SECTION

6 OF 6

APPENDIX G

NATIVE AMERICAN HUMAN HEALTH RISK ASSESSMENT

1

EXECUTIVE SUMMARY

This risk assessment evaluates the potential human health risks to Native Americans in selected areas of the Hanford Site's Central Plateau from exposure to contaminants formerly used at the site that are still present in subsurface soil and groundwater. The specific areas addressed are contaminants and radionuclides in the 200-ZP-1 Groundwater Operable Unit (OU) under the northern portion of the 200 West Area of the Hanford Site and at two representative soil sites, which include the 216-Z-1A Tile Field site located in the 200-PW-1 OU, and the 216-A-8 Crib site located in the 200-PW-3 OU. The 216-Z-1A Tile Field is located in the 200 West Area and the 216-A-8 Trench is located in the 200 East Area of the Central Plateau. These two soil sites were identified in *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 two of the five sites representative or unique of the 17 individual waste sites in these three OUs. For the other three representative or unique sites, there are no complete exposure pathways for Native Americans because impacted soil is present only at depths greater than 4.6 m (15 ft), the maximum reasonable depth for human health exposure as determined by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology). The results of the Native American risk assessment will be considered in the feasibility study (FS) during evaluation of the balancing criteria (e.g., evaluation of the protectiveness of a particular remedy).

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

Contaminant-impacted areas of the Central Plateau are not accessible to the public, Native American or otherwise, and institutional controls are in place that prevent soil disturbance and the use of groundwater. However, the Hanford Site is within Yakama Nation ceded territory, and the Confederated Tribes of the Umatilla Reservation (CTUIR) also have treaty fishing rights on portions of the Columbia River bordering the site. Because the Yakama Nation and the CTUIR have reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on

open unclaimed land (*Hanford Site Environmental Report for Calendar Year 2005* [PNNL-15892]), this appendix addresses future health risks for these two Native American populations from exposure to contaminants formerly used at the site that are still present in subsurface soil and groundwater. The risk assessment evaluates risks under future conditions (unrestricted land use if institutional controls fail in the future). The unrestricted Native American land use scenario assumes that land use controls will remain in place for 150 years. After that time, a failure of institutional controls is assumed, such that exposures to members of the Umatilla and Yakama Nation are hypothetically possible. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

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

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

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

For soil, the risk assessment primarily used the available soil data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for the 216-Z-1A Tile Field and 216-A-8 French Drain. In addition to soil data, screening-level soil gas data collected from the subsurface of the 216-Z-1A Tile Field were evaluated semi-quantitatively to assess whether vapor concentrations intruding into a future home basement might be a health concern. The screening-level soil gas evaluation identified potentially significant quantities of vapors beginning about 10 m (33 ft) below ground surface (bgs), with maximum vapor concentrations at depths of 15.2 to 21.3 m (50 to 70 ft). While the data were not compound-specific (only total volatiles were identified), analytical instrumentation calibrated to carbon tetrachloride and chloroform indicated that those contaminants likely represented the majority of soil gas volatiles.

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

Table ES-1. Selected Soil COPCs.

Contaminant	216-Z-1A Tile Field	216-A-8 Crib
Americium-241	√	
Carbon-14		√
Cesium-137		√
Neptunium-237		√
Plutonium-239	√	√
Plutonium-240	√	√
Radium-228		√
Technetium-99		√
Thallium		√
Thorium-228		√

EXPOSURE ASSESSMENT

Assuming institutional control failure at year 2150, exposure to impacted soil and groundwater was assessed for members of the Yakama Nation and CTUIR. At year 2150, it is assumed that someone could excavate soil for a house with a basement and bring the excavated soil to the surface, where it would be available for direct exposure and used to grow fruits and vegetables in a home garden. Native plants and animals were assumed to be minimally exposed, as contamination would be centered around a residence or "local" area (i.e., vegetable garden). For groundwater exposures, it was assumed that 200-ZP-1 groundwater would be used to irrigate the home garden, water domestic livestock, and as the water source in a sweatlodge.

Note that the risk assessment assumes there will be no reduction in current contaminant levels but uses current concentrations to assess risks 150 years in the future. While it is anticipated that remedial measures will reduce concentrations in groundwater over time, the extent of this reduction is not known. Concentrations in groundwater in the future are uncertain; however, the use of current concentrations ensures that estimates of future risks are protective of human health. It is important to note that use of current groundwater concentrations provides an overestimate of future risks because reductions in groundwater concentrations are anticipated to occur through the planned active groundwater treatment program and the natural degradation of organic compounds.

Soil risks were evaluated for the top 4.6 m (15 ft) of soil at the two waste sites, and groundwater risks were evaluated for three concentrations for each COPC (the 25th, 50th, and 90th percentile concentration of the plume). Thus, soil risks are waste-site-specific, and groundwater risks are evaluated for low, medium, and high COPC concentrations independent of location. Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site.

Because Native American exposures may be different than exposures that EPA has developed for a residential population (e.g., more time spent outdoors and greater consumption of native plants and animals), Native American exposure factors developed specifically for the Yakama Nation and CTUIR were preferentially used in the exposure assessment (*Yakama Nation*

Exposure Scenario for Hanford Risk Assessment [Ridolfi, 2007]; *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper, 2004]). Where parameters were not provided by these sources, EPA sources were used.

RISK ASSESSMENT RESULTS

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

Risks to Native American populations are at the maximum risk possible (approaching 1, or 100 percent), indicating that exposures to soil at the two waste sites and groundwater beneath the waste sites represent a significant risk should they occur in the future. Specifics for soil and groundwater are discussed below.

Risks from Soil Exposure

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and ingrowth of daughter products. There are no significant differences in cancer risks between the CTUIR and Yakama Nation exposures.

- For the 216-Z-1A Tile Field, total cancer risks approach the maximum possible value of 1 (nearly 100 percent), primarily as a result of ingesting three COPCs in soil (plutonium-239, plutonium-240, and americium-241) and ingesting homegrown produce grown in the soil. Risks at future time horizons are not significantly different for plutonium-239 and plutonium-240 than current risks, because the half-lives of these contaminants are long. Risks at 1,000 years in the future still approach 1. Americium-241 total risks decline from approximately 1 to 4×10^{-2} at 1,000 years.

- At the 216-A-8 Crib, total cancer risks are 3 x 10^{-1}, where cesium-137 is the risk driver (primarily as a result of external radiation), and total risks at future time horizons are lower. Total site risks drop below 10^{-4} after approximately 350 years because of the relatively short half-life of cesium-137 (approximately 30 years), which drops below a 10^{-4} risk level at that time. Beginning approximately 350 years in the future, the risk drivers at 216-A-8 become neptunium-237 and plutonium-239, with risks in the upper 10^{-5} range.

  Non-cancer hazards at 216-A-8 were from ingestion of thallium-containing soil and eating thallium-containing produce (thallium is the only nonradiological COPC in soil). Soil ingestion hazards are below 1 for both Native American populations and for ingestion of homegrown produce were above 1, with hazard quotients of 30 and 31 for the CTUIR and Yakama Nation, respectively.

Table ES-2 presents soil risk results (CTUIR risks are shown, and Yakama Nation risks are essentially the same), and Figure ES-1 shows the contribution of different pathways to total risk for both Native American populations and both waste sites.

Risks from Groundwater Exposure

As with soil, there are no significant differences in health risks between the CTUIR and Yakama Nation for groundwater exposures. Risks from groundwater exposures are assumed to occur 150 years in the future; however, current concentrations were used to calculate risks and hazards. Although not quantified, future concentration reductions will be significant for all contaminants due to the planned groundwater remediation activities. Even without remediation, significant concentration reductions will likely occur for the chlorinated solvents due to natural degradation processes. Therefore, future risks will be lower than those presented here.

Specifics of the post-2150 unrestricted land use scenario for groundwater exposure are below:

- At the 90th percentile groundwater concentration, cancer risks exceed 10^{-4} for all exposure pathways, except ingestion of beef for the CTUIR. The tap water and ingestion of homegrown produce pathways also exceed 10^{-4}, even at the 25th percentile groundwater concentration. The sweatlodge pathway exceeds 10^{-4} at the 90th and the 50th percentile groundwater concentrations. Table ES-3 presents a summary of risks by pathway for both the Yakama Nation and CTUIR. Figure ES-2 presents risks by pathway and contaminant

for the Yakama Nation (CTUIR are very similar, as shown in Table ES-3). Carbon tetrachloride is the risk driver for both the tap water and sweatlodge pathways. Carbon tetrachloride is also the risk driver for the ingestion of produce pathway. At 150 years in the future, carbon tetrachloride concentrations would be expected to be significantly lower than they are today. If that is the case, technetium-99 is the driver for cancer risks for all pathways except the sweatlodge. Technetium-99 risks are highest for the produce pathway; however, risks are also above 10^{-4} for the other food chain pathways.

- Non-cancer hazards from groundwater exposure are driven primarily by carbon tetrachloride for tap water and produce ingestion pathways, and by hexavalent chromium in the sweatlodge. In addition, nitrate and TCE each have non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentration. Table ES-4 presents a summary of non-cancer hazards from exposure to groundwater.

GROUNDWATER RESIDUAL RISK

In 150 years, groundwater concentrations are anticipated to be considerably lower than they are today due to planned groundwater remediation activities. In order to estimate what potential future risks might be for the Native American scenarios if groundwater concentrations met proposed cleanup levels, calculations of risks and hazards were estimated for eight of the groundwater COPCs: carbon tetrachloride, chromium (total), hexavalent chromium, iodine-129, nitrate, TCE, technetium-99, and tritium. If these COPCs were present in groundwater at concentrations equal to their proposed cleanup levels, risks would be significantly reduced for potential future Native American exposures. For the risk-driver carbon tetrachloride, cancer risks would be reduced to within EPA's acceptable range of 10^{-6} to 10^{-4} for all evaluated pathways for both the CTUIR and Yakama Nation scenarios, and all non-cancer hazards would also meet EPA non-cancer goals (HI $\leq$1). However, CTUIR and Yakama Nation non-cancer hazards would remain slightly above 1 for the tap water and produce pathways due to hexavalent chromium and TCE, and risks would remain above 10^{-4} for the produce pathway due to technetium-99. Reduction of concentrations of the main risk driver, carbon tetrachloride, to proposed cleanup levels clearly would significantly reduce potential Native American risks. Risk and hazard reduction for the other COPCs would likewise be significantly reduced.

UNCERTAINTIES

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

- Characterization of the top 4.6 m (15 ft) of soil was limited, with few samples representing that depth horizon because the shallower soil has not been impacted. Therefore, soil concentrations could be overestimated because samples were preferentially collected in the areas of the highest contamination.

- For groundwater, risk assessment guidance generally requires the use of unfiltered (total) data in the assessment of risks from human exposures to groundwater, particularly for metals, because humans swallow suspended particulate matter as well as the dissolved fraction. While both filtered (dissolved) and unfiltered (total) analyses were performed for the groundwater data (with the exception of uranium and nitrate), the majority of the groundwater data for metals is based on filtered samples. Concentrations are typically expected to be higher in unfiltered samples than in filtered samples because an unfiltered sample will also account for the contribution from metals suspended in the sample, rather than just the concentration measured in the dissolved phase. Therefore, the use of filtered data for metals potentially underestimates the concentrations present in groundwater. However, the use of filtered data for total chromium and hexavalent chromium does not affect the conclusions of the risk assessment, because hexavalent chromium is likely present in groundwater, primarily in the dissolved phase, and total chromium hazards are too low to be a health concern even if concentrations are underestimated.

- With regard to produce ingestion, risks and hazards are significantly above target health goals due to ingesting homegrown produce grown in impacted soil and watered with impacted groundwater. Calculated risks and hazards from ingestion of homegrown produce are dependent upon the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling that likely overestimates the amount of a COPC that could be in the plant. However, modeling necessarily simplifies complex environmental processes and,

therefore, concentrations in plants cannot be absolutely determined without field data. While transfer factors (i.e., estimates of how much contaminant gets into foods) are generally chosen to overestimate concentrations of contaminants in the food chain, it is possible that modeling also might underestimate actual plant concentrations in a future garden. With regard to uncertainties surrounding how much homegrown produce someone would eat, ingestion rates were obtained from Native American-specific information and represent a population that would be expected to receive a significant portion of their produce from their own garden. Risks from ingesting homegrown foods are overestimated if less produce is eaten, but would be underestimated if more produce was eaten.

- Cancer risk from exposure to volatile contaminants in groundwater in the sweatlodge is a primary exposure pathway with risks from exposure to carbon tetrachloride exceeding 10^{-3}. The major uncertainties for this pathway are related to assumptions regarding two components of the risk equations: the exposure factors used (frequency and exposure time during sweatlodge use), and the estimation of contaminant concentration within the sweatlodge (based primarily on the size of the sweatlodge and the temperature of the water). Conservative assumptions were used in the evaluation of exposures during sweatlodge activities for both of these components that are more likely to result in an overestimation of sweatlodge use and contaminant concentration. Therefore, risks and hazards calculated for this pathway result in a compounding of these conservative assumptions that could overestimate the risks from this pathway.

However, risks could also be underestimated for the sweatlodge pathway. The inhalation of non-volatile contaminants was not included in the quantitative assessment even though inhalation of non-volatiles could potentially occur in a sweatlodge and the pathway is complete. As water is poured over heated rocks to form steam, a portion of the water might become suspended into the air as a mist. Sweatlodge inhalation may be a particular concern for hexavalent chromium, which is likely present primarily in the dissolved phase in the water, and some of the soluble hexavalent chromium in the water also could become suspended in air (in the mist droplets) and subsequently inhaled. However, hexavalent chromium compounds have no vapor pressure and, therefore, are unlikely to be present in significant concentrations in saturated water vapor formed in the sweatlodge. The existing models used to estimate non-volatile contaminants potentially

present in saturated water vapor probably overestimate the non-volatile concentrations in air within the confined space of a sweatlodge; however, it is currently difficult to understand the potential magnitude of that overestimate. Therefore, potential inhalation exposures to non-volatiles are very uncertain for the sweatlodge pathway.

Furthermore, of the non-volatile COPCs in groundwater at 200-ZP-1, three have inhalation toxicity criteria and could potentially be assessed for their health risks via inhalation in a sweatlodge: hexavalent chromium, iodine-129, and technetium-99. Hexavalent chromium is classified by EPA as a known human carcinogen by inhalation. The methods and data used by EPA to quantitatively estimate the cancer risk from inhalation of hexavalent chromium create uncertainties when applied to the sweatlodge scenario. The cancer slope factor for estimating cancer risks from inhalation exposure to hexavalent chromium was developed from the lung cancer incidence observed in chromate workers who inhaled a mixture of chromium-containing dusts. These workers were exposed to a mixture of both soluble and slightly soluble hexavalent chromium compounds. Studies with laboratory animals indicate that slightly soluble hexavalent chromium compounds are more potent carcinogens than soluble hexavalent chromium compounds. By contrast, hexavalent chromium was released at the Hanford Site in the form of soluble sodium dichromate. This is an important distinction, because the lung cancer incidence observed in chrome plating workers, who are exposed to entirely soluble hexavalent chromium compounds, is lower than the cancer incidence observed in chromate workers. Finally, the methods used by EPA to calculate the cancer slope factor introduce uncertainties that could either overstate or understate cancer risks. Therefore, while a potential cancer risk might exist for the sweatlodge scenario from soluble hexavalent chromium, it is uncertain what the magnitude of those risks might be, given the kinds of health effects information available.

There are also potential non-cancer risks associated with inhalation of hexavalent chromium in the sweatlodge scenario. The EPA has estimated a reference concentration (RfC) for non-cancer effects, based on respiratory effects (nasal irritation and ulcerations) observed in chrome plating workers exposed to soluble hexavalent chromium mists. The EPA used the average concentrations in air that the workers were exposed, and applied uncertainty factors to the lowest observed-adverse-effect level (LOAEL) to calculate the RfC. More recent reviews of occupational exposure data suggest that short-term peak exposures to soluble hexavalent chromium in air along with multiple pathways of exposure are key factors in the occurrence of

adverse non-cancer respiratory effects in workers. These factors were not included as part of the RfC development; EPA's RfC probably overstates the non-cancer risks from inhalation of hexavalent chromium, but the magnitude of overstatement is uncertain.

Inhalation risks associated with the sweatlodge scenario may be underestimated by not including non-volatile contaminants in groundwater. However, DOE proposes to continue to work with the Yakama Nation and CTUIR to better understand the uncertainties associated with the inhalation exposure pathway in the sweatlodge scenario and to refine the methods used to estimate potential exposures through this pathway.

- Cumulative cancer risks from Native American exposures to soil and groundwater approach 1 (i.e., are nearly 100 percent). The *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) risk estimates are designed to support decisions relative to the CERCLA risk range, but risks approaching 1 are subject to additional uncertainties and technical limitations. It can generally be assumed that the dose-response relationship will be linear in the low-dose portion of the multi-stage model dose-response curve. In this case, the slope factor is a constant and risk can be directly related to intake. This linear relationship is valid only at relatively low-risk levels (i.e., below estimated risks of 0.01). For estimated risks above this level, alternative calculations are used. Since risk is generally understood as an estimate of cancer probability, and since probabilities are limited to the range between 0 and 1, one of the purposes of these alternative calculations is to avoid calculating risks that exceed 1 and, therefore, lose meaning (*Risk Assessment Guidance for Superfund Volume1 Human Health Evaluation Manual (Part A): Interim Final* [EPA/540/1-89/002]). The alternative formula was used for all the soil risk calculations and a number of the groundwater risk calculations because otherwise risks would have been calculated that were in excess of 1. Risks calculated based on large cumulative doses should, therefore, be interpreted with caution.

In summary, every aspect of the risk assessment contains multiple sources of uncertainty. Simplifying assumptions are often made so health risks can be estimated quantitatively. Because the exact amount of uncertainty cannot be quantified, the risk assessment process is designed to overestimate rather than underestimate probable risk. The results of this assessment, therefore,

are likely to be protective of health despite the inherent uncertainties in the process. Because risks and hazards greatly exceeded target health goals, even significant uncertainties in the risk assessment calculations are unlikely to lower risks such that target health goals are not exceeded.

Figure ES-1. Soil Risks by Exposure Pathway in 150 Years.

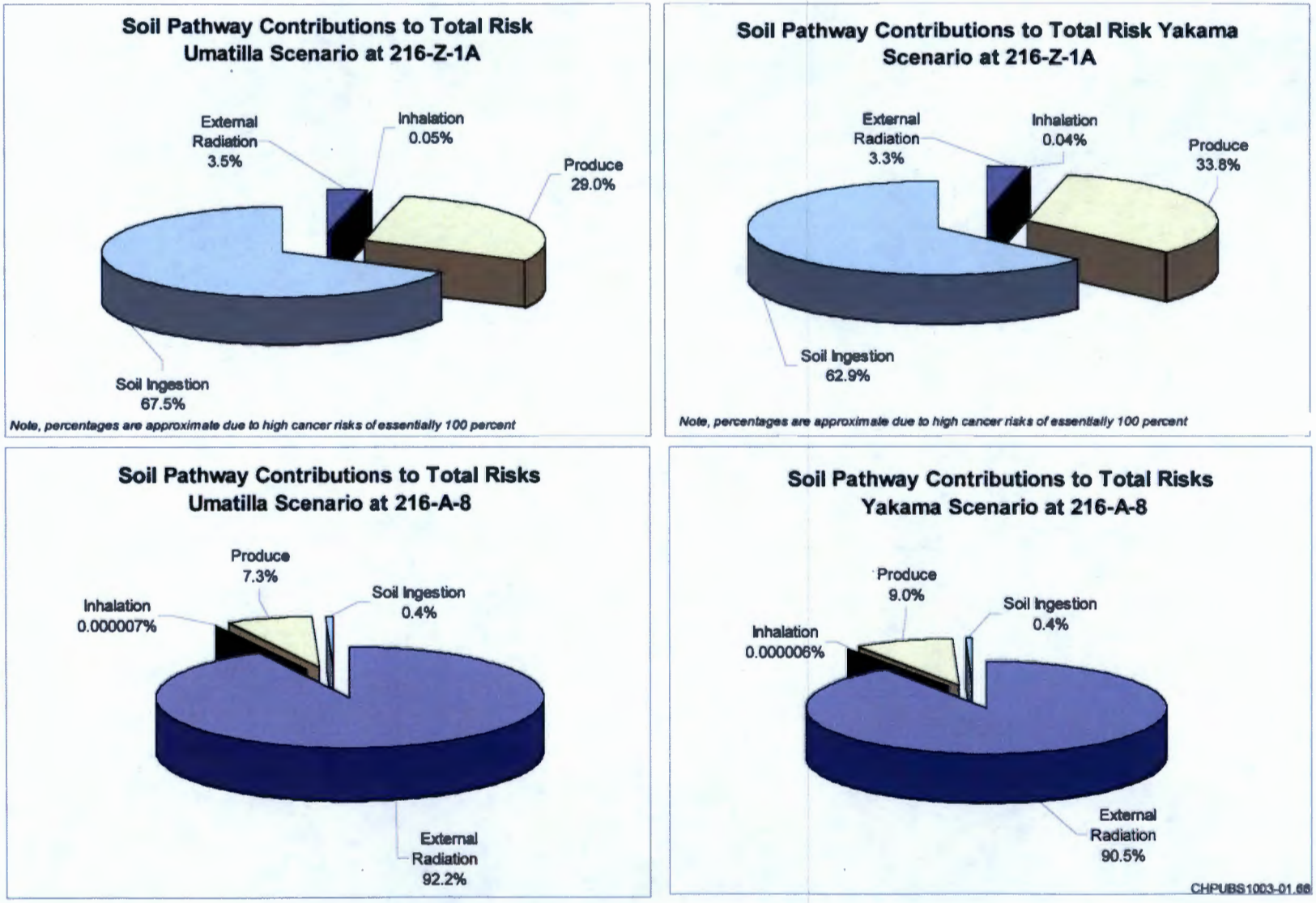
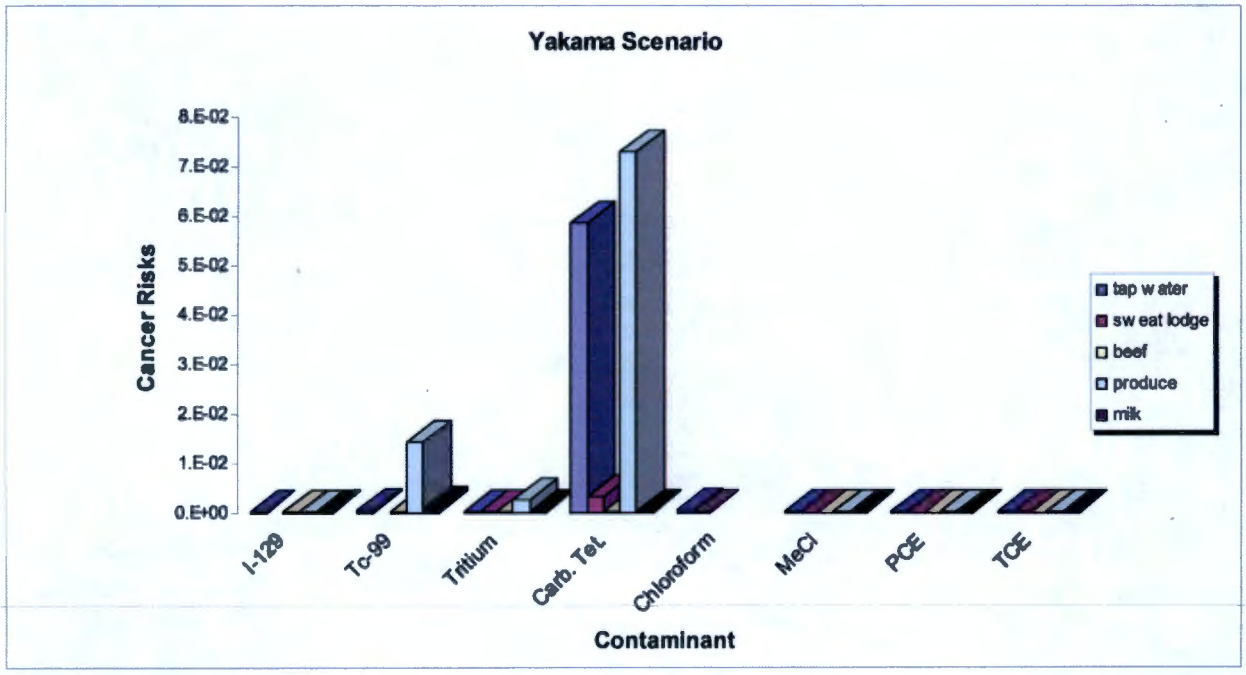
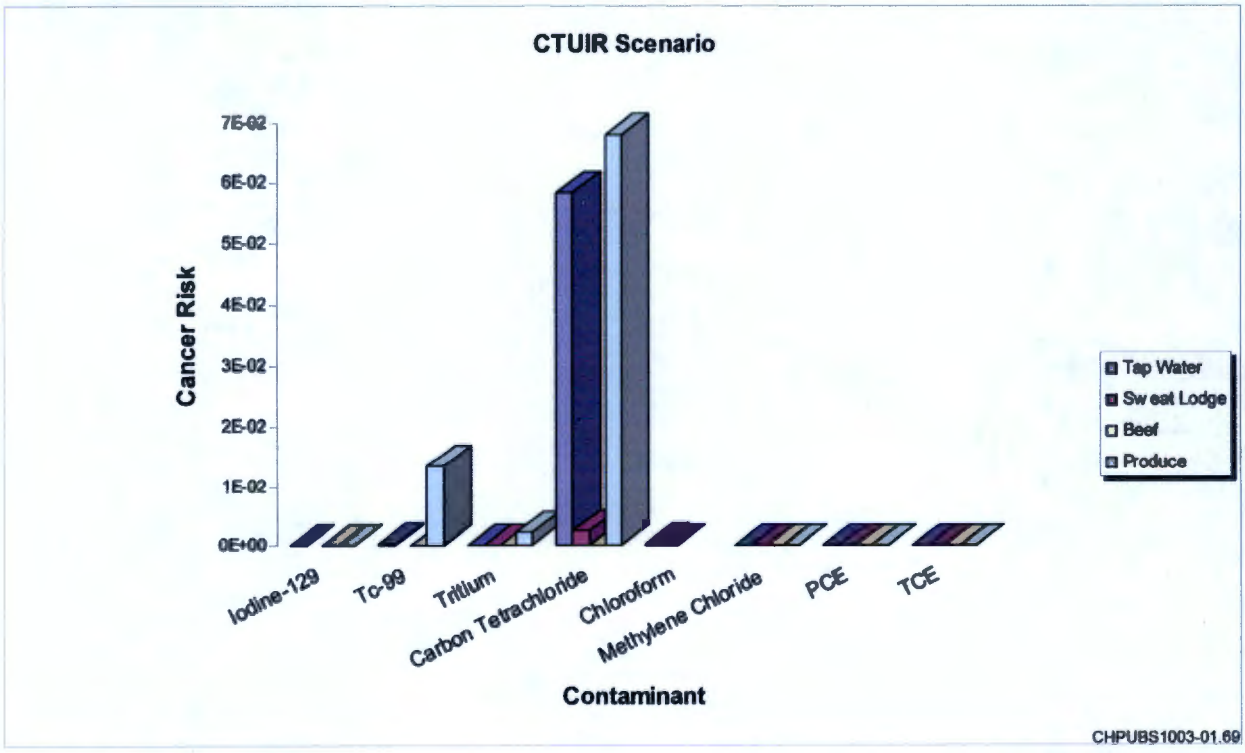


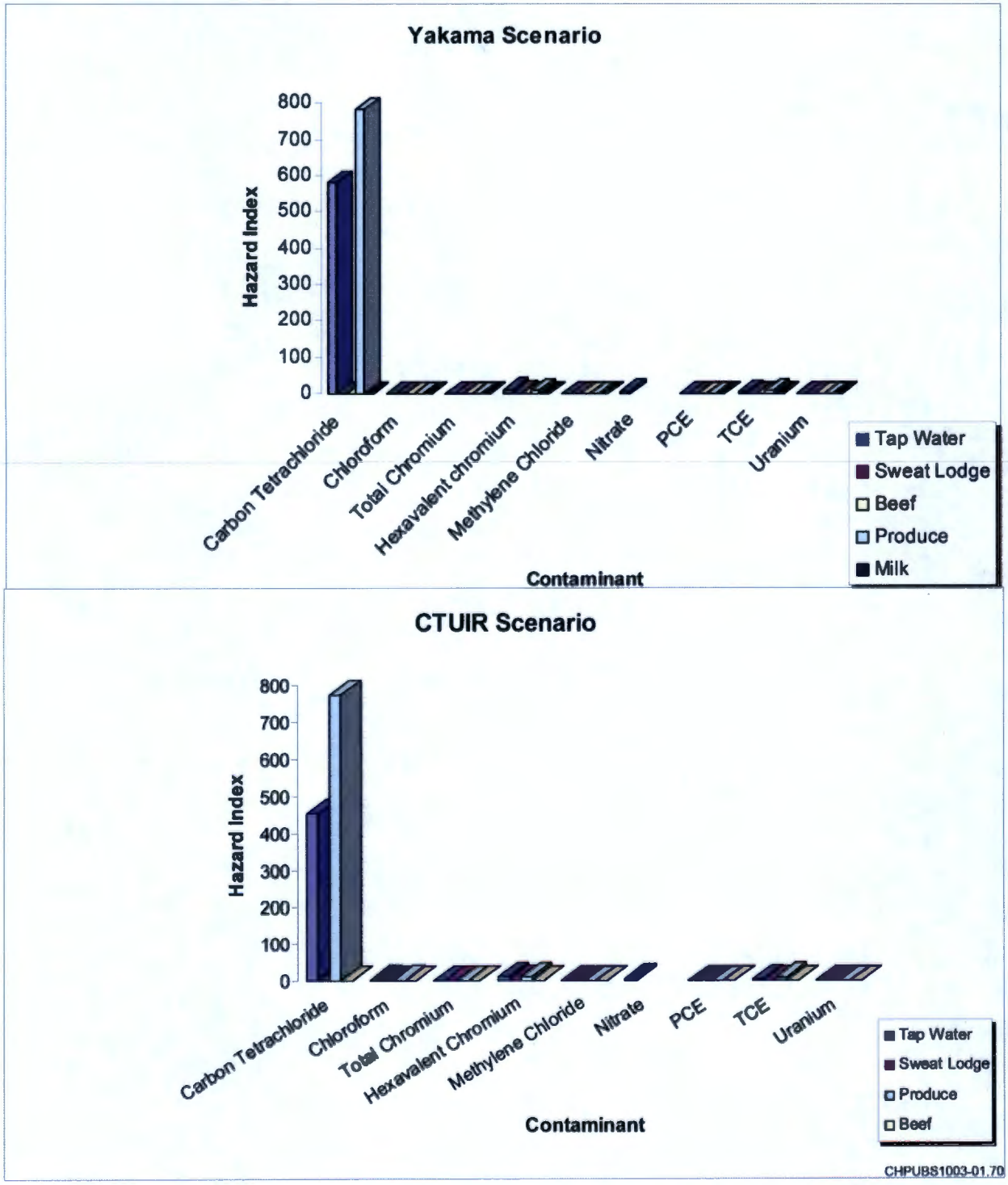
Figure ES-2. Native American 90th Percentile Groundwater Risks by Contaminant and Pathway.





NOTE: Not all exposure pathways are shown for each contaminant because not all contaminants are evaluated for every pathway (e.g., chloroform is not evaluated as a carcinogen in beef or produce because only non-cancer toxicity is a concern when the chemical is ingested).

Figure ES-3. Native American 90th Percentile Groundwater Hazards by Contaminant and Pathway.



NOTE: Not all exposure pathways are shown for each contaminant because not all contaminants are evaluated for every pathway (i.e., nitrate is not evaluated for its toxicity via the food chain).

Table ES-2. Summary of Cancer Risks for the CTUIR Native American Population from Soil.

Radionuclide or Contaminant	Total[a]	Direct-Exposure Pathways				Food Chain Pathway
		Inhalation	Ingestion	External Radiation	Radon	Produce[b]
216-Z-1A Tile Field						
Am-241	1E+00	4E-04	6E-01	5E-01	--	3E-01
Np-237[c]	2E-03	2E-08	4E-05	1E-03	--	4E-04
Pu-239	1E+00	6E-03	1E+00	5E-02	--	1E+00
Pu-240	1E+00	1E-03	9E-01	4E-03	--	6E-01
U-235[c]	2E-05	5E-10	1E-06	2E-05	--	1E-06
U-236[c]	1E-05	3E-09	7E-06	4E-08	--	7E-06
Total[d]–150 years	**1E+00**	**7E-03**	**1E+00**	**5E-01**	**9E-14**	**1E+00**
216-A-8 Crib						
C-14	4E-31	0E+00	0E+00	0E+00	--	4E-31
Cs-137	3E-01	7E-09	1E-03	3E-01	--	2E-02
Np-237	4E-05	5E-10	8E-07	3E-05	--	7E-06
Pu-239	3E-05	1E-08	2E-05	9E-08	--	9E-06
Pu-240	6E-06	2E-09	5E-06	7E-09	--	2E-06
Ra-228	2E-13	3E-19	7E-15	8E-14	--	1E-13
Tc-99	1E-05	8E-14	5E-09	4E-10	--	1E-05
Th-228	2E-13	2E-18	3E-15	2E-13	--	2E-15
Total–150 years	**3E-01**	**2E-08**	**1E-03**	**3E-01**	**7E-15**	**2E-02**
Total–500 years	**7E-05**	**1E-08**	**2E-05**	**3E-05**	**5E-18**	**2E-05**
Total–1,000 years	**6E-05**	**1E-08**	**2E-05**	**2E-05**	**2E-17**	**2E-05**

NOTES:

1. Shaded values exceed 1 x 10^{-4}. For those cancer risk values listed as 1, risks do not equal 1, but are approaching 100%.

2. Yakama Nation cancer risk results from soil are very similar to CTUIR results.

[a]Totals are calculated using unrounded values.

[b]Plants grown in impacted soil are the only food chain evaluated for soil. For beef and dairy cattle, exposures are from 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 is a daughter product and was not selected as a contaminant of potential concern.

[d]Totals may add to >1, but are only reported to approximately 1, because risk cannot be greater than or equal to 100%.

-- = indicates incomplete pathway or not applicable (i.e., radon column)
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Table ES-3. Summary of Cancer Risks from Native American Exposures to Groundwater.

Exposure Pathway	Nonradionuclide COPCs			Radionuclide COPCs			Cumulative Cancer Risk		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Yakama Nation									
Tap water	6E-02	1E-02	2E-04	6E-04	7E-05	2E-05	6E-02	1E-02	2E-04
Sweatlodge	3E-03	6E-04	8E-06	7E-05	7E-06	1E-06	3E-03	6E-04	9E-06
Beef	1E-05	2E-06	3E-08	2E-04	2E-05	5E-06	2E-04	2E-05	5E-06
Fruits and vegetables	7E-02	1E-02	2E-04	2E-02	2E-03	6E-04	9E-02	1E-02	8E-04
Milk	2E-05	3E-06	5E-08	8E-04	9E-05	3E-05	8E-04	1E-04	3E-05
Total	**1E-01**	**2E-02**	**3E-04**	**2E-02**	**2E-03**	**7E-04**	**2E-01**	**3E-02**	**1E-03**
CTUIR									
Tap water	6E-02	1E-02	2E-04	6E-04	7E-05	2E-05	6E-02	1E-02	2E-04
Sweatlodge	3E-03	5E-04	7E-06	6E-05	6E-06	9E-07	3E-03	5E-04	7E-06
Beef	2E-06	3E-07	6E-09	3E-05	3E-06	9E-07	3E-05	4E-06	9E-07
Fruits and vegetables	7E-02	1E-02	2E-04	2E-02	2E-03	6E-04	8E-02	1E-02	8E-04
Milk	a			a			a		
Total	**1E-01**	**2E-02**	**3E-04**	**2E-02**	**2E-03**	**6E-04**	**1E-01**	**2E-02**	**9E-04**

NOTE: Shaded values exceed 1×10^{-4}.

[a]The CTUIR do not have default milk ingestion rates to evaluate risks from exposure by this pathway.

COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Table ES-4. Summary of Non-Cancer Hazards from Native American Exposures to Groundwater.

Exposure Pathway	90th		50th		25th	
	Child	Adult	Child	Adult	Child	Adult
Yakama Nation						
Tap water	606	279	105	48	3	1
Sweatlodge	a	2	a	0.1	a	0.07
Beef	1	0.9	0.08	0.06	0.03	0.03
Fruits and vegetables	802	854	139	148	2	2
Milk	0.32	0.2	0.05	0.03	0.002	0.001
Total	**1,410**	**1,136**	**244**	**196**	**5**	**4**
CTUIR						
Tap water	471	279	81	48	2	1
Sweatlodge	a	1	a	0.09	a	0.05
Beef	a	0.2	a	0.01	a	0.0047
Fruits and vegetables	a	792	a	137	a	2
Milk	b		b		b	
Total	**471**	**1,072**	**81**	**185**	**2**	**4**

NOTE: Shaded values exceed 1.

[a]Child exposures were not evaluated for this pathway.

[b]The CTUIR do not have default milk ingestion rates to evaluate hazards from exposure by this pathway.

CTUIR = Confederated Tribes of the Umatilla Indian Reservation

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LIST OF TERMS

ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
CalEPA	California Environmental Protection Agency
CAS	Chemical Abstract Services
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
CTUIR	Confederated Tribes of the Umatilla Reservation
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objective
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FS	feasibility study
HEAST	*Health Effects Assessment Summary Tables: FY 1997 Update* (EPA 540-R-97-036)
HHRA	human health risk assessment
HHSL	human health screening level
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System
KM	Kaplan-Meir
LOAEL	lowest observed-adverse-effect level
MCL	maximum contaminant level
MRL	method reporting limit
MTCA	*Model Toxics Control Act*
NAS	National Academy of Sciences
NCEA	National Center for Environmental Assistance

NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAEL	no-observed-adverse-effect level
OEHHA	Office of Environmental Health Hazard Assessment (California)
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OU	operable unit
PCB	polychlorinated biphenyl
PCE	tetrachloroethylene
PEF	particulate emission factor
ppmv	parts per million by volume
ProUCL	EPA's software for calculating the upper confidence limit
RAIS	Risk Assessment Information System
RESRAD	RESidual RADioactivity (dose model)
RfC	reference concentration
RfD	reference dose
RfDi	reference dose for inhalation
RI	remedial investigation
RME	reasonable maximum exposure
SF	slope factor
SF_i	inhalation slope factor
SIF	summary intake factor
SSL	soil screening level
SVOC	semi-volatile organic compound
TAL	target action level
TCE	trichloroethylene
UCL	upper confidence limit
UF	uncertainty factor
URF	unit risk factor
VOC	volatile organic compound
WAC	*Washington Administrative Code*

G1.0 INTRODUCTION

This risk assessment evaluates potential human health risks for Native American populations who might reside in the future in selected areas of the Hanford Site's Central Plateau. Currently, contaminant-impacted areas of the Central Plateau are not accessible to the public, Native American or otherwise. However, the Hanford Site is within Yakama Nation ceded territory and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) also have treaty fishing rights on portions of the Columbia River bordering the site. Because the Yakama Nation and CTUIR have reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on open unclaimed land (*Hanford Site Environmental Report for Calendar Year 2005* [PNNL-15892]), this appendix addresses future health risks for these two Native American populations from exposure to contaminants formerly used at the Hanford Site that are still present in subsurface soil and groundwater.

With some exceptions, Native American exposures are similar in type to the residential farmer evaluated in the baseline risk assessment (which is included as Appendix A of this document) (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain). However, exposures may be different in kind (e.g., more time spent outdoors and greater consumption of native plants and animals) than the typical default exposures that the U.S. Environmental Protection Agency (EPA) has developed for a residential population (*Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final* [OSWER Directive 9285.6-03]; *Exposure Factors Handbook Volume 1: General Factors* [EPA 600/P-95-002Fa]; *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper, 2004]; *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment* [Ridolfi, 2007]). Therefore, Native American scenarios developed specifically for the Yakama Nation and CTUIR are addressed in this appendix.

Yakama Nation and CTUIR exposures will be evaluated for 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 two 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). Representative 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.

The soil sites evaluated in this appendix are the 216-A-8 Crib (a representative waste site in the 200-PW-3 OU) and the 216-Z-1A Tile Field (a representative waste site in the 200-PW-1 OU) because these are the only two representative sites with contamination within 4.6 m (15 ft) of the ground surface. This depth interval (0 to 4.6 m [0 to 15 ft]) is the interval where human exposure is most likely to occur. Excavation to soils deeper than 4.6 m (15 ft) is unlikely and generally does not need to be evaluated for residential populations, according to EPA and state guidelines and regulations (*Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* [OSWER 9355.4-24]; *Washington Administrative Code* [WAC] 173-340, "Model Toxics Control Act – Cleanup"). For the three additional representative sites evaluated in Appendix A (216-Z-8 French Drain and 216-Z-10 Injection/Reverse Well in 200-PW-6 OU and 216-Z-9 in 200-PW-1 OU), the depth to impacted soil is greater than 4.6 m (15 ft). Therefore, exposures at

these sites for future Native Americans would be incomplete. Figure G1-1 shows the 200 West and 200 East Areas of the Hanford Site, and Figures G1-2 and G1-3 show the locations of 216-Z-1A Tile Field in the 200 West Area and 216-A-8 Crib in the 200 East Area, respectively.

Previous investigations have identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West and East Areas 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 and East Areas are 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.

This risk assessment evaluates risks for a hypothetical Native American population under future conditions if institutional controls fail and site knowledge is lost (unrestricted land use post-2150). The unrestricted land use scenario assumes that exposures to Native Americans could occur if soil contamination is present in the top 4.6 m (15 ft) of soil and if groundwater is used for domestic purposes, crop irrigation, and stock watering. The intent of including a Native American scenario is to provide information on an unrestricted land use scenario for this population, fulfilling 40 *Code of Federal Regulations* (CFR) 300, "National Oil and Hazardous Substances Pollution Contingency Plan" (NCP), requirements for a risk evaluation under a no action scenario and EPA requirements to address current and future conditions (*Risk Assessment Guidance for Superfund Volume 1 Human Health Evaluation Manual (Part A): Interim Final* [EPA/540/1-89/002]). Cleanup concentration goals and decisions will not be based on potential Native American future exposures, consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future. The results of the Native American risk assessment will be considered in the feasibility study (FS) during evaluation of the balancing criteria (e.g., evaluation of the protectiveness of a particular remedy).

According to EPA, the U.S. Department of Energy (DOE), and Hanford-specific risk guidance, human health risk assessments (HHRAs) are composed of four basic steps, which the Native American scenarios will also follow. These steps are below:

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

The accuracy of the information presented in this HHRA depends, in part, on the quality and representativeness of the available sample, exposure, and toxicological data. Where information

is incomplete, conservative assumptions were made so that risk to human health was not underestimated. A discussion of uncertainties in the HHRA is presented in Section G6.0.

This appendix was prepared primarily in accordance with the exposure scenarios developed by each Nation (Ridolfi, 2007; Harris and Harper, 2004). However, current EPA, Hanford-specific, and DOE guidelines for risk assessment are also included where applicable (EPA/540/1-89/002; OSWER Directive 9285.6-03; EPA 600/P-95-002Fa; *EPA Region 10 Interim Final Guidance: Developing Risk-Based Cleanup Levels at Resource Conservation and Recovery Act Sites in Region 10* [EPA 910/R-98-001]; *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* [OSWER 9285.6-10]; OSWER 9355.4-24; and *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final* [EPA/540/R/99/005]; and *Hanford Site Risk Assessment Methodology* [DOE/RL-91-45]). In the absence of appropriate regulatory guidance (e.g., for site-specific conditions), the evaluation followed the available science.

This appendix is organized as follows:

- Section G1.0 contains an introduction.
- Section G2.0 summarizes the data for the risk assessment and the COPCs from the discussion in Appendix A, Section A2.0.
- Section G3.0 describes the exposure assessment, including the conceptual site model (CSM), the rationale for the selection/exclusion of exposure pathways, and the methodology and inputs that are used to calculate contaminant dose.
- Section G4.0 presents the toxicity criteria that are used in the risk and hazard calculations.
- Section G5.0 presents the results of the risk calculations for carcinogenic (cancer) risks and noncarcinogenic (non-cancer) hazards.
- Section G6.0 discusses the major uncertainties in the risk assessment.
- Section G7.0 summarizes the risk assessment and presents the conclusions.
- Section G8.0 provides the references used in preparing this document.

Figure G1-1. Site Vicinity and Location Map.

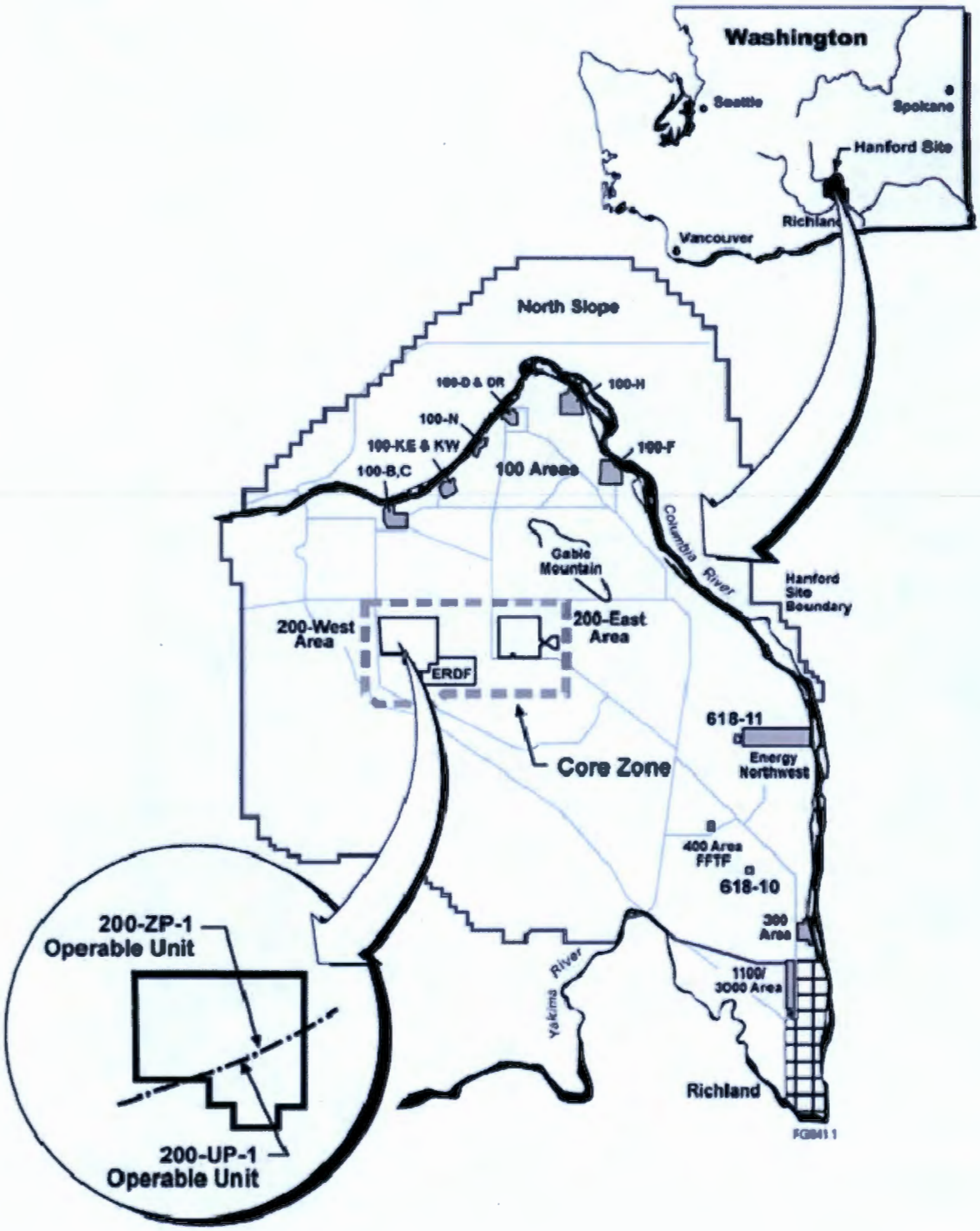


Figure G1-2. Location of 216-Z-1A Tile Field in the 200 West Area.

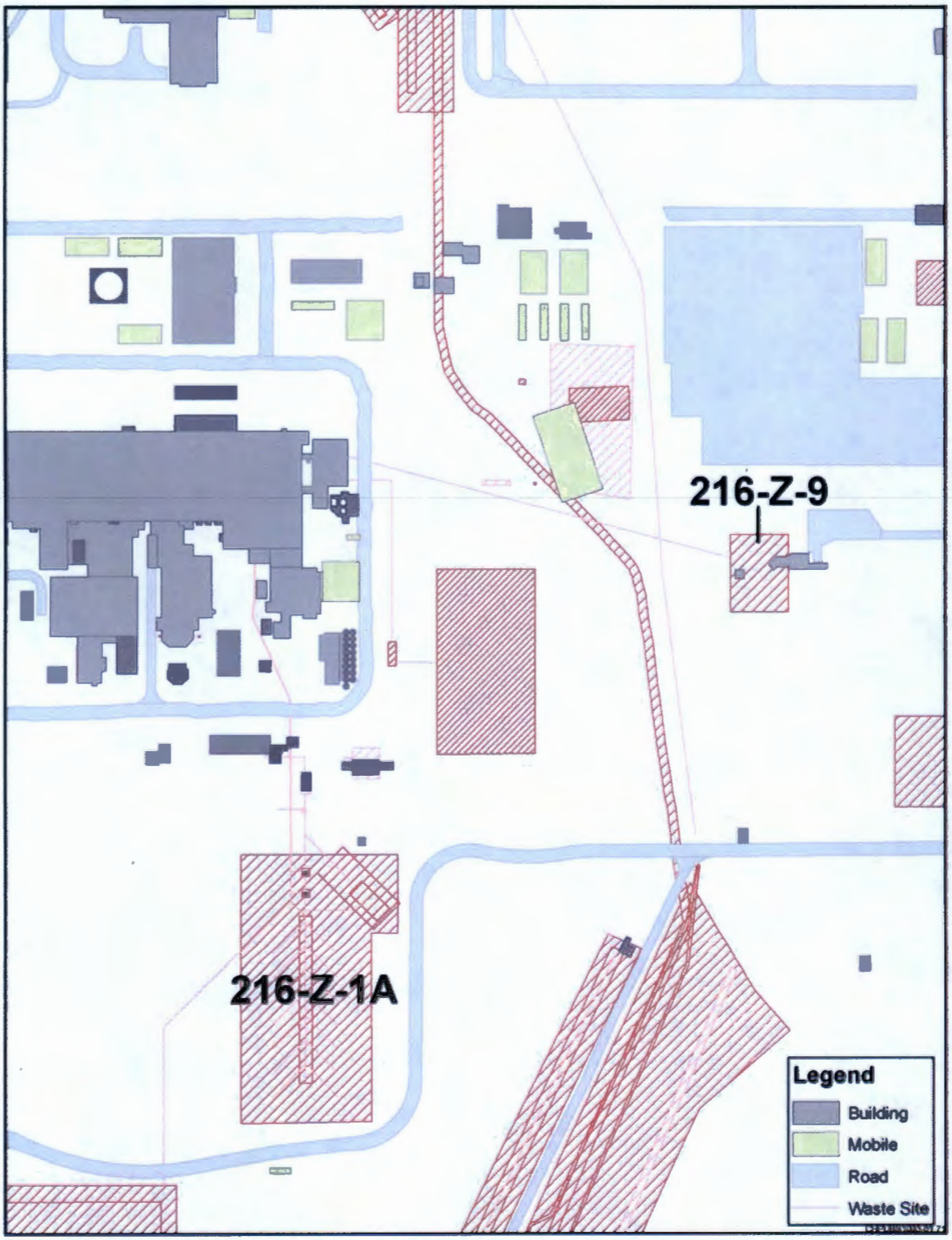
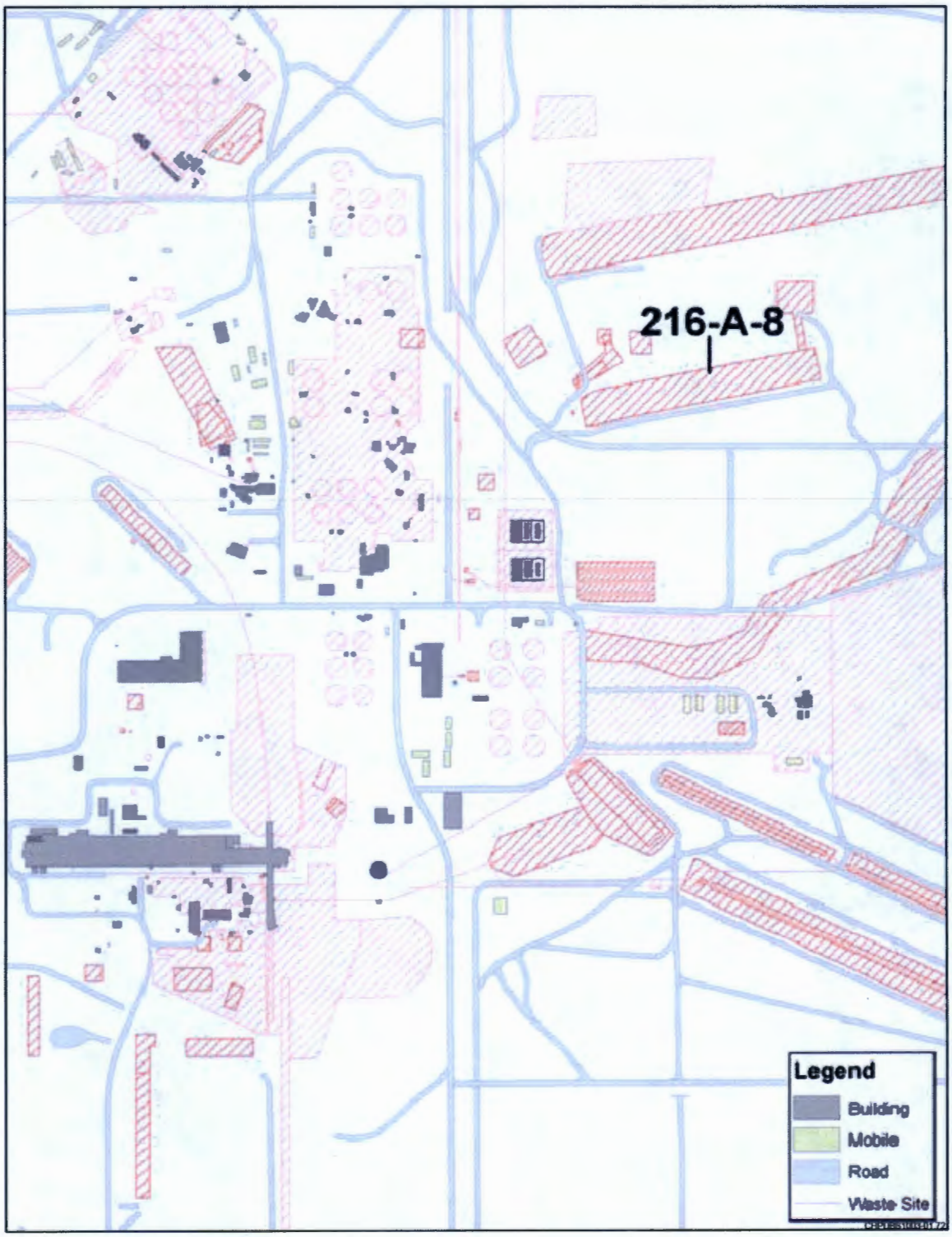


Figure G1-3. Location of 216-A-8 Crib in the 200 East Area.



G2.0 DATA EVALUATION AND SELECTION OF CONTAMINANTS OF POTENTIAL CONCERN

The primary objective of the data collection and evaluation process in the HHRA is to develop a data set of sufficient quality and quantity to adequately evaluate the potential constituent impacts to human receptors. The initial step has two parts: (1) the available sampling data and site information are reviewed to select data applicable to human health, and (2) constituent concentrations within the data set are evaluated to identify constituents and affected environmental media (i.e., soil) that are potential human health concerns requiring a more detailed assessment. The data evaluation process and selection of COPCs were completed in the baseline HHRA in Appendix A. Only summaries concerning the selection of data for soil and groundwater, and the selected COPCs are included here. Details on the sample numbers and locations included in the risk assessment and an evaluation of data usability and quality can be found in Appendix A (Section A2.1).

G2.1 SELECTION OF DATA APPLICABLE TO HUMAN HEALTH

Not all of the data available at a particular site are usually selected for inclusion in the risk assessment, because not all are relevant to human health exposures. For example, the quality of the data may be insufficient for the needs of the risk assessment, or the soil data may be from a depth interval for which there would be no human exposures. This section presents a summary of the soil and groundwater data selected for inclusion or exclusion in this risk assessment.

G2.1.1 Soil

The baseline HHRA in Appendix A used the available data from the 200-PW-1/3/6 remedial investigation (RI) report (DOE/RL-2006-51) for the representative soil sites. The data sources for the two sites evaluated in this appendix are below:

- At the 216-Z-1A Tile Field, the data used for screening are from the cone penetrometer rig locations in and around the 216-Z-1A Tile Field (Table 3-9 of the 200-PW-1/3/6 RI report [DOE/RL-2006-51], Appendix C of the RI report [circa 1992 to 1993 sampling], and Appendix D of the RI report [circa 1979 sampling]). Data are available from depth ranges of 1.5 to 46.6 m (5 to 153 ft) below ground surface (bgs). Sampling locations used in the screening analysis are tabulated in Table A2-1 of Appendix A. Figure A2-1 of Appendix A shows the sampling locations at the 216-Z-1A Tile Field. Table G2-1 and Figure G2-1 show those sample locations included in this Native American risk assessment for samples from 0 to 4.6 m (15 ft) bgs.

- At the 216-A-8 Crib, the data used for screening are from Appendix B of the 200-PW-1/3/6 RI report (DOE/RL-2006-51) (circa 2005 sampling). Data were available from a single location, C4545, with sample depths ranging from approximately 5.8 to 80 m (19 to 264.5 ft) bgs. Figure A2-4 of Appendix A shows the location of the boring. Table A2-2 of Appendix A shows the numbers of samples by constituent group available for the risk assessment.

As noted in Section G1.0, of the representative sites, only these two waste sites have contaminated soil in the top 4.6 m (15 ft). Therefore, potential Native American exposures are complete for soil only at these two sites.

G2.1.2 Groundwater

The groundwater data used in the baseline HHRA in Appendix A were also used in this appendix to evaluate potential Native American exposures. Data used for the 200-ZP-1 RI report (*Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit* [DOE/RL-2006-24]) consisted of groundwater monitoring well data from samples collected from 116 wells from 1988 through 2005. The baseline HHRA in Appendix A for site 200-ZP-1 OU used a subset of the RI data set. Specifically, the last 5 years of data were selected as representative of current conditions (samples collected from 2001 through 2005), and data prior to 2000 were excluded. 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 of Appendix A, and Table A2-2 of Appendix A shows the numbers of samples available per constituent or constituent group. The selected wells included in this Native American risk assessment are shown in Table G2-2.

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

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

For the remaining metals in groundwater, the majority of the groundwater data is based on filtered samples. Therefore, these filtered concentrations of antimony, iron, chromium (total), and hexavalent chromium potentially underestimate the total concentrations present in groundwater. Because antimony is present at background concentrations, and iron concentrations were orders of magnitude below a health-based level, the exclusion of these chemicals from the in-depth risk analysis (see Section G6.1.2) will not affect the conclusions of the risk assessment. The uncertainty associated with the use of filtered results for chromium (total) and hexavalent chromium is discussed in detail in the uncertainty section of Section G.6.1.2. Because the most toxic form of chromium, hexavalent, is expected to be present primarily in the dissolved form, the use of filtered data is not expected to impact the evaluation of Native American exposures in this appendix (Section G6.1.1.2).

G2.1.3 Soil Gas

Because of the high concentrations of carbon tetrachloride and other chlorinated solvents in groundwater beneath the 200-PW-1 OU (the location of 216-Z-1A Tile Field), soil gas sampling has occurred over a number of years. Soil gas data from the vicinity of the 216-Z-1A Tile Field collected in 2005 were reviewed to evaluate their suitability for inclusion in the risk assessment. Soil gas was collected from 17 sampling locations (see circled area in Figure G2-2) and analyzed for volatile organic compounds (VOCs) using field-screening procedures that measured total vapors but not individual compounds. Soil gas samples were screened at intervals ranging from 3 to 26.36 m (1 to 86.5 ft) bgs. Although the samples were analyzed for VOCs and not individual compounds, the samples were calibrated to five specific VOCs, including carbon tetrachloride and chloroform. These data are summarized in *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source Term Interim Characterization Report* (DOE/RL-2006-58). Generally, detected concentrations in the vicinity of the 216-Z-1A Tile Field ranged from 2 to 512 parts per million by volume (ppmv) (or 12.58 to 3,221.5 mg/m^3) for carbon tetrachloride and 2 to 27 ppmv (or 9.77 to 131.8 mg/m^3) for chloroform over all depth intervals[1]. Maximum concentrations for both carbon tetrachloride and chloroform were located at sampling location P30E. Other high concentrations were also found at location P29. Both sampling locations P29 and P30 are located in the center of the former tile field. Samples collected from these locations in the 15.24- to 21.34-m (50- to 70-ft) screening interval contain the highest concentrations of carbon tetrachloride and chloroform in soil gas. These sampling locations are in the dense nonaqueous phase liquid pool that was identified at this location (DOE/RL-2006-58). Therefore, these soil gas samples likely represent worst-case conditions for subsurface vapors.

Because these data were analyzed using field-screening methodology and the soil gas data were not analyzed for individual compounds, it cannot be used quantitatively for risk assessment. However, because vapors are present at depth in the subsurface, they could potentially migrate to a future building (no structures are currently above the 216-Z-1A Tile Field) and vapor intrusion is discussed qualitatively in Sections G3.0 and G5.0.

G2.2 SELECTION OF NATIVE AMERICAN-SPECIFIC COPCS

The COPCs selected in soil in the baseline HHRA in Appendix A were based on exceedances above health-protective residential screening values derived by EPA to protect the general U.S. population (see Section A2.2 of Appendix A and Section G2.3). Generic screening levels to protect a Native American population are not available. Because Native American exposures are higher than general population exposures for soil and groundwater (i.e., Native Americans ingest two to four times more soil and groundwater per day than EPA assumes for residential exposures), chemicals could be screened out using EPA screening levels, but might be retained if Native American exposures were assumed. Because safety factors are already used in the residential screening process (see Section G2.3), a separate screening was not done for this assessment to select COPCs for Native Americans using lower screening criteria. However, the uncertainties surrounding potential additional COPCs for a Native American population based on lower screening levels are discussed in Section G6.0.

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[1] A single chloroform concentration was reported of 234 ppmv at location P38. However, this result was an isolated occurrence and appears suspect. The other soil gas samples collected from location P38 in the same general depth range were significantly lower and ranged from 3 to 8 ppmv. Therefore, this chloroform result was not considered in this evaluation.

Groundwater COPCs evaluated in Appendix A were selected in the groundwater RI (DOE/RL-2006-24) based on target action levels (TALs) (most of which were risk-based) approved by the regulatory agencies, which are discussed further in Section G2.4. The potential for additional groundwater COPCs to be selected using lower screening levels is also discussed in Section G6.0.

Note that differences in COPC selection as a result of differences between residential and Native American screening levels would not occur if site contaminants were above or well below EPA screening levels. For example, if a maximum concentration is larger than an EPA screening level, then it does not matter if the contaminant is screened against a lower screening level; it would still be selected as a COPC. Therefore, the COPCs selected using EPA screening levels in Appendix A would also be selected for a Native American population, and risk drivers selected using EPA screening levels would also be risk drivers for a Native American population. In addition, if a contaminant is below background, it would not be selected for either standard residential or Native American populations; nor would the contaminant be selected if it was considerably lower than an EPA screening level. Therefore, the COPC selection issue is a potential concern for chemicals that are slightly below EPA screening levels and, therefore, would likely represent borderline risks for a Native American population. The issue is thus addressed as an uncertainty.

G2.3 RESULTS OF SCREENING FOR SOIL

This section summarizes the results of the screening processes for soil conducted in Appendix A. Tables A2-7 and A2-11 of Appendix A show data, screening levels, and results of screening. These two tables are reproduced here as Tables G2-3 and G2-4 for the 216-Z-1A Tile Field and 216-A-8 Crib, respectively. The maximum detected contaminant concentrations were compared to health-protective screening levels. Specifically, EPA's Region 6 human health screening levels (HHSLs) for residential soil were used as the risk-based screening values for nonradionuclides[2] (OSWER 9355.4-24), and EPA's generic residential screening levels for radionuclides (*Soil Screening Guidance for Radionuclides: Technical Background Document* [EPA/540-R-00-006]) were selected for the radiological evaluation. If contaminant concentrations were above screening values, they were considered for selection as COPCs. The COPCs selected for these two soil sites are summarized below.

- 216-Z-1A Tile Field:
  - Americium-241
  - Plutonium-239/240
- 216-A-8 Crib:
  - Carbon-14
  - Cesium-137
  - Neptunium-237
  - Plutonium-239/240
  - Radium-228
  - Technetium-99

[2] Where no Region 6 HHSL was available, EPA Region 9 preliminary remediation goals were used ("Region 9 PRG Table" [EPA, 2004]).

- Thallium
- Thorium-228.

The COPCs were selected based on a screening hazard quotient (HQ) of 0.1 and risk of 1×10^{-6}, providing a safety factor of 10 for noncarcinogens (HQs must exceed 1 before a health risk is present) and 100 for carcinogens (action is not typically taken at a site unless the cancer risk exceeds 10^{-4}). Included in Section G6.0 is a discussion of the selection of COPCs if the data were screened with lower safety factors: an HQ of 0.01 for noncarcinogens and a 1×10^{-8} risk level for carcinogens (obtained by dividing EPA standard residential values by a factor of 100). Also included in Section G6.0 is a discussion of contaminants that do not have screening values and thus cannot be evaluated in a risk assessment.

