
13 contaminant off-gassing from water. Of the three radionuclide COPCs in groundwater, only tritium is
14 considered volatile from groundwater. Therefore, the VF_w for tritium from Rittman (2004) was used to
15 quantify inhalation exposures from tritium during irrigation.

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

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

24
25 where:

26 k_{lg} = a conservative estimate of the overall mass transfer coefficient from the liquid phase to
27 the gas phase of 3.0E-6 m (EPA 8EPR-PS)

28 L = an average irrigation system length of up to 30 m (EPA 8EPR-PS)

29 H = an average breathing zone height of 2 m

30 μ = site-specific average wind speed of 7.6 mph (3.4 m/sec) over a year’s time

31 μL = air changes per day of 0.11/sec, assuming the wind flow is in the direction of the
32 irrigation system (3.4 m/sec ÷ 30 m) (EPA 8EPR-PS)

33 k = an air mixing rate between irrigation system and ambient air of 75 percent.

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

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

37 Subsistence farmers are assumed to consume homegrown fruits and vegetables from gardens that are
38 cultivated in post-intrusion contaminated soils and irrigated with groundwater and to consume beef and

1 dairy products from cattle that drink site groundwater and graze on pastures irrigated with groundwater.
 2 Table A3-16 presents the exposure factors used to quantify the ingestion of fruits and vegetables,
 3 ingestion of beef, and ingestion of dairy products pathways. Discussions regarding the selection of the
 4 ingestion rates for these pathways are provided hereafter. Some of the uncertainties in the different factors
 5 that could be selected to assess food chain exposures and how different assumptions might affect risk
 6 results are discussed in Section A6.2.4.

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

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

$$\text{Ingestion child/adult} = \text{Cti} \times \text{IRti} \times \text{EF} \times \text{ED} \times \text{CF} / \text{ATnc}$$

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

$$\text{Ingestion child/adult} = \text{Cti} \times \text{IRti} \times \text{EF} \times \text{ED} \times \text{CF} / \text{ATca}$$

Tissue Intake Factors - Radioactive COCs (pCi):

$$\text{Ingestion adult} = \text{Cti} \times \text{IRti} \times \text{EF} \times \text{ED}$$

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

1 ***Fruit and Vegetable Ingestion Rate***

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

10 ***Beef Ingestion Rate***

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

15 ***Dairy Ingestion Rate***

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

20 ***A3.3.2.2 Future Well Driller***

21 Future well drillers are assumed to be exposed to contaminants in soil during the course of drilling
22 a drinking water well. Table A3-17 presents the exposure factors used to quantify the soil exposure
23 pathways. The EPA OSWER Directive 9355.4-24 default exposure factors for outdoor industrial worker
24 and the exposures specific to drillers identified in Rittman (2004) were used to evaluate this pathway.
25 Discussions regarding the selection of the site-specific exposure factors for this pathway are
26 provided below.

27 ***Exposure Duration***

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

32 ***Particulate Emission Factor***

33 The PEF described above for construction workers and subsistence farmers was also used to evaluate well
34 driller exposures to COPCs in fugitive dust. Table A3-11 summarizes the inputs for the PEF equation.
35 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**

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

Ingestion adult = $C_w \times IR_a \times EF \times ED_a \times CF / AT_{nc} \times BW_a$

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)

Ingestion adult = $C_w \times IR_a \times EF \times ED \times CF / AT_{ca} \times BW_a$

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)

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

1

2

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

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

1 (EPA 540/R-97-036) update on April 16, 2001, which is based on Federal Guidance Report No. 13
 2 (EPA 402-R-99-001). Federal Guidance Report No. 13 incorporates state-of-the-art models and methods
 3 that take into account age- and gender-dependence of radionuclide intake, metabolism, dosimetry,
 4 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 $1.6E-6 \times 10$.

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

EPA = U.S. Environmental Protection Agency

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

1 A4.2 Non-Cancer Effects

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

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

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

33 In EPA's methodology used to derive chronic RfDs, uncertainty factors (UFs) are applied to the NOAEL
34 or LOAEL of the critical research study. These UFs are used to address the uncertainties/variabilities that
35 are present in the data set for each individual contaminant (see Section 4.4.5 of EPA/630/P-02/002F). The
36 uncertainty factors (up to five) are assigned values of either 10 or 3, these values are multiplied together,
37 and then the critical study NOAEL or LOAEL is divided by the total UF (see Section 4.4.5 of
38 EPA/630/P-02/002F). In general, EPA has estimated subchronic criteria from chronic criteria by
39 removing the UF of 10 to account for the use of a subchronic study to estimate chronic exposure;
40 therefore, the vast majority of the subchronic criteria presented in HEAST are an order of magnitude
41 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

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

- 5 • HEAST: Subchronic criteria from HEAST were used if the chronic RfD has not been updated since
6 1997 (i.e., the subchronic criteria are based on the same critical study as the chronic criteria).
- 7 • IRIS: Where the chronic criteria have been updated since 1997 and are in IRIS database, the IRIS file
8 was reviewed. If a UF was used to decrease a chronic value to account for subchronic to chronic
9 exposure, that UF was removed to obtain a subchronic criteria. In addition, if the NOAEL or LOAEL
10 was adjusted from a 5-day exposure to a 7-day exposure, that adjustment was removed to reflect the
11 worker population of concern (see Sections 4.4.2 and 4.4.3 in EPA/630/P-02/002F).
- 12 • NCEA (EPA's toxicity research arm): Where the source of the chronic criteria is the NCEA (this
13 information is listed on the EPA Region 9 PRG list), the backup documentation that NCEA used to
14 derive the chronic criteria was reviewed to evaluate whether sufficient information was provided to
15 make an adjustment to the chronic value as described above.

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

19 **A4.3 Oral Toxicity Criteria**

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

22 **A4.4 Inhalation Toxicity Criteria**

23 The criteria for inhalation are reference concentrations (RfCs) expressed in milligrams of contaminant per
24 cubic meter of air (mg/m³) for noncarcinogens and unit risk factors (URFs) expressed in cubic meters of
25 air per microgram of contaminant (m³/μg) for carcinogenic exposures. The RfCs and URFs are developed
26 in the same way as RfDs and SFs except that they include, as part of their development, a default
27 inhalation rate assumption of 20 m³ of air inhaled per day. Because the default inhalation rate is not
28 applicable to all the receptors in this risk assessment, RfCs and URFs were converted into reference doses
29 for inhalation (RfD_i) and inhalation slope factors (SF_i) according to the protocols presented by EPA
30 (EPA 540/1-89/002, OSWER Directive 9285.7-53). The conversions are below:

$$31 \quad \text{RfD}_i \text{ (mg/kg-day)} = \text{RfC (mg/m}^3\text{)} \times 20 \text{ (m}^3\text{/day)} \times 1 / 70 \text{ (kg)}$$

$$32 \quad \text{SF}_i \text{ (kg-day/mg)} = \text{URF (m}^3\text{/}\mu\text{g)} \times 1 / 20 \text{ (m}^3\text{/day)} \times 70 \text{ (kg)} \times 10^3 \text{ (}\mu\text{g/mg)}$$

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

38 **A4.5 Dermal Toxicity Criteria**

39 Most oral RfDs and SFs are expressed as an administered dose (i.e., the amount of substance taken into
40 the body by swallowing). In contrast, exposure estimates for the dermal route of exposure are expressed

1 as an absorbed dose (i.e., the amount of contaminant that is actually absorbed through the skin). Because
2 dermal toxicity criteria are not readily available, oral toxicity values are used in conjunction with an
3 absorption correction factor to adjust for the difference in administered to absorbed dose. The EPA
4 recommends absorption correction factors for a limited amount of inorganic contaminants in Exhibit 4-1
5 of EPA 540/R/99/05. For those contaminants that do not appear on the table, the recommendation is to
6 assume 100 percent absorption (EPA 540/R/99/05) (i.e., the dermal toxicity criteria would not differ from
7 the oral toxicity criteria).

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

13 **A4.6 Hexavalent Chromium and Cadmium Exposure Route Toxicity Differences**

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

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

33

1 A5 Risk Characterization

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

8 A5.1 Methodology for Evaluating Noncarcinogenic Hazards

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

$$12 \quad \text{HQ} = \frac{\text{Chemical Intake (mg/kg - day)}}{\text{RfD (mg/kg - day)}}$$

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

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

23 A5.2 Methodology for Evaluating Carcinogenic Risks

24 The potential for carcinogenic effects is evaluated by estimating the probability of developing cancer over
25 a lifetime based on exposure assumptions and constituent-specific toxicity criteria. The increased
26 likelihood of developing cancer from exposure to a particular contaminant is defined as the excess cancer
27 risk. Excess cancer risk is the risk in excess of a background cancer risk of one chance in three (0.3 , or $3 \times$
28 10^{-1}) for every American female and one chance in two (0.5 , or 5×10^{-1}) for every American male of
29 eventually developing cancer (*Cancer Facts and Figures – 2001* [ACS, 2001]). Cancer risk estimates are
30 the product of exposure assumptions (i.e., intake) and the contaminant or radiological-specific SF. Excess
31 lifetime cancer risks were estimated by multiplying the estimated contaminant intake or radiological dose
32 by the cancer SF, below:

$$33 \quad \text{Cancer risk (nonradionuclides)} = \text{contaminant intake (mg/kg-day)} \times \text{SF (mg/kg-day)}^{-1}$$

$$34 \quad \text{Cancer risk (radionuclides)} = \text{radiological dose (pCi)} \times \text{SF (risk/pCi)}$$

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

$$39 \quad \text{Cancer risk} = 1 - \{e^{-(\text{contaminant intake or radiological dose} \times \text{SF})}\}$$

1 The risk from exposure to multiple carcinogens is assumed to be additive but is bounded by 1,
2 corresponding to a 100 percent risk or certainty of developing cancer. Because risk is generally
3 understood as an estimate of cancer probability, and since probabilities are limited to the range between
4 0 and 1, another purpose of the non-linear calculation above is to avoid calculating risks that exceed 1
5 and, therefore, lose meaning (EPA 540/1-89/002). The total cancer risk is estimated by adding together
6 the estimated risk for each COPC and for each exposure pathway.

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

18 The EPA's target cancer risk range is 10^{-6} to 10^{-4} , and EPA considers risk levels as high as 4×10^{-4}
19 (the upper end of EPA's target risk range) to be acceptable under some circumstances (OSWER Directive
20 9355.0-30).

21 **A5.3 Summary of Risk Results**

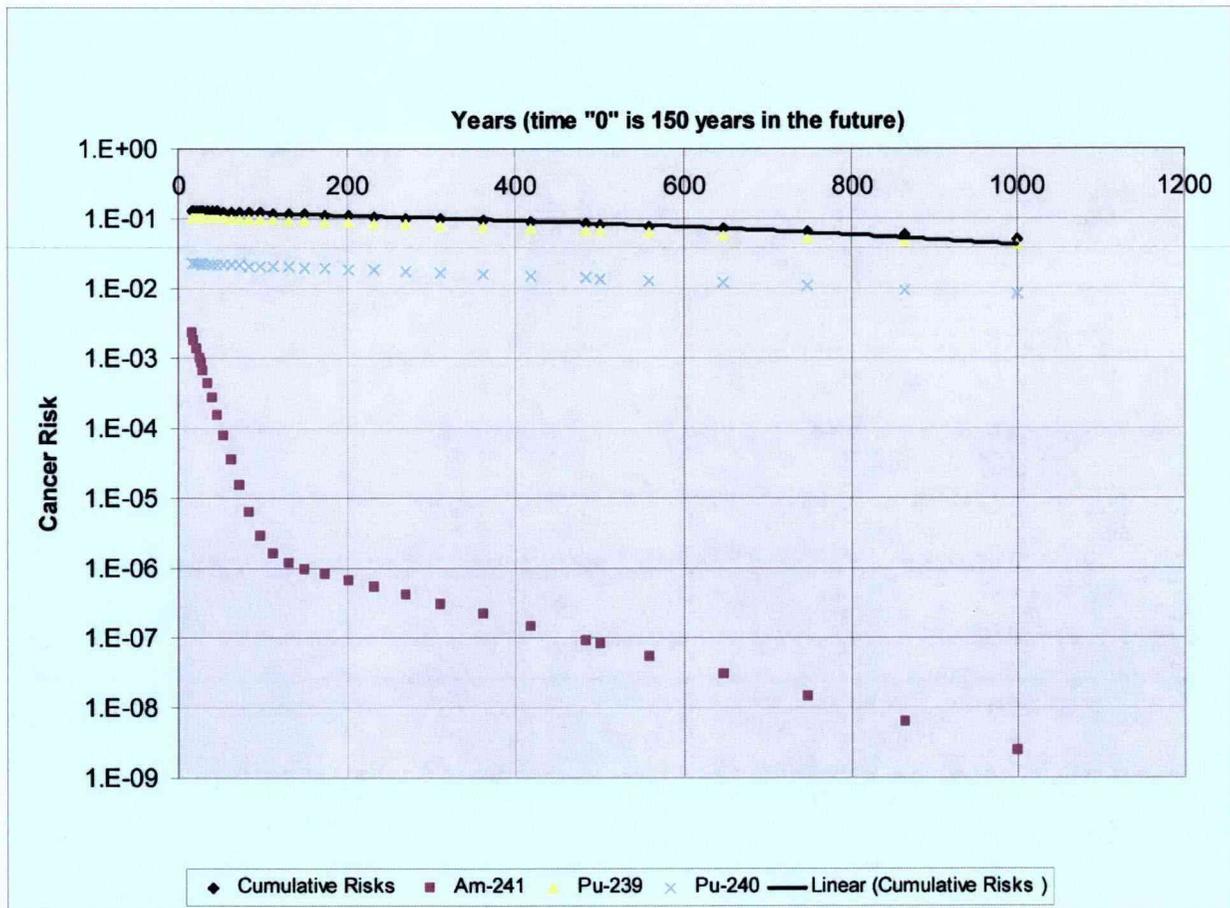
22 All final risk and hazard estimates up to 9 were presented to one significant figure only, as recommended
23 by EPA 540/1-89/002. Therefore, an HQ or HI of 1 could range between 0.95 and 1.4, and a risk of
24 2×10^{-5} could range between 1.5×10^{-5} and 2.4×10^{-5} . Hazards >9 were shown with all positive integers
25 (i.e., an HI of 312 was not rounded to 300). Tables A5-1 through A5-11 summarize the risk and hazard
26 results, presented to one significant figure. Details of the calculations, with risks and hazards presented to
27 at least two significant figures, are included in Attachment A-6 of this appendix for all nonradionuclides
28 in soil and the nonradionuclides and radionuclides in groundwater. For the radionuclide contaminants in
29 soil, summaries of the RESRAD computer model outputs are included in Attachment A-7.

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

- 35 • 17 years from now (2024)
- 36 • 28 years from now (2035)
- 37 • 150 years from now
- 38 • 500 years from now
- 39 • 1,000 years from now (maximum required time horizon in "Standards for Protection Against
40 Radiation," 10 CFR 20, Subpart E)

41 Because two of the three risk-driver radionuclides at the three Z Plant sites (216-Z-1A Tile Field, 216-Z-8
42 French Drain, and 216-Z-9 Trench) are plutonium isotopes with extremely long half-lives in soil
43 (24,000+ years for plutonium-239, and 6,500+ years for plutonium-240), the future risk calculations for

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

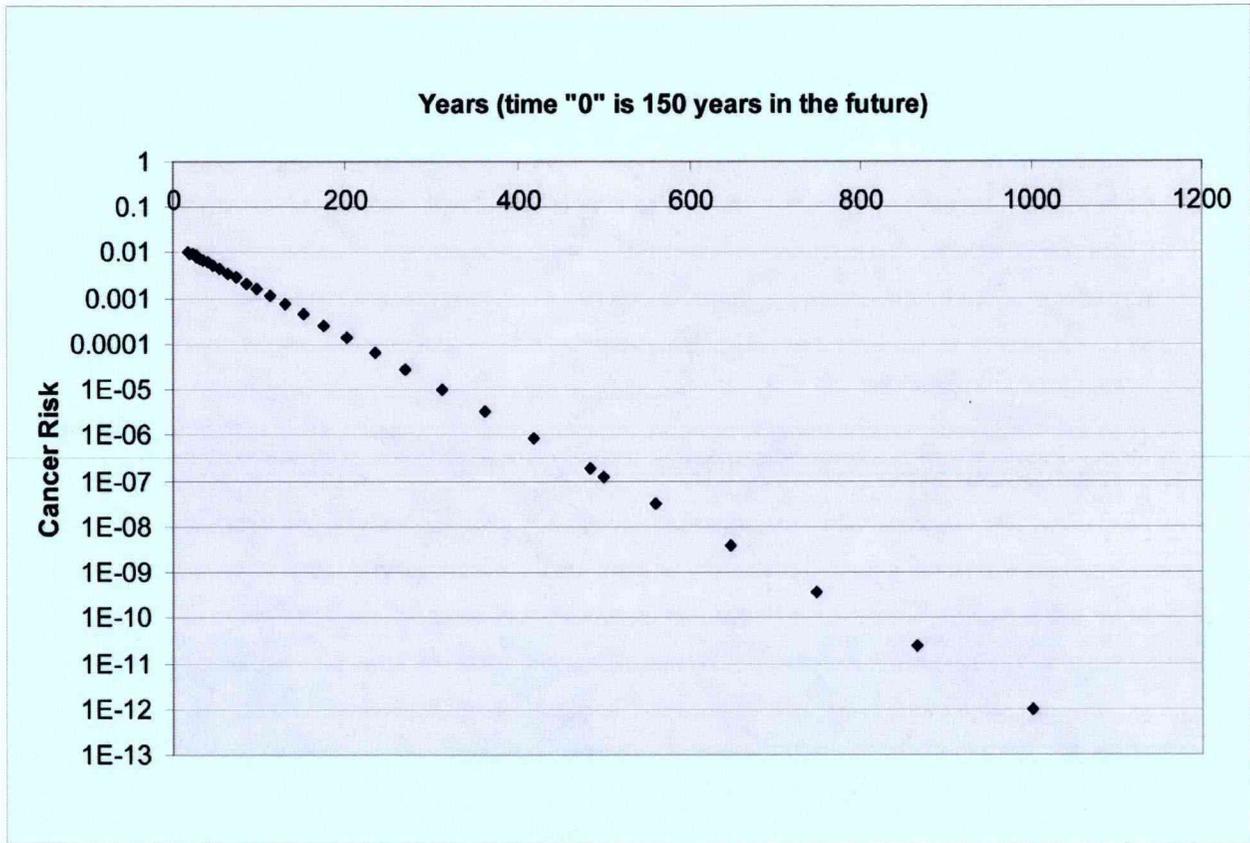


13
 14 **Figure A5-1. Decreases in Cancer Risks Over Time –**
 15 **Future Subsistence Farmer at the 216-Z-9 Trench**

16 For the 216-A-8 Crib, where cesium-137 is the risk-driving radionuclide, risks from future time horizons
 17 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.

1 and risks at 216-A-8 Crib decrease significantly within the 1,000 years evaluated in this assessment.
 2 Figure A5-2 shows the decrease in cancer risks for the future subsistence farmer for the 216-A-8 Crib.
 3 The decrease pattern is similar for the well driller and construction worker. Daughter products never
 4 contribute significantly to overall risks at any of the periods evaluated for 216-A-8 Crib, so daughter risks
 5 are included in Attachment A-7 of this appendix, but individual radionuclides for future time horizons are
 6 not presented in the risk summary tables in this section.



CHPUBS1003-01.19

7
8 **Figure A5-2. Decreases in Cancer Risks Over Time –**
9 **Future Subsistence Farmer at the 216-A-8 Crib**

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

11 Risks to construction workers were evaluated for all soil sites, except the 216-Z-9 Trench. At the 216-Z-9
 12 Trench, contamination does not begin until 6.4 m (21 ft) bgs, and the site is covered with a concrete cap.
 13 Risks were calculated for ingestion, inhalation, and external radiation exposure routes. In addition, risks
 14 from exposure to inhaled radon were also evaluated. Radon risks were extremely low at all three sites
 15 (orders of magnitude below the *de minimis* cancer risk level of 1×10^{-6}). Only radionuclides were selected
 16 as COPCs for construction workers at these sites. Cancer risks are presented for construction workers in
 17 Table A5-1, and the results are below:

- 18 • **216-Z-1A Tile Field:** Risks from exposure to all three COPCs exceed 10^{-4} (EPA's upper-bound risk
 19 range), with a total risk of 4×10^{-2} . Plutonium-239 has the highest risk (3×10^{-2} , 77 percent of the
 20 total risks), and the ingestion pathway is the pathway contributing the most to overall risk. External
 21 radiation risks from plutonium-239 and plutonium-240 were less than 10^{-4} , but the external radiation
 22 risk for americium-241 exceeded 10^{-4} .

- 1 • **216-Z-8 French Drain:** Risks were below 10^{-6} for all COPCs and exposure pathways evaluated.
- 2 • **216-A-8 Crib:** Only cesium-137 exceeded target health goals at this site, primarily due to external
3 radiation, with cumulative risks of 5×10^{-2} , and over 99 percent of the risks due to cesium-137. No
4 other contaminants exceeded 10^{-6} . Somewhere between 150 and 500 years in the future, cesium-137
5 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.

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

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

5 Under a future situation where all knowledge of the site is lost and there is a failure of institutional
6 controls, two worker populations were evaluated:

- 7 • A well driller exposed to contaminants in soil via drill cuttings while engaged in installing a water
8 supply well.
- 9 • A regular worker in the area who would drink groundwater from the well while at their place
10 of employment.

11 For the radionuclide COPCs, the risks presented on the summary tables are for 150 years in the future, as
12 it is anticipated that institutional controls would be unlikely to fail before that time. However, as noted
13 above for construction workers, on all sites but the 216-A-8, Crib, the long half-lives of the principal
14 radionuclides preclude risks changing significantly over 1,000 years.

15 **A5.3.2.1 Well Drillers**

16 A future water supply well could be constructed at any of the four waste sites; thus, potential risks to
17 drillers were evaluated at all four sites. The exposure routes evaluated are the same as those for the
18 construction worker (and for all the populations exposed to soil) and were inhalation (including radon),
19 ingestion, and external radiation. Two sites (216-Z-9 Trench and 216-A-8 Crib) have at least one
20 nonradionuclide COPC in addition to radionuclides. Table A5-2 presents risks for well drillers and
21 Table A5-3 presents non-cancer hazards for the 216-Z-9 Trench. Well driller risks were much less than
22 those for construction workers and did not exceed 10^{-4} at any site, but did exceed 10^{-6} at all sites except
23 216-Z-8 French Drain. The results are below:

- 24 • **216-Z-1A Tile Field:** Cumulative risks were 2×10^{-6} , due to americium-241 (80 percent of total
25 risks), followed by plutonium-239 (18 percent of total). Risks are driven by the external radiation
26 pathway for americium-241.
- 27 • **216-Z-8 French Drain:** Risks were below 10^{-6} for all COPCs and exposure pathways evaluated.
- 28 • **216-Z-9 Trench:** Cumulative risks were 2×10^{-5} for the radionuclides, with plutonium-239
29 (46 percent of total), americium-241 (43 percent of total risks), and plutonium-240 having risks in
30 excess of 10^{-6} . Carbon tetrachloride had the highest risks of the two nonradionuclide carcinogens,
31 with a risk of 2×10^{-6} . Ingestion of plutonium-239 and external radiation due to americium-241 are
32 the pathways contributing to overall risks. All non-cancer hazards (Table A5-3) were well below
33 a target HI of 1.
- 34 • **216-A-8 Crib:** Risks were 7×10^{-6} due almost entirely to cesium-137 via the external
35 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.

1

**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

2 A5.3.2.2 Regular Workers Drinking Groundwater Exposures

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

- 13 • **Cancer risks from radionuclides:** As shown in Table A5-4 under the high-exposure scenario
14 (i.e., using the 90th percentile groundwater concentration), cancer risks for the radionuclides are
15 4×10^{-5} , within EPA's acceptable risk range of 10^{-6} to 10^{-4} . Technetium-99 contributes the most to
16 the total cancer risk with a risk of 2×10^{-5} , followed by tritium and iodine-129 with cancer risks of
17 1×10^{-5} and 1×10^{-6} , respectively. Under the medium-exposure scenario (50th percentile), total
18 radionuclide cancer risks were approximately one order of magnitude lower, at 4×10^{-6} . Under the
19 low-exposure scenario (25th percentile), total cancer risks were even lower and were equal to the
20 *de minimis* cancer risk level of 10^{-6} .
- 21 • **Cancer risks from nonradionuclides:** As shown in Table A5-4, total nonradionuclide cancer risks
22 exceed 10^{-4} under both the high-exposure (90th percentile) and medium-exposure (50th percentile)
23 scenarios, at 3×10^{-3} and 4×10^{-4} , respectively. Total cancer risks under the low-exposure

1 (25th percentile) scenario are 7×10^{-6} . Carbon tetrachloride contributes the majority of the total cancer
 2 risk, followed by chloroform, with cancer risks nearly two orders of magnitude lower than that of
 3 carbon tetrachloride. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide
 4 cancer risks under both the high- and medium-exposure scenario but for only 88 percent of the total
 5 cancer risks under the low-exposure scenario. Approximately 50 percent of the cancer risks for
 6 carbon tetrachloride result from ingestion exposures, while the other 50 percent of the cancer risk for
 7 carbon tetrachloride results from inhalation exposures.

- 8 • **Non-cancer hazards:** As shown in Table A5-5, total non-cancer hazards exceeded 1 under both the
 9 high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios at 42 and 7,
 10 respectively. Total non-cancer hazard under the low-exposure (25th percentile) scenario is 0.2. Carbon
 11 tetrachloride contributes the majority of the non-cancer hazard and is the only single COPC with an
 12 HI >1. Carbon tetrachloride is responsible for over 95 percent of the total non-cancer hazard under
 13 both the high- and medium-exposure scenario but for only 44 percent of the total cancer risks under
 14 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

15

16

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.

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

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

7 A5.3.3.1 Soil Exposures

8 Subsistence farmer exposures to soil would occur via ingestion, inhalation, dermal absorption (only
9 cadmium at the 216-Z-9 Trench), and external radiation for the radionuclides. As with well drillers, under
10 the failure of institutional controls scenario, a future water supply well and residence could be constructed
11 at any of the four waste sites; thus, potential risks to subsistence farmers exposed to drill cuttings were
12 evaluated at all four waste sites. Table A5-6 presents risks for subsistence farmer soil exposures and
13 Table A5-7 presents non-cancer hazards for the 216-Z-9 Trench. Subsistence farmers' risks from direct
14 soil exposures were higher than for well drillers and were comparable to that of construction workers.
15 Although the concentrations to which residents would be exposed were lower than the concentrations for
16 construction workers and drillers due to the dilution that would occur by spreading and tilling the drill
17 cuttings, the resident's exposures occur over a longer period and include children's exposures. The results
18 are below:

- 19 • **216-Z-1A Tile Field:** Risks from exposure to all COPCs are above 10^{-4} , with a total risk of 2×10^{-3} .
20 As with all the Z Plant sites, risks are driven by americium-241 and plutonium-239. For this site, risks

- 1 are driven by the ingestion pathway for plutonium-239 and external radiation pathway for
2 americium-241.
- 3 • **216-Z-8 French Drain:** Cumulative risks are 3×10^{-6} ; only plutonium-239 has risks greater than 10^{-6} .
- 4 • **216-Z-9 Trench:** Cumulative risks are 2×10^{-2} for the radionuclides, with plutonium-239 (63 percent
5 of total risks), americium-241 (20 percent of total), plutonium-240 (16 percent of total),
6 neptunium-237, radium-226, and radon (including entire radon decay chain) all having risks in excess
7 of 10^{-4} . Carbon tetrachloride had the highest risks of the three nonradionuclide carcinogens, with
8 a risk of 5×10^{-5} . The ingestion and external radiation pathways are contributing the most to overall
9 risks; however, inhalation risks were also greater than 10^{-4} . All non-cancer hazards from direct
10 contact (i.e., not food chain) were well below a target HI of 1 (Table A5-7).
- 11 • **216-A-8 Crib:** Only cesium-137 exposures exceeded 10^{-4} , with risks of 2×10^{-2} due to external
12 radiation. No other radionuclides exceed 10^{-6} , with the exception of neptunium-237 with a risk of $3 \times$
13 10^{-6} . Somewhere between 150 and 500 years in the future, cesium-137 decays to the point where risks
14 fall below 10^{-4} (cumulative risks at 500 years are 2×10^{-6}). Health hazards due to thallium were well
15 below target health goals with an HI of 0.2 for child exposures and an HI of 0.02 for subsistence
16 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 HI	Child/Adult HI	Child HI	Child HI	Child/Adult HI	Child HI	Child/Adult HI	Child HI	Child/Adult HI	Child/Adult HI
216-Z-9 Trench										
Cadmium	0.04	0.005	0.04	0.004	0.004	0.004	0.0006	--	--	4
Carbon tetrachloride	0.2	0.02	0.2	0.02	--	--	--	--	--	35
Manganese	--	0.003	0.02	0.002	--	0.002	--	0.002	0.0009	2
Total	0.3	0.03	0.3	0.03	0.004	0.004	0.0006	0.002	0.0009	41
216-A-8 Crib										
Thallium	0.04	0.004	0.04	0.004	--	--	--	--	--	3
Total	0.04	0.004	0.04	0.004	--	--	--	--	--	3

Notes:

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

*Totals are calculated using unrounded values.

HI = hazard index

1 **A5.3.3.2 Groundwater Exposures**

2 Future child and adult subsistence farmers were evaluated for future exposures to groundwater used as tap
3 water (i.e., domestic supply) and groundwater used as an irrigation source. Child and adult residents were
4 evaluated for exposures to groundwater through the ingestion, dermal, and inhalation of vapors pathways.
5 In addition to exposures to groundwater from drinking and other domestic uses, future subsistence
6 farmers are assumed to use the groundwater as an irrigation source for their crops and livestock.
7 Therefore, adult subsistence farmers were evaluated for dermal (nonradionuclides) and inhalation
8 exposures to COPCs in groundwater during irrigation activities.

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

14 **Exposures to Groundwater as Tap Water**

15 The following summarizes the results for the tap water exposure scenario evaluated for the
16 subsistence farmer.

- 17 • **Cancer risks from radionuclides:** As shown in Table A5-8, under the high-exposure scenario,
18 cancer risks from tap water for the radionuclides are 10^{-4} , equal to the target risk goal. Technetium-99
19 contributes the most to the total cancer risk with a risk of 8×10^{-5} , followed by tritium and iodine-129
20 with cancer risks of 4×10^{-5} and 4×10^{-6} , respectively. Under the medium-exposure scenario
21 (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower, at
22 1×10^{-5} . Under the low-exposure scenario (25th percentile), total cancer risks were even lower
23 (4×10^{-6}).
- 24 • **Cancer risks from nonradionuclides:** As shown in Table A5-8, total nonradionuclide cancer risks
25 from tap water exposures exceed 10^{-4} under both the high-exposure (90th percentile) and
26 medium-exposure (50th percentile) scenarios, at 2×10^{-2} and 3×10^{-3} , respectively. Total cancer risks
27 under the low (25th percentile) exposure scenario is 5×10^{-5} . Carbon tetrachloride contributes the
28 majority of the total cancer risk, followed by chloroform, with cancer risks nearly two orders of
29 magnitude lower than for carbon tetrachloride. Carbon tetrachloride is responsible for 99 percent of
30 the total nonradionuclide cancer risks under both the high- and medium-exposure scenario but only
31 for 87 percent of the total cancer risks under the low-exposure scenario. As detailed in
32 Attachment A-6 of this appendix, total cancer risks from the nonradionuclides in tap water are
33 primarily driven by the inhalation pathway, which contributes 64 percent to the total cancer risk,
34 followed by the ingestion pathway (32 percent), and the dermal pathway (4 percent).
- 35 • **Non-cancer hazards:** As shown in Table A5-9, total child and adult non-cancer hazards exceed
36 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios.
37 Child and adult hazards under the high-exposure scenario are 316 and 135, respectively; child and
38 adult hazards under the medium-exposure scenario are 55 and 23, respectively; and child and adult
39 hazards under the low-exposure scenario are 1 (equal to the target health goal) and 0.6 (below the
40 target health goal), respectively. Carbon tetrachloride is by far the greatest contributor to total
41 non-cancer hazard in tap water exposures and contributes over 96 percent to the total hazard in the
42 high- and medium-exposure scenarios. Carbon tetrachloride is the only COPC that results in an HI >1
43 in both the high- and medium-exposure scenarios. In the high-exposure scenario, hexavalent
44 chromium (5 and 2, for child and adult), nitrate (3 and 1, for child and adult), and TCE (3 and 1, for

1 child and adult) also result in HIs >1. No individual contaminants have HIs >1 in the
2 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

3

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

1 Exposures during Irrigation Using Groundwater

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

1 **A5.3.3.3 Food Chain Exposures**

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

11 **Homegrown Produce**

- 12 • **Cancer risk from radionuclides:** The total radionuclide cancer risk from ingestion of homegrown
13 produce irrigated with groundwater exceeds 10^{-4} under both the high and medium groundwater
14 concentrations (Table A5-10) and for produce grown in soil for all soil sites except for the 216-Z-8
15 French Drain (Table A5-6). The highest produce consumption risks are from produce grown in the
16 216-Z-9 Trench soil where risks are 1×10^{-1} ; however, risks due to ingestion of produce grown in
17 impacted soil also exceeded 10^{-4} at 216-Z-1A and 216-A-8. For produce irrigated with impacted
18 groundwater, technetium-99 is the greatest contributor to total radionuclide cancer risk in the plant
19 ingestion pathway and is the only radionuclide that had an individual cancer risk greater than or equal
20 to 10^{-4} under each of the high-, medium-, and low-exposure scenarios. Note that current tritium
21 concentrations would result in produce ingestion risks greater than 10^{-4} under the high-exposure
22 scenario, as shown in Table 5A-10. However, as shown in Section 5.3.2.5, tritium concentrations
23 would be below levels of health concern in 150 years because tritium's half-life is only 12 years and
24 existing institutional controls are assumed to prevent use of groundwater until at least that time. Risks
25 from produce ingestion due to the contribution from soil at the 216-Z-1A Tile Field and the 216-Z-9
26 Trench are due primarily to americium-241, plutonium-239, and plutonium-240. Risks are highest for
27 plutonium-239, followed by plutonium-240, and then americium-241 at the Z Plant sites, and target
28 risks are exceeded at the 216-A-8 Crib primarily due to cesium-137 at the 216-A-8 Crib.
- 29 • **Cancer risk from nonradionuclides:** As shown in Table A5-10 for groundwater, the total
30 nonradionuclide cancer risk from ingestion of homegrown produce also exceeds 10^{-4} under both the
31 high- and medium-exposure scenarios. Total cancer risks under the high-exposure scenario are $1 \times$
32 10^{-2} , and total cancer risks under the medium-exposure scenario are 2×10^{-3} . Total cancer risks under
33 the low-exposure scenario are 3×10^{-5} . Carbon tetrachloride contributes the majority of the total
34 cancer risk, followed by PCE and TCE, with cancer risks nearly three orders of magnitude lower than
35 risks from carbon tetrachloride. As shown in Table A5-6, the only soil site with nonradionuclide
36 carcinogens is the 216-Z-9 Trench, where cancer risks due to ingestion of produce containing carbon
37 tetrachloride were 1×10^{-3} . However, this contaminant is unlikely to be a risk in soil 150 years from
38 now because its concentration would be considerably lower in the future and even if present, its
39 half-life in surface soil is relatively short (unlike irrigating the plants with groundwater, which would
40 provide a continuous source of COPCs, again depending on the type of irrigation system used).
- 41 • **Non-cancer hazards:** As shown in Table A5-11, total combined child and adult non-cancer hazards
42 exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile)
43 scenarios. Total non-cancer hazards under the high-exposure scenario are 362, total hazards under the
44 medium-exposure scenario are 63, and total hazards under the low-exposure scenario are 1 (equal to
45 the target health goal). Carbon tetrachloride is overwhelmingly the greatest contributor to total
46 non-cancer hazard in the ingestion of homegrown produce exposure scenario and contributes over

1 95 percent to the total hazard in the high- and medium-exposure scenarios. Carbon tetrachloride is the
2 only COPC that results in a hazard >1 in both the high- and medium-exposure scenarios. Non-cancer
3 hazards for carbon tetrachloride are 354 and 62 under the high- and medium-exposure scenarios,
4 respectively. In the high-exposure scenario, hexavalent chromium and TCE also have non-cancer
5 hazards that exceed 1 (each has a hazard of 4). No other contaminants have individual hazards >1
6 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

7 As shown in Table A5-7 for the two sites with non-cancer contaminants selected as COPCs in soil
8 (216-Z-9 Trench and 216-A-8 Crib), hazards exceeded 1 for all three of the COPCs at the 216-Z-9
9 Trench but were primarily due to carbon tetrachloride. However, carbon tetrachloride at the 216-Z-9
10 Trench is unlikely to be a hazard if impacted soil is brought to the surface in 150 years because once
11 exposed to the air, the half-life of carbon tetrachloride in soil is relatively short (i.e., 6 to 12 months)
12 (*Toxicological Profile for Carbon Tetrachloride* [ATSDR, 2005]). Therefore, carbon tetrachloride
13 concentrations in soil, and consequently plants, will not remain at the levels currently seen in
14 subsurface soil if they are at the surface for 30 years (the exposure duration for the subsistence
15 farmer). Hazards due to ingesting thallium at the 216-A-8 Crib (the only nonradionuclide COPC at
16 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	0.000001	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	0.000000007	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

1 **Ingestion of Beef**

- 2 • **Cancer risk from radionuclides:** As shown in Table A5-10, the total radionuclide cancer risk from
3 ingestion of beef is below 10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total
4 cancer risks under the high-exposure scenario are 3×10^{-5} , under the medium-exposure scenario are
5 3×10^{-6} , and under the low-exposure scenario are 8×10^{-7} . Technetium-99 is the greatest contributor
6 to total radionuclide cancer risk in the beef ingestion pathway. Technetium-99 is responsible for
7 approximately 60 percent, 68 percent, and 83 percent of the total radionuclide cancer risk under the
8 high-, medium-, and low-exposure scenarios, respectively. Tritium is the next greatest contributor to
9 total cancer risks, contributing approximately 32 percent, 30 percent, and 17 percent of the total
10 radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. The
11 contribution from iodine-129 is insignificant relative to the cancer risks from technetium-99
12 and tritium.
- 13 • **Cancer risk from nonradionuclides:** As shown in Table A5-10, the total nonradionuclide cancer
14 risk from ingestion of beef is also below 10^{-4} under each of the high-, medium-, and low-exposure
15 scenarios. Total cancer risks under the high-exposure scenario are 2×10^{-6} , under the
16 medium-exposure scenario are 3×10^{-7} , and under the low-exposure scenario are 5×10^{-9} . Carbon
17 tetrachloride contributes the majority of the total cancer risk and is the only single nonradionuclide
18 COPC with a cancer risk greater than the *de minimis* cancer risk level of 10^{-6} , with a cancer risk of
19 2×10^{-6} in the high-exposure scenario. Carbon tetrachloride is responsible for 99 percent of the total
20 nonradionuclide cancer risks under the high- and medium- exposure scenarios and for 73 percent of
21 the total nonradionuclide cancer risks under the low-exposure scenario.
- 22 • **Non-cancer hazards from nonradionuclides:** As shown in Table A5-11, total combined child and
23 adult non-cancer hazards for the beef ingestion pathway are below the target health goal of 1 under
24 each of the high-, medium-, and low-exposure scenarios. Total non-cancer hazards under the
25 high-exposure scenario are 0.3, under the medium-exposure scenario are 0.02, and under the
26 low-exposure scenario are 0.01. Hexavalent chromium is the greatest contributor to total non-cancer
27 hazard in the ingestion of beef pathway and contributes 86 percent, 66 percent, and 99 percent to the
28 total hazard in the high-, medium-, and low-exposure scenarios, respectively.

29 **Ingestion of Dairy Products from Dairy Cattle**

- 30 • **Cancer risk from radionuclides:** As shown in Table A5-10, the total radionuclide cancer risk from
31 ingestion of dairy products exceeds 10^{-4} under the high-exposure scenario, with total cancer risks of
32 2×10^{-4} . Total cancer risks under the medium-exposure scenario are approximately one order of
33 magnitude lower at 2×10^{-5} , and total cancer risks under the low-exposure scenario are 6×10^{-6} .
34 Technetium-99 is the greatest contributor to total radionuclide cancer risk in the dairy product
35 ingestion pathway, with cancer risks under the high-, medium-, and low-exposure scenarios of
36 1×10^{-4} , 2×10^{-5} , and 6×10^{-6} , respectively. Technetium-99 is responsible for approximately
37 75 percent, 80 percent, and 90 percent of the total radionuclide cancer risk under the high-, medium-,
38 and low-exposure scenarios, respectively. Tritium is the next greatest contributor to total cancer risks
39 using current concentrations, although as noted for plants, tritium concentrations are unlikely to be
40 a risk in 150 years. The contribution from iodine-129 is insignificant relative to the cancer risks from
41 technetium-99 and tritium.
- 42 • **Cancer risk from nonradionuclides:** The total nonradionuclide cancer risk from ingestion of dairy
43 products is below 10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total cancer
44 risks under the high-exposure scenario are 4×10^{-6} , under the medium-exposure scenario are 6×10^{-7} ,
45 and under the low-exposure scenario are 1×10^{-8} . Carbon tetrachloride contributes the majority of the
46 total cancer risk and is the only single nonradionuclide COPC with a cancer risk greater than the

1 *de minimis* cancer risk level of 10^{-6} , with a cancer risk of 3×10^{-6} under the high-exposure scenario.
2 Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under the
3 high- and medium-exposure scenarios and for 73 percent of the total nonradionuclide cancer risks
4 under the low-exposure scenario.

- 5 • **Non-cancer hazards from nonradionuclides:** As shown in Table A5-11, total combined child and
6 adult non-cancer hazards for the dairy ingestion pathway are well below the target health goal of 1
7 under each of the high-, medium-, and low-exposure scenarios. Total non-cancer hazards under the
8 high-exposure scenario are 0.09, under the medium-exposure scenario are 0.02, and under the
9 low-exposure scenario are 0.0006. Carbon tetrachloride is the greatest contributor to total non-cancer
10 hazard in the ingestion of dairy products pathway under the high- and medium-exposure scenarios,
11 contributing 95 percent and 96 percent of the total hazards of each scenario, respectively.

12 **Total Subsistence Farmer Exposures through the Food Chain Pathways**

13 It is possible for subsistence farmers to have combined exposures to groundwater through ingestion of all
14 three food chain pathways: homegrown produce, beef, and dairy products. Risks and hazards from
15 ingestion of beef and dairy products are much lower (by at least three orders of magnitude) than the risks
16 and hazards calculated from ingestion of homegrown produce. Therefore, the contributions from the
17 ingestion of beef and dairy products pathways to cumulative food chain exposures for the subsistence
18 farmer are insignificant relative to the ingestion through the homegrown produce exposure pathway.
19 Consequently, the cumulative cancer risks and hazards from the combined exposures are unchanged from
20 the homegrown produce cancer risks to one significant figure.

21 **A5.3.3.4 Vapor Intrusion Exposures**

22 Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater
23 beneath the 200-PW-1 OU (particularly near the 216-Z-9 Trench and 216-Z-1A Tile Field), soil gas
24 sampling has occurred over a number of years. Generally, low concentrations of soil gas are seen at most
25 of the 200-PW waste sites, with the exception of the 216-Z-9 Trench and 216-Z-1A Tile Field
26 (DOE/RL-2006-51). The greatest human health concern with respect to soil gas is the possibility for
27 subsurface vapors to move into basements of buildings and adversely impact indoor air. The EPA's vapor
28 intrusion guidance document (EPA 530-F-02-052) preferentially recommends collection of indoor air
29 samples, where possible, rather than modeling from soil gas or groundwater concentrations, due to the
30 uncertainties and limitations of modeling. Therefore, the three air samples collected from within the
31 216-Z-9 Trench area were selected for inclusion in the risk assessment as the most representative data of
32 what concentrations could be inside a basement. Section A2.4 identified carbon tetrachloride and
33 chloroform vapor concentrations in the 216-Z-9 Trench as a possible health concern for a subsistence
34 farming population if a home were ever built above the impacted soil at this site or possibly near the
35 216-Z-1A Tile Field (the waste areas with chlorinated solvents). This section presents a semi-quantitative
36 evaluation of the potential subsistence farming risks from vapor intrusion exposures.

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

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

12 **A5.3.4 Future Groundwater Risks for Subsistence Farmer**

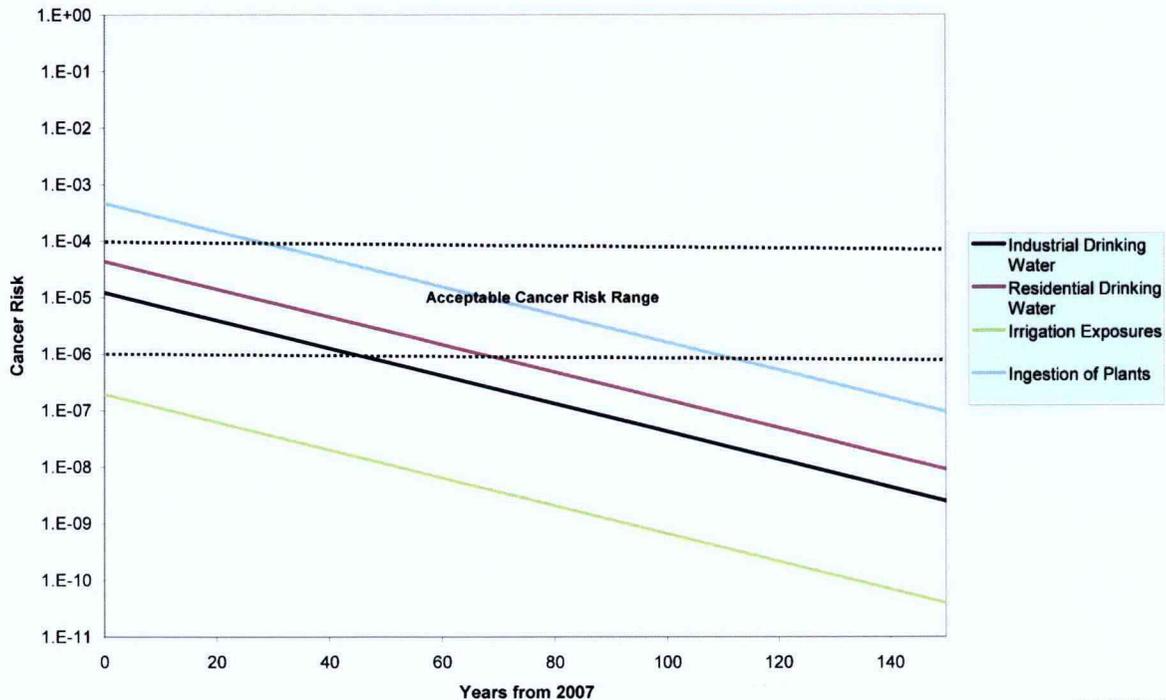
13 Risks for radionuclides were not calculated for future groundwater based on future concentrations
14 (150 years from now), as was done for soil. For the VOCs in groundwater, particularly for risk-driving
15 carbon tetrachloride, concentrations would be lower, but the methods required to model degradation are
16 complex and require many assumptions. Therefore, it can be concluded that carbon tetrachloride risks are
17 overestimated for the subsistence farmer, and it may be that the 25th percentile concentration risks are
18 more indicative of future groundwater risks under an institutional controls failure scenario.

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

26 Tritium has a half-life of only 12.26 years; therefore, the concentration of tritium in the environment
27 decreases rapidly relative to the other radionuclide COPCs. Thus, the cancer risks described in the
28 previous sections for tritium, based on current groundwater concentrations, significantly overestimate the
29 cancer risks from tritium 150 years into the future. Because the risk calculation equations are linear,
30 cancer risks from tritium decrease proportionally with decreasing groundwater concentrations.
31 Figure A5-3 depicts the decrease in cancer risk based on the 90th percentile groundwater concentrations of
32 tritium expected over the next 150 years. As shown in Figure A5-3, tritium cancer risks from each
33 exposure scenario decrease below the *de minimis* cancer risk level of 1×10^{-6} before 150 years is reached.
34 Therefore, tritium exposures in groundwater are not expected to result in unacceptable cancer risks after
35 150 years of decay. Based on the slope of the decay curve, cancer risks at 150 years can be predicted.

36 The following summarizes what cancer risks would be in 150 years for each groundwater pathway based
37 on the 90th percentile groundwater concentration of tritium:

- 38 • Regular worker drinking water: 3×10^{-9}
- 39 • Subsistence farmer drinking water: 1×10^{-8}
- 40 • Subsistence farmer irrigation exposures: 5×10^{-11}
- 41 • Subsistence farmer plant ingestion: 1×10^{-7}



CHPUBS1003-01.20

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

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

1 A5.5 Risk Characterization Summary and Conclusions

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

13 Under current industrial land use and institutional controls, exposures to contaminants and radionuclides
 14 in groundwater and soil are less likely, but still possible. Volatile or radiological emissions from the
 15 subsurface are insignificant. Institutional controls prevent the use of impacted groundwater, and impacted
 16 soil is covered by at least 1.8 m (6 ft) of unimpacted soil. However, if construction workers disturbed soil
 17 at depths at the 216-Z-1A Tile Field, 216-Z-8 French Drain, or 216-A-8 Crib, they could encounter
 18 COPCs. Under that unlikely scenario (i.e., existing institutional control programs at Hanford are designed
 19 to prevent unprotected digging in impacted soil), health risks would exceed 1×10^{-4} at the 216-Z-1A Tile
 20 Field and 216-A-8 Crib, indicating that remedial action would be necessary. Risks from digging in soil at
 21 the 216-Z-8 French Drain were less than 1×10^{-6} . Risks from subsurface soil exposures at the 216-Z-1A
 22 Tile Field were driven by plutonium-239, followed by plutonium-240, and then americium-241. Risks
 23 from subsurface soil at the 216-A-8 Crib are driven by cesium-137. None of the nonradionuclides in soil

1 are a health concern for construction workers. Construction workers were not evaluated for exposure to
2 subsurface soil at the 216-Z-9 Trench, due to the depth to impacted soil and because the area is covered
3 with a concrete cap.