G2.4 RESULTS OF SCREENING FOR GROUNDWATER

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

Table A2-14, of Appendix A is reproduced here as Table G2-5 and presents a summary of the last 5 years of data for the 15 contaminants identified in the 200-ZP-1 RI as contaminants of concern (COCs) (DOE/RL-2006-24). The following 12 COPCs were selected for quantitative evaluation in the risk assessment:

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

Uranium is retained as a COPC based on its chemical toxicity, not on its radioactive toxicity. The radioactive isotopes of uranium have either not been detected in recent groundwater monitoring rounds or have been detected at concentrations well below health-based levels

(DOE/RL-2003-55). Thus, only chemical toxicity is a concern for uranium. Uranium is unique in that its chemical toxicity occurs at or below levels that are a concern for radioactive toxicity.

Figure G2-1. 216-Z-1A Tile Field Sampling Locations for Soil (0 to 4.6 m).

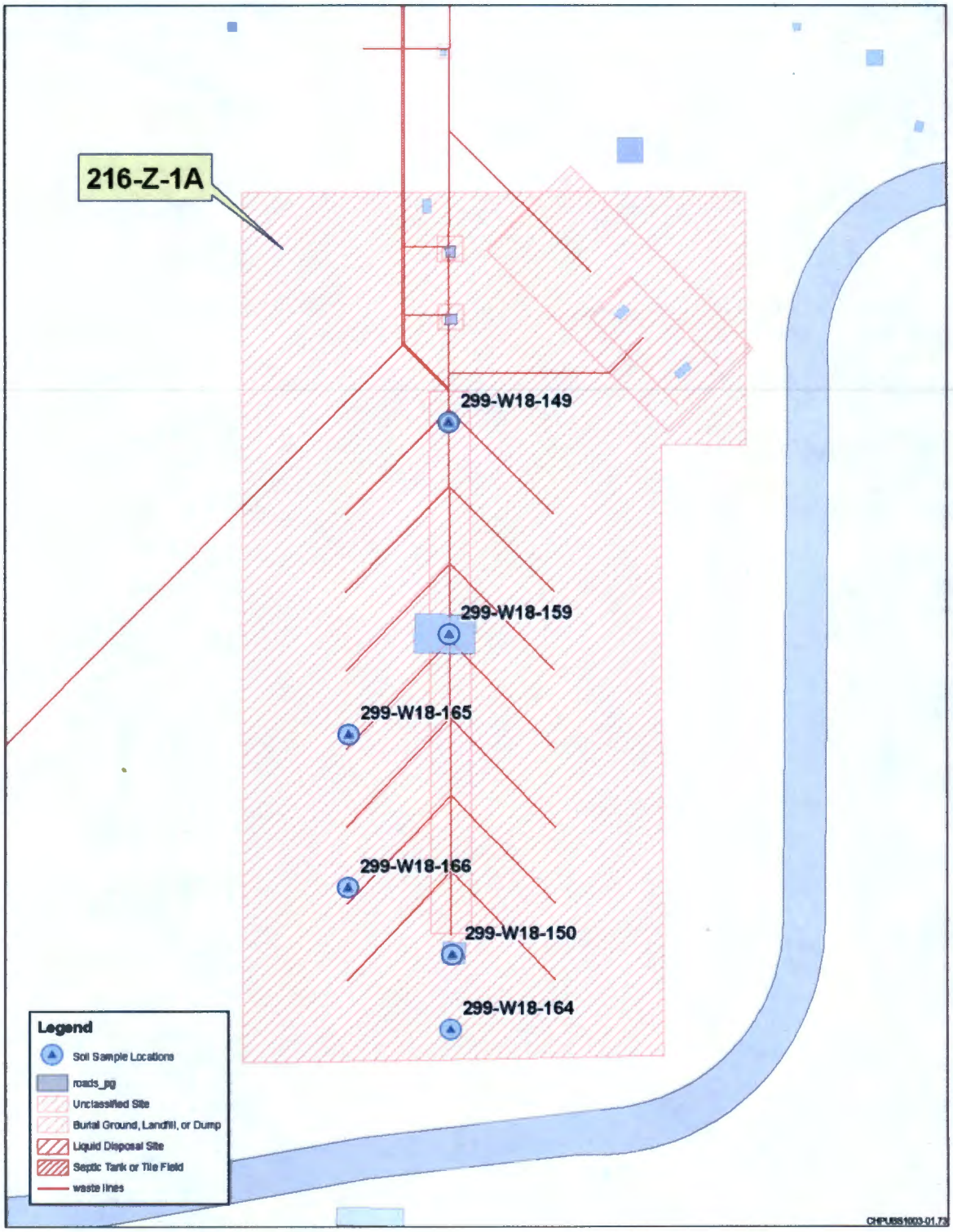


Figure G2-2. 216-Z-1A Tile Field Sampling Locations for Soil Gas.

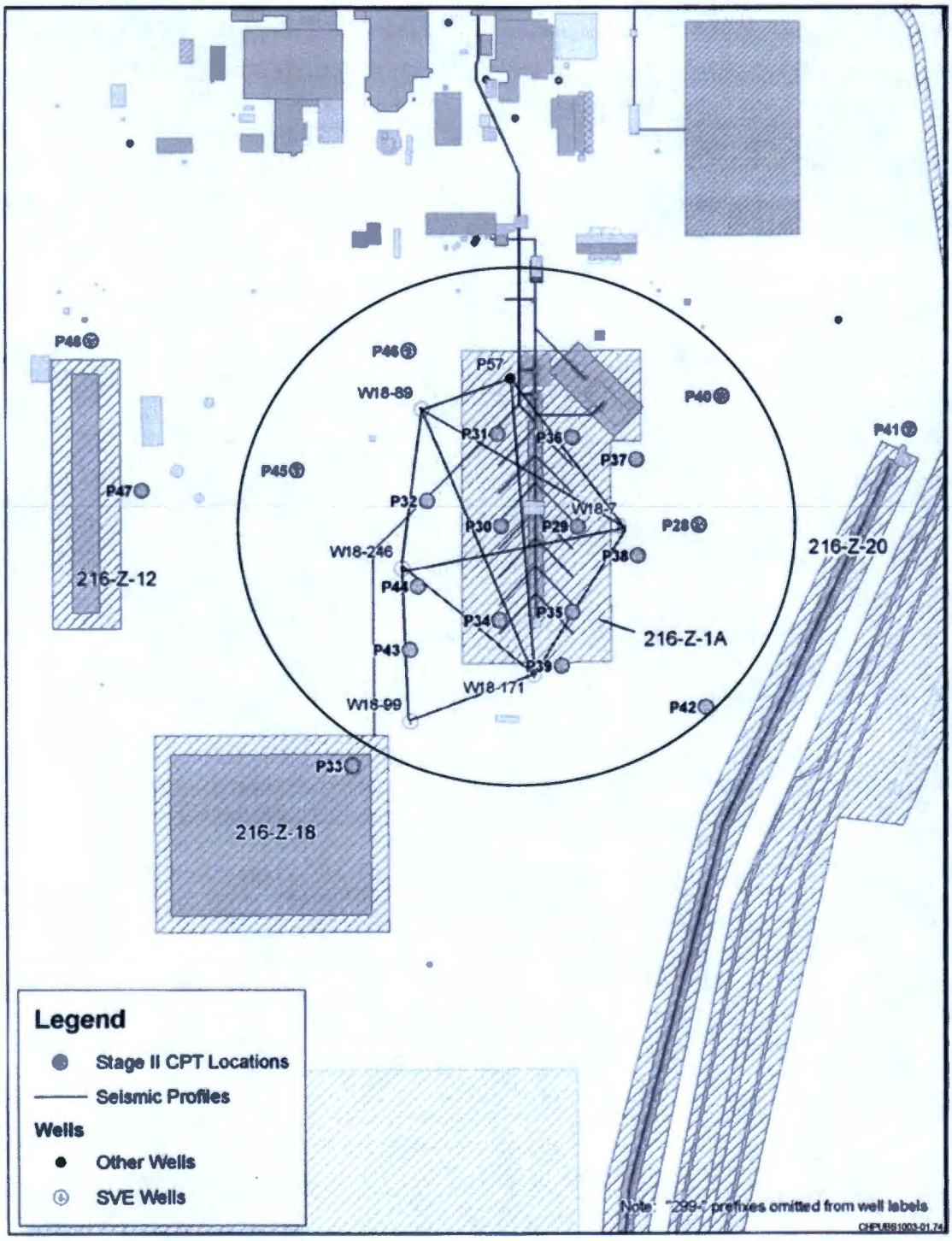


Table G2-1. Summary of Soil Data Sampling Locations Included in the Risk Assessment, 216-Z-1A Tile Field.

299-W18-149	299-W18-164
299-W18-150	299-W18-165
299-W18-159	299-W18-166

Table G2-2. Summary of Groundwater Data Sampling Locations Included in the Risk Assessment for the 200-ZP-1 Operable Unit.

299-W10-1	299-W11-7	299-W15-40	299-W7-4
299-W10-17	299-W12-1	299-W15-41	299-W7-5
299-W10-19	299-W13-1	299-W15-42	299-W7-6
299-W10-20	299-W14-13	299-W15-43	299-W7-7
299-W10-21	299-W14-14	299-W15-44	299-W7-8
299-W10-22	299-W14-15	299-W15-45	299-W7-9
299-W10-23	299-W14-16	299-W15-46	299-W8-1
299-W10-24	299-W14-17	299-W15-47	699-19-88[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[a]
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[a]
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	

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

Table G2-3. 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	Unit	Location/Sample No. of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale Contaminant Deletion or Selection[d]
Metals																
7440-39-3	Barium	44		160		mg/kg	299-W18-174	17/17	--	160	132	1,564		HHSL	NO	BSL
7440-41-7	Beryllium	0.3		0.7		mg/kg	299-W18-174	13/17	NA	0.7	1.51	15.4		HHSL	NO	BSL
7440-70-2	Calcium	5,900		230,000		mg/kg	299-W18-248	17/17	--	230,000	17,200	NE		NA	NO	NUT
7440-47-3	Chromium	4.8		19		mg/kg	299-W18-174	17/17	--	19	18.5	211	c	HHSL	NO	BSL
7440-48-4	Cobalt	3.8		10		mg/kg	299-W18-174	17/17	--	10	15.7	903	c	HHSL	NO	BSL
7440-50-8	Copper	8.6		24		mg/kg	299-W18-248/'299-W18-174	17/17	--	24	22	291		HHSL	NO	BSL
7439-89-6	**Iron**	**6,800**		**25,000**		**mg/kg**	**299-W18-248**	**17/17**	**--**	**25,000**	**32,600**	**5,475**		**HHSL**	**NO**	**BCK**
7439-92-1	Lead[e]	1.5		11		mg/kg	299-W18-174	17/17	--	11	10.2	400		HHSL	NO	BSL
7439-95-4	Magnesium	3,300		8,900		mg/kg	299-W18-248	17/17	--	8,900	7,060	NE		NA	NO	NUT
7439-96-5	**Manganese**	**200**		**760**		**mg/kg**	**299-W18-248**	**17/17**	**--**	**760**	**512**	**346.5**		**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 Organic Compounds																
75-09-2	Methylene chloride	0.005	B	0.008	B	mg/kg	P29C--C4917--P29C-60	4/23	0.0025 to 0.011	0.008	0	8.9	c	HHSL	NO	BSL
Radionuclides																
14596-10-2	**Am-241**	**-0.0436**		**259,0000**		**pCi/g**	**299-W18-149**	**283/458**	**-0.0752 to 20,900**	**2,590,000**	**NE**	**3.7**		**SSL**	**YES**	**ASL**
PU-239/240	**Pu-239/240**	**0.0135**		**38,200,000**		**pCi/g**	**299-W18-149**	**128/423**	**-250 to 188,000**	**38,200,000**	**0.0248**	**2.9**		**SSL**	**YES**	**ASL**
Other																
16887-00-6	Chloride	0.6		9.4		mg/kg	299-W18-248	17/17	--	9.4	100	NE		NA	NO	BCK
16984-48-8	Fluoride	0.3		16		mg/kg	299-W18-174	13/17	NA	16	2.81	367		HHSL	NO	BSL
14797-55-8	Nitrate	1		250		mg/kg	299-W18-174	17/17	--	250	52	12,167		CALC	NO	BSL
14797-65-0	Nitrite	0.4		1.6		mg/kg	299-W18-248	4/17	NA	1.6	NE	760		CALC	NO	BSL
14265-44-2	Phosphate	1		1		mg/kg	299-W18-174	1/17	NA	1	0.785	NE		NA	NO	BCK
14808-79-8	Sulfate	2		26		mg/kg	299-W18-248	17/17	--	26	237	NE		NA	NO	BCK

NOTE: Chemical bolded exceeded its screening value. Shaded chemicals were selected as COPCs.

[a]Minimum/maximum detected concentration. Includes analytical data from 1.5 to 46.6 m (5 to 153 ft) below ground surface.

[b]Background was assumed to be zero for volatile organic compounds. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, and DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes,* respectively.

[c]For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA, 2006, *Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*) 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 of EPA/540-R-00-006, *Soil Screening Guidance for Radionuclides: Technical Background Document*. Generic (no accounting for decay) SSLs are from 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

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

-- = contaminant has 100% detection frequency
B = analyte 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
EPA = U.S. Environmental Protection Agency
HHSL = human health screening level (EPA, 2006)
mg/kg = milligram per kilogram
NA = not applicable
NE = not established
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)
pCi/g = picocurie per gram

Table G2-4. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Unit	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 Organic 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 Organic Compounds																
104-76-7	2-Ethyl-1-hexanol	0.76	J	0.76	J	mg/kg	C4545-B1D7C7	1/1	-	0.76	0	NE		NA	NA	NA
67-64-1	Acetone	0.0033	J	0.019	J	mg/kg	C4545-B1D9Y4	3/10	0.0017 to 0.0021	0.019	0	1,415		HHSL	NO	BSL
75-05-8	Acetonitrile	0.012	J	0.012	J	mg/kg	C4545-B1DB24	1/10	0.0034 to 0.026	0.012	0	146.5		HHSL	NO	BSL
141-78-6	Ethyl acetate	0.013		0.023		mg/kg	C4545-B1DB24	2/2	--	0.023	0	1,874		HHSL	NO	BSL
Radionuclides																
14762-75-5	**C-14**	**4.34**		**89.7**		**pCi/g**	**C4545-B1D7C7**	**3/10**	**-1.11 to 0.004**	**89.7**	**NE**	**0.128**		**SSL**	**YES**	**ASL**
10045-97-3	**Cs-137**	**0.432**		**877,000**		**pCi/g**	**C4545-B1D9Y4**	**10/18**	**-0.001 to 0.15**	**877,000**	**1.05**	**0.044**		**SSL**	**YES**	**ASL**
14391-16-3	Eu-155	0.045		0.055		pCi/g	C4545-B1D7C9	2/18	-0.338 to 860	0.055	0.0539	0.9		SSL	NO	BSL
13994-20-2	**Np-237**	**0.015**		**3.53**		**pCi/g**	**C4545-B1D9Y4**	**2/4**	**0 to 0.27**	**3.53**	**NE**	**0.14**		**SSL**	**YES**	**ASL**
PU-239/240	**Pu-239/240**	**0.011**		**55.7**		**pCi/g**	**C4545-B1D9Y4**	**4/10**	**-0.002 to 0.043**	**55.7**	**0.0248**	**2.9**		**SSL**	**YES**	**ASL**
13966-00-2	**K-40**	**7.9**		**17.4**		**pCi/g**	**C4545-B1D994**	**8/10**	**1.7 to 6,200**	**17.4**	**16.6**	**0.14**		**SSL**	**NO**	**BCK**

Table G2-4. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

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

NOTE: Chemical bolded exceeded its screening value. Shaded chemicals were selected as COPCs.

[a]Minimum/maximum detected concentration. Includes analytical data from 5.8 to 80 m (19 to 264.5 ft) below ground surface.

[b]Background is assumed to be zero for SVOCs, PCBs, and VOCs. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, and DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, respectively.

[c]For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA, 2006, *Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*) 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 EPA/540-R-00-006, *Soil Screening Guidance for Radionuclides: Technical Background Document*, Table A.1. Generic (no accounting for decay) SSLs are from EPA/540-R-00-006.

[d]Rationale codes:

Selection reason: ASL = above screening level
ABCK = above background (magnitude of exceedance more than two times)
TXT = see uncertainty section of report for qualitative discussion of these chemicals

Deletion reason: BSL = below screening level
BCK = near or below background levels (magnitude of exceedance over background less than two times)
MAG = low magnitude of exceedance over the screening value (less than two times)

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

-- = compound has 100% detection frequency
B = analyte 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 = human health screening level (EPA, 2006)
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
mg/kg = milligram per kilogram
pCi/g = picocurie per gram
PRG = EPA Region 9 preliminary remediation goal for residential soil (EPA, 2004, "Region 9 PRG Table")
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 G2-5. Draft Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Groundwater (Based on Target Action Levels) at the 200-ZP-1 Operable Unit.

CAS No.	Chemical	Minimum Concentration[a]	Minimum Qualifier	Maximum Concentration[a]	Maximum Qualifier	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Concentration Used for Screening	Background Value[b]	Screening Value[c]		Screening Value Source	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Metals																
7440-36-0	**Antimony**	**2.4**	**B**	**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**
Radionuclides																
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**
Volatile Organic Compounds																
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**
Other																
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**

NOTE: Chemical bolded exceeded its 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 DOE/RL-96-61, *Hanford Site Background: Part 3, Groundwater Background.*

[c]Screening values are TALs from DOE/RL-2006-24, *Remedial Investigation Report for the 200-ZP-1 Groundwater Operable Unit*, Table 1-5.

[d]Rationale codes:

Selection reason: ASL = above screening level

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

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
µg/L = microgram per liter
N = The analysis indicates the presence of an analyte for which there is presumptive evidence to make a tentative identification.
NE = not established
pCi/L = picocurie per liter
TAL = target action level

G3.0 EXPOSURE ASSESSMENT

This section evaluates the sources, pathways, receptors, exposure duration and frequency, and routes of exposure to assess total human exposure to the substances of concern in groundwater (underlying site 216-Z-1A Tile Field) and soil for sites 216-Z-1A Tile Field and 216-A-8 Crib at Hanford. The goal of this section is to calculate the amount of contaminant that each receptor would encounter for each COPC and exposure pathway combination. Three elements are required to calculate the amount of contaminant (i.e., intake): first, a CSM must be developed that identifies complete pathways for the exposure of receptor populations to COPCs; second, estimates of media concentrations at the exposure point (the point of contact between the COPC and receptor) must be developed; and, third, factors must be selected that quantify the amount of exposure. The combination of media concentrations and exposure factors results in the intake[3] estimates for each contaminant.

G3.1 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 a characterization of the CTUIR and Yakama Nation populations under future conditions. 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 and RI documents for 200-ZP-1 (CP-16151; DOE/RL-2006-24) and the 200-PW OUs (DOE/RL-2006-51). (Table A2-5 in Appendix A provides 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 in order to identify the populations that could encounter the contaminants. 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 for the Native American exposure scenario.

G3.1.1 Affected Media and Land Use

Based on site investigative work, subsurface soil (defined for human health as between 0.6 and 4.6 m [2 to15 ft]) and groundwater have been identified as containing site-related contaminants. Two sites, the 216-Z-1A Tile Field and 216-A-8 Crib, were selected for inclusion in this risk assessment out of five sites evaluated in the baseline HHRA (Appendix A) because contamination begins at these sites at a depth of less than 4.6 m (15 ft) bgs.

[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 contaminant intake or "dose" of a regular contaminant is not equivalent to an absorbed dose of radionuclide. Where there are differences in terms and calculations between radiological contaminants and regular contaminants, these are noted in the text.

Currently, contaminants in the 200-ZP-1 groundwater plume have not reached the nearest surface water body (the Columbia River); therefore, surface water is currently not impacted by any of the waste sites evaluated in this report. Conservative modeling indicates that the groundwater plumes may reach the Columbia River in 75 years or more if no actions are taken. Because of the uncertainties in estimating groundwater concentrations at the river boundary 75 years or more in the future, these potential future pathways are not quantified in the risk assessment but are included as an uncertainty in exposure in Section G62.2.

Groundwater ranges from approximately 58 to 80 m (190 to 262 ft) bgs. Groundwater in the vicinity of the site is not being used for any purpose, and the current use of groundwater is restricted by institutional controls managed by DOE.

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

Land use at the 200 West and 200 East Areas is anticipated to remain industrial for the foreseeable future. These areas are part of the Central Plateau core zone, which is designated as an industrial exclusion zone that will be used for ongoing waste disposal operations and infrastructure services (DOE/RL-2006-51). Currently, contaminant-impacted areas of the Central Plateau are not accessible to the public, Native American or otherwise. However, the Hanford Site is within Yakama Nation ceded territory, and the CTUIR also have treaty fishing rights on portions of the Columbia River. Because the Yakama Nation and the CTUIR have also reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on open unclaimed land (PNNL-15892), this appendix addresses future health risks for these two Native American populations from exposure to contaminants formerly used at the site that are still present in subsurface soil and groundwater.

G3.1.2 Selected Populations

For this assessment, two Native American populations (the CTUIR and the Yakama Nation) have been selected to represent the future hypothetical Native American scenario, assuming institutional controls failure at year 2150. While land use is anticipated to remain industrial for the foreseeable future, because the radionuclides present in soil and groundwater have very long half-lives, these populations were evaluated assuming exposure to contaminants in groundwater and soil in the 200 West and 200 East Areas and also assuming additional exposures via the food chain (i.e., plants, meat, and milk). At year 2150, it is assumed that someone could excavate soil for a house with a basement and bring the excavated soil to the surface, where it would be available for direct exposure by future CTUIR and Yakama Nation populations. Native plants and animals would be expected to be minimally exposed, as contamination would be centered around a residence or "local" area (i.e., vegetable garden), and groundwater would be used to grow crops, water domestic livestock, and in a sweatlodge. Potential future "broad" area exposures (potentially affecting native plants and animals) are not quantified in this risk assessment because contamination is currently buried, but are included as an uncertainty in exposure (Section G6.2).

G3.1.3 Identification of Exposure Pathways

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

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

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

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

Only complete and significant pathways of exposure are quantitatively evaluated in this risk assessment. Complete but insignificant pathways of exposure generally do not require quantitative evaluation but are discussed qualitatively. The CSMs (see Figures G3-1 and G3-2) depict the complete pathways for future unrestricted land use and indicate which have been selected for quantitative evaluation. Figure G3-1 is a pictorial representation of the complete pathways, and Figure G3-2 provides a schematic of the complete pathways. Under a future hypothetical Native American scenario (post-2150), soil exposures at two waste sites within the study area and groundwater exposures are possible for CTUIR and Yakama Nation populations. These future exposure pathways are discussed in more detail below.

G3.1.3.1 *Contact with Soil*

At the two quantitatively evaluated soil sites, impacts to soil do not begin until more than 1 m (3 ft) bgs and contamination extends below 4.6 m (15 ft), the maximum depth interval at which direct human contact exposure is expected to occur. Specific depth intervals of soil contamination as established by the 200-PW-1/3/6 OUs RI report (DOE-RL 2006-51) and the *216-2-8 French Drain Study* (RHO-RE-EV-46P) are below:

- 216-Z-1A Tile Field: 1.8 to 30.5 m (6 to 100 ft)
- 216-A-8 Crib: 3.2 to 20 m (10.5 to 70 ft).

Note that these depths are not identical to the intervals where samples were collected, as described in Section G2.1.1.

Surface soil is defined by EPA as the top 2 cm (0.78 in.) (*Soil Screening Guidance: Technical Background Document* [EPA/540/R-95/128]), although depths of 0 to 0.61 m (0 to 2 ft) and 0 to 0.91 m (0 to 3 ft) are frequently used as the "surface soil" horizon as a protective measure (*Final Guidance for Conduct of Deterministic Human Health Risk Assessments* [ODEQ 2000];

Draft Risk Assessment Procedures Manual [ADEC 2005]). There is no contaminated surface soil at either of the two waste sites available for human contact. Therefore, in order for the CTUIR and Yakama Nation populations to come into contact with contamination in soil, the impacted materials at depth at the two waste sites must be brought to the surface. This scenario would only occur if all knowledge of the site is lost, as are any markers or indicators that could be placed on the site, and thus is not considered to be possible in this assessment until at least the year 2150. It was assumed for this assessment that the subsurface material will be brought to the surface by soil excavation for a home with a basement (4.6 m by 5 m by 10 m [15 ft by 33 ft by 16 ft]), and the excavated soil would be spread in the area surrounding a home and within a vegetable garden. Then, through daily activities, Native Americans could potentially be exposed to surface soil through ingestion, inhalation of fugitive dust and vapors, and external radiation. The dermal pathway is not significant for radionuclides or for thallium, the only metal selected as a COPC. Therefore, the dermal pathway to soil is incomplete and will not be evaluated.

The assumption of contamination brought to the surface as excavated soil is consistent with other Hanford documents, particularly the recent *Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment* (DOE/RL-2007-21).

G3.1.3.2 *Inhalation of Vapors in Indoor Air*

Exposures to VOCs in subsurface soil might be possible for a future Native American population through inhalation of vapors emanating from the subsurface into the ambient air. The top 4.6 m (15 ft) of soil do not contain significant concentrations of VOCs at either waste site. The only detected VOC at 216-Z-1A, methylene chloride, is most likely a lab contaminant (only 4 out of 23 samples were detected, and data were flagged as chemical also in the trip blank), and concentrations were below residential screening levels. All the VOCs detected at 216-A-8 were below method detection limits. However, groundwater beneath the 216-Z-1A Tile Field contains significant concentrations of VOCs, and a soil vapor extraction (SVE) system has been operating in the vicinity of the site for a number of years.

According to *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (EPA 530-F-02-052,), because the depth to groundwater is greater than 30.5 m (100 ft), the movement of vapors from groundwater into indoor air would not be a health concern at the 216-Z-1A Tile Field. Therefore, the groundwater to indoor air pathway is incomplete. However, there is ongoing vapor extraction in this area, and vapors have been detected in soil gas at depths greater than 4.6 m (15 ft) but shallower than 30.5 m (100 ft). Consequently, the vapor migration pathway is considered potentially complete for volatile contaminants in deep subsurface soil gas.

The subsurface soil to indoor air pathway is shown as potentially complete and significant in Figure G3-2. The pathway is only evaluated qualitatively as a potential health concern in Section G5.0 for the following reasons:

- There are no soil gas data of sufficient quality available to quantify this pathway.
- In 150 years, volatile concentrations are likely to be significantly lower than they are now.
- Indoor vapor concentrations are affected by the size of building, ventilation, and type of building construction, and there are many uncertainties in predicting what those parameters might be at a distant future date.

G3.1.3.3 *Contact with Groundwater*

If a well is drilled under an institutional controls failure scenario, then the water could be used for drinking and irrigation of crops and livestock. A future Native American population drinking the water would be exposed via ingestion, inhalation of VOCs, and dermal contact during domestic use of the water (e.g., showering and cleaning). In addition, there could also be dermal and inhalation exposures during sweatlodge use (only an adult population is evaluated for sweatlodge exposures). Inhalation of volatile contaminants only was quantified in the assessment of sweatlodge exposures. Because of a number of uncertainties, inhalation of non-volatiles in a sweatlodge was not quantified but is addressed qualitatively in the uncertainty section (Section G6.0). A contaminant was considered volatile if it met EPA's working definition of a volatile: a Henry's law constant greater than 10^{-5} and a molecular weight of less than 200 g. Using this definition, total chromium, hexavalent chromium, nitrate, technetium-99, iodine-129, and uranium are not volatile compounds and were not quantified for the inhalation pathway in the sweatlodge scenario. The external radiation pathway is generally only significant for photon emitters in soil (DOE/RL-91-45; EPA/540/1-89-002). Therefore, the external radiation pathway is considered insignificant for exposures to groundwater via domestic use or in a sweatlodge.

G3.1.3.4 *Food Chain Exposures*

To estimate an upper-bound risk value for the CTUIR and Yakama Nation populations, the risk assessment assumes that these populations will be consuming a portion of their diet from vegetables and fruit grown in surface soil that is mixed with excavated soil and irrigated with groundwater, eating cattle watered by groundwater, and drinking milk from the dairy cattle. Quantification of food chain risks from eating beef and drinking milk assume that the cattle are not pastured on impacted soil but do eat fodder that has been watered with groundwater.

G3.2 EXPOSURE POINT CONCENTRATIONS

To calculate a cancer risk or a non-cancer hazard, an estimate must be made of the contaminant concentration to which an individual may be exposed. According to EPA guidance (*Supplemental Guidance to RAGS: Calculating the Concentration Term* [OSWER Publication 9285.7-081]; OSWER 9285.6-10), the concentration term at the exposure point (the EPC) should be an estimate of the average concentration to which an individual would be exposed over a significant part of a lifetime. Different approaches were used to estimate the EPCs for soil and groundwater, and modeling was required to estimate EPCs in foods. The following subsections discuss the calculation of the EPCs for soil, groundwater, and living tissue (i.e., plant, cattle, and milk).

G3.2.1 Exposure Point Concentrations for Soil

Because of the uncertainty associated with estimating the true average concentration at a site, the EPA generally recommends the use of the 95 percent upper confidence limit (UCL) of the arithmetic mean as the appropriate estimate of the average site concentration for a RME scenario (OSWER Directive 9285.6-03; OSWER 9285.6-10). At the 95 percent UCL, the probability of under-estimating the true mean is <5 percent. The 95 percent UCL can address the uncertainties surrounding a distribution average because of limited sampling data.

The formula used to calculate a 95 percent UCL depends on the distribution of the data (i.e., the "shape" of the curve) (OSWER Publication 9285.7-081). A statistical test is performed for each

COPC data set to determine the best distribution assumption for the data set. The 95 percent UCL is then calculated using EPA's ProUCL software Version 3.00.02 (*ProUCL Version 3.0 User Guide* [EPA/600/R-04/079]). ProUCL Version 4 is currently available; however, to remain consistent with Appendix A, the older version of ProUCL was used, and an uncertainty discussion of how using Version 4 would affect risks is included in Section G6.2.1. The EPA previously recommended using one-half of the method reporting limit (MRL) as a surrogate concentration for nondetected samples if the contaminant is selected as a COPC (EPA/540/1-89/002), and this is the approach taken in ProUCL Version 3.00.02. However, ProUCL Version 4 uses a more sophisticated approach in addressing nondetected values.

The EPA methodology (EPA/540/1-89/002) for calculating the 95 percent UCL was employed for estimating the RME EPCs for soil whenever there were sufficient data. For data sets with fewer than seven samples, statistical analysis is generally not meaningful, and the maximum concentration was used as the RME EPC. Attachment G-1 to this appendix contains the ProUCL outputs for the COPCs. A discussion of how the local area EPCs were calculated for the Native American scenario is provided below.

G3.2.1.1 *Local Area Soil EPCs for the CTUIR and Yakama Nation*

It was assumed that 150 years in the future, a Native American would construct a home with a basement and would be directly exposed to excavated soil brought to the surface and spread over the local site area that would include a vegetable/fruit garden (see Figure G3-1). The following assumptions were made concerning the basement excavation and the site size:

- The basement size was assumed to be 4.6 m deep by 10 m wide by 5 m (15 ft by 33 ft by 16 ft) long. This corresponds to a small two-story house (approximately 92.9 m^2 [1,000 ft^2]), which is EPA's default residential home size (EPA 530-F-02-052). It is also the residential home dimension used in *Risk Assessment Report for the 100 Area and 300 Area Component for the River Corridor Baseline Risk Assessment* (DOE/RL-2007-21).
- The volume of excavated soil is 261 m^3 (341 yd^3).
- 4.6 m by 10 m by 5 m (1.7 kg/L/1.5 kg/L) = 261 m^3.
- The term (1.7/1.5) is the change in density of the soil from buried material (1.7 kg/L) to material on the surface (1.5 kg/L) (*Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment* [HNF-SD-WM-TI-707]).
- The volume of excavated soil is spread over an area of 1,500 m^2 (16,150 ft^2). This area is slightly smaller than EPA's default residential lot size of approximately 2,000 m^2 (0.5 acre) (EPA/540/1-89/002). However, it is a large enough size for both a home and a substantial home garden. It is large enough that the RESidual RADioactivity (RESRAD) modeling program (*User's Manual for RESRAD Version 6* [ANL/EAD-4]) will consider 100 percent of the soil intake as from the impacted area, and it was the spreading area used in the River Corridor baseline risk assessment (DOE/RL-2007-21).
- Spreading depth is 0.17 m (6.7 in.), based on the volume of soil spread over 1,500 m^2 (261 m^3/1,500 m^2 = 0.17 m).

Concentrations of contaminants in the excavated soil were estimated by calculating 95 percent UCLs for the top 4.6 m (15 ft) of soil for the 216-Z-1A Tile Field and were based on the maximum concentration at the shallowest depth where data have been collected (in most cases 5.8 to 6.6 m [19 to 21.5 ft] bgs) for the 216-A-8 Crib. The 95 percent UCLs calculated for current C_{waste} concentrations for 216-Z-1A Tile Field are presented in Table G3-1 and Attachment G-1.

The future Native American would not be exposed to contaminants in soil until 150 years in the future. Thus, current C_{waste} concentrations (see Table G3-1) for radionuclides were entered into the RESRAD Version 6.4 dose model (ANL/EAD-4) in order to obtain concentrations 150 years in the future taking into consideration radionuclide decay and ingrowth. RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials. These future C_{waste} concentrations were the basis for estimating EPCs for the future CTUIR and Yakama Nation EPCs (C_{local}).

The future C_{waste} concentrations (Table G3-2) were thus modified to reflect mixing throughout the soil column during spreading of the volume of the basement excavation to the area of a home and garden. Future soil concentrations for radionuclides and thallium are summarized in Table G3-2. After C_{waste} concentrations were aged in RESRAD, concentrations in the excavated soil (C_{local}) were calculated as follows:

$$C_{local} = (C_{waste} \times F_c) + (C_b \times F_b)$$

where:

C_{local} = exposure concentration in the excavated soil (mg/kg)
C_{waste} = concentration in the impacted soil (based on the 95 percent UCL or the shallowest maximum) (mg/kg)
F_c = fraction of the 4.6 m depth interval that is contaminated (i.e., the thickness of the waste) derived by dividing the thickness of the contaminated layer (L_{waste}) by the depth of the excavation (L_{exav}) (unit-less)
C_b = concentration in the unimpacted soil—background levels (mg/kg)
F_b = fraction of the 4.6 m depth interval that is unimpacted (unit-less) derived by dividing the thickness of the unimpacted layer (L_{back}) by (L_{eav}).

Details are presented in Attachment G-2 of this appendix.

G3.2.1.2 *Estimation of Plutonium-239 and Plutonium-240*

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

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

grade plutonium-239/240 is 61.5 mCi/g x 0.942 g = 57.9 mCi. The activity of plutonium-240 in 1 g of weapons-grade plutonium-239/240 is 227 mCi/g x 0.058 g = 13.2 mCi.

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

G3.2.1.3 *Estimation of Americium-241 Concentrations at 216-Z-1A Tile Field*

There are no available soil data for plutonium-241, which is the parent compound for americium-241. Plutonium-241 has a relatively short half-life of 14.5 years. The production of plutonium (including plutontium-241) started in 1944 at the Hanford Site. The final waste disposals to the major 200-PW-1/3/6 facilities varied and, therefore, some sites are further along the americium-241 ingrowth curve than others. Because the americium-241 data at the 216-Z-1A Tile Field are from 1979, americium-241 concentrations in the available data set likely do not represent the maximum ingrowth concentration of this radionuclide at this site (americium-241 is not a COPC at the 216-A-8 Crib). Therefore, maximum concentrations of americium-241 were estimated using the disposal date information, the date of the available americium-241 data, and RESRAD, which can estimate radiological concentrations in the future, taking into consideration radionuclide decay and ingrowth.

Maximum americium-241 concentrations were estimated below:

- Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969. The "0" year in RESRAD was, therefore, estimated to be 1967.
- Site-specific information on the vadose zone and the contaminant distribution for each site was entered into RESRAD (see Attachment G-3).
- The known americium-241 concentration was the 95 percent UCL of the available historical data. This was 1979 for the 216-Z-1A Tile Field (year 12 in RESRAD).
- Plutonium-241 concentrations at year 0 were entered into RESRAD until the americium-241 concentrations at the applicable year matched the existing data.

The resulting americium-241 and plutonium-241 ingrowth curves were graphed for shallow soils (0 to 4.6 m [0 to 15 ft] bgs) at the 216-Z-1A Tile Field and are presented in Figure G3-3. It appears that the maximum americium-241 concentration would occur around 60+ years from year 0. Therefore, current americium-241 concentrations are likely 20 to 25 years from their maximum values. Because current concentrations are aged to represent 150 years in the future for Native American populations, use of the maximum americium-241 concentration as the current concentration slightly overestimates americium-241 concentrations in the year 2150. Current (year 2005) concentrations are 93 percent of their maximum concentration (occurring approximately 73 years from time 0, or year 2040 if time 0 is 1967). Because this analysis is meant to be a reasonable approximation of a maximum americium-241 concentration, an exhaustive analysis has not been performed over exactly what year should be year 0. The maximum concentrations estimated as described above were used as reasonably health-protective, given the lack of plutonium-241 data and the uncertainties in the estimation process. This slight potential over-estimation does not have a significant effect on estimates of health risk (see also Section G6.1.1.1).

G3.2.2 Exposure Point Concentrations for Groundwater

Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest concentrations do not occur at the same location). In addition, a large amount of groundwater data has been collected at the site and includes samples collected at the water table (as well as samples collected from deeper in the aquifer) from over 100 wells. (The available groundwater data and the data selected for inclusion in the risk assessment are discussed in Section G2.1.2.) Using a well-by-well approach to estimate EPCs would generate a large amount of data of concentrations and health risks per well (i.e., risks at the concentrations found in well X, X1, X2, etc.), many of which would be similar. Because the purpose of the risk assessment is to provide risk managers with the information necessary to make remedial decisions, contaminants in groundwater were evaluated for a range of concentrations for each COPC, with the high end of the range sufficient to cover the RME to groundwater, rather than on a well-by-well basis.

The range of concentrations selected for EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing groundwater data set (i.e., from the last 5 years). These EPCs were used to evaluate "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. As recommended by EPA, one-half of the MRL was used as a surrogate concentration for nondetected results in the percentile calculations (EPA/540/1-89/002). Table G3-3 summarizes the range of groundwater EPCs for each COPC used in the risk calculations. This methodology does not provide risks at a specific location, but instead results in information on the range of possible risks for each COPC at the current concentrations. In addition, the cumulative risks from the 90th percentile evaluation represent a bounding exposure condition, or RME, because not all COPCs are at the 90th percentile concentration at the same location. Implications for the risk assessment results on using different groundwater concentrations (e.g., the more typical risk assessment methodology of the 95 percent UCL of the mean, or possible increase in risks if water were drunk at the location of a maximum concentration) are discussed further in the uncertainty section of this appendix (Section G6.2).

Risks were not calculated for future groundwater concentrations under baseline conditions. Future risks from groundwater are assumed to be at least as "risky" as current conditions. This approach is standard for nonradiological contaminants, where concentrations are assumed to be either staying the same (many inorganics) or reducing over time (mostly organic compounds). For the three radionuclides that are COPCs in groundwater, decay curves are provided to support the assumption that risks will not be worse in the future because of changes in contaminant composition or concentration. The potential lowering of future groundwater concentrations is further discussed in Section G5.3.5.

G3.2.3 Calculation of Tissue Concentrations from Groundwater and Soil Exposure Point Concentrations

The methodology recommended on Oak Ridge National Laboratory's (ORNL's) Risk Assessment Information System (RAIS) Web site (http://rais.ornl.gov) was applied to estimate concentrations in homegrown produce and farm-raised beef and milk for all COPCs in groundwater and for nonradionuclides in soil. The ORNL online database is part of the Toxicology and Risk Analysis Section in the Life Sciences Division at ORNL. ORNL is a DOE multi-program laboratory, and its risk information database is routinely used on a wide variety of public and private-sector risk assessment projects. The equations presented in RAIS use site-

specific soil and groundwater concentrations and bio-uptake factors to estimate concentrations in plants, beef, and milk, as described below. For the radionuclides in soil, RESRAD Version 6.4 was used to determine risks from eating produce grown in soil impacted with radionuclides. Because only soil concentrations can be used in the RESRAD model, the radionuclides in groundwater were calculated based on the ORNL methodology.

The baseline HHRA (Section A.3.2.3 in Appendix A) provides a detailed discussion of the calculation of tissue EPCs from groundwater and soil EPCs. The same approach was used to calculate EPCs for the Native American scenario. Tables G3-4 and G3-5 summarize the EPCs for the food chain pathways calculated using ORNL and RESRAD, respectively. Tables G3-6, G3-7, and G3-8 summarize the equations and factors used to calculate the EPCs for the food chain pathways.

G3.3 CALCULATION OF CONTAMINANT INTAKE

This section defines the magnitude, frequency, and duration of exposure for the populations and pathways selected for quantitative evaluation. Intakes were calculated only under RME conditions, as defined by EPA. The RME incorporates several conservative assumptions in estimating the contaminant intake rates and characteristics of the receptor population. The RME is, thus, an estimate of the highest exposure that reasonably can be expected to occur at the site. It may overestimate the actual risk for most of the population. As stated in Clay, 1991, "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions" (OSWER Directive 9355.0-30), ". . . the goal of RME is to combine upper-bound and mid-range exposure factors so that the result represents an exposure scenario that is both protective and reasonable; not the worst possible case." The RME is typically defined as a combination of upper-bound and average values that reflect exposures somewhere between the 90th and 98th percentile of the range of possible exposures that reasonably can be expected to occur at the site for a given population.

While different methods are used to calculate the dose from radionuclides and nonradionuclides, as described by EPA (EPA/540/1-89/002; "Distribution of OSWER Radiation Risk Assessment Q&A's Final Guidance" [Luftig and Page, 1999]), exposure assessment for both nonradionuclide and radionuclide contaminants follow the same basic steps. However, in addition to the exposure pathways considered for contaminants, external radiation is an important exposure pathway for radionuclides in surface soils. The dermal absorption pathway is not a significant exposure pathway for radionuclides or thallium in soil and was not considered in this risk assessment (as discussed in Section G3.1.3.1).

Exposure factors and formulas that were used together with the EPCs to quantify doses for the CTUIR and Yakama Nation are presented in Table G3-9 (ingestion and inhalation of contaminants in soil), Table G3-10 (ingestions, dermal, and inhalation exposure to contaminants in tap water), Table G3-11 (calculation of absorbed dose per event for contaminants in tap water), Table G3-12 (dermal and inhalation exposures to groundwater in a sweatlodge), Table G3-13 (calculation of the vaporization factor for contaminants in a sweatlodge), and Table G3-14 (food chain exposures). The tables also indicate the sources of the factors. For both soil and groundwater, Harris and Harper, 2004 were used as the source for CTUIR exposure factors and Ridolfi, 2007 was used as the source for Yakama Nation exposure factors. Both the CTUIR and Yakama Nation assume subsistence exposures occur 365 days/year for a 70-year lifetime (apportioned out as 64 years [adult] and 6 years [child]). Where parameters were not provided by these sources, EPA's default exposure factors were used (EPA 600/P-95-002Fa; OSWER

Directive 9285.6-03). Default exposure factors are included in Attachment G-4. The following discussions and cited tables are site-specific exposures to COPCs in soil and groundwater.

G3.3.1 Site-Specific Exposures to Soil

Future Native Americans could be exposed to COPCs in excavated soil around a home and in a garden. The COPCs at the two soil waste sites are made up of radionuclides and only one nonradionuclide contaminant, thallium. The dermal pathway is not significant for radionuclides or for thallium; therefore, the dermal pathway to soil is incomplete and will not be evaluated. Also, inhalation is not a significant pathway for thallium because there are no toxicity criteria available (see Section G4.0). For radionuclide exposures in soil, EPCs and site-specific information were entered into RESRAD Version 6.4 to determine risks. The RESRAD model can only be used to estimate radionuclide risks to adults based on site-specific soil concentrations. A discussion of site-specific values entered into RESRAD for soil is presented below (food chain ingestion rates are in Section G3.3.3). Attachment G-3 to this appendix contains a summary of the site-specific and default values entered into RESRAD to quantify radionuclide exposures in soil. Differences between RESRAD and EPA defaults for Native American populations and potential impacts on the risk results are discussed in Section G6.2.6.

The CTUIR and Yakama Nation have provided most of the exposure factors in Harris and Harper, 2004 and Ridolfi, 2007 for soil exposures. If available, Native American-specific factors were used rather than EPA residential defaults. The exposure factors used to quantify exposures through this pathway are discussed below and are presented in Table G3-9.

Particulate Emission Factor (PEF). The site-specific PEF calculated for the Hanford Site is 2.72×10^9 m^3/kg and was used in RESRAD. The PEF applies to inhalation of fugitive dust to non-volatile contaminants. Table G3-15 summarizes the inputs for the PEF equation.

Soil Ingestion Rate. The soil ingestion rate used in RESRAD (adults only) and for thallium calculations is 400 mg/day for both CTUIR adults and children and 200 mg/day for adults and 400 mg/day for children for the Yakama Nation.

Inhalation Rate. The adult inhalation rate used in RESRAD for the CTUIR is 30 m^3/day and for the Yakama Nation is 26 m^3/day, which are based on an active outdoor lifestyle.

Child Body Weight. The child body weight of 16 kg was used in calculating thallium risks for the CTUIR and Yakama Nation, based on the value provided by Ridolfi, 2007.

G3.3.2 Site-Specific Exposures to Groundwater

Future Native Americans could drink tap water from a groundwater well and use groundwater in a sweatlodge as a part of daily life. For tap water exposures, adults and children were evaluated for dermal and inhalation exposures to COPCs in groundwater when showering and drinking tap water. Only adults were evaluated for dermal and inhalation exposures to COPCs in groundwater while spending time in a sweatlodge. The CTUIR and Yakama Nation have provided most of the exposure factors necessary to quantify groundwater health risks in Harris and Harper, 2004 and Ridolfi, 2007, and those values were preferentially used, where available, rather than EPA residential defaults. Where Native American-specific factors were not provided, EPA defaults were used. A comparison table of Native American exposure factors with EPA residential default values is included in the uncertainty section (Section G6.0). The exposure factors used to quantify exposures through the tap water pathway are presented in Tables G3-10

and G3-11 and through the sweatlodge pathway in Tables G3-12 and G3-13. These pathways are discussed below.

Tap Water Ingestion Rate. The tap water ingestion rate for the CTUIR and Yakama Nation is 4 L/day for adults. Harris and Harper, 2004 estimated an average water ingestion rate of 3 L/day for adults for the CTUIR, based on total fluid intake for an arid climate. In addition, Ridolfi, 2007 reported a maximum groundwater ingestion rate of 3 L/day for Yakama Nation adults. Both the CTUIR and Yakama Nation assume that an additional L/day will be consumed during sweatlodge use. Therefore, the adult tap water ingestion rate of 4 L/day was used for both the CTUIR and Yakama Nation scenarios. The child tap water ingestion rates, which do not include water ingested in a sweatlodge, were 2 L/day and 1.5 L/day, for the Yakama Nation and CTUIR scenarios, respectively.

Inhalation Rate. The inhalation rates of 30 m^3/day and 8.2 m^3/day were used for the CTUIR adult and child, respectively. The inhalation rates of 26 m^3/day and 16 m^3/day were used for the Yakama Nation adult and child, respectively. These inhalation rates are based on an active outdoor lifestyle and were used for both the tap water and sweatlodge pathways (adults only). Inhalation of chemicals in tap water may occur throughout 70 years while showering, doing dishes, etc. Inhalation of chemicals in vapor from sweatlodge use was evaluated for adults over 68 years (excluding the first 2 years of life).

Child Body Weight. The child body weight of 16 kg was used in the tap water calculations for the CTUIR and Yakama Nation based on the value provided by Ridolfi, 2007.

Sweatlodge Vaporization Factor. Under typical groundwater exposure scenarios (i.e., domestic use of groundwater as tap water), EPA considers the inhalation pathway complete only for volatile contaminants, because there is no mechanism for release of non-volatile chemicals into the air in significant concentrations. EPA (EPA/540/R/99/005) defines a volatile chemical as having a Henry's Law constant greater than 10^{-5} and a molecular weight less than 200 g/mole. Of the nonradionuclide COPCs in groundwater, chloroform, carbon tetrachloride, methylene chloride, PCE, and TCE meet the definition of a volatile chemical. In addition, tritium is the only radionuclide COPC that is also considered volatile. Only those chemicals fitting this definition of volatility are typically evaluated for inhalation exposures from water pathways. This approach is based on Henry's Law, where equilibrium is established between the aqueous and gaseous concentrations. However, the sweatlodge scenario creates a unique environment where both volatile and non-volatile chemicals could potentially be present in air and available for inhalation exposures. In a sweatlodge, water contacts the hot rocks and becomes airborne not primarily by evaporation, but as aerosol particles; therefore, the Henry's Law approach does not hold true in a sweatlodge. A large portion of the humidity is likely due to aerosols.

The sweatlodge scenario assumes that groundwater will be poured over hot rocks within the sweatlodge to create steam. The presence of COPCs is assumed to be introduced into the sweatlodge predominantly through the water used to create steam. The airborne concentration of COPCs in the sweatlodge is dependant primarily upon the temperature of the sweatlodge, the volume of water used during the sweat, and the volume of air space within the sweatlodge.

Harris and Harper, 2004 describe a method for calculating a vaporization factor for the sweatlodge scenario. The vaporization factor is applied to the groundwater concentration to estimate the concentration of COPCs in steam in the sweatlodge. The method used to calculate the vaporization factor differs for volatile and semi-volatile compounds versus non-volatile

compounds. For volatile and semi-volatile compounds, it is assumed that a negligible quantity will deposit on surfaces or partition into condensed liquid. Thus, the bulk of contaminants added in the water will remain in the vapor phase throughout the sweat. For non-volatile chemicals, it is assumed that the COPC becomes airborne as an aerosol as the water it was carried in vaporizes, and that once airborne, non-volatile compounds deposit onto solid surfaces with aqueous condensation. Thus, the quantity of non-volatile compounds in the air phase is limited to that which is carried into the air phase by the volume of liquid water needed to create saturated conditions in the lodge.

Because of a number of uncertainties in the approach used to calculate the vaporization factor for non-volatile chemicals, airborne aerosol concentrations were not quantified but potential health risks are addressed qualitatively in the uncertainty section, see Section G6.0. Therefore, chemical inhalation exposures from total chromium, hexavalent chromium, and uranium were not quantified for the sweatlodge pathway. Note that even if airborne aerosol concentrations could be estimated, health risks due to inhaling total chromium and uranium cannot be quantified because there are no inhalation toxicity criteria available (see Section G4.0). With regard to the radionuclides, only tritium is volatile. Iodine in its pure form is a solid or gaseous diatomic molecule; however, on contact with water, iodine forms an anion with oxygen and becomes non-volatile. It does not convert back to the gaseous form, especially given the very low atom concentrations that would be typical for iodine-129 contamination in groundwater. Technetium is also known to exist in gaseous form as an impurity in the gaseous uranium enrichment process. However, in groundwater, technetium most likely exists as the TcO4 anion and can safely be considered non-volatile. Therefore, iodine-129, and technetium-99 were also considered non-volatile and risks from these radionuclides were not quantified in the sweatlodge scenario.

Table G3-13 summarizes the equations and assumptions used to calculate the vaporization factor for the volatile and semi-volatile COPCs. As shown in Table G3-13, the vaporization factor was calculated to be 0.955 L/m^3, for volatile and semi-volatile chemicals. As mentioned above, because of a number of uncertainties in the approach used to calculate the vaporization factor for non-volatile chemicals, risks from inhalation of non-volatiles in a sweatlodge were not quantified. Therefore, a vaporization factor for non-volatile compounds was not calculated. Not quantifying risks from inhalation of non-volatiles in the sweatlodge could lead to a significant underestimation for the sweatlodge pathway. Inhalation of non-volatiles is likely to occur in a sweatlodge because even non-volatile contaminants are potentially present in steam as aerosols within the confined space of a sweatlodge. This potential underestimation of risks is discussed in the uncertainty section (Section G6.0).

Sweatlodge Exposure Time. An exposure time of 1 hour/event for 365 days/year was used for the CTUIR and 2 hours/event for 260 days/year for the Yakama Nation. In the Yakama Nation exposure document (Ridolfi, 2007), 7 hours/day in the sweatlodge was recommended for the RME exposure. This time represented the maximum value reported from their sample size of 16 people. In accordance with EPA comments ("Memorandum re: Comments on Yakama Nation Exposure Scenario for Hanford Risk Assessment" [Stifelman, 2008]), 7 hours/day does not appear to be a reasonable maximum over a 70-year exposure time, but more likely represents more of a worst-case value. Therefore, for this assessment, two times the average reported Yakama Nation sweatlodge rate of 5 to 10 hours/week, which equates to an exposure time of 2 hours/day for 5 days/week or 260 days/year, was used as the RME time for the Yakama Nation. The uncertainty surrounding sweatlodge time and how changes in sweatlodge exposure times could affect the conclusions of the risk assessment are further discussed in Section G6.0.

Dermal Exposures to Groundwater in the Sweatlodge. As discussed above, exposures to groundwater in the sweatlodge can occur through both the inhalation and dermal exposure pathways. For dermal exposures (for nonradionuclides only), the method described in Harris and Harper, 2004 was used. The dermal pathway assumes dermal exposure can occur from exposures to chemicals both in the vapor as well as in the condensate. For volatile and semi-volatile constituents, Harris and Harper, 2004 assume that 100 percent of the constituent is in the vapor state within the sweatlodge and the concentration in the condensed water can be neglected. Therefore, for volatile and semi-volatile constituents, the concentration in the vapor derived using the vaporization factor for volatile and semi-volatile constituents is used to evaluate dermal exposures, as shown in Table G3-12.

For non-volatile constituents, Harris and Harper, 2004 assume that some of the constituent is present in the sweatlodge in the vapor state, while some is present in the condensate. The concentration of constituents in the sweatlodge vapor is the same as that calculated using the non-volatile vaporization factor described above and the concentration in the condensed water is assumed to be the same as the concentration in the water poured over the rocks to create the steam in the sweatlodge. The dermal exposure assumptions for non-volatile constituents result in a concentration that is equal to the sum of the vapor concentration and the condensate, as shown in Table G3-12.

G3.3.3 Exposures through Ingestion of Garden Produce, Beef, and Milk

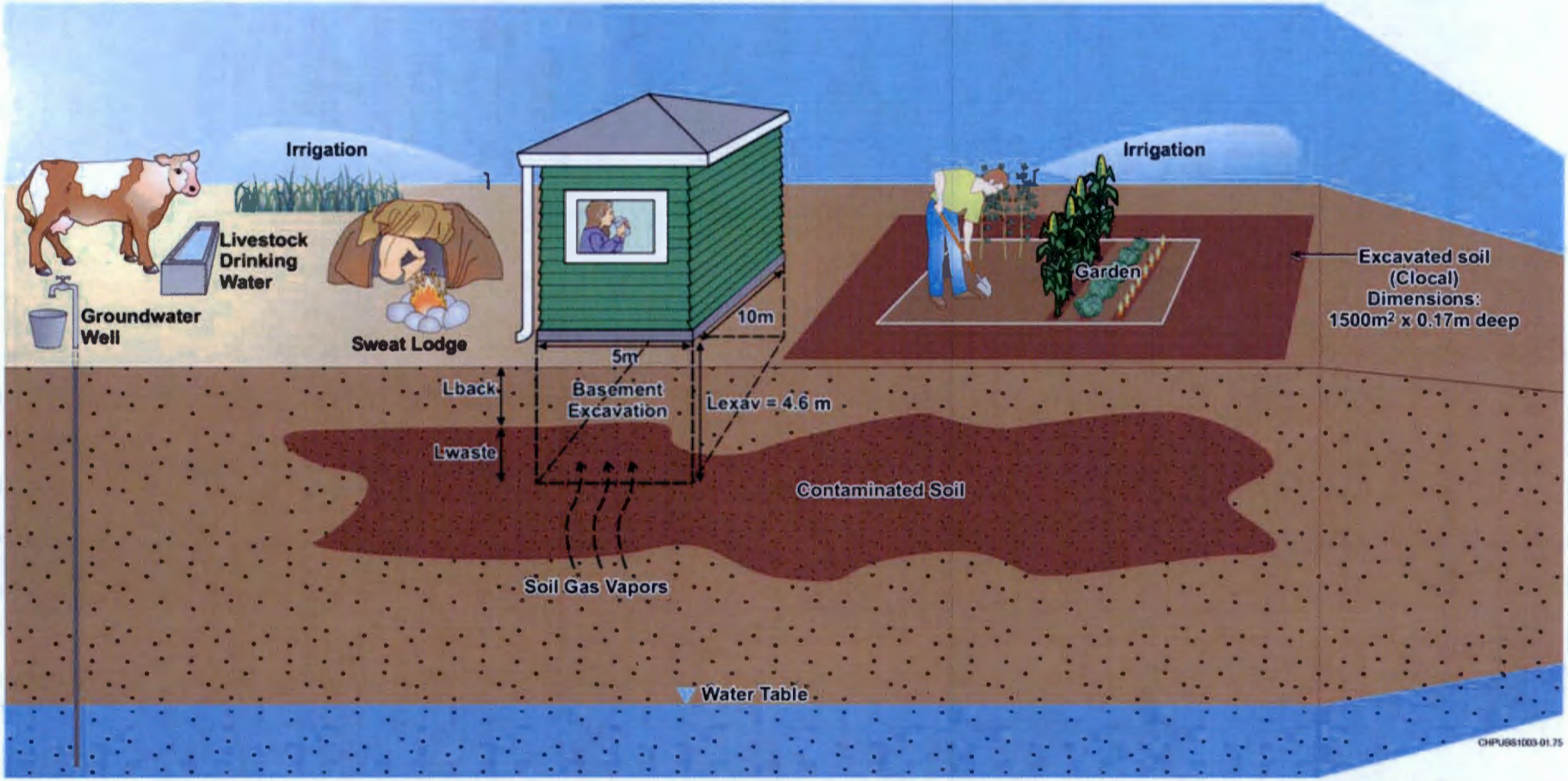
Native Americans are assumed to consume homegrown fruits and vegetables from gardens that are cultivated in contaminated soils and irrigated with groundwater and to consume beef and milk from cattle that drink site groundwater and graze on pastures irrigated with groundwater. Table G3-14 presents the exposure factors used to quantify the ingestion of fruits and vegetables, beef, and milk. As noted above for soil and groundwater, exposure factors were preferentially selected from documents prepared from the potentially affected tribal nations. Discussions regarding the selection of the ingestion rates for these pathways are provided below.

Fruit and Vegetable Ingestion Rate. Both Harris and Harper, 2004 and Ridolfi, 2007 indicated that a portion of the Native American diet is composed of domestic fruits and vegetables. Ridolfi (2007) reported that one-half of the total vegetable and fruit ingestion rates for the Yakama Nation are from domestic rather than wild plants. Harris and Harper, 2004 did not supply specific percentages, but indicated that site-specific values should be determined for CTUIR exposures. In the absence of more information, 50 percent of the total plant ingestion rate was used to represent the homegrown diet fraction for both the CTUIR and Yakama Nation. Adult CTUIR and Yakama Nation vegetable ingestion rates of 612.5 and 559 g/day used in the risk calculations are thus 50 percent of the total ingestion rate of 1,225 g/day (roots/greens/other) and 1,118 g/day (vegetable/root), respectively. The child Yakama Nation vegetable ingestion rate of 93.5 g/day is based on 50 percent of the ingestion rate of 187 g/day (vegetable/root). Adult CTUIR and Yakama Nation fruit ingestion rates are based on 50 percent of the total fruit ingestion rate of 125 g/day (fruits/berries) and 299 g/day (fruit), respectively. The child Yakama Nation fruit ingestion rate is based on 50 percent of the ingestion rate of 127 g/day (fruits/berries). Summing these intake rates together results in a total homegrown fruit and vegetable intake rate for adult CTUIR of 675 g/day or 9.64 g/kg-day, adult Yakama Nation of 708.5 g/day or 10.14 g/kg-day, and child Yakama Nation of 157 g/day or 9.8 g/kg-day. Child CTUIR ingestion rates were not provided. These ingestion rates are assumed to be constant over a lifetime.

Beef Ingestion Rate. Both Harris and Harper, 2004 and Ridolfi, 2007 indicated that a portion of the Native American diet is composed of domestic meat. As discussed above for homegrown produce, Ridolfi, 2007 reported that for the Yakama Nation approximate 60 percent of the total wild game/fowl ingestion rate is domestic meat rather than wild meat and the CTUIR did not list a specific percentage (Harris and Harper, 2004). Therefore, the assumption that 60 percent of the total meat/game/fowl ingestion rate was from a domestic, not wild, source was used for both CTUIR and Yakama Nation. Adult CTUIR and Yakama Nation meat ingestion rates of 75 g/day (1.07 g/kg-day) and 422.4 g/day (7.95 g/kg-day) are based on 60 percent of the ingestion rate of 125 g/day (game/fowl) and 704 g/day (meat/game), respectively. The CTUIR have a much lower total meat ingestion rate because their protein diet is river-based and mainly consists of fish. The child Yakama Nation meat ingestion rate of 127.2 g/day (7.95 g/kg-day) is based on 60 percent of the ingestion rate of 212 g/day (meat/game). The child CTUIR ingestion rates were not provided. These ingestion rates are assumed to be constant over a lifetime.

Dairy Ingestion Rate. Only the Yakama Nation (Ridolfi, 2007) provided information concerning milk ingestion rates and, therefore, only this population was evaluated. The milk ingestion rates are 1.2 L/day or 1,239 g/day for adults and 0.5 L/day or 515 g/day for children. The liquid measure (L/day) was converted to a weight measure (g/day) by using 1,030 g as equal to 1 L of milk.

Figure G3-1. Pictorial Human Health Conceptual Site Model for Future Native American Scenario.



$$C_{local} = \left(\frac{L_{back}}{L_{exav}} \times C_{back}\right) + \left(\frac{L_{waste}}{L_{exav}} \times C_{waste}\right)$$

Clocal = concentration of local site surface soil post excavation and spread over 1,500 m^2
Lback = depth thickness from ground surface to top of contaminated soil (concentrations assumed at background)
Lexav = depth of excavation from ground surface
Cback = background values taken from DOE/RL-96-12
Lwaste = contaminated depth thickness
Cwaste = concentration of waste using available data

Figure G3-2. Schematic Human Health Conceptual Site Model for Future Native American Scenario.

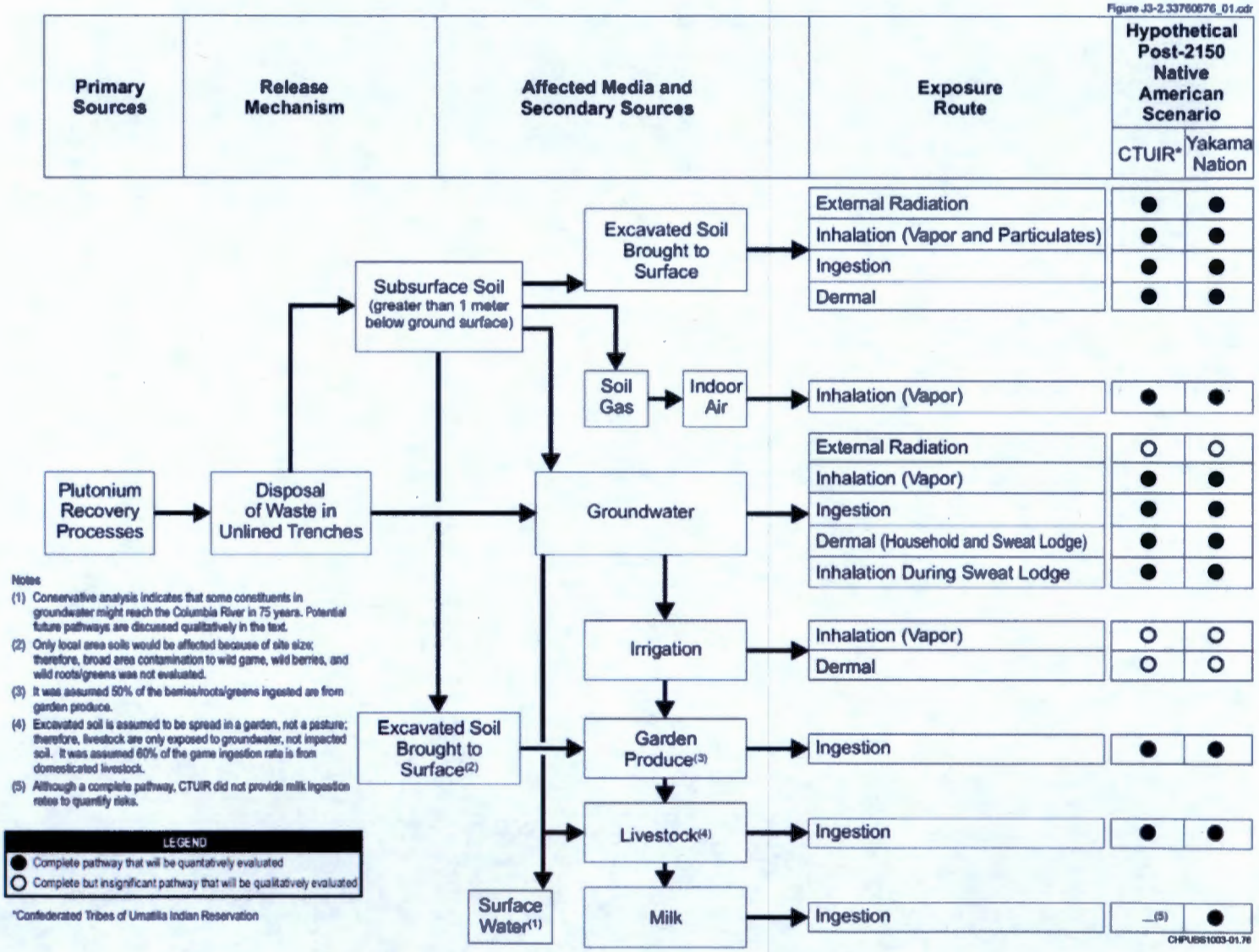


Figure G3-3. Ingrowth of Americium-241 and Plutonium-241 at 216-Z-1A Tile Field Shallow Soils (0 to 15 ft bgs).