4 Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate
5 radioactive decay and ingrowth of daughter products. For the three Z Plant sites (216-Z-1A Tile Field,
6 216-Z-8 French Drain, and 216-Z-9 Trench), where risks are driven by plutonium-239, plutonium-240,
7 and americium-241 (true for all soil scenarios), risks at future time horizons are not significantly different
8 than current risks because the half-lives of these contaminants are long (or, in the case of the well driller
9 and subsistence farmer, risks at 150 years are not very different than risks at 500 and 1,000 years). At the
10 216-A-8 Crib where cesium-137 is the risk driver for all soil scenarios, risks are significantly lower at
11 future time horizons due to the relatively short half-life of cesium-137 (approximately 30 years).

12 In the event that knowledge of the site is lost and institutional controls fail, a future unrestricted land use
13 scenario was evaluated where humans could encounter groundwater and subsurface soil brought to the
14 surface as drill cuttings from drilling a groundwater well. This scenario is assumed to occur 150 years in
15 the future. Therefore, radiological concentrations in soil were modeled assuming 150 years of decay
16 (although, as noted above, this assumption does not make a difference for the Z Plant sites). Two of the
17 three radionuclides selected as COPCs in groundwater, technetium-99 and iodine-129, have very long
18 half-lives and future concentrations would not be different from current concentrations. However, the
19 third radionuclide COPC, tritium, will be at concentrations that are below a health concern within
20 150 years. Specifics of the post-2150 unrestricted land use scenario are listed below:

- 21 • Risks to future well driller were much less than those for construction workers and did not exceed
22 10^{-4} at any site. Well driller risks were the highest at the 216-Z-9 Trench (risk = 2×10^{-5}).
- 23 • Future workers drinking groundwater at their place of employment exceeded a risk level of 10^{-4} only
24 for carbon tetrachloride at the 90th and 50th percentile concentrations. Carbon tetrachloride was also
25 the only contaminant with a non-cancer hazard above the target goal of 1.
- 26 • Future residents exposed to drill cuttings in their home yard had risks similar to those for construction
27 workers; risks were greater than 1×10^{-3} for all soil sites, except the 216-Z-8 French Drain, where
28 risks were 3×10^{-6} .
- 29 • Future residents drinking groundwater exceeded a risk level of 10^{-4} only for carbon tetrachloride at
30 the 90th and 50th percentile concentrations. Radionuclide risks were the highest for technetium-99
31 (8×10^{-5}), assuming that tritium concentrations decay to low levels in 150 years. Non-cancer hazards
32 are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In addition,
33 hexavalent chromium, nitrate, and TCE all have non-cancer hazards above the target goal of 1 at the
34 90th percentile groundwater concentration. However, carbon tetrachloride's HI is two orders of
35 magnitude higher than any other contaminant's HI.
- 36 • Future residents exposed to contaminants through their food chain would have risks greater than $1 \times$
37 10^{-1} , primarily due to growing produce in contaminated soils, although eating produce irrigated with
38 impacted groundwater resulted in risks in the 1×10^{-2} range. Of contaminants and radionuclides in
39 groundwater, carbon tetrachloride had the highest produce ingestion risks (1×10^{-2}), followed by
40 technetium-99 (3×10^{-3}). Risks from the dairy products pathway exceed 10^{-4} , whereas risks from
41 eating beef was below 10^{-4} .
- 42 • Carbon tetrachloride is the risk driver currently for all groundwater pathways (two orders of
43 magnitude higher than most other things), with the exception of the dairy products and meat

1 pathways, where risks from technetium-99 are the highest. In the future (post-150 years),
2 technetium-99 is likely to be the risk-driving contaminant in groundwater.

3 In summary, risks from exposure to soils at the 216-Z-8 French Drain are below levels that are a health
4 concern. Risks from soil exposures at the 216-Z-1A Tile Field and 216-A-8 Crib are similar and exceed
5 10^{-4} for construction workers and subsistence farmers. Risks from soil exposures at the 216-Z-9 Trench
6 were the highest for the four waste sites evaluated, with risks exceeding 1×10^{-2} for subsistence farmers.
7 Risks for future well drillers at all four soil sites were below 10^{-4} . Plutonium-239 and americium-241,
8 followed by plutonium-240, were the risk drivers in soil for the Z Plant sites, and; cesium-137 was the
9 risk driver in soil at the 216-A-8 Crib.

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

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

20
21

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.

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

9 For the second site with a limited data set, the 216-A-8 Crib, the area of contamination is potentially
10 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
11 single boring provides less certainty on what actual exposure concentrations for this location might be.
12 While the boring location was selected because that area had historically contained the highest
13 concentrations, the range of concentrations beneath this area has likely not been identified. Therefore, use
14 of the shallowest maximum concentration in the construction worker calculations has potentially
15 overestimated risk unless the concentrations at the single sample location (C4545) are similar throughout
16 the area. Risk estimates for the well driller and the subsistence farmer at this location used data from the
17 multiple depth samples, three to 18 samples depending on the compound. The data are valid if a well is
18 drilled at the location of the C4545 boring, but it is not known whether the remainder of the soil beneath
19 this site is as impacted.

20 At two sites, the 216-Z-9 Trench and 216-A-8 Crib, some compounds had maximum concentrations in
21 excess of screening values but were not selected as COPCs because <5 percent of the data exceeding
22 screening levels and/or the magnitude of exceedance over a screening level did not exceed a factor of 2
23 (see Tables A2-10 and A2-12). The two primary technical issues regarding screening are whether the
24 toxic additivity of contaminants is adequately addressed and whether the screening level is sufficiently
25 protective. Additivity is addressed through use of the maximum concentration for screening and by using
26 a screening level below the target health goal (i.e., dividing non-cancer screening levels by 10 and using
27 cancer screening levels based on a cancer risk of 1×10^{-6} when the target risk goal is 1×10^{-4}). Because
28 risks and hazards for soil were calculated using the 95 percent UCL (and not the maximum concentration)
29 for the evaluated populations at these sites (except construction workers at the 216-A-8 Crib) and
30 concentrations equal to the screening level represent an acceptable risk, it is highly unlikely that
31 contaminants not selected as COPCs represent an additive risk. In addition, for soil exposures at the
32 216-Z-9 Trench and 216-A-8 Crib, cancer risks are already extremely large for subsistence farmers, above
33 1×10^{-2} ; therefore, adding incremental additional contaminants (i.e., chloroform or europium-155) would
34 not make a significant difference in the conclusions or identification of risk drivers at the site. These
35 results indicate that contaminants that were screened out would not have added significantly to
36 risk/hazard totals, and health risks have not been underestimated by screening procedures.

37 **A6.1.1.1 Plutonium-241 Decay to Americium-241**

38 Americium-241 is a risk driver at both the 216-Z-1A Tile Field and 216-Z-9 Trench. At the 216-Z-8
39 French Drain, the maximum risks for a subsistence farmer were 2×10^{-8} , several orders of magnitude
40 below a level that is a health concern. The measured concentrations of americium-241 are the result of
41 ingrowth from decay of plutonium-241 released from the plutonium-production process at the Z Plant
42 sites. Because laboratory analysis for plutonium-241 is difficult, plutonium-241 has not been analyzed at
43 any of the Z Plant sites; therefore, the americium-241 concentrations measured at the sites may not be at
44 their maximum concentration, depending on how much plutonium-241 is present and how much has
45 decayed. In Section A.3.2.1.1, maximum americium-241 concentrations were estimated using RESRAD.
46 The resulting plutonium-241 decrease and americium-241 increase were graphed, and estimated

1 maximum americium-241 concentrations from the graphs were used in the risk equations for the
2 216-Z-1A Tile Field and 216-Z-9 Trench. Different concentration estimates are possible if a different year
3 "0" were to be selected, either closer to or further away from the date of the known concentrations. If
4 there is a larger length of time between time 0 and the known concentration, then the known
5 concentration is closer to maximum and vice versa. For example, if there were 20 years between time 0
6 and the known concentration of americium-241 at the 216-Z-1A Tile Field instead of the 12 years
7 assumed in Section A3.2.1.1, then the maximum concentration is only around 40 percent of the known
8 concentration instead of double the known concentration. Therefore, maximum americium-241
9 concentrations would only be underestimated if there was actually less time between time 0 and the
10 known concentration. Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969 and
11 at the 216-Z-9 Trench from 1955 to 1962. The year 0 in RESRAD was estimated to be 1967 for the
12 216-Z-1A Tile Field and 1960 for the 216-Z-9 Trench. The 0 years for both sites were, thus, close to the
13 end of the disposal period and, thus, changing year 0 to the end of the disposal period (i.e., shortening the
14 time between year 0 and the known concentration date) would not result in a significant increase in
15 americium-241 concentrations. The known americium-241 concentration was 1979 for the 216-Z-1A Tile
16 Field (year 12 in RESRAD) and 1973 for the 216-Z-9 Trench (year 13 in RESRAD).

17 Americium-241 concentration estimates were not performed for the 216-Z-8 French Drain. Even
18 substantial increases in americium-241 would not affect the risk assessment conclusions for the 216-Z-8
19 French Drain because risks are so far below target health goals. At the 216-Z-1A Tile Field and 216-Z-9
20 Trench, americium-241 risks already exceed the target cancer risk goal of 1×10^{-4} ; therefore, an increase
21 in americium-241 risks would not affect the conclusions of the risk assessment.

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

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

- 32 • 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,
33 14.3, 24.4, and 50.9 m (33, 47, 80, and 167 ft) bgs (shallow values may be from leaks around the
34 casing or from other nearby waste sites).
- 35 • 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.
- 36 • 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)
37 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
38 second well.

39 These three radionuclides are unlikely to represent a health risk at the 216-Z-10 Injection/Reverse Well,
40 even if analysis confirmed the above concentrations. This is due to the fact that these concentrations are
41 all relatively low and would be lower today because of the short half-lives of these radionuclides
42 (30.17 years for cesium-137, 5.27 years for cobalt-60, and 8.8 years for europium-154) and because there
43 are no more toxic constituents in their decay chains. Because plutonium was not detected within 4.6 m
44 (15 ft) of the well and the above radionuclides do not appear to be recent at levels that are a health

1 concern (although the data are only screening level), there are unlikely to be significant radionuclide
2 hazards present at the 216-Z-10 Injection/Reverse Well, even though there may be a limited area of
3 contamination above screening levels in the immediate vicinity of the well (i.e., <4.6 m [<15 ft]). It was
4 also noted that any lateral spreading of plutonium at the 216-Z-10 Injection/Reverse Well would likely be
5 less than the lateral spreading seen at 216-Z-8 French Drain, where contaminants are limited to a small
6 area and concentrations did not result in significant health risks. Therefore, while there is uncertainty
7 regarding the maximum plutonium concentrations at the 216-Z-10 Injection/Reverse Well, the site was
8 appropriately screened out of the risk assessment.

9 **A6.1.1.3 Method Reporting Limits**

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

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

28 **A6.1.2 Groundwater Data and Contaminant of Potential Concern Selection**

29 With the exception of hexavalent chromium, the groundwater data set for the COPCs is very robust, with
30 over 1,000 samples available from more than 107 wells that have been routinely sampled over many
31 years. Therefore, the groundwater data set is adequate for risk assessment. For hexavalent chromium,
32 there were analytical issues (which are discussed in the 200-ZP-1 RI report [DOE/RL-2006-24]) that
33 resulted in only 29 valid results available for the risk assessment compared to 835 samples for total
34 chromium. This amount of information is likely still sufficient for the purposes of risk assessment. It
35 should be noted that although hexavalent chromium and total chromium have been evaluated separately,
36 a significant portion of the chromium present in groundwater is potentially in the hexavalent state. Unlike
37 hexavalent chromium in surface materials (where it typically rapidly reduces to trivalent chromium),
38 chromium in groundwater can be stable in the hexavalent form under certain aquifer conditions
39 (EPA 910/R-98-001; *Laboratory Receive Latest Data on Chromium in Regional Aquifer* [LANL 2006];
40 *Human Health Fact Sheet for Chromium* [ANL 2005]). As shown in the groundwater percentile table
41 (Table A3-5), the concentrations of hexavalent chromium and total chromium are very similar (see also
42 the groundwater EPC discussion in Section A6.2.3 and Table A6-4). The similarity of the concentrations
43 provides some indication that the majority of the chromium in groundwater at the 200-ZP-1 OU is likely
44 in hexavalent form. Evaluating total chromium as hexavalent chromium does not change the results of the
45 risk analysis because the concentrations appear to be almost the same, with hexavalent chromium
46 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

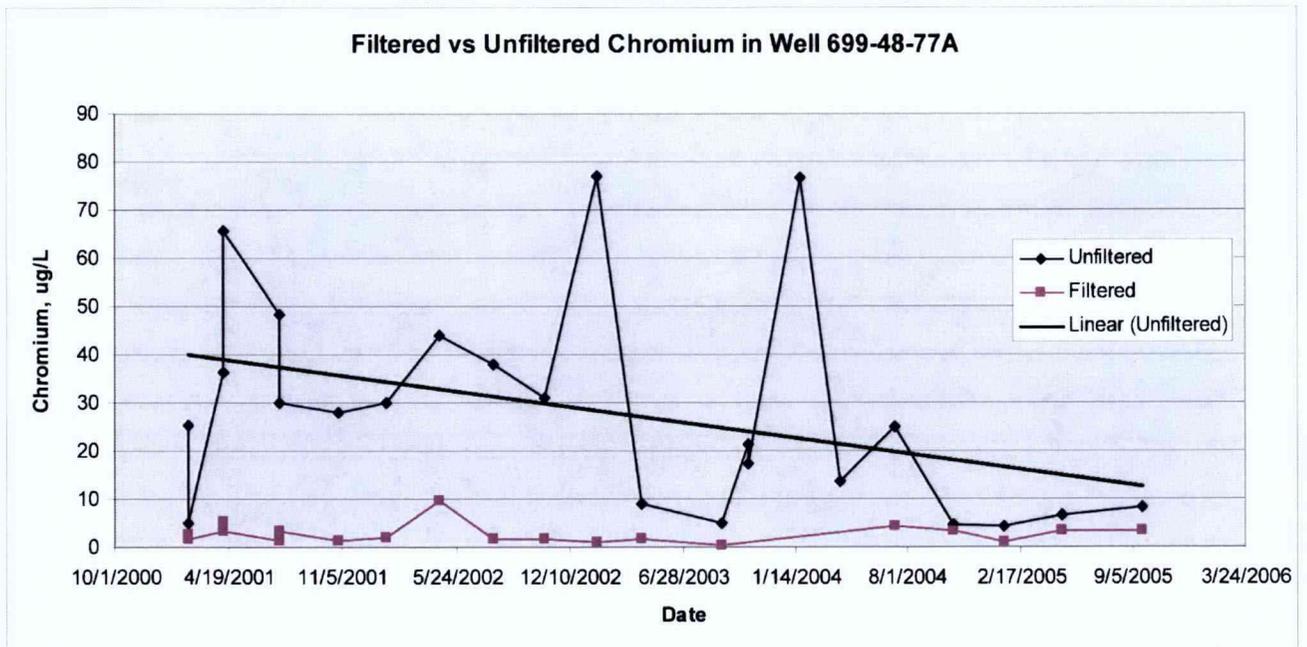
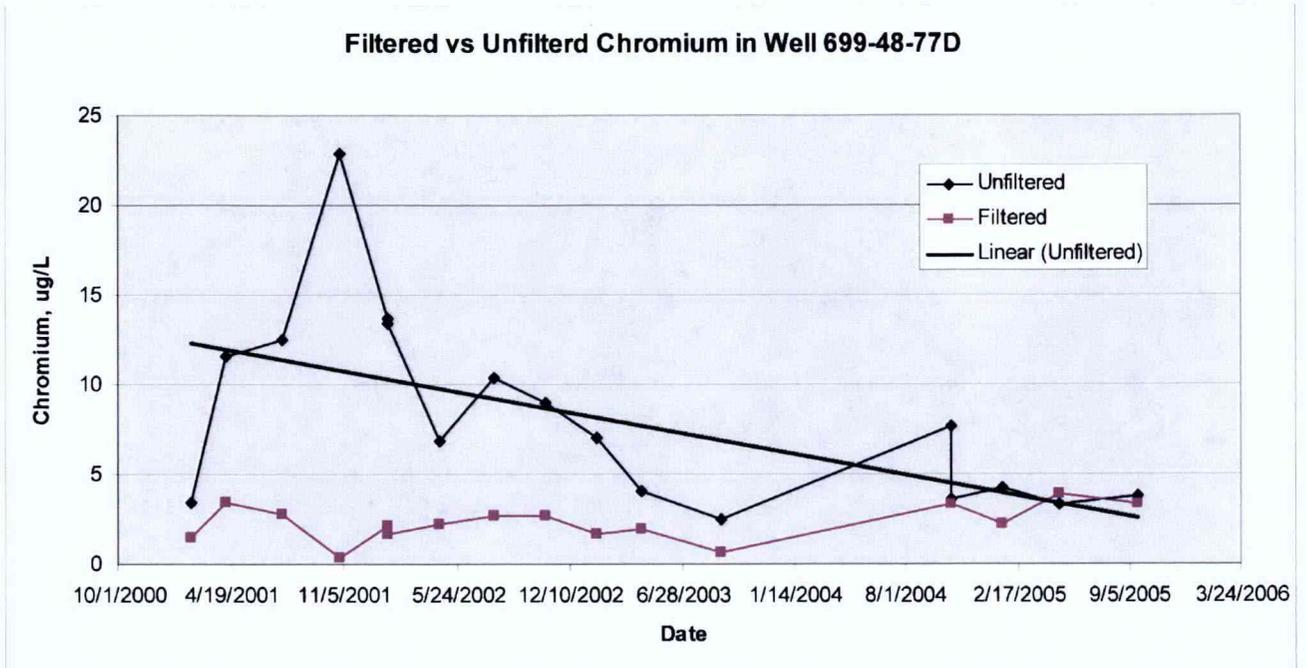
1 change the extent of the plume. Hexavalent chromium in drinking water exceeded an HI of 1 (HI = 5 for
2 children) only at the 90th percentile concentration, a very minor contaminant when compared to a child HI
3 of 304 for carbon tetrachloride at the 90th percentile concentration (Table A5-9).

4 **A6.1.2.1 Use of Filtered versus Unfiltered Data**

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

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

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



1
 2
 3

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

CHPUBS1003-01 21

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

11 **A6.1.2.2 Additional COPCs**

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

21 **A6.2 Uncertainties Related to Exposure**

22 For estimating the RME, 95 percent UCL values (or upper-bound estimates of national averages)
23 are generally used for exposure assumptions, and exposed populations and exposure scenarios are also
24 selected to represent upper-bound exposures. The intent of the RME, as discussed by the EPA Deputy
25 Administrator and the Risk Assessment Council (*Guidance on Risk Characterization for Risk Managers
26 and Risk Assessors* [Habicht, 1992]), is to present risks as a range from central tendency to high-end risk
27 (i.e., above the 90th percentile of the population distribution). This descriptor is intended to estimate the
28 risks that are expected to occur in small but definable “high-end” segments of the subject population
29 (Habicht, 1992). The EPA distinguishes between those scenarios that are possible but highly improbable
30 and those that are conservative but more likely to occur within a population, with the latter being favored
31 in risk assessment. The RME calculations, thus, overestimate risk for most of a hypothetical population,
32 even though not all assumptions may be at their maximum. The following subsections evaluate the
33 populations not selected for evaluation, the exposure concentrations, and exposure assumptions to
34 qualitatively evaluate where exposures (and, thus, risks) might be over- or underestimated.

35 **A6.2.1 Tribal Subsistence Exposures**

36 As discussed in Section A3.1.2, Native Americans currently live near the Hanford Site and could
37 potentially be exposed to contaminants in groundwater and subsurface soil in the 200 West Area under
38 a future failure of institutional controls scenario, similar to a subsistence farming population.
39 A subsistence farming population was selected to represent the RME “bounding” scenario because this
40 population has more widely used exposure factors that have been used over many years at many
41 CERCLA sites. In addition, the range of exposure factors for residential populations has been estimated
42 providing information on population distributions, average values, and RME values. These data are
43 generally not available for Native American populations.

1 However, based on the ongoing work evaluating the differences between a Tribal scenario and
2 a subsistence farmer scenario, Native Americans likely have increased exposure to many environmental
3 media, although with few exceptions, Native American exposure pathways are the same as the
4 subsistence farmer (e.g., both groups could be exposed via direct contact with contaminated materials and
5 the food chain). Table A6-3 compares the exposure factors for the Umatilla (Harris and Harper, 2004) and
6 Yakama Nation (Ridolfi, 2007), with the subsistence farmer for the exposure pathways that are the same.
7 The subsistence farmer results for soil listed in Table A6-3 are based on the methodology described in
8 Appendix G (i.e., basement excavation) rather than the intruder scenario; therefore, the soil risk results
9 listed in this table are not directly comparable to the risk results listed in Table A5-6. As shown in
10 Table A6-3, because the multimedia cumulative cancer risks for the subsistence farmer already approach
11 the maximum risk possible (i.e., approaching 100 percent), increased exposures for a Native American
12 population do not necessarily result in an increase in risks. Because soil risks are at their maximum,
13 differences in risk in this assessment between subsistence farmer and the Native American scenario
14 quantified in Appendix G are not dramatic.

15

1
2

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
<p>Notes:</p> <p>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.</p> <p>a. COPC rationale for selection/deletion:</p> <p>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.</p> <p>BCK = Near or below background levels (magnitude of exceedance over background less than two times).</p> <p>EVAL = selected as a COPC and evaluated in the risk assessment</p> <p>FRQ = low frequency of samples exceeding the screening value (<5 percent).</p> <p>b. Hexavalent chromium screening value is used for the chromium screening value and elemental mercury is used for the mercury screening value.</p> <p>c. Screening values are from EPA Region 3 Risk-Based Concentrations (EPA 2005).</p> <p>c = cancer endpoint</p> <p>COPC = contaminant of potential concern</p> <p>NA = not applicable</p> <p>NE = not established</p> <p>SV = screening value (1/10th of non-cancer or full value of cancer from EPA Region 6 [2006] Tap Water)</p>														

1
2

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).

1 **A6.2.2 Other Exposure Pathways and Populations Not Quantified**

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

9 As noted in Section A3.1, groundwater plumes from the 200-ZP-1 OU have not reached the nearest
10 surface water body (i.e., the Columbia River) but may reach the river in 75 years or more if actions are
11 not taken. As a result of the uncertainties in estimating groundwater concentrations at the river boundary
12 75 years or more in the future, these potential future pathways were not quantified in the risk assessment
13 but represent an area of future uncertainty. Depending on the concentrations reaching the river, there
14 could be a human health concern via contact with contaminants in sediment or surface water during
15 recreational activities, or through ingestion of impacted fish.