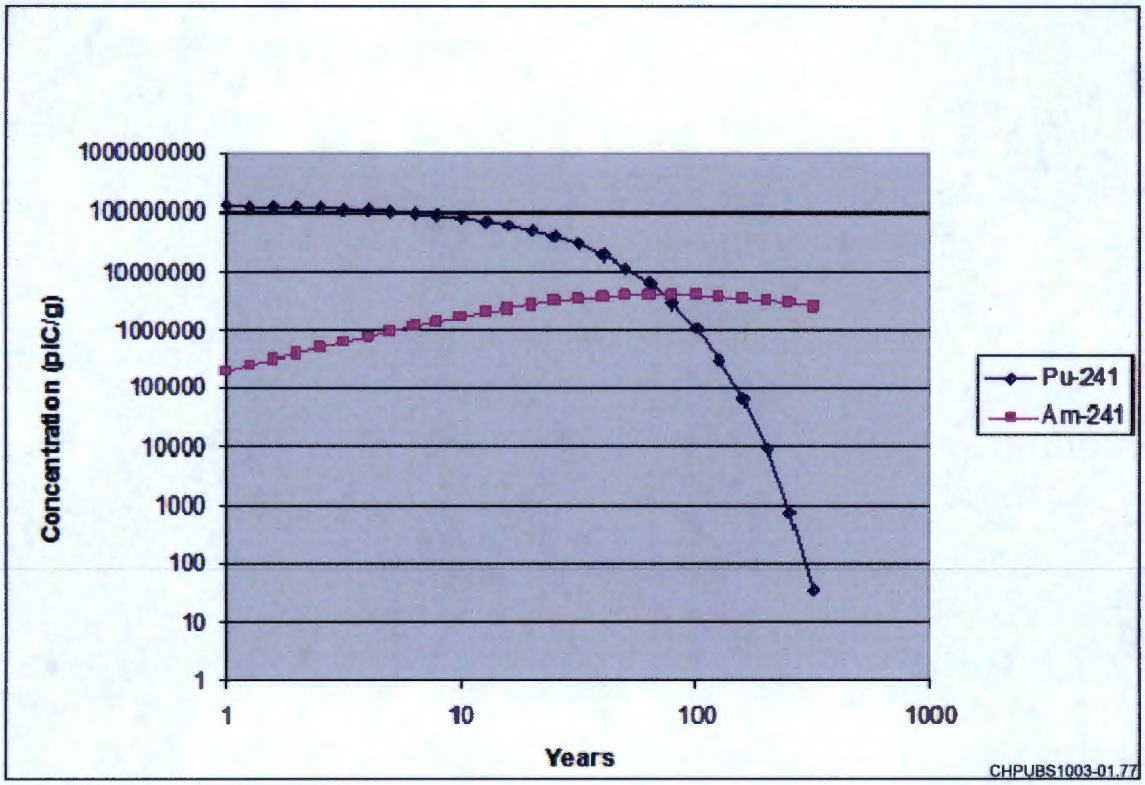


Table G3-1. Summary of Exposure Point Concentrations for Current Concentration of Waste in Soil (C_{waste}).

COPC	C_{waste}	Unit	EPC Rationale	Number of Samples
216-Z-1A Tile Field				
Am-241[a]	2,028,358	pCi/g	95% Chebyshev (Mean, Sd) UCL	17
Pu-239/240	15,509,199	pCi/g	95% Chebyshev (Mean, Sd) UCL	17
Pu-239	12,637,125	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
Pu-240	2,872,074	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	--
216-A-8 Crib				
C-14	81	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	Shallowest maximum concentration
Cs-137	877,000	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	
Np-237	3.5	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	
Pu-239/240	56	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	
Pu-239	45	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	
Pu-240	10	pCi/g	Ratio of 4.4:1 (Pu-239:Pu-240)	
Ra-228	1.1	pCi/g	Maximum at depth 6.8 to 7.6 m (22.5 to 25 ft bgs)	
Tc-99	80	pCi/g	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	
Thallium	2.5	mg/kg	Maximum at depth 5.8 to 6.6 m (19 to 21.5 ft) bgs	
Th-228	0.70	pCi/g	Maximum at depth 6.8 to 7.6 m (22.5 to 25 ft bgs)	

[a]Americium-241 concentrations estimated based on methodology in Section G3.2.1.3. The statistical analysis was done on the historical data set.

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

Table G3-2. Summary of Exposure Point Concentrations for Future Local Area Soil (C_{local}).

COPC	C_{waste} 150 Years in the Future	CTUIR/Yakama Nation EPC C_{local} 150 Years in the Future	Unit
216-Z-1A Tile Field			
Am-241	1,569,000	941,400	pCi/g
Pu-239	12,940,000	7,764,000	pCi/g
Pu-240	2,854,000	1,712,400	pCi/g
216-A-8 Crib			
C-14	3.8E-23	1.3E-23	pCi/g
Cs-137	27,410	9,137	pCi/g
Np-237	3.5	1.2	pCi/g
Pu-239	45	15	pCi/g
Pu-240	10	3.4	pCi/g
Ra-228	1.5E-08	5.1E-09	pCi/g
Tc-99	26	8.6	pCi/g
Thallium	--	0.83	mg/kg
Th-228	2.3E-08	7.7E-09	pCi/g

COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
EPC = exposure point concentration

Table G3-3. Summary of Exposure Point Concentrations for Groundwater for 200-ZP-1 Operable Unit Source Area.

COPC	Percentiles			Unit
	25th	50th	90th	
Carbon tetrachloride	6.53	505	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
PCE	0.18	0.36	2.5	µg/L
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
Tc-99	59	180	1442	pCi/L
Tritium	513.75	3,605	36,200	pCi/L

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

Table G3-4. Summary of Food Chain Pathway Exposure Point Concentrations (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants (Nonradionuclides Only). (2 sheets)

COPC	Unit	200-ZP-1 Groundwater Area			Soil Waste Site
		25th [a]	50th [a]	90th [a]	216-A-8 Crib
Homegrown Produce					
Carbon tetrachloride	mg/kg	1.26E-01	9.78E+00	5.62E+01	b
Chloroform	mg/kg	1.90E-02	2.10E-01	7.86E-01	b
Chromium (total)	mg/kg	4.66E-02	1.33E-01	1.68E+00	b
Chromium (VI)	mg/kg	9.06E-02	1.41E-01	2.63E+00	b
Methylene chloride	mg/kg	7.77E-03	1.20E-02	1.77E-01	b
PCE	mg/kg	2.86E-03	5.72E-03	3.97E-02	b
TCE	mg/kg	3.69E-03	4.05E-02	2.59E-01	b
Thallium[c]	mg/kg	b	b	b	0.83
Uranium	mg/kg	1.10E-02	1.52E-02	1.08E-01	b
I-129	pCi/g	ND	3.93E-04	1.53E-02	b
Tc-99	pCi/g	8.02E+00	2.45E+01	1.96E+02	d
Tritium[e]	pCi/g	1.30E+01	9.50E+01	9.50E+02	b
Meat					
Carbon tetrachloride	mg/kg	3.10E-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	
PCE	mg/kg	2.71E-06	5.42E-06	3.77E-05	
TCE	mg/kg	3.40E-07	3.73E-06	2.39E-05	
Uranium	mg/kg	5.00E-05	7.30E-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[e]	pCi/g	5.00E-01	3.60E+00	3.60E+01	
Milk					
Carbon tetrachloride	mg/kg	1.46E-05	1.13E-03	6.49E-03	Cattle are assumed to be directly exposed only to groundwater.
Chloroform	mg/kg	2.76E-07	3.04E-06	1.14E-05	
Chromium (total)	mg/kg	1.12E-05	3.20E-05	4.04E-04	
Chromium (VI)	mg/kg	2.18E-05	3.39E-05	6.32E-04	

Table G3-4. Summary of Food Chain Pathway Exposure Point Concentrations (ORNL Methodology) Groundwater to Plants and Animals, Soil to Plants (Nonradionuclides Only). (2 sheets)

COPC	Unit	200-ZP-1 Groundwater Area			Soil Waste Site
		25th [a]	50th [a]	90th [a]	216-A-8 Crib
Methylene chloride	mg/kg	1.99E-08	3.07E-08	4.54E-07	Cattle are assumed to be directly exposed only to groundwater.
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	1.00E-04	1.47E-04	1.03E-03	
I-129	pCi/g	ND	1.14E-04	4.45E-03	
Tc-99	pCi/g	2.00E-01	6.10E-01	4.89E+00	
Tritium[e]	pCi/g	5.00E-01	3.60E+00	3.60E+01	

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

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

[c]Thallium is the only nonradionuclide chemical, and the produce exposure point concentration was calculated from a soil concentration of 0.83 mg/kg outside of RESRAD using Oak Ridge National Laboratory's Risk Assessment Information System (RAIS) (see Section G3.2.3).

[d]Technetium-99 in soil was evaluated for the food chain pathways through use of the RESRAD dose model.

[e]The uptake of tritium in the food chain is evaluated differently than the other contaminants. Tritium is discussed separately in Section G5.3.5 of this appendix.

COPC = contaminant of potential concern
ND = not detected
ORNL = Oak Ridge National Laboratory
PCE = tetrachloroethylene
RESRAD = RESidual RADioactivity (dose model)
TCE = trichloroethylene

Table G3-5. Summary of Homegrown Produce Exposure Point Concentrations Soil to Plant Pathway (RESRAD Methodology) 150 Years from Now.

Radionuclide	Homegrown Produce EPC[a] (pCi/g)
216-Z-1A Tile Field	
Am-241	359
Np-237[b]	0.4
Pu-239	2972
Pu-240	648
216-A-8 Crib	
C-14	2E-23
Cs-137	138
Np-237	0.009
Pu-239	0.006
Pu-240	0.001
Ra-228	8E-11
Tc-99	16
Th-228	3E-12

NOTE: 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.

[a]The EPC is the sum of leafy and non-leafy plant concentrations estimated by the RESRAD dose model.

[b]This radionuclide is a daughter product and was not selected as a COPC.

COPC = contaminant of potential concern
EPC = exposure point concentration
RESRAD = RESidual RADioactivity (dose model)

Table G3-6. Plant Tissue Modeling Calculations for Future Native American, 200-ZP-1 Operable Unit Groundwater and Soil (Nonradionuclides).

Calculation of Plant Concentration from Groundwater Used for Irrigation:

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

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

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

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

Calculation of Plant Concentration Grown in Post-2150 Soil:

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

Variable	Variable Definition	Unit	Value	Source
Bv wet	Soil to plant transfer factor wet weight	kg/kg	Contaminant-specific	Table G3-7
CF	Conversion factor	kg/g	0.001[a]	Not applicable
C	Contaminant concentration in plant	mg/kg or pCi/g	Calculated value	Equations 1 and 5
Cw	Contaminant concentration in water	mg/L or pCi/L	Contaminant-specific	Table G3-3
Cs	Contaminant concentration in soil	mg/kg	Contaminant-specific	Table G3-2
F	Irrigation period	unitless	0.25	Default value, ORNL RAIS
If	Interception fraction	unitless	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	unitless	Bv wet	Default value, ORNL RAIS
Res	Resuspension multiplier	unitless	MLF	Default value, ORNL RAIS
Ir	Irrigation rate	L/m^2-day	3.62	Default value, ORNL RAIS
MLF	Plant mass loading factor	unitless	0.26	Default value, ORNL RAIS
P	Area density for root zone	kg/m^2	240	Default value, ORNL RAIS
T	Translocation factor	unitless	1	Default value, ORNL RAIS
tb	Long-term deposition and buildup	day	10950	Default value, ORNL RAIS
Tr	Half-life	day	Chemical-specific[a]	HNF-SD-WM-TI-707
tv	Aboveground exposure time	day	60	Default value, ORNL RAIS
tw	Weathering half-life	day	14	Default value, ORNL RAIS
Yv	Plant yield (wet)	kg/m^2	2	Default value, ORNL RAIS
Lb	Effective rate for removal	1/day	Li + Lhl	Default value, ORNL RAIS
LE	Decay for removal on produce	1/day	Li + (0.693/tw)	Default value, ORNL RAIS
Lhl	Soil leaching rate	1/day	0.000027	Default value, ORNL RAIS
Li	Decay	1/day	0.693/Tr*	Default value, ORNL RAIS

[a]Radionuclides only

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment*

ORNL RAIS = Oak Ridge National Laboratory Risk Assessment Information System

1 Table G3-7. 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)		Milk (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	g	--	g	--	g	--	g
Cadmium	0.18	b	--	b	--	d	--	d
Carbon tetrachloride	0.18	b	0.18	b	1.69E-05	d	5.34E-06	d
Chloroform	0.554	b	0.554	b	2.33E-06	d	7.37E-07	d
Chromium	0.0002	b	0.0002	b	9.00E-03	d	1.00E-05	d
Chromium (VI)	0.0002	b	0.0002	b	9.00E-03	d	1.00E-05	d
Manganese	0.055	b	--	f	--	f	--	f
Methylene chloride	1.45	b	1.45	b	4.45E-07	d	1.40E-07	d
Nitrate	--	e	--	e	--	e	--	e
PCE	0.0822	b	0.0822	b	6.28E-05	d	1.98E-05	d
TCE	0.304	b	0.304	b	6.58E-06	d	2.08E-06	d
Thallium	0.00012	b	--	f	--	f	--	f
Uranium	0.001888	b	0.001888	b	3.00E-04	d	4.00E-04	d

[a]The transfer coefficients used to estimate concentrations in fruits and vegetables for radionuclides are based on the weighted average of Bv (dry weight) values presented in HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment* , for leafy vegetables, root vegetables, and fruits relative to the consumption rates for a residential farmer. The transfer coefficients were adjusted from dry weight to wet weight by applying the dry to wet ratio of 0.2 presented in HNF-SD-WM-TI-707.

[b]The transfer coefficients used to estimate contaminant concentrations in fruits and vegetables and cattle fodder were obtained from HNF-SD-WM-TI-707. 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 HNF-SD-WM-TI-707.

[c]The transfer coefficients used to estimate concentrations in cattle fodder for radionuclides are based on the values presented in HNF-SD-WM-TI-707for 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 HNF-SD-WM-TI-707for fodder.

[d]The transfer coefficients used to estimate concentrations in beef tissue and dairy products were obtained from HNF-SD-WM-TI-707.

[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 G5.3.5 of this appendix for discussion on tritium.

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

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Table G3-8. Beef Tissue and Milk Modeling Calculations, 200-ZP-1 Operable Unit Groundwater.

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

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

Variable	Variable Definition	Unit	Value	Source
Cb	Contaminant concentration in beef	mg/kg	Calculated value	Equation 1
Cm	Contaminant concentration in milk	mg/kg	Calculated value	Equation 2
Cp	Contaminant concentration in fodder	mg/kg	Calculated value	Table G3-6
CF	Conversion factor	kg/g	0.001[a]	Not applicable
Cw	Contaminant concentration in water	mg/L	Site-specific	Analytical data
fp	Fraction of year animal is on site	unitless	1	Default value, ORNL RAIS
fs	Fraction of animal's food from site	unitless	1	Default value, ORNL RAIS
Fb	Beef transfer coefficient	day/kg	Contaminant-specific	Table G3-7
Fm	Milk transfer coefficient	day/kg	Contaminant-specific	Table G3-7
Qp	Quantity of pasture ingested	kg/day	11.77	Default value, ORNL RAIS
Qw	Quantity of water ingested	L/day	53	Default value, ORNL RAIS

[a]Radionuclides only

ORNL RAIS = Oak Ridge National Laboratory Risk Assessment Information System

1 Table G3-9. Intake Assumptions for Children and Adults—Ingestion and
2 Inhalation Exposure to Soil.

Soil Intake Factors - Nonradioactive COPCs, Non-Cancer (mg/kg-day):
Ingestion child = CS x IRc x EF x EDc x CF1 / ATnc-c x BWc
Ingestion adult = CS x IRs x EF x EDa x CF1 / ATnc-a x BWa
Soil Intake Factors - Nonradioactive COPCs, Cancer (mg/kg-day):
Ingestion child/adult = (CS x EF x CF1 / ATca) x (IRc x EDc/ BWc + IRa x EDa/ Bwa)
Soil Intake Factors - Radioactive COPCs (pCi):
Ingestion child/adult = (CS x EF x CF2) x (IRc x EDc + IRa x EDa)
Inhalation child/adult = (CS x EF x (1/PEF) x CF3) x (InhRc xEDc + InhRa xEDa)

3

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
AT	Averaging time			
	Noncarcinogenic (ED x 365 days)			
	ATnc-a: Adult	23,360	23,360	days
	ATnc-c: Child[c]	2,190	2,190	
	Carcinogenic			
	ATca: Lifetime (adult/child)	25,550	25,550	days
BW	Body weight			
	BWa: Adult	70	70	kg
	BWc: Child	16	16	
CF1	Conversion factor 1	1.00E-06	1.00E-06	kg/mg
CF2	Conversion factor 2	1.00E-03	1.00E-03	g/mg
CF3	Conversion factor 3	1.00E+03	1.00E+03	g/kg
CS	Contaminant concentration in soil	Contaminant-specific	Contaminant-specific	mg/kg or pCi/g
EF	Exposure frequency (adult/child)	365	365	days/year
ED	Exposure duration			
	EDa: Adult	64	64	years
	EDc: Child	6	6	
InhR	Inhalation rate (adult/child)			
	InhRa: Adult	30	26	m^3/day
	InhRc: Child	8.2	16	
IR	Ingestion rate, soil			
	IRa: Adult	400	200	mg/day
	IRc: Child	400	400	
PEF	Particulate emission factor[d]	2.72E+09	2.72E+09	m^3/kg

[a]Source is Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*.

[b]Source is Ridolfi, 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment*.

[c]The Yakama Nation (Ridolfi, 2007) child body weight of 16 kg was also used for CTUIR, because Harris and Harper, 2004 did not provide a child body weight.

[d]A site-specific particulate emission factor and contaminant-specific volatilization factors were calculated using EPA equations in EPA/540/R/99/005, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final* (see Table G3-15).

CTUIR = Confederated Tribes of the Umatilla Indian Reservation
EPA = U.S. Environmental Protection Agency

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Table G3-10. Intake Assumptions for Children (2 to 6 Years) and Adults—Ingestion, Dermal, and Inhalation Exposure to Tap Water. (2 sheets)

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

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

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

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

Water Intake Factors - Radioactive COPCs (pCi):

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

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
AT	Averaging time			
	Noncarcinogenic (ED x 365 days)			
	ATnc-a: Adult	23,360	23,360	days
	ATnc-c: Child	2,190	2,190	
	Carcinogenic			
	ATca: Lifetime (adult/child)	25,550	25,550	days
BW	Body weight			
	BWa: Adult	70	70	kg
	BWc: Child[c]	16	16	
CW	Contaminant concentration in water	Contaminant -specific	Contaminant-specific	µg/L or pCi/L
CF	Conversion factor	1.00E-03	1.00E-03	mg/µg
DAevent	Absorbed dose per event	Contaminant -specific	Contaminant-specific	mg/cm^2-event
EF	Exposure frequency	365	365	days/year
ED	Exposure duration			
	EDa: Adult	64	64	years
	EDc: Child	6	6	
EVw	Event frequency – water contact	1	1	events/day

Table G3-10. Intake Assumptions for Children (2 to 6 Years) and Adults—Ingestion, Dermal, and Inhalation Exposure to Tap Water. (2 sheets)

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
InhR	Inhalation rate (adult/child)			
	InhRa: Adult	30	26	m^3/day
	InhRc: Child	8.2	16	
IR	Ingestion rate, water			
	IRa: Adult	4	4	L/day
	IRc: Child	1.5	2	
SA	Skin surface area[d]			
	SAa: Adult	18,000	18,000	cm^2
	SAc: Child	6,600	6,600	

[a]Source is Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways.*

[b]Source is Ridolfi, 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment.*

[c]The Yakama Nation (Ridolfi, 2007) child body weight of 16 kg was also used for CTUIR, because Harris and Harper, 2004 did not provide a child body weight.

[d]EPA's default residential exposure factors (EPA/540/R/99/005, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final*) were used for skin surface area and the volatilization factor.

CTUIR = Confederated Tribes of the Umatilla Indian Reservation
EPA = U.S. Environmental Protection Agency

Table G3-11. Absorbed Dose Per Event Dermal Exposure to Tap Water.

DA_{event}:

Organic Contaminants:

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

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

Inorganic Contaminants:

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

Intake Parameter		Value	Source
DA_{event}	Absorbed dose per event (mg/cm^2-event)	Calculated value	Equation 1, 2, or 3
FA	Fraction absorbed (dimensionless)	Contaminant-specific	Exhibit B-3 of EPA/540/R/99/005
PC	Permeability constant (cm/hr)	Contaminant-specific	Exhibit B-3 of EPA/540/R/99/005
Cw	Contaminant concentration in water (mg/cm^3)	Site-specific	Analytical data
t_{event}	Event duration (hr/event): Duration for adult showering event Duration for child bathing event	 0.17 0.33	 EPA 600/P-95-002Fa EPA 600/P-95-002Fa
t*	Time to reach steady-state (hr) = 2.4 x Tau_{event}	Contaminant-specific	Exhibit B-3 of EPA Region 9 preliminary remediation goal
Tau_{event}	Lag time per event (hr/event)	Contaminant-specific	Exhibit B-3 of EPA/540/R/99/005
B	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimensionless)	Contaminant-specific	Exhibit B-3 of EPA/540/R/99/005

EPA/540/R/99/005, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final*
EPA 600/P-95/002Fa, *Exposure Factors Handbook Volume 1: General Factors*

Table G3-12. Intake Assumptions for Adults—Dermal and Inhalation Exposure to Groundwater in Sweatlodge. (2 sheets)

VOLATILE AND SEMI-VOLATILE COMPOUNDS (including tritium)

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

Dermal Absorption adult = Cw x VForg x PC x SA x ET x EVw x EF x ED x CF1 / ATnc x BW

Inhalation adult = Cw x VForg x InhR x EF x ED x ET x EVw x CF2 / ATnc x BW

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

Dermal Absorption adult = Cw x VForg x PC x SA x ET x EVw x EF x ED x CF1 / ATca x BW

Inhalation adult = Cw x VForg x InhR x EF x ED x ET x EVw x CF2 / ATca x BW

Water Intake Factors - Tritium (pCi)

Inhalation adult = Cw x VForg x InhR x EF x ED x ET x EVw x CF2

NON-VOLATILE COMPOUNDS (including metals and radionuclides, except tritium)

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

Dermal Absorption adult = (Cw x CF3) x PC x SA x ET x EVw x EF x ED / ATnc x BW

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

Dermal Absorption adult = (Cw x CF3) x PC x SA x ET x EVw x EF x ED / ATca x BW

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
AT	Averaging time			
	ATnc: Noncarcinogenic (ED x 365 days)	24,820	24,820	days
	ATca: Lifetime	25,550	25,550	
BW	Body weight	70	70	kg
CF1	Conversion factor 1	1.00 E-06	1.00 E-06	m^3/cm^3
CF2	Conversion factor 2	0.042	0.042	day/hour
CF3	Conversion factor 3	0.001	0.001	L/cm^3
CW	Contaminant concentration in groundwater	Contaminant-specific	Contaminant-specific	mg/L or pCi/L
PC	Permeability Constant[c]	Contaminant-specific	Contaminant-specific	cm/hour
ED	Exposure duration	68	68	years
EF	Exposure frequency	365	260[d]	days/year
ET	Exposure time	1	2[d]	hours/day
EVw	Event frequency – water contact	1	1	events/day
InhR	Inhalation rate	30	26	m^3/day

Table G3-12. Intake Assumptions for Adults—Dermal and Inhalation Exposure to Groundwater in Sweatlodge. (2 sheets)

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
SA	Skin surface area	18,000	18,000	cm^2
VF	Vaporization factor[c]			
	VForg: Organics (including tritium)	0.955	0.955	L/m^3

[a]Source: Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways.*

[b]Source: Ridolfi, 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment.*

[c]Values obtained from EPA/540/R/99/005, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final.*

[d]Exposure frequency and time for the Yakama Nation is based on 10 hours/week or 2 times the average rate of 5 hours/week, which equates to an exposure time of 2 hours/day for 5 days/week, or 260 days/year.

[e]See Table G3-13 for equations and input parameters.

CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Table G3-13. Calculation of the Vaporization Factor for the Sweatlodge Scenario.

Formula for Volatile and Semi-Volatile Organic Compounds (including Tritium):

$$C_v = C_w \times VF_{org}$$

where,

$$VF_{org} = \frac{V_{w,total}}{2 \times 2/3 \times pi \times r^3}$$

Parameter	Definition (unit)	Value
C_v	Concentration in sweatlodge vapor (mg/m^3)	Chemical – specific
C_w	Concentration in groundwater (mg/L or pCi/L)	Chemical – specific
$V_{w,total}$	Total volume of water used to create steam (L)	4
r	Radius of sweatlodge (m)	1
MW_w	Molecular weight of water (g/gmole)	18
R	Ideal gas law constant ($mmHg*m^3/gmole*K$)	0.06237
T	Temperature of sweatlodge (K)	339
ρ_w	Density of liquid water (g/L)	1000
p^*	Partial pressure of water at temp K (mmHg)	194.89
VF_{org}	**Vaporization factor, organic chemicals (L/m^3)**	**0.955**

Source: Equations and input parameters for the calculation of the vaporization factor for the sweatlodge scenario were obtained from Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways.*

Table G3-14. Intake Assumptions for Child and Adults – Food Chain Pathways.

Tissue Intake Factors - Nonradioactive COCs, Non-Cancer (mg/kg BW-day):
Ingestion child/adult = Cti x IRti x EF x ED x CF / ATnc
Tissue Intake Factors - Nonradioactive COCs, Cancer (mg/kg BW-day):
Ingestion child/adult = Cti x IRti x EF x ED x CF / ATca
Tissue Intake Factors - Radioactive COCs (pCi):
Ingestion adult = Cti x IRti x EF x ED

Intake Parameter		CTUIR[a]	Yakama Nation[b]	Unit
AT	Averaging time			
	Noncarcinogenic	(ED x 365 days)		
	ATnc-a: Adult	23,360	23,360	days
	ATnc-c: Child	2,190	2,190	
	Carcinogenic			
	ATca: Lifetime (adult/child)	25,550	25,550	days
Cti	Contaminant concentration in tissue	Contaminant-specific	Contaminant-specific	mg/kg or pCi/g
CF	Conversion factor	1.00 E-03	1.00 E-03	kg/g
EF	Exposure frequency	365	365	days/year
ED	Exposure duration			
	EDa: Adult	70	64	years
	EDc: Child	6	6	
IRti	Ingestion rate of tissue			
	IRti-a: Adult plant ingestion rate[c]	8.75 (612.5 g/day)	8 (559 g/day)	g/kg-day
	IRti-c: Child plant ingestion rate[d]	NA	5.8 (93.5 g/day)	
	IRti-a: Adult Berry/Fruit ingestion rate[e]	0.89 (62.5 g/day)	2.14 (149.5 g/day)	
	IRti-c: Child Berry/Fruit ingestion rate[f]	NA	3.97 (63.5 g/day)	
	IRti-a: Adult Beef ingestion rate[g]	1.07 (75 g/day)	6.03 (422.4 g/day)	
	IRti-c: Child Beef ingestion rate[h]	NA	7.95 (127.2 g/day)	
	IRti-a: Adult Milk ingestion rate[i]	NA	17.66 (1,236 g/day or 1.2 L/day)	
	IRti-c: Child Milk ingestion rate[i]	NA	32.19 (515 g/day or 0.5 L/day)	

[a]Source: Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways.*

[b]Source: Ridolfi, 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment.*

[c]Adult CTUIR and Yakama Nation rates are based on 50 percent of the ingestion rate of 1,225 g/day (roots/greens/other) and 1,118 g/day (vegetable/root), respectively.

[d]Child Yakama Nation rate is based on 50 percent of the ingestion rate of 187 g/day (vegetable/root).

[e]Adult CTUIR and Yakama Nation rates are based on 50 percent of the ingestion rate of 125 g/day (fruits/berries) and 299 g/day (fruit), respectively.

[f]Child Yakama Nation rate is based on 50 percent of the ingestion rate of 127 g/day (fruits/berries).

[g]Adult CTUIR and Yakama Nation rates are based on 60 percent of the ingestion rate of 125 g/day (game/fowl) and 704 g/day (meat/game), respectively. CTUIR is a river-based diet mainly consisting of fish.

[h]Child Yakama Nation rates are based on 60 percent of the ingestion rate of 212 g/day (meat/game).

[i]One liter of milk is equal to 1,030 g.

CTUIR = Confederated Tribes of the Umatilla Indian Reservation
NA = not available

Table G3-15. Summary of Volatilization Factor and Particulate Emission Factor Inputs and Equations.

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

Parameter	Definition (Unit)	Value	Source
Q/C	Dispersion coefficient (g/m^2-s per kg/m^3)	71.23	Site-specific. Used Boise, Idaho, defaults from OSWER 9355.4-24
V	Fraction of vegetative cover (unit-less)	0.5	Default value, OSWER 9355.4-24
U_m	Mean annual wind speed (m/s)	3.4	Site-specific (HNF-SD-WM-TI-707)
U_t	Equivalent threshold value of wind speed at 7 m (m/s)	11.32	Default value, OSWER 9355.4-24
F(x)	Function dependent on U_m/U_t	0.194	Default value, OSWER 9355.4-24
PEF	Particulate emission factor (m^3/kg)	2.72 E+09	Calculated value

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment*

OSWER 9355.4-24, 2002, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*

EPA = U.S. Environmental Protection Agency

OSWER = EPA Office of Solid Waste and Emergency Response

G4.0 TOXICITY CRITERIA

The purpose of the toxicity assessment is to weigh the available and relevant evidence regarding the potential for contaminants to cause adverse health effects in exposed individuals and to provide a quantitative estimate of the relationship between the magnitude of exposure and the likelihood of adverse effects (EPA/540/1-89/002). A fundamental principle of toxicology is that the dose determines the severity of the effect. Accordingly, the toxicity criteria describe the quantitative relationship between the dose of a contaminant and the type and incidence of the toxic effect. This relationship is referred to as the dose response. The types of toxicity criteria are described in the following subsections. Tables G4-1 and G4-2 present the carcinogenic toxicity criteria for the nonradionuclides and the radionuclides, respectively, for the COPCs in this assessment. Table G4-3 lists the noncarcinogenic toxicity criteria used for the COPCs in this assessment. Attachment G-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 (SIF) listed in Tables G3-9 through G3-14 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 nonradionuclides:

1. Integrated Risk Information System (IRIS) database
2. EPA Interim Toxicity Criteria published by the National Center for Environmental Assistance (NCEA)
3. EPA 540-R-97-036, *Health Effects Assessment Summary Tables: FY 1997 Update* (HEAST)
4. Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profiles.

G4.1 CANCER EFFECTS

The cancer SF (expressed as $[mg/kg\text{-}day]^{-1}$) expresses excess cancer risk as a function of dose. The dose-response model is based on high- to low-dose extrapolation and assumes there is no lower threshold for the initiation of toxic effects. Specifically, cancer effects observed at high doses in laboratory animals or from occupational or epidemiological studies are extrapolated using mathematical models to low doses common to environmental exposures. These models are essentially linear at low doses, so no dose is without some risk of cancer. The cancer SFs for each of the nonradionuclide COPCs are presented in Table G4-1.

The SFs for radionuclides are incremental cancer risks resulting from exposure to radionuclides via inhalation, ingestion, and external exposure pathways (the dermal pathway is not significant). The SFs represent the probability of cancer incidence as a result of unit exposure to a given

radionuclide averaged over a lifetime. The cancer SFs for the radionuclide COPCs are presented in Table G4-2. These values are from the HEAST (EPA 540-R-97-036) update on April 16, 2001, which is based on Federal Guidance Report No. 13 (*Cancer Risk Coefficients for Environmental Exposure to Radionuclides* [EPA 402-R-99-001]). Federal Guidance Report No. 13 incorporates state-of-the-art models and methods that take into account age- and gender-dependence of radionuclide intake, metabolism, dosimetry, radiogenic cancer risk, and competing risks.

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

G4.2 NON-CANCER EFFECTS

Chronic RfDs are defined as an estimate of a daily exposure level for the human population (including sensitive subpopulations) that are likely to be without appreciable risk of non-cancer effects during a lifetime of exposure (EPA 402-R-99-001). Chronic RfDs are specifically developed to be protective for long-term exposure to a contaminant and are generally used to evaluate the potential non-cancer effects associated with exposure periods of 7 years to a lifetime. The RfDs are expressed as mg/kg-day and are calculated using lifetime average body weight and intake assumptions. The non-cancer toxicity criteria for nonradionuclide COPCs are presented in Table G4-3.

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

Chronic RfDs, as discussed above, are used in the evaluation of tribal exposures, because the long-term exposure (7 years to a lifetime) to relatively low-contaminant concentrations are of greatest concern for that population. In EPA's methodology used to derive chronic RfDs, UFs are applied to the NOAEL or LOAEL of the critical research study. These UFs are used to address the uncertainties/variabilities that are present in the data set for each individual contaminant (see Section 4.4.5 of *A Review of the Reference Dose and Reference Concentration Processes*, Final Report [EPA/630/P-02/002F]). The UFs (up to 5) are assigned values of either 10 or 3, the values are multiplied together, and then the critical study NOAEL or LOAEL is divided by the total UF (see Section 4.4.5 of EPA/630/P-02/002F). Table G4-3 summarizes the chronic RfDs for each nonradionuclide COPC.

G4.3 ORAL TOXICITY CRITERIA

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

G4.4 INHALATION TOXICITY CRITERIA

The criteria for inhalation are reference concentrations (RfC) expressed in milligrams of contaminant per cubic meter of air (mg/m^3) for noncarcinogens and unit risk factors (URF) expressed in cubic meters of air per microgram of contaminant ($m^3/\mu g$) for carcinogenic exposures. The RfCs and URFs are developed in the same way as RfDs and SFs, except that they include, as part of their development, a default inhalation rate assumption of 20 m^3 of air inhaled per day. Because the default inhalation rate is not applicable to all the receptors in this risk assessment, RfCs and URFs were converted into reference doses for inhalation (RfD_i) and inhalation slope factors (SF_i), according to the protocols presented by EPA (EPA/540/1-89/002; "Human Health Toxicity Values in Superfund Risk Assessments" [Cook, 2003, OSWER Directive 9285.7-53]). The conversions are below:

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

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

Route-to-route extrapolation from the oral route to the inhalation route was not performed because of the toxicological uncertainties involved in assuming that contaminants are as toxic and have the same toxic endpoint by ingestion as by inhalation. Therefore, contaminants that do not have inhalation toxicity criteria were not evaluated by the inhalation route. The impacts of not evaluating all COPCs by the inhalation route are discussed in the uncertainty section (Section G6.0).

G4.5 DERMAL TOXICITY CRITERIA

The dermal toxicity criteria were applied to groundwater only. Most oral RfDs and SFs are expressed as an administered dose (i.e., the amount of substance taken into the body by swallowing). In contrast, exposure estimates for the dermal route of exposure are expressed as an absorbed dose (i.e., the amount of contaminant that is actually absorbed through the skin). Because dermal toxicity criteria are not readily available, oral toxicity values are used in conjunction with an absorption correction factor to adjust for the difference in administered to absorbed dose. The EPA recommends absorption correction factors for a limited amount of inorganic contaminants in Exhibit 4-1 of EPA/540/R/99/005. For those contaminants that do not appear on the table, the recommendation is to assume 100 percent absorption (EPA/540/R/99/005) (i.e., the dermal toxicity criteria would not differ from the oral toxicity criteria).

In this instance, trivalent and hexavalent chromium have recommended absorption correction factors. Absorption correction factors of 1.3 and 2.5 percent were used to derive the dermal RfDs for trivalent chromium and hexavalent chromium, respectively. The specifics are discussed in the toxicity profiles for each contaminant in Attachment G-5.

Table G4-1. Carcinogenic Toxicity Criteria for the Nonradionuclide Contaminants of Potential Concern.

Contaminant	Oral Cancer: Slope Factor $(mg/kg\text{-}day)^{-1}$	Inhalation Cancer: Slope Factor $(mg/kg\text{-}day)^{-1}$	Tumor Type	EPA Cancer Classification[a]	Reference
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	Lung (human)	A	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

CalEPA = California Environmental Protection Agency
EPA = U.S. Environmental Protection Agency
IRIS = Integrated Risk Information System - online database (EPA, 2008)
PCE = tetrachloroethylene
TCE = trichloroethylene

Table G4-2. Radionuclide Carcinogenic Toxicity Criteria for Contaminants of Potential Concern.

Radionuclide	Ingestion (Risk/pCi)			Inhalation (Risk/pCi)	External (Risk/yr per pCi/g)
	Soil	Food	Water		
Am-241	2.17E-10	1.34E-10	[a]	2.81E-08	2.76E-08
C-14	2.79E-12	2.00E-12	[a]	7.07E-12	7.83E-12
Cs-137	4.33E-11	3.7E-11	[a]	1.19E-11	5.32E-10
I-129	[a]	3.2E-10[b]	1.50E-10	6.10E-11	6.10E-09
Np-237	1.46E-10	8.29E-11	[a]	1.77E-08	5.36E-08
Pu-239	2.76E-10	1.74E-10	[a]	3.33E-08	2.00E-10
Pu-240	2.77E-10	1.74E-10	[a]	3.33E-08	6.98E-11
Ra-228	2.28E-09	1.43E-09	[a]	5.18E-09	[a]
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	[a]	1.32E-07	5.59E-09
Tritium	[a]	1.40E-13	5.10E-14	5.6E-14[c]	[a]

NOTE: The U.S. Environmental Protection Agency classifies all radionuclides as Group A, known human carcinogens. Values are from EPA 540-R-97-036, *Health Effects Assessment Summary Tables: FY 1997 Update*, updated April 16, 2001, which is based on EPA 402-R-99-001, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (Federal Guidance Report No. 13).

[a]Radionuclide not evaluated by this pathway.

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

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

Table G4-3. Noncarcinogenic Toxicity Criteria for Contaminants of Potential Concern.

Contaminant	Chronic RfD (mg/kg-day)	Toxic Endpoint	Critical Study	Chronic RfD UF[a]	RfD Source
Inhalation					
Carbon tetrachloride	None[b]	--	--	--	--
Chloroform	1.30E-02	Liver, kidney, and central nervous system toxicity	Subchronic mouse	100	NCEA
Chromium (total)	None[b]	--	--	--	--
Chromium (VI) (hexavalent) – mists and aerosols	2.3E-06	Nasal septum atrophy	Subchronic human occupational	90	IRIS
Methylene chloride	8.6E-01	Hepatotoxicity	2-year chronic rat	100	HEAST
Nitrate	None[b]	--	--	--	--
PCE	1.1E-01	--	--	--	NCEA
Thallium	None[b]	--	--	--	--
TCE	1.10E-02	Central nervous system, liver, and endocrine toxicity	Subchronic human occupational	1,000	EPA/600/P -01/002A
Uranium	None[b]	--	--	--	--
Ingestion					
Carbon tetrachloride	7.0E-04	Liver lesions	Subchronic rat	1,000	IRIS
Chloroform	1.0E-02	Liver, kidney, and central nervous system toxicity	Chronic dog study	100	IRIS
Chromium (total) – based on trivalent chromium	1.5E+00	None observed	Chronic oral rat study	1,000	IRIS
Chromium (VI) (hexavalent)	3.0E-03	None reported	One-year rat drinking water study	1,000	IRIS
Methylene chloride	6.0E-02	Liver toxicity	Chronic rat	100	IRIS
Nitrate	1.6E+00	Methemoglobinemia in infants	Human epidemiological studies	1	IRIS
PCE	1.0E-02	Hepatotoxicity	6-week mouse gavage study	1,000	IRIS
Thallium[c]	6.6E-05	None reported	Rat oral subchronic study	3,000	IRIS
TCE	3.0E-04	Central nervous system, liver, and endocrine toxicity	Subchronic mouse	3,000	EPA/600/P -01/002A
Uranium	3.0E-03	Weight loss, nephrotoxicity	30-day rat bioassay	1,000	IRIS

[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 criterion for this contaminant for this pathway.

[c]The oral reference dose (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 (EPA, 2004, "Region 9 PRG Table").

EPA/600/P-01/002A, *Trichloroethylene Health Risk Assessment: Synthesis and Characterization*

EPA = U.S. Environmental Protection Agency
HEAST = *Health Effects Assessment Summary Tables: FY 1997 Update* (EPA 540-R-97-036)
IRIS = EPA's Integrated Risk Information System (online database) (EPA, 2008)
NCEA = EPA's National Center for Environmental Assessment
PCE = tetrachloroethylene
RfD = reference dose
TCE = trichloroethylene
UF = uncertainty factor

G5.0 RISK CHARACTERIZATION

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

G5.1 METHODOLOGY FOR EVALUATING NONCARCINOGENIC HAZARDS

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

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

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

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

G5.2 METHODOLOGY FOR EVALUATING CARCINOGENIC RISKS

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

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

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

The linear equation is valid only for risks below 1 in 100 (1×10^{-2}). For risks above 1×10^{-2}, the following "one-hit" equation is used[4] (EPA/540/1-89/002). The one-hit model is based on the concept that a cancer can be induced after a single susceptible target or receptor has been exposed to a single effective dose unit of a carcinogen (*Proposed Guidelines for Carcinogen Risk Assessment* [EPA/600/P-92/003C]):

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

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

Because of differences in the methodology used to estimate their SFs, radiological and nonradiological cancer risks are tabulated and summed separately on the summary cancer risk tables. However, in general EPA does recommend assuming that radiological and nonradiological cancer risks are additive (Luftig and Page, 1999). For most contaminant (nonradiological) carcinogens, laboratory experiments and animal data are the basis for estimates of risk. In the case of radionuclides, however, the data come primarily from epidemiological studies of exposure to humans. Another important difference is that the SFs used for contaminant carcinogens generally represent an upper-bound or 95 percent UCL of risk, while radionuclide SFs are based on the most likely estimates values. At the 216-Z-1A Tile Field and the 216-A-8 Crib, there were only radionuclide COPCs and no nonradiological carcinogens selected as COPCs in soil. For groundwater, there are a number of nonradiological carcinogens, in addition to the three radionuclides that are COPCs in groundwater.

The EPA's target cancer risk range is 10^{-6} to 10^{-4}, and EPA considers risk levels as high as 4×10^{-4} (the upper end of EPA's target risk range) to be acceptable under some circumstances (Clay, 1991 [OSWER Directive 9355.0-30]).

G5.3 SUMMARY OF RISK RESULTS

All final risk and hazard estimates up to 9 were presented to one significant figure only, as recommended by EPA/540/1-89/002. Therefore, an HQ or HI of 1 could range between 0.95 and 1.4, and a risk of 2×10^{-5} could range between 1.5×10^{-5} and 2.4×10^{-5}. Hazards >9 were shown with all positive integers (i.e., an HI of 312 was not rounded to 300). The risk and hazard results, presented to one significant figure, are summarized in Tables G5-1 through G5-11. Details of the calculations, with risks and hazards presented to at least two significant figures, are included in Attachment G-6 of this appendix for all nonradionuclides in soil and the nonradionuclides and radionuclides in groundwater. For the radionuclide contaminants in soil, summaries of the RESRAD computer model outputs are included in Attachment G-7.

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[4] RESRAD does not use the adjusted formula in its calculations. Therefore, for both the 216-Z-1A Tile Field and the 216-A-8 Crib sites, RESRAD risk outputs showed risks >1. For RESRAD risk outputs greater than 10^{-2}, the RESRAD risk results were entered into the EPA "one-hit" formula to calculate a risk <1.

In an institutional control failure scenario, a Native American could be exposed to contaminants in soil if soil at depth was brought to the surface. As described in earlier sections, the scenario selected to evaluate this possibility is through soil excavation and subsequent exposure to excavated soil spread over a vegetable garden and near a residential home. In addition to the soil exposures, it was assumed that water from a groundwater well would be used for domestic supply, sweatlodge, and watering of gardens and livestock.

G5.3.1 Soil Exposures

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

- 150 years from now
- 500 years from now
- 1,000 years from now (maximum required time horizon in 10 CFR 20, "Standards for Protection Against Radiation," Subpart E, "Radiological Criteria for License Termination").

Because two risk-driver radionuclides at the 216-Z-1A Tile Field are plutonium isotopes with extremely long half-lives in soil (24,000+ years for plutonium-239, and 6,500+ years for plutonium-240), the future risk calculations are not different than current risks, nor are there daughter products that become significant (from a health risk perspective) in the 1,000-year timeframe. Risks approach 100 percent (a cancer risk level approaching 1) for 1,000 years. The other risk-driver radionuclide, americium-241, has a shorter half-life (432 years) than the plutonium isotopes and a significantly toxic daughter product (neptunium-237) with a long half-life. Risks from americium-241 (including daughter products) do decrease over the 1,000-year period[5] from nearly 1 to 4 x 10^{-2}. However, the 1,000-year risk is still well above 10^{-4}, and cumulative risks do not change within 1,000 years. Therefore, future time-horizon risks and additional daughter products not selected as initial COPCs are not included in the risk summary Tables G5-1 and G5-2 presented in this section (unless the daughter product had a risk exceeding 10^{-6}). Current and future risk results, including daughter product risks, are included in the tables in Attachment G-7.

For the 216-A-8 Crib where cesium-137 is the risk-driving radionuclide, risks from future time horizons are presented in the summary tables in this section. Cesium-137 has a half-life of approximately 30 years. Risks at the 216-A-8 Crib decrease significantly within the 1,000 years evaluated in this assessment, dropping below 1 x 10^{-4} approximately 350 to 400 years in the future as the cesium-137 decays. At that point, neptunium-237 and plutonium-239 become the risk drivers, with cumulative risks in the upper 10^{-5} range. Figure G5-1 shows the decrease in cancer risks for the future CTUIR population for the 216-A-8 Crib (there are no significant

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

differences in cancer risk between the CTUIR and the Yakama Nation). Daughter products never contribute significantly to overall risks at any of the time periods evaluated for the 216-A-8 Crib, so daughter risks are included in Attachment G-7 but are not included in the risk summary Tables G5-1 and G5-2 in this section (i.e., only the original COPCs are shown).

Exposures to soil would occur via ingestion, inhalation, and external radiation for the radionuclides. In addition, risks from exposure to produce grown in contaminated soil and inhaled radon were also evaluated. Radon risks were extremely low at both sites (orders of magnitude below the *de minimis* cancer risk level of 1×10^{-6}). Risks for soil exposures to the CTUIR and Yakama Nation are presented in Tables G5-1 and G5-2, respectively. The non-cancer hazards for both the CTUIR and Yakama Nation at the 216-A-8 Crib site are presented in Table G5-3. Overall, there are subtle differences between the risk results of the two populations, but these differences do not significantly affect risk totals. The Yakama Nation had slightly lower inhalation risks (because of a lower inhalation rate) and slightly higher produce risks (because of a higher plant ingestion rate) than the CTUIR. The year 2150 results are below:

- 216-Z-1A Tile Field: Cancer risks from exposure to all COPCs are well above 1×10^{-4} for both the CTUIR and Yakama Nation, with a total risk approaching 1, a 100 percent chance of contracting cancer from site exposures. Risks are driven by americium-241, plutonium-239, and plutonium-240. Cumulative risks are driven by the produce and ingestion pathways, with external radiation from americium-241 a distant third risk pathway, as shown in Figure G5-2 for both the CTUIR and Yakama Nation.

- 216-A-8 Crib: Only cesium-137 exposures exceeded 1×10^{-4}, with risks of 3 x 10- due to external radiation. Three other radionuclides exceed 1×10^{-6}, including neptunium-237 with a risk of 4×10^{-5} (driven by external radiation), plutonium-239 with a risk of 3×10^{-5} (driven by ingestion and produce), and plutonium-240 with a risk of 6×10^{-6} (driven by ingestion and produce). Approximately 350 years in the future, cesium-137 decays to the point where risks fall below 1×10^{-4} (cumulative risks at 500 years are 7×10^{-5}). Figure G5-2 presents the percent contribution by pathway to the cumulative risks 150 years from now at the 216-A-8 Crib for both Native American scenarios. Health hazards due to thallium (the only nonradionuclide COPC) in soil were well below the target health goal of 1 for soil ingestion with an HI of 0.3 for CTUIR child exposures, an HI of 0.1 for Yakama Nation child exposures, and an HI of 0.07 for CTUIR and Yakama Nation adult exposures. However, the HI is 30 for adult CTUIR ingestion of produce, and the adult and child ingestion of produce for Yakama Nation HIs are 31 and 30, respectively. Non-cancer hazards are summarized in Table G5-3.

In summary, soil risks at the 216-Z-1A Tile Field are driven by plutonium-239, but risks from all COPCs were significantly above 10^{-4}. At the 216-A-8 Crib, only cesium-137 had risks exceeding 10^{-4}. Risks due to cesium-137 drop below 10^{-4} around 350 years in the future. Risks are driven by the soil ingestion and produce ingestion pathways for 216-Z-1A and by external radiation at the 216-Z-8 Crib French Drain (see Figure G5-2). Homegrown produce ingestion risks from growing fruits and vegetables in contaminated soil are discussed further in Section G5.3.3.

G5.3.2 Direct-Contact Groundwater Exposures

Future Native American children and adults were evaluated for future exposures to groundwater used as tap water (i.e., domestic supply) and future adult exposures to groundwater used in a sweatlodge. Child and adult residents were evaluated for exposures to groundwater used as

tap water through the ingestion, dermal (for nonradionuclides), and inhalation of vapors pathways. The primary pathway of exposure to COPCs in groundwater in the sweatlodge is through the inhalation of volatile constituents. In the unique environment of a sweatlodge where there are hot temperatures producing steam in a small enclosed space, inhalation of non-volatiles (including metals, iodine-129, and technetium-99) as aerosolized droplets is also likely a complete pathway. However, inhalation of non-volatile constituents in the sweatlodge was not quantified due to uncertainties in the estimation of the concentration of non-volatiles in water droplets and some toxicity-related issues, see the uncertainty section for a discussion of the potential risk underestimation. It was also assumed that the COPCs could deposit onto the skin by aqueous condensation. Therefore, dermal exposures to COPCs in groundwater within the sweatlodge were also evaluated (for nonradionuclides). In addition to exposures to groundwater used as tap water and in the sweatlodge, future Native American populations are assumed to use the groundwater as an irrigation source for their crops and livestock. Therefore, exposures to groundwater through the food chain pathways were also evaluated for the Native American scenario and are discussed in Section G5.3.3.

Tables G5-4 and G5-5 summarize the cancer risks from exposures to groundwater through use as tap water and in the sweatlodge for the low-, medium-, and high-exposure scenarios for the CTUIR and Yakama Nation, respectively. Tables G5-6 and G5-7 summarize the non-cancer hazards from exposures to groundwater for the CTUIR and Yakama Nation, respectively. These tables present the combined risks and hazards from the ingestion, dermal, and inhalation pathways under each exposure scenario. For a detailed presentation of the risks and hazards for each of the individual pathways, refer to the summary tables in Attachment G-6. Overall, there are subtle differences between the risk results of the two populations because of slightly different exposure assumptions used in the risk calculations for each population. However, cumulative cancer risks for each population are the same to one significant figure. Cumulative adult non-cancer hazards are nearly the same for each population. Cumulative child non-cancer hazards are lower for CTUIR because of slightly lower tap water ingestion rates and inhalation rates for children. Figure G5-3 shows the percent contribution of each pathway to cumulative groundwater risks and hazards for both Native American scenarios. Figures G5-4 and G5-5 show pathway contributions to total risks and hazards by contaminants, respectively, for the Yakama Nation. Pathway contributions for the CTUIR are almost identical to the Yakama Nation.

The risks and hazards presented in this section are assumed to occur 150 years in the future; however, current concentrations were used to calculate risks and hazards. Although not quantified, future concentration reductions will be significant for all contaminants due to the planned groundwater remediation activities. Even without remediation, significant concentration reductions will likely occur for the chlorinated solvents due to natural degradation processes. Therefore, future risks will be lower than those presented here.

G5.3.2.1 *Exposures to Groundwater as Tap Water*

The following summarizes the results for the tap water exposure scenario:

- Cancer risks from radionuclides: As shown in Tables G5-4 and G5-5, under the high-exposure scenario (90th percentile groundwater concentration), cancer risks from tap water for the radionuclides exceed 1×10^{-4} for both the CTUIR and Yakama Nation at 6×10^{-4} for both Native American populations. Technetium-99 contributes the most to the total cancer risk with a risk of 4×10^{-4}, followed by tritium and iodine-129 with cancer

risks of 2×10^{-4} and 2×10^{-5}, respectively. Under the medium-exposure scenario (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower, at 7×10^{-5}. Under the low-exposure scenario (25th percentile), total cancer risks were even lower (2×10^{-5}).

- Cancer risks from nonradionuclides: As shown in Tables G5-4 and G5-5, total nonradionuclide cancer risks from tap water exposures significantly exceed 1×10^{-4} under the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios for both the CTUIR and Yakama Nation, at 6×10^{-2} and 1×10^{-2} for both Native American populations. Total cancer risks under the low (25th percentile) exposure scenario slightly exceeded 1×10^{-4} for both the CTUIR and Yakama Nation with total cancer risks of 2×10^{-4}. Carbon tetrachloride contributes the majority of the total cancer risk, followed by chloroform and PCE, each with cancer risks more than two orders of magnitude lower than for carbon tetrachloride. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under both the high- and medium-exposure scenario, but only for 87 percent of the total cancer risks under the low-exposure scenario. As detailed in Attachment G-6 of this appendix, total cancer risks from the nonradionuclides in tap water are driven by the inhalation and ingestion pathways, which contribute 55 percent and 40 percent to the total cancer risk, respectively, followed by the dermal pathway (5 percent).

- Non-cancer hazards: As shown in Tables G5-6 and G5-7, total child and adult non-cancer hazards significantly exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios for both the CTUIR and Yakama Nation. The CTUIR child and adult hazards (Table G5-6) under the high-exposure scenario are 471 and 279, respectively; child and adult hazards under the medium-exposure scenario are 81 and 48, respectively; and child and adult hazards under the low-exposure scenario are 2 and 1 (equal to the target health goal), respectively. Yakama Nation child and adult hazards (Table G5-7) under the high-exposure scenario are 606 and 279, respectively; child and adult hazards under the medium-exposure scenario are 105 and 48, respectively; and child and adult hazards under the low-exposure scenario are 3 and 1 (equal to the target health goal), respectively. Carbon tetrachloride is by far the greatest contributor to the total non-cancer hazard in tap water exposures and contributes over 96 percent to the total hazard in the high- and medium-exposure scenarios. Carbon tetrachloride is the only COPC that results in an HI >1 in all of the exposure scenarios (the high-, medium-, and low-exposure scenarios). However, in the high-exposure scenario, hexavalent chromium (child and adult hazards of 9 and 5 for the CTUIR and 11 and 5 for Yakama Nation, respectively), nitrate (child and adult hazards of 5 and 3 for the CTUIR and 6 and 3 for Yakama Nation, respectively), and TCE (child and adult hazards of 4 and 2 for the CTUIR and 5 and 2 for Yakama Nation, respectively) also result in HIs >1. The child non-cancer hazard for nitrate in the medium-exposure scenario of 2 for Yakama Nation also exceeded 1. No individual contaminants have HIs >1 in the low-exposure scenario.

In summary, tap water cancer risks and non-cancer hazards are driven by carbon tetrachloride. Technetium-99 and tritium also have cancer risks exceeding 1×10^{-4} (however, tritium will decay to levels below a 10^{-4} risk in the near future), and, for non-cancer, hexavalent chromium, nitrate, and TCE have HIs >1.

G5.3.2.2 *Exposures to Groundwater in the Sweatlodge*

As discussed above and in Section G3.0, exposures to groundwater in the sweatlodge were evaluated for the inhalation of volatile contaminants and dermal pathways (nonradionuclides only). Inhalation of non-volatile contaminants in the sweatlodge was not evaluated because of the uncertainties in estimating aerosol concentrations (see uncertainty section). This section presents the total risks and hazards for inhalation and dermal exposures combined. Attachment G-6 details the cancer risks and non-cancer hazards for the individual exposure routes. Risks and hazards for the sweatlodge scenario are driven almost entirely by the inhalation pathway. The following summarizes the results from the sweatlodge exposure scenario:

- Cancer risks from radionuclides: As shown in Tables G5-4 and G5-5, of the radionuclide COPCs only tritium was evaluated for the sweatlodge pathway, because it is the only radionuclide that is considered volatile. Radionuclide cancer risks from exposures to groundwater in the sweatlodge are approximately one order of magnitude lower than tap water risks, and are below the maximum acceptable cancer risk of 10^{-4}. Total radionuclide cancer risks in the high-exposure scenario (90th percentile) are 6×10^{-5} for the CTUIR and 7×10^{-5} for the Yakama Nation. Under the medium-exposure scenario (50th percentile), total radionuclide cancer risks were approximately one order of magnitude lower at 6×10^{-6} and 7×10^{-6} for the CTUIR and Yakama Nation, respectively. Under the low-exposure scenario (25th percentile), total cancer risks were even lower (9×10^{-7} and 1×10^{-6} for the CTUIR and Yakama Nation, respectively).

- Cancer risks from nonradionuclides: As with the radionuclides, nonradionuclide cancer risks from exposures to groundwater in the sweatlodge are lower than for tap water exposures (see Tables G5-4 and G5-5) but still exceed 10^{-4} in the high- and medium-exposure with total cancer risks of 3×10^{-3} and 5×10^{-4}, respectively, for the CTUIR and total cancer risks of 3×10^{-3} and 6×10^{-4}, respectively, for the Yakama Nation. Cancer risks for the low-exposure scenario were within EPA's acceptable cancer risk range of 10^{-6} to 10^{-4} for both the CTUIR and Yakama Nation, with cancer risks of 7×10^{-6} and 8×10^{-6}, respectively. Carbon tetrachloride is by far the greatest cancer risk driver of all of the COPCs (including radionuclides) for the sweatlodge pathway, with cancer risks exceeding 10^{-4} in each of the high-, and medium-exposure scenarios at 3×10^{-3} and 4×10^{-4}, respectively, for the CTUIR and 3×10^{-3} and 5×10^{-4}, respectively, for the Yakama Nation. Carbon tetrachloride contributes approximately 99 percent of the total nonradionuclide cancer risks. No other chemicals have cancer risks that exceed 10^{-4} under any of the high-, medium-, or low-exposure scenarios.

- Non-cancer hazards: Non-cancer hazards for the sweatlodge pathway are presented in Tables G5-6 and G5-7 for the CTUIR and Yakama Nation, respectively. Non-cancer hazards are equal to 1, the non-cancer target health goal, under the high-exposure scenario for the CTUIR. For the Yakama Nation, non-cancer hazards under the high-exposure scenario of 2 slightly exceed the target health goal. Non-cancer hazards are due almost entirely to dermal contact with hexavalent chromium in the sweatlodge. No other individual COPC had an HI >1. Because non-volatile contaminants were not evaluated for inhalation in the sweatlodge, risks and hazards could be underestimated (see the uncertainty section).

In summary, of the radionuclide and nonradionuclide COPCs, sweatlodge cancer risks are driven by carbon tetrachloride, the only chemical with risks exceeding 10^{-4}. Hexavalent chromium was the risk driver for non-cancer hazards (however, it barely exceeded an HI of 1) and no other non-cancer contaminants were a health concern. Cancer risks because of sweatlodge exposures are lower than cancer risks estimated from domestic use of the water in the home (tap water exposures [see Figure G5-3]).

G5.3.3 Food Chain Exposures

Native Americans are assumed to consume 50 percent of their fruits and vegetables intake from homegrown gardens that are cultivated in contaminated soils and irrigated with groundwater and to consume beef and milk from cattle that drink site groundwater and graze on pastures irrigated with groundwater. For beef and milk, the source of site contaminants is groundwater; for plants, the source of contaminants is obtained from both soil (grown in impacted soil from excavation) and groundwater (irrigation). The risk and hazard results for food chain pathways for the COPCs in soil are presented in Tables G5-1 through G5-3 (soil summary tables). The food chain pathway cancer risk results for the COPCs in groundwater are shown in Tables G5-8 and G5-9 for the CTUIR and Yakama Nation, respectively, and the food chain pathway non-cancer hazards are shown in Tables G5-10 and G5-11 for the CTUIR and Yakama Nation, respectively. The following subsections summarize the risk and hazard results for the food chain pathways.

G5.3.3.1 *Homegrown Produce*

The following summarizes the results for the produce exposure scenario:

- Cancer risk from radionuclides: The total radionuclide cancer risk from ingestion of homegrown produce exceeds 1×10^{-4} for produce grown in soil for the 216-Z-1A Tile Field and 216-A-8 Crib (Tables G5-1 and G5-2 for the CTUIR and Yakama Nation, respectively) and also under the high-, medium-, and low-exposure scenarios for groundwater used for irrigation (Tables G5-8 and G5-9 for CTUIR and Yakama Nation, respectively).

The produce consumption risks for soil were nearly 1 (approaching 100 percent risk) for both populations at 216-Z-1A Tile Field and were 2×10^{-2} for the CTUIR and 3×10^{-2} for Yakama Nation at 216-A-8 Crib. Risks from produce ingestion because of the contribution from soil at 216-Z-1A Tile Field are due primarily to americium-241, plutonium-239, and plutonium-240, where risks are highest for plutonium-239, followed by plutonium-240 and then americium-241. Target risks are exceeded at the 216-A-8 Crib primarily because of cesium-137.

As shown in Tables G5-8 and G5-9, for produce irrigated with impacted groundwater, total radionuclide cancer risks under the high-exposure scenario are 2×10^{-2} for both the CTUIR and Yakama Nation. Under the medium-exposure scenario, cancer risks were approximately an order of magnitude lower at 2×10^{-3} for the CTUIR and Yakama Nation. Under the low-exposure scenario, cancer risks are even lower but still exceed 1×10^{-4} at 6×10^{-4} for both the CTUIR and Yakama Nation. Technetium-99 is by far the greatest contributor to total radionuclide cancer risk in the plant ingestion pathway for both populations (contributing 85 percent, 88 percent, and 94 percent under high, medium, and low exposures, respectively). It is the only radionuclide that had an individual cancer risk greater than 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios. Note that current tritium concentrations would result in produce ingestion risks greater than 1×10^{-4} under the high- and medium-exposure scenarios (as shown in

Tables G5-8 and G5-9). However, as shown in Section G5.3.5, tritium concentrations would be below levels of health concern in 150 years because tritium's half-life is only 12 years, and existing institutional controls are assumed to prevent use of groundwater until at least that time.

- Cancer risk from nonradionuclides: None of the nonradionuclides selected as COPCs at either of the two soil sites is associated with carcinogenic effects. Therefore, nonradionuclide cancer risks from ingestion of produce grown in impacted soil at the 216-Z-1A Tile Field and 216-A-8 Crib were not calculated. For produce irrigated with groundwater, total nonradionuclide cancer risk from ingestion of homegrown produce exceeds 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios (Tables G5-8 and G5-9 for CTUIR and Yakama Nation, respectively). Total cancer risks are 7×10^{-2}, 1×10^{-2}, and 2×10^{-4} under the high-, medium-, and low-exposure scenarios, respectively, for both the CTUIR and Yakama Nation. Carbon tetrachloride contributes the majority of the total cancer risk, contributing more than 99 percent to the total cancer risk under the high- and medium-exposure scenarios and more than 90 percent to the total cancer risk under the low-exposure scenario. Under the high-exposure scenario, PCE also had cancer risks that exceeded 1×10^{-4}, with a cancer risk of 2×10^{-4} for both the CTUIR and Yakama Nation. However, the cancer risks from PCE are nearly three orders of magnitude less than those calculated for carbon tetrachloride.

- Non-cancer hazards: Health hazards because of thallium in soil for the produce ingestion pathway are above 1, where the adult CTUIR HI is 30, and the adult and child Yakama Nation HIs are 31 and 30, respectively.

For the CTUIR (Table G5-10), total adult non-cancer hazards due to ingestion of produce irrigated with groundwater significantly exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios for the CTUIR, with total hazards of 792 and 137, respectively. Under the low-exposure scenario, total non-cancer hazards of 2 only slightly exceeded 1. (Child fruit and vegetable ingestion rates for the CTUIR are not available. Therefore, child non-cancer hazards were not calculated for the CTUIR.) While non-cancer hazards for hexavalent chromium and TCE exceeded 1 under the high-exposure scenario (each has a hazard of 8), carbon tetrachloride is by far the greatest contributor to total non-cancer hazards and is the only contaminant with hazards exceeding 1 under each of the high-, medium-, and low-exposure scenarios. Adult non-cancer hazards for carbon tetrachloride are 774, 135, and 2 for the high-, medium-, and low-exposure scenarios, respectively, and are responsible for 98 percent, 99 percent, and 79 percent of the total hazards, respectively.

For the Yakama Nation (Table G5-11), total adult non-cancer hazards significantly exceed 1 under both the high-exposure (90th percentile) and medium-exposure (50th percentile) scenarios for the Yakama Nation, with total hazards of 854 and 148, respectively. Under the low-exposure scenario, total non-cancer hazards of 2 only slightly exceeded 1. While non-cancer hazards for hexavalent chromium and TCE exceeded 1 under the high-exposure scenario (each has a hazard of 9 for adults), carbon tetrachloride is by far the greatest contributor to total non-cancer hazards and is the only contaminant with hazards exceeding 1 under each of the high-, medium-, and low-exposure scenarios. Adult non-cancer hazards for carbon tetrachloride are 835, 145, and 2 for the high-, medium-, and low-exposure scenarios, respectively, and are responsible for 98 percent, 99 percent, and 79 percent of the total hazards, respectively. Child non-cancer hazards for carbon tetrachloride are similar to adult non-cancer hazards at 784, 137, and 2.

In summary, ingestion of produce grown in impacted soil and irrigated with impacted groundwater results in risks equal to 100 percent at the 216-Z-1A Tile Field (due primarily to plutonium-239 in soil). At the 216-A-8 Crib, risks were in the 10^{-2} range from soil and would be increased to the 10^{-1} range if produce was watered with groundwater containing 90th percentile contaminants. Risk drivers for the produce pathway from groundwater were carbon tetrachloride and technetium-99.

G5.3.3.2 *Ingestion of Beef*

The following summarizes the results for the beef exposure scenario:

- Cancer risk from radionuclides: As shown in Table G5-8, the total radionuclide cancer risk from ingestion of beef is below 1 x 10^{-4} under each of the high-, medium-, and low-exposure scenarios for the CTUIR. Total cancer risks under the high-exposure scenario are 3 x 10^{-5}, under the medium-exposure scenario are 3 x 10^{-6}, and under the low-exposure scenario are 9 x 10^{-7}. For the Yakama Nation (Table G5-9), total radionuclide cancer risks slightly exceed 1 x 10^{-4}. Under the high-exposure scenario, radionuclide cancer risks for ingestion of beef for the Yakama Nation are 2 x 10^{-4}. Under the medium-exposure scenario, cancer risks are approximately an order of magnitude lower at 2 x 10^{-5}, and under the low-exposure scenario, risks are even lower at 5 x 10^{-6}. For both the CTUIR and Yakama Nation, technetium-99 is the greatest contributor to total radionuclide cancer risk in the beef ingestion pathway. Technetium-99 is responsible for approximately 59 percent, 68 percent, and 84 percent of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. Tritium is the next greatest contributor to total cancer risks, contributing approximately 32 percent, 29 percent, and 16 percent of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. The contribution from iodine-129 is insignificant relative to the cancer risks from technetium-99 and tritium.

- Cancer risk from nonradionuclides: As shown in Tables G5-8 and G5-9, the total nonradionuclide cancer risk from ingestion of beef is also below 1 x 10^{-4} under each of the high-, medium-, and low-exposure scenarios for both the CTUIR and Yakama Nation. For the CTUIR (Table G5-8), total cancer risks under the high-exposure scenario are 2 x 10^{-6}, under the medium-exposure scenario are 3 x 10^{-7}, and under the low-exposure scenario are 6 x 10^{-9}. For the Yakama Nation (Table G5-9), total cancer risks under the high-exposure scenario are 1 x 10^{-5}, under the medium-exposure scenario are 2 x 10^{-6}, and under the low-exposure scenario are 3 x 10^{-8}. Carbon tetrachloride contributes the majority of the total cancer risk and is the only single nonradionuclide COPC with a cancer risk greater than the *de minimis* cancer risk level of 1 x 10^{-6}, with a cancer risk of 2 x 10^{-6} in the high-exposure scenario for CTUIR and cancer risks of 1 x 10^{-5} and 2 x 10^{-6} for the high- and medium-exposure scenarios, respectively, for the Yakama Nation. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under the high- and medium- exposure scenarios and for 73 percent of the total nonradionuclide cancer risks under the low-exposure scenario.

- Non-cancer hazards from nonradionuclides: As shown in Table G5-10, total adult non-cancer hazards for the beef ingestion pathway are below the target health goal of 1 under each of the high-, medium-, and low-exposure scenarios for the CTUIR. Total non-cancer hazards under the high-exposure scenario are 0.2, under the medium-exposure

scenario are 0.01, and under the low-exposure scenario are 0.005. (Child beef ingestion rates for the CTUIR are not available. Therefore, child non-cancer hazards were not calculated for the CTUIR.) As shown in Table G5-11, total child non-cancer hazards for the Yakama Nation from ingestion of beef are equal to 1 under the high-exposure scenario and are below 1 for the medium- and low-exposure scenarios. Total adult non-cancer hazards are below 1 for each of the high-, medium- and low-exposure scenarios. For both the CTUIR and Yakama Nation, hexavalent chromium is the greatest contributor to total non-cancer hazard in the ingestion of beef pathway and contributes 86 percent, 66 percent, and 98 percent to the total hazard in the high-, medium-, and low-exposure scenarios, respectively.

In summary, cumulative cancer risks barely exceeded 10^{-4} primarily because of technetium-99, orders of magnitude below the cumulative risks due to ingestion of produce. No non-cancer contaminant is a concern.

G5.3.3.3 *Ingestion of Milk from Dairy Cattle*

The following summarizes the results for the milk exposure scenario. As indicated in Tables G5-8 and G5-10 and discussed in Section G3.0, the CTUIR were not evaluated for risks and hazards from ingestion of milk because no milk ingestion rate is available to evaluate exposure for the CTUIR (see discussion in Section G6.2). Therefore, the following paragraphs refer to risks and hazards for the Yakama Nation.

- Cancer risk from radionuclides: As shown in Table G5-9, the total radionuclide cancer risk from ingestion of milk by the Yakama Nation exceeds 1×10^{-4} under the high-exposure scenario, with total cancer risks of 8×10^{-4}. Total cancer risks under the medium-exposure scenario are approximately one order of magnitude lower at 9×10^{-5}, and total cancer risks under the low-exposure scenario are 3×10^{-5}. Technetium-99 is the greatest contributor to total radionuclide cancer risk in the milk ingestion pathway, with cancer risks under the high-, medium-, and low-exposure scenarios of 6×10^{-4}, 8×10^{-5}, and 3×10^{-5}, respectively. Technetium-99 is responsible for approximately 75 percent, 81 percent, and 92 percent of the total radionuclide cancer risk under the high-, medium-, and low-exposure scenarios, respectively. Tritium is the next greatest contributor to total cancer risks using current concentrations and results in a cancer risk of 2×10^{-4} under the high-exposure scenario. Although as noted for plants, tritium concentrations are unlikely to be a risk in 150 years. The contribution from iodine-129 is insignificant relative to the cancer risks from technetium-99 and tritium.

- Cancer risk from nonradionuclides: As shown in Table G5-9, the total nonradionuclide cancer risk from ingestion of milk is below 1×10^{-4} under each of the high-, medium-, and low-exposure scenarios. Total cancer risks under the high-exposure scenario are 2×10^{-5}, under the medium-exposure scenario are 3×10^{-6}, and under the low-exposure scenario are 5×10^{-8}. Carbon tetrachloride contributes the majority of the total cancer risk and is the only single nonradionuclide COPC with a cancer risk greater than the *de minimis* cancer risk level of 1×10^{-6}, with a cancer risk of 2×10^{-5} under the high-exposure scenario and 3×10^{-6} under the medium-exposure scenario. Carbon tetrachloride is responsible for 99 percent of the total nonradionuclide cancer risks under the high- and medium-exposure scenarios and for 73 percent of the total nonradionuclide cancer risks under the low-exposure scenario.

- Non-cancer hazards from nonradionuclides: As shown in Table G5-11, total child and adult non-cancer hazards for the milk pathway are well below the target health goal of 1 under each of the high-, medium-, and low-exposure scenarios. Total child non-cancer hazards are 0.3, 0.05, and 0.002 under the high-, medium-, and low-exposure scenarios, respectively. Total adult non-cancer hazards are 0.2, 0.03, and 0.001 under the high-, medium-, and low-exposure scenarios, respectively. Carbon tetrachloride is the greatest contributor to total non-cancer hazard in the ingestion of dairy products pathway under the high- and medium-exposure scenarios, contributing 94 percent and 96 percent of the total hazards of each scenario, respectively.

In summary, risks from ingesting milk exceeded 10^{-4} (8×10^{-4}) primarily because of technetium-99. No non-cancer contaminant is a health concern.

G5.3.3.4 *Total Native American Exposures through Food Chain Pathways*

It is possible for Native American populations to have combined exposures to groundwater through ingestion of all three food chain pathways: homegrown produce, beef, and milk. Risks and hazards from ingestion of beef and dairy products are much lower (by at least three orders of magnitude) than the risks and hazards calculated from ingestion of homegrown produce. Therefore, the contributions from the ingestion of beef and dairy products pathways to cumulative food chain exposures for the Native American are insignificant relative to the ingestion of homegrown produce exposure pathway. Consequently, the cumulative cancer risks and hazards from the combined exposures are unchanged from the homegrown produce cancer risks to one significant figure. See Figure G5-3 for an illustration of the contribution of the beef and milk ingestion pathways to total risks and hazards relative to the contribution from the ingestion of fruits and vegetables pathways.

G5.3.4 Vapor Intrusion Exposures

Section G2.1 summarized the available soil gas data and noted that its quality was insufficient for quantitative risk assessment because data were collected using field-screening methods and were analyzed as total volatiles. However, these screening data were calibrated to five specific VOCs, including carbon tetrachloride and chloroform, and concentrations are sufficiently high to indicate that vapor concentrations in the 216-Z-1A Tile Field are a possible health concern if a home were ever built above the impacted soil at this site.

The soil gas samples collected from the subsurface beneath the 216-Z-1A Tile Field were compared to residential screening levels (EPA Region 6 HHSLs) in air (EPA, 2008), calculated to be protective of a 1×10^{-6} cancer risk level. Carbon tetrachloride and chloroform both exceeded EPA Region 6 HHSLs by many orders of magnitude. If the concentrations of carbon tetrachloride and chloroform identified in the soil gas are assumed to be the same concentrations as one would find in the basement of a residential home, then these concentrations would correspond to cancer risks approaching 1 (or 100 percent) for carbon tetrachloride and chloroform, which is significantly greater than the target cancer risk level of 1×10^{-4}.

The concentrations of VOCs that are a possible health concern via this pathway (based on 2006 data) are declining over time, because of their removal via the active SVE system, and also because of their natural decrease in environmental media through volatization and breakdown in the environment. Thus, it is not known whether the indoor air pathway would still be a concern 150 years in the future if institutional controls were to fail. In addition, indoor vapor

concentrations are affected by the size of building, ventilation, and type of building construction, and there are many uncertainties in predicting what those parameters might be at a distant future date. Therefore, while this pathway is shown as potentially complete and significant, as shown in Figure G3-2, these risks are only considered to be semi-quantitative because of the simplification of the evaluation process. Regardless of the semi-quantitative nature of this evaluation, vapor concentrations in the 216-Z-1A Tile Field will have to decrease by at least five orders of magnitude over the next 150 years before the vapor intrusion pathway is not a concern.

G5.3.5 Future Groundwater Risks

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

For the three radionuclides that are COPCs in groundwater, concentration decay curves are provided in Figure G5-6 based on the half-lives of the radionuclides. These decay curves are based on the 90th percentile groundwater concentrations. Because the half-lives of iodine-129 and technetium-99 are so long (16 million and 213,000 years, respectively), no change in groundwater concentrations is expected over a 1,000-year period for these radionuclides. Therefore, the cancer risks described in the previous sections for iodine-129 and technetium-99 based on current groundwater concentrations also represent the cancer risks expected up to 1,000 years in the future.

Tritium has a half-life of only 12.26 years. Therefore, the concentration of tritium in the environment decreases rapidly, relative to the other radionuclide COPCs. Thus, the cancer risks described in the previous sections for tritium, based on current groundwater concentrations, significantly overestimate the cancer risks from tritium 150 years into the future. Because the risk calculation equations are linear, cancer risks from tritium decrease proportionally with decreasing groundwater concentrations. Figure G5-7 depicts the decrease in cancer risk based on the 90th percentile groundwater concentrations of tritium expected over the next 150 years. As shown in Figure G5-7, tritium cancer risks from each exposure scenario decrease below the *de minimis* cancer risk level of 1×10^{-6} before 150 years is reached. Therefore, tritium exposures in groundwater are not expected to result in unacceptable cancer risks after 150 years of decay. Based on the slope of the decay curve, cancer risks at 150 years can be predicted. The following summarizes what cancer risks would be in 150 years for each groundwater pathway based on the 90th percentile groundwater concentration of tritium:

- Drinking water: 4×10^{-8}
- Sweatlodge exposures: 2×10^{-8}
- Plant ingestion: 5×10^{-7}.

G5.3.6 Cumulative Risks from Multiple Exposure Pathways

A Native American could potentially build a house at the 216-Z-1A Tile Field or the 216-A-8 Crib and be exposed to contaminants in soil, groundwater, and the food chain at the same time. Risks and hazards from all media exposures should be combined to fully evaluate total health

risks. However, as shown in Tables G5-1 and G5-2, cancer risks from soil exposures at the 216-Z-1A Tile Field approached 100 percent for both the CTUIR and Yakama Nation. Therefore, cancer risks cannot increase any higher at the 216-Z-1A Tile Field, and evaluation of combined exposures from multiple media at the 216-Z-A1 Tile Field will not provide any further useful information. The groundwater OU evaluated in this assessment, 200-ZP-1, does not extend beneath the 216-A-8 Crib. Therefore, a well drilled near that waste site would not have the concentrations and contaminants evaluated in this assessment. Because this assessment did not evaluate the groundwater beneath the 216-A-8 Crib, it is not known what actual groundwater risks would be for someone who lived at that site and drilled a nearby well. If someone lived at the 216-A-8 Crib and drank well water from 200-ZP-1 at the 90th percentile, cumulative risks would approximately double, to 5 x 10^{-1}, as shown in Table G5-12.

G5.4 RISK CHARACTERIZATION SUMMARY AND CONCLUSIONS

Risks were evaluated for the CTUIR and Yakama Nation populations exposed to soil, groundwater, homegrown produce, and beef and dairy cattle impacted with site COPCs. Soil risks were evaluated at two different waste sites, and groundwater risks were evaluated for three concentrations for each COPC, the 25th, 50th, and 90th percentile concentration of the plume. Thus, soil risks are waste-site-specific, and groundwater risks are evaluated for low, medium, and high concentrations independent of location. Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site.

Under current industrial land use and institutional controls, there are no exposures to contaminants and radionuclides in groundwater and soil. Volatile or radiological emissions from the subsurface are insignificant. Institutional controls prevent the use of impacted groundwater, and impacted soil is covered by at least 1.8 m (6 ft) of unimpacted soil. However, in the event that knowledge of the site is lost and institutional controls fail, a future hypothetical Native American scenario was evaluated where humans could come into contact with groundwater and subsurface soil brought to the surface as excavated soil from a basement. This scenario is assumed to occur 150 years in the future. Therefore, radiological concentrations in soil were modeled assuming 150 years of decay (although, as noted above, this assumption does not make a difference for the 216-Z-1A Tile Field site). For 200-ZP-1 groundwater, two of the three radionuclides selected as COPCs (technetium-99 and iodine-129) have very long half-lives, and future concentrations would not be different from current concentrations. However, the third radionuclide groundwater COPC, tritium, will be at concentrations that are below a health concern within 150 years. Specific risk results of the scenario are listed below:

- Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and ingrowth of daughter products. Total risk results for the CTUIR and Yakama Nation are very similar at each site. For the 216-Z-1A Tile Field site, total risks approach 100 percent for the risk drivers plutonium-239, plutonium-240, and americium-241. Risks at future time horizons are not significantly different for plutonium-239 and plutonium-240 from current risks because the half-lives of these contaminants are long. Americium-241 total risks, decline from nearly 1 to 4 x 10^{-2} at 1,000 years. At the 216-A-8 Crib site, total risks are 3 x 10^{-1} with cesium-137 as the risk driver, and total risks at future time horizons are lower (cesium-137 risks drop below 10^{-4}

after approximately 350 years) because of the relatively short half-life of cesium-137 (approximately 30 years). Beginning approximately 350 years in the future, the risk drivers at the 216-A-8 Crib are neptunium-237 and plutonium-239 and risks are in the upper 10^{-5} range.

- Health hazards due to thallium (the only nonradionuclide COPC) in soil were well below the target health goal of 1 for soil ingestion with an HI of 0.3 for CTUIR child exposures, an HI of 0.1 for Yakama Nation child exposures, and an HI of 0.07 for CTUIR and Yakama Nation adult exposures. However, the HI is 30 for adult CTUIR ingestion of produce, and the adult and child ingestion of produce for Yakama Nation HIs are 31 and 30, respectively. Non-cancer hazards are summarized in Table G5-3.

- Table G5-13 summarizes the cumulative cancer risks calculated for the Native American population exposure to groundwater through the tap water, and food chain pathways. Cumulative cancer risks were lower than those estimated for soil but are still well above 10^{-4} for all three groundwater concentration percentiles evaluated. Future Native American populations exposure to groundwater through tap water, and ingestion of fruits and vegetables exceeded a risk level of 10^{-4} under high (90th percentile), medium (50th percentile), and low (25th percentile) exposures. Exposures to groundwater in the sweatlodge exceeded a risk level of 10^{-4} under the high- and medium-exposure scenarios almost entirely because of carbon tetrachloride. Ingestion of beef and milk cancer risks exceed 10^{-4} only under the high-exposure scenario almost entirely because of technetium-99. Figure G5-3 summarizes the relative contribution of each of the pathways evaluated for groundwater to the total cancer risks. As indicated in Figure G5-3, the tap water pathway contributes nearly 40 percent to total cancer risks. As discussed in Section G5.3.3 and as indicated in Figure G5-4, carbon tetrachloride is the greatest risk driver for the tap water and ingestion of fruits and vegetables pathways. However, as discussed further in the uncertainty section, cancer risks are likely underestimated for the sweatlodge pathway, because inhalation exposures of non-volatiles in the sweatlodge were not quantified due to the uncertainty associated with estimating concentrations of non-volatile chemicals in the steam of a sweatlodge. This may be of particular concern for hexavalent chromium, a metal that is generally present in groundwater in the dissolved phase and is known to be a potent carcinogen through the inhalation pathway. This underestimation of cancer risks for the sweatlodge pathway is discussed in the uncertainty section.

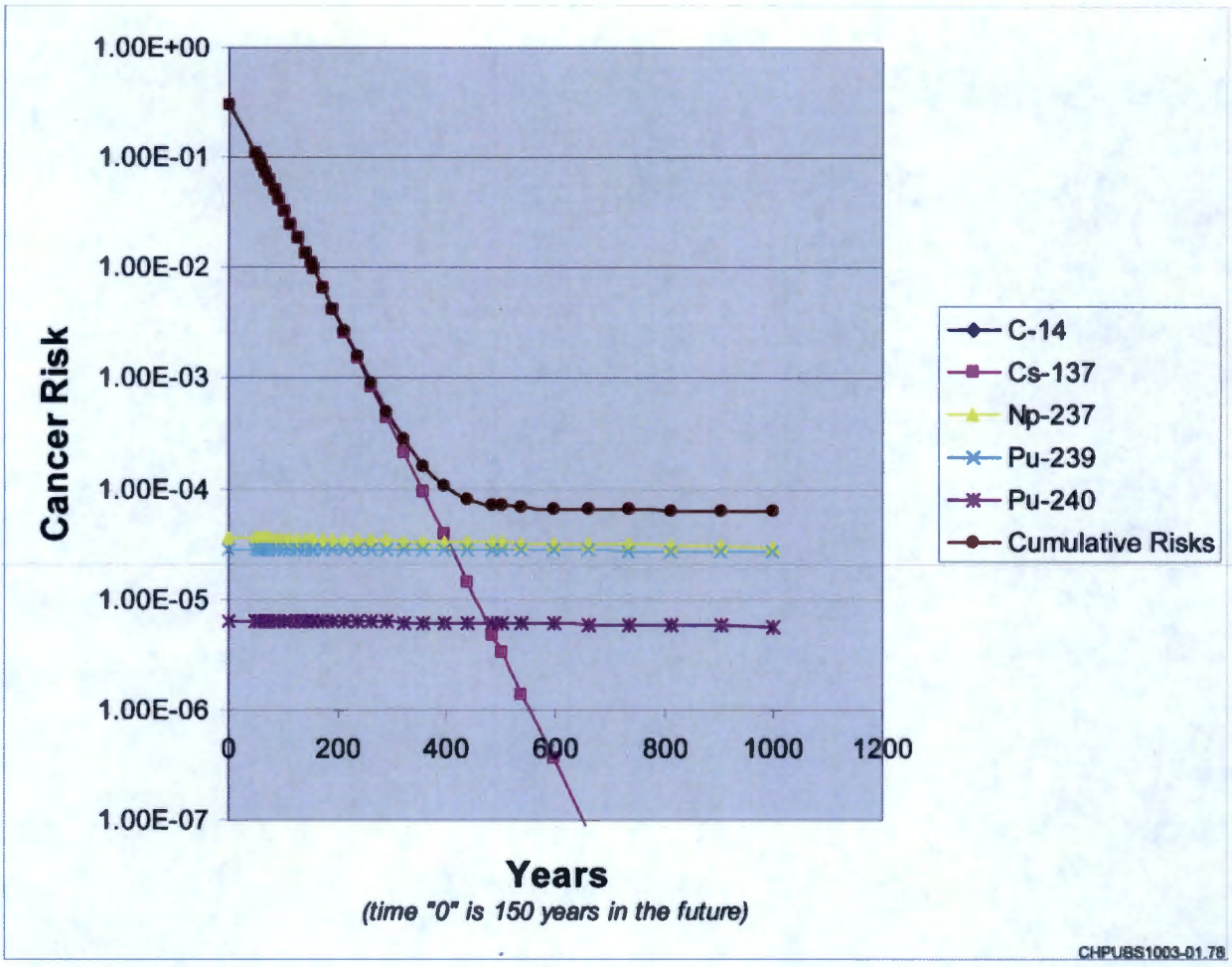
- Table G5-14 summarizes the non-cancer hazards calculated for the Native American population exposures to groundwater through the tap water, sweatlodge, and food chain pathways. Cumulative hazards exceed 1 under the high-, medium-, and low-exposure scenarios. Future Native American population exposure to groundwater through tap water, and ingestion of fruits and vegetables exceeded 1 under the high-, medium-, and low-exposure scenarios. Non-cancer hazards for the sweatlodge pathway are equal to 1 under the high-exposure scenario for the CTUIR and exceed 1 under the high-exposure scenario for the Yakama Nation. Figure G5-3 summarizes the relative contribution of each of the pathways evaluated for groundwater to the total cancer risks and non-cancer hazards. As indicated in Figure G5-3, the ingestion of fruits and vegetables pathway contributes approximately 60 percent to total non-cancer hazards. As discussed in Section G5.3.3 and as indicated in Figure G5-5, carbon tetrachloride is the greatest risk

driver for the tap water and ingestion of fruits and vegetables pathways. However, as discussed above, non-cancer hazards for the sweatlodge scenario are potentially underestimated because inhalation exposures of non-volatiles in the sweatlodge was not quantified, see uncertainty section (Section G6.0) discussion.

- Non-cancer hazards were conservatively summed across contaminants and pathways to derive total hazards. However, EPA guidelines allow for contaminant hazards associated with different toxic endpoints to be considered individually. Of the nine contaminants selected as COPCs in groundwater and evaluated for noncarcinogenic effects, carbon tetrachloride, chloroform, methylene chloride, PCE, and TCE all have some form of effect on the liver (as indicated in Table G4-3). Chromium, nitrate, and uranium do not have toxic endpoints that affect the same organ system. However, carbon tetrachloride drives non-cancer hazards for every pathway by a significant margin. Hexavalent chromium, nitrate, and TCE hazards marginally exceed 1 for the tap water pathway, and hexavalent chromium and TCE hazards marginally exceed 1 for the fruits and vegetables pathway, but only under the high-exposure scenario. Therefore, non-cancer hazards, excluding the sweatlodge pathway, do not increase significantly over hazards calculated for carbon tetrachloride if all contaminant hazards are summed. For the sweatlodge pathway, dermal exposures from hexavalent chromium drives non-cancer hazards by a significant margin. No other COPCs have hazards >1 for the sweatlodge scenario. Therefore, for the sweatlodge pathway, cumulative hazards do not increase significantly over hazards calculated for hexavalent chromium if all contaminant hazards are summed.

In summary, risks from exposure to soils for the CTUIR and Yakama Nation at both sites were at the maximum risk possible, approaching 1 (100 percent), significantly exceeding the 10^{-4} target level, and are a potential health concern should this future scenario ever occur. At the 216-Z-1A Tile Field, soil risks are still approaching 100 percent at 1,000 years. At the 216-A-8 Crib, risks drop below 10^{-4} after 350 years. Non-cancer hazards for thallium in soil exceeded 1 for ingestion of produce by adult CTUIR and by adult and child Yakama Nation populations. Cancer risks from exposures to groundwater through the tap water, sweatlodge, and food chain pathways were lower than soil, but risks also exceeded the 10^{-4} target cancer risk level under the high-, medium-, and low-exposure scenarios. Therefore, the groundwater pathways are also a potential health concern, should groundwater ever be used. Cancer risk from exposure to groundwater for both drinking water and food chain exposures were primarily because of carbon tetrachloride, followed by technetium-99. Carbon tetrachloride was also the primary cancer risk driver for exposures in the sweatlodge. Non-cancer hazards are also driven by carbon tetrachloride, followed by hexavalent chromium. Although reductions in future concentrations were not quantified for carbon tetrachloride in groundwater, its concentrations will be decreasing relatively rapidly over time in comparison to technetium-99, with a half-life of 213,000 years. Therefore, while carbon tetrachloride concentrations represent some of the highest current risks in groundwater, in the future, technetium-99 will likely become the groundwater risk driver.

Figure G5-1. Decline in Risks over Time for Soil Exposures at Site 216-A-8 Crib – CTUIR Exposures.



CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Figure G5-2. Soil Risks by Exposure Pathway in 150 Years.

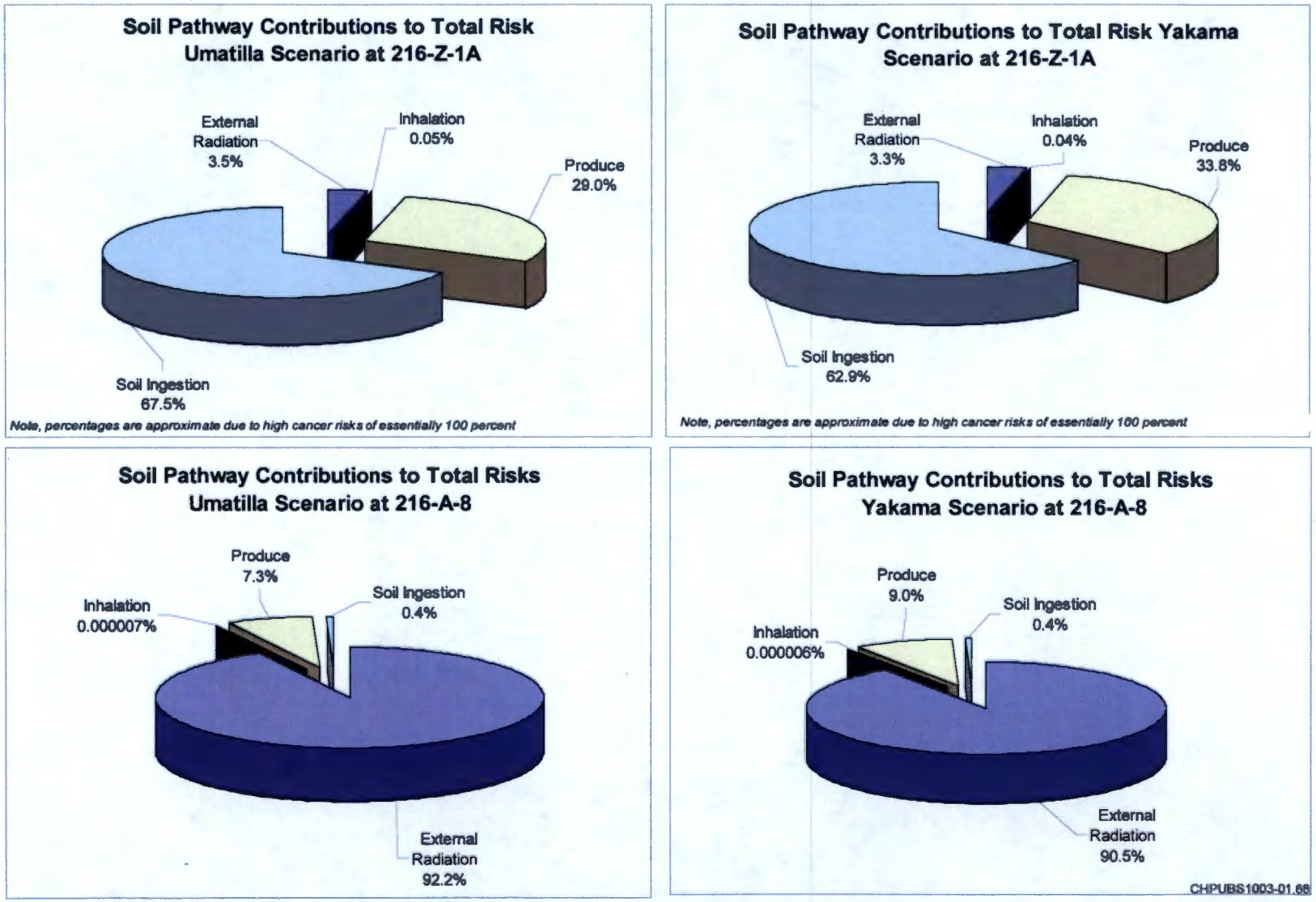
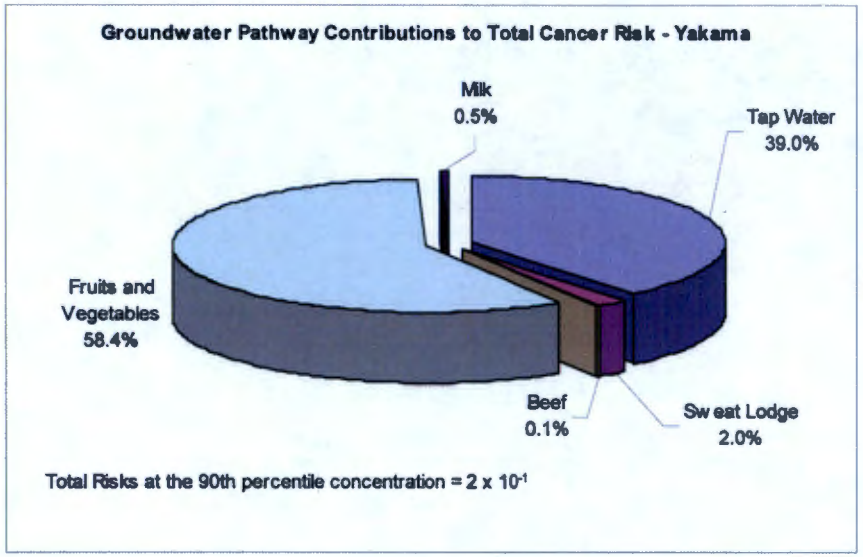
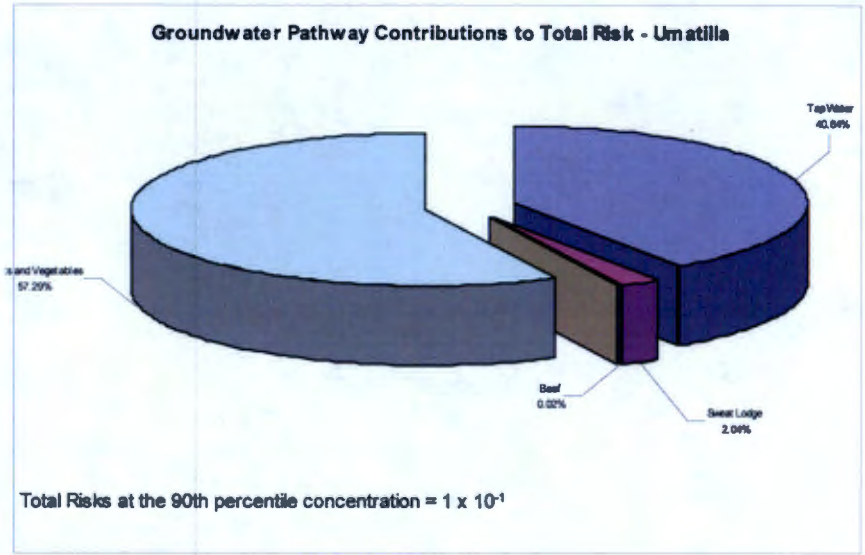
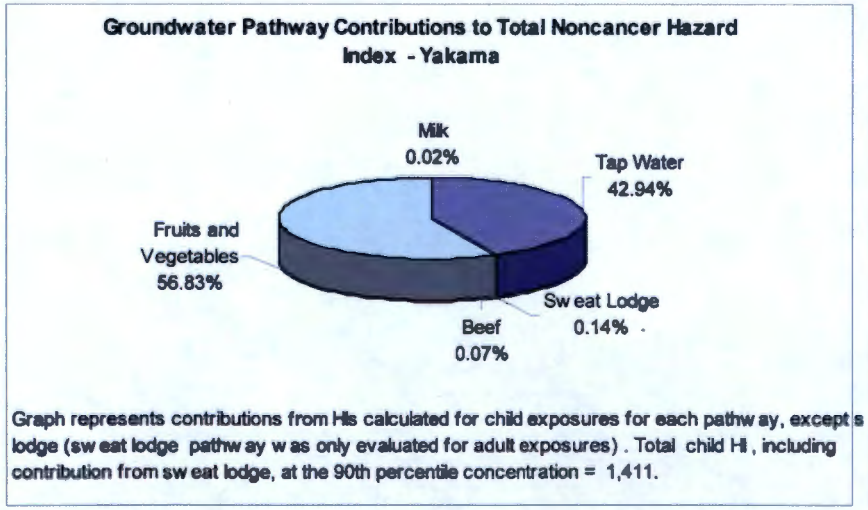


Figure G5-3. Groundwater Risks and Hazards by Exposure Pathway.







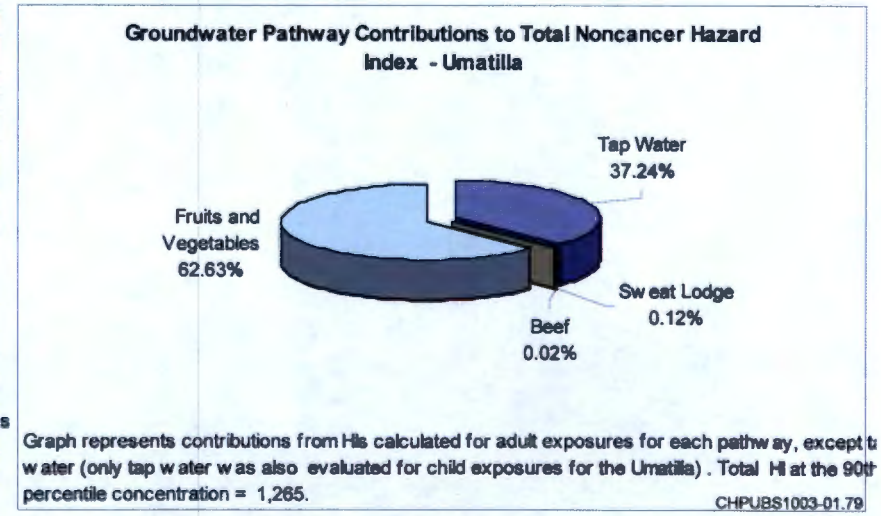
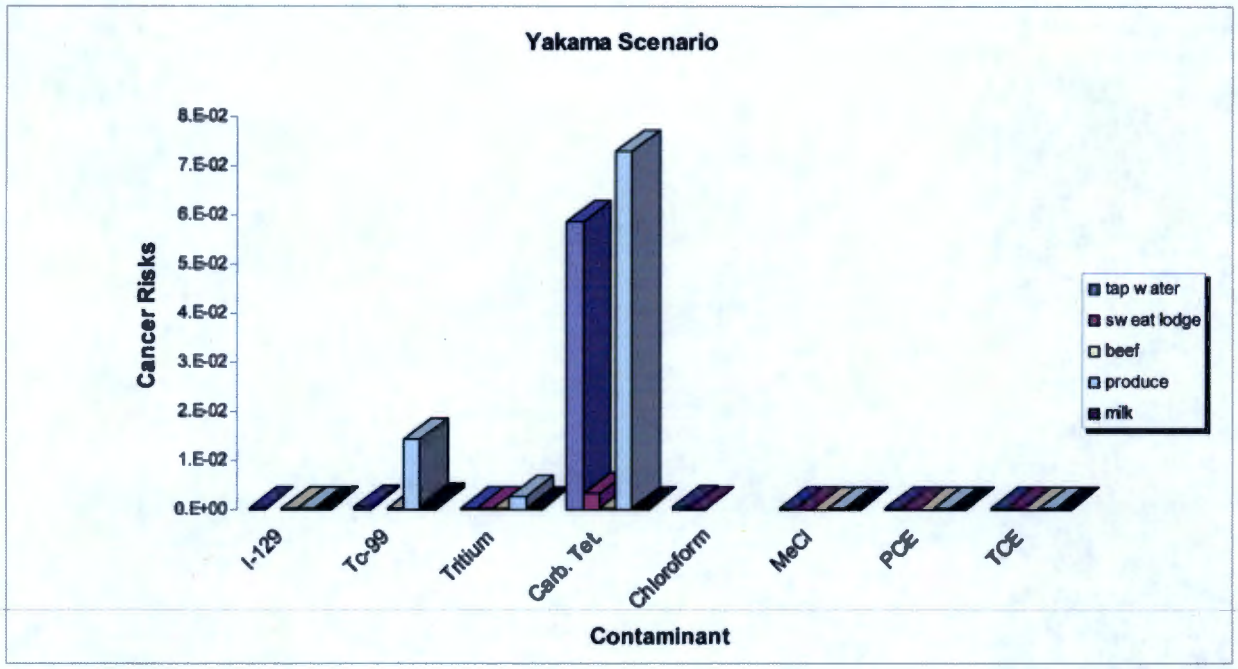
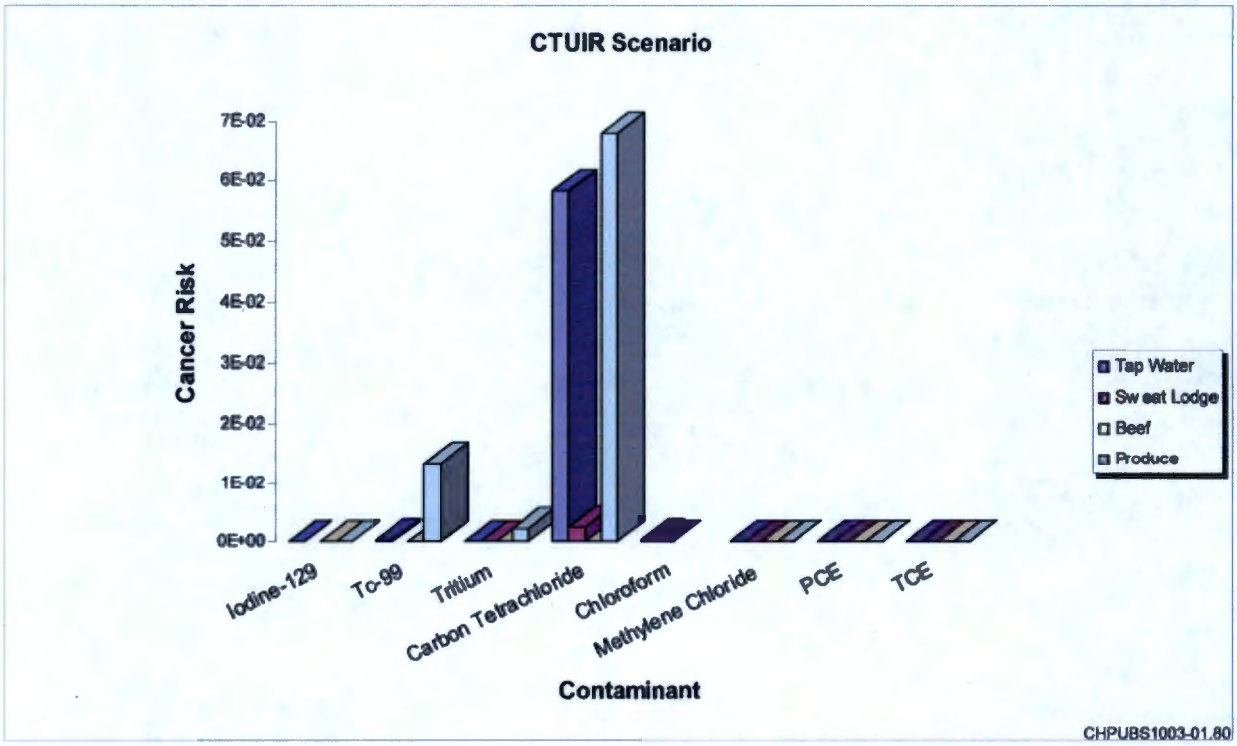


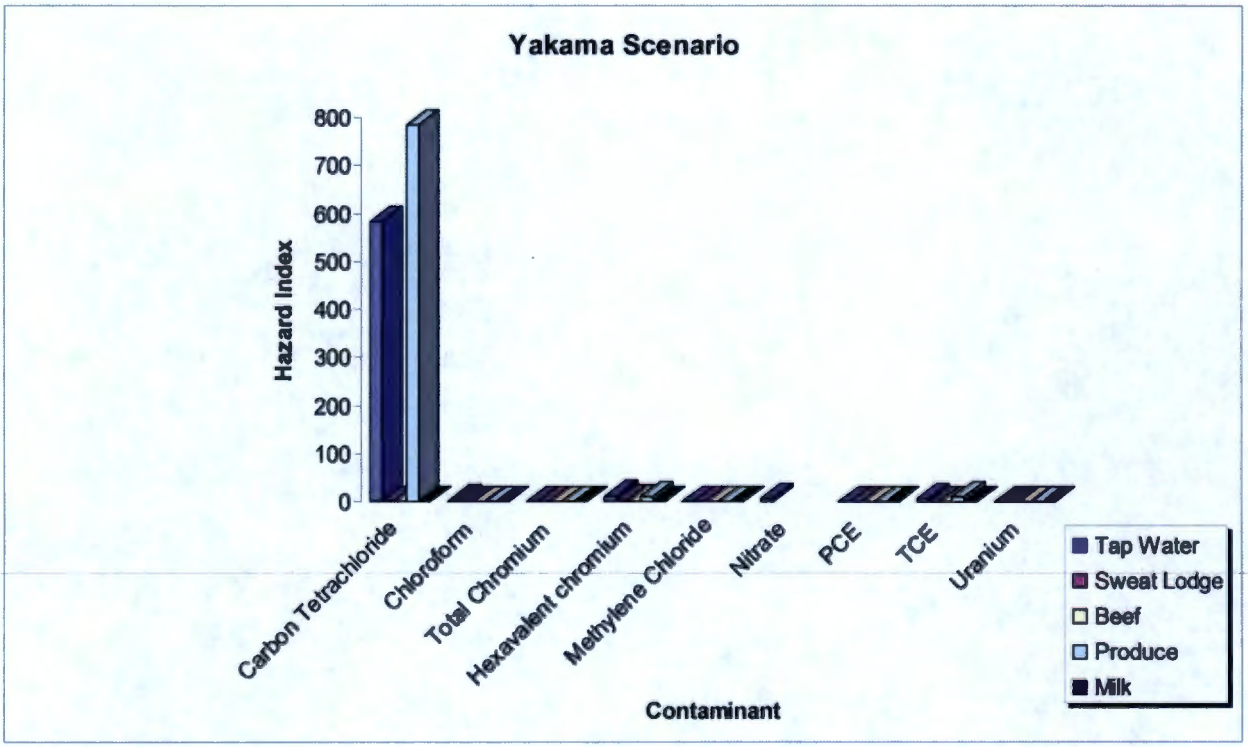
Figure G5-4. Native American 90th Percentile Groundwater Risks by Contaminant and Pathway.

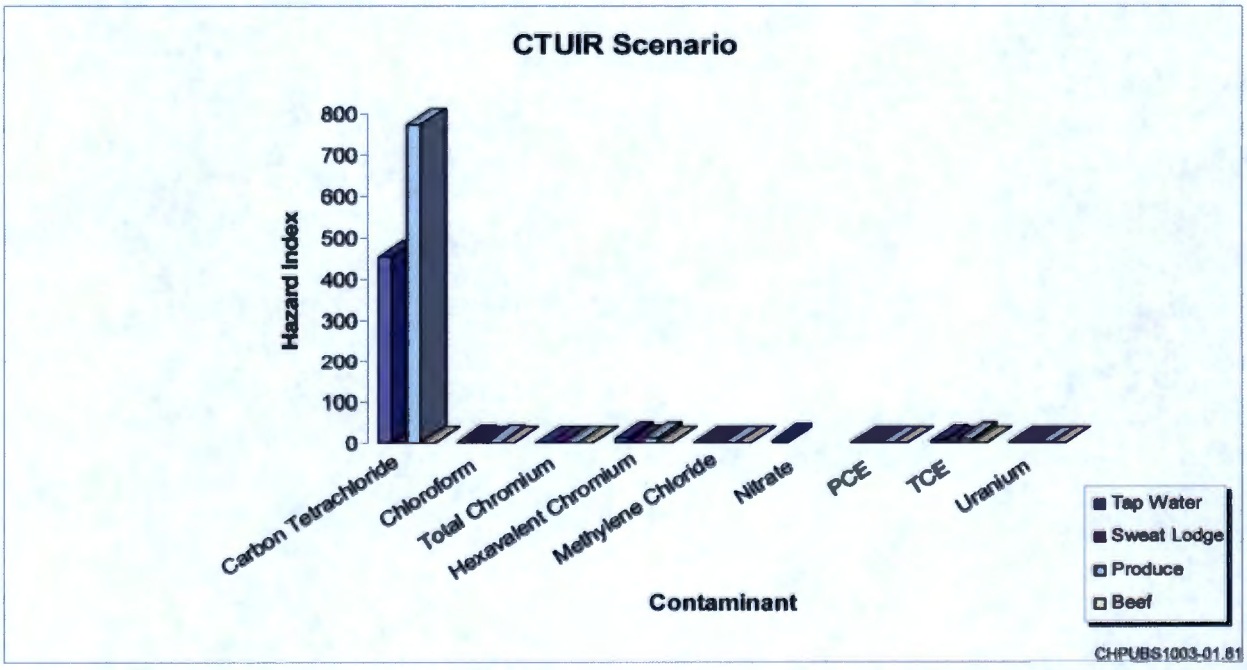




NOTE: Not all exposure pathways are shown for each contaminant because not all contaminants are evaluated for every pathway (e.g., chloroform is not evaluated as a carcinogen in beef or produce because only non-cancer toxicity is a concern when the chemical is ingested).
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Figure G5-5. Native American 90th Percentile Groundwater Hazards by Contaminant and Pathway.





NOTE: Not all exposure pathways are shown for each contaminant because not all contaminants are evaluated for every pathway (i.e., nitrate is not evaluated for its toxicity via the food chain).
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Figure G5-6. Decay of Radionuclide Concentrations in Groundwater.

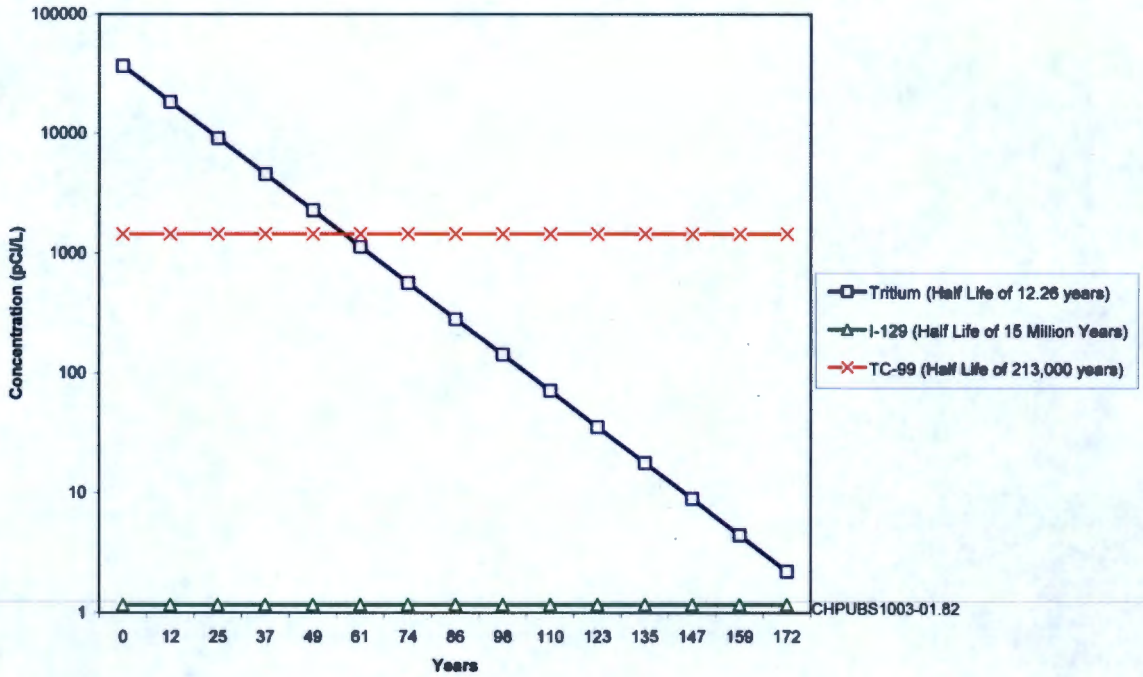


Figure G5-7. Cancer Risks for Yakama Nation from Tritium in Groundwater over Time.

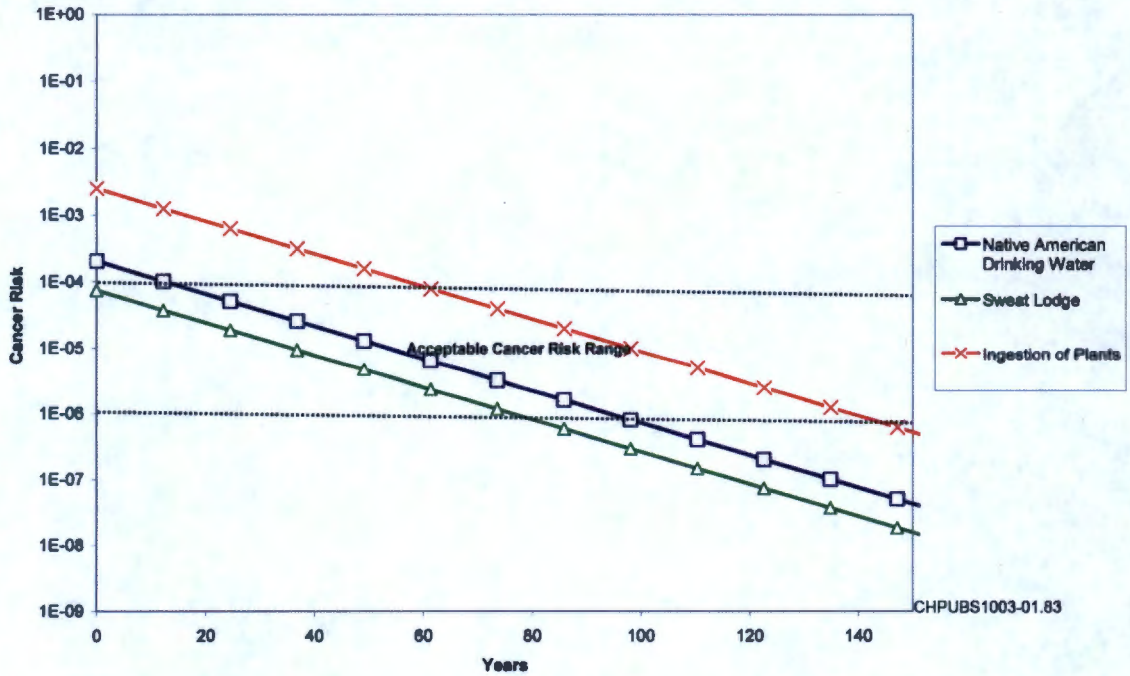


Table G5-1. Summary of Cancer Risks for the Future CTUIR Population from Exposures to Soil.

Radionuclide or Contaminant	Total[a]	Direct-Exposure Pathways				Food Chain Pathway
		Inhalation	Ingestion	External Radiation	Radon	Produce[b]
216-Z-1A Tile Field						
Am-241	1E+00	4E-04	6E-01	5E-01	--	3E-01
Np-237[c]	2E-03	2E-08	4E-05	1E-03	--	4E-04
Pu-239	1E+00	6E-03	1E+00	5E-02	--	1E+00
Pu-240	1E+00	1E-03	9E-01	4E-03	--	6E-01
U-235	2E-05	5E-10	1E-06	2E-05	--	1E-06
U-236	1E-05	3E-09	7E-06	4E-08	--	7E-06
Total[d] – 150 years	**1E+00**	**7E-03**	**1E+00**	**5E-01**	**9E-14**	**1E+00**
216-A-8 Crib						
C-14	4E-31	0E+00	0E+00	0E+00	--	4E-31
Cs-137	3E-01	7E-09	1E-03	3E-01	--	2E-02
Np-237	4E-05	5E-10	8E-07	3E-05	--	7E-06
Pu-239	3E-05	1E-08	2E-05	9E-08	--	9E-06
Pu-240	6E-06	2E-09	5E-06	7E-09	--	2E-06
Ra-228	2E-13	3E-19	7E-15	8E-14	--	1E-13
Tc-99	1E-05	8E-14	5E-09	4E-10	--	1E-05
Th-228	2E-13	2E-18	3E-15	2E-13	--	2E-15
Total – 150 years	**3E-01**	**2E-08**	**1E-03**	**3E-01**	**7E-15**	**2E-02**
Total – 500 years	**7E-05**	**1E-08**	**2E-05**	**3E-05**	**5E-18**	**2E-05**
Total – 1,000 years	**6E-05**	**1E-08**	**2E-05**	**2E-05**	**2E-17**	**2E-05**

NOTES:

1. Shaded values exceed 10^{-4}. For those cancer risk values listed as 1, risks do not equal 1, but are approaching 100 percent.
2. Yakama Nation cancer risk results from soil are very similar to CTUIR results.

[a]Totals are calculated using unrounded values.

[b]Plants grown in impacted soil are the only food chain evaluated for soil. For beef and dairy cattle, exposures are from impacted drinking 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 is a daughter product and was not selected as a contaminant of potential concern.

[d]Totals may add to >1, but are only reported to approximately 1, because risk cannot be greater than or equal to 100 percent.

-- = indicates incomplete pathway or not applicable (i.e., radon column)
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Table G5-2. Summary of Cancer Risks for the Future Yakama Nation Population from Exposures to Soil.

Radionuclide or Contaminant	Total[a]	Direct-Exposure Pathways				Food Chain Pathway
		Inhalation	Ingestion	External Radiation	Radon	Produce[b]
216-Z-1A Tile Field						
Am-241	1E+00	4E-04	6E-01	5E-01	--	4E-01
Np-237[c]	2E-03	2E-08	4E-05	1E-03	--	5E-04
Pu-239	1E+00	5E-03	1E+00	5E-02	--	1E+00
Pu-240	1E+00	1E-03	9E-01	4E-03	--	7E-01
U-235[c]	3E-05	4E-10	1E-06	2E-05	--	1E-06
U-236[c]	2E-05	3E-09	7E-06	4E-08	--	9E-06
Total[d]–150 years	**1E+00**	**6E-03**	**1E+00**	**5E-01**	**8E-14**	**1E+00**
216-A-8 Crib						
C-14	5E-31	0E+00	0E+00	0E+00	--	5E-31
Cs-137	3E-01	6E-09	1E-03	3E-01	--	3E-02
Np-237	4E-05	4E-10	8E-07	3E-05	--	9E-06
Pu-239	3E-05	9E-09	2E-05	9E-08	--	1E-05
Pu-240	6E-06	2E-09	5E-06	7E-09	--	2E-06
Ra-228	2E-13	3E-19	7E-15	8E-14	--	1E-13
Tc-99	1E-05	7E-14	5E-09	4E-10	--	1E-05
Th-228	2E-13	1E-18	3E-15	2E-13	--	2E-15
Total–150 years	**3E-01**	**2E-08**	**1E-03**	**3E-01**	**7E-15**	**3E-02**
Total–500 years	**7E-05**	**1E-08**	**2E-05**	**3E-05**	**5E-18**	**2E-05**
Total–1,000 years	**6E-05**	**1E-08**	**2E-05**	**2E-05**	**2E-17**	**2E-05**

NOTES:

1. Shaded values exceed 10^{-4}. For those cancer risk values listed as 1, risks do not equal 1, but are approaching 100 percent.
2. CTUIR cancer risk results from soil are very similar to Yakama Nation results.

[a]Totals are calculated using unrounded values.

[b]Plants grown in impacted soil are the only food chain evaluated for soil. For beef and dairy cattle, exposures are from impacted drinking 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 is a daughter product and was not selected as a contaminant of potential concern.

[d]Totals may add to >1, but are only reported to approximately 1, because risk cannot be greater than or equal to 100 percent.

-- = indicates incomplete pathway or not applicable (i.e., radon column)
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

Table G5-3. Summary of Non-Cancer Hazards from Exposures to Soil – Future CTUIR and Yakama Nation.

Contaminant	Total[a]		Ingestion		Produce	
	Child HI	Adult HI	Child HI	Adult HI	Child HI	Adult HI
216-A-8 Crib – CTUIR						
Thallium	0.3	30	0.3	0.07	--	30
216-A-8 Crib – Yakama Nation						
Thallium	30	31	0.1	0.07	30	31

NOTE: Shaded values exceed 1.

[a]Totals are calculated using unrounded values.

-- = indicates incomplete pathway or not applicable
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
HI = hazard index

Table G5-4. Cancer Risks from Exposures to Groundwater Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future CTUIR.

COPC	Tap Water			Sweatlodge		
	90th	50th	25th	90th	50th	25th
Radionuclides						
Iodine-129	2E-05	5E-07	(a)	(c)	(c)	(a)
Technetium-99	4E-04	5E-05	2E-05	(c)	(c)	(c)
Tritium	2E-04	2E-05	3E-06	6E-05	6E-06	9E-07
Total	6E-04	7E-05	2E-05	6E-05	6E-05	9E-07
Nonradionuclides						
Carbon tetrachloride	6E-02	1E-02	1E-04	3E-03	4E-04	6E-06
Chloroform	4E-04	1E-04	1E-05	3E-05	9E-06	8E-07
Hexavalent chromium	(b)	(b)	(b)	(c)	(c)	(c)
Methylene chloride	2E-06	1E-07	1E-07	7E-08	5E-09	3E-09
PCE	1E-04	2E-05	8E-06	9E-07	1E-07	6E-08
TCE	3E-05	4E-06	4E-07	1E-06	2E-07	2E-08
Total	**6E-02**	**1E-02**	**2E-04**	**3E-03**	**5E-04**	**7E-06**

NOTE: Shaded values exceed 1×10^{-4}.

(a) Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

(b) Chromium VI is only associated with carcinogenic effects through the inhalation pathway. The inhalation pathway for groundwater used as tap water is only complete for volatile contaminants. Therefore, chromium VI was not evaluated for carcinogenic effects from exposures to groundwater used as tap water.

(c) Inhalation of non-volatile contaminants in the sweatlodge scenario were not evaluated due to uncertainties in the estimation of non-volatile concentrations in airborne steam. Therefore, because iodine-129 and technetium-99 are non-volatile and radionuclides are not evaluated for the dermal pathway, exposures to these radionuclide COPCs in the sweatlodge were not quantified. The nonradionuclide COPC, hexavalent chromium, is only carcinogenic through the inhalation pathway; thus, it was not evaluated in the sweatlodge for the same reasons as noted for iodine-129 and technetium-99. See uncertainty section discussion of this issue.

COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
PCE = tetrachloroethylene
TCE = trichloroethylene

Table G5-5. Cancer Risks from Exposures to Groundwater Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future Yakama Nation.

COPC	Tap Water			Sweatlodge		
	90th	50th	25th	90th	50th	25th
Radionuclides						
I-129	2E-05	5E-07	(a)	(c)	(c)	(a)
Tc-99	4E-04	5E-05	2E-05	(c)	(c)	(c)
Tritium	2E-04	2E-05	3E-06	7E-05	7E-06	1E-06
Total	**6E-04**	**7E-05**	**2E-05**	**7E-05**	**7E-06**	**1E-06**
Nonradionuclides						
Carbon tetrachloride	6E-02	1E-02	1E-04	3E-03	5E-04	7E-06
Chloroform	4E-04	1E-04	1E-05	4E-05	1E-05	1E-06
Hexavalent chromium	(b)	(b)	(b)	(c)	(c)	(c)
Methylene chloride	2E-06	2E-07	1E-07	9E-08	6E-09	4E-09
PCE	1E-04	2E-05	9E-06	1E-06	2E-07	8E-08
TCE	3E-05	4E-06	4E-07	2E-06	2E-07	2E-08
Total	**6E-02**	**1E-02**	**2E-04**	**3E-03**	**6.0E-04**	**8E-06**

NOTE: Shaded values exceed 1×10^{-4}.

(a) Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

(b) Hexavalent chromium is only associated with carcinogenic effects through the inhalation pathway. The inhalation pathway for groundwater used as tap water is only complete for volatile contaminants. Therefore, hexavalent chromium was not evaluated for carcinogenic effects from exposures to groundwater used as tap water.

(c) Inhalation of non-volatile contaminants in the sweatlodge scenario were not evaluated due to uncertainties in the estimation of non-volatile concentrations in airborne steam. Therefore, because iodine-129 and technetium-99 are non-volatile and radionuclides are not evaluated for the dermal pathway, exposures to these radionuclide COPCs in the sweatlodge were not quantified. The nonradionuclide COPC, hexavalent chromium, is only carcinogenic through the inhalation pathway; thus, it was not evaluated in the sweatlodge for the same reasons as noted for iodine-129 and technetium-99. See uncertainty section discussion of this issue.

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

Table G5-6. Non-Cancer Hazards from Exposures to Groundwater Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future CTUIR.

COPC	Tap Water						Sweatlodge		
	90th		50th		25th		90th	50th	25th
	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult
Carbon tetrachloride	453	268	79	47	1	0.6	0.02	0.003	0.00004
Chloroform	0.7	0.5	0.2	0.1	0.02	0.01	0.03	0.008	0.0008
Chromium	0.01	0.006	0.0009	0.0005	0.0003	0.0002	0.002*	0.0001*	0.00005*
Hexavalent chromium	9	5	0.5	0.3	0.3	0.2	1*	0.07*	0.05*
Methylene chloride	0.005	0.003	0.0004	0.0002	0.0002	0.0001	0.00005	0.000004	0.000002
Nitrate	5	3	1	0.8	0.8	0.5	--	--	--
PCE	0.04	0.02	0.005	0.003	0.003	0.002	0.0004	0.00006	0.00003
TCE	4	2	0.6	0.4	0.06	0.04	0.02	0.003	0.0002
Uranium	0.3	0.2	0.04	0.02	0.03	0.02	0.001*	0.0002*	0.0001*
Total	**471**	**279**	**81**	**48**	**2**	**1**	**1**	**0.09**	**0.05**

NOTE: Shaded values exceed 1.

*Inhalation of non-volatile contaminants in the sweatlodge scenario was not evaluated (see uncertainty section discussion). Hazards presented for these chemicals are based only on exposures through the dermal pathway.

--=No toxicity criteria available for this contaminant to quantify non-cancer hazards through this pathway of exposure.
COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
PCE = tetrachloroethylene
TCE = trichloroethylene

Table G5-7. Non-Cancer Hazards from Exposures to Groundwater Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future Yakama Nation.

COPC	Tap Water						Sweatlodge		
	90th		50th		25th		90th	50th	25th
	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult
Carbon tetrachloride	582	268	101	47	1	0.6	0.02	0.004	0.00005
Chloroform	1	0.5	0.3	0.1	0.03	0.01	0.04	0.01	0.0009
Chromium	0.01	0.006	0.001	0.0005	0.0004	0.0002	0.002*	0.0002*	0.00007*
Hexavalent chromium	11	5	0.6	0.3	0.4	0.2	2*	0.1*	0.07*
Methylene chloride	0.007	0.003	0.0005	0.0002	0.0003	0.0001	0.00007	0.000005	0.000003
Nitrate	6	3	2	0.8	1	0.5	--	--	--
PCE	0.05	0.02	0.007	0.003	0.004	0.002	0.0005	0.00007	0.00003
TCE	5	2	0.8	0.4	0.08	0.03	0.02	0.003	0.0003
Uranium	0.3	0.2	0.05	0.02	0.03	0.02	0.002*	0.0003*	0.0002*
Total	**606**	**279**	**105**	**48**	**3**	**1**	**2**	**0.1**	**0.07**

NOTE: Shaded values exceed 1.

[b]Inhalation of non-volatile contaminants in the sweatlodge scenario was not evaluated (see uncertainty section discussion). Hazards presented for these chemicals are based only on exposures through the dermal pathway.

--=No toxicity criteria available for this contaminant to quantify non-cancer hazards through this pathway of exposure.
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

Table G5-8. Cancer Risks from Food Chain Pathways Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future CTUIR.

COPC	Beef			Fruits and Vegetables			Milk[a]		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Radionuclides									
I-129[b]	3E-06	8E-08	--	4E-05	1E-06	--	--		
Tc-99	2E-05	2E-06	8E-07	1E-02	2E-03	5E-04			
Tritium	1E-05	1E-06	1E-07	2E-03	2E-04	3E-05			
Total	**3E-05**	**3E-06**	**9E-07**	**2E-02**	**2E-03**	**6E-04**			
Nonradionuclides									
Carbon tetrachloride	2E-06	3E-07	4E-09	7E-02	1E-02	2E-04	--		
Methylene chloride	8E-12	5E-13	3E-13	1E-05	9E-07	6E-07			
PCE	2E-08	3E-09	2E-09	2E-04	3E-05	1E-05			
TCE	3E-10	5E-11	5E-12	3E-05	5E-06	5E-07			
Total	**2E-06**	**3E-07**	**6E-09**	**7E-02**	**1E-02**	**2E-04**			

NOTE: Shaded values exceed 1 x 10^{-4}.

[a]The CTUIR do not have default milk ingestion rates to evaluate risks from exposure by this pathway.

[b]Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

-- = not applicable
COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
PCE = tetrachloroethylene
TCE = trichloroethylene

Table G5-9. Cancer Risks from Food Chain Pathways Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations—Future Yakama Nation.