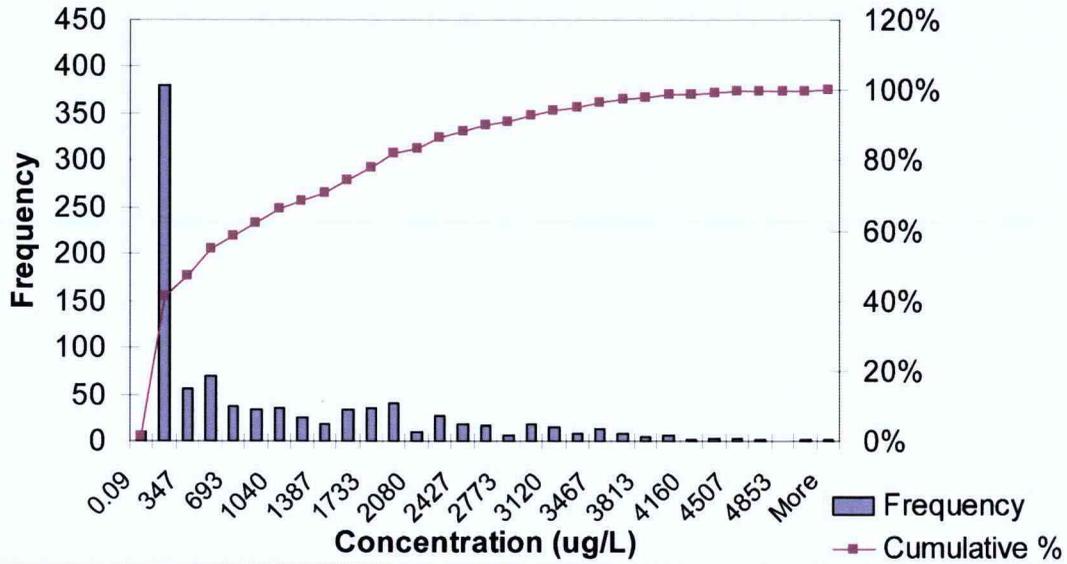
16 **A6.2.3 Exposure Point Concentrations**

17 The EPCs for groundwater were the 25th, 50th, and 90th percentile concentrations, selected in order to
18 evaluate “low,” “medium,” and “high” groundwater concentrations for the groundwater exposure routes.
19 This methodology does not provide risks at a specific location but results in information on the range of
20 possible risks for each COPC at the current concentrations. Typical risk assessment methodology is to
21 calculate a 95 percent UCL on the mean as the EPC (OSWER Directive 9285.6-10) using data from
22 within the exposure area or, in the case of groundwater, the data from one well location. To provide
23 additional information on possible ranges of concentrations in groundwater EPCs for the COPCs,
24 Table A6-4 shows the percentile concentrations used in the risk calculations, as well as the maximum
25 concentrations, average concentrations, and 95 percent UCL concentrations using all of the data. For the
26 risk-driving contaminants in groundwater, carbon tetrachloride and technetium-99, the 90th percentile
27 values are above the 95 percent UCL values because the data set is robust. Generally the larger the data
28 set, the closer the 95 percent UCL is to the mean concentration. For example, carbon tetrachloride’s
29 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.
30 Therefore, 90th percentile values are reasonable upper bounds of concentrations for the purposes of the
31 risk assessment. However, if a well was drilled at the location of the maximum concentration, risks would
32 be significantly underestimated for the COPCs where the maximum concentration is considerably larger
33 than the 90th percentile value (true for eight of the 12 COPCs where the maximum concentration is more
34 than an order of magnitude larger than the 90th percentile). Because only 10 percent of the data exceed the
35 90th percentile values, these very high concentrations are few and represent a very limited areal extent.
36 Figures A6-2a and A6-2b present histograms of the carbon tetrachloride and technetium-99 groundwater
37 concentrations. From these two figures, it can be noted that a large majority of the concentrations are
38 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									

1
2

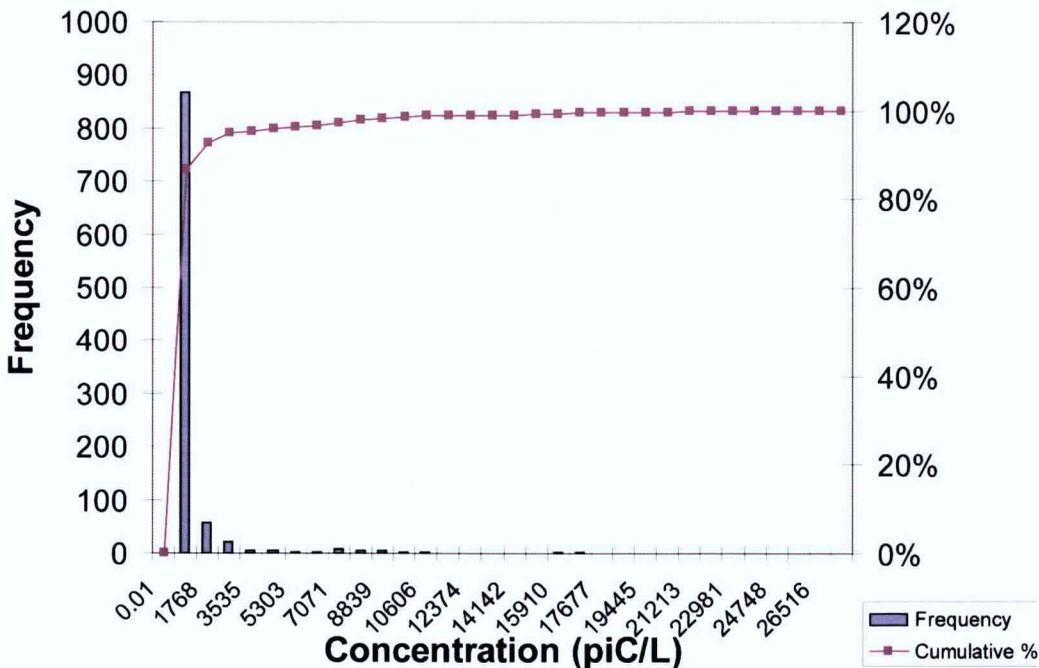


CHPUBS1003-01.22

1

2

Figure A6-2a. Carbon Tetrachloride Groundwater Concentration Frequencies



CHPUBS1003-01.23

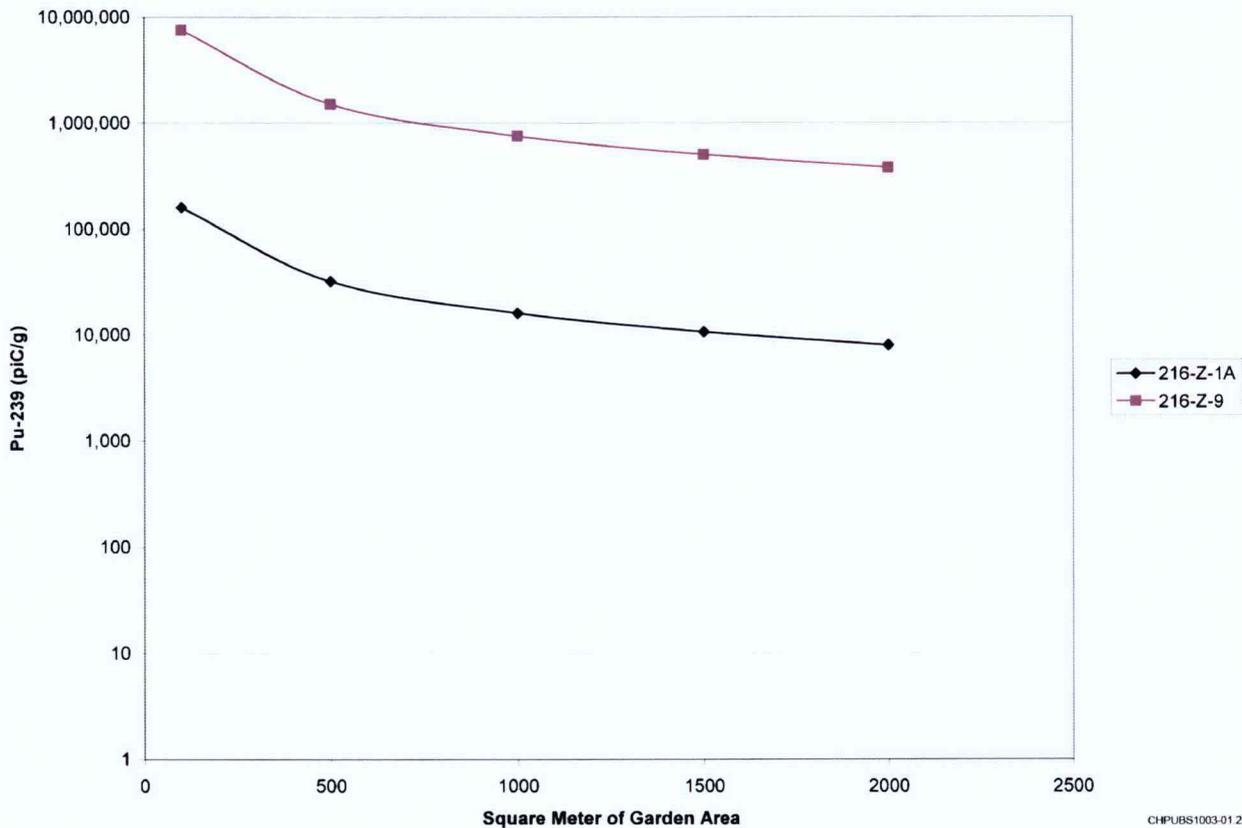
3

4

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

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

1 For subsistence farmer soil concentrations, concentrations are dependent on the size of the garden over
 2 which drill cuttings would be spread. The risk calculations assumed a 100-m² (1,076-ft²) garden from the
 3 analysis performed for the tank waste performance assessment (Rittman 2004). The value of 100 m²
 4 (1,076 ft²) is based on an area that could likely supply at 25 percent of vegetables and fruit for a family of
 5 four. Larger-size gardens or other types of spreading areas would result in a decrease in concentrations.
 6 Figure A6-3 presents the plutonium-239 concentrations at the 216-Z-1A Tile Field and 216-Z-9 sites for
 7 a subsistence farmer, assuming garden sizes of 100 m², 500 m², 1,000 m², 1,500 m², and 2,000 m²
 8 (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
 9 reduced over an order of magnitude (the relationship of concentration to garden size is linear). Because
 10 the concentrations of plutonium-239 are so high at both of these waste sites, concentration reductions by
 11 an order of magnitude would still result in risks well above 1 x 10⁻⁴ for the soil pathways.



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

13 **A6.2.4 Uncertainties in Food Chain Ingestion Rates**

14 The evaluation of the food chain pathways has resulted in risks and hazards significantly above the target
 15 health goals, primarily due to ingestion of homegrown produce, and this pathway has resulted in risks and
 16 hazards that are equal to or greater than direct ingestion of groundwater used as a drinking water source.
 17 The two main factors that drive the calculated risks and hazards from ingestion of homegrown produce
 18 are: (1) the concentration in the plant tissue, and (2) the plant ingestion rate. The uncertainties associated
 19 with these factors and their impacts on the conclusions of the risk assessment are discussed below.
 20

21 The modeling used to calculate plant tissue concentrations for COPCs in groundwater is based on
 22 a conservative approach developed by ORNL RAIS (<http://rais.ornl.gov/>). For the soil-to-plant pathway,
 23 risks were estimated using RESRAD based on site soil concentrations. Both models are designed to be

1 health protective in an attempt to overestimate, rather than underestimate, the potential concentrations of
2 contaminants in plant tissues irrigated with contaminated groundwater or grown in contaminated soil. The
3 plant tissue calculations depend largely on the transfer factor used to estimate the uptake of contaminants
4 by the plant from the soil. The transfer factors used in the plant tissue EPC calculations for groundwater
5 were generally obtained from Rittman (2004) and, for most contaminants, these factors are consistent
6 with the default transfer factors used by ORNL and are similar to those in RESRAD (although Rittman
7 [2004] used site-specific data for Hanford where the data were available). Transfer factors are based on
8 the assumed behavior of the contaminant in the environment, as well as the assumed affinity of the
9 contaminant to reside in plant tissues. For some contaminants, the transfer factors are greater than unity,
10 which indicates that the concentration in plant tissue is higher than the concentration in soil and that the
11 plant has a tendency to bio-accumulate the contaminant in the plant tissues. Transfer factors could vary
12 depending on the type of plant being cultivated and specific soil conditions. However, to simplify the
13 process for modeling plant tissue concentrations and because the specific future conditions in which
14 produce might be grown 150 years from now are not known, the health-protective default transfer factors
15 that can be applied to most types of plant grown in most any type of soil conditions were used in this
16 assessment. In lieu of site-specific bio-transfer data, use of these transfer factors provides a method for
17 quantifying exposures through this pathway. It is likely that this modeling process overestimates the
18 amount of COPC estimated to be in plant tissue. In addition, this modeling process does not take into
19 account high concentrations in soil or groundwater that could result in direct toxicity to the plant, through
20 either stunting growth and/or yield or resulting in plant death.

21 The second area of uncertainty associated with the plant ingestion pathway is the ingestion rate used in
22 the risk calculations. The ingestion rate used in the risk calculations is based on the mean (average) total
23 homegrown fruit intake for households that farm in the west of 1.85 g/kg-day and the mean (average)
24 total homegrown vegetable intake for households that farm in the west of 2.73 g/kg-day, as shown in
25 Tables 13-12 and 13-17 of EPA/600/P-95-002Fa. EPA/600/P-95-002Fa recommends using mean intake
26 rates rather than an upper percentile value (as is commonly used for many RME exposure values) for
27 these particular ingestion rates because of the uncertainties in the higher percentile estimates. Seasonally
28 adjusted intake rates from EPA/600/P-95-002Fa could be more representative of long-term exposures and
29 were lower than those for households that farm in the west of 2.73 g/kg-day (see Table A6-5 sources are
30 Tables 13-12 and 13-17 in EPA/600/P-95-002Fa). However, because food-preparation methods could
31 result in eating homegrown food all year around, and because of uncertainties in intake rates between
32 humans who live in the west (but may not be farmers) and specifically those who engage in farming
33 activities, the unadjusted intake rates for households that farm were deemed the best RME values for
34 a future farming population. These values were also not adjusted for cooking or preparation loss, again
35 because of uncertainties regarding actual food preparation methods, but cooking and certain types of food
36 preparation (e.g., peeling) can reduce concentrations of contaminants in food.

37

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)

- 1 Summing fruit and vegetable rates for households that farm together results in a total mean homegrown
2 fruit and vegetable intake rate for households that farm in the west of 4.56 g/kg-day (equivalent to
3 319 g/day for a 70 kg person, or approximately 0.75 lb of fruits and vegetables eaten every day for
4 30 years) (Table A6-5). This is equivalent to producing around 60 percent of a person's total fruit and
5 vegetable intake using USDA average consumption rates (521 g/day, as cited in Rittman [2004]) or
6 49 percent of a person's total fruit and vegetable intake using EPA's mean capita consumption rates
7 (*Analysis of Total Food Intake and Composition of Individual's Diet Based on USDA's 1994-1996, 1998*
8 *Continuing Survey of Food Intake by Individuals [CSFII]* [EPA/600/R-05/062F]). If total fruit and
9 vegetable consumption rates for high consumers are compared to the ingestion rates used in this risk
10 assessment, the ingestion rates used in this assessment are 16 percent of total consumption rates
11 (EPA/600/R-05/062F). While the ingestion rates used in this assessment may be an overestimate of the
12 amount of vegetables and fruit (grains are excluded) that could be produced from a 100-m² (1,076-ft²)
13 garden for a family of four or more humans (Rittman [2004] assumed that a 100-m² [1,076-ft²] garden
14 could produce 25 percent of total fruit and vegetables for a family of four) (see Table A6-5), this value
15 was used as an upper bound because of the issues around using irrigation water for a larger-size garden
16 than the drill cuttings could reasonably be spread over (without lowering concentrations in soil
17 significantly). A recent evaluation at another DOE site identified 200 m² (2,153 ft²) as adequate to
18 provide half the entire yearly intake of vegetables (ORNL-TM/13401, as cited in Rittman [2004]).
- 19 The produce intake rates used in this assessment are more than double those presented in the HSRAM
20 (DOE/RL-91-45) (see Table A6-5). The values in the risk assessment methodology were obtained from
21 OSWER Directive 9285.6-03. OSWER Directive 9285.6-03 estimates that an average fruit and vegetable
22 consumption is 340 g/day (less than the USDA estimate and much less than the current EPA estimates
23 presented in EPA/600/R-05/062F), and that 30 percent to 40 percent of that value represented an RME
24 consumption for homegrown fruits and vegetables. This information has been updated in
25 EPA/600/P-95-002Fa, which was the source of the values used in this assessment.
- 26 In conclusion, the homegrown produce intake rates used here likely overestimate the amount of produce
27 that could be grown in a 100-m² (1,076-ft²) garden but may be representative of a larger garden area
28 irrigated with impacted groundwater. If intake rates were lowered one third, risks would lower slightly

1 but would still be well above 1×10^{-4} for all risk drivers for this pathway (e.g., technetium-99 produce
2 ingestion risks from plants irrigated with groundwater would change from 3×10^{-3} to 9×10^{-4}).

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

7 **A6.2.5 Uncertainties in Other Exposure Factors**

8 Intake rates of soil for construction workers assumed a soil ingestion of 330 mg/day. This value for
9 construction workers is the 95th percentile ingestion rate from a mass-balance study conducted with
10 10 adults who were followed over a 4-week period (280 subject-days). The average and median amounts
11 of soil ingested in the study were 10 mg/day and 1 mg/day, respectively (*Soil Ingestion in Adults –*
12 *Results of a Second Pilot Study* [Stanek et al., 1997]). Because of the small population and the large
13 variability in the data, the 95th percentile value is highly uncertain. Soil exposures for the radionuclides
14 used the default exposure assumptions in RESRAD for the subsistence farmer risks. The RESRAD
15 default assumptions differ from EPA residential defaults below:

- 16 • There is no increase in soil ingestion rate for young children. RESRAD assumes a total ingestion rate
17 of 36.5 g/yr (equivalent to 100 mg/day, the default adult outdoor ingestion rate used in the
18 nonradionuclide subsistence farmer equations, for 365 days/yr). Of the total, RESRAD assumes only
19 10 percent would come from the impacted garden area of 100 m² (1,076 ft²). This means that the
20 RESRAD soil risks are significantly lower than the EPA defaults.
- 21 • RESRAD assumes that only 75 percent of a person's time will be spent at Hanford; EPA residential
22 defaults assume that 96 percent of a person's time will be spent at home.
- 23 • RESRAD assumes an annual inhalation rate of 8,400 m³/yr, corrected to account for time spent
24 offsite, time indoors (50 percent), and an indoor dust reduction factor (0.4), to 3,780 m³/yr (45 percent
25 reduction of annual inhalation rate due to site exposures). This is equivalent to a daily on Hanford
26 property inhalation rate for 350 days/yr of 10.8 m³/day, approximately one-half the EPA residential
27 default of 20 m³/day. However, the dust inhalation pathway for radionuclides at this site is not
28 significant in comparison to ingestion and external radiation, with inhalation risks several orders of
29 magnitude below ingestion and external radiation.

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

35 If the EPA time on site defaults were changed to match those in RESRAD, the nonradionuclide risks
36 would fall. This decrease would not change the overall risks at the 216-Z-9 Trench (the only soil site with
37 nonradionuclide carcinogens), which are driven by the radionuclides for the direct-contact pathways.
38 However, because the nonradionuclide cancer risks at the 216-Z-9 Trench were primarily due to ingestion
39 of produce (risks = 1×10^{-3}), lowering soil ingestion risks at least 25 percent to account for time spent
40 offsite would not affect the overall nonradionuclide cancer risks at the site (direct-contact soil pathway
41 risks were only 6×10^{-5}) (see Table A5-6). It is reasonable to assume that most humans typically do not
42 spend 96 percent of their time at home, and other risk assessments at Hanford have assumed a 60/20/20
43 factor (i.e., 60 percent inside, 20 percent outside, and 20 percent offsite), assuming less time outdoors and
44 less time at Hanford lowers risk estimates.

1 **A6.3 Uncertainties in Assessment of Toxicity**

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

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

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

23 **A6.3.1 Radionuclides Slope Factors**

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

33 All of the epidemiological studies used in the development of radiation risk models involve high radiation
34 doses delivered over relatively short periods. Evidence indicates the response per unit dose at low doses
35 and dose rates from low linear-energy transfer radiation (primarily gamma rays) may be overestimated if
36 extrapolations are made from high doses acutely delivered. The degree of overestimation is often
37 expressed in terms of a dose. A dose-rate effectiveness factor is used to adjust risks observed from high
38 doses and dose rates for estimating risks from exposures at environmental levels. The EPA models for
39 radiation risk include a dose and dose-rate effectiveness factor of 2, applicable to most low linear-energy
40 transfer radiation exposure. For high linear-energy transfer radiation (e.g., alpha particles), the differences
41 in relative biological effect are accounted for in weighting factors applied in the calculation of dose
42 and risk.

43 The SFs used in this risk assessment for the radionuclides are morbidity SFs. For a given radionuclide and
44 exposure mode, they represent an estimate of the average total risk of experiencing a radiogenic cancer,

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

10 **A6.3.2 Radionuclide Dose Versus Risk Estimates**

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

- 21 • **Nominal dose-to risk conversion versus radionuclide-specific conversion factors:** The connection
22 between dose and risk can be made using the "nominal" dose-to-risk conversion factor of 0.05 risk/Sv
23 (5.0×10^{-7} risk/mrem) stated in *Recommendations of the International Commission on Radiological*
24 *Protection* (ICRP Publication 60). Using this conversion factor, a dose of 100 mrem/yr corresponds to
25 a 1-year cancer risk of 5×10^{-5} , less than the target health goal of 1×10^{-4} . Conversely, assuming a
26 30-year exposure, the lifetime risk corresponding to 100 mrem/yr is 1.5×10^{-3} , more than 10 times the
27 1×10^{-4} risk criterion. However, the dose-to-risk conversion factor can vary significantly from the
28 "nominal" value of 0.05 risk/Sv for some radionuclides. For the radionuclides evaluated here,
29 cesium-137 has a dose-to-risk conversion factor very close to nominal, while americium-241 and the
30 plutonium isotopes do not. Therefore, a 100 mrem/yr RBC and the 1×10^{-4} cancer risk cleanup level
31 would be similar for cesium-137 but are very different for americium-241 and the plutonium isotopes
32 (dose-based cleanup levels are approximately two orders of magnitude lower).
- 33 • **Differences in the use of organ and tissue weighting factors between the dose factors and the**
34 **cancer risk factors:** The effective dose equivalent (EDE) factors in Federal Guidance Report No. 11
35 (*Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for*
36 *Inhalation, Submersion, and Ingestion* [EPA-520/1-88-020]) are a *weighted* sum of the organ and
37 tissue doses; the risk factors in Federal Guidance Report No. 13 (EPA 402-R-99-001) are a *simple*
38 sum of the organ and tissue risks. The distinction between the weighted sum and the simple sum is
39 not very important for cesium-137 because the organ-specific dose factors are all about the same. For
40 americium and the plutonium isotopes, the organ-specific ingestion dose factors vary significantly
41 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),
42 while the (weighted) EDE factor is 9.56×10^{-7} Sv/Bq. Therefore, weighted sum and simple sum
43 differences are much larger. This causes the ratio of risk to EDE to vary significantly from the
44 nominal value of ICRP Publication 60.

1 The relationship between dose and risk can be quantified for individual radionuclides by taking the ratio
 2 of the radionuclide-specific dose and risk factors. In this analysis, dose conversion factors were taken
 3 from Federal Guidance Report No. 11 (EPA-520/1-88-020) for ingestion and inhalation and from Federal
 4 Guidance Report No. 12 (*External Exposure to Radionuclides in Air, Water, and Soil*
 5 [EPA 402-R-93-081]) for external exposure. Risk factors were taken from Federal Guidance Report
 6 No. 13 (EPA 402-R-99-001) for cancer morbidity (see Table A6-6). Table A6-7 shows the risks that
 7 correspond to a dose of 100 mrem/yr from individual exposure pathways. The top portion of the table
 8 shows the risks from a 1-year dose of 100 mrem. The lower portion of the table shows the risks from
 9 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).

10

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

1 The risks in Table A6-7 show an interesting relationship between 1-year exposure and chronic exposures.
2 For a 1-year exposure, the only risk to exceed 1×10^{-4} was the cesium-137 inhalation pathway. Therefore,
3 the 100-mrem criterion is more protective than 1×10^{-4} risk in all cases, except for the cesium-137
4 inhalation pathway. The 100-mrem criterion, therefore, provides greater protection for a 1-year exposure,
5 such as the construction scenario. For 30-year exposures, the situation is very different. In this case, all of
6 the exposure pathway risks exceed 1×10^{-4} except for the americium-241 ingestion pathway. Therefore,
7 the 1×10^{-4} risk criterion is generally more protective for chronic exposure scenarios where the exposure
8 is for long term.

9 Turning to cleanup criteria, it is clear that dose- and risk-based criteria can result in very different cleanup
10 standards for some radionuclides. For the case of the plutonium-239 ingestion pathway, the 1×10^{-4} risk
11 criterion is comparable to the 100 mrem/yr criterion for a 30-year exposure duration. In contrast, for the
12 cesium-137 ingestion pathway, the 1×10^{-4} risk criterion is at least 10 times more protective than the
13 100 mrem/yr dose criterion for a 30-year exposure duration. For americium-241 and the plutonium
14 isotopes, a 100 mrem/yr dose corresponds to risk less than 1×10^{-4} for 1-year exposure duration;
15 therefore, the soil RBCs based on the 100 mrem/yr dose are smaller than those based on a target risk of
16 1×10^{-4} .

17 Therefore, for the construction scenario (1 year or less exposure), the difference between the risk and dose
18 criteria appears greater than if the exposure was for long term.

19 **A6.3.3 Trichloroethylene Slope Factors**

20 The cancer SF values for TCE used in this assessment were those established by the California EPA
21 (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) and are generally being
22 recommended for use in risk assessment. The SFs derived by OEHHA are an inhalation slope factor (SF_i)
23 of $0.007 \text{ (mg/kg-day)}^{-1}$ (as presented in *Technical Support Document for Describing Available Cancer*
24 *Potency Factors* [OEHHA, 2002]) and an oral SF of $0.013 \text{ (mg/kg-day)}^{-1}$ (as presented in *Public Health*
25 *Goal for Trichloroethylene in Drinking Water* [OEHHA, 1999]).

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

34 The U.S. Department of Defense (DOD) has published a critique of EPA's proposed SF range for TCE
35 (*Critique of the U.S. Environmental Protection Agency's Draft Trichloroethylene Health Risk Assessment*
36 *[EPA/600/P-01/002A]* [AFIERA, 2001]). In particular, they note that the upper end of the proposed
37 recommended range, $0.4 \text{ (mg/kg-day)}^{-1}$, is based on a residential drinking water study where the
38 confidence interval around the calculated relative risk included one. The relative risk is defined as the
39 cancer incidence rate in the exposed population relative to an unexposed population. If the relative risk is
40 one, then cancer incidence rates are equal for the exposed and unexposed populations and the study
41 cannot conclude that there is an increased association between cancer and site exposures relative to an
42 unexposed population. Generally, if the confidence interval around the relative risk includes one, then
43 cancer incidence rates for the two populations (exposed and unexposed) are not significantly different.
44 Therefore, the DOD review concluded that there was insufficient evidence to conclude that TCE
45 exposures in drinking water were associated with an increase in non-Hodgkins lymphoma; thus, no

1 SF should be calculated based on that study. Only one study associated non-Hodgkins lymphoma with
2 TCE exposure.

3 Because of the uncertainty surrounding EPA's new proposed SF and because of the criticisms that the
4 health assessment document has received, this risk assessment has selected the California values as more
5 appropriate at this time. If the EPA provisional value were used to estimate TCE risks in groundwater,
6 risks at the 90th percentile go from barely exceeding *de minimis* levels (8×10^{-6}) to 4×10^{-4} , greater than
7 the upper-bound target risk goal. TCE is currently identified as a slight potential hazard in groundwater at
8 the 90th percentile concentration with a child HI of 3. There is some uncertainty regarding whether
9 exposure to 90th percentile TCE concentrations in groundwater represents a potential cancer risk in excess
10 of target health goals. If the OEHHA SFs are revised upward and/or the higher EPA SFs are validated,
11 cancer risks due to TCE might have been underestimated. However, risks due to domestic use of
12 groundwater at 90th percentile concentrations are driven by carbon tetrachloride with risks of 2×10^{-2} .
13 Increasing TCE risks even to 4×10^{-4} does not make a significant difference in the overall cumulative
14 cancer risks from groundwater.