COPC	Beef			Fruits and Vegetables			Milk		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Radionuclides									
I-129*	2E-05	4E-07	--	4E-05	1E-06	--	5E-05	1E-06	--
Tc-99	1E-04	1E-05	4E-06	1E-02	2E-03	6E-04	6E-04	8E-05	3E-05
Tritium	6E-05	6E-06	8E-07	2E-03	2E-04	4E-05	2E-04	2E-05	2E-06
Total	**2E-04**	**2E-05**	**5E-06**	**2E-02**	**2E-03**	**6E-04**	**8E-04**	**9E-05**	**3E-05**
Nonradionuclides									
Carbon tetrachloride	1E-05	2E-06	2E-08	7E-02	1E-02	2E-04	2E-05	3E-06	4E-08
Methylene chloride	5E-11	3E-12	2E-12	1E-05	9E-07	6E-07	6E-11	4E-12	3E-12
PCE	1E-07	2E-08	9E-09	2E-04	3E-05	2E-05	2E-07	3E-08	1E-08
TCE	2E-09	3E-10	3E-11	3E-05	5E-06	5E-07	3E-09	4E-10	4E-11
Total	**1E-05**	**2E-06**	**3E-08**	**7E-02**	**1E-02**	**2E-04**	**2E-05**	**3E-06**	**5E-08**

NOTE: Shaded values exceed 1 x 10^{-4}.

*Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

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

Table G5-10. Non-Cancer Hazards from Food Chain Pathways Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future CTUIR.

COPC	Beef			Fruits and Vegetables			Milk[b]
	90th Adult[a]	50th Adult[a]	25th Adult[a]	90th Adult[a]	50th Adult[a]	25th Adult[a]	
Carbon tetrachloride	0.02	0.004	0.00005	774	135	2	--
Chloroform	0.000003	0.0000007	0.00000006	0.8	0.2	0.02	
Chromium	0.0002	0.00001	0.000005	0.01	0.0009	0.0003	
Hexavalent chromium	0.1	0.007	0.005	8	0.5	0.3	
Methylene chloride	0.00000002	0.000000001	0.0000000008	0.03	0.002	0.001	
Nitrate[c]	--	--	--	--	--	--	
PCE	0.000004	0.0000006	0.0000003	0.04	0.006	0.003	
TCE	0.00009	0.00001	0.000001	8	1	0.1	
Uranium	0.0002	0.00003	0.00002	0.3	0.05	0.03	
Total	**0.2**	**0.01**	**0.005**	**792**	**137**	**2**	

NOTE: Shaded values exceed 1.

[a]The CTUIR do not provide child ingestion rates for beef or fruits and vegetables. Therefore, only adult exposures were evaluated.

[b]The CTUIR do not have default milk ingestion rates to evaluate hazards from exposure by this pathway.

[c]Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.

-- = not applicable
COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
PCE = tetrachloroethylene
TCE = trichloroethylene

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1 Table G5-11. Non-Cancer Hazards from Food Chain Pathways Based on the 90th, 50th, and 25th Percentile Groundwater Concentrations – Future Yakama Nation.

COPC	Beef						Fruits and Vegetables						Milk					
	90th		50th		25th		90th		5oth		25th		90th		50th		25th	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Carbon tetrachloride	0.2	0.1	0.03	0.02	0.0004	0.0003	784	835	137	145	2	2	0.3	0.2	0.05	0.03	0.0007	0.000369
Chloroform	0.00002	0.00001	0.000005	0.000004	0.0000005	0.0000004	0.8	0.8	0.2	0.2	0.02	0.02	0.00004	0.00002	0.00001	0.000005	0.0000009	0.0000005
Chromium	0.001	0.001	0.0001	0.00008	0.00004	0.00003	0.01	0.01	0.0009	0.0009	0.0003	0.0003	0.000009	0.000005	0.0000007	0.0000004	0.0000002	0.0000001
Hexavalent chromium	1	0.8	0.05	0.04	0.03	0.03	9	9	0.5	0.5	0.3	0.3	0.007	0.004	0.0004	0.0002	0.0002	0.0001
Methylene chloride	0.0000001	0.0000001	0.000000009	0.000000007	0.000000006	0.000000004	0.03	0.03	0.002	0.002	0.001	0.001	0.0000002	0.0000001	0.00000002	0.000000009	0.00000001	0.000000006
Nitrate*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
PCE	0.00003	0.00002	0.000004	0.000003	0.000002	0.000002	0.04	0.04	0.006	0.006	0.003	0.003	0.00006	0.00003	0.000008	0.000005	0.000004	0.000002
TCE	0.0006	0.0005	0.0001	0.00007	0.000009	0.000007	8	9	1	1	0.1	0.1	0.001	0.0007	0.0002	0.0001	0.00002	0.000009
Uranium	0.001	0.001	0.0002	0.0001	0.0001	0.0001	0.4	0.4	0.05	0.05	0.03	0.04	0.01	0.006	0.002	0.0009	0.001	0.0006
Total	**1**	**0.9**	**0.08**	**0.06**	**0.03**	**0.03**	**802**	**854**	**139**	**148**	**2**	**2**	**0.32**	**0.2**	**0.05**	**0.03**	**0.002**	**0.001**

NOTE: Shaded values exceed 1.

*Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.

-- = not applicable
COPC = contaminant of potential concern
PCE = tetrachloroethylene
TCE = trichloroethylene

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Table G5-12. Cumulative Risks for Future Yakama Nation from Exposures to Soil and Groundwater.

Exposure Pathway	Receptor Age[a]	Contaminant Group	Risk
Total Cancer Risks for Soil at 216-A-8 Crib[b]			
Inhalation	Child/adult	Radionuclides	2E-08
		Nonradionuclides	--
Ingestion	Child/adult	Radionuclides	1E-03
		Nonradionuclides	--
External radiation	Child/adult	Radionuclides	3E-01
Radon	Child/adult	Radionuclides	7E-15
Ingestion of produce	Child/adult	Radionuclides	3E-02
		Cumulative cancer risks for soil	**3E-01**
Total Cancer Risks for Groundwater (High)[b]			
Tap water	Child/adult	Radionuclides	6E-04
		Nonradionuclides	6E-02
Sweatlodge	Adult	Radionuclides	7E-05
		Nonradionuclides	3E-01
Meat (beef)	Child/adult	Radionuclides	2E-04
		Nonradionuclides	1E-05
Ingestion of produce	Child/adult	Radionuclides	2E-02
		Nonradionuclides	7E-02
Milk	Child/adult	Radionuclides	8E-04
		Nonradionuclides	2E-05
		Cumulative cancer risks for groundwater	**2E-01**
		Cumulative risks to Native American at 216-A-8 Crib	**5E-01**

NOTE: Shaded values exceed 1 x 10^{-4}.

[a]The child/adult receptor age corresponds to a lifetime of exposure.

[b]The Yakama Nation cancer risks for 216-A-8 Crib in soil and groundwater high were chosen as examples to provide cumulative risks.

Table G5-13. Summary of Cancer Risks from Native American Exposures to Groundwater.

Exposure Pathway	Nonradionuclide COPCs			Radionuclide COPCs			Cumulative Cancer Risk		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Yakama Nation									
Tap water	6E-02	1E-02	2E-04	6E-04	7E-05	2E-05	6E-02	1E-02	2E-04
Sweatlodge	3E-03	6E-04	8E-06	7E-05	7E-06	1E-06	3E-03	6E-04	9E-06
Beef	1E-05	2E-06	3E-08	2E-04	2E-05	5E-06	2E-04	2E-05	5E-06
Fruits and vegetables	7E-02	1E-02	2E-04	2E-02	2E-03	6E-04	9E-02	1E-02	8E-04
Milk	2E-05	3E-06	5E-08	8E-04	9E-05	3E-05	8E-04	1E-04	3E-05
Total	**1E-01**	**2E-02**	**3E-04**	**2E-02**	**2E-03**	**7E-04**	**2E-01**	**3E-02**	**1E-03**
Confederated Tribes of the Umatilla Indian Reservation (CTUIR)									
Tap water	6E-02	1E-02	2E-04	6E-04	7E-05	2E-05	6E-02	1E-02	2E-04
Sweatlodge	3E-03	5E-04	7E-06	6E-05	6E-06	9E-07	3E-03	5E-04	7E-06
Beef	2E-06	3E-07	6E-09	3E-05	3E-06	9E-07	3E-05	4E-06	9E-07
Fruits and vegetables	7E-02	1E-02	2E-04	2E-02	2E-03	6E-04	8E-02	1E-02	8E-04
Milk*	--			--			--		
Total	**1E-01**	**2E-02**	**3E-04**	**2E-02**	**2E-03**	**6E-04**	**1E-01**	**2E-02**	**9E-04**

NOTE: Shaded values exceed 1×10^{-4}.

*The CTUIR do not have default milk ingestion rates to evaluate risks from exposure by this pathway.

-- = not applicable
COPC = contaminant of potential concern

Table G5-14. Summary of Non-Cancer Hazards from Native American Exposures to Groundwater.

Exposure Pathway	90th		50th		25th	
	Child	Adult	Child	Adult	Child	Adult
Yakama Nation						
Tap water	606	279	105	48	3	1
Sweatlodge[a]	--	2	--	0.1	--	0.07
Beef	1	0.9	0.08	0.06	0.03	0.03
Fruits and vegetables	802	854	139	148	2	2
Milk	0.32	0.2	0.05	0.03	0.002	0.001
Total	**1,410**	**1,136**	**244**	**196**	**5**	**4**
Confederated Tribes of the Umatilla Indian Reservation (CTUIR)						
Tap water	471	279	81	48	2	1
Sweatlodge[a]	--	1	--	0.09	--	0.05
Beef[a]	--	0.2	--	0.01	--	0.0047
Fruits and vegetables[a]	--	792	--	137	--	2
Milk[b]	--		--		--	
Total	**471**	**1,072**	**81**	**185**	**2**	**4**

NOTE: Shaded values exceed 1.
[a]Child exposures were not evaluated for these pathways.
[b]The CTUIR do not have default milk ingestion rates to evaluate hazards from exposure by this pathway.
-- = not applicable

G6.0 UNCERTAINTIES IN RISK ASSESSMENT

The purpose of this risk assessment is to identify potential risks and hazards from exposure to contaminants and radionuclides 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. The sampling strategies for contaminants in this assessment were, in general, designed to prevent underestimation of media concentrations, thus avoiding an underestimation of the risks to public health.

There are uncertainties regarding the quantification of health risks in terms of several assumptions about exposure and toxicity. Based on the conservative assumptions used because of the 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., a 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., a false-negative conclusion). In the risk assessment, uncertainties were handled conservatively (i.e., a 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.

G6.1 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.

G6.1.1 Soil Data and Selection of Contaminants of Potential Concern

Soil data were relatively limited in extent at the 216-Z-1A Tile Field, with 17 samples from six locations over an area of 2,416 m^2 (26,000 ft^2) available for selecting COPCs and identifying the range of potential concentrations of contaminants. However, at the 216-Z-1A Tile Field, sampling locations were biased to identify the maximum concentrations in the vicinity of the known sources. Thus, concentrations of the COPCs were likely biased high, and health risks have not been underestimated. Data at the 216-Z-1A Tile Field were collected in 1979 and 1992 through 1993. While these data are not recent, the radionuclides of concern at this site have

sufficiently long half-lives that concentrations have not been underestimated (with the possible exception of americium-241 [see Section G6.1.1.1]). In the 1992 to 1993 sampling event, there were no detections of VOCs or SVOCs in the top 4.6 m (15 ft); therefore, the lack of more recent data for organic compounds is not a data gap. Because of the large amount of information on Hanford's history and past practices, the available samples were analyzed for contaminants based on the known sources of constituents at the various waste sites. Thus, contaminant classes have not been left out of the COPC selection process.

For the 216-A-8 Crib, data were limited and only collected from a single sampling location selected in the area expected to have the highest concentrations. The area of the 216-A-8 Crib is 1,580 m^2 (17,000 ft^2) and, thus, the single boring provides less certainty on what actual exposure concentrations throughout the entire area of the 216-A-8 Crib might be. While the boring location was selected because that area had historically contained the highest concentrations, the range of concentrations beneath this area has likely not been identified. Therefore, use of the shallowest maximum concentration in the Native American calculations has potentially overestimated risk, unless the concentrations throughout the area for the depth internal of 0 to 4.6 m (0 to 15 ft) are similar to the shallowest maximum concentration in the single sampling location (C4545). The data are representative of exposure if the soil excavation is done at the location of the C4545 boring, but it is not known whether the remainder of the soil beneath this site at the depth interval of 0 to 4.6 m (0 to 15 ft) is as impacted.

The COPCs selected in soil in the baseline HHRA in Appendix A were based on exceedances above health-protective residential screening values derived by EPA to protect the general U.S. population (see Section A2.2 of Appendix A and Section G2.3). Generic screening levels to protect a Native American population are not available. Because Native American exposures are higher than general population exposures for soil and groundwater (i.e., Native Americans ingest two to four times more soil and groundwater per day than EPA assumes for residential exposures), chemicals could be screened out using EPA screening levels, but might be retained if Native American exposures were assumed. Tables G6-1 and G6-2 provide information on potential COPCs if the maximum concentrations in soil were compared to EPA Region 6 residential soil HHSLs at an HI of 0.01 and risk level of 10^{-8}, or to EPA SSLs for radionuclides at a risk level of 10^{-8} (in Section A2.2 of Appendix A, COPCs were selected using residential soil HHSLs at an HI of 0.1 and risk level of 10^{-6}, or EPA SSLs for radionuclides at a risk level of 10^{-6}). For the 216-Z-1A Tile Field (Table G6-1), no additional chemicals would be selected as COPCs in soil, because the additional chemicals that exceeded the more conservative screening values in Table G6-1 are at background levels. For the 216-A-8 Crib (Table G6-2), the following additional chemicals might be selected as COPCs in soil:

- Antimony (non-cancer hazard)
- Chromium (non-cancer hazard in soil)
- Uranium (non-cancer hazard)
- Aroclor-1254 (cancer risk and non-cancer hazard)
- Thorium-230 (cancer risk)
- Tritium (cancer risk).

Because risks and hazards for soil at the 216-A-8 Crib are greater than 10^{-4} and 1 for Native Americans, adding incremental additional contaminants (i.e., Aroclor-1254 or tritium) would not change risk assessment conclusions or identification of risk drivers at the site. Risks for the risk driver at this site, cesium-137, were in the 10^{-1} range for both Native American scenarios.

The addition of low risks from tritium, Aroclor-1254, and thorium-230 would not significantly change the cumulative risk totals. In addition, for Aroclor-1254 and thorium-230, there was only one detected value (although the total sample numbers are only 10 and 4, respectively), and tritium concentrations will be decreasing relatively rapidly because the half-life for tritium is only 12 years. The only non-cancer hazard chemical evaluated at 216-A-8 Crib was thallium, with maximum hazards of around 30 (HI = 31 for Yakama Nation child). The low concentrations of antimony, chromium, uranium, and Aroclor-1254 present in the 216-A-8 Crib soil are unlikely to significantly affect non-cancer HI totals, and those totals already exceed the target health goal of an HI >1.

These results indicate that contaminants that were screened out would not have added significantly to risk or hazard totals (risk drivers have been appropriately selected, and risk assessment conclusions would not change), and health risks have not been significantly underestimated by using standard residential screening procedures for Native American exposures. However, non-cancer HI values would slightly increase if the additional chemicals were added to the risk assessment.

G6.1.1.1 *Plutonium-241 Decay to Americium-241*

Americium-241 is a risk driver at the 216-Z-1A Tile Field. The measured concentrations of americium-241 are the result of ingrowth from decay of plutonium-241 released from the plutonium-production process at the Z Plant sites. Because laboratory analysis for plutonium-241 is difficult, plutonium-241 has not been analyzed at any of the Z Plant sites. Therefore, the americium-241 concentrations measured in 1979 at the 216-Z-1A Tile Field may not be at their maximum concentration, depending on how much plutonium-241 was present and how much has decayed. In Section G.3.2.1.3, maximum americium-241 concentrations were estimated using RESRAD. The resulting plutonium-241 decrease and americium-241 increase were graphed, and estimated maximum americium-241 concentrations from the graphs were used in the risk equations for the 216-Z-1A Tile Field. Different concentration estimates are possible if a different year zero were to be selected, either closer to or further away from the date of the known concentrations. If there is a larger length of time between time zero and the known concentration, the known concentration is closer to maximum and vice versa. For example, if there were 20 years between time zero and the known concentration of americium-241 at the 216-Z-1A Tile Field instead of the 12 years assumed in Section G3.2.1.3, the maximum concentration is only around 40 percent of the known concentration, instead of double the known concentration. Therefore, maximum americium-241 concentrations would only be underestimated if there were actually less time between time zero and the known concentration. Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969. The year zero in RESRAD was estimated to be 1967 for the 216-Z-1A Tile Field. The year zero was close to the end of the disposal period, and, thus, changing year zero to the end of the disposal period (i.e., shortening the time between year zero and the known concentration date) would not result in a significant increase in americium-241 concentrations. The year of the known americium-241 concentration was 1979 for the 216-Z-1A Tile Field (year 12 in RESRAD).

G6.1.1.2 *Method Reporting Limits*

As shown in Table G6-3, laboratory MRLs exceeded screening values for Aroclor-1254 and several radionuclides in soil at the 216-A-8 Crib. The majority of contaminants with this issue were either selected as COPCs and, thus, included in the exposure and risk calculations, or

detected concentrations were at background levels. Because maximum concentrations were used instead of 95 percent UCLs to calculate the exposure concentration, this uncertainty is unlikely to affect the conclusions of the risk assessment.

The contaminants listed in Table G6-3 were never detected and, thus, were not carried through the risk assessment, but all had at least some MRLs above generic residential health-based screening levels. Thus, there is some uncertainty regarding whether these contaminants are actually present at concentrations above a screening level, and there might be additional contaminants on this list if lower health-based screening levels were used in the evaluation. While it is likely that the risk-driver contaminants have been appropriately identified because of their high concentrations and association with a known source, these nondetected constituents remain an area of uncertainty in the risk assessment. However, risks already exceed target health goals.

G6.1.2 Groundwater Data and Selection of Contaminants of Potential Concern

With the exception of hexavalent chromium, the groundwater data set for the COPCs is robust, with 100+ to 800+ samples (depending on the contaminant) available from 107 wells of which more than 40 have been routinely sampled over many years. Therefore, the groundwater data set is adequate for risk assessment. For hexavalent chromium, there were analytical issues (discussed in the 200-ZP-1 Groundwater OU RI report [DOE/RL-2006-24]) that resulted in only 29 valid results available for the risk assessment, compared to 835 samples for total chromium. This amount of information for hexavalent chromium is likely still sufficient for the purposes of risk assessment. It should be noted that although hexavalent chromium and total chromium have been evaluated separately, a significant portion of the chromium present in groundwater is potentially in the hexavalent state. Unlike hexavalent chromium in surface materials (where it typically rapidly reduces to trivalent chromium), chromium in groundwater can be stable in the hexavalent form under certain aquifer conditions (EPA 910/R-98-001; *Laboratory Receive Latest Data on Chromium in Regional Aquifer* [LANL 2006]; *Human Health Fact Sheet for Chromium* [ANL 2005]). As shown in the groundwater percentile table (Table G3-3), the concentrations of hexavalent chromium and total chromium are very similar (see also the groundwater EPC discussion in Appendix A, Section A6.2.3 and Table A6-4). The similarity of the concentrations provides some indication that the majority of the chromium in groundwater at the 200-ZP-1 OU is likely in hexavalent form. Evaluating chromium (total) as hexavalent chromium does not change the results of the risk analysis, because the concentrations appear to be almost the same, with hexavalent chromium concentrations slightly higher. If chromium (total) is mostly in the hexavalent form, it could possibly change the extent of the hexavalent chromium plume. Hexavalent chromium in drinking water exceeded an HI of 1 (HI = 11 for child Yakama Nation tap water exposures and similar for CTUIR) only at the 90th percentile concentration, which makes hexavalent chromium a very minor contaminant when compared to the child HI of 582 for carbon tetrachloride at the 90th percentile concentration (Table G5-7).

G6.1.2.1 *Use of Filtered Versus Unfiltered Data*

Risk assessment guidance (EPA/540/1-89/002) generally requires the use of unfiltered (total) data in the assessment of risks from human exposures to groundwater, particularly for metals, where humans swallow suspended particulate matter as well as the dissolved fraction. While both filtered (dissolved) and unfiltered (total) analyses were performed for the groundwater data, the majority of the groundwater data for metals is based on filtered samples, with the exception

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

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

- Erratic, high levels of chromium are seen in unfiltered samples. This is consistent with relatively coarse (>0.45 μm) particulate matter from the well construction. Unfiltered samples are highly variable and do not show a consistent trend. See Figure G6-1 for filtered versus unfiltered total chromium data for two of the 200-ZP-1 OU wells used in the risk assessment data set.

- Hexavalent chromium (the species of concern from a risk perspective) is highly soluble in groundwater, but trivalent chromium is not. Hexavalent chromium will pass through the filters. Trivalent chromium will be immobile in groundwater, but may be present in particles in unfiltered samples. For the majority of the data set there is a strong 1:1 correlation between filtered chromium measurements and hexavalent chromium, showing that the hexavalent chromium contamination is effectively detected by measuring filtered chromium.

The 90th percentile concentration for hexavalent chromium used in the risk calculations of 203 μg/L is higher than the total chromium 90th percentile value of 130 μg/L. If all the filtered total chromium data were assumed to be hexavalent chromium, the concentrations of hexavalent chromium used in the risk calculations would be lower. Therefore, health risks for hexavalent chromium have not been underestimated. Non-cancer hazards from chromium have probably been underestimated by the use of the filtered data. However, chromium health hazards (see Table G5-6 in Section G5.0) are several orders of magnitude below an HI of 1. Consequently, an increase in chromium concentrations because of using filtered samples would probably not impact the risk assessment conclusions. For the limited paired data available, chromium (total) appears to be about 30 percent higher in unfiltered versus filtered samples.

G6.1.2.2 *COPC Selection for Native American Populations*

The HHRA typically selects COPCs in water for nonradionuclides by comparing maximum concentrations to screening values based on EPA tap water levels, not MCLs or the other levels used in the groundwater RI to select RI COCs. As shown in Table G6-4, if the maximum concentrations in groundwater for nonradionuclides were compared to EPA Region 6 HHSLs for tap water at an HI of 0.01 and risk level of 10^{-8}, the following additional contaminants might be selected as COPCs:

- Barium (non-cancer hazard)
- Manganese (non-cancer hazard)
- Nickel (cancer risk by inhalation, non-cancer hazard by ingestion)
- Strontium (non-cancer hazard)
- Thallium (non-cancer hazard)
- Vanadium (non-cancer hazard)
- Fluoride (non-cancer hazard).

However, adding these contaminants to the risk assessment would not significantly affect the total risks or the conclusions of the report, because risks are already well above target health goals (risks exceed 10^{-2} and HIs exceed 1,000). Non-cancer hazards, however, would potentially increase approximately 5 percent to 10 percent by adding the additional chemicals. The increases would be primarily from thallium, which was only detected in nine of 38 samples.

For radionuclides, there are no generic risk-based levels as there are for nonradionuclides. Radionuclide COPC selection in the groundwater RI was based on exceedances above primary MCLs.

G6.2 UNCERTAINTIES RELATED TO EXPOSURE

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

An analysis of RME for Native American populations cannot be thoroughly conducted because the underlying data used to select the exposure factors in the Yakama Nation and CTUIR scenarios are not publicly available. Thus, the uncertainties with regard to the exposure factors used in this appendix cannot be assessed as to their likelihood to underestimate or overestimate exposures, or whether their exposures represent a "reasonable maximum," except in comparison to regular EPA residential exposure factors for a different human population. Information on some of the uncertainties associated with the residential farmer population and a brief comparison between residential farmer and Native American risks and hazards is included in the

baseline HHRA (Appendix A, Section A6.2). Note that Native American risks were approximately one order of magnitude higher than those for residential farmer in Appendix A, primarily because of the sweatlodge and increased produce and soil ingestion rates for Native Americans. Native American risks were truncated at approximately 100 percent because risks greater than that are not possible. Therefore, in an assessment with lower risks, the differences between Native American and residential farmer scenarios could be greater than one order of magnitude. Table G6-5 presents the differences in exposure factors for the Yakama Nation and CTUIR, as well as the residential farmer inputs used in the baseline HHRA (Appendix A). The soil risk results shown in this table are based on spreading excavated soil from excavating a basement rather than from spreading drill cuttings on the ground surface.

The following subsections address exposure uncertainties that can be evaluated: use of different ProUCL versions in calculating EPCs, food chain exposures not quantified, and the exposure concentrations to qualitatively evaluate where exposures (and, thus, risks) might be overestimated or underestimated.

G6.2.1 Calculation of Exposure Point Concentrations Using Different ProUCL Versions

The 95 percent UCLs used as EPCs in the risk calculations for the baseline HHRA in Appendix A were calculated using ProUCL Version 3. By the time the Native American analysis was conducted, ProUCL Version 4 was available. However, Version 3 was used for the Native American HHRA to maintain consistency with the baseline HHRA. If Version 4 were used to calculate the 95 percent UCLs for the 216-Z-1A Tile Field, the new calculated 95 percent UCLS for site COPCs would be approximately half of 95 percent UCLs calculated using Version 3 (e.g., plutonium-239/240 is 9,166,806, instead of 15,509,199). This large difference in concentrations is because the latest version of ProUCL uses the Kaplan-Meier (KM) method to deal with nondetected samples. This newer methodology has been incorporated into Version 4 because the EPA no longer recommends the former default assumption of using half of the MRL as a surrogate for nondetected samples (*ProUCL Version 4 User Guide* [EPA/600/R-07/038]). Therefore, a different test is selected (in this case, the 95 percent KM Percent Bootstrap instead of 95 percent Chebychev [mean, standard deviation]) and results in a more refined 95 percent UCL. However, because the Native American total risks at the 216-Z-1A Tile Field add up to more than 100 percent, even if the lower 95 percent UCLs were used, risks would still add up to more than 1 (driven by exposure to plutonium-239, soil ingestion).

G6.2.2 Food Chain Exposures Not Quantified

This appendix evaluated food chain exposures only for the portion of the diet that would be homegrown, because the selected waste sites were both too small to support significant amounts of wild game or plants. Therefore, the food chain pathways were assessed using the waste site concentrations, which are local area concentration values. Both the CTUIR and Yakama Nation indicated that a large proportion of their diets could be obtained from "wild" sources. Under a no action scenario, it might be possible for a Native American to live at a waste site (or offsite) and collect wild food over a much larger area of the Hanford Site. Exposures would be evaluated using a broad area concentration value. However, broad-area EPCs have not yet been derived. Therefore, risks due to the potential for wild-caught food to come from a contaminated source cannot be quantified. If wild-caught food were to come from a contaminated area, the food chain risks presented in this appendix would be underestimated. If the proportion of wild-caught food to homegrown food were different than assumed for this appendix (60 percent of meat and milk

homegrown and 50 percent of fruits and vegetables homegrown), then risks could be either overestimated or underestimated depending on the proportion of the diet that is homegrown.

Another potential food chain underestimation is the lack of an evaluation of any dairy products, except milk (e.g., butter and cheese). The Yakama Nation provided Tribal-specific ingestion rates for milk consumption, but not other dairy products. The CTUIR noted that milk was not a significant portion of the Native American diet, except for children, and did not provide milk ingestion rates. If Tribal members will be using the milk from their home dairy cow in other dairy products, the risks from milk ingestion calculated in this assessment could be underestimated. Yakama Nation risks from milk ingestion were driven by carbon tetrachloride and were 2×10^{-5}, an order of magnitude below the target risk level of 10^{-4}. Therefore, milk consumption would have to increase an order of magnitude before health risks would exceed 10^{-4}.

G6.2.3 Sweatlodge Exposure Pathway

As discussed in Section G.5.3 and shown in Figure G5-3, cancer risks from exposure to groundwater in the sweatlodge are the greatest risk driver for total cancer risks from groundwater exposures. However, many uncertainties are associated with quantitative evaluation of this pathway, and although this pathway was quantitatively evaluated, the results should be interpreted with caution. The uncertainties for this pathway are related to assumptions regarding two components of the risk equations: the exposure factors used (frequency and exposure time during sweatlodge use) and the estimation of contaminant concentrations within the sweatlodge. Conservative assumptions were used in the evaluation of exposures during sweatlodge activities for both of these components. Therefore, risks and hazards calculated for this pathway result in a compounding of these conservative assumptions that likely greatly overestimate the actual risks from this pathway. The uncertainties regarding each of these components are discussed in this section.

For the CTUIR, it was assumed that a person at the age of 2 would begin participating in sweatlodge activities and would do so 1 hour/day, every day, for a lifetime. This value was obtained from Harris and Harper, 2004. For the Yakama Nation, it was assumed that a person would spend 2 hours/day in a sweatlodge, 5 days per week, for a lifetime. This 10 hours/week value is twice the average time spent in a sweatlodge of 5 hours/week reported in Ridolfi, 2007. Ridolfi, 2007 reports that the Yakama Nation individuals spend varying amounts of time inside a sweatlodge, and times ranged from a total of 90 minutes/year to as much as 7 hours/sweat. This variation is likely also true for the CTUIR, although Harris and Harper, 2004 did not provide such detail. Therefore, there is a wide range of exposure assumptions that are possible for the sweatlodge scenario. The risk assessment selected the best approximation of what would be expected of an RME. Although there is a great deal of variability associated with the exposure assumptions that could be used in the risk calculations for the sweatlodge scenario, the conclusions of the risk assessment are not likely to change. Table G6-6 summarizes the cancer risks calculated using various exposure assumptions in the sweatlodge scenario. Cancer risks are still above 10^{-4}, until it is assumed that a Native American only spent 15 minutes twice per week in the sweatlodge.

The fundamental assumption surrounding evaluation of the sweatlodge pathway is that COPCs are introduced into the sweatlodge predominantly through the use of groundwater to create steam. The primary pathway of exposure to COPCs in groundwater in the sweatlodge is through

the inhalation pathway. However, it was also assumed that the COPCs could deposit onto the skin with aqueous condensation. Regardless of the pathway, the concentration of COPCs in the steam is the same. The method described by Harris and Harper, 2004 was used to calculate the vapor concentration within the sweatlodge for the groundwater COPCs for the volatile contaminants. The airborne concentration of volatile COPCs in the sweatlodge is dependent primarily upon the temperature of the sweatlodge, the volume of water used during the sweat, and the volume of air space within the sweatlodge. The method and assumptions described by Harris and Harper, 2004 were used to calculate the volatile vaporization factors for the sweatlodge scenario. The vaporization factor is applied to the groundwater concentration to estimate the concentration of COPCs in steam in the sweatlodge. Harris and Harper, 2004 assumed that the sweatlodge temperature would be maintained at 150°F (or 339°K) for the duration of the sweat, the volume of water used would be 4 L (1.1 gal), and the volume of air space within the sweatlodge would be based on an internal diameter of 1.8 m (6 ft), which equates to a radius of 1 m (3.28 ft). The risk assessment selected the best approximation of what would be expected of an RME scenario. Although there is a great deal of variability associated with the assumptions that could be used to calculate the vaporization factor for volatiles, the conclusions of the risk assessment are not likely to change. Table G6-6 summarizes the cancer risks calculated using various exposure assumptions in the sweatlodge scenario. Cancer risks in the sweatlodge decrease to 1×10^{-4} when it is assumed that the radius of the sweatlodge is increased to 1.25 m (4.1 ft) and the exposure frequency is decreased to 15 minutes twice per week.

The method described by Harris and Harper, 2004 for estimating concentrations in sweatlodge of non-volatile compounds are based on the following assumptions:

- Non-volatile compounds become airborne as an aerosol as the water they were carried in vaporizes.
- Once airborne, non-volatile compounds deposit onto solid surfaces with aqueous condensation.
- The ideal gas law can be applied to air and water vapor at the temperature and pressure of the sweatlodge (this assumption does not imply that the non-volatile contaminants are vaporizing).

With these assumptions, the quantity of non-volatile constituents in the air phase is assumed to be limited to that which is carried into the air phase by the volume of liquid water needed to create saturated conditions in the lodge (Harris and Harper, 2004).

The assumption that non-volatile compounds could become airborne as an aerosol is plausible and could result in a potentially complete exposure pathway in the sweatlodge scenario. However, the model used to calculate concentrations of non-volatile contaminants in sweatlodge air does not include any formulation for aerosol resuspension. The Harris and Harper, 2004 model applies the Ideal Gas Law to calculate the quantity of water vapor occupying the volume of the sweatlodge, then multiplies that term by the concentration of the non-volatile contaminant in groundwater. This calculation does not reflect the previously stated conceptual model, "non-volatile compounds become airborne as an aerosol as the water they were carried in vaporizes." No terms are included in the equation that reflects the physical properties associated with entrainment of liquid droplets into the air.

A review of the literature of airborne release fractions associated with different types of releases of hazardous substances (*Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities. Volume 1 – Analysis of Experimental Data* [DOE-HDBK-3010-94]) provides alternate conceptual models for estimating concentrations of non-volatiles in air from resuspension of water droplets. As described in this review, liquid droplets become entrained into the air generated from boiling aqueous solutions by bubbles bursting, splashing, or foaming. The conceptual model for entrainment of water droplets from boiling aqueous solutions includes factors such as liquid and gas surface tensions, density differences between gas and liquid, gas viscosity, and height above the surface of the liquid, which are factors not reflected in the existing sweatlodge model. Several studies are summarized in DOE-HDBK-3010-94 that describe the entrainment of water droplets during the heating of aqueous solutions. These studies subsequently provide a range of airborne resuspension factors. Further evaluation of these studies may provide the basis for a more refined model of non-volatile contaminant concentrations in air from use of contaminated groundwater in sweatlodges.

Therefore, while the airborne concentration is uncertain, it is likely that some non-volatiles will be present in sweatlodge steam (though likely at lower concentrations than the source water) and the sweatlodge risks are potentially underestimated. Sweatlodge inhalation may be a particular concern for hexavalent chromium, which is likely present primarily in the dissolved phase in the water and is thus more likely to be carried into the air in airborne water droplets.

G6.2.4 Potential Exposures to Groundwater During Irrigation

Because it was assumed that groundwater could be used as an irrigation source for homegrown fruits and vegetables and to water cattle, exposures to groundwater during irrigation activities could be possible. However, this pathway was not quantitatively evaluated for this risk assessment for Native American exposures. Although this pathway is potentially complete, it is considered to be insignificant relative to the other pathways evaluated for Native American populations. Exposures during irrigation would be limited to potential dermal exposures and inhalation exposures. The irrigation pathway was evaluated for the residential farmer scenario presented in Appendix A and was found to result in risks and hazards significantly lower than the tap water and food chain pathways, and irrigation exposures were below target health goals for the residential farmer. Exposures to groundwater during irrigation activities for a Native American population are not likely to be significantly different than those assumed for the residential farmer scenario. In addition, Native American risks and hazards from exposures to groundwater through domestic use and in the sweatlodge were significantly high, such that the additional risks and hazards that could be attributed from exposures during irrigation would not significantly increase the total risks and hazards for the Native American populations and the conclusions of the risk assessment would not change.

G6.2.5 Media Not Evaluated

As noted in Section G3.1.1, groundwater plumes from the 200-ZP-1 OU have not reached the nearest surface water body (i.e., the Columbia River), but may reach the river in 75 years or more if actions are not taken. Because of the uncertainties in estimating groundwater concentrations at the river boundary 75 years or more in the future, these potential future pathways were not quantified in the risk assessment, but represent an area of future uncertainty. Active groundwater remediation is occurring and every effort is being made to ensure

contaminants do not reach the Columbia River. However, if some contaminant concentrations did reach the river at some point in the future, depending on the concentrations reaching the river, there could be a human health concern via contact with contaminants in sediment or surface water during gathering activities, or through ingestion of impacted fish.

G6.2.6 Exposure Point Concentrations

Uncertainties in calculating EPCs for groundwater and soil are discussed in the following subsections.

G6.2.6.1 *Groundwater EPCs*

The EPCs for groundwater were the 25th, 50th, and 90th percentile concentrations, selected to evaluate low, medium, and high groundwater concentrations for the groundwater exposure routes. This methodology does not provide risks at a specific location, but results in information on the range of possible risks for each COPC at the current concentrations. Typical risk assessment methodology is to calculate a 95 percent UCL on the mean as the EPC (OSWER 9285.6-10) using data from within the exposure area or, in the case of groundwater, data from one well location. To provide additional information on possible ranges of concentrations in groundwater EPCs for the COPCs, Table G6-7 shows the percentile concentrations used in the risk calculations, as well as the maximum concentrations, average concentrations, and 95 percent UCL concentrations using all of the data. For the risk-driving contaminants in groundwater (carbon tetrachloride and technetium-99), the 90th percentile values are above the 95 percent UCL values because the data set is robust. Generally the larger the data set, the closer the 95 percent UCL is to the arithmetic mean concentration. For example, carbon tetrachloride's 95 percent UCL is 1,491 µg/L and the arithmetic mean is 1,009 µg/L. In contrast, the 90th percentile is 2,900 µg/L. Therefore, 90th percentile values are reasonable upper bounds of concentrations for the purposes of the risk assessment. However, if a well was drilled at the location of the maximum concentration, risks would be significantly underestimated for the COPCs where the maximum concentration is considerably larger than the 90th percentile value (true for eight of the 12 COPCs where the maximum concentration is more than one order of magnitude larger than the 90th percentile). Because only 10 percent of the data exceed the 90th percentile values, these very high concentrations are few and represent a very limited areal extent. In Appendix A, Figures A6-2 and A6-3 present histograms of the carbon tetrachloride and technetium-99 groundwater concentrations. These two figures demonstrate that a large majority of the groundwater concentrations are lower than the 90th percentile values.

G6.2.6.2 *Soil EPCs*

The EPCs for soil were calculated based on a basement size of 5 m by 10 m, a spreading area of 1,500 m^2, and thickness of 0.17 m. If the spreading area increased, the thickness of the contaminated layer would decrease, and soil concentrations would decrease. If the amount of excavated material were increased, spread in a smaller but thicker layer, then concentrations could potentially increase (but overall exposure could decrease, because there could be less exposure if the area was smaller). However, no matter which of these assumptions were adjusted, even those that could significantly reduce soil concentrations, there would still be unacceptable risks at the soil sites because concentrations are so high. For example, at 216-Z-1A Tile Field, if the RESRAD inputs for area were increased to 15,000 m^2 (10 times the area used in the risk assessment), the thickness input was decreased to 0.017 m (one-tenth the thickness used in the

risk assessment), and using the original C_{local} EPCs, total risks would still add up to >1. Therefore, the selection of a larger spreading area, basement size, or thickness would not significantly decrease EPCs to the point that risks would be within the acceptable risk range of 10^{-6} to 10^{-4}.

G6.2.7 Uncertainties in Other Exposure Factors

Soil exposures for the radionuclides used the default exposure assumptions in RESRAD for the Native American risks for some exposure parameters. The RESRAD default assumptions could underestimate or overestimate risk as below:

- RESRAD assumes that only 75 percent of a person's **time will be spent onsite.** Thus, if a Native American spent more or less time on the 1,500-m^2 site, risks would be either underestimate or overestimated for soil ingestion, dust inhalation, and external radiation.
- RESRAD also adjusts the annual **inhalation rate** by time indoors and adjusts dust inhalation accordingly. In this appendix, the annual inhalation rates entered into RESRAD were 10,950 or 9,940 m^3/yr for the CTUIR and Yakama Nation, respectively. RESRAD calculated risks with the inhalation rate adjusted to account for time spent offsite, time indoors (50 percent), and an indoor dust reduction factor (0.4), resulting in inhalation rates of 4,928 and 4,473 m^3/yr for the CTUIR and Yakama Nation, respectively (a 45 percent reduction of annual inhalation rate because of site exposures). This is equivalent to a daily onsite inhalation rate for 365 days/yr of 13.5 m^3/day and 12.3 m^3/yr for the CTUIR and Yakama Nation, respectively. More time spent outdoors versus indoors would increase dust inhalation and thus health risks, and more time indoors would decrease dust inhalation. However, the dust inhalation pathway for radionuclides at these sites is not significant in comparison to soil ingestion, homegrown produce ingestion, and external radiation, with inhalation risks several orders of magnitude below these risk-driving pathways.

G6.3 UNCERTAINTIES IN ASSESSMENT OF TOXICITY

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

G6.3.1 Cancer Toxicity Criteria

Traditionally, EPA has developed toxicity criteria for carcinogens by assuming that all carcinogens are nonthreshold contaminants. However, EPA has recently published revised cancer guidelines (*Guidelines for Carcinogen Risk Assessment* [EPA/630/P-03/001F]) where they have modified their former position of assuming nonthreshold action for all carcinogens. This new guidance emphasizes establishing the specific toxicokinetic mode of action that leads to development of cancer. Toxicity criteria for carcinogens in the U.S. will be developed in the future assuming no threshold only for contaminants that exhibit genotoxic modes of action, or

where the mode of action is not known. However, currently available EPA toxicity criteria for carcinogens were all derived assuming a no-threshold model.

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

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

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

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

The cancer SF values for TCE used in this assessment were those established by the California EPA (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) and are generally being recommended for use in risk assessment. The SFs derived by OEHHA are an SF_i of 0.007 $(mg/kg\text{-}day)^{-1}$ (as presented in *Air Toxics Hot Spots Program Risk Assessment Guidelines: Part II Technical Support Document for Describing Available Cancer Potency Factors* [OEHHA, 2002]) and an oral SF of 0.013 $(mg/kg\text{-}day)^{-1}$ (as presented in *Public Health Goal for Trichloroethylene in Drinking Water* [OEHHA, 1999]).

The OEHHA values are considerably lower than EPA's selection of 0.4 $(mg/kg\text{-}day)^{-1}$ for both oral and inhalation exposures from EPA's *Trichloroethylene Health Risk Assessment: Synthesis and Characterization* (EPA/600/P-01/002A). This document is an external review draft to which EPA is soliciting comments, and the findings are subject to change. However, the findings have sparked controversy in the regulatory and scientific community and have been the subject of a National Academy of Sciences (NAS) review. Until EPA addresses the NAS findings and revises their TCE risk assessment, most jurisdictions in the U.S. are recommending use of the CalEPA values. However, Ecology is currently recommending use of the 0.4 $(mg/kg\text{-}day)^{-1}$ value.

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

Because of the uncertainty surrounding EPA's new proposed SF and because of the criticisms that the health assessment document has received, this risk assessment has selected the CalEPA SF values as more appropriate at this time. If the EPA provisional value were used to estimate TCE risks in groundwater, risks at the 90th percentile go from being within EPA's target risk range of 6×10^{-5} to 2×10^{-3}, which is greater than the upper-bound target risk goal. TCE is currently also identified as a potential hazard in groundwater at the 90th percentile concentration, with a child HI of 14. Thus, there is some uncertainty regarding whether exposure to 90th percentile TCE concentrations in groundwater represents a potential cancer risk in excess of target health goals. If the OEHHA SFs are revised upward and/or the higher EPA SFs are validated, cancer risks from TCE might have been underestimated. However, risks from domestic use of groundwater at 90th percentile concentrations are driven by carbon tetrachloride, with risks of 1×10^{-1}. Increasing TCE risks even to 2×10^{-3} does not make a significant difference in the overall cumulative cancer risks from groundwater.

G6.3.2 Sweatlodge Toxicity

Also potentially contributing to the uncertainty in the hazard/risk calculations for the sweatlodge scenario is the assumption that that COPCs inhaled in steam can result in noncarcinogenic and carcinogenic health effects similar to those associated with inhalation of COPCs in studies cited in the IRIS database for the derivation of RfDi and SFs. For carbon tetrachloride (the only groundwater COPC to exceed a 10^{-4} risk level in the sweatlodge) the inhalation SF (there is no RfC) is derived from studies where the chemical was injected or swallowed by various rodent species, which is a very different exposure scenario than a sweatlodge.

Non-volatile chemicals were not quantitatively evaluated in the sweatlodge. Three of the non-volatiles (hexavalent chromium, iodine-129, and technetium-99) have inhalation toxicity criteria and could potentially be evaluated in sweatlodge steam if an airborne concentration could be estimated. Of these three contaminants, the largest potential risk underestimation is likely hexavalent chromium. Hexavalent chromium compounds are known to be human carcinogens through inhalation based on sufficient evidence of carcinogenicity in humans. Several epidemiological studies have consistently reported an increased risk of lung cancer among chromate production workers, chromate pigment production workers, and chrome plating workers (*Report on Carcinogens* [NTP, 2005]); however, carcinogenic potency can vary depending on the solubility of the hexavalent chromium compound and whether the compound is inhaled in the form of a dust or as a mist/aerosol. The EPA's inhalation SF for hexavalent chromium is derived from a study of chromate production workers, who were exposed primarily to dusts that contained a mixture of soluble and sparingly soluble forms of hexavalent chromium compounds (EPA IRIS database [EPA, 2008]; *Toxicological Review of Hexavalent Chromium in Support of Summary Information on the Integrated Risk Information System* [EPA, 1998]; *Health Assessment Document for Chromium* [EPA-600/8-83-014F]).

Studies with laboratory animals have shown that the sparingly soluble forms of hexavalent chromium (such as calcium or zinc chromate) have greater carcinogenic potency compared with soluble hexavalent chromium compounds ("Occupational Exposure to Hexavalent Chromium" [71 FR 10100]). Potential exposures to hexavalent chromium in groundwater at the Hanford Site are likely to consist entirely of soluble hexavalent chromium. Hexavalent chromium in groundwater originated from the use of sodium dichromate (a soluble form of hexavalent chromium) as an anticorrosion agent in cooling water (Williams et al., 2000). Therefore, the EPA's inhalation SF is based on an exposure (i.e., dusts and a mixture of hexavalent chromium compounds of varying solubility) that is different from the sweatlodge scenario (aerosols and only a soluble hexavalent chromium compound), which creates uncertainties that may affect the characterization of risks from the potential inhalation exposure to hexavalent chromium.

In particular, exposures to slightly soluble hexavalent chromium compounds in dusts appear to result in a stronger carcinogenic response than exposures to soluble hexavalent chromium compounds in mists/aerosols. Epidemiological and industrial hygiene studies show that chromate workers are exposed to soluble sodium dichromate dusts and are also exposed to several slightly soluble chromate compounds in dusts such as calcium chromate (chromate workers) and zinc and strontium chromate (chromate pigment workers). In contrast, chrome plating workers are exposed to soluble dichromates in mists. Studies of the mechanisms of hexavalent chromium toxicity indicate that slightly soluble chromate compounds produce higher concentrations of hexavalent chromium near target cells in the lung, than compared to soluble chromates and this greater concentration likely is the mechanism explaining the stronger carcinogenic effect

(71 FR 10100). Exposures of chrome plating workers, who are exposed to soluble chromates in mists, resulted in lower numbers of workers with lung cancer than in the chromate industry for similar levels of exposure (71 FR 10100). The chrome plating exposure setting is probably a better representation of the potential risks associated with inhalation in the sweatlodge scenario; however, a quantitative risk assessment of the risks is not available for chrome plating workers.

The comparison of exposure settings between chromate workers (the basis for EPA's inhalation SF) and the potential exposure pathway in the sweatlodge suggests that the inhalation SF would overstate cancer risks from hexavalent chromium in the sweatlodge scenario. A direct comparison of risks is not available between chromate workers and chrome plating workers, and this statement of the uncertainty in estimating hexavalent chromium risks is indirectly supported by the comparative toxicology of soluble and slightly soluble hexavalent chromium compounds, coupled with the observation that chromate workers are exposed to both soluble chromates and the more potent slightly soluble chromate compounds.

There may also be potential non-cancer health risks associated with inhalation of hexavalent chromium in the sweatlodge scenario. Assessment of these potential non-cancer risks would involve comparison of estimated concentrations in air with a RfC. The EPA has estimated an RfC for non-cancer effects, based on respiratory effects (nasal irritation and ulcerations) observed in chrome plating workers exposed to soluble hexavalent chromium mists, an exposure setting more similar to the sweatlodge than EPA's SF exposure setting (EPA, 2008). However, the basis of EPA's RfC is derived from a study conducted in 1983 (cited in EPA, 2008) where the toxic endpoint (nasal tissue atrophy) was derived based on an estimate of average exposure concentrations over time. More recent reviews of occupational exposure data conducted by the Occupational Safety and Health Administration (OSHA) (71 FR 10100) concluded that exposure to hexavalent chromium mists is likely associated with nasal damage and asthma; however, they found insufficient data available to support quantitative risk assessment. OSHA indicated the available studies, including the one used by EPA to derive the RfC, were lacking because they did not include an assessment of short-term peak exposures (potentially a key factor in the toxic response), did not account for other potentially important pathways of exposure (i.e., hand-to-nose transfer of hexavalent chromium), or had a cross-sectional study design such that cause and effect relationships between exposure and toxic outcome were difficult to determine (71 FR 10100).

Short-term peak exposures are not included in the sweatlodge modeling equations in Harris and Harper, 2004, which would provide an estimate of the average concentration in sweatlodge air. Nor are short-term peaks included in EPA's RfC, which was based on estimated average concentrations in the workplace. Short-term peak concentrations in air might occur in a sweatlodge. Therefore, while use of groundwater with hexavalent chromium in a sweatlodge scenario might result in potential inhalation exposures, there are uncertainties in what the magnitude of potential inhalation effects might be.

G6.4 UNCERTAINTIES IN RISK CHARACTERIZATION

Radiation is naturally present in the environment, and the radionuclide risks estimated in this assessment have not been corrected to account for natural background radiation. The impacts of background are typically described in terms of radiation dose (millirem, or mrem). For the U.S. as a whole, the average radiation dose from background sources is approximately 300 mrem/yr, and approximately 200 mrem/yr is from radon inhalation. Radon emanates from the uranium

decay series naturally present in soil and rock. (Note that the radon risk levels at all of the waste sites evaluated in this assessment were insignificant [see Attachment G-7]). The remaining 100 mrem of radiation from background sources is from radioactive potassium-40 (present on the Hanford Site), cosmic rays, and direct exposure from radioactive sources in soils and rocks. The background total varies with altitude (cosmic radiation increases with altitude) and geology (determines radon and gamma sources at the ground surface). A general estimate of the range of variability in background radiation dose in the U.S. is from 100 to 1,000 mrem/yr. For comparison, the upper end of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) risk range, which represents the level below which CERCLA decisions are typically made, generally corresponds to dose rates that are less than 15 mrem/yr. Because the radiation health risks in soil at this site are so high for the risk drivers (and this would also be true if dose estimates were calculated), the contribution of background to overall dose for cesium-137, americium-241, plutonium-239, and plutonium-240 in soil is insignificant at both sites.

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

G6.4.1 Uncertainties Associated with Large Estimates of Risk

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

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

A third consideration regarding large dose estimates is the effect of multiple contaminants. Standard risk assessment practice is to add the estimated risks from contaminants. These risk-summation techniques assume intakes of individual substances are small, there are no synergistic or antagonistic interactions among contaminants, and all contaminants have the same effect (i.e.,

cancer). This is an approximation that is useful when the total estimated cancer risk is <0.1. However, because SFs are often 95th percentile estimates of potency, and because upper 95th percentiles of probability distributions are not strictly additive, the total cancer risk estimate may become more of an artificial overestimate as risks from a number of different carcinogens are summed. If the individual contaminant risks are themselves large, or if the number of contaminants is large, or if the assumptions applied are otherwise incorrect, simple risk summation may result in large estimates of cumulative cancer risk that lose some usefulness (EPA/540/1-89/002).

G6.4.2 Uncertainties in Radiation Risk Assessment

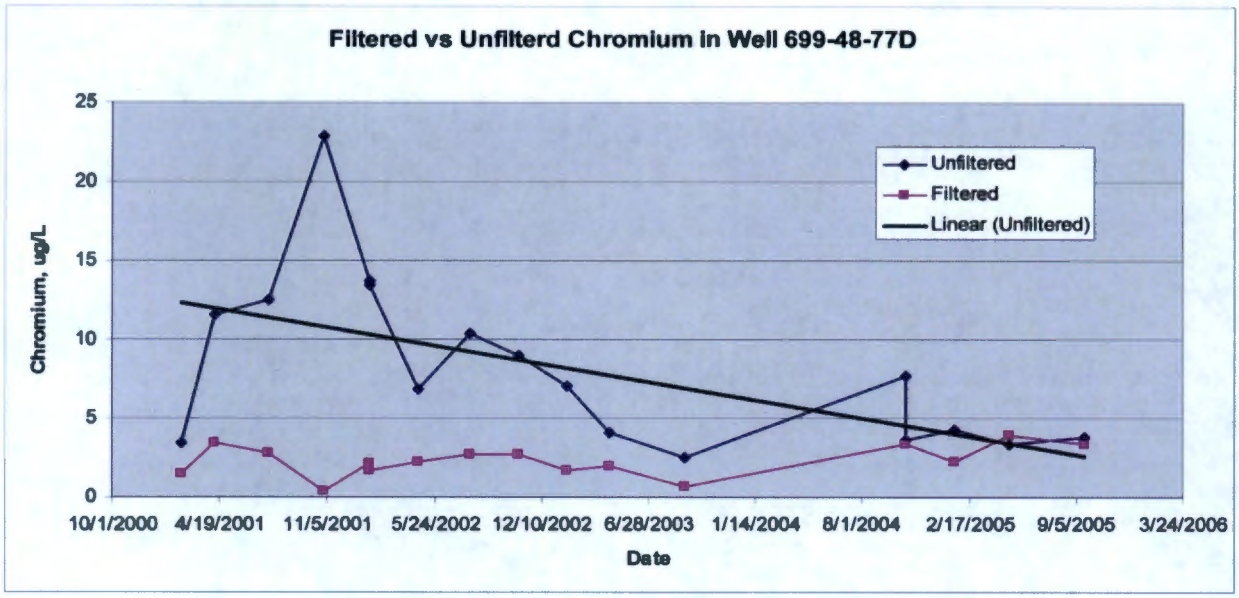
The uncertainties associated with the SFs are likely to be larger than those due to analytical uncertainties. EPA's Federal Guidance Report No. 13 (EPA 402-R-99-001) does not provide specific quantitative uncertainty estimates of the cancer SFs. NCRP Report No. 126, *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection*, examined the question of uncertainties in SFs for the relatively simple case of external radiation exposure to low linear-energy transfer radiation (primarily gamma). The conclusion was that the 90 percent confidence interval was approximately three times higher or lower than the central risk estimate. Since estimates of risk from ingestion of soil and food necessarily involve the added complexity of modeling of physiological processes to determine dose and risk, the uncertainties in this context are likely to be even greater.

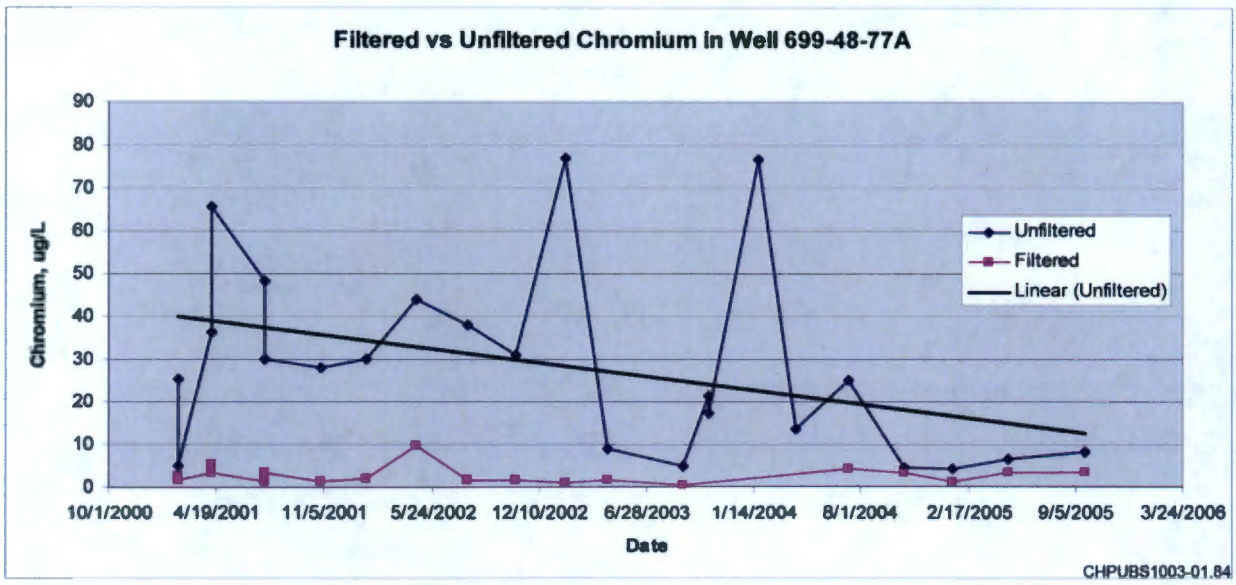
The BEIR V report (BRER-K-97-01-A) addressed the issue of uncertainty in risk estimates for low doses from low linear-energy transfer radiation. The report considered the assumptions inherent in modeling such risks and concluded that at low doses and dose rates, it must be acknowledged that the lower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

G6.5 SUMMARY OF UNCERTAINTY

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

Figure G6-1. Filtered Versus Unfiltered Chromium in Two 200-ZP-1 Groundwater Wells.





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1 Table G6-1. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-Z-1A Tile Field.

CAS No.	Chemical	Unit	Maximum Concentration[a]	Screening Value[b]	Detection Frequency	No. of Samples Exceeding SV	Percent Exceedance (Based on SV)	Magnitude of Exceedance (Based on SV)	Background Value[c]	No. of Samples Exceeding Background	Percent Exceedance (Based on Background)	Magnitude of Exceedance Ratio (Based on Background)	COPC Flag	Rationale Contaminant Deletion or Selection[d]
Metals														
7440-39-3	Barium	mg/kg	160	156.4	17/17	1	6%	1	132	1	6%	1	NO	BCK
7440-70-2	Calcium	mg/kg	230,000	NE	17/17	NA	NA	NA	17,200	2	12%	13	NO	NUT
7440-47-3	Chromium	mg/kg	19	2.11 c	17/17	17	100%	9	18.5	1	6%	1	NO	BCK
7440-48-4	Cobalt	mg/kg	10	9.03 c	17/17	1	6%	1	15.7	0	NA	NA	NO	BCK
7439-89-6	Iron	mg/kg	25,000	547.5	17/17	17	100%	46	32,600	0	NA	NA	NO	BCK
7439-92-1	Lead	mg/kg	11	4	17/17	11	65%	3	10.2	1	6%	1	NO	BCK
7439-95-4	Magnesium	mg/kg	8,900	NE	17/17	NA	NA	NA	7,060	3	18%	1	NO	NUT
7439-96-5	Manganese	mg/kg	760	34.65	17/17	17	100%	22	512	1	6%	1	NO	BCK
7440-02-0	Nickel	mg/kg	16	15.6	12/17	2	12%	1	19.1	0	NA	NA	NO	BCK
7440-09-7	Potassium	mg/kg	2,700	NE	17/17	NA	NA	NA	2,150	4	24%	1	NO	NUT
7440-23-5	Sodium	mg/kg	1,600	NE	17/17	NA	NA	NA	690	2	12%	2	NO	NUT
7440-62-2	Vanadium	mg/kg	59	3.9	16/17	16	94%	15	85.1	0	NA	NA	NO	BCK
Radionuclides														
14596-10-2	**Am-241**	**pCi/g**	**2,590,000**	**0.037 c**	**283/458**	**269**	**59%**	**70,000,000**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
PU-239/240	**Pu-239/240**	**pCi/g**	**38,200,000**	**0.029 c**	**128/423**	**124**	**29%**	**1,317,241,379**	**0.0248**	**124**	**729%**	**1,540,322,581**	**YES**	**EVAL**
Other														
16887-00-6	Chloride	mg/kg	9.4	NE	17/17	NA	NA	NA	100	0	NA	NA	NO	BCK
14265-44-2	Phosphate	mg/kg	1	NE	1/17	NA	NA	NA	0.785	1	6%	1	NO	TXT
14808-79-8	Sulfate	mg/kg	26	NE	17/17	NA	NA	NA	237	0	NA	NA	NO	BCK

NOTE: Bolded chemicals were evaluated as COPCs in the risk assessment.

[a]Minimum/maximum detected concentration. Includes analytical data from 1.5 to 46.6 m (5 to 153 ft) below ground surface.

[b]For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*) and were adjusted to be protective of a non-cancer hazard of 0.01 and a cancer risk of 10^{-8}. 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 of EPA/540-R-00-006, *Soil Screening Guidance for Radionuclides: Technical Background Document*, and are protective of a cancer risk of 10^{-8}. Generic (no accounting for decay) SSLs are from EPA/540-R-00-006).

[c]Background was assumed to be zero for volatile organic compounds. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, and DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, respectively.

[d]Rationale codes:

Selection reason: EVAL = selected as a COPC and evaluated in the risk assessment

Deletion reason: BSL = below screening level

BCK = near or below background levels (magnitude of exceedance over background less than two times)
NUT = essential nutrient
c = cancer
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
HHSL = human health screening level (EPA, 2006)
EPA = U.S. Environmental Protection Agency
mg/kg = milligram per kilogram
NA = not applicable
NE = not established
pCi/g = microcurie per gram
SSL = soil screening level; generic (no accounting for decay) soil screening levels from Table A.1 (EPA/540-R-00-006)

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Table G6-2. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

CAS No.	Chemical	Unit	Maximum Concentration[a]	Screening Value[b]	Detection Frequency	No. of Samples Exceeding SV	Percent Exceedance (Based on SV)	Magnitude of Exceedance Based on SV)	Background Value[c]	No. of Samples Exceeding Background	Percent Exceedance (Based on Background)	Magnitude of Exceedance Ratio Based on Background)	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Metals														
7440-36-0	Antimony	mg/kg	1.9	0.31	3/3	3	100%	6	NE	NA	NA	NA	YES	ASL
7440-38-2	Arsenic	mg/kg	2.45	0.0039 c	10/10	10	100%	628	6.47	0	NA	NA	NO	BCK
7440-69-9	Bismuth	mg/kg	102	NE	3/10	NA	NA	NA	NE	NA	NA	NA	NO	TXT
7440-47-3	Chromium	mg/kg	41.8	2.11 c	10/10	10	100%	20	18.5	1	10%	2	YES	ASL
7439-92-1	Lead	mg/kg	5.34	4	10/10	1	10%	1	10.2	0	NA	NA	NO	BCK
7439-97-6	Mercury	mg/kg	0.3	0.23	2/10	1	10%	1	0.33	0	NA	NA	NO	BCK
7440-02-0	Nickel	mg/kg	30.6	15.6	10/10	2	20%	2	19.1	2	20%	2	NO	BCK
7723-14-0	Phosphorus	mg/kg	1430	NE	10/10	NA	NA	NA	NE	NA	NA	NA	NO	TXT
7440-28-0	**Thallium**	**mg/kg**	**2.5**	**0.055**	**3/3**	**3**	**100%**	**45**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
7440-61-1	Uranium	mg/kg	2.16	0.16	10/10	10	100%	14	NE	NA	NA	NA	YES	ASL
Polychlorinated Biphenyls														
11097-69-1	Aroclor-1254	mg/kg	0.039	0.0022 c	1/10	1	10%	18	0	1	10%	NA	YES	ASL
Semi-Volatile Compounds														
124-18-5	Decane	mg/kg	0.5	NE	1/7	NA	NA	NA	0	1	14%	NA	NO	TXT
629-92-5	Nonadecane	mg/kg	1.6	NE	1/1	NA	NA	NA	0	1	100%	NA	NO	TXT
126-73-8	Tributyl phosphate	mg/kg	0.59	NE	1/10	NA	NA	NA	0	1	10%	NA	NO	TXT
Volatile Compounds														
104-76-7	2-Ethyl-1-hexanol	mg/kg	0.76	NE	1/1	NA	NA	NA	0	1	100%	NA	NO	TXT
Radionuclides														
14762-75-5	**C-14**	**pCi/g**	**89.7**	**0.00128 c**	**3/10**	**3**	**30%**	**70,078**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
10045-97-3	**Cs-137**	**pCi/g**	**877,000**	**0.00044 c**	**10/18**	**10**	**56%**	**1,993,181,818**	**1.05**	**6**	**33%**	**835,238**	**YES**	**EVAL**
14391-16-3	Eu-155	pCi/g	0.055	0.009 c	2/18	2	11%	6	0.054	1	6%	1	NO	BCK
13994-20-2	**Np-237**	**pCi/g**	**3.53**	**0.0014 c**	**2/4**	**2**	**50%**	**2,521**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
PU-239/240	**Pu-239/240**	**pCi/g**	**55.7**	**0.029 c**	**4/10**	**1**	**10%**	**1,921**	**0.0248**	**1**	**10%**	**2246**	**YES**	**EVAL**
13966-00-2	K-40	pCi/g	17.4	0.0014 c	8/10	8	80%	12,429	16.6	1	10%	1	NO	BCK
13982-63-3	Ra-226	pCi/g	0.617	0.00013 c	7/11	7	64%	4,746	0.815	0	NA	NA	NO	BCK
15262-20-1	**Ra-228**	**pCi/g**	**1.1**	**0.00025 c**	**7/11**	**7**	**64%**	**4,400**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
14133-76-7	**Tc-99**	**pCi/g**	**79.6**	**0.000704 c**	**3/10**	**3**	**30%**	**113,068**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
14274-82-9	**Th-228**	**pCi/g**	**0.884**	**0.00014 c**	**9/14**	**9**	**64%**	**6,314**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
14269-63-7	Th-230	pCi/g	0.378	0.039 c	1/4	1	25%	10	NE	NA	NA	NA	YES	ASL
TH-232	Th-232	pCi/g	1.1	0.034 c	9/14	9	64%	32	1.32	0	NA	NA	NO	BCK
10028-17-8	Tritium	pCi/g	8.5	0.045 c	6/10	6	60%	189	NE	NA	NA	NA	YES	ASL
U-233/234	U-233/234	pCi/g	0.36	0.0496 c	9/10	9	90%	7	1.1	0	NA	NA	NO	BCK
15117-96-1	U-235	pCi/g	0.02	0.0021 c	4/20	4	20%	10	0.109	0	NA	NA	NO	BCK
U-238	U-238	pCi/g	0.469	0.0098 c	9/20	9	45%	48	1.06	0	NA	NA	NO	BCK

Table G6-2. Occurrence, Distribution, and Selection of Contaminants of Potential Concern in Soil at the 216-A-8 Crib. (2 sheets)

CAS No.	Chemical	Unit	Maximum Concentration[a]	Screening Value[b]	Detection Frequency	No. of Samples Exceeding SV	Percent Exceedance (Based on SV)	Magnitude of Exceedance (Based on SV)	Background Value[c]	No. of Samples Exceeding Background	Percent Exceedance (Based on Background)	Magnitude of Exceedance Ratio (Based on Background)	COPC Flag	Rationale for Contaminant Deletion or Selection[d]
Other														
16887-00-6	Chloride	mg/kg	5.28	NE	4/10	NA	NA	NA	100	0	NA	NA	NO	BCK
14265-44-2	Phosphate	mg/kg	2.6	NE	3/10	NA	NA	NA	0.785	3	30%	3	NO	TXT
14808-79-8	Sulfate	mg/kg	107	NE	5/10	NA	NA	NA	237	0	NA	NA	NO	BCK

NOTE: Shaded chemicals were not selected as COPCs and may represent an under-estimation of health risks. Bolded chemicals were evaluated as COPCs in the risk assessment.

[a]Minimum/maximum detected concentration. Includes analytical data from 5.79 to 80.62 m (19 to 264.5 ft) below ground surface.

[b]For nonradionuclides, the residential soil screening values are from EPA Region 6 HHSLs (EPA, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*) and were adjusted to be protective of a non-cancer hazard of 0.01 and a cancer risk of 10^{-8}. 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 of EPA/540-R-00-006, *Soil Screening Guidance for Radionuclides: Technical Background Document*, and are protective of a cancer risk of 10-8. Generic (no accounting for decay) SSLs are from EPA/540-R-00-006.

[c]Background is assumed to be zero for SVOCs, PCBs, and VOCs. Radionuclide and nonradionuclide background values were taken from DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, and DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, respectively.

[d]Rationale codes:

Selection reason: ASL = above screening levels and would be selected as a COPC based on the screening values used on this table
EVAL = selected as a COPC and evaluated in the risk assessment

Deletion reason: BCK = near or below background levels (magnitude of exceedance over background less than two times)
TXT = see text for qualitative discussion of these chemicals

c = cancer
CAS = Chemical Abstract Services
COPC = contaminant of potential concern
EPA = U.S. Environmental Protection Agency
HHSL = human health screening level (EPA, 2006)
mg/kg = milligram per kilogram
NA = not applicable
NE = not established
PCB = polychlorinated biphenyl
pCi/g = picocurie per gram
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 G6-3. Contaminants Analyzed in Soil but Never Detected with Method Detection Limits Exceeding Screening Values.

Contaminant	Range of Detection Limits	Risk Assessment Screening Value*	Total Number of Samples (All Nondetect)	Number of Samples Exceeding Screening Value	Frequency of Exceedance (%)
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

*See Section G2.3

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Table G6-4. 200-ZP-1 Contaminants in Groundwater Detected Above One One-Hundredth EPA Region 6 Residential 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														
7429-90-5	Aluminum	µg/L	964	365	150/475	1	<1	3	7.11	150	32	136	NO	FRQ
7440-36-0	Antimony	µg/L	46.2	0.146	46/831	46	6	308	55.1	0	0	0	NO	BCK
7440-38-2	Arsenic	µg/L	14	0.00045	86/105	86	82	31235	7.85	3	3	2	NO	BCK
7440-39-3	Barium	µg/L	362	73	474/475	137	29	5	105	53	11	3	YES	ASL
7440-41-7	Beryllium	µg/L	1.9	0.73	95/475	28	6	3	2.29	0	0	0	NO	BCK
7440-43-9	Cadmium	µg/L	4.7	0.183	15/835	13	2	26	0.916	11	1	5	NO	FRQ
7440-47-3	**Chromium[b]**	**µg/L**	**769**	**1.095**	**688/835**	**683**	**82**	**702**	**2.4**	**649**	**78**	**320**	**YES**	**EVAL**
7440-50-8	Copper	µg/L	51.5	13.56	94/477	7	2	4	0.81	87	18	64	NO	BCK
18540-29-9	**Hexavalent Chromium**	**µg/L**	**730**	**1.095**	**27/29**	**27**	**93**	**667**	**NE**	**NA**	**NA**	**NA**	**YES**	**EVAL**
7439-89-6	Iron	µg/L	2080	256	470/830	26	3	8	570	11	1	4	NO	FRQ
7439-96-5	Manganese	µg/L	2030	17	626/829	96	12	119	38.5	46	6	53	YES	ASL
7439-97-6	Mercury[b]	µg/L	0.12	0.0063	2/216	2	1	19	0.003	2	1	40	NO	FRQ
7440-02-0	Nickel	µg/L	328	7.3	239/829	124	15	45	1.56	235	28	210	YES	ASL
7440-22-4	Silver	µg/L	85	1.825	52/831	40	5	47	5.28	12	1	16	NO	FRQ
7440-24-6	Strontium	µg/L	1570	219	438/438	241	55	7	323	92	21	5	YES	ASL
7440-62-2	Vanadium	µg/L	92.9	1.825	821/829	821	99	51	1.67	821	99	56	YES	ASL
7440-28-0	Thallium	µg/L	57.7	0.02555	9/38	9	24	2258	9.85	8	21	6	YES	ASL
7440-61-1	**Total Uranium[c]**	**µg/L**	**367**	**1.1**	**182/186**	**106**	**57**	**334**	**11.5**	**12**	**7**	**32**	**YES**	**EVAL**
7440-66-6	Zinc	µg/L	747	109.5	304/475	8	2	7	21.8	25	5	34	NO	FRQ
Organics														
79-00-5	1,1,2-Trichloroethane	µg/L	0.086	0.002	1/130	1	1	43	0	1	1	NA	NO	FRQ
107-06-2	1,2-Dichloroethane	µg/L	1	0.0012	8/462	8	2	812	0	8	2	NA	NO	FRQ
106-46-7	1,4-Dichlorobenzene	µg/L	0.22	0.0047	2/128	2	2	47	0	2	2	NA	NO	FRQ
67-64-1	Acetone	µg/L	250	54.75	181/581	11	2	5	0	181	31	NA	NO	FRQ
71-43-2	Benzene	µg/L	0.35	0.004	4/516	4	1	99	0	4	1	NA	NO	FRQ
74-83-9	Bromomethane	µg/L	0.33	0.087	1/3	1	33	4	0	1	33	NA	NO	UNC
56-23-5	**Carbon tetrachloride**	**µg/L**	**5,200**	**0.0017**	**468/574**	**468**	**82**	**3035617**	**0**	**468**	**82**	**NA**	**YES**	**EVAL**
67-66-3	**Chloroform**	**µg/L**	**420**	**0.0017**	**452/581**	**452**	**78**	**251425**	**0**	**457**	**78**	**NA**	**YES**	**EVAL**
75-09-2	**Methylene chloride**	**µg/L**	**740.52**	**0.043**	**132/581**	**132**	**23**	**17320**	**0**	**132**	**23**	**NA**	**YES**	**EVAL**
127-18-4	**Tetrachloroethylene**	**µg/L**	**5**	**0.001**	**191/581**	**191**	**33**	**4784**	**0**	**191**	**33**	**NA**	**YES**	**EVAL**
79-01-6	**Trichloroethylene**	**µg/L**	**36**	**0.0003**	**353/581**	**353**	**61**	**128503**	**0**	**353**	**61**	**NA**	**YES**	**EVAL**
75-69-4	Trichloromonofluoromethane	µg/L	25	12.9	4/42	2	5	2	0	4	10	NA	NO	FRQ, MAG
57-12-5	Cyanide[b]	µg/L	13.4	7.3	5/31	3	10	2	8.41	3	10	2	NO	MAG, BCK
16984-48-8	Fluoride	µg/L	10,500	21.9	908/911	908	100	480	1047	236	26	10	YES	ASL
NO3-N	**Nitrogen in Nitrate[c]**	**µg/L**	**1,720,000**	**580**	**1013/1015**	**942**	**93**	**2966**	**28063**	**373**	**37**	**61**	**YES**	**EVAL**
NO2-N	Nitrogen in Nitrite[c]	µg/L	8,100	37	54/911	38	4	219	629	7	1	13	NO	FRQ

NOTE: Shaded chemicals were not selected as COPCs and may represent an underestimation of health risks. Bolded chemicals were evaluated as COPCs in the risk assessment.

[a]COPC rationale for selection/deletion:

[b]Hexavalent chromium, elemental mercury, and free cyanide screening values are used for chromium, mercury, and cyanide, respectively.

[c]Screening values are from EPA, 2005, *EPA Region III Risk-Based Concentration Tables*.

ASL = above screening levels and would be selected as a COPC using SVs shown in this table, but were not selected using target action levels (TALs). See Section G.2 for description of TALs.
BCK = near or below background levels (magnitude of exceedance over background less than two times)
EVAL = selected as a COPC and evaluated in the risk assessment
FRQ = low frequency of samples exceeding the screening value (<5%)
MAG = low magnitude of exceedance over the screening value (less than two times)
UNC = uncertainty due to lack of data points and no identifiable source found in groundwater of the remedial investigation
COPC = contaminant of potential concern
NA = not applicable
NE = not established
SV = screening values (1/100th of EPA Region 6 [EPA, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*] residential water values)

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Table G6-5. Risk Results and Exposure Factor Comparison of the CTUIR and Yakama Nation with the Residential Farmer Scenario – Groundwater from 200-ZP-1 and Soil from 216-Z-1A.

Exposure Pathway	CTUIR (Intake Rates from Harris and Harper, 2004)		Yakama Nation |(Intake Rates from Ridolfi, 2007)		Residential Farmer (Soil at 216-Z-1A; 90th Percentile Groundwater)	
	Intake Rate	**Risk**	**Intake Rate**	**Risk**	**Intake Rate**	**Risk**
Groundwater Exposure (Radionuclides and Nonradionuclides)						
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
Sweatlodge (inhalation of vapor)	30 m^3/day, 70 years	3E-03	26 m^3/day, 70 years	3E-03	Not evaluated for residential 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% of the wild game/fowl value and the plant ingestion rate is 50% of the wild roots/greens and fruit values in the respective reports as described in detail in Section G3.

[b]Produce (fruits and vegetables) ingestion rates used in the risk assessment calculation are 16% of total per capita consumption rates for high-end consumers (95th percentile) and are 49% of total per capita average consumption rates from EPA/600/R-05/062F, *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).*

Harris and Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*

Ridolfi, 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment*

RESRAD = RESidual RADioactivity (dose model)

Table G6-6. Matrix of Cancer Risks for Sweatlodge Scenario Using Various Sweatlodge and Exposure Assumptions.

Various Sweatlodge Assumptions	Various Exposure Assumptions			
	1 Hour/Day	2 Hours, Twice Per Week	15 Minutes/Day	15 Minutes, Twice Per Week
1-m radius, temperature of 339°K	3E-03	2E-03	7E-04	3E-04
1.25-m radius, temperature of 339°K	1E-03	8E-04	4E-04	1E-04
1-m radius, temperature of 325°K	3E-03	2E-03	7E-04	3E-04
1.25-m radius, temperature of 325°K	1E-03	8E-04	4E-04	1E-04

NOTE: Italicized text identifies assumptions used in the risk calculations.

Table G6-7. Groundwater Percentile Concentrations and Summary Statistics.

COPC	Unit	Percentile Concentrations					Summary Statistics		
		5th	25th	50th	90th	95th	Max.	Mean	95% UCL
Groundwater									
Carbon tetrachloride	µg/L	0.08	6.53	505	2,900	3,300	5,200	1,009	1,491
Chloroform	µg/L	0.04	0.58	6.40	24.00	28.00	420	10	19
Chromium (total)	µg/L	1.7	3.6	10.3	130	235.2	769	50	74
Hexavalent chromium (chromium [VI])	µg/L	2.1	7.00	10.90	203.40	311.00	730	74.9	176
Methylene chloride	µg/L	0.06	0.12	0.185	2.734	25	740.52	8	20
Nitrate	µg/L	326	14,000	21,900	81,050	156,000	1,720,000	44,750	63,187
PCE	µg/L	0.05	0.18	0.36	2.5	12.375	60	2.5	4
TCE	µg/L	0.07	0.155	1.7	10.9	15	60	4.7	7
Uranium	µg/L	0.1545	0.808	1.18	8.295	33.1	367	10.14	29.45
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	1442	3913	27400	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

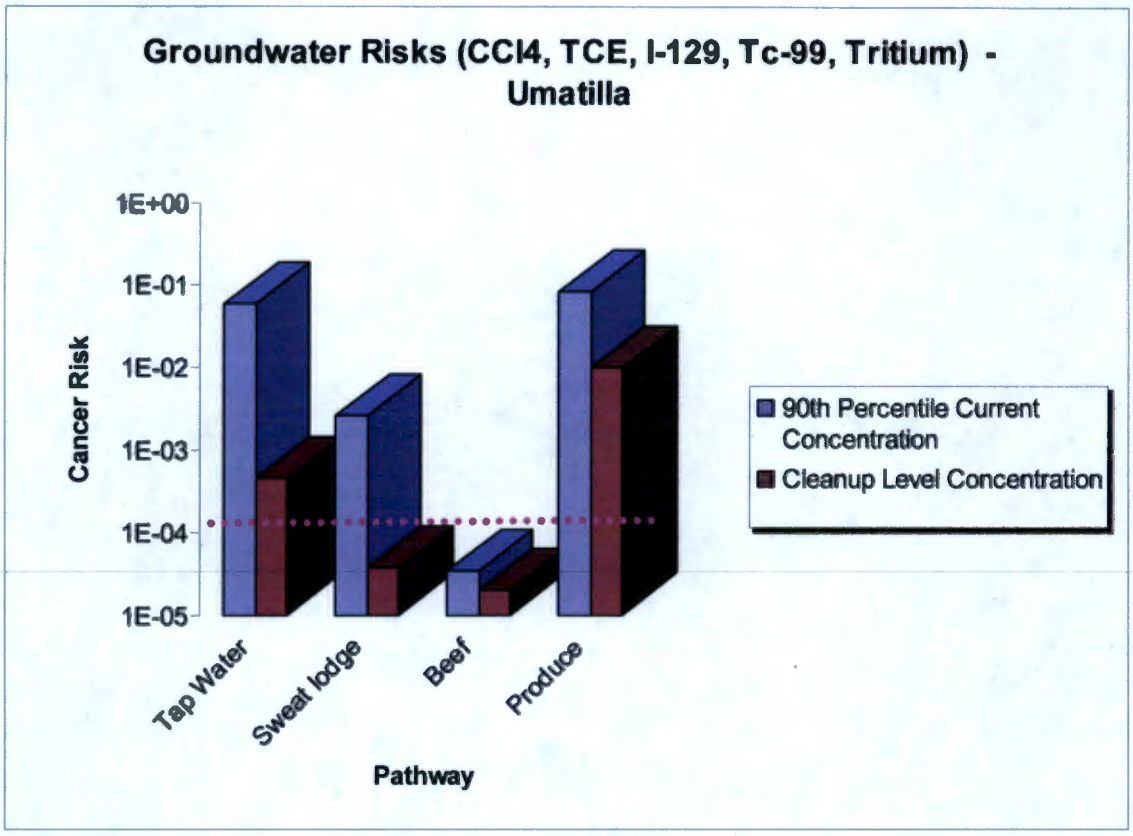
G7.0 GROUNDWATER RESIDUAL RISK

In 150 years, groundwater concentrations are anticipated to be considerably lower than they are today due to planned groundwater remediation activities. In order to estimate what potential future risks might be for the Native American scenarios if groundwater concentrations met the proposed cleanup levels presented in the FS report, calculations of risks and hazards were estimated for the following eight COPCs: carbon tetrachloride, chromium (total), hexavalent chromium, iodine-129, nitrate, TCE, technetium-99, and tritium.

The risk results presented in Section G5.0 indicated the highest cancer risks based on current concentrations were due to carbon tetrachloride and technetium-99 and, other than carbon tetrachloride, hexavalent chromium had the highest non-cancer hazards. Figures G7-1 and G7-2 show a comparison between the 90th percentile risks and hazards derived from current site groundwater concentrations, and the residual risks and hazards calculated for proposed cleanup levels for both the CTUIR and Yakama Nation to assess potential risk reductions from current concentrations (total values inclusive of the eight COPCs). Tables G7-1 and G7-2 provide summaries of the residual risks and hazards calculated at the proposed cleanup levels. If groundwater concentrations were at the proposed cleanup level for carbon tetrachloride, risks would be reduced to within EPA's acceptable range of 10^{-6} to 10^{-4} for all evaluated pathways for both the CTUIR and Yakama Nation scenarios. However, the CTUIR and Yakama Nation non-cancer hazards would remain slightly above 1 for the tap water and produce pathways due to hexavalent chromium and TCE. If groundwater concentrations were at the proposed cleanup level for technetium-99, risks exceed 10^{-4} for tap water and produce for both the CTUIR and Yakama Nation scenarios, and cancer risks also exceed 10-^{4} for the Yakama Nation milk pathway (due to technetium-99). Also, tritium risks exceed 10^{-4} for produce for both the CTUIR and Yakama Nation scenarios; however, as noted in Section G5.0, tritium risks will be acceptable in 150 years due to tritium decay (half-life of 12 years). Detailed proposed cleanup level concentration risk and hazards for both scenarios and the eight COPCs are included in Attachment G8. Reduction of concentrations of the main risk driver, carbon tetrachloride, to proposed cleanup levels clearly would significantly reduce potential Native American risks. Risk and hazard reduction for the other groundwater COPCs would likewise be significantly reduced.

At this point, residual risks for soil COPCs were not calculated because proposed cleanup plans for the soil sites are still in progress. As with groundwater, it is anticipated that soil concentrations would be lower, at least for the nonradionuclides, and therefore risks would be lower in 150 years. Radionuclide concentrations are likely to also be lower depending on the final determination of soil remedies and cleanup levels.

Figure G7-1. Summary of CTUIR Risks and Hazards for the 90th Percentile and Proposed Cleanup Level Groundwater Concentrations.



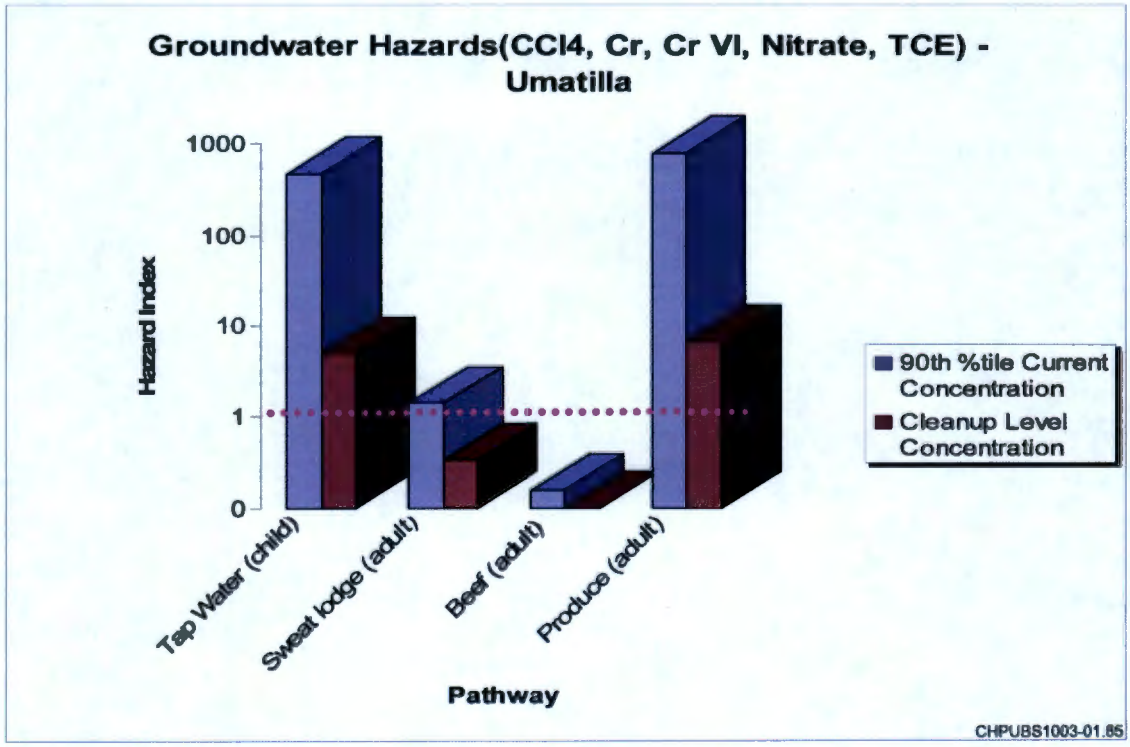
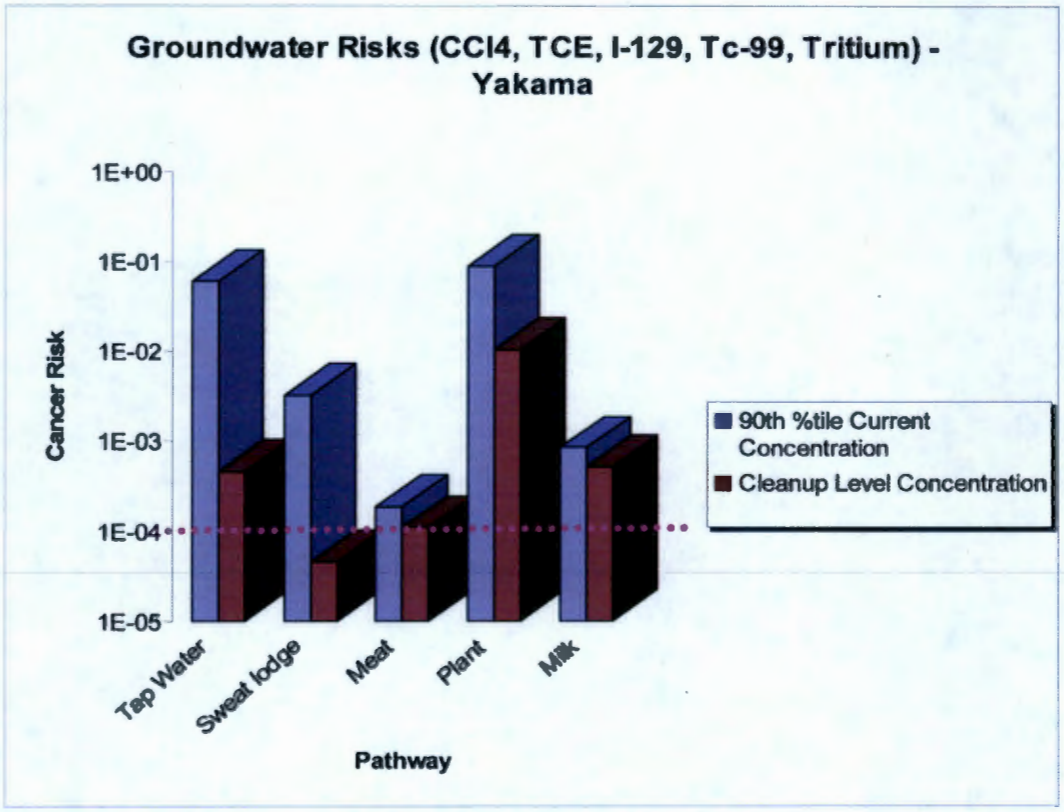


Figure G7-2. Summary of Yakama Nation Risks and Hazards for the 90th Percentile and Proposed Cleanup Level Groundwater Concentrations.



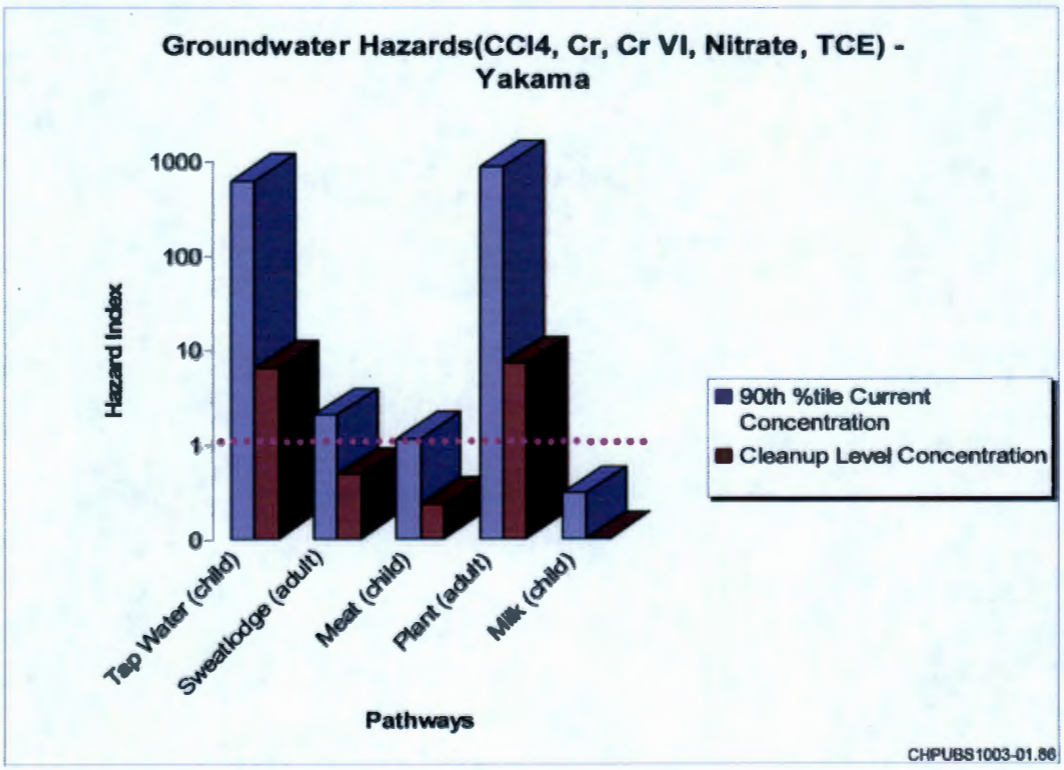


Table G7-1. Summary of CTUIR and Yakama Nation Cancer Risks at the Proposed Cleanup-Level Groundwater Concentrations.

	Proposed Groundwater Cleanup Level (µg/L)	Tap Water	Sweatlodge[a]	Beef	Produce	Milk[b]
CTUIR						
Carbon tetrachloride	3.4	7E-05	3E-06	2E-09	8E-05	--
I-129	1	2E-05	--	3E-06	4E-05	--
Tc-99	900	3E-04	--	1E-05	8E-03	--
TCE	5	1E-05	6E-07	2E-10	1E-05	--
TCE	1.1	3E-06	1E-07	3E-11	3E-06	--
Tritium	20,000	1E-04	3E-05	6E-06	1E-03	--
Total[c]		**5E-04**	**4E-05**	**2E-05**	**1E-02**	**--**
Yakama Nation						
Carbon tetrachloride	3.4	7E-05	4E-06	1E-08	9E-05	2E-08
I-129	1	2E-05	--	1E-05	4E-05	4E-05
Tc-99	900	3E-04	--	7E-05	9E-03	4E-04
TCE	5	1E-05	7E-07	9E-10	2E-05	1E-09
TCE	1.1	3E-06	2E-07	2E-10	4E-06	3E-10
Tritium	20,000	1E-04	4E-05	3E-05	1E-03	9E-05
Total[c]		**5E-04**	**5E-05**	**1E-04**	**1E-02**	**5E-04**

[a]Non-volatile chemicals are not evaluated for this pathway

[b]The CTUIR do not have default milk ingestion rates to evaluate risks from exposure by this pathway.

[c]Totals include the risks for TCE based on a CUL of 5 µg/L.

-- not applicable
CUL = proposed cleanup level
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
TCE = trichloroethylene

Table G7-2. Summary of CTUIR and Yakama Nation Non-Cancer Hazards at the Proposed Cleanup Level Groundwater Concentrations.

	Proposed Groundwater Cleanup Level (µg/L)	Tap Water		Sweatlodge	Beef		Produce		Milk	
		Child	Adult	Adult	Child[a]	Adult	Child[a]	Adult	Child[a]	Adult[a]
CTUIR										
Carbon tetrachloride	3.4	0.5	0.3	0.00002	--	0.00002	--	0.9	--	--
Chromium (total)	100	0.008	0.005	0.001	--	0.0001	--	0.008	--	--
Chromium VI	48	2	1	0.3	--	0.03	--	2	--	--
Nitrate[b]	10,000	0.6	0.4	--	--	--	--	--	--	--
TCE	5	2	1	0.008	--	0.00004	--	4	--	--
TCE	1.1	0.4	0.2	0.002	--	0.000009	--	0.8	--	--
Total[c]		**5**	**3**	**0.3**	**--**	**0.03**	**--**	**7**	**--**	**--**
Yakama Nation										
Carbon tetrachloride	3.4	0.7	0.3	0.00003	0.0002	0.0001	0.9	1	0.0004	0.0002
Chromium (total)	100	0.01	0.005	0.002	0.001	0.0007	0.008	0.009	0.000007	0.000004
Chromium VI	48	3	1	0.5	0.2	0.2	2	2	0.002	0.0009
Nitrate	10,000	0.8	0.4	--	--	--	--	--	--	--
TCE	5	2	1	0.01	0.0003	0.0002	4	4	0.0006	0.0003
TCE	1.1	0.5	0.2	0.002	0.00006	0.00005	0.9	0.9	0.0001	0.00007
Total[c]		**6**	**3**	**0.5**	**0.2**	**0.2**	**7**	**7**	**0.003**	**0.001**

[a]The CTUIR do not have default ingestion rates for child beef, produce, and milk or adult milk to evaluate hazards from exposure by these pathways.

[b]Inhalation of non-volatile chemicals are not evaluated and/or no toxicity criteria are available for these pathways.

[c]Totals include the hazards for TCE based on a CUL of 5 µg/L.

-- = not evaluated
CUL = cleanup level
CTUIR = Confederated Tribes of the Umatilla Indian Reservation

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G8.0 SUMMARY AND CONCLUSIONS

This section provides a summary of the Native American HHRA that was conducted for selected areas in the Hanford Site's Central Plateau. 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 two soil sites, one in the 200-PW-1 OU (216-Z-1A Tile Field) and one in the 200-PW-3 OU (216-A-8 Crib). This risk assessment evaluates potential human health risks for two Native American populations (the CTUIR and Yakama Nation) who might reside in the future in these areas of the Hanford Site's Central Plateau.

Previous investigations have identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater and subsurface soil in the 200 West and East Areas 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 and 200 East Areas are still being used for industrial purposes (e.g., various storage and waste management activities).

This risk assessment evaluates risks for hypothetical Native American populations under future conditions if institutional controls fail and site knowledge is lost (unrestricted land use post-2150). The unrestricted land use scenario assumes that exposures to Native Americans could occur if soil contamination is present in the top 4.6 m (15 ft) of soil and if groundwater is used for domestic purposes, crop irrigation, and watering livestock. The intent of including a Native American scenario is to provide information on an unrestricted land use scenario for this population to site managers and the public. Cleanup concentration goals and decisions will not be based on potential Native American future exposures, consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

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

G8.1 DATA EVALUATION

The first step in an HHRA is an evaluation of the data 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)
- Hexavalent chromium
- Iodine-129
- Methylene chloride

- Nitrate
- PCE
- TCE
- Technetium-99
- Tritium
- Uranium (contaminant toxicity only).

The risk assessment primarily used the available soil data from the 200-PW-1/3/6 RI report (DOE/RL-2006-51) for the representative soil sites, supplemented by additional historical data reports. In addition to soil data, soil gas data collected in the vicinity of the 216-Z-1A Tile Field were also reviewed to evaluate its suitability for inclusion in the risk assessment.

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

Maximum detected concentrations in soil from each of the waste sites were compared to EPA Region 6 HHSLs for residential soil and EPA generic residential screening levels for radionuclides (EPA/540-R-00-006) to select COPCs in soil. The selected COPCs are as follows:

Contaminant	216-Z-1A Tile Field	216-A-8 Crib
Americium-241	√	
Carbon-14		√
Cesium-137		√
Neptunium-237		√
Plutonium-239	√	√
Plutonium -240	√	√
Radium-228		√
Technetium-99		√
Thallium		√
Thorium-228		√

G8.2 EXPOSURE ASSESSMENT

After the COPCs have been selected, the second step in risk assessment is an evaluation of the exposure pathways by which humans could encounter contaminants. The exposure assessment identifies the populations potentially exposed to contaminants at the site, the means by which exposure occurs, and the amount of contaminant received from each exposure medium (i.e., the contaminant intake). Only complete exposure pathways are quantitatively evaluated. Complete pathways consist of four elements: (1) a source and mechanism of contaminant release, (2) a retention or transport medium (e.g., groundwater), (3) a point of potential human contact with the affected medium, and (4) a means of entry into the body at the contact point. The CSMs (see Figures G3-1 and G3-2) depict the complete pathways for future unrestricted land use and indicate which have been selected for quantitative evaluation. Figure G3-1 is a pictorial

representation of the complete pathways and Figure G3-2 provides a schematic of the complete pathways.

The risk assessment evaluated risks from exposures to contaminants in groundwater and soil and additional exposures via the food chain (i.e., fruits and vegetables, meat, and milk) for a hypothetical Native American scenario under future conditions if institutional controls fail and site knowledge is lost (unrestricted land use post-2150). While land use is anticipated to remain industrial for the foreseeable future, because the majority of the radionuclides present in soil and groundwater have very long half-lives, a future Native American population was selected for evaluation. At year 2150, it is assumed that someone could excavate a basement for a home and spread the excavated soil on the surface, where it would be available for direct exposure by future Native Americans. Child and adult future Native American populations were evaluated for the following exposures:

- Direct contact with impacted soil brought to the surface
- Exposures to groundwater as drinking water
- Inhalation of water vapor and dermal contact with water in a sweatlodge (inhalation evaluated for volatile contaminants only[6])
- Ingestion of homegrown produce cultivated in contaminated soil and irrigated with groundwater
- Ingestion of beef and milk from cattle watered with groundwater and grazing in pastures irrigated with groundwater
- Inhalation of vapors emanating from the subsurface into the ambient air (assessed qualitatively because of data quality issues and uncertainties regarding future building construction).

For the quantification of exposures to COPCs in soil, either 95 percent UCL or maximum concentrations were used as reasonable maximum EPCs. Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest concentrations do not occur at the same location). Therefore, a range of concentrations was selected for EPCs to evaluate "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. These EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing groundwater data set. Use of the existing data set (rather than modeling future concentrations) likely overestimates future concentrations, particularly for tritium and the VOCs.

G8.3 TOXICITY ASSESSMENT

The third step in risk assessment is an evaluation of the toxicity of the COPCs by an assessment of the relationship between the dose of a contaminant and the occurrence of toxic effects. Contaminant toxicity criteria, which are based on this relationship, consider both cancer effects

[6] Because of a number of uncertainties, risks from inhalation of non-volatiles in a sweatlodge were not quantified but are addressed qualitatively in the uncertainty section, see Section J6.0. A contaminant was considered volatile if it met EPA's working definition of a volatile: a Henry's law constant greater than 10^{-5} and a molecular weight of less than 200 g. Using this definition, total chromium, hexavalent chromium, nitrate, technetium-99, iodint-129, and uranium are not volatile compounds.

and effects other than cancer (non-cancer effects). The toxicity criteria are required in order to quantify the potential health risks from the COPCs. Only cancer effects are of concern for the radionuclides (except for uranium). However, a number of the nonradionuclide COPCs are considered toxic for both their potential to induce cancer and to cause non-cancer toxic effects.

G8.4 RISK CHARACTERIZATION

The last step in HHRA is a characterization of the health risks. The exposure factors, media concentrations, and toxicity criteria are combined to calculate health risks. Health risks are calculated differently for contaminants that cause cancer and for contaminants that cause non-cancer effects. The calculation of cancer risk assumes that no level of the contaminant is without some risk, whereas for contaminants with non-cancer effects, a "threshold" dose exists. Risks (for cancer) and hazards (for non-cancer effects) are calculated for an RME scenario for each pathway, a calculation that overestimates risks for the majority of the population to ensure public health is protected. Cancer risk estimates represent the potential for cancer effects by estimating the probability over a lifetime of developing cancer because of site exposures. Non-cancer hazards assume there is a level of contaminant intake that is not associated with an adverse health effect even in sensitive individuals. Target health goals for carcinogens are 10^{-4} to 10^{-6} (EPA's acceptable risk range) and target health goals for non-cancer hazards are an HI >1.

While different methods are used to calculate the dose from radionuclides and nonradionuclides (as described in EPA/540/1-89/002), exposure assessment for both nonradionuclide contaminants and radionuclides follow the same basic steps. However, in addition to the exposure pathways considered for contaminants, external radiation is an important exposure pathway for radionuclides in surface soils. The dermal absorption pathway is typically not a significant exposure pathway for radionuclides and was not considered in this risk assessment, as discussed in Section G3.0. For radionuclide exposures in soil, the EPCs for radionuclides and site-specific information were entered into RESRAD Version 6.4 to determine risks. RESRAD is a computer model designed to estimate radiation doses and risks from residual radioactive materials (ANL/EAD-4). The RESRAD model requires site-specific soil concentrations and other site-specific data to estimate radionuclide risk.

Soil risks were evaluated at two different waste sites, and groundwater risks were evaluated for three concentrations for each COPC based on concentration ranges throughout the groundwater plumes. Thus, soil risks are waste site specific, and groundwater risks are specific to concentration ranges but independent of location. Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information for risk managers regarding the range of possible groundwater risks throughout the site. The soil, groundwater, and food chain pathway risks are summarized in the sections below.

These risks are assumed to occur 150 years in the future; however, current concentrations were used to calculate risks and hazards. Although not quantified, future concentration reductions will be significant for all contaminants due to the planned groundwater remediation activities. Even without remediation, significant concentration reductions will likely occur for the chlorinated solvents due to natural degradation processes. Tritium cancer risks are likely to be below target health goals in 150 years. Therefore, future risks will be lower than those presented here.

G8.4.1 Soil Risk Summary

Impacted soil is covered by at least 1.8 m (6 ft) of unimpacted soil, and regular human contact is typically only to the top few centimeters (EPA/540/R-95/128). However, if Native Americans disturbed soil in the future at depth at the 216-Z-1A Tile Field or 216-A-8 Crib by excavating soil for a home basement, they could come into contact with COPCs. EPA considers a depth of 4.6 m (15 ft) to be the deepest level at which human contact is likely to occur. Therefore, soil risks are based on contamination in the top 4.6 m (15 ft) of soil. Radiological concentrations in this depth interval of soil were modeled assuming 150 years of decay before contaminants would be excavated. Under that unlikely scenario (existing institutional control programs at Hanford are designed to prevent digging in impacted soil), health risks would significantly exceed 10^{-4} at the 216-Z-1A Tile Field and 216-A-8 Crib, indicating that radionuclide contamination may be a health concern for future Native American populations. Risks from subsurface soil exposures at the 216-Z-1A Tile Field were driven by plutonium-239, followed by plutonium-240 and then americium-241. Risks from subsurface soil at the 216-A-8 Crib were driven by cesium-137. In addition, the non-cancer hazard for ingesting soil containing thallium (the only nonradionuclide in soil is at the 216-A-8 Crib) were below 1. However, for ingestion of produce containing thallium, the hazard exceeded 1 and may be a health concern for future Native Americans. Specifics of the post-2150 unrestricted land use scenario for soil exposure are below:

- For both the CTUIR and Yakama Nation populations, total direct soil contact risks were well above 10^{-4} for both soil sites: 216-Z-1A Tile Field risks were approximately 1 (i.e., nearly 100 percent), which is the maximum possible risk (driven by plutonium-239 ingestion), and 216-A-8 Crib risks were 3×10^{-1} (driven by cesium-137 external radiation).
- The CTUIR and Yakama Nation population risks from ingestion of homegrown produce cultivated in contaminated soil were similar to soil, well above 10^{-4} for both soil sites: 216-Z-1A Tile Field risks were also approaching the maximum possible (nearly 100 percent), and risks at 216-A-8 Crib were 3×10^{-2} (Yakama Nation) and 2×10^{-2} (CTUIR).
- Non-cancer hazards at the 216-A-8 Crib were from ingestion of thallium-containing soil and eating thallium-containing produce. Soil ingestion hazards were below 1 for both Native American populations and for ingestion of homegrown produce, were above 1, with HQs of 30 and 31 for the CTUIR and Yakama Nation, respectively.

Risks from radionuclide soil exposures were modeled up to 1,000 years in the future to evaluate radioactive decay and ingrowth of daughter products. For the 216-Z-1A Tile Field where risks are driven by plutonium-239, plutonium-240, and americium-241, cumulative risks at future time horizons are not significantly different than current risks because the half-lives of the plutonium contaminants are long (cumulative risks at 1,000 years still approach the maximum risk, nearly 100 percent). However, americium-241 risks do decline significantly over 1,000 years, but at 1,000 years risks are still above 10^{-4}. At the 216-A-8 Crib where cesium-137 is the risk driver, risks are significantly lower at future time horizons because of the relatively short half-life of cesium-137 (approximately 30 years), and risks drop below 10^{-4} approximately 350 years in the future.

G8.4.2 Groundwater Risk Summary

Institutional controls currently prevent the use of impacted groundwater. However, for the future Native American, groundwater exposures are assumed not to occur until at least the year 2150. Two of the three radionuclides selected as COPCs in groundwater, technetium-99 and iodine-129, have very long half-lives (213,000 and 16 million years, respectively), and future concentrations would not be different than current concentrations. However, the third radionuclide COPC, tritium, has a short half-life (12 years) and will be at concentrations that are below a health concern ($<1 \times 10^{-6}$) within 150 years. Current concentrations of radionuclides and nonradionuclides in groundwater were used to access hazard/risk. Specifics of the post-2150 unrestricted land use scenario for groundwater exposure are below:

- Both the CTUIR and Yakama Nation risks from **exposure to chemicals while drinking groundwater** exceeded a risk level of 1×10^{-4} for carbon tetrachloride, chloroform, and PCE at the 90th percentile concentrations and for carbon tetrachloride at the 50th percentile concentrations. Non-cancer hazards are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In addition, hexavalent chromium, nitrate, and TCE all have non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentrations.

- Both the CTUIR and Yakama Nation risks from **exposure to current concentrations of radionuclides while drinking groundwater** were highest for technetium-99 (4×10^{-4}), followed by tritium at 2×10^{-4} for the 90th percentile concentrations. The 25th and 50th percentile concentrations were below 1×10^{-4} for radionuclides.

- Both the CTUIR and Yakama Nation risks from **exposure to chemicals during sweatlodge** use exceeded a risk level of 1×10^{-4} from inhalation of carbon tetrachloride at the 90th and 50th percentile concentrations. Non-cancer hazards for the Yakama Nation are also significant (HQ >1) for dermal exposures to hexavalent chromium at the 90th percentile concentrations. Only inhalation of volatile contaminants was evaluated for the sweatlodge scenario due to the uncertainties associated with calculating concentrations of non-volatiles in the steam of the sweatlodge. Therefore, risks and hazards for the sweatlodge pathway could be underestimated.

- Both the CTUIR and Yakama Nation risks from **exposure to radionuclides during sweatlodge** use at the 90th, 50th, and 25th percentile concentrations were below 1×10^{-4}. Of the three radionuclide COPCs, only tritium is considered volatile and was quantitatively evaluated in the sweatlodge scenario.

- Both the CTUIR and Yakama Nation risks from **ingestion of homegrown produce irrigated with chemicals in groundwater** exceeded a risk level of 1×10^{-4} for carbon tetrachloride and PCE at the 90th percentile concentrations and for carbon tetrachloride at the 50th and 25th percentile concentrations. Non-cancer hazards were significant for carbon tetrachloride at the 90th, 50th, and 25th percentile concentrations. In addition, hexavalent chromium and TCE both had non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentrations.

- Both the CTUIR and Yakama Nation risks from **ingestion of homegrown produce irrigated with radionuclides in groundwater** were highest for technetium-99 (1×10^{-2}), followed by tritium at 2×10^{-3} (CTUIR) and 3×10^{-3} (Yakama Nation) each for the

90th percentile concentrations. The risks for the 50th percentile concentration was 2×10^{-3} for technetium-99, and the risk for tritium was 2×10^{-4} (CTUIR) and 3×10^{-4} (Yakama Nation). The risks for the 25th percentile concentration were 6×10^{-4} for technetium-99 and below 1×10^{-4} for tritium.

- Only the Yakama Nation risks from ingestion of milk were above the 1×10^{-4} risk goal at 6×10^{-4} for technetium-99. No other hazard or risk was above target goals from the **ingestion of beef and milk** from cattle watered with groundwater and grazing in pastures irrigated with groundwater.

The risk drivers, chemicals or radionuclides above target goals of 1 or 1×10^{-4}, associated with each exposure pathway for each soil site and for groundwater (90th percentile concentrations) are summarized in Table G7-1.

G8.5 UNCERTAINTIES IN RISK ASSESSMENT

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

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

There are uncertainties regarding the quantification of health risks in terms of several assumptions about exposure and toxicity, including site-specific and general uncertainties, particularly for the food chain pathways. Based on the conservative assumptions used because of the uncertainty when quantifying exposure and toxicity, the health risks and hazards presented in this risk assessment are more likely to overestimate risk. However, for the sweatlodge pathway, inhalation risks associated with the sweatlodge scenario may be underestimated by not including non-volatile contaminants in groundwater. However, DOE proposes to continue to work with the Yakama Nation and CTUIR to better understand the uncertainties associated with the inhalation exposure pathway in the sweatlodge scenario and to refine the methods used to estimate potential exposures through this pathway.

Section G6.0 provides a detailed assessment of the uncertainties inherent in the risk assessment process, as well as the uncertainties that are specific to this risk assessment.

G8.6 GROUNDWATER RESIDUAL RISK

In 150 years, groundwater concentrations are anticipated to be considerably lower than they are today due to planned groundwater remediation activities. In order to estimate what potential future risks might be for the Native American scenarios if groundwater concentrations met the proposed cleanup levels presented in the FS report, calculations of risks and hazards were estimated for the following eight COPCs: carbon tetrachloride, chromium (total), hexavalent

chromium, iodine-129, nitrate, TCE, technetium-99, and tritium. If groundwater concentrations were at the proposed cleanup level for carbon tetrachloride, risks would be reduced to within EPA's acceptable range of 10^{-6} to 10^{-4} for all evaluated pathways for both the CTUIR and Yakama Nation scenarios. However, CTUIR and Yakama Nation non-cancer hazards would remain slightly above 1 for the tap water and produce pathways due to hexavalent chromium and TCE. If groundwater concentrations were at the proposed cleanup level for technetium-99, risks exceed 10^{-4} for tap water and produce for both the CTUIR and Yakama Nation scenarios, and risks exceed for the Yakama Nation milk pathway. Also, tritium risks exceed 10^{-4} for produce for both the CTUIR and Yakama Nation scenarios; however, as noted in Section G5.0, tritium risks will be acceptable in 150 years due to tritium decay (half-life of 12 years). Reduction of concentrations of the main risk driver, carbon tetrachloride, to proposed cleanup levels clearly would significantly reduce potential Native American risks. Risk and hazard reduction for the other COPCs would likewise be significantly reduced.

Table G8-1. Summary of Risk Drivers (Above an HI of 1 or a Cancer Risk of 1×10^{-4}) for Soil and Groundwater (90th Percentile Concentrations).

Soil		Groundwater					
COPC	**Direct Contact/Produce**	**COPC**	**Drinking Groundwater**	**Sweatlodge**	**Produce**	**Meat**	**Milk**
216-Z-1A Tile Field		Carbon tetrachloride	◐	◖	◐		
Am-241	◖	Chloroform	◖				
Np-237[a]	◖	Chromium (total)					
Pu-239	◖	Hexavalent chromium	◗	◗	◗		
Pu-240	◖	Iodine-129					
216-A-8 Crib		PCE			◖		
C-14		Methylene chloride					
Cs-137	◖	Nitrate	◗				
Np-237		Technetium-99	◖		◖		◖
Pu-239		TCE	◗		◗		
Pu-240		Tritium	◖		◖		◖
Ra-228		Uranium					
Tc-99							
Thallium	◗						
Th-228							

NOTES:

◖ - cancer risk exceeds 1×10^{-4}

◗ - HI exceeds 1

◐ - cancer risk exceeds 1×10^{-4} and HI exceeds 1

[a]Neptunium-237 was not selected as a COPC at 216-Z-1A Tile Field but is a daughter product as a result of americium decay.

COPC = contaminant of potential concern
HI = hazard index
PCE = tetrachloroethylene
TCE = trichloroethylene

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APPENDIX G

ATTACHMENT 1

PROUCL OUTPUTS FOR CONTAMINANTS OF POTENTIAL CONCERN IN SOIL

1

2

APPENDIX G

ATTACHMENT 1

TABLE OF CONTENTS

216-Z-1A TILE FIELD

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

1

Table 1-1. ProUCL Output Summary for 216-Z-1A Tile Field – Concentration in Waste (0 to 15 ft).

Variable Name	EPC	Units	Distribution	Recommendation	NumObs	Minimum	Maximum	Mean	Median	Sd	CV	Skewness	Variance
Am-241 (ingrowth)	2028358	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	0	5180000	596009.18	14500	1354866	2.27323	2.9162794	1.84E+12
Pu-239/240	15509199	pCi/g	Non-parametric	95% Chebyshev (Mean, Sd) UCL	17	-0.185	38200000	4838799.9	305000	10093187	2.08589	2.7627451	1.02E+14

Date File

Variable: Am-241 0to15

Raw Statistics

Number of Valid Samples	17
Number of Unique Samples	17
Minimum	0
Maximum	5180000
Mean	596009.2
Median	14500
Standard Deviation	1354866
Variance	1.84E+12
Coefficient of Variation	2.27323
Skewness	2.916279

Normal Distribution Test

Shapiro-Wilk Test 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	1169712

Gamma Statistics Not Available

Lognormal Statistics Not Available

95% Non-parametric UCLs

CLT UCL	1136513
Adj-CLT UCL (Adjusted for skewness)	1384859
Mod-t UCL (Adjusted for skewness)	1208449
Jackknife UCL	1169712
Standard Bootstrap UCL	1115963
Bootstrap-t UCL	2711884
Hall's Bootstrap UCL	3256298
Percentile Bootstrap UCL	1197557
BCA Bootstrap UCL	1374380
95% Chebyshev (Mean, Sd) UCL	2028358
97.5% Chebyshev (Mean, Sd) UCL	2648136
99% Chebyshev (Mean, Sd) UCL	3865571

RECOMMENDATION

Data are Non-parametric (0.05)

Use 95% Chebyshev (Mean, Sd) UCL

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

Raw Statistics		Normal Distribution Test	
Number of Valid Samples	17	Shapiro-Wilk Test 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	38200000		
Mean	4838800	95% UCL (Assuming Normal Distribution)	
Median	305000	Student's-t UCL	9112648
Standard Deviation	10093187		
Variance	1.02E+14		
Coefficient of Variation	2.085886		
Skewness	2.762745		

Gamma Statistics Not Available

Lognormal Statistics Not Available

	95% Non-parametric UCLs	
	CLT UCL	8865331
	Adj-CLT UCL (Adjusted for skewness)	10618003
	Mod-t UCL (Adjusted for skewness)	9386030
	Jackknife UCL	9112648
	Standard Bootstrap UCL	8892804
	Bootstrap-t UCL	18764160
RECOMMENDATION	Hall's Bootstrap UCL	25118717
Data are Non-parametric (0.05)	Percentile Bootstrap UCL	9089027
	BCA Bootstrap UCL	10787012
Use 95% Chebyshev (Mean, Sd) UCL	95% Chebyshev (Mean, Sd) UCL	15509199
	97.5% Chebyshev (Mean, Sd) UCL	20126289
	99% Chebyshev (Mean, Sd) UCL	29195668

1

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APPENDIX G

ATTACHMENT 2

CWASTE DETAILS AND EXPOSURE POINT CONCENTRATION CALCULATIONS FOR UMATILLA AND YAKAMA NATION SCENARIOS

1

2

Attachment 2-1. Exposure Point Concentration Calculations for Umatilla and Yakama Nation Scenarios. (2 sheets)

Basement Excavation

Site Name	CZthick (m)	CZarea (m^2)	Vexca (m^3)	Length (m)	Width (m)	Height (m)	Change in Density
216-Z-1A Tile Field/ 216-A-8 Crib	0.17	1,500	261	5	10	4.6	1.13

Vexcav = l x w x h x (Dinitial/Dfinal)

Vexcav = volume of excavated soil for a basement (m^3)
h = height (4.6 m)
l = length (5 m)
w = width (10 m)

Dfinal = density of excavated soil on surface (1.5 kg/L)
Dinitial = density of undisturbed soil (1.7 kg/L)
pg 7 of tank report Rittman, P.D. (2004)

CZthick = Vexcav/CZarea

CZthick = thickness of contamination spread over contamination zone area (m)
Vexcav = volume of excavated soil for a basement (m^3)
CZarea = contaminated zone area (m^2)

Dilution of Contamination from Excavation

Site Name	Contaminated %	Background %	Lwaste (ft)	Lfill (ft bgs)	Lexav (ft bgs)
216-Z-1A Tile Field	0.6	0.4	9	6	15
216-A-8 Crib	0.33	0.67	5	10	15

Clocal = (Lback/Lexav x Cback) + (Lwaste/Lexav x Cwaste)
Clocal – concentration of local site surface soil post excavation and spread over 1,500 m^2
Lback – depth thickness from ground surface to top of contaminated soil (concentrations assumed at background)
Lexav – depth of basement excavation from ground surface
Cback – background values taken from DOE/RL-96-12
Lwaste – contaminated depth thickness
Cwaste – concentration of waste using available data

Attachment 2-1. Exposure Point Concentration Calculations for Umatilla and Yakama Nation Scenarios. (2 sheets)

Exposure Point Concentration Calculations

Site Name	Chemical Name	Cwaste - Now (pCi/g or mg/kg)	Note Concerning Cwaste - Now Derivation	From RESRAD Cwaste - 150 years (pCi/g or mg/kg)	Background	Umatilla/ Yakama Nation EPC Clocal - 150 years (pCi/g or mg/kg)
216-Z-1A Tile Field	Americium-241	2,028,358	95% Chebychev (Mean, Sd) UCL	1,569,000	NE	941,400
	Neptunium-237	--	--	86	NE	52
	Plutonium-239/240	15,509,199	95% Chebychev (Mean, Sd) UCL	--	0.0248	--
	Plutonium-239*	12,637,125	--	12,940,000	0.0202	7,764,000
	Plutonium-240*	2,872,074	--	2,854,000	0.0046	1,712,400
	Uranium-235	--	--	1.9	0.109	1.19
	Uranium-236	--	--	12.8	1.06	8.1
216-A-8 Crib	Carbon-14	81	Maximum (19 to 21.5 ft bgs)	3.8E-23	NE	1.3E-23
	Cesium-137	877,000	Maximum (19 to 21.5 ft bgs)	27,410	1.05	9,137
	Neptunium-237	3.5	Maximum (19 to 21.5 ft bgs)	3.5	NE	1.2
	Plutonium-239/240	56	Maximum (19 to 21.5 ft bgs)	--	0.0248	--
	Plutonium-239*	45	Maximum (19 to 21.5 ft bgs)	45	0.0202	15
	Plutonium-240*	10	Maximum (19 to 21.5 ft bgs)	10	0.0046	3.4
	Radium-228	1.1	Maximum (22.5 to 25 ft bgs)	1.5E-08	NE	5.1E-09
	Technetium-99	80	Maximum (19 to 21.5 ft bgs)	26	NE	8.6
	Thallium	2.5	Maximum (19 to 21.5 ft bgs)	--	NE	0.83
	Thorium-228	0.70	Maximum (22.5 to 25 ft bgs)	2.3E-08	NE	7.7E-09

* Ratio of 4.4:1 (Pu 239:Pu 240).

APPENDIX G

ATTACHMENT 3

RESRAD INPUT PARAMETERS AND VALUES FOR CTUIR AND YAKAMA NATION SCENARIOS

APPENDIX G

ATTACHMENT 3

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Table 3-1 RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios

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Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Soil Concentrations				
Basic Radiation Dose Limit	mrem/yr	15		40 CFR Part 141; OSWER Directive 9200.4-31P
Number of nuclides		varies		Depends on the site
Nuclide (#1)		varies		Depends on the site
Nuclide (#1) Concentration	pCi/g			Site-specific concentration set manually
Transport Factors (for nuclide #1):	-----	-----		-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----		-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Options:	-----	-----		-----
Water Concentration: Time since material placement	year	0		*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)		*default value*
Solubility Limit	Mol/L	0		*default value*
Leach Rate	/year	0		*default value*
Use Plant/Soil ratio?	yes/no	no		*default value*
Nuclide (#2)		varies		Depends on the site
Nuclide (#2) Concentration	pCi/g			Site-specific concentration set manually
Transport Factors (for nuclide #2):	-----	-----		-----
Contaminated Zone Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Saturated Zone Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Number of Unsaturated Zones = 3	-----	-----		-----
Unsaturated Zone 1 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Unsaturated Zone 2 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Unsaturated Zone 3 Distribution Coefficient	cm^3/g	varies		*chemical-specific*
Options:	-----	-----		-----
Water Concentration: Time since material placement	year	0		*default value*
Water Concentration: Groundwater Concentration	pCi/L	greyed out (t=0)		*default value*
Solubility Limit	Mol/L	0		*default value*
Leach Rate	/year	0		*default value*
Use Plant/Soil ratio?	Yes/no	no		*default value*

Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Calculation Times				
1	years	0		site-specific
2	years	50		site-specific
3	years	150		site-specific
4	years	500		site-specific
5	years	1000		site-specific
Contaminated zone parameters				
Area of contaminated zone	m^2	1,500		DOE/RL-2007-21
Thickness of contaminated zone	m	0.17		Based on volume of excavated soil spread over 1,500 m^2
Length parallel to aquifer flow	m	9.1		Site-specific information used for all sites (9.1 m [30 ft])
Co-ver/hydrol				**Contaminated Zone = Hanford Sands**
Cover Depth	m	0		*default value (assumes contaminated soil is at the surface)*
Density of cover material	g/cm^3	greyed out		*default value = 1.5*
Cover Erosion Rate	m/year	greyed out		*default value = 0.001*
Density of contaminated zone	g/cm^3	1.85		Hanford Sands = 1.4 - 2.3
Contaminated zone erosion rate	m/year	0		Set to zero (assumes no erosion over time)
Contaminated zone total porosity		0.3		Hanford Sands value
Contaminated zone field capacity		0.1		Hanford Sands value
Contaminated zone hydraulic conductivity	m/year	1577		Hanford Sands = 0.005 cm/s; 1577 m/yr
Contaminated zone b parameter		4.05		RESRAD value for sand from Appendix E
Humidity in air	g/cm^3	greyed out		*default value = 8*
Evapotranspiration coefficient		0.91		WDOH/320-015
Wind Speed	m/s	3.4		Hanford site average; PNNL-12087
Precipitation	m/year	0.16		Based on 16 cm (6.3 in.) annual rainfall; DOE/RL-90-07
Irrigation	m/year	0		assume for Hanford Sands (default was 0.2)
Irrigation mode (overhead or ditch?)		overhead		*default value*
Runoff coefficient		0		assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	m^2	1000000		*default value*
Accuracy for water/soil computations		0.001		*default value*
Saturated Zone				**Saturated Zone = Ringold**
Density of saturated zone	g/cm^3	1.5		*default value*
Saturated zone total porosity		0.33		Ringold value
Saturated zone effective porosity		0.18		Ringold value
Saturated zone field capacity		0.21		Ringold value

Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Saturated zone hydraulic conductivity	m/year	7,300		Ringold value = 7,300 m/yr
Saturated zone hydraulic gradient		0.002		Ringold value
Saturated zone b parameter		4.05		RESRAD value for sand from Appendix E
Water table drop rate	m/year	0.2		Ringold value
Well pump intake depth	m below water table	4.6		Typical RCRA well screen length
Model for Water Transport Parameters (nondispersion or mass-Balance)		nondispersion		*default value*
Well pumping rate	m^3/year	250		*default value*
Unsaturated	**Unsaturated Zones = Hanford Sands, CCU, and Ringold**			
Number of Unsaturated Zones	**3**			number of zones set manually
Unsaturated Zone #1	Hanford Sands			
Thickness	m	33.5		33.5 m (110 ft)
Density	g/cm^3	1.85		Hanford Sands = 1.4 – 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.3		Hanford Sands value; WHC-EP-0883, Appendix A
Effective Porosity		0.25		Hanford Sands value; WHC-EP-0883, Appendix A
Field Capacity		0.25		Hanford Sands value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	m/year	1577		Hanford Sands = 0.005 cm/s; 1577 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05		RESRAD value for sand from Appendix E; Table E.2
Unsaturated Zone #2	CCU (silt values; ignored caliche for model)			
Thickness	m	3.1		3.1 m (10 ft)
Density	g/cm^3	2.0		CCU (silt) value; WHC-EP-0883, Appendix A
Total Porosity		0.37		CCU (silt) value; WHC-EP-0883, Appendix A
Effective Porosity		0.29		CCU (silt) value; WHC-EP-0883, Appendix A
Field Capacity		0.29		CCU (silt) value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	m/year	2740		CCU value = 8.69E-03 cm/sec; 2740 m/year; WHC-EP-0883, Appendix A
b parameter		5.3		RESRAD value for silty loam from Appendix E; Table E.2
Unsaturated Zone #3	Ringold			
Thickness	m	32.3		32.3 m (106 ft)
Density	g/cm^3	1.85		Ringold = 1.4 - 2.3; WHC-EP-0883, Appendix A
Total Porosity		0.22		Ringold value; WHC-EP-0883, Appendix A

Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Effective Porosity		0.13		Ringold value; WHC-EP-0883, Appendix A
Field Capacity		0.13		Ringold value; WHC-EP-0883, Appendix A
Hydraulic Conductivity	m/year	7300		Ringold = 7300 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05		RESRAD value for sand from Appendix E; Table E.2
Occupancy				
Inhalation Rate – adult	m^3/year	10,950	9,490	Umatilla assumes 30 m^3/day and Yakama assumes 26 m^3/day for 365 days/year
Mass Loading for Inhalation	g/m^3	3.70E-07		Site-specific based on a PEF of 2.72E+09 m^3/kg
Exposure duration	years	70		Subsistence exposure duration
Indoor Dust Filtration Factor		0.4		*default value*
External gamma shielding factor		0.4		EPA/540-R-00-007, (Equation 4)
Indoor time fraction		0.5		*default value*
Outdoor time fraction		0.25		*default value*
Shape of contaminated zone		circular		*default value*
Ingestion - Dietary				
Fruits, vegetables, and grain	kg/year	169	209	CTUIR is 50 percent of combined roots 800 g/d and berries/fruits 125 g/d; Yakama Nation is 50 percent combined veg./root 1,118 g/d minus 274 g/d leafy (assume upper bound default of 100 kg/year) and fruit/berry 299 g/d.
Leafy vegetable	kg/year	78	100	CTUIR is 50 percent of combined greens 300 g/d and other 125 g/d; Yakama Nation is upper bound RESRAD default 100 kg/year
Milk	L/year	greyed out		*This pathway was not used (default = 92)*
Meat and poultry	kg/year	greyed out		*This pathway was not used (default = 23)*
Soil Ingestion	g/year	146		400 mg/day over 365 days/year
Contamination fraction - Drinking water		greyed out		*This pathway was not used (default = 1)*
Contamination fraction - Household water		1		*This pathway was not used*
Contamination fraction - Livestock water		greyed out		*This pathway was not used (default = 1)*
Contamination fraction - Irrigation water		1		*default value*
Contamination fraction - Plant food		1		Assumes 100% contaminated fraction
Contamination fraction - Meat		0		*This pathway was not used*
Contamination fraction - Milk		0		*This pathway was not used*
Ingestion - Non-Dietary				
Livestock fodder intake from meat	kg/day	greyed out		*This pathway was not used (default = 68)*
Fodder intake from milk	kg/day	greyed out		*This pathway was not used (default = 55)*

Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Livestock water intake for meat	L/day	greyed out		*This pathway was not used (default = 50)*
Livestock water intake for milk	L/day	greyed out		*This pathway was not used (default = 160)*
Livestock water intake of soil		greyed out		*This pathway was not used (default = 0.5)*
Drinking water fraction from groundwater		greyed out		*This pathway was not used (default = 1)*
Household water fraction from groundwater		1		*This pathway was not used*
Livestock water fraction from groundwater		greyed out		*This pathway was not used (default = 1)*
Irrigation fraction from groundwater		1		*default value*
Mass loading for foliar deposition	g/m^3	0.0001		*default value*
Depth of soil mixing layer	m	0.15		*default value*
Depth of roots	m	0.9		*default value*
Plant Factors				
Wet weight crop yield for Non-Leafy	kg/m^2	0.7		*default value*
Wet weight crop yield for Leafy	kg/m^2	1.5		*default value*
Wet weight crop yield for Fodder	kg/m^2	greyed out		*This pathway was not used (default = 1.1)*
Growing season for Non-Leafy	years	0.17		*default value*
Growing season for Leafy	years	0.25		*default value*
Growing season for Fodder	years	greyed out		*This pathway was not used (default =0.08)*
Translocation Factor for Non-Leafy		0.1		*default value*
Translocation Factor for Leafy		1		*default value*
Translocation Factor for Fodder		greyed out		*This pathway was not used (default = 1)*
Dry Foliar Interception Fraction for Non-Leafy		0.25		*default value*
Dry Foliar Interception Fraction for Leafy		0.25		*default value*
Dry Foliar Interception Fraction for Fodder		greyed out		*This pathway was not used (default = 0.25)*
Wet Foliar Interception Fraction for Non-Leafy		0.25		*default value*
Wet Foliar Interception Fraction for Leafy		0.25		*default value*
Wet Foliar Interception Fraction for Fodder		greyed out		*This pathway was not used (default = 0.25)*
Weathering Removal Constant for Vegetation	1/year	20		*default value*
Radon Data				
Cover Total Porosity		0.4		*default value*
Cover Volumetric Water Content		0.05		*default value*
Cover Radon Diffusion Coefficient	m^2/sec	0.000002		*default value*
Bldg Foundation Thickness	m	0.15		*default value*
Bldg Foundation Density	g/cm^3	2.4		*default value*
Bldg Foundation Total Porosity		0.1		*default value*

Table 3-1. RESRAD Key Input Parameters and Values for CTUIR and Yakama Nation Scenarios. (6 sheets)

RESRAD v 6.4; Pathways = plant and soil ingestion, external radiation, inhalation of particulates, and inhalation of radon

	Units	CTUIR Value	Yakama Nation Value	Comments
Bldg Foundation Volumetric Water Content		0.03		*default value*
Bldg Foundation Radon Diffusion Coefficient	m^2/sec	0.0000003		*default value*
Contaminated Radon Diffusion Coefficient	m^2/sec	0.000002		*default value*
Radon Vertical Dimension of Mixing	m	2		*default value*
Building Air Exchange Rate	1/hr	0.5		*default value*
Height of Bldg. (room)	m	2.5		*default value*
Building Indoor Area Factor		0		*default value*
Foundation Depth Below Ground Surface	m	-1		*default value*
Ra-222 emanation coefficient		0.25		*default value*
Ra-220 emanation coefficient		0.15		*default value*
Storage Times				
Fruits, non-leafy vegetables, and grain	days	14		*default value*
Leafy vegetables	days	1		*default value*
Milk	days	greyed out		*This pathway was not used (default = 1)*
Meat and poultry	days	greyed out		*This pathway was not used (default = 20)*
Fish	days	greyed out		*This pathway was not used (default = 7)*
Crustacea and mollusks	days	greyed out		*This pathway was not used (default = 7)*
Well water	days	1		*default value*
Surface water	days	1		*default value*
Livestock fodder	days	greyed out		*This pathway was not used (default = 45)*
C-14				**For Site A-8 only**
Concentration in local water	g/cm^3	0.00002		*default value*
Concentration in contaminated soil	g/g	0.03		*default value*
Fraction of vegetation in carbon absorbed from soil		0.02		*default value*
Fraction of vegetation in carbon absorbed from air		0.98		*default value*
Thickness of evasion layer of C-14 in soil	m	0.3		*default value*
C-14 evasion flux rate from soil	1/sec	0.0000007		*default value*
C-12 evasion flux rate from soil	1/sec	1.00E-10		*default value*
Grain fraction in livestock feed (balance is hay/fodder)				*default value*
Beef cattle		0.8		*default value*
Milk cow		0.2		*default value*

APPENDIX G

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DEFAULT EXPOSURE FACTORS

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The following default exposure factors were used in the risk assessment for the 200-ZP-1 Groundwater Operable Unit and the representative soil waste sites. Site-specific exposure factors are discussed in Section G3.3 of the human health risk assessment (Appendix G).