15 **A6.4 Uncertainties in Risk Characterization**

16 Radiation is naturally present in the environment. The radionuclide risks estimated in this assessment
17 have not been corrected to account for natural background radiation. The impacts of background are
18 typically described in terms of radiation dose (millirem, or mrem). For the U.S. as a whole, the average
19 radiation dose from background sources is approximately 300 mrem/yr, and approximately 200 mrem/yr
20 is from radon inhalation. Radon emanates from the uranium decay series naturally present in soil and
21 rock. (Note that the radon risk levels at all of the waste sites evaluated in this assessment were
22 insignificant [see Attachment A-7 of this appendix]). The remaining 100 mrem of radiation from
23 background sources is primarily from radioactive potassium-40 (present on the Hanford Site), cosmic
24 rays, and direct exposure from radioactive sources in soils and rocks. The background total varies with
25 altitude (cosmic radiation increases with altitude) and geology (determines radon and gamma sources at
26 the ground surface). A general estimate of the range of variability in background radiation dose in the
27 U.S. is from 100 to 1,000 mrem/yr. For comparison, the upper end of the CERCLA risk range, which
28 represents the level below which CERCLA decisions are typically made, generally corresponds to dose
29 rates that are less than 15 mrem/yr. Because the radiation doses at this site are so high for the risk drivers
30 (thousands or even tens of thousands of mrem/yr), the contribution of background to overall dose for
31 cesium-137, americium-241, plutonium-239, and plutonium-240 is insignificant at all sites, except the
32 216-Z-8 French Drain. The dose levels at 216-Z-8 French Drain are below 15 mrem/yr for the
33 construction worker and well driller and were only 49 mrem/yr for the subsistence farmer due to ingestion
34 of homegrown produce.

35 Studies have not been able to relate variations in health effects to variation in background radiation doses.
36 Based on international studies, the National Research Council reports that in areas of high natural
37 background radiation an increased frequency of chromosome aberrations has been noted. However, no
38 increase in the frequency of cancer has been documented in populations residing in areas of high natural
39 background radiation (*Health Effects of Exposure to Low Levels of Ionizing Radiation, Committee on the*
40 *Biological Effects of Ionizing Radiation [BEIR V] [BRER-K-97-01-A]*).

41 **A6.4.1 Uncertainties Associated with Large Estimates of Risk**

42 The CERCLA risk estimates are designed to support decisions relative to the CERCLA risk range, but
43 risks approaching 1 are subject to additional uncertainties and technical limitations. Because relatively
44 low intakes are most likely from environmental exposures at Superfund sites, it can generally be assumed
45 that the dose-response relationship will be linear in the low-dose portion of the multi-stage model

1 dose-response curve. In this case, the SF is a constant and risk can be directly related to intake. This linear
2 relationship is valid only at relatively low-risk levels (i.e., below estimated risks of 0.01). For estimated
3 risks above this level, alternative calculations are used. Since risk is generally understood as an estimate
4 of cancer probability, and since probabilities are limited to the range between 0 and 1, one of the purposes
5 of these alternative calculations is to avoid calculating risks that equal or exceed 1 and, therefore, lose
6 meaning (EPA 540/1-89/002).

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

12 A third consideration regarding large dose estimates is the effect of multiple contaminants. Standard risk
13 assessment practice is to add the estimated risks from contaminants. These risk-summation techniques
14 assume that intakes of individual substances are small, that there are no synergistic or antagonistic
15 interactions among contaminants, and that all contaminants have the same effect (i.e., cancer). This is an
16 approximation that is useful when the total estimated cancer risk is <0.1 . However, because SFs are often
17 95th percentile estimates of potency, and because upper 95th percentiles of probability distributions are not
18 strictly additive, the total cancer risk estimate may become more of an artificial overestimate as risks from
19 a number of different carcinogens are summed. If the individual contaminant risks are themselves large,
20 or if the number of contaminants is large, or if the assumptions applied are otherwise incorrect, simple
21 risk summation may result in large estimates of cumulative cancer risk that lose some usefulness
22 (EPA 540/1-89/002).

23 **A6.4.2 Uncertainties in Radiation Risk Assessment**

24 The uncertainties associated with the SFs are likely to be larger than those due to analytical uncertainties.
25 EPA's Federal Guidance Report No. 13 (EPA 540/1-89/002) does not provide specific quantitative
26 uncertainty estimates of the cancer SFs. *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation*
27 *Protection* (NCRP Report No. 126) examined the question of uncertainties in SFs for the relatively simple
28 case of external radiation exposure to low linear energy transfer (primarily gamma) radiation (NCRP
29 Report No. 126). The conclusion was that the 90 percent confidence interval was approximately three
30 times higher or lower than the central risk estimate. Since estimates of risk from ingestion of food
31 necessarily involve the added complexity of modeling of physiological processes to determine dose and
32 risk, the uncertainties in this context are likely to be even greater.

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

37 **A6.5 Summary of Uncertainty**

38 Every aspect of the risk assessment contains multiple sources of uncertainty. Simplifying assumptions are
39 often made so health risks can be estimated quantitatively. Because the exact amount of uncertainty
40 cannot be quantified, the risk assessment is intended to overestimate rather than underestimate probable
41 risk. The results of this assessment, therefore, are likely to be protective of health despite the inherent
42 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

1 unacceptable risk and the risks should be characterized in standard Agency risk language consistent with
 2 CERCLA guidance.” Therefore, RBC values based on a target risk level of 1×10^{-4} were calculated and
 3 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

4 The RBCs for dose and risk were obtained from the RESRAD dose model and site-specific
 5 input parameters, as detailed in Attachment A-6 of this appendix. The RBCs were calculated using
 6 the same site-specific inputs and exposure assumptions for construction workers (see Attachment A-3,
 7 Tables 3-2 and 3-5 of this appendix) that were used in the RESRAD model during the calculation of
 8 radionuclide risks for construction workers. Concentrations of soil were input into the RESRAD model
 9 until the target cancer incidence risk level of 1×10^{-4} for the COPC was achieved. The process to
 10 calculate the risk-based RBCs for the radionuclides in soil considered combined exposures through the
 11 soil ingestion, dust inhalation, and external radiation pathways, so the RBC is protective of a 1×10^{-4}
 12 cancer risk level across all pathways combined. Because the site size affects the RESRAD output results
 13 (although the size only significantly affects results if the size is much smaller than the sizes assumed here
 14 [see Section A7.2]), it is necessary to calculate RBCs for radionuclides in soil that are specific to the site.
 15 Therefore, site-specific RBCs were calculated for the risk drivers at both the 216-Z-1A Tile Field and
 16 216-A-8 French Drain sites. The RBCs were calculated for the following radionuclides as they are the
 17 primary risk drivers for these sites:

- 18 • 216-Z-1A: americium-241, plutonium-239, and plutonium-240
- 19 • 216-A-8: cesium-137

20 Details of the RBC calculations for the radionuclides in soil based on a 1×10^{-4} cancer risk at these sites
 21 are provided in Attachment A-8, Table 8-5, in this appendix. The RBCs for each contaminant are
 22 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:

$$RBC_{nc} = \frac{HQ \times RfD}{SIF}$$

$$RBC_{ca} = \frac{TCR}{SF \times SIF}$$

where:

- RBC_{nc} = non-cancer RBC
- RBC_{ca} = 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

1 collocated with each other. Therefore, although risk managers should consider potential cumulative
2 exposures to the COPCs when applying the RBCs in the evaluation of the protectiveness of various
3 remedies during the FS process, a downward adjustment to account for cumulative exposures may not
4 be necessary.

5 A sensitivity analysis was performed using RESRAD on the soil data for the 216-Z-1A Tile Field and
6 216-A-8 Crib to determine if changes to the site area size and contaminant thickness would affect risks
7 for the summed pathways, including external radiation, inhalation, and ingestion under current conditions.
8 It was noted that external radiation risks and the median calculated risks that were done in this risk
9 assessment were not affected by increasing or decreasing site area or contaminant thickness by five times.
10 The contaminant thickness was increased and decreased by five times. There were no significant
11 differences between these risks and the median calculated risks that were performed in this risk
12 assessment. In addition, the site area size was increased and decreased by five times. There were no
13 significant differences between risks from the larger site and the median calculated risks that were
14 performed in this risk assessment. However, risks that were calculated using a site area that was five
15 times lower were between two and three times lower than the median calculated risks that were performed
16 in the risk assessment. For example, the inhalation and ingestion risks for americium-241 decreased from
17 7×10^{-5} to 3×10^{-5} , the inhalation and ingestion risks for plutonium-239 decreased from 1×10^{-4} to
18 5×10^{-5} , and the inhalation and ingestion risks for cesium-137 decreased from 6×10^{-7} to 2×10^{-7} . In
19 conclusion, the sensitivity analysis indicates that different site area sizes may affect risks, particularly if
20 the site area is small. Therefore, site size should be considered when using the calculated the RBCs
21 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

1 For soil, the risk assessment primarily used the available soil data from the 200-PW-1/3/6 RI report
 2 (DOE/RL-2006-51) for the representative soil sites, supplemented by additional historical data reports. In
 3 addition to soil data, soil gas data collected near the 216-Z-1A Tile Field and air samples collected from
 4 within the 216-Z-9 Trench were also reviewed to evaluate their suitability for inclusion in the risk
 5 assessment. The three air samples collected from within the 216-Z-9 Trench were selected for inclusion in
 6 the risk assessment as the most representative data of what concentrations might be possible in vapor
 7 intruding into basements.

8 Typically, not all contaminants present at a site pose health risks or contribute significantly to overall site
 9 risks. The EPA guidelines (EPA 540/1-89/002) recommend focusing on a group of COPCs based on
 10 inherent toxicity, site concentration, and the behavior of the contaminants in the environment. To identify
 11 these COPCs, health-protective, risk-based screening values are compared to site concentrations of
 12 detected contaminants to select COPCs for soil and soil gas.

13 Maximum detected concentrations in soil from each of the waste sites were compared to EPA Region 6
 14 HHSLs for residential soil and EPA generic residential screening levels for radionuclides
 15 (EPA/540-R-00-006) to select COPCs in soil. The selected COPCs are listed in Table A8-1. No
 16 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			√	

1 The air samples collected from within the 216-Z-9 Trench were compared to both residential screening
2 levels (EPA Region 6 HHSLs) in air (EPA, 2007) and worker PELs established through WISHA
3 (WAC 296-841-20025). Carbon tetrachloride and chloroform both exceeded the EPA Region 6 HHSLs
4 by many orders of magnitude and were selected as COPCs in indoor air for a future subsistence farming
5 population. COPCs are present in soil gas at both the 216-Z-9 Crib and 216-Z-1A Tile Field; no VOCs
6 were detected in soil at the 216-Z-1A Tile Field down to 26 m (85 ft) bgs, but deep soil gas may be
7 present because the operating SVE system at the site is still capturing VOCs. Air levels inside the trench
8 did not exceed PELs; thus, are not a concern for a working population.

9 **A8.2 Exposure Assessment**

10 After the COPCs have been selected, the second step in risk assessment is an evaluation of the exposure
11 pathways by which humans could encounter contaminants. The exposure assessment identifies the
12 populations potentially exposed to contaminants at the site, the means by which exposure occurs, and the
13 amount of contaminant received from each exposure medium (i.e., the dose). Only complete exposure
14 pathways are quantitatively evaluated. Complete pathways consist of four elements:

- 15 1. A source and mechanism of contaminant release
- 16 2. A retention or transport medium (e.g., groundwater)
- 17 3. A point of potential human contact with the affected medium
- 18 4. A means of entry into the body at the contact point

19 Figures A3-1 and A3-2 present the CSMs, which depict the complete pathways for this site under the
20 current industrial land use and the future unrestricted land use scenarios, respectively.

21 The risk assessment evaluated risks from exposures to contaminants in groundwater and soil for two
22 broad categories: restricted land use and unrestricted land use. The following briefly summarizes the
23 pathways selected for quantitative evaluation:

- 24 • **Restricted (current industrial) land use:** A current construction worker population was evaluated,
25 assuming exposures to contaminants in subsurface soil at three of the four waste sites where COPCs
26 were selected. Construction workers were not evaluated at the 216-Z-9 Trench because of the depth
27 of impacted material (6.4 m [21 ft] bgs) and because the 216-Z-9 Trench is covered with a concrete
28 cap, making any digging activity more difficult. Typically in risk assessment, construction workers
29 are not assumed to dig deeper than 4.6 m (15 ft) bgs. However, where impacted materials began very
30 close to, or slightly deeper than the 4.6-m (15-ft) level and there was no barrier to prevent digging,
31 contact with impacted materials for current construction workers was considered possible. (Note that
32 contact with buried materials by construction workers assumed for the purposes of the risk evaluation
33 is very unlikely to actually occur for an unprotected worker due to the existing institutional controls
34 program at the Hanford Site.) Construction workers were evaluated for exposures to subsurface soil
35 through the ingestion, inhalation (of fugitive dust and vapors), dermal contact, and external radiation
36 exposure routes.

37 Current regular worker populations (i.e., outdoor and indoor workers not engaged in active soil
38 disturbance) will not be exposed to subsurface soil because impacted material is too deep, that is,
39 below the 1-m (3.3 ft)-bgs limit considered as surface soil in most risk assessments. They will not be
40 exposed to groundwater because, under existing institutional controls, the water cannot be used
41 for drinking.

- 42 • **Post-2150 unrestricted land use:** While land use is anticipated to remain industrial for the
43 foreseeable future, because the radionuclides present in soil and groundwater have very long

1 half-lives, a future subsistence farming population was also selected for evaluation. This assumes
2 exposure to contaminants in groundwater and soil if institutional controls fail at some point in the
3 future and additional exposures via the food chain (i.e., fruits and vegetables, meat, and dairy
4 products). The future point selected for subsistence farming exposures to begin is the year 2150. At
5 this time, it is assumed that someone could drill a well and bring drill cuttings to the surface where
6 they would be available for direct exposure by future subsistence farmers. Child and adult future
7 subsistence farming populations were evaluated for the following:

- 8 – Direct contact with impacted soil brought to the surface as drill cuttings
- 9 – Exposures to groundwater as drinking water
- 10 – Ingestion of homegrown produce cultivated in contaminated soil and irrigated with groundwater
- 11 – Ingestion of beef and dairy products from cattle watered with groundwater and grazing in
12 pastures irrigated with groundwater
- 13 • Adult subsistence farmers were also evaluated for exposures to groundwater through irrigation of
14 gardens and livestock. Exposures to VOCs in subsurface through inhalation of vapors emanating from
15 the subsurface into the ambient air based on the 2006 data were evaluated semi-quantitatively.

16 Under this post-2150 scenario, the groundwater from a well could be used by residents or at
17 a business. Thus, a future regular working population could be exposed to soil during drilling (future
18 well drillers), and a separate working population was evaluated assuming exposure to groundwater
19 via drinking it at their place of work (future regular workers).

20 For the quantification of exposures to COPCs in soil, either 95 percent UCL or maximum concentrations
21 were used as reasonable maximum EPCs. Impacted groundwater beneath the site is widely dispersed,
22 consisting of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest
23 concentrations do not occur at the same location). Therefore, a range of concentrations was selected for
24 EPCs to evaluate “low,” “medium,” and “high” groundwater concentrations for the groundwater exposure
25 routes. These EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing
26 groundwater data set.

27 **A8.3 Toxicity Assessment**

28 The third step in risk assessment is an evaluation of the toxicity of the COPCs by an assessment of the
29 relationship between the dose of a contaminant and the occurrence of toxic effects. Contaminant toxicity
30 criteria, which are based on this relationship, consider both cancer effects and effects other than cancer
31 (non-cancer effects). The toxicity criteria are required in order to quantify the potential health risks due to
32 the COPCs. Only cancer effects are of concern for the radionuclides (except for uranium); however,
33 a number of the nonradionuclide COPCs are considered toxic for their potential to induce cancer and
34 because of their non-cancer toxic effects.

35 **A8.4 Risk Characterization**

36 The last step in HHRA is a characterization of the health risks. The exposure factors, media
37 concentrations, and toxicity criteria are combined to calculate health risks. Health risks are calculated
38 differently for contaminants that cause cancer and for contaminants that cause non-cancer effects. The
39 calculation of cancer risk assumes that no level of the contaminant is without some risk, whereas for
40 contaminants with non-cancer effects, a “threshold” dose exists. Risks (for cancer) and hazards (for
41 non-cancer effects) are calculated for a RME scenario for each pathway, a calculation that overestimates

1 risks for the majority of the population in order to ensure that public health is protected. Cancer risk
2 estimates represent the potential for cancer effects by estimating the probability of developing cancer over
3 a lifetime due to site exposures. Non-cancer hazards assume that there is a level of contaminant intake
4 that is not associated with an adverse health effect, even in sensitive individuals.

5 While different methods are used to calculate the dose from radionuclides and nonradionuclides
6 (as described in EPA 540/1-89/002), exposure assessment for both nonradionuclide contaminants and
7 radionuclides follow the same basic steps. However, in addition to the exposure pathways considered for
8 contaminants, external radiation is an important exposure pathway for radionuclides in surface soils. The
9 dermal absorption pathway is typically not a significant exposure pathway for radionuclides. It was not
10 considered in this risk assessment, as discussed in Section A3.1.3.1. For radionuclide exposures in soil,
11 the EPCs and site-specific information were entered into RESRAD Version 6.3 to determine risks.
12 RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive
13 materials (ANL/EAD-4). The RESRAD model requires site-specific soil concentrations and other
14 site-specific data to estimate radionuclide risk.

15 Soil risks were evaluated at four different waste sites, and groundwater risks were evaluated for three
16 concentrations for each COPC based on concentration ranges throughout the groundwater plumes. Thus,
17 soil risks are waste-site-specific, and groundwater risks are specific to concentration ranges but are
18 independent of location. Because a groundwater well could be drilled at any location and plume
19 configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the
20 best information for risk managers regarding the range of possible groundwater risks throughout the site.

21 Under current industrial land use and institutional controls, exposures to contaminants and radionuclides
22 in groundwater or soil are less likely, but still possible. Volatile or radiological emissions from the
23 subsurface are insignificant for a working population. Institutional controls prevent the use of impacted
24 groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of unimpacted soil. However, if
25 construction workers disturbed soil at depth at the 216-Z-1A Tile Field, 216-Z-8 French Drain, or
26 216-A-8 Crib, they could encounter COPCs. Under that unlikely scenario (existing institutional control
27 programs at Hanford are designed to prevent digging in impacted soil), health risks would exceed 10^{-4}
28 at the 216-Z-1A Tile Field and 216-A-8, Crib, indicating remedial action would be necessary (risks from
29 digging in soil at the 216-Z-8 French Drain were less than 10^{-6}). Risks from subsurface soil exposures at
30 the 216-Z-1A Tile Field were driven by plutonium-239, followed by plutonium-240, and then
31 americium-241. Risks from subsurface soil at 216-A-8 are driven by cesium-137. No nonradionuclides in
32 soil are a health concern for construction workers.

33 Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate
34 radioactive decay and ingrowth of daughter products. For the three Z Plant sites (216-Z-1A Tile Field,
35 216-Z-8 French Drain, and 216-Z-9 Trench), where risks are driven by plutonium-239, plutonium-240,
36 and americium-241 (true for all soil scenarios), cumulative risks at future time horizons are not
37 significantly different than current risks. This is due to the fact that the half-lives of the plutonium
38 contaminants are long (or, in the case of the future well driller and future subsistence farmer, risks at
39 150 years are not very different than risks at 500 and 1,000 years). However, americium-241 risks do
40 decline significantly over 1,000 years. At the 216-A-8 Crib where cesium-137 is the risk driver for all soil
41 scenarios, risks are significantly lower at future time horizons due to the relatively short half-life of
42 cesium-137 (approximately 30 years). Although construction worker exposures were not quantified at the
43 216-Z-9 Trench due to the depth to impacted soil and the concrete cover over the site, if exposure to the
44 soils beneath the bottom of the trench were ever to occur, risks would likely exceed 10^{-4} .

1 Because future subsistence farmer, well driller, or regular worker groundwater exposures are assumed not
2 to occur until at least the year 2150, radiological concentrations in soil for these populations were
3 modeled assuming 150 years of decay (although, as noted above, this assumption does not make
4 a difference for the Z Plant sites). Two of the three radionuclides selected as COPCs in groundwater,
5 technetium-99 and iodine-129, have very long half-lives (213,000 years and 16 million years,
6 respectively) and future concentrations would not be different from current concentrations. However, the
7 third radionuclide COPC, tritium, will be at concentrations that are below a health concern within
8 150 years. Specifics of the post-2150 unrestricted land use scenario are below:

- 9 • Future well driller risks were much less than those for construction workers and did not exceed 10^{-4} .
10 Driller risks were the highest at the 216-Z-9 Trench (2×10^{-5}).
- 11 • Future workers drinking groundwater at their place of employment exceeded a risk level of 10^{-4} only
12 for carbon tetrachloride at the 90th and 50th percentile concentrations. Four additional COPCs
13 (technetium-99, tritium, PCE, and chloroform) exceed a 1×10^{-6} risk level at the 90th percentile.
14 Carbon tetrachloride was also the only contaminant with a non-cancer hazard above the target goal
15 of 1.
- 16 • Future residents exposed to drill cuttings in their home yard had risks similar to those for construction
17 workers. Risks from direct soil exposure were above 10^{-4} for all soil sites, except the 216-Z-8 French
18 Drain where risks were 3×10^{-6} .
- 19 • Future residents drinking groundwater exceeded a risk level of 10^{-4} only for carbon tetrachloride at
20 the 90th and 50th percentile concentrations. Radionuclide risks were highest for technetium-99
21 (8×10^{-5}). Tritium concentrations will decay to levels less than 10^{-6} risk in 150 years. Non-cancer
22 hazards are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In
23 addition, hexavalent chromium, nitrate, and TCE all have non-cancer hazards above the target goal of
24 1 at the 90th percentile groundwater concentration. Carbon tetrachloride's HI is two orders of
25 magnitude higher than any other contaminant's HI.
- 26 • Future residents exposed to contaminants through their food chain would have risks greater than 10^{-4}
27 (all sites except the 216-Z-8 French Drain) and as high as 1×10^{-1} (216-Z-9 Trench) primarily due to
28 growing produce in contaminated soils (plutonium-239 and plutonium-240 are risk drivers), although
29 eating produce irrigated with impacted groundwater resulted in risks in the 1×10^{-2} range. For
30 produce irrigated with groundwater, carbon tetrachloride had the highest produce ingestion risks
31 (1×10^{-2}), followed by technetium-99 (3×10^{-3}). Risks from the dairy products pathway exceed 10^{-4} ,
32 and the risks from eating beef are below 10^{-4} .
- 33 • Carbon tetrachloride is currently the risk driver for all groundwater pathways (two orders of
34 magnitude higher than most other contaminants), with the exception of the dairy products and meat
35 pathways, where risks from technetium-99 are the highest. In the future (post-150 years),
36 technetium-99 is likely to be the risk-driving contaminant in groundwater due to the natural
37 degradation of carbon tetrachloride at much faster rates than are expected for technetium-99.

38 In summary, risks from exposure to soils at the 216-Z-8 French Drain are below levels that are a health
39 concern. Risks from soil exposures at the 216-Z-1A Tile Field and 216-A-8 Crib are similar and exceed
40 1×10^{-4} for construction workers and subsistence farmers. Risks from soil exposures at the 216-Z-9
41 Trench were the highest for the four waste sites evaluated, with risks exceeding 1×10^{-1} for subsistence
42 farmers. Risks for future well drillers at all four soil sites were below 10^{-4} . Plutonium-239 and
43 americium-241, followed by plutonium-240, were the risk drivers in soil for the Z Plant sites. Cesium-137
44 was the risk driver in soil at the 216-A-8 Crib.

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

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

11 **A8.5 Uncertainties in Risk Assessment**

12 Estimating and evaluating health risk from exposure to environmental contaminants is a complex process
13 with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions
14 must be made to quantify health risks.

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

22 There are uncertainties regarding the quantification of health risks in terms of several assumptions about
23 exposure and toxicity, including site-specific and general uncertainties, particularly for the food chain
24 pathways. Based on the anticipation of uncertainty when quantifying exposure and toxicity, the health
25 risks and hazards presented in this risk assessment are more likely to overestimate risk.

26 Section A6.0 provides a detailed assessment of the uncertainties inherent in the risk assessment process,
27 as well as the uncertainties that are specific to this risk assessment.

28 **A8.6 Risk-Based Concentrations**

29 Although risks were calculated under both a current and future industrial land use scenario, as well as for
30 a future unrestricted land use scenario, cleanup goals and decisions will generally be based on industrial
31 land use exposures as consistent with the current industrial nature of the site. Therefore, the RBCs were
32 calculated based only on industrial land use. These levels may be used in the FS process to evaluate
33 remedial options. For groundwater, RBCs are based on future regular workers drinking the water and for
34 soil are based on the current construction worker.