NATIVE AMERICAN EXPOSURE FACTORS

(Exposures to Soil, Tap Water, Sweatlodge, Homegrown Produce, and Livestock)

Averaging Time. For carcinogens, an averaging time of 70 years (equivalent to a lifetime), or 25,550 days, was used (EPA 540/1-89-002). For noncarcinogens, an averaging time is equal to the exposure duration multiplied by 365 days, or 2,190 days for children and 23,360 days for adults (EPA 540/1-89-002).

Adult Body Weight. An adult body weight of 70 kg was assumed. This is the average body weight for adult men and women combined, rounded to 70 kg (OSWER Directive 9285.6-03).

Skin Surface Area. For Native American exposures to tap water, surface area values for children and adults represent the median (50th percentile) values from the *Exposure Factors Handbook* (EPA/600/P-95-002Fa). Children have 6,600 cm^2 and adults have 18,000 cm^2 of exposed total skin surface area (EPA, 2004). The Native American tap water scenario assumes dermal contact while bathing or showering, thus, total skin surface values are used. In addition, the default total adult skin surface area of 18,000 cm^2 was used for the sweatlodge scenario.

Volatilization Factor for Water. The volatilization factor is 0.5 L/m^3 for volatile chemicals only. The number was derived by Andelman (1990), as cited in *Supplemental Risk Assessment Guidance for Superfund* (EPA, 1991). It is assumed that the transfer efficiency weighted by water use is 50 percent (i.e., half of the concentration of each chemical in water will be transferred into air by all water uses).

REFERENCES

Andelman, J. B., 1990, *Total Exposure to Volatile Organic Chemicals in Potable Water*, N. M. Ram, R. F. Christman, and K. P. Cantor (eds.), Lewis Publishers, Boca Raton, Florida.

EPA, 1991, *Supplemental Risk Assessment Guidance for Superfund*, dated August 16, 1991, EPA Region 10, U.S. Environmental Protection Agency, Olympia, Washington.

EPA, 2004, *Final Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*, dated July 2004, U.S. Environmental Protection Agency, Washington, D.C.

EPA 540/1-89/002, 1989, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual*, Part A, Interim Final, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA/600/P-95-002Fa, 1997b, *Exposure Factors Handbook*, Volumes I–III, update to *Exposure Factors Handbook*, EPA/600/8-89/043 (May 1989), EPA/600/P-95-002Fa (August 1997), U.S. Environmental Protection Agency, Washington, D.C.

OSWER Directive 9285.6-03, 1991, Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual. Supplemental Guidance: Standard Default Exposure Factors, Interim Final, U.S. Environmental Protection Agency, Washington, D.C.

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APPENDIX G

ATTACHMENT 5

TOXICITY PROFILES FOR EACH CONTAMINANT OF POTENTIAL CONCERN

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APPENDIX G

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AMERICIUM-241

Americium is a human-made radioactive element. There are no naturally occurring or stable isotopes of americium. The two major isotopes of americium are americium-241 and americium-243, both of which have the same chemical behavior in the environment. These two isotopes emit alpha particles and gamma rays to decay into neptunium isotopes, neptunium-237 and neptunium-239, which are also radioactive isotopes. The half-life of americium-241 is 432 years, and the half-life of americium-243 is 7,370 years (ATSDR, 2004).

The primary concern for exposure to americium is the risk of exposure to ionizing alpha and gamma radiation. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for americium isotopes. The oral slope factor for americium-241 is 2.17×10^{-10} risk per pCi for soil ingestion, 2.81×10^{-8} risk per pCi for inhalation, and 2.76×10^{-8} risk per pCi for external effects.

Information on adverse human health effects is mainly limited to a single case report of an individual accidentally exposed to high levels of americium that resulted in a significant internal dose. In this case, adverse effects of lymphopenia, thrombocytopenia, and histological signs of bone marrow peritrabecular fibrosis, bone cell depletion, and bone marrow atrophy were noted. These data are supported by findings in laboratory animals exposed to large doses of americium in which degenerative changes in bone, liver, kidneys, and thyroid have been observed following ingestion and inhalation exposure. Increases in bone cancer have been observed in animal studies. Information on the dermal absorption of americium in humans or animals is extremely limited. At very high doses of americium, there is an increased risk for gamma radiation to cause dermal and subdermal effects such as erythema, ulceration, or even tissue necrosis. All these adverse effects have been attributed to the ionizing radiation of americium. No non-ionizing radiation effects of americium were identified (ATSDR, 2004). In the absence of relevant data, provisional non-cancer risk assessment values based on americium-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ATSDR, 2004, *Toxicological Profile for Americium*, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

CARBON-14

A naturally occurring radioactive isotope of carbon, carbon-14 is found at low concentrations in all carbon. Carbon-14 emits beta particles as it decays and has a half-life of 5,700 years (ANL, 2007).

The primary concern for exposure to carbon-14 is the risk of exposure to ionizing radiation from beta particles. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for carbon isotope 14. The oral slope factor for carbon-14 is 2.79×10^{-12} risk per pCi for soil ingestion, 7.07×10^{-12} risk per pCi for inhalation, and 7.83×10^{-12} risk per pCi for external effects.

Although the radiation energy of carbon-14 is quite low, this isotope does have the potential to induce cancer through radiation. Since carbon-14 does not emit gamma rays and the beta particle that it does emit cannot penetrate tissue deeply or travel far in air, the primary pathway of concern is ingestion. Once taken into the body, carbon may travel to any organ and has the potential to induce cancer. Carbon is an essential component of living tissue and no non-ionizing radiation effects of carbon-14 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on carbon-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

CARBON TETRACHLORIDE

Carbon tetrachloride is a solvent that has been used in the past as a cleaning fluid or degreasing agent in industrial applications. Although most uses have been discontinued, the possibility still exists for carbon tetrachloride to be released to the environment, primarily through industrial processes. Degradation of carbon tetrachloride occurs slowly in the environment, which contributes to the accumulation of the chemical in the atmosphere, as well as the groundwater. Carbon tetrachloride is widely dispersed and persistent in the environment but is not detected frequently in foods.

Because of carbon tetrachloride's widespread use in medical, industrial, and residential applications, there is a reasonable amount of toxicity information available. The principal toxic effects are on the liver, kidneys, and the central nervous system (ATSDR, 2005). Studies in animals, combined with limited observations in humans, indicate that the principal adverse health effects associated with inhalation exposure to carbon tetrachloride are central nervous system depression, liver damage, and kidney damage. Case reports in humans and studies in animals indicate that the liver, kidney, and central nervous system are also the primary targets of toxicity following oral exposure to carbon tetrachloride.

A number of well-conducted animal studies indicate that exposure to carbon tetrachloride produces liver tumors; however, data for humans is limited (EPA, 2007). Two kinds of processes appear to contribute to the carcinogenicity of carbon tetrachloride (EPA, 2005). Genotoxicity, primarily covalent binding to DNA in the liver, results from the direct binding of reactive carbon tetrachloride metabolites or lipid peroxidation products in animals exposed orally or by intraperitoneal injection. There is some evidence that carbon tetrachloride may also cause cancer by a nongenotoxic mechanism involving cellular regeneration (EPA, 2005). The U.S. Department of Health and Human Services has determined that carbon tetrachloride may reasonably be anticipated to be a carcinogen. International Agency for Research on Cancer (IARC) has classified carbon tetrachloride in Group 2B, possibly carcinogenic to humans. The EPA has determined that carbon tetrachloride is a probable human carcinogen (EPA, 2005).

The EPA has derived an oral slope factor for carbon tetrachloride of 0.13 $(mg/kg\text{-}day)^{-1}$ based on studies in rats, mice, and hamsters that exhibited increased incidence of liver tumors upon higher dose exposures (EPA, 2007). The geometric mean of the unit risks derived from four studies was used as the basis for the oral slope factor. According to EPA (2007), all four of the studies used were all deficient in some respect, precluding the choice of any one study as most appropriate. The EPA did not assign a confidence level to the derived slope factor. From these studies, EPA (2007) has also derived an inhalation slope factor for this chemical of 0.0525 $(mg/kg\text{-}day)^{-1}$. The EPA is currently working to revise the carcinogenicity assessment for carbon tetrachloride (ATSDR, 2005).

The EPA has established an oral RfD of 0.0007 mg/kg-day. The RfD is based on liver lesions in rats from a subchronic study and EPA has assigned an uncertainty factor of 1,000 to the RfD and listed their confidence in the value as medium. There is no RfC for this chemical; therefore, non-cancer inhalation effects were not evaluated in this assessment.

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CESIUM-137

Cesium is a naturally occurring element that is typically found in rocks, soil, and dust at low concentrations. Natural cesium is present in the environment in only one stable form, cesium-133. The two most important radioactive isotopes of cesium are cesium-134 and cesium-137. Each atom of cesium-137 decays into the stable isotope, barium-137, by emitting beta particles and gamma radiation (ATSDR, 2004). The half-life of cesium-137 is approximately 30 years.

Although inhalation exposure is possible, the most important exposure routes for radioisotopes of cesium are external exposure to the radiation released by the radioisotopes and ingestion of radioactive cesium-contaminated food sources. The primary concern for exposure to cesium is the risk of exposure to ionizing radiation from beta particles and gamma rays. Ionizing radiation has been shown to be a human carcinogen, and EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for cesium-137. The oral slope factor for cesium-137 is 4.33×10^{-11} risk per pCi for soil ingestion, 1.19×10^{-11} risk per pCi for inhalation, and 5.32×10^{-10} risk per pCi for external effects.

Typical signs and symptoms of acute toxicity to cesium-137 are similar to those of exposure to ionizing radiation in general. These symptoms include vomiting, nausea, diarrhea, skin and ocular lesions, neurological signs, chromosomal abnormalities, compromised immune function, and death. Repeated exposures may cause reduced male fertility, abnormal neurological development following exposure during critical stages of fetal development, and genotoxic effects. Long-term cancer studies on exposed individuals have not been completed to date, and no studies were available that specifically address cesium-137 cancer effects on humans. Animal studies, however, indicate an increased risk of cancer from external or internal exposure to relatively high doses of cesium-137 radiation. No non-ionizing radiation effects of cesium were identified (ATSDR, 2004). In the absence of relevant data, provisional non-cancer risk assessment values based on cesium-induced effects that are not attributable to ionizing radiation have not been derived.

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CHLOROFORM

Chloroform is primarily used to produce the refrigerant chlorodifluoromethane, which is used in home air conditioners and large grocery store freezers. Other past uses of this chemical include its use as a solvent, a medium in fire extinguishers, an intermediate in dyes and pesticides, and as an anesthetic. However, it currently has limited medical uses in dental procedures and medications (ATSDR 1997). Chloroform is also a common disinfection byproduct of chlorinated drinking water. The potential for human exposure is generally through exposure to drinking water via the oral, dermal, and inhalation routes (EPA, 2006, ATSDR, 1997).

The effects of chloroform on human health were observed when inhaled (used as an anesthetic) and ingested (EPA/635/R-01/001). In addition, several studies have been performed on animals that support the human data (EPA/635/R-01/001). The major effects observed when chloroform was inhaled as an anesthetic include liver, kidney, and central nervous system toxicity (ATSDR, 1997; EPA/635/R-01/001). The minor effects noted when chloroform was inhaled as an anesthetic (less than 22,500 ppm), include increase respiratory rates, cardiac hypotension and arrhythmia, and nausea and vomiting (ATSDR, 1997). Phoon et al. (1983) reported workers exposed to chloroform concentrations ranging from 14 to 400 ppm for 1 to 6 months developed toxic hepatitis and other effects including jaundice, nausea, and vomiting (ATSDR, 1997).

Similar major and minor health effects that occur from inhalation also occur after oral exposure to chloroform but at lower concentrations (less than 2,000 ppm) (EPA/635/R-01/001). Several studies (Piersol et al., 1933, Schroeder, 1965; Storms, 1973) reported that deep coma occurred immediately after intentional or accidental ingestion of 2,410 or 3,755 ppm (ATSDR, 1997). ATSDR (1997) reported that the overall human data are insufficient to conclude carcinogenicity from oral consumption; however, several animal studies found oral consumption to be carcinogenic. Chloroform has been shown to cause increased incidence of liver and kidney tumors in several species by several exposure routes (EPA/635/R-01/001).

EPA reports an oral RfD for chloroform of 0.01 mg/kg-day, based on a study of eight male and eight female dogs that were fed 15 or 30 mg chloroform/kg-day, 6 days/week for 7.5 years. The observed effects were fatty cysts forming on the liver. The RfD is based on a benchmark dose approach (coincidentally the same value as that obtained using the traditional NOAEL/LOAEL methodology) yielding a BMDL10 (benchmark dose limit associated with a 10 percent risk) of 1.2 mg/kg-day, an uncertainty factor of 100, and a modifying factor of 1. The EPA's overall confidence in the RfD is rated medium, based on the sufficiency of animal data; a higher rating is not given due to the limited human data (EPA, 2007).

The NCEA has derived a provisional inhalation reference concentration for chloroform of 0.05 mg/m^3 (0.014 mg/kg-day) (NCEA, 2002). The studies considered in the derivation of the inhalation reference concentration include studies in humans exposed to chloroform in the workplace, as well as inhalation studies of systemic and reproductive effects in animals (NCEA, 2002). Effects on liver and kidney have been observed following inhalation exposures in both humans and animals, and these effects are the most sensitive and characteristic indicators of toxicity following oral exposure. For these reasons, toxicity to liver and/or kidney was identified as the most appropriate effects for derivation of inhalation reference concentrations for chloroform. The critical studies selected for the derivation of the inhalation reference concentration were two subchronic studies in mice that measured histological and labeling index

changes in liver and kidney following exposure for 6 hr/day, 5 to 7 days/week, for 90 days. The reference concentration was calculated from the NOAEL (adjusted to the human equivalent concentration) of 4.5 mg/m^3. An uncertainty factor of 100 was assigned, of which a factor of 10 was employed to account for protection of sensitive human subpopulations, a factor of 3 for potential interspecies variability, and a factor of 3 to account for uncertainties in the database. An added uncertainty factor was not used to account for use of a subchronic study since the available data indicate that effects following inhalation exposure are not strongly duration-dependent (NCEA, 2002).

According to the IRIS database (EPA, 2007), chloroform is classified as a probable human carcinogen (B2) based on increased incidence of tumors in rats, mice, and dogs from ingesting chloroform in food and water. However, as reported in the recent toxicological review of chloroform (EPA/635/R-01/001), under the EPA's guidelines for carcinogen risk assessment (EPA/630/P-03/001F), chloroform is likely to be carcinogenic to humans by all routes of exposure under high-dose conditions that lead to cytotoxicity and cell regeneration; and chloroform is not likely to be carcinogenic to humans by any routes of exposure at a dose level that does not cause cytotoxicity and cell regeneration. This weight-of-evidence conclusion indicates that noncarcinogenic effects from exposure to chloroform are the primary concern for human health, while carcinogenicity is secondary. This conclusion is supported by the finding that chloroform is not a strong mutagen and is not likely to cause cancer through a genotoxic mode of action (EPA/635/R-01/001). Thus, an oral slope factor has not been derived for chloroform and exposures that occur at or below the RfD will not result in cancer incidence at levels in excess of target health goals.

The IRIS database (EPA, 2007) reports an inhalation unit risk for chloroform of 2.3×10^{-5} $(\mu g/m^3)^{-1}$, which is equivalent to an inhalation slope factor of $0.081(mg/kg\text{-}day)^{-1}$. This inhalation slope factor is based on increased incidence of hepatocellular carcinomas in female mice dosed with chloroform by oral gavage. However, EPA cautions the use of this slope factor in the evaluation of the carcinogenicity of chloroform through the inhalation pathway, because this value was derived in 1987 and does not incorporate newer data or the EPA's guidelines for carcinogen risk assessment (EPA/630/P-03/001F). The EPA is currently working to revise the assessment for inhalation exposure.

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CHROMIUM (TOTAL, HEXAVALENT)

Chromium is a naturally occurring element found in rocks, soil, plants, animals, and in volcanic dust and gases. The most common environmental forms are chromium (0), chromium (III), and chromium (VI). Chromium (0), the metal chromium, is a gray solid and has a high melting point. This form is primarily used to make steel and other alloys. Chromium (III) is used to line high-temperature industrial furnaces. Chromium-containing compounds are used in many industrial processes, such as stainless-steel welding, chrome plating, and leather tanning (ATSDR, 2002).

Chromium (III) is considered an essential nutrient that helps to maintain normal metabolism of glucose, cholesterol, and fat in humans. The minimum human daily requirement of chromium for optimal health is not known, but a daily ingestion of 50 to 200 μg/day (0.0007 to 0.003 mg/kg bw/day) has been estimated to be safe and adequate. The long-term effects of eating diets low in chromium are difficult to evaluate (ATSDR, 2002).

The three major forms differ in their effects on health. Chromium (VI) is irritating, and short-term, high-level exposure can result in adverse effects at the site of contact, such as ulcers of the skin, irritation of the nasal mucosa and perforation of the nasal septum, and irritation of the gastrointestinal tract. Chromium (VI) may also cause adverse effects in the kidney and liver. Chromium (III) does not result in these effects and is the form that is an essential food nutrient when ingested in small amounts, although very large doses may be harmful. For example, ingesting large amounts can cause stomach upset and ulcers, convulsions, kidney and liver damage. Very limited data suggest that chromium (III) may have respiratory effects on humans. No data on chronic or subchronic effects of inhaled chromium (III) in animals can be found. Adequate reproductive and developmental toxicity data do not exist. Information on chromium (0) health effects is limited. Animal studies have found that inhalation exposure had increased frequencies of chromosomal aberrations and sister chromatid exchanges in peripheral lymphocytes (ATSDR, 2002).

The oral RfD for chromium (III) is 1.5 mg/kg-day based on a chronic rat feeding study and a NOAEL of 1,468 mg/kg-day. The uncertainty factor of 100 represents two 10-fold decreases in mg/kg bw-day dose that account for both the expected interhuman and interspecies variability to the toxicity of the chemical in lieu of specific data. An additional 10-fold modifying factor is applied to reflect database deficiencies. The overall confidence in this RfD assessment was rated low because of the lack of explicit detail on study protocol and results, the lack of high-dose supporting data, and the lack of an observed effect level. Thus, the RfD as given should be considered conservative (EPA, 2007).

Data are considered to be inadequate for development of an inhalation RfD for chromium (III) due to the lack of a relevant toxicity study addressing respiratory effects of chromium (III) (EPA, 2007). Data from animal studies have identified the respiratory tract as the primary target of chromium toxicity following inhalation of hexavalent chromium and these data have been used for development of an RfC for hexavalent chromium particulates. However, these data do not demonstrate that the effects observed following inhalation of hexavalent chromium particulates are relevant to inhalation of trivalent chromium, and these data are considered to be inappropriate for development of an RfC for trivalent chromium (EPA, 2007).

The oral RfD for chromium (VI) is 0.003 mg/kg-day based on a 1-year rat drinking water study and a NOAEL of 2.5 mg/kg-day. The uncertainty factor is 300. A factor of 10 each accounts for inter- and intra-species variability. An additional uncertainty factor of 3 was applied to

compensate for the less-than-lifetime exposure duration of the principal study. A modifying factor of 3 was also applied to account for concerns raised by other studies. The overall confidence in this RfD assessment was rated low because of the lack of explicit detail on study protocol and results, the lack of high-dose supporting data, and the lack of an observed effect level. Thus, the RfD as given should be considered conservative (EPA, 2006).

The oral toxicity factor is adjusted to characterize risk from the dermal exposure pathway. This adjustment is made to estimate the absorbed dose from the toxicity indices that are based on administered dose. The percent gastrointestinal absorption for chromium (VI) is 2.5 percent of the oral RfD as recommended in the *Supplemental Guidance for Dermal Risk Assessment*, resulting in a dermal RfD of 0.000075 mg/kg/day (EPA, 2004).

As described in EPA (2007) two inhalation RfCs have been derived for chromium (VI), one based on nasal mucosal atrophy following occupational exposures to chromic acid mists and dissolved hexavalent chromium aerosols, and a second based on lower respiratory effects following inhalation of chromium (VI) particulates in rats. For inhalation exposures to chromium (VI) in mists and aerosols, the RfC of 8×10^{-6} mg/m^3 is based on a human subchronic occupational study for upper respiratory effects caused by chromic acid mists and dissolved hexavalent chromium aerosols. The study LOAEL based on a TWA exposure to chromic acid was adjusted to account for continuous exposure and uncertainty factors of 3, 3, and 10 were applied to extrapolate from a subchronic to a chronic exposure, to account for extrapolation from a LOAEL to a NOAEL, and to account for interhuman variation, respectively. The total uncertainty factor applied to the LOAEL is 90. Inhalation of non-volatiles in the sweatlodge scenario was not quantitatively evaluated because of the uncertainties associated with calculating the concentrations of non-volatiles in the steam of a sweatlodge. However, if the pathway had been quantified, the inhalation RfC of 8×10^{-6} mg/m^3 could be used in this risk assessment to evaluate inhalation exposures to chromium (VI) in sweatlodge vapors.

EPA (2007) has also derived an inhalation RfC for chromium (VI) of 1×10^{-4} mg/m^3 to evaluate exposures to chromium (VI) in particulates and dusts. This value is based on a subchronic rat study that showed increased incidences of adverse effects on lung function. The inhalation RfC was calculated using the benchmark dose approach. An uncertainty factor of 300 was applied to the benchmark dose to account for pharmacodynamic differences, less-than-lifetime exposure, and variation in the human population. This RfC was not used in this risk assessment, because chromium (VI) was not selected as a COPC in soil and inhalation exposures to chromium (VI) in particulates and dusts were not evaluated.

Of the three forms of chromium of toxicological importance, chromium (VI) is the most toxic. Chromium (VI) is classified by the EPA as a Group A, human carcinogen by inhalation, based on evidence that indicates sufficient cancer data in both animals and humans. Several epidemiological studies found an association between chromium exposure and lung cancer. The inhalation cancer SF for total chromium (one-sixth ratio of chromium VI:III) is 42 (mg/kg-day)-1 and is based on benign and malignant stomach tumor data in female mice (EPA, 2007). The inhalation SF for chromium (VI) was derived by multiplying the total chromium value by 7, yielding a inhalation slope factor of 290 (mg/kg-day)$^{-1}$.

Hexavalent chromium is a carcinogen by inhalation, but not by ingestion. Hexavalent chromium was not selected as a COPC in soil and was not evaluated for noncarcinogenic or carcinogenic effects in soil. During regular domestic water use, inhalation of non-volatiles is insignificant and hexavalent chromium was evaluated only for its non-cancer hazards via ingestion. However, for

the sweatlodge scenario evaluated for Native American populations, even nonvolatile contaminants could be suspended in the steam created within the sweatlodge. However inhalation of non-volatiles in the sweatlodge scenario was not quantitatively evaluated because of the uncertainties associated with calculating the concentrations of non-volatiles in the steam of a sweatlodge. If the pathway had been quantified hexavalent chromium could be evaluated for carcinogenic effects using this slope factor.

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IODINE-129

Iodine is a naturally occurring element primarily found as iodine-127, its most stable form. Iodine-129 is one of two radioactive isotopes that form naturally in the upper atmosphere (EPA, 2002). Iodine-129 and iodine-131 are emitted as beta and gamma radiation during iodine's decay process. Iodine-129 can be found in wastes from nuclear power facilities and defense-related government facilities (EPA, 2002; ANL, 2005). Both iodine nuclide forms have also been produced during nuclear weapons testing. However, the amount of anthropogenic iodine-129 is still less than naturally occurring levels. Of the two types, iodine-129 is the form with a long enough half-life to warrant long-term concern. The radiation and half-life information for iodine-129 and iodine-131 are presented in the table below. Iodine-129 has a half-life of 16 million years compared to approximately 8 days for iodine-131 (ANL, 2005).

Isotope	Half-Life	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha (α)	Beta (β)	Gamma (γ)
Iodine-129	16 million years	0.00018	β	-	0.064	0.025
Iodine-131	8.0 days	130,000	β	-	0.19	0.38

NOTE: Values from (ANL, 2005).

Iodine is a basic component of the human diet and is taken into the human body through all exposure pathways. Historically, a significant pathway for iodine-129 and iodine-131 ingestion has been the consumption of fruits and vegetables or milk from an iodine-contaminated area. Incidents such as Chernobyl can expose populations in the fallout area to high concentrations of both types of iodine, as well as long-term exposure to iodine-129 through all pathways. Following ingestion and inhalation, iodine is readily absorbed by the bloodstream from both the gastrointestinal tract and lungs. Approximately 30 percent of iodine in the human body ends up in the thyroid gland where it is used in hormone production (ANL, 2005). The primary radiological concern related to iodine-129 is the risk associated with exposure to beta radiation, which varies based on the dose of iodine isotopes (EPA, 2002). As a result, the main health concerns from iodine-129 and iodine-131 radiation are the development of thyroid tumors. In addition, the uptake of radioactive iodine by the thyroid gland is inversely related to the amount of stable iodine available (EPA, 2002); thus, exposures to accidental releases of iodine isotopes are often treated by the ingestion of large doses of stable iodine. Stable iodine has its own health effects related to large doses that must also be considered in this treatment.

Iodine-129 is a Group A radionuclide, which are classified by the EPA as known human carcinogens. The lifetime cancer mortality risk coefficients for iodine-129 are presented in the previous table. Epidemiological studies for iodine-129 have shown children to be the group most susceptible to thyroid cancer. Cancer treatment from radioactive iodine exposure must be evaluated on a case-by-case basis. Treatment concerns center around the use of radiation to treat tumors caused by radioactive isotopes. Treatments are typically only initiated when the benefits outweigh the risks.

Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for iodine-129. The slope factors for iodine-129 is 3.2×10^{-10} risk per pCi for food ingestion, 1.5×10^{-10} risk per pCi for water ingestion, 6.1×10^{-11} risk per pCi for inhalation, and 6.1×10^{-9} risk per pCi for external effects (EPA, 2001).

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METHYLENE CHLORIDE

Methylene chloride, also known as dichloromethane, is a colorless liquid that has a mild sweet odor, evaporates easily, and does not easily burn. The odor threshold for methylene chloride in air is approximately 200 ppm. Methylene chloride is primarily used as an industrial solvent and paint stripper. It can be found in certain aerosol and pesticide products and is used in the manufacture of photographic film. The chemical may be found in some spray paints, automotive cleaners, and other household products. Methylene chloride does not appear to occur naturally in the environment. Most of the methylene chloride released to the environment results from its use as an end product by various industries and the use of aerosol products and paint removers in the home (ATSDR, 2000).

In humans, acute inhalation exposure to methylene chloride at concentrations of 300 ppm or greater is known to impair hearing and vision (Winneke, 1974). Exposure to 800 ppm or greater methylene chloride can slow reaction time, impair motor skills, and cause dizziness, nausea, and drunkenness (Stewart et al., 1972; Winneke, 1974). Dermal exposure to methylene chloride causes intense burning and mild redness of the skin. Methylene chloride has not been shown to cause cancer in humans with chronic inhalation exposures to vapors in the workplace. In animals, inhalation of methylene chloride has been shown to adversely affect the liver and kidneys of rats (Stewart et al., 1974), and the corneas of rabbits (Ballantyne et al., 1976).

The EPA has established an oral RfD for methylene chloride of 0.06 mg/kg-day, based on a study reporting histological alterations of the liver in rats exposed to 50, 125, and 250 mg/kg-day methylene chloride for 2 years (NCA, 1982). The oral RfD was calculated by applying an uncertainty factor of 100 (to account for interspecies extrapolation and intraspecies extrapolation to protect sensitive human populations) and a modifying factor of 1 to the reported NOAEL of 5.85 mg/kg-day. Although the study used to derive the RfD was given a high confidence rating, the overall confidence in the RfD is rated medium because only a few studies support the NOAEL (EPA, 2007).

The EPA has established an inhalation RfC for methylene chloride of 3.0 mg/m^3, based on a 2-year chronic exposure study reporting hepatic toxicity in rats exposed to methylene chloride (Nitschke et al., 1988). The inhalation RfC was calculated by applying an uncertainty factor of 100 (to account for interspecies extrapolation and intraspecies extrapolation to protect sensitive individuals) to the reported NOAEL of 694.8 mg/m^3.

The EPA has classified methylene chloride as a probable human carcinogen (Group B2) based on increased incidence of tumors in several organs of rats and mice, including the liver (NCA 1982; 1983), lung (NTP, 1986), mammary and salivary glands (Burek et al., 1984; NTP, 1986), and blood (NTP, 1986). This classification is supported by some positive genotoxicity data, although results in mammalian systems are generally negative. The oral slope factor for methylene chloride (calculated using data from the NCA and NTP studies) is 0.0075 $(mg/kg\text{-}day)^{-1}$. The inhalation slope factor for methylene chloride (calculated using data from the NTP study) is 4.7E-07 $(\mu g/cm^3)^{-1}$.

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NEPTUNIUM-237

Roughly twice as dense as lead, neptunium is an artificially produced metal created through neutron capture reactions by uranium. All 17 known isotopes are radioactive. Neptunium-237 has a half-life of 2.1 million years and releases alpha, beta, and gamma radiation as it decays (ANL, 2007).

The primary concern for exposure to neptunium-237 is the risk of exposure to ionizing alpha, beta, and gamma radiation. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for neptunium-237. The oral slope factor for neptunium-237 is 1.46×10^{-10} risk per pCi for soil ingestion, 1.77×10^{-8} risk per pCi for inhalation, and 5.36×10^{-8} risk per pCi for external effects (EPA, 2001).

Neptunium entering the bloodstream tends to be deposited in the skeleton but is also preferentially deposited in the liver and other soft tissues. Cancer may result from ionizing radiation emitted by neptunium deposits on the bone surfaces, liver, and soft tissues. The external risk posed by neptunium is predominantly due to its gamma radiation emissions and the radiation released by its short-lived decay product, protactinium-233. No non-ionizing radiation effects of neptunium were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on neptunium-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

NITRATE

Nitrate (NO_3^-) and nitrite (NO_2^-) are part of the naturally occurring nitrogen cycle. Microbial activity in soil or water breaks down wastes that contain organic nitrogen into ammonia, which are later oxidized to nitrate and nitrite. Nitrogen-containing compounds are generally soluble in soil and quickly enter the groundwater. Nitrite is then readily oxidized to its more toxic form of nitrate. Nitrate is naturally occurring in groundwater and surface waters; however, these levels can be raised significantly by contamination with nitrogen-containing fertilizers (including animal or human natural organic wastes or anhydrous ammonia). The use of shallow groundwater wells in the U.S. means that many humans have the potential to consume drinking water contaminated by nitrates. Nitrates are also naturally occurring in various foods including meats, vegetables, and prepared foods (e.g., sausages).

A condition known as "blue baby syndrome." which leads to bluish lips and sometimes death, affects infants less than 3 months old (ATSDR, 2001). This condition is often caused by formula that has been diluted with water from a water source with high nitrate levels. Since infants often have a higher gut pH, it enhances the conversion of ingested nitrate to the more toxic nitrite. It has been shown that the incidence of gastroenteritis with vomiting and diarrhea can exacerbate nitrite formation.

The toxicity associated with nitrate is the result of its conversion to nitrite. Nitrite in the bloodstream oxidizes the iron in hemoglobin from Fe(+2) to Fe(+3), resulting in methemoglobin (ATSDR, 2001). Methoglobin leads to reduced oxygen transport from the lungs to tissues because it does not bind with oxygen. It is not uncommon for individuals to have low levels of methemoglobin from 0.5 percent to 2.0 percent because blood has a large capacity to carry oxygen (ATSDR, 2001). As a result, even levels under 10 percent are not associated with any significant clinical signs (ATSDR, 2001). Concentrations that exceed 10 percent can lead to cyanosis (a bluish color to skin and lips), and concentrations that exceed 25 percent can lead to weakness, rapid pulse, and tachypnea (ATSDR, 2001). Methoglobin levels that exceed 50 percent to 60 percent may lead to death.

The NOAEL oral RfD of 1.6 mg/kg/day for nitrate was derived based on two studies in the 1950s, which determined that infantile methemoglobinemia only occurs at concentrations in water greater than 10 mg nitrate-nitrogen/L (EPA, 2007). The typical daily intake of an adult in the U.S. is about 75 mg/day (about 0.2 to 0.3 mg nitrate- nitrogen/kg/day) (ATSDR, 2001). The assigned uncertainty factor for nitrate is 1 because of the NOAEL value for humans is based on the most sensitive case (EPA, 2007).

A RfC for chronic inhalation exposure is not available at this time.

Carcinogenicity

The carcinogenicity of nitrate is not available at this time.

REFERENCES

ATSDR, 2001, *Case Studies in Environmental Medicine Nitrate/Nitrite Toxicity*, dated January 2001, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

PLUTONIUM

Plutonium is a radioactive metal that is produced when uranium absorbs an atomic particle. Small amounts of plutonium occur naturally, but large amounts have been produced in nuclear reactors. All plutonium isotopes are radioactive, and three common plutonium isotopes are plutonium-238, -239, and -240. Alpha, beta, and gamma radiation are released as plutonium decays (ATSDR, 1990; ANL, 2007). The half-lives of plutonium-238, plutonium-239, and plutonium-240 are 86 years, 24,000 years, and 6,500 years, respectively.

The primary concern for exposure to plutonium is the risk of exposure to ionizing alpha, beta, and gamma radiation. Ionizing radiation has been shown to be a human carcinogen, and the EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for plutonium isotopes -238, -239, and -240. The oral slope factors for plutonium-238, plutonium-239, and plutonium-240 are $2.72 \times 10\text{-}^{10}$, 2.76×10^{-10}, and 2.77×10^{-10} risk per pCi. For inhalation, the slope factors for plutonium-238, plutonium-239, and plutonium-240 are 3.36×10^{-8}, 3.33×10^{-8}, and 3.33×10^{-8} risk per pCi, respectively. For external effects, slope factors for these isotopes are 7.22×10^{-11}, 2.00×10^{-10}, and 6.98×10^{-11} risk per pCi, respectively.

Although plutonium has not definitively been shown to cause adverse health effects in humans, animal studies have reported increased lung, liver, and bone cancers, as well as adverse effects on the blood and immune system from plutonium exposure. Animal studies have also found lung diseases from short-term exposure to high concentrations of plutonium. No non-ionizing radiation effects of plutonium were identified (ATSDR, 1990). In the absence of relevant data, provisional non-cancer risk assessment values based on plutonium-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ATSDR, 1990, *Toxicological Profile for Plutonium*, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

RADIUM

Radium is an alkaline earth metal that has 25 isotopes with atomic weights ranging from -206 to -230; all of the radium isotopes are radioactive. The four naturally occurring radium isotopes are radium-223, radium-224, radium-226, and radium-228. Radium-223 and radium-224 are alpha emitters with relatively short half-lives of 11.4 and 3.6 days, respectively (ATSDR, 1990). Radium-226 is also an alpha emitter but has a very long half-life (1,600 years). Radium-228 is a beta emitter with a half-life of 5.7 years.

The primary concern for exposure to radium is the risk of exposure to ionizing radiation from alpha or beta particles. Ionizing radiation has been shown to be a human carcinogen, and the EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for radium isotopes. The oral slope factors for radium-223, radium-224, radium-226, and radium-228 are 2.34×10^{-10}, 1.49×10^{-10}, $2.95 \times 10\text{-}^{10}$, and 2.46×10^{-10} risk per pCi, respectively, and the inhalation slope factors are 3.60×10^{-9}, 2.25×10^{-9}, 2.72×10^{-9}, and 9.61×10^{-10} risk per pCi, respectively (EPA, 2001).

A number of adverse effects (including death, anemia, leukemia, and osteosarcomas) were observed in humans and animals following oral, inhalation, and/or dermal exposure to radium isotopes. These effects have been attributed to the ionizing radiation. No studies examining non-ionizing radiation effects of radium were identified (ATSDR, 1990;, EPA, 1988). In the absence of relevant data, provisional non-cancer and cancer risk assessment values based on radium-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ATSDR, 1990, *Toxicological Profile for Radium*, TP-90-22, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 1988, *Health Effects Assessment for Radium (226Ra, 228Ra, 224Ra)*, U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office, Cincinnati, Ohio.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TECHNETIUM-99

Essentially all of technetium found on earth is present as a result of human action. All isotopes of this silver-gray metal are radioactive and of its 10 major isotopes, only three are long-lived. The most important of these isotopes is technetium-99, with a half-life of 213,000 years. This isotope decays to the stable isotope ruthenium-99 by emitting a beta particle. With its long half-life, the radiation produced by this isotope is somewhat of less concern than other radioactive materials.

The primary concern for exposure to technetium is the risk of exposure to ionizing radiation from beta particles. Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for technetium-99. The oral slope factor for technetium-99 is 7.66×10^{-12} risk per pCi for soil ingestion, 1.41×10^{-11} risk per pCi for inhalation, and 8.14×10^{-11} risk per pCi for external effects (EPA, 2001).

Technetium pertechnetate (TcO4) is well absorbed by the intestines and lungs following ingestion or inhalation. After reaching the bloodstream, technetium pertechnetate preferentially deposits in the thyroid, stomach wall, and the liver (ANL, 2007). Specific target organs for technetium deposits vary depending on the chemical form of technetium. With no associated gamma radiation, technetium poses little external harm. No non-ionizing radiation effects of technetium-99 were identified. In the absence of relevant data, provisional non-cancer risk assessment values based on technetium-induced effects that are not attributable to ionizing radiation have not been derived.

REFERENCES

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Science Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TETRACHLOROETHYLENE

Tetrachloroethylene (PCE) is a synthetic chlorinated hydrocarbon used as an industrial solvent and degreaser. It is also extensively used in the dry cleaning and textile industries and as an intermediate in the manufacture of other chemicals (ATSDR, 1997). Chronic inhalation exposure of mice and rats to concentration of PCE resulted in liver cell carcinomas in male and female mice, an increased incidence of mononuclear cell leukemia in male and female rats, and an increase of renal tubular cell tumors in male rats (ATSDR, 1997).

The slope factors for PCE are not available on the IRIS database, although they are reported in the risk assessment issue paper for carcinogenicity information for tetrachloroethylene (NCEA in EPA, 1998) and in EPA Region 6's human health screening level tables (EPA, 2006). The oral slope factor as listed was 0.54 $(mg/kg\text{-}d)^{-1}$ and the inhalation SF was 0.021 $(mg/kg\text{-}d)^{-1}$ for PCE.

The chronic oral RfD of 1.0×10^{-2} mg/kg-day for PCE was derived based on a 6-week gavage study in mice that resulted in liver toxicity (EPA, 1998). The assigned uncertainty factor of 1,000 for PCE accounts for intraspecies variability and extrapolation of a subchronic effect level to its chronic equivalent. The RfD confidence level is considered medium (EPA, 1998). The inhalation RfD of 0.114 mg/kg-day used in the risk assessment was reported in the EPA Region 6 human health screening level tables (EPA, 2006).

REFERENCES

ATSDR, 1997, *Toxicological Profile for Tetrachloroethylene*, dated September 1997, U.S, Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 1998, *National Center for Environmental Assessment (NCEA) Risk Assessment Issue Papers on PCE and TCE*, dated November 1998, U.S. Environmental Protection Agency, Superfund Technical Support Center, Washington, D.C.

EPA, 2006, *EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*, dated December 14, 2006, U.S. Environmental Protection Agency, Dallas, Texas.

THALLIUM

Thallium is one of the more toxic metals. At varying concentrations, thallium affects the neurological, hepatic, and renal systems. Temporary hair loss and decreased visual abilities have occurred in the occupational setting after ingestion of thallium. Chronic effects from ingestion in humans have been reported (as case studies) to produce gastrointestinal effects, liver, and kidney damage, although the kidney evidence is weak (ATSDR, 1992).

Toxic Effects

The oral RfD of 6.6×10^{-5} mg/kg-day for thallium and compounds is reported by EPA (2006). An IRIS record is available for thallium sulfate (EPA, 2007). This compound was used by EPA (2006) to derive RfDs for thallium compounds. The RfD reported in IRIS for thallium sulfate is 8×10^{-5} mg/kg-day and is based on NOAEL from a 90-day study in rats by EPA (1986). The IRIS record notes that no histopathological effects were observed, nor were there any differences between control and experimental groups in body weight, weight gain, food consumption, or absolute and relative organ weights. Dose-related increases were reported for alopecia (hair loss), lacrimation (tearing), and exophthalmos (bulging of eyes). Possible subtle changes in blood chemistry were also reported including increased enzyme levels of serum glutamic oxaloacetic transaminase (SGOT) and lactate dehydrogenase (LDH), increased sodium, and decreased glucose (EPA, 1986). Not all changes were significantly different from controls for both sexes. EPA (1986) also concluded that liver function was probably not affected because of lack of changes in serum glutamic pyruvic transaminase (SGPT) levels, and none of the blood chemistry changes observed significantly affected the health of the animals. In addition, differences in blood chemistry parameters were greatest between treated animals receiving thallium sulfate and non-treated controls. Differences between animals receiving thallium sulfate and vehicle controls receiving water were more subtle.

The uncertainty factor is relatively high (3,000) and likely incorporates factors of 10 to account for interspecies conversion, extrapolation from a subchronic study, variation in individual sensitivity, and an additional modifying factor of 1. The chronic RfD was withdrawn from the IRIS database and is currently under review by the EPA. ATSDR (1992) reports general lack of animal and human data by all routes of exposure for thallium.

Carcinogenicity

Thallium is listed as a Class D carcinogen (EPA, 2003). The basis for the classification is a lack of carcinogenicity data available for either humans or animals. The two human studies reviewed by the EPA were judged inadequate to determine carcinogenic effects because one study had no exposure quantification data, a small sample size, and an unknown length of observation period, and the other study's evaluation of exposure did not include a measure of carcinogenic response.

REFERENCES

ATSDR, 1992, *Toxicological Profile for Thallium*, dated July 1992, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2006, *U.S. EPA Region 6 Human Health Medium-Specific Screening Levels 2007 and Supplemental Information*, dated December 14, 2006, U.S. Environmental Protection Agency, Dallas, Texas.

EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in April 2007, http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

THORIUM

Thorium is a metallic element in the actinide series; the atomic weight of the 12 thorium isotopes range from -223 to -234; all of the isotopes are radioactive. The predominant thorium isotope found in the environment is thorium-232; this isotope makes up 99.99 percent of the naturally occurring thorium. The other two thorium isotopes found in the environment are thorium-228 and thorium-230. Thorium-232, -228, and -230 are alpha emitters with half-lives of 1.4×10^{10} years, 1.91 years, and 7.54×10^{4} years, respectively.

The primary concern for exposure to thorium is the risk of exposure to ionizing radiation from alpha particles. Ionizing radiation has been shown to be a human carcinogen, and the EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slopes factors have been derived for thorium isotopes. The oral slope factors for thorium-228, thorium-230, and thorium-232 are 6.29×10^{-11}, 3.75×10^{-11}, and 3.28×10^{-11} risk per pCi, respectively and the inhalation slope factors are 9.45×10^{-8}, 1.72×10^{-8}, and 1.93×10^{-8} risk per pCi, respectively (EPA, 2001).

Most of the available data on the toxicity and carcinogenicity of thorium in humans are derived from individuals exposed to thorotrast (colloidal thorium-232 dioxide) administered intravenously as a radiological contrast medium. The most common adverse effects associated with thorotrast exposure are cirrhosis of the liver, hepatic tumors, and blood dyscrasias; these effects have been attributed to the alpha radiation (ATSDR, 1990). Respiratory effects and increased incidences of pancreatic, lung, and hematopoietic cancers have been reported in humans and animals following inhalation exposure to thorium (ATSDR, 1990); these effects have also been attributed to alpha radiation. No non-ionizing radiation effects of thorium were identified (ATSDR, 1990). In the absence of relevant data, provisional non-cancer and cancer risk assessment values were not derived for thorium-induced effects not attributable to ionizing radiation.

REFERENCES

ATSDR, 1990, *Toxicological Profile for Thorium*, TP-90-25, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Washington, D.C.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

TRICHLOROETHYLENE

Trichloroethylene (TCE) has been in commercial production for more than 75 years in the U.S.. TCE has been extensively used for degreasing of fabricated metal parts, in dry cleaning, and as a solvent for oils, resins, waxes, paints, lacquers, printing inks, fabric dyes, disinfectants, and as an intermediate in the manufacture of other chemicals.

The EPA recently evaluated health risks from exposure to TCE in a document titled *Trichloroethylene Health Risk Assessment: Synthesis and Characterization* (EPA/600/P-01/002A). This document is an external review draft to which EPA is soliciting comments and its findings are subject to change; however, its findings are used in this report as the latest available information for TCE.

Previous investigations suggested that TCE's cancer classification be on a B2 to C continuum, indicating that there was some evidence for its carcinogenicity in animals and no evidence in humans. However, EPA's recent review of the literature recommended that TCE be considered "highly likely" to produce cancer in humans and has proposed that TCE be classified as a B1 carcinogen – a probable human carcinogen with sufficient evidence in animals and limited evidence in humans. The reasons for the increased certainty in the chemical's ability to cause cancer in humans are due to new epidemiological evidence and new information on the ways in which TCE could be inducing cancer (modes of action). The information on TCE carcinogenicity is complex and consistent responses are not seen across species. The metabolism of TCE is also complex and various metabolites are likely involved in the carcinogenic process. In addition, humans are exposed to TCE metabolites from other sources than just TCE, and some researchers consider that background exposures to these metabolites may affect a person's response to TCE. There is also some evidence that the human population could have subpopulations that are particularly sensitive to TCE because of (1) genetic predisposition, (2) environmental factors such as the consumption of alcohol, and (3) age (i.e., children may be more sensitive than adults).

Five types of cancer in humans are potentially linked with TCE exposure: liver, kidney, lymph-hematopoietic, cervical, and prostate. Given the complexity of the cancer data, several studies with liver, kidney, and lymphoma cancer data (for which there is supporting animal information) were used to derive a range of slope factors from 0.02 $(mg/kg\text{-}day)^{-1}$ to 0.4 $(mg/kg\text{-}day)^{-1}$. The EPA considers that these slope factors represent "a middle range of risk estimates where confidence is greatest." The lower end of this range, 0.02 $(mg/kg\text{-}day)^{-1}$ is based on the incidence of kidney cancer in German cardboard workers exposed to TCE in the workplace, while the higher end is based on the incidence of non-Hodgkin's lymphoma in females exposed to TCE in their drinking water.

The external review draft also evaluated the non-cancer effects associated with TCE exposures. An inhalation RfD of 0.011 mg/kg-day was derived from five studies (four in humans and one in rodents) based on effects in the central nervous system, liver, and endocrine system (EPA/600/P-01/002A). The EPA has selected an uncertainty factor of 1,000 for this RfD to account for subchronic to chronic extrapolation, interspecies variability and intraspecies variability.

The EPA recommends an oral RfD of 0.0003 mg/kg-day based on central nervous system, liver, and endocrine effects in a subchronic mouse study. The NCEA used EPA's maximum uncertainty factor of 3,000 to adjust the study NOAEL to an oral RfD, by NCEA considered the data sufficiently equivocal that even an uncertainty factor of 5,000 might be appropriate (EPA/600/P-01/002A).

The U.S. Department of Defense (DOD) has published a critique of EPA's proposed slope factor range for TCE (AFIERA, 2001). In particular, they note that the upper end of the proposed recommended range, 0.4 $(mg/kg\text{-}day)^{-1}$, is based on a residential drinking water study where the confidence interval around the calculated relative risk included one. The relative risk is defined as the cancer incidence rate in the exposed population relative to an unexposed population. If the relative risk is one, cancer incidence rates are equal for the exposed and unexposed populations and the study cannot conclude that there is an increased association between cancer and site exposures relative to an unexposed population. Generally, if the confidence interval around the relative risk includes one, cancer incidence rates for the two populations (exposed and unexposed) are not significantly different. Therefore, the DOD review concluded there was insufficient evidence to conclude that TCE exposures in drinking water were associated with an increase in non-Hodgkins lymphoma and thus, no slope factor should be calculated based on that study. Only one study had non-Hodgkins lymphoma associated with TCE exposure.

The DOD review also criticized the study on which the low end of EPA's proposed slope factor range was based, which was an inhalation study where TCE exposures were associated with an increase in kidney cancer. The DOD noted that the particular study has been highly criticized in the open literature and concluded that without that study, the remaining data do not confirm an increased relative risk of kidney cancer from TCE exposure (AFIERA, 2001).

Because of the uncertainty surrounding the new proposed slope factor range, and because of the criticisms the health assessment document has received, currently the oral and inhalation slope factors derived by the California EPA (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA) for are generally being recommended for use in risk assessment. The slope factors derived by OEHHA are an inhalation slope factor of 0.007 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA (2002) and an oral slope factor of 0.013 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA (1999).

REFERENCES

AFIERA, 2001, *Critique of the U.S. Environmental Protection Agency's Draft Trichloroethylene Health Risk Assessment (EPA/600/P-01/002A)*, dated December 2001, Air Force Institute for Environment, Safety and Occupational Health Risk Analysis, Brooks Air Force Base, Texas.

EPA/600/P-01/002A, 2001, *Trichloroethylene Health Risk Assessment: Synthesis and Characterization*, External Review Draft, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

OEHHA, 1999, *Public Health Goal for Trichloroethylene in Drinking Water*, dated February 1999, California Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Sacramento, California.

OEHHA, 2002, *Air Toxics Hot Spots Program Risk Assessment Guidelines. Part II: Technical Support Document for Describing Available Cancer Potency Factors*, dated December 2002, California Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Sacramento, California.

TRITIUM

Tritium (H-3) is the only radioactive isotope of hydrogen. The most common forms are tritium gas and tritium oxide or "tritiated water." Tritium has a high specific activity and is produced both naturally and artificially. Tritium emits low-energy beta particles as it decays and has a half-life of 12 years (ANL, 2007).

The primary concern for tritium exposure is only if it ingested (especially in the form of tritiated water) because it cannot penetrate deeply into tissue or travel far in air. Once ingested, tritium may cause cell damage and lead to cancer. Ionizing radiation has been shown to be a human carcinogen, and the EPA classifies all radionuclides as Group A carcinogens (EPA, 2001). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for tritium. The slope factor s for tritium are 5.1×10^{-14} risk per pCi for water ingestion, 1.4×10^{-13} risk per pCi for food ingestion, 2.2×10^{-13} risk per pCi for soil ingestion, 5.6×10^{-14} risk per pCi for vapor inhalation, and 2×10^{-13} risk per pCi for particulate inhalation (EPA, 2001).

REFERENCES

ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analysis for Contaminated Areas*, dated March 2007, Argonne National Laboratory, Environmental Assessment Division, Argonne, Illinois.

EPA, 2001, *Update of Radionuclide Toxicity of the Health Effects Assessment Summary Tables (HEAST)*, dated April 16, 2001, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

URANIUM

Uranium is an actinide element that occurs naturally as one of three radioactive isotopes: uranium-238, uranium-235, and uranium-234. All three natural uranium isotopes decay by alpha particle emission. The term "natural uranium" refers to uranium that has a uranium isotopic composition reflecting the natural abundance of uranium-238, uranium-235, and uranium-234, as presented in the table below. This distinguishes natural uranium from other anthropogenic uranium isotope mixtures. The term "enriched uranium" refers to isotope mixtures that contain a higher percentage of the fissionable isotope, uranium-235 (and also uranium-234, a byproduct of the enrichment process), and a lower percentage of uranium-238 than natural uranium. Enriched uranium is produced as fuel for reactors and nuclear fission weapons. Other isotopes of uranium are produced by humans in controlled or uncontrolled (explosive) nuclear reactions (e.g., uranium isotopes -227 through -240).

Natural Abundances and Radioactive Half-Lives of Uranium Isotopes

Uranium Isotope	Natural Abundance	Radioactive Half-Life (years)
Uranium-238	99.27%	4.46×10^9
Uranium-235	0.72%	7.04×10^8
Uranium-234	0.0055%	2.45×10^5

NOTE: Values from (EPA/600/P-95-002FA).

The primary radiological concern related to uranium is the risk associated with exposure to ionizing radiation, which will vary with the dose of uranium, the isotopic form, and other factors that affect uranium bioavailability, tissue distribution, and retention. Ionizing radiation has been shown to be a carcinogen in humans, and the EPA classifies all radionuclides as Group A carcinogens (EPA, 1997). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for the naturally occurring isotopes of uranium (EPA, 1997). Natural uranium has a relatively low radioactivity (less than 1 μCi/g) compared to enriched uranium, which has a higher abundance of the more highly radioactive isotopes uranium-235 and uranium-234 and can have a radioactivity that is approximately 100 times that of natural uranium. Therefore, the radiological hazard of enriched uranium can be considerably greater than that of natural uranium.

Uranium occurs naturally predominantly in valence states +4 and +6, although valence states +2, +3, and +5 can also occur naturally or be produced by humans (EPA, 1988). Uranium compounds vary widely in their water solubility. Uranium oxides are practically soluble in water while salts of tetravalent (+4) and hexavalent (+6) uranium can be highly water soluble (Gindler, 1973). Differences in water solubility and other chemical properties can be expected to give rise to differences in bioavailability and dose-response relationships when intakes occur through either the inhalation or oral routes (EPA, 1988).

Non-cancer (RfD and RfC) and cancer risk values for natural uranium are not listed in the IRIS database (EPA, 1998) or in the *Health Effects Assessment Summary Tables* (HEAST) (EPA, 1997). Based on the NOAEL of 0.2 mg U/kg-day (Gilman et al., 1998a; 1998b; and 1998c), a provisional chronic oral RfD of 2×10^{-4} mg/kg-day was estimated by the Superfund Technical Support Center (2001). A chronic oral RfD of 3×10^{-3} mg U/kg-day for soluble uranium salts is in found in the IRIS database (EPA, 2007).

The EPA developed a health effects assessment for natural uranium (EPA, 1988) and drinking water standards for uranium (EPA, 2000). The ATSDR (1997) derived a chronic-duration inhalation minimum risk level (MRL) for uranium of 1.0×10^{-3} mg U/m^3 and an intermediate-duration oral MRL of 1.0×10^{-3} mg U/kg-day.

Derivation of a Provisional Oral RfD for Soluble Uranium Salts

Non-cancer (RfD and RfC) and cancer risk values for natural uranium are not listed on IRIS or in HEAST (EPA, 2007; 1997; 2001). A chronic oral RfD of 3×10^{-3} mg U/kg-day for soluble uranium salts is on IRIS (EPA, 2007). The available data on the inhalation toxicology of natural uranium compounds do not provide an adequate basis for deriving inhalation RfCs (EPA, 2007). The most substantial gap in the data are the lack of chronic inhalation studies of adequate quality that examine the respiratory tract as well as other suspected target organs such as the kidney. Based on chronic studies of natural uranium dioxide, it is possible that chronic exposures to 5 mg U/m^3 may have yielded either a chemical and/or radiological dose to the lung that was sufficient to induce injury to the respiratory tract.

Derivation of Provisional Cancer Risk Values for Inhalation of Soluble Uranium Salts

An increase risk of lung cancer has been observed in populations of uranium miners and uranium processing workers. However, this excess risk is thought to result, at least in part, if not primarily, from radiological exposures. Data are not adequate to assess the nonradiological carcinogenicity of natural uranium. The EPA classifies all radionuclides, including uranium, as Group A carcinogens (EPA, 1997). Based on the carcinogenicity of ionizing radiation, cancer slope factors have been derived for the naturally occurring isotopes of uranium.

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APPENDIX G

ATTACHMENT 6

NATIVE AMERICAN RISK CALCULATIONS

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APPENDIX G

ATTACHMENT 6

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Table 6-1. Native American Exposures (Nonradioactive Chemicals) Ingestion of Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard = CW x SIFnc / RfD
Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Water (CW)	µg/L	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Water (IR)	L/day	1.5	4	2	4
Exposure frequency (EF)	days/year	365	365	365	365
Exposure duration (ED)	years	6	64	6	64
Body weight (BW)	kg	16	70	16	70
Conversion Factor (CF)	mg/µg	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging time (non-cancer) (ATnc)	days	2,190	23,360	2,190	23,360
Averaging time (cancer) (ATc)	days	25550	25550	25550	25550
SIFnc = (IR*EF*ED*CF)/(BW*ATnc)	L-mg/µg-kg-d	9.38E-05	5.71E-05	1.25E-04	5.71E-05
IngFadj (Ingestion Adjusted Factor) = (IRch*EDch/BWch) + (IRa*EDa/BWa)	L-year/hr-kg	4.22	4.22	4.41	4.41
SIFc = (IngFadj*EF*CF)/ATc	L-mg/µg-kg-d	6.03E-05	6.03E-05	6.30E-05	6.30E-05

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.00E-04	1.30E-01
Chloroform	1.00E-02	--
Chromium III	1.50E+00	--
Chromium VI (groundwater)	3.00E-03	--
Methylene Chloride	6.00E-02	7.50E-03
Nitrate	1.60E+00	--
PCE	1.00E-02	5.40E-01
TCE	3.00E-04	1.30E-02
Uranium	3.00E-03	--

Total Inorganics Chemical	90th Percentile CW (µg/L)	Umatilla Intake$_{nc}$ Child (mg/kg-d)	Intake$_{nc}$ Adult (mg/kg-d)	Intake$_{c}$ Lifetime (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Lifetime	Yakama Intake$_{nc}$ child (mg/kg-d)	Intake$_{nc}$ adult (mg/kg-d)	Intake$_{c}$ lifetime (mg/kg-d)	HQ child	HQ adult	Cancer Risk lifetime
Carbon Tetrachloride	2900.00	2.72E-01	1.66E-01	1.75E-01	388.393	236.735	2.2E-02	3.63E-01	1.66E-01	1.83E-01	5.18E+02	236.735	2.3E-02
Chloroform	24.00	2.25E-03	1.37E-03	1.45E-03	0.225	0.137	--	3.00E-03	1.37E-03	1.51E-03	3.00E-01	0.137	--
Total Chromium	130.00	1.22E-02	7.43E-03	7.84E-03	0.008	0.005	--	1.63E-02	7.43E-03	8.18E-03	1.08E-02	0.005	--
Chromium VI	203.40	1.91E-02	1.16E-02	1.23E-02	6.356	3.874	--	2.54E-02	1.16E-02	1.28E-02	8.48E+00	3.874	--
Methylene Chloride	2.73	2.56E-04	1.56E-04	1.65E-04	0.004	0.003	1.2E-06	3.42E-04	1.56E-04	1.72E-04	5.70E-03	0.003	1.3E-06
Nitrate	81050.00	7.60E+00	4.63E+00	4.89E+00	4.749	2.895	--	1.01E+01	4.63E+00	5.10E+00	6.33E+00	2.895	--
PCE	2.50	2.34E-04	1.43E-04	1.51E-04	0.023	0.014	8.1E-05	3.13E-04	1.43E-04	1.57E-04	3.13E-02	0.014	8.5E-05
TCE	10.90	1.02E-03	6.23E-04	6.57E-04	3.406	2.076	8.5E-06	1.36E-03	6.23E-04	6.86E-04	4.54E+00	2.076	8.9E-06
Uranium	8.30	7.78E-04	4.74E-04	5.00E-04	0.259	0.158	--	1.04E-03	4.74E-04	5.22E-04	3.46E-01	0.158	--
Total					**403**	**246**	**2.3E-02**				**538**	**246**	**2.4E-02**

Table 6-2. Native American Exposures (Nonradioactive Chemicals) Inhalation of Vapor.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard = CA x SIFnc x VFw / RfD
Cancer Risk = CA x SIFc x VFw x CSF

Parameter	Unit	Umatilla Child	Umatilla Adult	Yakama Child	Yakama Adult
Chemical Concentration in Water (CW)	µg/L	chem-specific	chem-specific	chem-specific	chem-specific
Inhalation Rate (InhR)	m^3/day	8.2	30	16	26
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	64	6	64
Body Weight (BW)	kg	16	70	16	70
Conversion Factor (CF)	mg/µg	1.0E-03	1.0E-03	1.0E-03	1.0E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	23,360	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550	25,550	25,550	25,550
SIFnc = (InhR*EF*ED*CF)/(BW*ATnc)	m^3-mg/µg-kg-day	5.13E-04	4.29E-04	1.00E-03	3.71E-04
InhFadj (Inhalation Adjusted Factor) = (InhRch*EDch/BWch) + (InhRa*EDa/BWa)	m^3-yr/hr-kg	3.05E+01	3.05E+01	2.98E+01	2.98E+01
SIFc = (InhFadj*EF*CF)/ATc	m^3-mg/µg-kg-day	4.36E-04	4.36E-04	4.25E-04	4.25E-04

Chemical	RfDi (mg/kg-d)	CSFi $(mg/kg\text{-}d)^{-1}$	VFw* (L/m3)
Carbon Tetrachloride	--	5.3E-02	5.0E-01
Chloroform	1.3E-02	8.1E-02	5.0E-01
Chromium III	--	--	--
Chromium VI (groundwater)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	5.0E-01
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	5.0E-01
TCE	1.1E-02	7.0E-03	5.0E-01
Uranium	--	--	--

* A volatilization factor (VFw) of 0.5 is only applicable for volatile chemicals.