35 The RBCs for current construction workers were calculated for four radionuclides (americium-241,
36 plutonium-239, plutonium-240, and cesium-137) because these constituents exceed the 10^{-4} target cancer
37 risk level. For groundwater used post-2150 under an industrial land use scenario, for future regular
38 worker exposures to drinking water, only carbon tetrachloride exceeds 10^{-4} and is also the only
39 contaminant with a non-cancer HI >1. Therefore, a future regular worker RBC was calculated only for
40 carbon tetrachloride.

41 The RBCs for each of the risk drivers were calculated to be protective of the cancer risk level of 1×10^{-4} ,
42 or an HI of 1, whichever was lower. Combined exposures to each of the risk drivers at the RBCs could

1 result in an exceedance of target health goals. For example, if concentrations of the two radionuclide risk
2 drivers in soil are present at the same location as the RBC concentrations, the soil exposure would result
3 in a cumulative cancer risk of 2×10^{-4} . Nevertheless, RBCs were not adjusted downward to account for
4 cumulative exposures because risk drivers may not all be present at the same location, nor may the high
5 concentrations of the risk drivers be collocated with each other. Therefore, risk managers will address
6 cumulative exposures to the COPCs when applying RBCs at specific locations in the evaluation of the
7 protectiveness of various remedies during the FS process, a downward adjustment to account for
8 cumulative exposures will be made, if necessary.

A9 References

- 1
2 10 CFR 20, Subpart E, "Standards for Protection Against Radiation," *Code of Federal Regulations*.
3 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of*
4 *Federal Regulations*.
5 ACS, 2001, *Cancer Facts and Figures – 2001*, American Cancer Society, Atlanta, Georgia.
6 AFIERA, 2001, *Critique of the U.S. Environmental Protection Agency's Draft Trichloroethylene Health*
7 *Risk Assessment (EPA/600/P-01/002A)*, dated December 2001, Air Force Institute for
8 Environment, Safety, and Occupational Health Risk Analysis, Brooks Air Force Base, Texas.
9 ANL/EAD-4, 2001, *User's Manual for RESRAD Version 6*, Environmental Assessment Division,
10 Argonne National Laboratory, Argonne, Illinois.
11 ARH-2915, 1973, *Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench*, Atlantic Richfield
12 Hanford, Richland, Washington.
13 ATSDR, 2005, *Toxicological Profile for Carbon Tetrachloride*, dated August 2005, U.S. Department of
14 Health and Human Services, Agency for Toxic Substances and Disease Registry,
15 Washington, D.C.
16 BRER-K-97-01-A, 1990, *Health Effects of Exposure to Low Levels of Ionizing Radiation, Committee on*
17 *the Biological Effects of Ionizing Radiation (BEIR V)*, National Academy of Sciences,
18 Washington, D.C.
19 CERCLA, *Comprehensive Environmental Response, Compensation, and Liability Act of 1989*,
20 42 U.S.C. 103, et seq.
21 CP-16151, 2007, *Data Quality Objectives Summary Report Supporting the 200-ZP-1 Operable Unit*
22 *Remedial Investigation/Feasibility Study Process*, Fluor Hanford, Inc., Richland, Washington.
23 DOE-EM/GJ918-2005, 2005, *299-W15-59 (A7360) Log Data Report*, U.S. Department of Energy, Grand
24 Junction Office, Grand Junction, Colorado.
25 DOE-EM/GJ919-2005, 2005, *299-W15-60 (A7361) Log Data Report*, U.S. Department of Energy, Grand
26 Junction Office, Grand Junction, Colorado.
27 DOE-EM/GJ920-2005, 2005, *299-W15-61 (A7362) Log Data Report*, U.S. Department of Energy, Grand
28 Junction Office, Grand Junction, Colorado.
29 DOE/RL-91-45, 1995, *Hanford Site Risk Assessment Methodology*, Rev. 3, U.S. Department of Energy,
30 Richland Operations Office, Richland, Washington.
31 DOE/RL-92-24, 2001, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*,
32 Rev. 4, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
33 DOE/RL-96-12, 1996, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, Rev. 0,
34 U.S. Department of Energy, Richland Operations Office, Richland, Washington.
35 DOE/RL-96-24, 1996, *Radioactive Air Emission Notice of Construction Use of a Portable Exhauster on*
36 *241-A-101 Tank During Saltwell Pumping and Other Routine Activities*, U.S. Department of
37 Energy, Richland Operations Office, Richland, Washington.

- 1 DOE/RL-96-61, 1997, *Hanford Site Background: Part 3, Groundwater Background*, Rev. 0,
2 U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- 3 DOE/RL-2003-55, 2004, *Remedial Investigation Work Plan for 200-ZP-1 Groundwater Operable Unit*,
4 *Hanford*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland,
5 Washington.
- 6 DOE/RL-2005-37, 2005, *Status of Hanford Site Risk Assessment Integration, FY 2005*, Rev. 0,
7 U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- 8 DOE/RL-2006-24, 2006, *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit*,
9 Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- 10 DOE/RL-2006-51, 2006, *Remedial Investigation Report for the Plutonium/Organic-Rich Process*
11 *Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and*
12 *200-PW-6 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office,
13 Richland, Washington.
- 14 DOE/RL-2008-01, 2008, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*, Rev. 0,
15 U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- 16 EPA, 1999, *Memorandum re: Distribution of OSWER Radiation Risk Assessment Q&A's, Final*
17 *Guidance*, dated December 17, 1999, U.S. Environmental Protection Agency, Office of
18 Radiation and Indoor Air, Washington, D.C.
- 19 EPA, 2001, *Trichloroethylene Health Risk Assessment: Synthesis and Characterization*, External Review
20 Preliminary Draft, dated August 1, 2001, U.S. Environmental Protection Agency,
21 Washington, D.C.
- 22 EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, U.S. Environmental Protection
23 Agency, Washington, D.C. Available at: <http://www.epa.gov/iris/index.html>.
- 24 EPA 8EPR-PS, 1999, *Derivation of a Volatilization Factor to Estimate Upper Bound Exposure Point*
25 *Concentration for Workers in Trenches Flooded with Groundwater Off-Gassing Volatile*
26 *Organic Contaminants*, dated July 29, 1999, U.S. Environmental Protection Agency,
27 Region 8, Denver, Colorado.
- 28 EPA 402-R-93-081, 1993, *External Exposure to Radionuclides in Air, Water, and Soil*, Federal Guidance
29 Report No. 12, U.S. Environmental Protection Agency, Washington, D.C.
- 30 EPA 402-R-99-001, 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*,
31 Federal Guidance Report No. 13, U.S. Environmental Protection Agency, Office of Radiation
32 and Indoor Air, Washington, D.C.
- 33 EPA-520/1-88-020, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose*
34 *Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report
35 No. 11, U.S. Environmental Protection Agency, Washington, D.C.
- 36 EPA 530-F-02-052, 2002, *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway*
37 *from Groundwater and Soils*, U.S. Environmental Protection Agency, Washington, D.C.
- 38 EPA 540/1-89/002, 1989, *Risk Assessment Guidance for Superfund: Volume 1 - Human Health*
39 *Evaluation Manual, Part A, Interim Final*, U.S. Environmental Protection Agency, Office of
40 Emergency and Remedial Response, Washington, D.C.

- 1 EPA/540-R-00-006, 2000, *Soil Screening Guidance for Radionuclides: Technical Background Document*,
2 OSWER Directive 9355.4-16, U.S. Environmental Protection Agency, Office of Solid Waste
3 and Emergency Response, Washington, D.C.
- 4 EPA/540/R-95/128, 1996, *Soil Screening Guidance: Technical Background Document*,
5 U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response,
6 Washington, D.C.
- 7 EPA 540/R-97-036, 1997, *Health Effects Assessment Summary Tables*, U.S. Environmental Protection
8 Agency, Office of Emergency and Remedial Response, Washington, D.C.
- 9 EPA 540/R/99/05, 2004, *Final Risk Assessment Guidance for Superfund Volume I: Human Health*
10 *Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*, OSWER
11 Directive 9285.7-02EP, dated July 2004, U.S. Environmental Protection Agency,
12 Washington, D.C.
- 13 EPA/600/8-85/002, 1985, *Rapid Assessment of Exposure to Particulate Emissions from Surface*
14 *Contamination*, NTIS PB85-192219, U.S. Environmental Protection Agency, Office of Health
15 and Environmental Assessment, Washington, D.C.
- 16 EPA/600/8-89/043, 1989, *Exposure Factors Handbook*, Office of Health and Environmental Assessment,
17 U.S. Environmental Protection Agency, Washington, D.C.
- 18 EPA/600/P-92/003C, 1996, *Proposed Guidelines for Carcinogen Risk Assessment*, U.S. Environmental
19 Protection Agency, Office of Research and Development, Washington, D.C.
- 20 EPA/600/P-95-002Fa, 1997, *Exposure Factors Handbook*, Volumes I–III, update to *Exposure Factors*
21 *Handbook*, EPA/600/8-89/043 (May 1989), dated August 1997, U.S. Environmental
22 Protection Agency, Washington, D.C.
- 23 EPA/600/R04/079, 2004, *ProUCL Version 3.0 User Guide*, U.S. Environmental Protection Agency,
24 Office of Research and Development, Washington, D.C.
- 25 EPA/600/R-05/062F, 2007, *Analysis of Total Food Intake and Composition of Individual's Diet Based on*
26 *USDA's 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII)*,
27 U.S. Environmental Protection Agency, Washington, D.C.
- 28 EPA/600/R-97/006, 1997, *The Lognormal Distribution in Environmental Applications*, EPA Technology
29 Support Center Issue, U.S. Environmental Protection Agency, Office of Research and
30 Development, Washington, D.C.
- 31 EPA/630/P-02/002F, 2002, *A Review of the Reference Dose and Reference Concentration Processes,*
32 *Final Report*, U.S. Environmental Protection Agency, Washington, D.C.
- 33 EPA/630/P-03/001F, 2005, *Guidelines for Carcinogen Risk Assessment*, U.S. Environmental Protection
34 Agency, Washington, D.C.
- 35 EPA 910/R-98-001, 1998, *EPA Region 10, Interim Final Guidance: Developing Risk-Based Cleanup*
36 *Levels at Resource Conservation and Recovery Act Sites in Region 10*, U.S. Environmental
37 Protection Agency, Washington, D.C.
- 38 EPA Region 6, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and*
39 *Supplemental Information*, dated December 14, 2006, U.S. Environmental Protection Agency,
40 Region 6, Dallas, Texas.

- 1 EPA Region 9, 2004, *U.S. EPA Region 9 Preliminary Remediation Goal (PRG) Table and Supplemental*
2 *Information*, dated October 2004, U.S. Environmental Protection Agency, Region 9,
3 San Francisco, California.
- 4 Habicht, H., 1992, *Guidance on Risk Characterization for Risk Managers and Risk Assessors*, dated
5 February 26, 1992, U.S. Environmental Protection Agency, Office of the Administrator,
6 Washington, D.C.
- 7 Harris, S., and B. Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*, dated
8 September 15, 2004, Confederated Tribes of the Umatilla Indian Reservation, Department of
9 Science and Engineering, Pendleton, Oregon.
- 10 Hewitt, A. D., 1994, "Dynamic Study of Common Well Screen Materials" in *Ground Water Monitoring*
11 *Review*, Winter 1994, pp. 87-94.
- 12 HW-9671, 1948, *Underground Waste Disposal at Hanford Works*, General Electric,
13 Richland, Washington.
- 14 HW-23769, 1952, *Calculation Constants Used by Regional Survey*, General Electric,
15 Richland, Washington.
- 16 ICRP Publication 60, 1990, *Recommendations of the International Commission on Radiological*
17 *Protection*, International Commission on Radiological Protection, Stockholm, Sweden.
- 18 LANL, 2006, *Laboratory Receive Latest Data on Chromium in Regional Aquifer*, dated March 2006 at
19 www.lanl.gov/news/index.php/fuseaction/home.story/story_id/8097, Los Alamos National
20 Laboratory, Los Alamos, New Mexico.
- 21 Marratt, M. C., A. E. Van Luik, and R. B. Kasper, 1984, *The 216-Z-8 French Drain Characterization*
22 *Study*, dated September 1984, prepared for the U.S. Department of Energy, Richland
23 Operations Office, Richland, Washington.
- 24 McKone, T. E., 1994, "Uncertainty and Variability in Human Exposures to Soil Contaminants Through
25 Home-Grown Food: a Monte Carlo Assessment," in *Risk Anal.*, 14(4):449-463.
- 26 NCRP Report No. 126, 1997, *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection*,
27 National Council on Radiation Protection and Measurements, Bethesda, Maryland.
- 28 ODEQ, 2000, *Final Guidance for Conduct of Deterministic Human Health Risk Assessments*, dated
29 May 2000, Oregon State Department of Environmental Quality, Portland, Oregon.
- 30 OEHHA, 1999, *Public Health Goal for Trichloroethylene in Drinking Water*, dated February 1999,
31 California Office of Environmental Health Hazard Assessment, Sacramento, California.
- 32 OEHHA, 2002, *Technical Support Document for Describing Available Cancer Potency Factors*, dated
33 December 2002, California Office of Environmental Health Hazard Assessment, Air
34 Toxicology and Epidemiology Section, Sacramento, California.
- 35 OSWER Directive No. 9200.4-18, 1997, *Establishment of Cleanup Levels for CERCLA Sites with*
36 *Radioactive Contamination*, U.S. Environmental Agency, Office of Solid Waste and
37 Emergency Response, Washington, D.C.

- 1 OSWER Directive 9285.6-03, 1991, *Risk Assessment Guidance for Superfund: Volume 1 - Human Health*
2 *Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors, Interim*
3 *Final*, U.S. Environmental Agency, Office of Solid Waste and Emergency Response,
4 Washington, D.C.
- 5 OSWER Directive 9285.6-10, 2002, *Calculating Upper Confidence Limits for Exposure Point*
6 *Concentrations at Hazardous Waste Sites*, U.S. Environmental Protection Agency, Office of
7 Solid Waste and Emergency Response, Washington, D.C.
- 8 OSWER Directive 9285.7-081, 1992, *Supplemental Guidance to RAGS: Calculating the Concentration*
9 *Term*, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency
10 Response, Washington, D.C.
- 11 OSWER Directive 9285.7-01B, 1991, *Risk Assessment Guidance for Superfund, Volume 1: Human*
12 *Health Evaluation Manual, Development of Risk-Based Preliminary Remediation Goals*
13 *(Part B)*, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency
14 Response, Washington, D.C.
- 15 OSWER Directive 9285.7-09A, 1992, *Final Guidance for Data Usability in Risk Assessment, Parts A and*
16 *B*, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response
17 Washington, D.C.
- 18 OSWER Directive 9285.7-53, 2003, *Human Health Toxicity Values in Superfund Risk Assessments*,
19 memorandum from M. B. Cook (Director, Office of Superfund Remediation and Technology
20 Innovation) to Superfund National Policy Managers, Regions 1-10, dated December 5, 2003,
21 U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response,
22 Washington, D.C.
- 23 OSWER Directive 9355.0-30, 1991, *Role of the Baseline Risk Assessment in Superfund Remedy Selection*
24 *Decisions*, U.S. Environmental Protection Agency, Office of Emergency and Remedial
25 Response, Washington, D.C.
- 26 OSWER Directive 9355.4-24, 2002, *Supplemental Guidance for Developing Soil Screening Levels for*
27 *Superfund Sites*, U.S. Environmental Protection Agency, Office of Solid Waste and
28 Emergency Response, Washington, D.C.
- 29 PNNL-15892, 2006, *Hanford Site Environmental Report for Calendar Year 2005*, Pacific Northwest
30 National Laboratory, Richland, Washington.
- 31 *ProUCL Version 3.00.02*, accessed in April 2004. Available at:
32 <http://www.epa.gov/nerlesd1/tsc/form.htm>, U.S. Environmental Protection Agency,
33 Washington, D.C.
- 34 RHO-RE-EV-46P, 1984, *The 216-2-8 French Drain Study*, Rockwell Hanford Operations,
35 Richland, Washington.
- 36 Ridolfi Inc., 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment*, prepared for the
37 Yakama Nation, Richland, Washington.
- 38 Rittman, P. D., 2004, *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance*
39 *Assessment*, Rev. 4, U.S. Department of Energy, Richland Operations Office,
40 Richland, Washington.

- 1 Stanek, E .J., E. J. Calabrese, R. Barnes, and P. Pekow, 1997, *Soil Ingestion in Adults – Results of*
2 *a Second Pilot Study*, dated July 22, 1996, Department of Biostatistics and Epidemiology and
3 Department of Environmental Health Sciences, School of Public Health and Health Sciences,
4 and Chemistry Department, University of Massachusetts, Amherst, Massachusetts.
- 5 WAC 173-340, “Model Toxics Control Act – Cleanup,” *Washington Administrative Code*.
- 6 WAC 296-841-20025, Washington State Industrial Safety and Health Act (WISHA), “Airborne
7 Contaminants,” *Washington Administrative Code*.

APPENDIX A

ATTACHMENT 1

**PROUCL OUTPUTS FOR CONTAMINANTS
OF POTENTIAL CONCERN IN SOIL**

ATTACHMENT 1

TABLE OF CONTENTS

216-Z-1A Tile Field

Table 1-1 ProUCL Output Summary for 216-Z-1A Tile Field – Resident and Driller Concentration in Waste

Table 1-2 ProUCL Output Summary for 216-Z-1A Tile Field - Construction Soil

216-Z-8 French Drain

Table 1-3 ProUCL Output Summary for 216-Z-8 French Drain Soil

216-Z-9 Trench

Table 1-4 ProUCL Output Summary for 216-Z-9 Trench–Resident and Driller Concentration in Waste

216-A-8 Crib

Table 1-5 ProUCL Output Summary for 216-A-8 Crib–Resident and Driller Concentration in Waste

216-Z-1A Tile Field

Table 1-1. ProUCL Output Summary for 216-Z-1A Tile Field-Resident and Driller Concentration in Waste.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241 (ingrowth)	122,527.6	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	458	-0.0872	5,180,000	61,113.03	41.3	301,527.7	4.933935	12.63184	9.09E+10
Pu-239/240	698,677.7	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	423	-125	38,200,000	235,363.4	6.45	2,186,095	9.28817	14.64864	4.78E+12

Data File

Variable: Am-241 ingrowth

Raw Statistics

Number of Valid Samples	458
Number of Unique Samples	393
Minimum	-0.0872
Maximum	5,180,000
Mean	61,113.03
Median	41.3
Standard Deviation	301,527.7
Variance	9.09E+10
Coefficient of Variation	4.933935
Skewness	12.63184

Normal Distribution Test

Lilliefors Test Statistic	0.419693
Lilliefors 5% Critical Value	0.0414
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)

Student's-t UCL	84,335.21
-----------------	-----------

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	84,288.14
Adj-CLT UCL (Adjusted for skewness)	93,174.19
Mod-t UCL (Adjusted for skewness)	85,721.25
Jackknife UCL	84,335.21
Standard Bootstrap UCL	84,431.08
Bootstrap-t UCL	104,477.9
Hall's Bootstrap UCL	184,676.7
Percentile Bootstrap UCL	87,392.24
BCA Bootstrap UCL	96,583.27
95% Chebyshev (Mean, Sd) UCL	122,527.6
97.5% Chebyshev (Mean, Sd) UCL	149,101.7
99% Chebyshev (Mean, Sd) UCL	201,301.4

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z_1A\COPY of
 SoiltoLoadZ-1A_NBR_02.20.06-
 Data File hak.xls

Variable: Pu-239-240

Raw	
Statistics	
Number of Valid Samples	423
Number of Unique Samples	351
Minimum	-125
Maximum	38,200,000
Mean	235,363.4
Median	6.45
Standard Deviation	2,186,095
Variance	4.78E+12
Coefficient of Variation	9.28817
Skewness	14.64864

Normal Distribution Test	
Lilliefors Test Statistic	0.457108
Lilliefors 5% Critical Value	0.043079
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	410,582.1

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs	
CLT UCL	410,197.5
Adj-CLT UCL (Adjusted for skewness)	491,089.7
Mod-t UCL (Adjusted for skewness)	423,199.7
Jackknife UCL	410,582.1
Standard Bootstrap UCL	410,576.2
Bootstrap-t UCL	941,103
Hall's Bootstrap UCL	1,016,959
Percentile Bootstrap UCL	435,919.5
BCA Bootstrap UCL	530,598.1
95% Chebyshev (Mean, Sd) UCL	698,677.7
97.5% Chebyshev (Mean, Sd) UCL	899,154.1
99% Chebyshev (Mean, Sd) UCL	1,292,951

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Table 1-2. ProUCL Output Summary for 216-Z-1A Tile Field–Construction Soil.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241(ingrowth)	2,028,358	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	0	5,180,000	596,009.2	14,500	1,354,866	2.27323	2.916279	1.84E+12
Pu-239/240	15,509,199	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	-0.185	38,200,000	4,838,800	305,000	10,093,187	2.085886	2.762745	1.02E+14

NOTE: Includes data from 0 to 15 ft.

Data File

Variable: Am-241 0to15

Raw Statistics

Number of Valid Samples	17
Number of Unique Samples	17
Minimum	0
Maximum	5,180,000
Mean	596,009.2
Median	14,500
Standard Deviation	1,354,866
Variance	1.84E+12
Coefficient of Variation	2.27323
Skewness	2.916279

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.517712
Shapiro-Wilk 5% Critical Value	0.892
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	1,169,712

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	1,136,513
Adj-CLT UCL (Adjusted for skewness)	1,384,859
Mod-t UCL (Adjusted for skewness)	1,208,449
Jackknife UCL	1,169,712
Standard Bootstrap UCL	1,115,963
Bootstrap-t UCL	2,711,884
Hall's Bootstrap UCL	3,256,298
Percentile Bootstrap UCL	1,197,557
BCA Bootstrap UCL	1,374,380
95% Chebyshev (Mean, Sd) UCL	2,028,358
97.5% Chebyshev (Mean, Sd) UCL	2,648,136
99% Chebyshev (Mean, Sd) UCL	3,865,571

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Soil Data\Z_1A\
Copy of SoiltoLoadZ-
Data File 1A_NBR_02.20.06- hak.xls Variable: Pu-239-240

Raw		Normal Distribution Test	
Statistics			
Number of Valid Samples	17	Shapiro-Wilk Test Statistic	0.557117
Number of Unique Samples	17	Shapiro-Wilk 5% Critical Value	0.892
Minimum	-0.185	Data not normal at 5% significance level	
Maximum	38,200,000	95% UCL (Assuming Normal Distribution)	
Mean	4,838,800	Student's-t UCL	9,112,648
Median	305,000		
Standard Deviation	10,093,187		
Variance	1.02E+14		
Coefficient of Variation	2.085886		
Skewness	2.762745		

Gamma Statistics Not Available

Lognormal Statistics Not Available

RECOMMENDATION		95% Non-parametric UCLs	
Data are Non-parametric (0.05)		CLT UCL	8,865,331
		Adj-CLT UCL (Adjusted for skewness)	10,618,003
		Mod-t UCL (Adjusted for skewness)	9,386,030
		Jackknife UCL	9,112,648
		Standard Bootstrap UCL	8,892,804
		Bootstrap-t UCL	18,764,160
		Hall's Bootstrap UCL	25118717
		Percentile Bootstrap UCL	9,089,027
		BCA Bootstrap UCL	10,787,012
Use 95% Chebyshev (Mean, Sd) UCL		95% Chebyshev (Mean, Sd) UCL	15,509,199
		97.5% Chebyshev (Mean, Sd) UCL	20,126,289
		99% Chebyshev (Mean, Sd) UCL	29,195,668

216-Z-8 French Drain

Table 1-3. ProUCL Output Summary for 216-Z-8 French Drain Soil.

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241	457	pCi/g	Gamma	Maximum, adjusted gamma exceeds max	8	0.0901	457	110.5145	4.9955	189.3509	1.713358	1.4757375	35,853.755
Pu-238	77.5	pCi/g	Gamma	Maximum, adjusted gamma exceeds max	8	0.0143	77.5	10.80115	0.491	27.02562	2.502106	2.7980155	730.38421
Pu-239/240	4,620	pCi/g	Gamma	Maximum, adjusted gamma exceeds max	8	0.92	4,620	1,183.251	45.1	2,060.368	1.741276	1.4303542	4,245,114.6

NOTE: Includes data from 17 to 35 ft bgs

Data File Z:\Hanford\Z-8\COPY of Z-8_SlData.xls Variable: Am241

Raw Statistics

Number of Valid Samples	8
Number of Unique Samples	8
Minimum	0.0901
Maximum	457
Mean	110.5145
Median	4.9955
Standard Deviation	189.3509
Variance	35,853.75
Coefficient of Variation	1.713358
Skewness	1.475738

Gamma Statistics

k hat	0.209537
k star (bias corrected)	0.214294
Theta hat	527.4235
Theta star	515.7152
nu hat	3.352585
nu star	3.428699
Approx. Chi Square Value (.05)	0.509773
Adjusted Level of Significance	0.01946
Adjusted Chi Square Value	0.299402

Log-transformed Statistics

Minimum of log data	-2.40684
Maximum of log data	6.124683
Mean of log data	1.218547
Standard Deviation of log data	3.748667
Variance of log data	14.0525

RECOMMENDATION
 Data follow gamma distribution (0.05)

 Use Adjusted Gamma UCL

Recommended UCL exceeds the maximum observation

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.645095
Shapiro-Wilk 5% Critical Value	0.818
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)

Student's-t UCL	237.3483
-----------------	----------

Gamma Distribution Test

A-D Test Statistic	0.701619
A-D 5% Critical Value	0.832197
K-S Test Statistic	0.294748
K-S 5% Critical Value	0.322703

Data follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	743.3133
Adjusted Gamma UCL	1,265.592

Lognormal Distribution Test

Shapiro-Wilk Test Statistic	0.820202
Shapiro-Wilk 5% Critical Value	0.818
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	4.49E+10
95% Chebyshev (MVUE) UCL	1,230.399
97.5% Chebyshev (MVUE) UCL	1,658.203
99% Chebyshev (MVUE) UCL	2,498.541

95% Non-parametric UCLs

CLT UCL	220.6303
Adj-CLT UCL (Adjusted for skewness)	257.9525
Mod-t UCL (Adjusted for skewness)	243.1698
Jackknife UCL	237.3483
Standard Bootstrap UCL	213.3997
Bootstrap-t UCL	1,336.548
Hall's Bootstrap UCL	1,876.583
Percentile Bootstrap UCL	224.7306
BCA Bootstrap UCL	242.6668
95% Chebyshev (Mean, Sd) UCL	402.3238
97.5% Chebyshev (Mean, Sd) UCL	528.5899
99% Chebyshev (Mean, Sd) UCL	776.6153

Data File Z:\Hanford\Z-8\Coppy of Z-8_SlData.xls Variable: Pu238

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	8	Shapiro-Wilk Test Statistic	0.471093
Number of Unique Samples	8	Shapiro-Wilk 5% Critical Value	0.818
Minimum	0.0143	Data not normal at 5% significance level	
Maximum	77.5	95% UCL (Assuming Normal Distribution)	
Mean	10.80115	Student's-t UCL	28.90385
Median	0.491	Gamma Distribution Test	
Standard Deviation	27.02562	A-D Test Statistic	0.65109
Variance	730.3842	A-D 5% Critical Value	0.82033
Coefficient of Variation	2.502106	K-S Test Statistic	0.255249
Skewness	2.798016	K-S 5% Critical Value	0.320749
Gamma Statistics		Data follow gamma distribution at 5% significance level	
k hat	0.240264	95% UCLs (Assuming Gamma Distribution)	
k star (bias corrected)	0.233498	Approximate Gamma UCL	65.08649
Theta hat	44.9553	Adjusted Gamma UCL	108.3981
Theta star	46.25791	Lognormal Distribution Test	
nu hat	3.844227	Shapiro-Wilk Test Statistic	0.963939
nu star	3.735975	Shapiro-Wilk 5% Critical Value	0.818
Approx. Chi Square Value (.05)	0.619988	Data are lognormal at 5% significance level	
Adjusted Level of Significance	0.01946	95% UCLs (Assuming Lognormal Distribution)	
Adjusted Chi Square Value	0.372265	95% H-UCL	453,060
Log-transformed Statistics		95% Chebyshev (MVUE) UCL	41.18952
Minimum of log data	-4.2475	97.5% Chebyshev (MVUE) UCL	55.22036
Maximum of log data	4.350278	99% Chebyshev (MVUE) UCL	82.78123
Mean of log data	-0.59559	95% Non-parametric UCLs	
Standard Deviation of log data	2.857899	CLT UCL	26.51773
Variance of log data	8.167585	Adj-CLT UCL (Adjusted for skewness)	36.61761
RECOMMENDATION		Mod-t UCL (Adjusted for skewness)	30.47922
Data follow gamma distribution (0.05)		Jackknife UCL	28.90385
Use Adjusted Gamma UCL		Standard Bootstrap UCL	25.04163
Recommended UCL exceeds the maximum observation		Bootstrap-t UCL	499.2393
		Hall's Bootstrap UCL	269.2376
		Percentile Bootstrap UCL	29.41486
		BCA Bootstrap UCL	39.56836
		95% Chebyshev (Mean, Sd) UCL	52.45043
		97.5% Chebyshev (Mean, Sd) UCL	70.47211
		99% Chebyshev (Mean, Sd) UCL	105.8722

Data File Z:\Hanford\Z-8\Coppy of Z- Variable: Pu239

8_SIData.xls

Raw Statistics	
Number of Valid Samples	8
Number of Unique Samples	8
Minimum	0.92
Maximum	4,620
Mean	1,183.251
Median	45.1
Standard Deviation	2,060.368
Variance	4,245,115
Coefficient of Variation	1.741276
Skewness	1.430354

Gamma Statistics	
k hat	0.213146
k star (bias corrected)	0.21655
Theta hat	5,551.355
Theta star	5,464.106
nu hat	3.410342
nu star	3.464797
Approx. Chi Square Value (.05)	0.522252
Adjusted Level of Significance	0.01946
Adjusted Chi Square Value	0.307486

Log-transformed Statistics	
Minimum of log data	-0.08338
Maximum of log data	8.43815
Mean of log data	3.657681
Standard Deviation of log data	3.595035
Variance of log data	12.92428

RECOMMENDATION
Data follow gamma distribution (0.05)

Use Adjusted Gamma UCL

Recommended UCL exceeds the maximum observation

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.60902
Shapiro-Wilk 5% Critical Value	0.818
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	2,563.357

Gamma Distribution Test	
A-D Test Statistic	0.714831
A-D 5% Critical Value	0.830803
K-S Test Statistic	0.286701
K-S 5% Critical Value	0.322474

Data follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	7,850.098
Adjusted Gamma UCL	13,333.07

Lognormal Distribution Test	
Shapiro-Wilk Test Statistic	0.847747
Shapiro-Wilk 5% Critical Value	0.818
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	8.02E+10
95% Chebyshev (MVUE) UCL	10,667.69
97.5% Chebyshev (MVUE) UCL	14,368.31
99% Chebyshev (MVUE) UCL	21,637.47

95% Non-parametric UCLs	
CLT UCL	2,381.445
Adj-CLT UCL (Adjusted for skewness)	2,775.066
Mod-t UCL (Adjusted for skewness)	2,624.754
Jackknife UCL	2,563.357
Standard Bootstrap UCL	2,314.488
Bootstrap-t UCL	20,653.06
Hall's Bootstrap UCL	28,524.89
Percentile Bootstrap UCL	2,306.136
BCA Bootstrap UCL	2,835.618
95% Chebyshev (Mean, Sd) UCL	4,358.491
97.5% Chebyshev (Mean, Sd) UCL	5,732.42
99% Chebyshev (Mean, Sd) UCL	8,431.237

216-Z-9 Trench

Table 1-4. ProUCL Output Summary for 216-Z-9 Trench–Resident and Driller Concentration in Waste.

From File

Z:\Hanford\Z-9\COPY of Z-9_SoilData_All_rev03.30.07 hak.xls

ProUCL

Variable Name	EPC	Units	Distribution	Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241	300,556	pCi/g	Gamma	Adjusted Gamma UCL	41	0.0045	3,713,432	141,568	40,000	576,536.8	4.072508	6.2428041	3.32E+11
Cd	22.39928	mg/kg	Gamma	Adjusted Gamma UCL	24	0.035	118	10.36946	2.545	24.89633	2.400929	3.8985018	619.8272
Carbon tet	99.44115	mg/kg	Non-parametric	99% Chebyshev (Mean, Sd) UCL	42	8.00E-05	380	9.512263	0.03225	58.57418	6.157755	6.4764679	3,430.935
Eu-152	74.62122	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	30	-0.091	350.5	19.4715	0.3075	69.29903	3.558998	4.3398745	4,802.356
Mn	738.3181	mg/kg	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24	157	2,240	374	296	409.4582	1.094808	4.4540946	167,656
Np-237	87.18264	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	23	-0.0015	252	29.22737	0.0685	63.76466	2.181676	2.6792333	4,065.931
Pu-238	2,884.77	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	24	-109	9,600	879.4467	3.05	2,253.789	2.562735	3.1484161	5,079,563
Pu-239/240	8,903,844	pCi/g	Lognormal	99% Chebyshev (Mean, Sd) UCL	25	0.001	20,296,010	834,963.9	2,260	4,054,765	4.856216	4.9984798	1.64E+13
Ra-226	17.2231	pCi/g	Non-parametric	99% Chebyshev (Mean, Sd) UCL	18	0.292	21.5	2.971333	0.739	6.076974	2.045201	2.7301023	36.92961
Ra-228	12.33369	pCi/g	Lognormal	95% Chebyshev (MVUE) UCL	18	0.145	33	5.308389	1.435	9.671092	1.821851	2.4620907	93.53002
Tc-99	99.82143	pCi/g	Non-parametric	97.5% Chebyshev (Mean, Sd) UCL	16	-2.385	272	25.53288	0.8675	68.17185	2.669964	3.5824985	4,647.401
Th-228	17.7264	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	31	-29.05	83	4.312452	1.025	17.13407	3.973162	3.2844905	293.5764
Th-230	19.2267	pCi/g	Normal	Student's-t UCL	14	-115.5	72	-1.23929	2.135	43.24088	-34.8918	-1.10746	1,869.773

Z:\Hanford\Soil 95 UCLs\
 Data File EPCS_Z-9(Historical Data) rev2.xls

Variable: AM-241 (ingrowth)

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	41	Shapiro-Wilk Test Statistic	0.239062
Number of Unique Samples	41	Shapiro-Wilk 5% Critical Value	0.941
		Data not normal at 5% significance level	
Minimum	0.0045		
Maximum	3,713,432		
Mean	141,568	95% UCL (Assuming Normal Distribution)	
Median	40,000	Student's-t UCL	293,181.8
Standard Deviation	576,536.8		
Variance	3.32E+11	Gamma Distribution Test	
Coefficient of Variation	4.072508	A-D Test Statistic	1.117117
Skewness	6.242804	A-D 5% Critical Value	0.915467
		K-S Test Statistic	0.145628
		K-S 5% Critical Value	0.153484
		Data follow approximate gamma distribution at 5% significance level	
		95% UCLs (Assuming Gamma Distribution)	
		Approximate Gamma UCL	292,401.9
		Adjusted Gamma UCL	300,556.2
		Lognormal Distribution Test	
		Shapiro-Wilk Test Statistic	0.836863
		Shapiro-Wilk 5% Critical Value	0.941
		Data not lognormal at 5% significance level	
		95% UCLs (Assuming Lognormal Distribution)	
		95% H-UCL	2.70E+12
		95% Chebyshev (MVUE) UCL	5.99E+08
		97.5% Chebyshev (MVUE) UCL	8.09E+08
		99% Chebyshev (MVUE) UCL	1.22E+09
		95% Non-parametric UCLs	
		CLT UCL	289,670.5
		Adj-CLT UCL (Adjusted for skewness)	383,470.6
		Mod-t UCL (Adjusted for skewness)	307,812.7
		Jackknife UCL	293,181.8
		Standard Bootstrap UCL	298,645.2
		Bootstrap-t UCL	115,261.7
		Hall's Bootstrap UCL	798,834.7
		Percentile Bootstrap UCL	321,802.9
		BCA Bootstrap UCL	414,510.8
		95% Chebyshev (Mean, Sd) UCL	534,042.9
		97.5% Chebyshev (Mean, Sd) UCL	703,867.1
		99% Chebyshev (Mean, Sd) UCL	1,037,454
RECOMMENDATION			
Assuming gamma distribution (0.05)			
Use Adjusted Gamma UCL			

Z:\Hanford\Z-9\
Copy of Z-9_SoilData_All_rev03.30.07

Data File hak.xls

Variable: Cd

Raw Statistics	
Number of Valid Samples	24
Number of Unique Samples	22
Minimum	0.035
Maximum	118
Mean	10.36946
Median	2.545
Standard Deviation	24.89633
Variance	619.8272
Coefficient of Variation	2.400929
Skewness	3.898502

Gamma Statistics	
k hat	0.332195
k star (bias corrected)	0.318449
Theta hat	31.21493
Theta star	32.5624
nu hat	15.94538
nu star	15.28554
Approx. Chi Square Value (.05)	7.459383
Adjusted Level of Significance	0.0392
Adjusted Chi Square Value	7.076246

Log-transformed Statistics	
Minimum of log data	-3.35241
Maximum of log data	4.770685
Mean of log data	0.29734
Standard Deviation of log data	2.451743
Variance of log data	6.011044

RECOMMENDATION
Data follow gamma distribution (0.05)

Use Adjusted Gamma UCL

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.446464
Shapiro-Wilk 5% Critical Value	0.916
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	19.07925

Gamma Distribution Test	
A-D Test Statistic	0.797431
A-D 5% Critical Value	0.843994
K-S Test Statistic	0.167838
K-S 5% Critical Value	0.192367

Data follow gamma distribution
at 5% significance level

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	21.24878
Adjusted Gamma UCL	22.39928

Lognormal Distribution Test	
Shapiro-Wilk Test Statistic	0.918468
Shapiro-Wilk 5% Critical Value	0.916
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	316.7228
95% Chebyshev (MVUE) UCL	70.59346
97.5% Chebyshev (MVUE) UCL	93.15594
99% Chebyshev (MVUE) UCL	137.4756

95% Non-parametric UCLs	
CLT UCL	18.72851
Adj-CLT UCL (Adjusted for skewness)	23.04969
Mod-t UCL (Adjusted for skewness)	19.75327
Jackknife UCL	19.07925
Standard Bootstrap UCL	18.61767
Bootstrap-t UCL	38.36575
Hall's Bootstrap UCL	43.84014
Percentile Bootstrap UCL	19.44425
BCA Bootstrap UCL	23.95873
95% Chebyshev (Mean, Sd) UCL	32.52113
97.5% Chebyshev (Mean, Sd) UCL	42.10618
99% Chebyshev (Mean, Sd) UCL	60.93414

Data File Z:\Hanford\Z-9\COPY of Z-9_SoilData_All_rev03.30.07 hak.xls

Variable: Carbon tet

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	42	Shapiro-Wilk Test Statistic	0.166203
Number of Unique Samples	35	Shapiro-Wilk 5% Critical Value	0.942
Minimum	8.00E-05	Data not normal at 5% significance level	
Maximum	380	95% UCL (Assuming Normal Distribution)	
Mean	9.512263	Student's-t UCL	24.72244
Median	0.03225	Gamma Distribution Test	
Standard Deviation	58.57418	A-D Test Statistic	5.389183
Variance	3,430.935	A-D 5% Critical Value	0.945324
Coefficient of Variation	6.157755	K-S Test Statistic	0.279075
Skewness	6.476468	K-S 5% Critical Value	0.153539
Gamma Statistics		Data do not follow gamma distribution at 5% significance level	
k hat	0.132292	95% UCLs (Assuming Gamma Distribution)	
k star (bias corrected)	0.138716	Approximate Gamma UCL	22.17731
Theta hat	71.9035	Adjusted Gamma UCL	22.88803
Theta star	68.57382	Lognormal Distribution Test	
nu hat	11.11253	Shapiro-Wilk Test Statistic	0.909448
nu star	11.65212	Shapiro-Wilk 5% Critical Value	0.942
Approx.Chi Square Value (.05)	4.99781	Data not lognormal at 5% significance level	
Adjusted Level of Significance	0.044286	95% UCLs (Assuming Lognormal Distribution)	
Adjusted Chi Square Value	4.842618	95% H-UCL	451.381
Log-transformed Statistics		95% Chebyshev (MVUE) UCL	30.60308
Minimum of log data	-9.43348	97.5% Chebyshev (MVUE) UCL	40.93227
Maximum of log data	5.940171	99% Chebyshev (MVUE) UCL	61.22196
Mean of log data	-3.66212	95% Non-parametric UCLs	
Standard Deviation of log data	3.57811	CLT UCL	24.37877
Variance of log data	12.80287	Adj-CLT UCL (Adjusted for skewness)	34.02984
RECOMMENDATION		Mod-t UCL (Adjusted for skewness)	26.22781
Data are Non-parametric (0.05)		Jackknife UCL	24.72244
Use Hall's Bootstrap UCL		Standard Bootstrap UCL	24.31989
Recommended UCL exceeds the maximum observation		Bootstrap-t UCL	760.0957
In case Hall's Bootstrap method yields an erratic, unreasonably large UCL value, use 99% Chebyshev (Mean, Sd) UCL		Hall's Bootstrap UCL	593.5827
		Percentile Bootstrap UCL	27.51828
		BCA Bootstrap UCL	45.46445
		95% Chebyshev (Mean, Sd) UCL	48.90883
		97.5% Chebyshev (Mean, Sd) UCL	65.95576
		99% Chebyshev (Mean, Sd) UCL	99.44115

Z:\Hanford\Z-9\COPY of Z-9_SoilData_All_rev03.30.07
 Data File hak.xls

Variable: Eu-152

Raw Statistics

Number of Valid Samples	30
Number of Unique Samples	30
Minimum	-0.091
Maximum	350.5
Mean	19.4715
Median	0.3075
Standard Deviation	69.29903
Variance	4,802.356
Coefficient of Variation	3.558998
Skewness	4.339875

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.319683
Shapiro-Wilk 5% Critical Value	0.927
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	40.96922

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	40.28254
Adj-CLT UCL (Adjusted for skewness)	50.99437
Mod-t UCL (Adjusted for skewness)	42.64004
Jackknife UCL	40.96922
Standard Bootstrap UCL	40.08738
Bootstrap-t UCL	233.3827
Hall's Bootstrap UCL	187.3592
Percentile Bootstrap UCL	42.104
BCA Bootstrap UCL	54.61752
95% Chebyshev (Mean, Sd) UCL	74.62122
97.5% Chebyshev (Mean, Sd) UCL	98.48455
99% Chebyshev (Mean, Sd) UCL	145.3594

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z-9\COPY of Z-9_SoilData_All_rev03.30.07

Data File hak.xls

Variable: Mn

Raw Statistics	
Number of Valid Samples	24
Number of Unique Samples	24
Minimum	157
Maximum	2,240
Mean	374
Median	296
Standard Deviation	409.4582
Variance	167,656
Coefficient of Variation	1.094808
Skewness	4.454095

Gamma Statistics	
k hat	2.514166
k star (bias corrected)	2.227673
Theta hat	148.7571
Theta star	167.8882
nu hat	120.68
nu star	106.9283
Approx. Chi Square Value (.05)	84.05927
Adjusted Level of Significance	0.0392
Adjusted Chi Square Value	82.63385

Log-transformed Statistics	
Minimum of log data	5.056246
Maximum of log data	7.714231
Mean of log data	5.712394
Standard Deviation of log data	0.538309
Variance of log data	0.289777

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.420188
Shapiro-Wilk 5% Critical Value	0.916
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	517.2459

Gamma Distribution Test	
A-D Test Statistic	2.21363
A-D 5% Critical Value	0.753029
K-S Test Statistic	0.235072
K-S 5% Critical Value	0.179686

Data do not follow gamma distribution at 5% significance level

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	475.7499
Adjusted Gamma UCL	483.9565

Lognormal Distribution Test	
Shapiro-Wilk Test Statistic	0.804186
Shapiro-Wilk 5% Critical Value	0.916
Data not lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	438.027
95% Chebyshev (MVUE) UCL	521.4815
97.5% Chebyshev (MVUE) UCL	596.8055
99% Chebyshev (MVUE) UCL	744.7649

95% Non-parametric UCLs	
CLT UCL	511.4774
Adj-CLT UCL (Adjusted for skewness)	592.674
Mod-t UCL (Adjusted for skewness)	529.9109
Jackknife UCL	517.2459
Standard Bootstrap UCL	511.8557
Bootstrap-t UCL	858.7087
Hall's Bootstrap UCL	1,035.487
Percentile Bootstrap UCL	527.25
BCA Bootstrap UCL	630.0417
95% Chebyshev (Mean, Sd) UCL	738.3181
97.5% Chebyshev (Mean, Sd) UCL	895.9588
99% Chebyshev (Mean, Sd) UCL	1,205.613

Z:\Hanford\Z-9\COPY of Z-
 Data File 9_SoilData_All_rev03.30.07 hak.xls Variable: Np-237

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	23	Shapiro-Wilk Test Statistic	0.538227
Number of Unique Samples	19	Shapiro-Wilk 5% Critical Value	0.914
Minimum	-0.0015	Data not normal at 5% significance level	
Maximum	252	95% UCL (Assuming Normal Distribution)	
Mean	29.22737	Student's-t UCL	52.05826
Median	0.0685		
Standard Deviation	63.76466		
Variance	4,065.931		
Coefficient of Variation	2.181676		
Skewness	2.679233		

Gamma Statistics Not Available

Lognormal Statistics Not Available

		95% Non-parametric UCLs	
		CLT UCL	51.0971
		Adj-CLT UCL (Adjusted for skewness)	59.03385
		Mod-t UCL (Adjusted for skewness)	53.29623
		Jackknife UCL	52.05826
		Standard Bootstrap UCL	50.70344
		Bootstrap-t UCL	80.43056
		Hall's Bootstrap UCL	64.30795
		Percentile Bootstrap UCL	52.17687
		BCA Bootstrap UCL	61.25676
		95% Chebyshev (Mean, Sd) UCL	87.18264
		97.5% Chebyshev (Mean, Sd) UCL	112.2599
		99% Chebyshev (Mean, Sd) UCL	161.5194

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z-9\COPY of Z-
 Data File 9_SoilData_All_rev03.30.07 hak.xls Variable: Pu-238

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	24	Shapiro-Wilk Test Statistic	0.46714
Number of Unique Samples	24	Shapiro-Wilk 5% Critical Value	0.916
Minimum	-109	Data not normal at 5% significance level	
Maximum	9,600	95% UCL (Assuming Normal Distribution)	
Mean	879.4467	Student's-t UCL	1,667.918
Median	3.05		
Standard Deviation	2,253.789		
Variance	5,079,563		
Coefficient of Variation	2.562735		
Skewness	3.148416		

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs	
CLT UCL	1,636.166
Adj-CLT UCL (Adjusted for skewness)	1,952.084
Mod-t UCL (Adjusted for skewness)	1,717.195
Jackknife UCL	1,667.918
Standard Bootstrap UCL	1,612.989
Bootstrap-t UCL	2,751.75
Hall's Bootstrap UCL	1,994.805
Percentile Bootstrap UCL	1,699.563
BCA Bootstrap UCL	2,004.143
95% Chebyshev (Mean, Sd) UCL	2,884.77
97.5% Chebyshev (Mean, Sd) UCL	3,752.475
99% Chebyshev (Mean, Sd) UCL	5,456.913

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Soil 95 UCLs\rev1\EPCS_Z-
 Data File 9(Historical Data) rev1.xls

Variable: PU-239/240

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	25	Shapiro-Wilk Test Statistic	0.213266
Number of Unique Samples	25	Shapiro-Wilk 5% Critical Value	0.918
Minimum	0.001	Data not normal at 5% significance level	
Maximum	20,296,010	95% UCL (Assuming Normal Distribution)	
Mean	834,963.9	Student's-t UCL	2,222,409
Median	2,260	Gamma Distribution Test	
Standard Deviation	4,054,765	A-D Test Statistic	1.725285
Variance	1.64E+13	A-D 5% Critical Value	0.951531
Coefficient of Variation	4.856216	K-S Test Statistic	0.231697
Skewness	4.99848	K-S 5% Critical Value	0.197775
Gamma Statistics		Data do not follow gamma distribution at 5% significance level	
k hat	0.097805	95% UCLs (Assuming Gamma Distribution)	
k star (bias corrected)	0.112735	Approximate Gamma UCL	3,230,982
Theta hat	8,537,045	Adjusted Gamma UCL	3,570,926
Theta star	7,406,438	Lognormal Distribution Test	
nu hat	4.89024	Shapiro-Wilk Test Statistic	0.936057
nu star	5.636744	Shapiro-Wilk 5% Critical Value	0.918
Approx. Chi Square Value (.05)	1.456671	Data are lognormal at 5% significance level	
Adjusted Level of Significance	0.0395	95% UCLs (Assuming Lognormal Distribution)	
Adjusted Chi Square Value	1.317999	95% H-UCL	9.20E+17
Log-transformed Statistics		95% Chebyshev (MVUE) UCL	9.07E+08
Minimum of log data	-6.90776		
Maximum of log data	16.82593		
Mean of log data	5.308572		
Standard Deviation of log data	6.42297		

Variance of log data	41.25454	97.5% Chebyshev (MVUE) UCL	1.23E+09
		99% Chebyshev (MVUE) UCL	1.85E+09
		95% Non-parametric UCLs	
		CLT UCL	2,168,863
		Adj-CLT UCL (Adjusted for skewness)	3,035,114
		Mod-t UCL (Adjusted for skewness)	2,357,526
		Jackknife UCL	2,222,409
		Standard Bootstrap UCL	2,131,796
		Bootstrap-t UCL	1.35E+08
		Hall's Bootstrap UCL	88,219,103
		Percentile Bootstrap UCL	2,447,377
		BCA Bootstrap UCL	3,278,958
		95% Chebyshev (Mean, Sd) UCL	4,369,826
		97.5% Chebyshev (Mean, Sd) UCL	5,899,364
		99% Chebyshev (Mean, Sd) UCL	8,903,844

RECOMMENDATION

Data are lognormal (0.05)

Use Hall's Bootstrap UCL

Recommended UCL exceeds the maximum observation

In case Hall's Bootstrap method yields
 an erratic, unreasonably large UCL value,
 use 99% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z-9\COPY of Z-
 Data File 9_SoilData_All_rev03.30.07 hak.xls Variable: Ra-226

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	18	Shapiro-Wilk Test Statistic	0.460257
Number of Unique Samples	18	Shapiro-Wilk 5% Critical Value	0.897
Minimum	0.292	Data not normal at 5% significance level	
Maximum	21.5	95% UCL (Assuming Normal Distribution)	
Mean	2.971333	Student's-t UCL	5.46307
Median	0.739	Gamma Distribution Test	
Standard Deviation	6.076974	A-D Test Statistic	2.662123
Variance	36.92961	A-D 5% Critical Value	0.789942
Coefficient of Variation	2.045201	K-S Test Statistic	0.309545
Skewness	2.730102	K-S 5% Critical Value	0.213414
Gamma Statistics		Data do not follow gamma distribution at 5% significance level	
k hat	0.614836	95% UCLs (Assuming Gamma Distribution)	
k star (bias corrected)	0.5494	Approximate Gamma UCL	5.499315
Theta hat	4.832729	Adjusted Gamma UCL	5.848645
Theta star	5.408324	Lognormal Distribution Test	
nu hat	22.13408	Shapiro-Wilk Test Statistic	0.806317
nu star	19.7784	Shapiro-Wilk 5% Critical Value	0.897
Approx.Chi Square Value (.05)	10.68646	Data not lognormal at 5% significance level	
Adjusted Level of Significance	0.03574	95% UCLs (Assuming Lognormal Distribution)	
Adjusted Chi Square Value	10.04818	95% H-UCL	5.153073
Log-transformed Statistics		95% Chebyshev (MVUE) UCL	4.964818
Minimum of log data	-1.231	97.5% Chebyshev (MVUE) UCL	6.213557
Maximum of log data	3.068053	99% Chebyshev (MVUE) UCL	8.666464
Mean of log data	0.087666	95% Non-parametric UCLs	
Standard Deviation of log data	1.187334	CLT UCL	5.32735
Variance of log data	1.409762	Adj-CLT UCL (Adjusted for skewness)	6.312209
RECOMMENDATION		Mod-t UCL (Adjusted for skewness)	5.616688
Data are Non-parametric (0.05)		Jackknife UCL	5.46307
Use 99% Chebyshev (Mean, Sd) UCL		Standard Bootstrap UCL	5.214231
		Bootstrap-t UCL	26.12459
		Hall's Bootstrap UCL	19.27188
		Percentile Bootstrap UCL	5.331056
		BCA Bootstrap UCL	6.380611
		95% Chebyshev (Mean, Sd) UCL	9.21483
		97.5% Chebyshev (Mean, Sd) UCL	11.9164
		99% Chebyshev (Mean, Sd) UCL	17.2231

Z:\Hanford\Z-9\COPY of Z-
 Data File 9_SoilData_All_rev03.30.07 hak.xls

Variable: Ra-228

Raw Statistics	
Number of Valid Samples	18
Number of Unique Samples	18
Minimum	0.145
Maximum	33
Mean	5.308389
Median	1.435
Standard Deviation	9.671092
Variance	93.53002
Coefficient of Variation	1.821851
Skewness	2.462091

Gamma Statistics	
k hat	0.57601
k star (bias corrected)	0.517046
Theta hat	9.215787
Theta star	10.26677
nu hat	20.73637
nu star	18.61364
Approx. Chi Square Value (.05)	9.834382
Adjusted Level of Significance	0.03574
Adjusted Chi Square Value	9.225294

Log-transformed Statistics	
Minimum of log data	-1.93102
Maximum of log data	3.496508
Mean of log data	0.590087
Standard Deviation of log data	1.430468
Variance of log data	2.046237

RECOMMENDATION
 Data are lognormal (0.05)
 Use 95% Chebyshev (MVUE) UCL

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.547261
Shapiro-Wilk 5% Critical Value	0.897
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)	
Student's-t UCL	9.273819

Gamma Distribution Test	
A-D Test Statistic	1.352362
A-D 5% Critical Value	0.793386
K-S Test Statistic	0.235761
K-S 5% Critical Value	0.213984

Data do not follow gamma distribution
 at 5% significance level

95% UCLs (Assuming Gamma Distribution)	
Approximate Gamma UCL	10.04725
Adjusted Gamma UCL	10.7106

Lognormal Distribution Test	
Shapiro-Wilk Test Statistic	0.951045
Shapiro-Wilk 5% Critical Value	0.897
Data are lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)	
95% H-UCL	16.0022
95% Chebyshev (MVUE) UCL	12.33369
97.5% Chebyshev (MVUE) UCL	15.707
99% Chebyshev (MVUE) UCL	22.33321

95% Non-parametric UCLs	
CLT UCL	9.05783
Adj-CLT UCL (Adjusted for skewness)	10.4713
Mod-t UCL (Adjusted for skewness)	9.494292
Jackknife UCL	9.273819
Standard Bootstrap UCL	8.971703
Bootstrap-t UCL	19.98466
Hall's Bootstrap UCL	23.08774
Percentile Bootstrap UCL	9.187
BCA Bootstrap UCL	10.88483
95% Chebyshev (Mean, Sd) UCL	15.24449
97.5% Chebyshev (Mean, Sd) UCL	19.54385
99% Chebyshev (Mean, Sd) UCL	27.98911

Data File Z:\Hanford\Z-9\Coppy of Z-9_SoilData_All_rev03.30.07 hak.xls Variable: Tc-99

Raw Statistics

Number of Valid Samples	16
Number of Unique Samples	16
Minimum	-2.385
Maximum	272
Mean	25.53288
Median	0.8675
Standard Deviation	68.17185
Variance	4,647.401
Coefficient of Variation	2.669964
Skewness	3.582498

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.436921
Shapiro-Wilk 5% Critical Value	0.887
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	55.41004

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	53.56605
Adj-CLT UCL (Adjusted for skewness)	69.87596
Mod-t UCL (Adjusted for skewness)	57.95406
Jackknife UCL	55.41004
Standard Bootstrap UCL	52.24682
Bootstrap-t UCL	222.7488
Hall's Bootstrap UCL	164.8865
Percentile Bootstrap UCL	56.87741
BCA Bootstrap UCL	74.06884
95% Chebyshev (Mean, Sd) UCL	99.82143
97.5% Chebyshev (Mean, Sd) UCL	131.9661
99% Chebyshev (Mean, Sd) UCL	195.1082

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z-9\COPY of Z-
 Data File 9_SoilData_All_rev03.30.07 hak.xls Variable: Th-228

Raw Statistics	
Number of Valid Samples	31
Number of Unique Samples	30
Minimum	-29.05
Maximum	83
Mean	4.312452
Median	1.025
Standard Deviation	17.13407
Variance	293.5764
Coefficient of Variation	3.973162
Skewness	3.284491

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.564074
Shapiro-Wilk 5% Critical Value	0.929
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	9.53555

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs	
CLT UCL	9.374275
Adj-CLT UCL (Adjusted for skewness)	11.31403
Mod-t UCL (Adjusted for skewness)	9.838113
Jackknife UCL	9.53555
Standard Bootstrap UCL	9.283271
Bootstrap-t UCL	13.80307
Hall's Bootstrap UCL	36.46488
Percentile Bootstrap UCL	9.722871
BCA Bootstrap UCL	11.30942
95% Chebyshev (Mean, Sd) UCL	17.7264
97.5% Chebyshev (Mean, Sd) UCL	23.53062
99% Chebyshev (Mean, Sd) UCL	34.9319

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Z:\Hanford\Z-9\COPY of Z-
Data File 9_SoilData_All_rev03.30.07 hak.xls Variable: Th-230

Raw Statistics	
Number of Valid Samples	14
Number of Unique Samples	14
Minimum	-115.5
Maximum	72
Mean	-1.23929
Median	2.135
Standard Deviation	43.24088
Variance	1,869.773
Coefficient of Variation	-34.8918
Skewness	-1.10746

Normal Distribution Test	
Shapiro-Wilk Test Statistic	0.88449
Shapiro-Wilk 5% Critical Value	0.874
Data are normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	19.2267

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs	
CLT UCL	17.76965
Adj-CLT UCL (Adjusted for skewness)	14.11475
Mod-t UCL (Adjusted for skewness)	18.65661
Jackknife UCL	19.2267
Standard Bootstrap UCL	16.85922
Bootstrap-t UCL	16.09397
Hall's Bootstrap UCL	16.10144
Percentile Bootstrap UCL	15.96357
BCA Bootstrap UCL	13.83571
95% Chebyshev (Mean, Sd) UCL	49.13481
97.5% Chebyshev (Mean, Sd) UCL	70.93172
99% Chebyshev (Mean, Sd) UCL	113.7475

RECOMMENDATION
Data are normal (0.05)

Use Student's-t UCL

216-A-8 Crib

Table 1-5. ProUCL Output Summary for 216-A-8 Crib-Resident and Driller Concentration in Waste.

From File Z:\Hanford\A_8\EPC data for A-8.xls

Variable Name	EPC	Units	Distribution	ProUCL Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
C-14	67.03	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.555	89.7	17.44635	-0.00775	35.97456	2.062011	1.7852805	1,294.169
Cs-137	261,460.45	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	18	-0.0005	877,000	49,206.55	0.485	206,592.8	4.198481	4.2424493	4.27E+10
Pu-239/240	29.85	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.001	55.7	5.5798	0.01125	17.61044	3.156107	3.1622765	310.1278
Ra-228	433.02	pCi/g	Non-parametric	Use 99% Chebyshev (Mean, Sd) UCL	11	0.1935	435	40.07032	0.688	130.9837	3.268845	3.3165958	17,156.72
Tc-99	42.81	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	10	-0.003	79.6	8.25645	0.06525	25.07114	3.036552	3.1605953	628.5619
Th-228	124.75	pCi/g	Non-parametric	Use 95% Chebyshev (Mean, Sd) UCL	14	0	325	23.73296	0.6925	86.711	3.65361	3.7415995	7,518.798

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: C14

Raw Statistics

Number of Valid Samples	10
Number of Unique Samples	10
Minimum	-0.555
Maximum	89.7
Mean	17.44635
Median	-0.00775
Standard Deviation	35.97456
Variance	1,294.169
Coefficient of Variation	2.062011
Skewness	1.78528

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.544351
Shapiro-Wilk 5% Critical Value	0.842
Data not normal at 5% significance level	
95% UCL (Assuming Normal Distribution)	
Student's-t UCL	38.30012

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	36.15846
Adj-CLT UCL (Adjusted for skewness)	43.02096
Mod-t UCL (Adjusted for skewness)	39.37054
Jackknife UCL	38.30012
Standard Bootstrap UCL	35.15268
Bootstrap-t UCL	449.5298
Hall's Bootstrap UCL	650.5096
Percentile Bootstrap UCL	35.081
BCA Bootstrap UCL	43.58905
95% Chebyshev (Mean, Sd) UCL	67.03386
97.5% Chebyshev (Mean, Sd) UCL	88.49041
99% Chebyshev (Mean, Sd) UCL	130.6377

RECOMMENDATION
 Data are Non-parametric (0.05)
 Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Cs137

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	18	Shapiro-Wilk Test Statistic	0.255819
Number of Unique Samples	18	Shapiro-Wilk 5% Critical Value	0.897
Minimum	-0.0005	Data not normal at 5% significance level	
Maximum	877,000	95% UCL (Assuming Normal Distribution)	
Mean	49,206.55	Student's-t UCL	133,915.6
Median	0.485		
Standard Deviation	206,592.8		
Variance	4.27E+10		
Coefficient of Variation	4.198481		
Skewness	4.242449		

Gamma Statistics Not Available

Lognormal Statistics Not Available

RECOMMENDATION		95% Non-parametric UCLs	
Data are Non-parametric (0.05)		CLT UCL	129,301.7
Use 95% Chebyshev (Mean, Sd) UCL		Adj-CLT UCL (Adjusted for skewness)	181,330
		Mod-t UCL (Adjusted for skewness)	142,031
		Jackknife UCL	13,3915.6
		Standard Bootstrap UCL	127,840.5
		Bootstrap-t UCL	14,431,865
		Hall's Bootstrap UCL	11,454,120
		Percentile Bootstrap UCL	146,519.3
		BCA Bootstrap UCL	195,537.9
		95% Chebyshev (Mean, Sd) UCL	261,460.5
		97.5% Chebyshev (Mean, Sd) UCL	353,302.9
		99% Chebyshev (Mean, Sd) UCL	533,709.6

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Pu239-240

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	10	Shapiro-Wilk Test Statistic	0.366363
Number of Unique Samples	10	Shapiro-Wilk 5% Critical Value	0.842
Minimum	-0.001	Data not normal at 5% significance level	
Maximum	55.7	95% UCL (Assuming Normal Distribution)	
Mean	5.5798	Student's-t UCL	15.78824
Median	0.01125		
Standard Deviation	17.61044		
Variance	310.1278		
Coefficient of Variation	3.156107		
Skewness	3.162277		

Gamma Statistics Not Available

Lognormal Statistics Not Available

		95% Non-parametric UCLs	
		CLT UCL	14.73984
		Adj-CLT UCL (Adjusted for skewness)	20.69031
		Mod-t UCL (Adjusted for skewness)	16.71639
		Jackknife UCL	15.78824
		Standard Bootstrap UCL	14.21224
		Bootstrap-t UCL	15,363.43
		Hall's Bootstrap UCL	5,607.084
		Percentile Bootstrap UCL	16.7169
		BCA Bootstrap UCL	22.2865
		95% Chebyshev (Mean, Sd) UCL	29.85412
		97.5% Chebyshev (Mean, Sd) UCL	40.35764
		99% Chebyshev (Mean, Sd) UCL	60.98977

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data
 for A-8.xls

Variable: Ra228

Raw Statistics

Number of Valid Samples	11
Number of Unique Samples	11
Minimum	0.1935
Maximum	435
Mean	40.07032
Median	0.688
Standard Deviation	130.9837
Variance	17,156.72
Coefficient of Variation	3.268845
Skewness	3.316596

Gamma Statistics

k hat	0.195489
k star (bias corrected)	0.20278
Theta hat	204.9744
Theta star	197.6047
nu hat	4.300767
nu star	4.461164
Approx. Chi Square Value (.05)	0.911559
Adjusted Level of Significance	0.02783
Adjusted Chi Square Value	0.683331

Log-transformed Statistics

Minimum of log data	-1.64248
Maximum of log data	6.075346
Mean of log data	-0.08725
Standard Deviation of log data	2.127732
Variance of log data	4.527242

RECOMMENDATION
 Data are Non-parametric (0.05)

Use 99% Chebyshev (Mean, Sd) UCL

Normal Distribution Test

Shapiro-Wilk Test Statistic	0.347063
Shapiro-Wilk 5% Critical Value	0.85
Data not normal at 5% significance level	

95% UCL (Assuming Normal Distribution)

Student's-t UCL	111.65
-----------------	--------

Gamma Distribution Test

A-D Test Statistic	3.020341
A-D 5% Critical Value	0.861665
K-S Test Statistic	0.517976
K-S 5% Critical Value	0.282133

Data do not follow gamma distribution
 at 5% significance level

95% UCLs (Assuming Gamma Distribution)

Approximate Gamma UCL	196.1038
Adjusted Gamma UCL	261.6012

Lognormal Distribution Test

Shapiro-Wilk Test Statistic	0.605603
Shapiro-Wilk 5% Critical Value	0.85
Data not lognormal at 5% significance level	

95% UCLs (Assuming Lognormal Distribution)

95% H-UCL	350.4608
95% Chebyshev (MVUE) UCL	21.7282
97.5% Chebyshev (MVUE) UCL	28.73452
99% Chebyshev (MVUE) UCL	42.49708

95% Non-parametric UCLs

CLT UCL	105.0306
Adj-CLT UCL (Adjusted for skewness)	147.2292
Mod-t UCL (Adjusted for skewness)	118.2321
Jackknife UCL	111.65
Standard Bootstrap UCL	102.7759
Bootstrap-t UCL	2,2544.5
Hall's Bootstrap UCL	7,871.242
Percentile Bootstrap UCL	119.0388
BCA Bootstrap UCL	158.576
95% Chebyshev (Mean, Sd) UCL	212.2166
97.5% Chebyshev (Mean, Sd) UCL	286.7044
99% Chebyshev (Mean, Sd) UCL	433.0213

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Tc99

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	10	Shapiro-Wilk Test Statistic	0.379108
Number of Unique Samples	10	Shapiro-Wilk 5% Critical Value	0.842
Minimum	-0.003	Data not normal at 5% significance level	
Maximum	79.6	95% UCL (Assuming Normal Distribution)	
Mean	8.25645	Student's-t UCL	22.78972
Median	0.06525		
Standard Deviation	25.07114		
Variance	628.5619		
Coefficient of Variation	3.036552		
Skewness	3.160595		

Gamma Statistics Not Available

Lognormal Statistics Not Available

		95% Non-parametric UCLs	
		CLT UCL	21.29716
		Adj-CLT UCL (Adjusted for skewness)	29.76404
		Mod-t UCL (Adjusted for skewness)	24.11038
		Jackknife UCL	22.78972
		Standard Bootstrap UCL	20.42788
		Bootstrap-t UCL	621.1088
		Hall's Bootstrap UCL	442.3178
		Percentile Bootstrap UCL	24.08435
		BCA Bootstrap UCL	32.0215
		95% Chebyshev (Mean, Sd) UCL	42.81463
		97.5% Chebyshev (Mean, Sd) UCL	57.76798
		99% Chebyshev (Mean, Sd) UCL	87.14094

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

Data File Z:\Hanford\A_8\EPC data for A-8.xls Variable: Th228

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	14	Shapiro-Wilk Test Statistic	0.299589
Number of Unique Samples	14	Shapiro-Wilk 5% Critical Value	0.874
Minimum	0	Data not normal at 5% significance level	
Maximum	325	95% UCL (Assuming Normal Distribution)	
Mean	23.73296	Student's-t UCL	64.77344
Median	0.6925		
Standard Deviation	86.711		
Variance	7,518.798		
Coefficient of Variation	3.65361		
Skewness	3.741599		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	61.85161
	Adj-CLT UCL (Adjusted for skewness)	86.6135
	Mod-t UCL (Adjusted for skewness)	68.63579
	Jackknife UCL	64.77344
	Standard Bootstrap UCL	60.46024
	Bootstrap-t UCL	9,924.31
	Hall's Bootstrap UCL	4,736.945
	Percentile Bootstrap UCL	70.08564
	BCA Bootstrap UCL	93.31571
RECOMMENDATION	95% Chebyshev (Mean, Sd) UCL	124.7482
Data are Non-parametric (0.05)	97.5% Chebyshev (Mean, Sd) UCL	168.4576
Use 95% Chebyshev (Mean, Sd) UCL	99% Chebyshev (Mean, Sd) UCL	254.3162

APPENDIX A

ATTACHMENT 2

**CWASTE DETAILS AND EXPOSURE POINT
CONCENTRATION CALCULATIONS FOR WELL DRILLER
AND SUBSISTENCE FARMER**

Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Soil Site Characteristics

Site Name	Vcut (m ³)	Ratio Lwaste&Lwell	Lwaste -Thickness of waste (m)	Lwell-Depth of Well (m)	Depth to Groundwater (m)
216-Z-1A Tile Field	5.480579867	0.3	28.04	87	71
216-Z-8 French Drain	5.268303886	0.1	5.79	83	68
216-Z-9 Trench	5.268303886	0.4	30.18	83	68
216-A-8 Crib	6.020918727	0.2	18.14	95	80

$V_{cut} = \pi \times r^2 \times h \times (D_{initial}/D_{final})$
 $h =$ Lwell-depth of the well from surface to groundwater, plus 15.24 m (50 ft)
 $\pi = 3.14159$
 $r =$ radius of 26.67 cm (10.5 inch) well
 $V_{cut} =$ volume of cuttings
 $D_{final} =$ density of soil cuttings on surface (1.5 kg/L)
 $D_{initial} =$ density of undisturbed soil (1.7 kg/L)

Pi	radius of well ²	change in density	Vcut (m ³)
3.14159	0.017782223	1.133333333	5.480579867
3.14159	0.017782223	1.133333333	5.268303886
3.14159	0.017782223	1.133333333	5.268303886
3.14159	0.017782223	1.133333333	6.020918727

$C_{cut} = C_{waste} (L_{waste}/L_{well})$
 $C_{cut} =$ concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)
 $C_{waste} =$ concentration of radionuclide/chemical in the disposal site; maximum or calculated 95 UCL of the analytical data (pCi/g or mg/kg)
 $L_{waste} =$ thickness of the waste (m)
 $L_{well} =$ depth of the well from surface to groundwater (m)

$C_{garden} = C_{cut} (V_{cut}/V_{garden})$
 $C_{garden} =$ concentration of a radionuclide/chemical in garden soil (pCi/g or mg/kg)
 $C_{cut} =$ concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)
 $V_{cut} =$ volume of cuttings (m³)
 $V_{garden} =$ volume of garden soil (15 m³)

Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Site Name	Chemical Name	Cwaste-Now (pCi/g or mg/kg)	From RESRAD Cwaste-150 years (pCi/g or mg/kg)	Well Driller EPC-Ccut in 150 years (pCi/g or mg/kg)	Residential Farmer EPC-Cgarden in 150 years (pCi/g or mg/kg)
216-Z-1A Tile Field	Americium-241	122,528	89,640	29,037	10,609
	Neptunium-237	--	5.10	1.65	0.60
	Plutonium-239/240	698,678	--	--	--
	Plutonium-239 ^a	569,293	566,400	183,471	67,035
	Plutonium-240 ^a	129,385	127,300	41,236	15,066
	Uranium-235	--	0.083	0.027	0.010
	Uranium-236	--	0.56	0.18	0.066
	Americium-241	457	253.5	17.64	6.20
	Neptunium-237	--	0.017	0.0012	0.00040
	Plutonium-238	77.5	23.61	1.64	0.58
216-Z-8 French Drain	Plutonium-239/240	4,620	--	--	--
	Plutonium-239 ^a	3,764	3,735	259.89	91.28
	Plutonium-240 ^a	856	839.5	58.41	20.52
	Uranium-234	--	0.018	0.0012	0.00043
	1,2-Dibromo-3-chloropropane	0.588	--	0.21	0.07
	Actinium-227	--	12.32	4.47	1.57
	Americium-241	300,556	221,000	80,156	28,152
	Cadmium	22.4	--	8.12	2.85
	Carbon tetrachloride	99.4	--	36.07	12.67
	Europium-152	74.6	0.03052	0.01107	0.003888
216-Z-9 Trench	Manganese	738.3	--	267.78	94.05
	Neptunium-237	87.2	114.7	41.60	14.61
	Nickel-63	2,360	798	289.39	101.64
	Lead-210	--	16.84	6.11	2.15
	Plutonium-238	2,885	882	319.72	112.29
	Plutonium-239/240	8,903,844	--	--	--
	Plutonium-239 ^a	7,254,984	7,264,000	2,634,617	925,331
	Plutonium-240 ^a	1,648,860	1,574,000	570,882	200,505
	Protactinium-231	12.9	12.5	4.54	1.59
	Radium-226	17.2	17.0	6.17	2.17

Baseline EPC Calculations for Well Driller and Residential Farmer. (3 sheets)

Site Name	Chemical Name	Cwaste-Now (pCi/g or mg/kg)	From RESRAD Cwaste-150 years (pCi/g or mg/kg)	Well Driller EPC-Ccut in 150 years (pCi/g or mg/kg)	Residential Farmer EPC-Cgarden in 150 years (pCi/g or mg/kg)
216-Z-9 Trench cont'd	Radium-228	12.3	1.93E-07	6.98E-08	2.45E-08
	Strontium-90	13.4	0.36	0.13	0.046
	Technetium-99	99.8	3.67E-06	1.33E-06	4.68E-07
	Thorium-228	17.7	2.76E-07	1.00E-07	3.52E-08
	Thorium-230	19.23	19.17	6.95	2.44
	Uranium-233	--	0.066	0.024	0.0084
	Uranium-234	--	0.71	0.26	0.090
	Uranium-235	--	1.1	0.38	0.14
	Uranium-236	--	6.95	2.52	0.89
	Carbon-14	67.03	2.63E-35	5.02E-36	2.02E-36
216-A-8 Crib	Cesium-137	261,460	8,167	1,557.87	625.32
	Neptunium-237	3.53	3.50	0.67	0.27
	Plutonium-239/240	29.85	--	--	--
	Plutonium-239 ^a	24.33	24.2	4.62	1.85
	Plutonium-240 ^a	5.53	5.44	1.04	0.42
	Radium-228	433.02	5.88E-06	1.12E-06	4.51E-07
	Technetium-99	42.81	1.83E-11	3.50E-12	1.40E-12
	Thallium	2.5	--	0.48	0.19
	Thorium-228	124.75	8.83E-06	1.68E-06	6.76E-07

^aRatio of 4.4:1 (Pu 239: Pu 240)

APPENDIX A

ATTACHMENT 3

RESRAD INPUT SUMMARY

ATTACHMENT 3 TABLE OF CONTENTS

- Table 3-1 RESRAD Key Input Parameters and Values for Resident Farmer Direct-Contact Pathways.
- Table 3-2 RESRAD Key Input Parameters and Values for Construction Worker Direct-Contact Pathways.
- Table 3-3 RESRAD Key Input Parameters and Values for Well Driller Direct-Contact Pathways.
- Table 3-4 RESRAD Key Input Parameters and Values for Construction Worker – External Radiation.
- Table 3-5 RESRAD Key Input Parameters and Values for Well Driller External Radiation.
- Table 3-6 Site-Specific RESRAD Input Parameters for the Soil Sites.