Dissolved Inorganics Chemical	90th Percentile CW (µg/L)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_c$ Lifetime (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Lifetime	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_c$ Lifetime (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Lifetime
Carbon Tetrachloride	2,900.00	7.43E-01	6.21E-01	6.32E-01	--	--	3.3E-02	1.45E+00	5.39E-01	6.17E-01	--	--	3.2E-02
Chloroform	24.00	6.15E-03	5.14E-03	5.23E-03	0.47	0.40	4.2E-04	1.20E-02	4.46E-03	5.10E-03	0.92	0.34	4.1E-04
Total Chromium	130.00	--	--	--	--	--	--	--	--	--	--	--	--
Chromium VI	203.40	--	--	--	--	--	--	--	--	--	--	--	--
Methylene Chloride	2.73	7.01E-04	5.86E-04	5.96E-04	0.0008	0.00068	9.5E-07	1.37E-03	5.08E-04	5.81E-04	0.0016	0.00059	9.3E-07
Nitrate	8,1050.00	--	--	--	--	--	--	--	--	--	--	--	--
PCE	2.50	6.41E-04	5.36E-04	5.45E-04	0.0058	0.0049	1.1E-05	1.25E-03	4.64E-04	5.32E-04	0.011	0.0042	1.1E-05
TCE	10.90	2.79E-03	2.34E-03	2.37E-03	0.25	0.21	1.7E-05	5.45E-03	2.02E-03	2.32E-03	0.50	0.18	1.6E-05
Uranium	8.30	--	--	--	--	--	--	--	--	--	--	--	--
Total					**0.73**	**0.61**	**3.3E-02**				**1.43**	**0.53**	**3.3E-02**

Table 6-3a. Native American Exposures (Nonradioactive Chemicals) Intermediate Dermal Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American Subsistence
Receptor Age: Children and Adults

Exposure Parameters		Units
Fraction absorbed	FA	unitless
Dermal permeability coefficient	PC	cm/hour
Concentration in surface water	CW	mg/m^3
Lag time per event	T event	hour/event
Time to reach steady state	t*	hours
Event duration	t event	hour/event
Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis	B	unitless
Absorbed dose per event	DA event	mg/cm^2-event

Formulas Used to Calculate Absorbed Dose per Event (DAevent):

ORGANIC CHEMICALS:

If $t_{event} \leq t^*$, then $DA_{event} = 2\ FA \times PC \times Cw\ (6 \times T_{event} \times t_{event}/Pi)^{0.5}$

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

INORGANIC CHEMICALS:

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

Chemical	FA	PC	Cw	T_{event}	t*	t_{event} hr/event		Pi	B	DAevent mg/cm^2-event	
	unitless	cm/hr	mg/cm^3	hr/event	hours	Adult	Child	unitless	unitless	Adult	Child
Carbon Tetrachloride	1	1.60E-02	2.90E-03	0.78	1.86	0.58	1	3.14	0.1	8.63E-05	1.13E-04
Chloroform	1	6.80E-03	2.40E-05	0.5	1.19	0.58	1	3.14	0	2.43E-07	3.19E-07
Total Chromium	--	0.001	1.30E-04	--	--	0.58	1	3.14	--	7.54E-08	1.30E-07
Chromium VI	--	2.00E-03	2.03E-04	--	--	0.58	1	3.14	--	2.36E-07	4.07E-07
Methylene Chloride	1	3.50E-03	2.73E-06	0.32	0.76	0.58	1	3.14	0	1.14E-08	1.57E-08
Nitrate	--	--	8.11E-02	--	--	0.58	1	3.14	--	--	--
PCE	1	3.30E-02	2.50E-06	0.91	2.18	0.58	1	3.14	0.2	1.66E-07	2.18E-07
TCE	1	1.20E-02	1.09E-05	0.58	1.39	0.58	1	3.14	0.1	2.10E-07	2.75E-07
Uranium	--	2.00E-03	8.30E-06	--	--	0.58	1	3.14	--	9.62E-09	1.66E-08

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Table 6-3b. Native American Exposures (Nonradioactive Chemicals) Dermal Contact with Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer HQ =DAevent x SIFnc / RfD
Cancer Risk = DAevent x SIFc x CSF

Parameter	Units	Umatilla		Yakama	
		Adult	Child	Adult	Child
Absorbed dose per event (DAevent)	(mg/cm^2-event)	chem-specific	chem-specific	chem-specific	chem-specific
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	64	6	64	6
Event Frequency (EV)	events/day	1	1	1	1
Surface Area Available for Contact (SA)	cm^2	18,000	6,600	18,000	6,600
Body Weight (BW)	kilograms	70	16.6	70	16.6
Averaging Time (non-cancer) (ATnc)	days	23,360	2,190	23,360	2,190
Averaging Time (cancer) (ATc)		25,550	25,550	25,550	25,550
SIFnc(child) = ((EF*EDc*SAc)/(BWc*ATnc-c))	ev-cm^2/kg-d	2.57E+02	3.98E+02	2.57E+02	3.98E+02
DFadj (Dermal Adjusted Factor) = (EDc*EFc*EVc*SAc/BWc)+(EDa*EFa*EVa*SAa/BWa)	ev-cm^2/kg	6.88E+06		6.88E+06	
SIFc(child/adult) = DFadj/ATc	ev-cm^2/kg-d	2.69E+02		2.69E+02	

Chemical	RfD-D (mg/kg-d)	CSF-D (mg/kg-d)$^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	2.0E-02	--
Chromium VI (groundwater)	7.5E-05	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	--	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	DA event (mg/cm^2-event) Child	DA event (mg/cm^2-event) Adult	Umatilla Intake$_{nc}$ Child (mg/kg-d)	Umatilla Intake$_{nc}$ Adult (mg/kg-d)	Umatilla Intake$_c$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Risk Child/Adult	Yakama Intake$_{nc}$ Child (mg/kg-d)	Yakama Intake$_{nc}$ Adult (mg/kg-d)	Yakama Intake$_c$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Risk Child/Adult
Carbon Tetrachloride	1.13E-04	8.63E-05	4.50E-02	2.22E-02	2.32E-02	64	32	3.02E-03	4.50E-02	2.22E-02	2.32E-02	64	32	3.02E-03
Chloroform	3.19E-07	2.43E-07	1.27E-04	6.25E-05	6.54E-05	0.0127	0.0062	--	1.27E-04	6.25E-05	6.54E-05	0.0127	0.0062	--
Total Chromium	1.30E-07	7.54E-08	5.17E-05	1.94E-05	2.03E-05	0.00265	0.00099	--	5.17E-05	1.94E-05	2.03E-05	0.00265	0.00099	--
Chromium VI	4.07E-07	2.36E-07	0.00016174	6.07E-05	6.35E-05	2.16	0.81	--	0.00016174	6.07E-05	6.35E-05	2.16	0.81	--
Methylene Chloride	1.57E-08	1.14E-08	6.24E-06	2.93E-06	3.07E-06	0.000104	0.000049	2.30E-08	6.24E-06	2.93E-06	3.07E-06	0.000104	0.000049	2.30E-08
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--	--
PCE	2.18E-07	1.66E-07	8.65E-05	4.26E-05	4.46E-05	0.0087	0.0043	2.41E-05	8.65E-05	4.26E-05	4.46E-05	0.0087	0.0043	2.41E-05
TCE	2.75E-07	2.10E-07	1.09E-04	5.39E-05	5.65E-05	0.36	0.18	7.34E-07	1.09E-04	5.39E-05	5.65E-05	0.36	0.18	7.34E-07
Uranium	1.66E-08	9.62E-09	6.60E-06	2.47E-06	2.59E-06	0.00220	0.00082	--	6.60E-06	2.47E-06	2.59E-06	0.00220	0.00082	--
Total						67	33	3.0E-03				67	33	3.0E-03

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Table 6-4a. Native American Exposures (Nonradioactive Chemicals)
Intermediate Sweatlodge Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Sweatlodge Vapor
Receptor Population: Native American Subsistence
Receptor Age: Adults

Formula for Volatile and Semi-volatile Organic Compounds:

$$C_v = C_w * VF_{org}$$

where,

$$VF_{org} = \frac{V_{w,total}}{2 * 2/3 * pi * r^3}$$

Formula for Nonvolatile and Chemicals and Radionuclides (except Tritium):

$$C_v = C_w * VF_{m,r}$$

where,

$$VF_{m,r} = \frac{MW_w * p^*}{R * T * \rho_w}$$

and,

$$p^* = EXP(18.3036-3816.44/(T-46.13))$$

Parameter	Definition (units)	Value
C_v	Concentration in sweatlodge vapor (mg/m^3)	chem.-specific
C_w	Concentration in groundwater (mg/L or pCi/L)	chem.-specific
$V_{w,total}$	total volume of water used to create steam (L)	4
r	radius of sweatlodge (m)	1
MW_w	molecular weight of water (g/gmole)	18
R	ideal gas law constant (mmHg*m^3/gmole*K)	0.06237
T	temperature of sweatlodge (K)	339
ρ_w	density of liquid water (g/L)	1,000
p^*	partial pressure of water at temp K (mmHg)	194.89
VF_{org}	**Vaporization factor, organic chemicals (L/m^3)**	**0.955**

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Table 6-4b. Native American Exposures (Nonradioactive Chemicals) Inhalation of Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater
Exposure Point: Sweatlodge
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard = CW x $VF_{(org\ or\ m,r)}$ x SIFnc / RfD
Cancer Risk = CW x $VF_{(org\ or\ m,r)}$ x SIFc x CSF

Parameter	Unit	Umatilla Adult	Yakama Adult
Chemical Concentration in Water (CW)	mg/L	chem-specific	chem-specific
Inhalation Rate (InhR)	m^3/day	30	26
Exposure Frequency (EF)	days/year	365	260
Event Time (ET)	hours/event	1	2
Event frequency (EvF)	events/day	1	1
Exposure Duration (ED)	years	68	68
Body Weight (BW)	kg	70	70
Conversion Factor (CF)	days/hour	4.2E-02	4.2E-02
Averaging Time (non-cancer) (ATnc)	days	24,820	24,820
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc = (InhR*EF*ED*ET*EvF*CF)/(BW*ATnc)	m^3/kg-day	1.79E-02	2.20E-02
SIFc = (InhR*EF*ED*ET*EvF*CF)/(BW*ATc)	m^3/kg-day	1.73E-02	2.14E-02

Chemical	RfDi (mg/kg-d)	CSFi $(mg/kg\text{-}d)^{-1}$	VF_{org} or $VF_{m,r}$ (L/m^3)
Carbon Tetrachloride	--	5.3E-02	0.955
Chloroform	1.3E-02	8.1E-02	0.955
Chromium III	--	--	--*
Chromium VI (aerosols)	2.3E-06	2.9E+02	--*
Methylene Chloride	8.6E-01	1.6E-03	0.955
Nitrate	--	--	0.955
PCE	1.1E-01	2.1E-02	0.955
TCE	1.1E-02	7.0E-03	0.955
Uranium	--	--	--[a]

Dissolved Inorganics Chemical	90th Percentile CW (mg/L)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_c$ Lifetime (mg/kg-d)	Umatilla HQ Adult	Umatilla Cancer Risk Lifetime	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_c$ Lifetime (mg/kg-d)	Yakama HQ Adult	Yakama Cancer Risk Lifetime
Carbon Tetrachloride	2.90	5.18E-02	5.03E-02	--	2.5E-03	6.39E-02	6.21E-02	--	3.1E-03
Chloroform	0.024	4.29E-04	4.16E-04	0.031	3.2E-05	5.29E-04	5.14E-04	0.039	4.0E-05
Total Chromium	0.13	--*	--*	--*	--*	--*	--*	--*	--*
Chromium VI	0.20	--*	--*	--*	--*	--*	--*	--*	--*
Methylene Chloride	0.0027	4.88E-05	4.74E-05	0.000054	7.2E-08	6.03E-05	5.86E-05	0.000067	9.0E-08
Nitrate	81.05	1.45E+00	1.41E+00	--	--	1.79E+00	1.74E+00	--	--
PCE	0.0025	4.46E-05	4.34E-05	0.00039	8.7E-07	5.51E-05	5.35E-05	0.00048	1.1E-06
TCE	0.0109	1.95E-04	1.89E-04	0.017	1.3E-06	2.40E-04	2.33E-04	0.021	1.6E-06
Uranium	0.0083	--*	--*	--*	--*	--*	--*	--*	--*
Total				**0.049**	**2.6E-03**			**0.060**	**3.2E-03**

* Inhalation of non-volatile chemicals in the sweatlodge was not evaluated.

Table 6-4c. Native American Exposures (Nonradioactive Chemicals) Dermal Contact with Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater
Exposure Point: Sweatlodge
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard (non-VOCs) = PC x [(SIFnc$_{(dissolved)}$ x Cw) + (SIFnc$_{(vapor)}$ x Cv)] / RfD
Cancer Risk (non-VOCs) = PC x [(SIFca$_{(dissolved)}$ x Cw) + (SIFca$_{(vapor)}$ x Cv)] x CSF
Non-Cancer Hazard (VOCs and SVOCs) = PC x SIFnc$_{(vapor)}$ x Cv / RfD
Cancer Risk (VOCs and SVOCs) = PC x SIFca$_{(vapor)}$ x Cvx CSF

Parameter	Units	RME Umatilla	RME Yakama
Permeability Constant (PC)	(cm/hour)	chem-specific	chem-specific
Exposure Frequency (EF)	days/year	365	260
Exposure Duration (ED)	years	68	68
Event Frequency (EV)	events/day	1	1
Exposure Time (ET)	hours/event	1	2
Surface Area Available for Contact (SA)	cm^2	18,000	18,000
Conversion Factor 1 (CF1)	m^3/cm^3	0.000001	0.000001
Conversion Factor 2 (CF2)	L/cm^3	0.001	0.001
Body Weight (BW)	kilograms	70	70
Averaging Time (non-cancer) (ATnc)	days	24,820	24,820
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc(dissolved) = SA*ET*EV*EF*ED*CF2/(BW*ATnc)	hour-L/cm-kg-day	2.6E-01	3.7E-01
SIFnc(vapor) = SA*ET*EV*EF*ED*CF1/(BW*ATnc)	hour-m^3/cm-kg-day	2.6E-04	3.7E-04
SIFca(dissolved) = SA*ET*EV*EF*ED*CF2/(BW*ATca)	hour-L/cm-kg-day	2.5E-01	3.6E-01
SIFca(vapor) = SA*ET*EV*EF*ED*CF1/(BW*ATca)	hour-m^3/cm-kg-day	2.5E-04	3.6E-04

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$	PC (cm/hr)	VF_{org} or $VF_{in,r}$ (L/m^3)	VOC or SVOC?
Carbon Tetrachloride	7.0E-04	1.3E-01	1.6E-02	0.955414013	y
Chloroform	1.0E-02	--	6.8E-03	0.955414013	y
Chromium III	2.0E-02	--	1.0E-03	--*	n
Chromium VI (groundwater)	7.5E-05	--	2.0E-03	--*	n
Methylene Chloride	6.0E-02	7.5E-03	3.5E-03	0.955414013	y
Nitrate	--	--	--	0.955414013	n
PCE	1.0E-02	5.4E-01	3.3E-02	0.955414013	y
TCE	3.0E-04	1.3E-02	1.2E-02	0.955414013	y
Uranium	3.0E-03	--	2.0E-03	--*	n

Chemical	90th Percentile Dissolved GW Concentration Cw (mg/L)	90th Percentile Vapor Phase Concentration Cv (mg/m^3)	Umatilla Intake$_{nc}$ Child/Adult (mg/kg-d)	Umatilla Intake$_c$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla Risk Child/Adult	Yakama Intake$_{nc}$ Child/Adult (mg/kg-d)	Yakama Intake$_c$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama Risk Child/Adult
Carbon Tetrachloride	2.90E+00	2.77E+00	1.14E-05	1.11E-05	0.016	1.44E-06	1.62E-05	1.58E-05	0.023	2.05E-06
Chloroform	2.40E-02	2.29E-02	4.01E-08	3.89E-08	0.0000040	--	5.71E-08	5.55E-08	0.0000057	--
Total Chromium	1.30E-01	--[a]	3.34E-05	3.25E-05	0.0017	--	4.76E-05	4.63E-05	0.0024	--
Chromium VI	2.03E-01	--[a]	1.05E-04	1.02E-04	1.39	--	1.49E-04	1.45E-04	1.987	--
Methylene Chloride	2.73E-03	2.61E-03	2.35E-09	2.28E-09	0.000000039	1.71E-11	3.35E-09	3.25E-09	0.000000056	2.44E-11
Nitrate	8.11E+01	7.74E+01	--	--	--	--	--	--	--	--
PCE	2.50E-03	2.39E-03	2.03E-08	1.97E-08	0.0000020	1.06E-08	2.89E-08	2.81E-08	0.0000029	1.51E-08
TCE	1.09E-02	1.04E-02	3.21E-08	3.12E-08	0.0001071	4.06E-10	4.58E-08	4.45E-08	0.0001526	5.78E-10
Uranium	8.30E-03	--[a]	4.27E-06	4.14E-06	0.00142	--	6.08E-06	5.90E-06	0.0020	--
Total					1.4	1.5E-06			2.0	2.1E-06

* Inhalation of non-volatile chemicals in the sweatlodge was not evaluated.

Table 6-5. Native American Exposures (Nonradioactive Chemicals) Ingestion of Plant Tissue (from Irrigation Water).

Future

Exposure Medium: Groundwater (used for irrigation)
Exposure Point: Fruits and Vegetables
Receptor Population: Native American
Receptor Age: Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla Child	Umatilla Adult	Yakama Child	Yakama Adult
Chemical Concentration in Tissue (CTi)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/kg-day	--*	9.64	9.77	10.4
Fraction of Plant from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	9.64E-03	9.77E-03	1.04E-02
SIFc = (FC*EF*CF/ATc)*(IRc*Edc+IRa*Eda)	$(day)^{-1}$	9.64E-03		1.03E-02	

* No plant ingestion rate is provided for Umatilla child exposures.

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

1

Chemical	90th Percentile CTi (mg/kg)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_c$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Child/Adult	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_c$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Child/Adult
Carbon Tetrachloride	5.62E+01	--	5.42E-01	5.42E-01	--	774	6.8E-02	5.5E-01	5.84E-01	5.81E-01	784	834.6	7.3E-02
Chloroform	7.86E-01	--	7.57E-03	7.57E-03	--	0.76	--	7.7E-03	8.17E-03	8.13E-03	0.77	0.82	--
Total Chromium	1.68E+00	--	1.62E-02	1.62E-02	--	0.0108	--	1.6E-02	1.75E-02	1.74E-02	0.011	0.012	--
Chromium VI	2.63E+00	--	2.54E-02	2.54E-02	--	8	--	2.6E-02	2.74E-02	2.72E-02	8.6	9.1	--
Methylene Chloride	1.77E-01	--	1.71E-03	1.71E-03	--	0.028	1.3E-05	1.7E-03	1.84E-03	1.83E-03	0.03	0.03	1.4E-05
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
PCE	3.97E-02	--	3.83E-04	3.83E-04	--	0.038	2.1E-04	3.9E-04	4.13E-04	4.11E-04	0.04	0.04127	2.2E-04
TCE	2.59E-01	--	2.50E-03	2.50E-03	--	8	3.3E-05	2.5E-03	2.70E-03	2.68E-03	8	8.99	3.5E-05
Uranium	1.08E-01	--	1.04E-03	1.04E-03	--	0.35	--	1.1E-03	1.12E-03	1.12E-03	0.35	0.37	--
Total					--	792	6.8E-02				802	854	7.3E-02

Table 6-6. Native American Exposures (Nonradioactive Chemicals) Ingestion of Beef Tissue.

Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Beef Cattle
Receptor Population: Native American
Receptor Age: Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla		Yakama	
		child	adult	child	adult
Chemical Concentration in Tissue (CTi)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Beef Tissue (IR)	g/kg-day	--*	1.07	7.95	6.03
Fraction of Beef from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	1.07E-03	7.95E-03	6.03E-03
SIFc = (FC*EF*CF/ATc)*(IRc*Edc+IRa*Eda)	$(day)^{-1}$	1.07E-03		6.20E-03	

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

1 * No beef ingestion rate is provided for Umatilla child exposures.

Chemical	90th Percentile CTi (mg/kg)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_{c}$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Child/Adult	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_{c}$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Child/Adult
Carbon Tetrachloride	1.38E-02	--	1.48E-05	1.48E-05	--	0.0211	1.9E-06	1.1E-04	8.31E-05	8.54E-05	0.16	0.11872	1.1E-05
Chloroform	2.45E-05	--	2.63E-08	2.63E-08	--	0.0000026	--	1.9E-07	1.48E-07	1.52E-07	0.000019	0.000015	--
Total Chromium	2.40E-01	--	2.57E-04	2.57E-04	--	0.00017	--	1.9E-03	1.45E-03	1.49E-03	0.0013	0.00097	--
Chromium VI	3.76E-01	--	4.03E-04	4.03E-04	--	0.134	--	3.0E-03	2.27E-03	2.33E-03	0.996	0.756	--
Methylene Chloride	9.92E-07	--	1.06E-09	1.06E-09	--	0.000000018	8.0E-12	7.9E-09	5.99E-09	6.15E-09	0.00000013	0.00000010	4.6E-11
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
PCE	3.77E-05	--	4.03E-08	4.03E-08	--	0.0000040	2.2E-08	3.0E-07	2.27E-07	2.33E-07	0.000030	0.00002272	1.3E-07
TCE	2.39E-05	--	2.56E-08	2.56E-08	--	0.000085	3.3E-10	1.9E-07	1.44E-07	1.48E-07	0.00063	0.000481	1.9E-09
Uranium	5.13E-04	--	5.50E-07	5.50E-07	--	0.000183	--	4.1E-06	3.10E-06	3.18E-06	0.00136	0.00103	--
Total					--	0.16	1.9E-06				1.156	0.87734	1.1E-05

Table 6-7. Native American Exposures (Nonradioactive Chemicals) Ingestion of Dairy Products.

Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Dairy Cattle
Receptor Population: Native American
Receptor Age: Adults

Non-Cancer Hazard = CMi x SIFnc / RfD
Cancer Risk = CMi x SIFc x CSF

Parameter	Unit	Umatilla child	Umatilla adult	Yakama child	Yakama adult
Chemical Concentration in Milk (CM)	mg/kg	chem-specific		chem-specific	
Ingestion Rate of Milk Products (IR)	g/kg-day	--*	--*	32.19	17.66
Fraction of Dairy Cattle from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	--	3.22E-02	1.77E-02
SIFc = (FC*EF*CF/ATc)*(IRc*EDc+IRa*EDa)	$(day)^{-1}$	--		1.89E-02	

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (groundwater)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

1 * No milk ingestion rate is provided for Umatilla.

Chemical	90th Percentile CM (mg/kg)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_{c}$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Child/Adult	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_{c}$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Child/Adult
Carbon Tetrachloride	6.49E-03	--	--	--	--	--	--	2.1E-04	1.15E-04	1.23E-04	0.30	0.1638	1.6E-05
Chloroform	1.14E-05	--	--	--	--	--	--	3.7E-07	2.02E-07	2.16E-07	0.000037	0.000020	--
Total Chromium	4.04E-04	--	--	--	--	--	--	1.3E-05	7.13E-06	7.64E-06	0.0000087	0.000005	--
Chromium VI	6.32E-04	--	--	--	--	--	--	2.0E-05	1.12E-05	1.19E-05	0.0068	0.0037	--
Methylene Chloride	4.54E-07	--	--	--	--	--	--	1.5E-08	8.02E-09	8.59E-09	0.00000024	0.00000013	6.4E-11
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
PCE	1.78E-05	--	--	--	--	--	--	5.7E-07	3.15E-07	3.37E-07	0.0000574	0.00003149	1.8E-07
TCE	1.12E-05	--	--	--	--	--	--	3.6E-07	1.98E-07	2.12E-07	0.0012	0.000660	2.8E-09
Uranium	1.03E-03	--	--	--	--	--	--	3.3E-05	1.82E-05	1.95E-05	0.0111	0.0061	--
Total					--	--	--				0.32	0.17431	1.6E-05

Table 6-8. Summary of Umatilla Cancer Risk Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration											
Carbon Tetrachloride	2900	2.2E-02	3.3E-02	3.0E-03	5.8E-02	2.5E-03	1.4E-06	2.5E-03	1.9E-06	6.8E-02	c
Chloroform	24	b	4.2E-04	b	4.2E-04	3.2E-05	b	3.2E-05	b	b	c
Chromium III	130	b	a	b	--	d	b	--	b	b	c
Chromium VI (groundwater)	203.4	b	a	b	--	d	b	--	b	b	c
Methylene Chloride	2.734	1.2E-06	9.5E-07	2.3E-08	2.2E-06	7.2E-08	1.7E-11	7.3E-08	8.0E-12	1.3E-05	c
Nitrate	81050	b	b	b	--	b	b	--	b	b	c
PCE	2.5	8.1E-05	1.1E-05	2.4E-05	1.2E-04	8.7E-07	1.1E-08	8.8E-07	2.2E-08	2.1E-04	c
TCE	10.9	8.5E-06	1.7E-05	7.3E-07	2.6E-05	1.3E-06	4.1E-10	1.3E-06	3.3E-10	3.3E-05	c
Uranium	8.295	b	a	b	--	d	b	--	b	b	c
	TOTAL	2.3E-02	3.3E-02	3.0E-03	5.9E-02	2.6E-03	1.5E-06	2.6E-03	1.9E-06	6.8E-02	c
50th Percentile Groundwater Concentration											
Carbon Tetrachloride	505	3.9E-03	5.7E-03	5.3E-04	1.0E-02	4.4E-04	2.5E-07	4.4E-04	3.3E-07	1.2E-02	c
Chloroform	6.4	b	1.1E-04	b	1.1E-04	8.6E-06	b	8.6E-06	b	b	c
Chromium III	10.3	b	a	b	--	d	b	--	b	b	c
Chromium VI (groundwater)	10.9	b	a	b	--	d	b	--	b	b	c
Methylene Chloride	0.185	8.4E-08	6.4E-08	1.6E-09	1.5E-07	4.9E-09	1.2E-12	4.9E-09	5.4E-13	8.7E-07	c
Nitrate	21900	B	b	b	--	b	b	--	b	b	c
PCE	0.36	1.2E-05	1.6E-06	3.5E-06	1.7E-05	1.3E-07	1.5E-09	1.3E-07	3.1E-09	3.0E-05	c
TCE	1.7	1.3E-06	2.6E-06	1.1E-07	4.0E-06	2.0E-07	6.3E-11	2.0E-07	5.2E-11	5.1E-06	c
Uranium	1.18	b	a	b	--	d	b	--	b	b	c
	TOTAL	3.9E-03	5.9E-03	5.3E-04	1.0E-02	4.5E-04	2.5E-07	4.5E-04	3.4E-07	1.2E-02	c
25th Percentile Groundwater Concentration											
Carbon Tetrachloride	6.525	5.1E-05	7.4E-05	6.8E-06	1.3E-04	5.7E-06	3.2E-09	5.7E-06	4.3E-09	1.5E-04	c
Chloroform	0.58	b	1.0E-05	b	1.0E-05	7.8E-07	b	7.8E-07	b	b	c
Chromium III	3.6	b	a	b	--	d	b	--	b	b	c
Chromium VI (groundwater)	7	b	a	b	--	d	b	--	b	b	c
Methylene Chloride	0.12	5.4E-08	4.2E-08	1.0E-09	9.7E-08	3.2E-09	7.5E-13	3.2E-09	3.5E-13	5.6E-07	c
Nitrate	14000	b	b	B	--	b	b	--	b	b	c
PCE	0.18	5.9E-06	8.2E-07	1.7E-06	8.4E-06	6.3E-08	7.7E-10	6.3E-08	1.6E-09	1.5E-05	c
TCE	0.155	1.2E-07	2.4E-07	1.0E-08	3.7E-07	1.8E-08	5.8E-12	1.8E-08	4.7E-12	4.6E-07	c
Uranium	0.808	b	a	b	--	d	b	--	b	b	c
	TOTAL	5.7E-05	8.5E-05	8.5E-06	1.5E-04	6.6E-06	4.0E-09	6.6E-06	5.9E-09	1.7E-04	c
Average Groundwater Concentration											
Carbon Tetrachloride	1009.346901	7.8E-03	1.1E-02	1.1E-03	2.0E-02	8.9E-04	5.0E-07	8.9E-04	6.7E-07	2.4E-02	c
Chloroform	10.65784854	b	1.9E-04	b	1.9E-04	1.4E-05	b	1.4E-05	b	b	c
Chromium III	50.47738949	b	a	b	--	d	b	--	b	b	c
Chromium VI (groundwater)	74.88172414	b	a	b	--	d	b	--	b	b	c
Methylene Chloride	8.176735395	3.7E-06	2.9E-06	6.9E-08	6.6E-06	2.2E-07	5.1E-11	2.2E-07	2.4E-11	3.8E-05	c
Nitrate	44750.15468	b	b	b	--	b	b	--	b	b	c
PCE	2.528977663	8.2E-05	1.2E-05	2.4E-05	1.2E-04	8.8E-07	1.1E-08	8.9E-07	2.2E-08	2.1E-04	c
TCE	4.749072165	3.7E-06	7.2E-06	3.2E-07	1.1E-05	5.5E-07	1.8E-10	5.5E-07	1.5E-10	1.4E-05	c
Uranium	10.14	b	a	b	--	d	b	--	b	b	c
	TOTAL	7.9E-03	1.2E-02	1.1E-03	2.1E-02	9.0E-04	5.1E-07	9.0E-04	6.9E-07	2.4E-02	c

Table 6-8. Summary of Umatilla Cancer Risk Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
UCL95 Groundwater Concentration											
Carbon Tetrachloride	1491.25435	1.2E-02	1.7E-02	1.6E-03	3.0E-02	1.3E-03	7.4E-07	1.3E-03	9.9E-07	3.5E-02	c
Chloroform	19.04887518	b	3.4E-04	b	3.4E-04	2.6E-05	b	2.6E-05	b	b	c
Chromium III	74.3007144	b	a	b	--	d	b	--	b	b	c
Chromium VI (groundwater)	176.203697	b	a	b	--	d	b	--	b	b	c
Methylene Chloride	20.0438464	9.1E-06	7.0E-06	1.7E-07	1.6E-05	5.3E-07	1.3E-10	5.3E-07	5.8E-11	9.4E-05	c
Nitrate	63187.22787	b	b	b	--	b	b	--	b	b	c
PCE	4.865663035	1.6E-04	2.2E-05	4.7E-05	2.3E-04	1.7E-06	2.1E-08	1.7E-06	4.2E-08	4.0E-04	c
TCE	7.165849848	5.6E-06	1.1E-05	4.8E-07	1.7E-05	8.3E-07	2.7E-10	8.3E-07	2.2E-10	2.1E-05	c
Uranium	29.45	b	a	b	--	d	b	--	b	b	c
	TOTAL	1.2E-02	1.7E-02	1.6E-03	3.1E-02	1.3E-03	7.6E-07	1.3E-03	1.0E-06	3.5E-02	c

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = Chemical not associated with carcinogenic effects through this pathway from groundwater.
c = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
d = Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.
-- = no value to sum

Table 6-9. Summary of Umatilla Non-Cancer Hazard Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
90th Percentile Groundwater Concentration																		
Carbon Tetrachloride	2,900	388	237	b	b	64	32	453	268	b	0.016	0.0163	c	0.021	c	774	d	d
Chloroform	24	0.23	0.137	0.47	0.40	0.0127	0.0062	0.71	0.54	0.031	0.0000040	0.0315	c	0.0000026	c	0.76	d	d
Chromium III	130	0.0081	0.0050	a	a	0.00265	0.00099	0.0108	0.0059	f	0.0017	0.0017	c	0.00017	c	0.011	d	d
Chromium VI (groundwater)	203.4	6	4	a	a	2.16	0.81	9	5	f	1.4	1.4	c	0.134	c	8.5	d	d
Methylene Chloride	2.734	0.0043	0.0026	0.0008	0.00068	0.000104	0.000049	0.0052	0.0033	0.0000542	0.000000039	0.000054	c	0.000000018	c	0.02845	d	d
Nitrate	81,050	4.75	2.89	b	b	b	b	5	3	b	b	--	c	e	c	e	d	d
PCE	2.5	0.023	0.0143	0.0058	0.0049	0.0087	0.0043	0.038	0.023	0.0003877	0.0000020	0.00039	c	0.0000040	c	0.0383	d	d
TCE	10.9	3	2	0.25	0.21	0.36	0.18	4.03	2.47	0.01691	0.00011	0.0170	c	0.000085	c	8.34	d	d
Uranium	8.295	0.26	0.16	a	a	0.00220	0.00	0.26	0.159	f	0.00142	0.0014	c	0.00018	c	0.35	d	d
TOTAL		403	246	0.73	0.61	67	33	471	279	0.049	1.4	1.5	c	0.16	c	792	d	d
50th Percentile Groundwater Concentration																		
Carbon Tetrachloride	505	68	41	b	b	11	6	79	47	b	0.003	0.0028	c	0.0037	c	135	d	d
Chloroform	6.4	0.06	0.037	0.13	0.11	0.0034	0.0017	0.19	0.14	0.008	0.0000011	0.0084	c	0.0000007	c	0.20	d	d
Chromium III	10.3	0.0006	0.0004	a	a	0.00021	0.00008	0.0009	0.0005	f	0.0001	0.00014	c	0.000014	c	0.001	d	d
Chromium VI (groundwater)	10.9	0.34	0.21	a	a	0.12	0.04	0.46	0.25	f	0.075	0.075	c	0.0072	c	0.5	d	d
Methylene Chloride	0.185	0.00029	0.00018	0.00006	0.00005	0.000007	0.000003	0.0004	0.0002	0.0000037	0.000000003	0.000004	c	0.000000001	c	0.00193	d	d
Nitrate	21,900	1.28	0.78	b	b	b	b	1.3	0.8	b	b	--	c	e	c	e	d	d
PCE	0.36	0.003	0.0021	0.0008	0.0007	0.0012	0.0006	0.005	0.003	0.0000558	0.00000029	0.00006	c	0.0000006	c	0.0055	d	d
TCE	1.7	0.53	0.32	0.04	0.03	0.06	0.03	0.63	0.38	0.00264	0.000017	0.0027	c	0.0000133	c	1.30	d	d
Uranium	1.18	0.04	0.02	a	a	0.00031	0.00012	0.04	0.023	f	0.0002	0.0002	c	0.000026	c	0.05	d	d
TOTAL		70	43	0.2	0.14	11	6	81	48	0.011	0.078	0.089	c	0.011	c	137	d	d
25th Percentile Groundwater Concentration																		
Carbon Tetrachloride	6.525	0.87	0.53	b	b	0.14	0.07	1	1	b	0.000	0.0000	c	0.000047	c	2	d	d
Chloroform	0.58	0.01	0.003	0.0114	0.0096	0.00031	0.00015	0.02	0.01	0.001	0.0000001	0.0008	c	0.000000063	c	0.02	d	d
Chromium III	3.6	0.0002	0.0001	a	a	0.000073	0.000028	0.0003	0.0002	f	0.000047	0.000047	c	0.0000048	c	0.000	d	d
Chromium VI (groundwater)	7	0.22	0.13	a	a	0.074	0.028	0.29	0.16	f	0.048	0.048	c	0.0046	c	0.3	d	d
Methylene Chloride	0.12	0.0002	0.0001	0.000036	0.000030	0.0000046	0.0000021	0.0002	0.0001	0.0000024	0.000000002	0.000002	c	0.0000000008	c	0.00125	d	d
Nitrate	14,000	0.82	0.50	b	b	b	b	1	1	b	b	--	c	e	c	e	d	d
PCE	0.18	0.002	0.0010	0.00042	0.00035	0.00062	0.00031	0.003	0.002	0.0000279	0.00000015	0.00003	c	0.00000029	c	0.0028	d	d
TCE	0.155	0	0.03	0.0036	0.0030	0.0052	0.0026	0.06	0.04	0.00024	0.000002	0.0002	c	0.0000012	c	0.12	d	d
Uranium	0.808	0.03	0.02	a	a	0.00021	0.00008	0.03	0.015	f	0.00014	0.00014	c	0.000018	c	0.03	d	d
TOTAL		2.0	1.2	0.015	0.013	0.23	0.10	2	1	0.001	0.048	0.049	c	0.0047	c	2.2	d	

Table 6-9. Summary of Umatilla Non-Cancer Hazard Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
Average Groundwater Concentration																		
Carbon Tetrachloride	1009.346901	135	82	b	b	22	11	158	93	b	0.006	0.0057	c	0.0073	c	269	d	d
Chloroform	10.65784854	0.10	0.061	0.21	0.18	0.0056	0.0028	0.32	0.24	0.014	0.0000018	0.0140	c	0.0000012	c	0.34	d	d
Chromium III	50.47738949	0.0032	0.0019	a	a	0.00103	0.00039	0.0042	0.0023	f	0.00067	0.00067	c	0.000067	c	0.004	d	d
Chromium VI (groundwater)	74.88172414	2.34	1.43	a	a	0.79	0.30	3.13	1.72	f	0.51	0.51	c	0.049	c	3.1	d	d
Methylene Chloride	8.176735395	0.0128	0.0078	0.00244	0.00204	0.000311	0.000146	0.0155	0.0100	0.0001622	0.000000117	0.000162	c	0.000000053	c	0.08509	d	d
Nitrate	44750.15468	2.62	1.60	b	b	b	b	3	2	b	b	--	c	e	c	e	d	d
PCE	2.528977663	0.024	0.0145	0.0059	0.0049	0.0088	0.0043	0.038	0.024	0.0003922	0.00000205	0.00039	c	0.0000041	c	0.0387	d	d
TCE	4.749072165	1	0.90	0.11	0.09	0.16	0.08	1.75	1.08	0.00737	0.000047	0.0074	c	0.000037	c	3.63	d	d
Uranium	10.14	0.32	0.19	a	a	0.00269	0.00101	0.32	0.194	f	0.0017	0.0017	c	0.00022	c	0.42	d	d
TOTAL		142	87	0.3	0.28	23	11	166	98	0.022	0.52	0.54	c	0.057	c	277	d	d
UCL95 Groundwater Concentration																		
Carbon Tetrachloride	1491.25435	200	122	b	b	33	16	233	138	b	0.008	0.0084	c	0.011	c	398	d	d
Chloroform	19.04887518	0.18	0.109	0.38	0.31	0.0101	0.0050	0.56	0.43	0.025	0.0000032	0.0250	c	0.0000021	c	0.60	d	d
Chromium III	74.3007144	0.0046	0.0028	a	a	0.00151	0.00057	0.0062	0.0034	f	0.0010	0.0010	c	0.00010	c	0.006	d	d
Chromium VI (groundwater)	176.203697	5.51	3.36	a	a	1.87	0.70	7.37	4.06	f	1.2	1.2	c	0.116	c	7.3	d	d
Methylene Chloride	20.0438464	0.0313	0.0191	0.00597	0.00499	0.000762	0.000358	0.0381	0.0244	0.0003976	0.000000287	0.000398	c	0.00000013	c	0.20858	d	d
Nitrate	63187.22787	3.70	2.26	b	b	b	b	4	2	b	b	--	c	e	c	e	d	d
PCE	4.865663035	0.046	0.0278	0.0113	0.0095	0.0168	0.0083	0.074	0.046	0.0007547	0.00000394	0.00076	c	0.0000079	c	0.0745	d	d
TCE	7.165849848	2	1.36	0.17	0.14	0.24	0.12	2.65	1.62	0.01111	0.000070	0.0112	c	0.000056	c	5.48	d	d
Uranium	29.45	0.92	0.56	a	a	0.00781	0.00293	0.93	0.564	f	0.00505	0.00505	c	0.00065	c	1.23	d	d
TOTAL		212	129	0.6	0.47	35	17	248	147	0.037	1.2	1.3	c	0.13	c	413	d	d

a Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b No toxicity criteria are available for this chemical to quantify non-cancer hazards through this pathway of exposure.
c The Umatilla do not provide child-specific ingestion rates.
d The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
e Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
f Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.
-- = no value to sum

Table 6-10. Summary of Yakama Nation Cancer Risk Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration											
Carbon Tetrachloride	2900	2.3E-02	3.2E-02	3.0E-03	5.9E-02	3.1E-03	2.1E-06	3.1E-03	1.1E-05	7.3E-02	1.6E-05
Chloroform	24	b	4.1E-04	b	4.1E-04	4.0E-05	b	4.0E-05	b	b	b
Chromium III	130	b	a	b	--	c	b	--	b	b	b
Chromium VI (groundwater)	203.4	b	a	b	--	c	b	--	b	b	b
Methylene Chloride	2.734	1.3E-06	9.3E-07	2.3E-08	2.2E-06	9.0E-08	2.4E-11	9.0E-08	4.6E-11	1.4E-05	6.4E-11
Nitrate	81050	b	b	b	--	b	b	--	b	b	b
PCE	2.5	8.5E-05	1.1E-05	2.4E-05	1.2E-04	1.1E-06	1.5E-08	1.1E-06	1.3E-07	2.2E-04	1.8E-07
TCE	10.9	8.9E-06	1.6E-05	7.3E-07	2.6E-05	1.6E-06	5.8E-10	1.6E-06	1.9E-09	3.5E-05	2.8E-09
Uranium	8.295	b	a	b	--	c	b	--	b	b	b
	TOTAL	2.4E-02	3.3E-02	3.0E-03	5.9E-02	3.2E-03	2.1E-06	3.2E-03	1.1E-05	7.3E-02	1.6E-05
50th Percentile Groundwater Concentration											
Carbon Tetrachloride	505	4.1E-03	5.6E-03	5.3E-04	1.0E-02	5.5E-04	3.6E-07	5.5E-04	1.9E-06	1.3E-02	2.8E-06
Chloroform	6.4	b	1.1E-04	b	1.1E-04	1.1E-05	b	1.1E-05	b	b	b
Chromium III	10.3	b	a	b	--	c	b	--	b	b	b
Chromium VI (groundwater)	10.9	b	a	b	--	c	b	--	b	b	b
Methylene Chloride	0.185	8.7E-08	6.3E-08	1.6E-09	1.5E-07	6.1E-09	1.7E-12	6.1E-09	3.1E-12	9.3E-07	4.4E-12
Nitrate	21900	b	b	b	--	b	b	--	b	b	b
PCE	0.36	1.2E-05	1.6E-06	3.5E-06	1.7E-05	1.5E-07	2.2E-09	1.6E-07	1.8E-08	3.2E-05	2.6E-08
TCE	1.7	1.4E-06	2.5E-06	1.1E-07	4.0E-06	2.4E-07	9.0E-11	2.4E-07	3.0E-10	5.4E-06	4.3E-10
Uranium	1.18	b	a	b	--	c	b	--	b	b	b
	TOTAL	4.1E-03	5.7E-03	5.3E-04	1.0E-02	5.6E-04	3.6E-07	5.6E-04	2.0E-06	1.3E-02	2.8E-06
25th Percentile Groundwater Concentration											
Carbon Tetrachloride	6.525	5.3E-05	7.2E-05	6.8E-06	1.3E-04	7.1E-06	4.6E-09	7.1E-06	2.5E-08	1.6E-04	3.6E-08
Chloroform	0.58	b	1.0E-05	b	1.0E-05	9.6E-07	b	9.6E-07	b	b	b
Chromium III	3.6	b	a	b	--	c	b	--	b	b	b
Chromium VI (groundwater)	7	b	a	b	--	c	b	--	b	b	b
Methylene Chloride	0.12	5.7E-08	4.1E-08	1.0E-09	9.9E-08	3.9E-09	1.1E-12	3.9E-09	2.0E-12	6.0E-07	2.8E-12
Nitrate	14000	b	b	b	--	b	b	--	b	b	b
PCE	0.18	6.1E-06	8.0E-07	1.7E-06	8.7E-06	7.7E-08	1.1E-09	7.8E-08	9.1E-09	1.6E-05	1.3E-08
TCE	0.155	1.3E-07	2.3E-07	1.0E-08	3.7E-07	2.2E-08	8.2E-12	2.2E-08	2.7E-11	5.0E-07	3.9E-11
Uranium	0.808	b	a	b	--	c	b	--	b	b	b
	TOTAL	5.9E-05	8.3E-05	8.5E-06	1.5E-04	8.1E-06	5.7E-09	8.1E-06	3.4E-08	1.8E-04	4.9E-08

Table 6-10. Summary of Yakama Nation Cancer Risk Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat	Plant	Milk
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total	Ingestion	Ingestion	Ingestion
Average Groundwater Concentration											
Carbon Tetrachloride	1009.346901	8.2E-03	1.1E-02	1.1E-03	2.0E-02	1.1E-03	7.1E-07	1.1E-03	3.9E-06	2.5E-02	5.6E-06
Chloroform	10.65784854	b	1.8E-04	b	1.8E-04	1.8E-05	b	1.8E-05	b	b	b
Chromium III	50.47738949	b	a	b	--	c	b	--	b	b	b
Chromium VI (groundwater)	74.88172414	b	a	b	--	c	b	--	b	b	b
Methylene Chloride	8.176735395	3.9E-06	2.8E-06	6.9E-08	6.7E-06	2.7E-07	7.3E-11	2.7E-07	1.4E-10	4.1E-05	1.9E-10
Nitrate	44750.15468	b	b	b	--	b	b	--	b	b	b
PCE	2.528977663	8.6E-05	1.1E-05	2.4E-05	1.2E-04	1.1E-06	1.5E-08	1.1E-06	1.3E-07	2.2E-04	1.8E-07
TCE	4.749072165	3.9E-06	7.1E-06	3.2E-07	1.1E-05	6.8E-07	2.5E-10	6.8E-07	8.4E-10	1.5E-05	1.2E-09
Uranium	10.14	b	a	b	--	c	b	--	b	b	b
	TOTAL	8.3E-03	1.1E-02	1.1E-03	2.1E-02	1.1E-03	7.3E-07	1.1E-03	4.0E-06	2.6E-02	5.7E-06
UCL95 Groundwater Concentration											
Carbon Tetrachloride	1491.25435	1.2E-02	1.7E-02	1.6E-03	3.0E-02	1.6E-03	1.1E-06	1.6E-03	5.7E-06	3.7E-02	8.2E-06
Chloroform	19.04887518	b	3.3E-04	b	3.3E-04	3.2E-05	b	3.2E-05	b	b	b
Chromium III	74.3007144	b	a	b	--	c	b	--	b	b	b
Chromium VI (groundwater)	176.203697	b	a	b	--	c	b	--	b	b	b
Methylene Chloride	20.0438464	9.5E-06	6.8E-06	1.7E-07	1.6E-05	6.6E-07	1.8E-10	6.6E-07	3.4E-10	1.0E-04	4.7E-10
Nitrate	63187.22787	b	b	b	--	b	b	--	b	b	b
PCE	4.865663035	1.7E-04	2.2E-05	4.7E-05	2.3E-04	2.1E-06	2.9E-08	2.1E-06	2.5E-07	4.3E-04	3.5E-07
TCE	7.165849848	5.9E-06	1.1E-05	4.8E-07	1.7E-05	1.0E-06	3.8E-10	1.0E-06	1.3E-09	2.3E-05	1.8E-09
Uranium	29.45	b	a	b	--	c	b	--	b	b	b
	TOTAL	1.2E-02	1.7E-02	1.6E-03	3.1E-02	1.7E-03	1.1E-06	1.7E-03	6.0E-06	3.8E-02	8.6E-06

a Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b Chemical not associated with carcinogenic effects through this pathway from groundwater.
c Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.
-- = no value to sum

Table 6-11. Summary of Yakama Nation Non-Cancer Hazard Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
90th Percentile Groundwater Concentration																		
Carbon Tetrachloride	2,900	518	237	b	b	64	32	582	268	b	0.023	0.0232	0.16	0.12	784	835	0.30	0.16
Chloroform	24	0.30	0.137	0.92	0.34	0.0127	0.0062	1.24	0.49	0.039	0.0000057	0.0389	0.000019	0.000015	0.77	0.82	0.000037	0.00002
Chromium III	130	0.0108	0.005	a	a	0.00265	0.00099	0.0135	0.0059	d	0.0024	0.0024	0.00127	0.00097	0.011	0.012	0.0000087	0.0000048
Chromium VI (groundwater)	203.4	8	4	a	a	2.16	0.81	11	5	d	2.0	2.0	0.996	0.756	8.6	9.1	0.0068	0.0037
Methylene Chloride	2.734	0.0057	0.0026	0.0016	0.00059	0.000104	0.000049	0.0074	0.0032	0.000067	0.000000056	0.000067	0.00000013	0.0000001	0.0288	0.03069	0.00000024	0.00000013
Nitrate	81,050	6.33	2.89	b	b	b	b	6	3	b	b	--	c	c	c	c	c	c
PCE	2.5	0.031	0.0143	0.0114	0.0042	0.0087	0.0043	0.051	0.023	0.0004788	0.0000029	0.00048	0.00003	0.000023	0.0388	0.0413	0.000057	0.000031
TCE	10.9	5	2	0.50	0.18	0.36	0.18	5.40	2.44	0.02087	0.00015	0.021	0.00063	0.00048	8.45	8.99	0.00120	0.00066
Uranium	8.295	0.35	0.16	a	a	0.00220	0.00082	0.35	0.159	d	0.002	0.002	0.0014	0.0010	0.35	0.37	0.0111	0.0061
TOTAL		538	246	1.4	0.53	67	33	606	279	0.06	2.0	2.1	1.16	0.88	802	854	0.32	0.17
50th Percentile Groundwater Concentration																		
Carbon Tetrachloride	505	90	41	b	b	11	6	101	47	b	0.004	0.0040	0.03	0.02	137	145	0.05	0.03
Chloroform	6.4	0.08	0.037	0.25	0.09	0.0034	0.0017	0.33	0.13	0.010	0.0000015	0.0104	0.000005	0.000004	0.20	0.22	0.00001	0.000005
Chromium III	10.3	0.0009	0.0004	a	a	0.00021	0.00008	0.0011	0.0005	d	0.0002	0.0002	0.00010	0.00008	0.001	0.001	0.0000007	0.0000004
Chromium VI (groundwater)	10.9	0.45	0.21	a	a	0.12	0.04	0.57	0.25	d	0.11	0.11	0.053	0.041	0.5	0.5	0.0004	0.0002
Methylene Chloride	0.185	0.00039	0.00018	0.00011	0.00004	0.000007	0.000003	0.0005	0.0002	0.0000045	0.000000004	0.000005	0.00000001	0.00000001	0.0020	0.00208	0.00000002	0.00000001
Nitrate	21,900	1.71	0.78	b	b	b	b	2	1	b	b	--	c	c	c	c	c	c
PCE	0.36	0.005	0.0021	0.0016	0.0006	0.0012	0.0006	0.007	0.003	0.0000689	0.00000042	0.00007	0.000004	0.000003	0.0056	0.0059	0.000008	0.000005
TCE	1.7	0.71	0.32	0.08	0.03	0.06	0.03	0.84	0.38	0.00326	0.000024	0.0033	0.00010	0.00007	1.32	1.40	0.00019	0.00010
Uranium	1.18	0.05	0.02	a	a	0.00031	0.00012	0.05	0.023	d	0.0003	0.0003	0.0002	0.0001	0.05	0.05	0.0016	0.0009
TOTAL		93	43	0.3	0.12	11	6	105	48	0.014	0.11	0.12	0.08	0.06	139	148	0.05	0.03
25th Percentile Groundwater Concentration																		
Carbon Tetrachloride	6.525	1.17	0.53	b	b	0.14	0.07	1	1	b	0.00005	0.0001	0.0004	0.0003	2	2	0.00067	0.00037
Chloroform	0.58	0.01	0.003	0.0223	0.0083	0.00031	0.00015	0.03	0.01	0.001	0.0000001	0.0009	0.0000005	0.0000004	0.02	0.02	0.00000089	0.00000049
Chromium III	3.6	0.0003	0.0001	a	a	0.000073	0.000028	0.0004	0.0002	d	0.000	0.0001	0.00004	0.00003	0.000	0.000	0.00000024	0.00000013
Chromium VI (groundwater)	7	0.29	0.13	a	a	0.074	0.028	0.37	0.16	d	0.068	0.068	0.034	0.026	0.3	0.3	0.00023	0.00013
Methylene Chloride	0.12	0.0003	0.0001	0.00007	0.000026	0.0000046	0.0000021	0.0003	0.0001	0.00000	0.000000002	0.000003	0.00000001	0.000000004	0.0013	0.00135	0.000000011	0.000000006
Nitrate	14,000	1.09	0.50	b	b	b	b	1	1	b	b	--	c	c	c	c	c	c
PCE	0.18	0.002	0.001	0.00082	0.0003	0.00062	0.00031	0.004	0.002	0.0000345	0.00000021	0.00003	0.000002	0.000002	0.0028	0.003	0.0000041	0.0000023
TCE	0.155	0.0646	0.0295	0.0070	0.0026	0.0052	0.0026	0.0768	0.03	0.00030	0.0000022	0.0003	0.0000090	0.00001	0.12	0.13	0.000017	0.000009
Uranium	0.808	0.03	0.02	a	a	0.00021	0.00008	0.03	0.015	d	0.00020	0.0002	0.0001	0.0001	0.03	0.04	0.0011	0.00059
TOTAL		2.7	1.2	0.030	0.011	0.23	0.10	3	1	0.0013	0.069	0.070	0.03	0.03	2.2	2.4	0.0020	0.0011

Table 6-11. Summary of Yakama Nation Non-Cancer Hazard Results for Nonradionuclides in Groundwater. (2 sheets)

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat		Plant		Milk	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total	Ingestion		Ingestion		Ingestion	
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
Average Groundwater Concentration																		
Carbon Tetrachloride	1009.346901	180	82	b	b	22	11	203	93	b	0.008	0.0081	0.05	0.04	273	290	0.10	0.06
Chloroform	10.65784854	0.13	0.061	0.41	0.15	0.0056	0.0028	0.55	0.22	0.017	0.0000025	0.0173	0.000009	0.000007	0.34	0.36	0.000016	0.000009
Chromium III	50.47738949	0.0042	0.0019	a	a	0.00103	0.00039	0.0052	0.0023	d	0.0009	0.0009	0.00049	0.00038	0.004	0.005	0.0000034	0.0000018
Chromium VI (groundwater)	74.88172414	3.12	1.43	a	a	0.79	0.30	3.91	1.72	d	0.7	0.7	0.367	0.278	3.2	3.4	0.0025	0.0014
Methylene Chloride	8.176735395	0.017	0.0078	0.00475	0.00177	0.000311	0.000146	0.0221	0.0097	0.0002003	0.000000167	0.0002	0.00000039	0.0000003	0.0862	0.09180	0.00000073	0.00000040
Nitrate	44750.15468	3.50	1.6	b	b	b	b	3	2	b	b	--	c	c	c	c	c	c
PCE	2.528977663	0.032	0.0145	0.0115	0.0043	0.0088	0.0043	0.052	0.023	0.0004843	0.00000292	0.00049	0.000030	0.000023	0.0392	0.0418	0.000058	0.000032
TCE	4.749072165	2	0.90	0.22	0.08	0.16	0.08	2.35	1.06	0.00909	0.000066	0.0092	0.00028	0.00021	3.68	3.92	0.00052	0.00029
Uranium	10.14	0.42	0.19	a	a	0.00269	0.00101	0.43	0.194	d	0.00248	0.0025	0.0017	0.0013	0.43	0.46	0.0135	0.0074
TOTAL		189	87	0.6	0.24	23	11	213	98	0.027	0.74	0.77	0.42	0.32	281	299	0.12	0.07
UCL95 Groundwater Concentration																		
Carbon Tetrachloride	1491.25435	266	122	b	b	33	16	299	138	b	0.012	0.0119	0.08	0.06	403	429	0.15	0.08
Chloroform	19.04887518	0.24	0.109	0.73	0.27	0.0101	0.0050	0.98	0.39	0.031	0.0000045	0.0309	0.000015	0.000012	0.61	0.65	0.000029	0.000016
Chromium III	74.3007144	0.0062	0.0028	a	a	0.00151	0.00057	0.0077	0.0034	d	0.0014	0.0014	0.00073	0.00055	0.006	0.007	0.0000050	0.0000027
Chromium VI (groundwater)	176.203697	7.34	3.36	a	a	1.87	0.70	9.21	4.06	d	1.7	1.7	0.863	0.655	7.4	7.9	0.0059	0.0032
Methylene Chloride	20.0438464	0.0418	0.0191	0.01165	0.00433	0.000762	0.000358	0.0542	0.0238	0.0004910	0.000000409	0.000491	0.00000096	0.00000073	0.2114	0.22502	0.00000179	0.00000098
Nitrate	63187.22787	4.94	2.26	b	b	b	b	5	2	b	b	--	c	c	c	c	c	c
PCE	4.865663035	0.061	0.0278	0.0221	0.0082	0.0168	0.0083	0.1	0.044	0.0009318	0.00000562	0.00094	0.000058	0.000044	0.0755	0.0803	0.000112	0.000061
TCE	7.165849848	3	1.36	0.33	0.12	0.24	0.12	3.55	1.60	0.01372	0.000100	0.0138	0.00042	0.00032	5.55	5.91	0.00079	0.00043
Uranium	29.45	1.23	0.56	a	a	0.00781	0.00293	1.23	0.564	d	0.00719	0.0072	0.0048	0.0037	1.25	1.33	0.0392	0.0215
TOTAL		283	129	1.1	0.41	35	17	319	147	0.046	1.7	1.8	0.95	0.72	418	445	0.20	0.11

a Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b No toxicity criteria are available for this chemical to quantify non-cancer hazards through this pathway of exposure.
c Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
d Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.

-- = no value to sum

Table 6-12. Native American Exposures (Radioactive Chemicals) Ingestion of Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Ingestion Rate of Water (IR)	L/day	4	4
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*EF*ED)	L	1.02E+05	1.02E+05

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.5E-10
Tc-99	2.75E-12
Tritium	5.07E-14

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk lifetime	Yakama Cancer Risk lifetime
Iodine-129	1.2	1.8E-05	1.8E-05
Tc-99	1,442	4.1E-04	4.1E-04
Tritium	36,200	1.9E-04	1.9E-04
TOTAL		**6.1E-04**	**6.1E-04**

Table 6-13. Native American Exposures (Radioactive Chemicals) Inhalation of Vapor.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CA x SIFc x VF x CSF

Parameter	Units	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Inhalation Rate of Air (InhR)	m^3/day	30	26
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (InhR*EF*ED*VF)	m^3	7.7E+05	6.6E+05

Chemical	CSFi (risk/pCi)	VF (L/m3)
I-129 (non-dairy)	1.60E-10	--
Tc-99	--	--
Tritium	5.62E-14	0.011675

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk lifetime	Yakama Cancer Risk lifetime
Iodine-129	1.17	--	--
Tc-99	1,442	--	--
Tritium	36,200	1.8E-05	1.6E-05
Total		**1.8E-05**	**1.6E-05**

Table 6-14a. Native American Exposures (Radioactive Chemicals) Intermediate Sweatlodge Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Sweatlodge Vapor
Receptor Population: Native American
Receptor Age: Adults

Formula for Volatile and Semi-volatile Organic Compounds:

$$C_v = C_w * VF_{org}$$

where,

$$VF_{org} = \frac{V_{w,total}}{2 * 2/3 * pi * r^3}$$

Formula for Nonvolatile and Chemicals and Radionuclides (except Tritium):

$$C_v = C_w * VF_{m,r}$$

where,

$$VF_{m,r} = \frac{MW_w * p^*}{R * T * p_w}$$

and,

$$p^* = EXP(18.3036-3816.44/(T-46.13))$$

Parameter	Definition (units)	Value
C_v	Concentration in sweatlodge vapor (mg/m^3)	chem -specific
C_w	Concentration in groundwater (mg/L or pCi/L)	chem -specific
$V_{w,total}$	total volume of water used to create steam (L)	4
r	radius of sweatlodge (m)	1
MW_w	molecular weight of water (g/gmole)	18
R	ideal gas law constant (mmHg*m^3/gmole*K)	0.06237
T	temperature of sweatlodge (K)	339
p_w	density of liquid water (g/L)	1,000
p^*	partial pressure of water at temp K (mmHg)	194.89
VF_{org}	**Vaporization factor, organic chemicals (L/m^3)**	**0.955**
$VF_{m,r}$	**Vaporization factor, metals and radionuclides (L/m^3)**	**0.166**

Table 6-14b. Native American Exposures (Radioactive Chemicals) Inhalation of Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater
Exposure Point: Sweatlodge
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CA x $VF_{(org\ or\ m,r)}$ x SIFc x CSF

Parameter	Units	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Inhalation Rate of Air (InhR)	m^3/day	30	26
Event Time (ET)	hours/event	1	2
Event frequency (EvF)	events/day	1	1
Exposure Frequency (EF)	days/year	365	260
Exposure Duration (ED)	years	68	68
Conversion Factor (CF)	days/hour	4.2E-02	4.2E-02
SIFc = (InhR*EF*ED*ET*EvF*CF)	m^3	3.1E+04	3.8E+04

Chemical	CSFi (risk/pCi)	VF_{org} or $VF_{m,r}$ (L/m^3)
I-129 (non-dairy)	1.60E-10	--*
Tc-99	1.41E-11	--*
Tritium	5.62E-14	0.955

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1.17	--*	--*
Tc-99	1,442	--*	--*
Tritium	36,200	6.0E-05	7.4E-05
Total		**6.0E-05**	**7.4E-05**

* Inhalation of non-volatile constituents in the sweatlodge was not evaluated.

Table 6-15. Native American Exposures (Radioactive Chemicals) Ingestion of Plant Tissue.

Current/Future

Exposure Medium: Plant Tissue
Exposure Point: Plants
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Tissue (CTi)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/day	675	709
Fraction of Plant from Contaminated Source (FC)	unitless	1	1
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*FC*EF*ED)	g	1.72E+07	1.81E+07

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
Tc-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1.53E-02	4.3E-05	4.5E-05
Tc-99	1.96E+02	1.3E-02	1.4E-02
Tritium	9.50E+02	2.4E-03	2.5E-03
Total		**1.6E-02**	**1.7E-02**

Table 6-16. Native American Exposures (Radioactive Chemicals) Ingestion of Livestock Animal Tissue.

Future

Exposure Medium: Animal Tissue
Exposure Point: Livestock
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Tissue (CTi)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Animal Tissue (IR)	g/day	75	422.4
Fraction of Tissue from Contaminated Source (FC)	unitless	1	1
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*FC*EF*ED)	g	1.92E+06	1.08E+07

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
Tc-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	9.82E-03	3.0E-06	1.7E-05
Tc-99	2.43E+00	1.9E-05	1.0E-04
Tritium	3.62E+01	1.0E-05	5.6E-05
Total		**3.2E-05**	**1.8E-04**

Table 6-17. Native American Exposures (Radioactive Chemicals) Ingestion of Milk.

Future

Exposure Medium: Milk
Exposure Point: Milk
Receptor Population: Native American
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Milk (CM)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Milk (IR)	g/day	--*	1236
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*EF*ED)	g	--	3.16E+07

* No milk ingestion rate is provided for Umatilla.

Chemical	CSFo (risk/pCi)
I-129 (dairy)	3.22E-10
Tc-99	4.0E-12
Tritium	1.44E-13

Chemical	90th Percentile CM (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	0.004	--	4.5E-05
Tc-99	4.890	--	6.2E-04
Tritium	36.200	--	1.6E-04
Total		--	**8.3E-04**

Table 6-18. Summary of Umatilla Cancer Risk Results for Radionuclides in Groundwater.

COPC	Groundwater Concentration (pCi/L)	Tap Water			Sweatlodge	Meat	Plant	Milk
		Ingestion	Inhalation	Total	Inhalation	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration								
Iodine-129	1.170	1.8E-05	a	1.8E-05	d	3.0E-06	4.3E-05	c
Tc-99	1,442	4.1E-04	a	4.1E-04	d	1.9E-05	1.3E-02	c
Tritium	36,200	1.9E-04	1.8E-05	2.1E-04	6.0E-05	1.0E-05	2.4E-03	c
	TOTAL	6.1E-04	1.8E-05	6.3E-04	6.0E-05	3.2E-05	1.6E-02	c
50th Percentile Groundwater Concentration								
Iodine-129	0.030	4.6E-07	a	4.6E-07	d	7.8E-08	1.1E-06	c
Tc-99	180	5.1E-05	a	5.1E-05	d	2.3E-06	1.7E-03	c
Tritium	3,605	1.9E-05	1.8E-06	2.0E-05	6.0E-06	9.9E-07	2.3E-04	c
	TOTAL	7.0E-05	1.8E-06	7.2E-05	6.0E-06	3.4E-06	1.9E-03	c
25th Percentile Groundwater Concentration								
Iodine-129	ND	b	b	b	d	b	b	c
Tc-99	59	1.7E-05	a	1.7E-05	d	7.6E-07	5.5E-04	c
Tritium	513.75	2.7E-06	2.6E-07	2.9E-06	8.6E-07	1.4E-07	3.3E-05	c
	TOTAL	1.9E-05	2.6E-07	2.0E-05	8.6E-07	9.0E-07	5.8E-04	c
Average Groundwater Concentration								
Iodine-129	1.309	2.0E-05	a	2.0E-05	d	3.4E-06	4.8E-05	c
Tc-99	793.11	2.2E-04	a	2.2E-04	d	1.0E-05	7.4E-03	c
Tritium	51,030	2.6E-04	2.6E-05	2.9E-04	8.5E-05	1.4E-05	3.3E-03	c
	TOTAL	5.1E-04	2.6E-05	5.3E-04	8.5E-05	2.8E-05	1.1E-02	c
UCL95 Groundwater Concentration								
Iodine-129	2.408	3.7E-05	a	3.7E-05	d	6.2E-06	8.8E-05	c
Tc-99	1,160	3.3E-04	a	3.3E-04	d	1.5E-05	1.1E-02	c
Tritium	87,345	4.5E-04	4.4E-05	5.0E-04	1.5E-04	2.4E-05	5.7E-03	c
	TOTAL	8.2E-04	4.4E-05	8.6E-04	1.5E-04	4.5E-05	1.7E-02	c

a Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.

b I-129 was not detected in the 25th percentile of the groundwater concentrations.

c The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.

d Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.

Table 6-19. Summary of Yakama Nation Cancer Risk Results for Radionuclides in Groundwater.

COPC	Groundwater Concentration (pCi/L)	Tap Water			Sweatlodge	Meat	Plant	Milk
		Ingestion	Inhalation	Total	Inhalation	Ingestion	Ingestion	Ingestion
90th Percentile Groundwater Concentration								
Iodine-129	1.170	1.8E-05	a	1.8E-05	c	1.7E-05	4.5E-05	4.5E-05
Tc-99	1,442	4.1E-04	a	4.1E-04	c	1.0E-04	1.4E-02	6.2E-04
Tritium	36,200	1.9E-04	1.6E-05	2.0E-04	7.4E-05	5.6E-05	2.5E-03	1.6E-04
	TOTAL	6.1E-04	1.6E-05	6.3E-04	7.4E-05	1.8E-04	1.7E-02	8.3E-04
50th Percentile Groundwater Concentration								
Iodine-129	0.030	4.6E-07	a	4.6E-07	c	4.4E-07	1.1E-06	1.2E-06
Tc-99	180	5.1E-05	a	5.1E-05	c	1.3E-05	1.8E-03	7.7E-05
Tritium	3,605	1.9E-05	1.6E-06	2.0E-05	7.4E-06	5.6E-06	2.5E-04	1.6E-05
	TOTAL	7.0E-05	1.6E-06	7.1E-05	7.4E-06	1.9E-05	2.0E-03	9.5E-05
25th Percentile Groundwater Concentration								
Iodine-129	ND	b	b	b	c	b	b	b
Tc-99	59	1.7E-05	a	1.7E-05	c	4.3E-06	5.8E-04	2.5E-05
Tritium	513.75	2.7E-06	2.2E-07	2.9E-06	1.1E-06	8.0E-07	3.5E-05	2.3E-06
	TOTAL	1.9E-05	2.2E-07	1.9E-05	1.1E-06	5.1E-06	6.1E-04	2.8E-05
Average Groundwater Concentration								
Iodine-129	1.309	2.0E-05	a	2.0E-05	c	1.9E-05	5.0E-05	5.1E-05
Tc-99	793.11	2.2E-04	a	2.2E-04	c	5.8E-05	7.8E-03	3.4E-04
Tritium	51,030	2.6E-04	2.2E-05	2.9E-04	1.0E-04	7.9E-05	3.5E-03	2.3E-04
	TOTAL	5.1E-04	2.2E-05	5.3E-04	1.0E-04	1.6E-04	1.1E-02	6.2E-04
UCL95 Groundwater Concentration								
Iodine-129	2.408	3.7E-05	a	3.7E-05	c	3.5E-05	9.2E-05	9.3E-05
Tc-99	1160	3.3E-04	a	3.3E-04	c	8.4E-05	1.1E-02	5.0E-04
Tritium	87345	4.5E-04	3.8E-05	4.9E-04	1.8E-04	1.4E-04	6.0E-03	4.0E-04
	TOTAL	8.2E-04	3.8E-05	8.5E-04	1.8E-04	2.6E-04	1.7E-02	9.9E-04

a = Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.

b = I-129 was not detected in the 25th percentile of the groundwater concentrations.

c = Inhalation of non-volatile chemicals in the sweatlodge is not evaluated.

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Table 6-20. Native American Exposures (Nonradioactive Chemicals) Incidental Ingestion of Soil.

Future

Exposure Medium: Surface Soil
Exposure Point: Yard/Garden
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard = CS x SIFnc x ABSo / RfD
Cancer Risk = CS x SIFc x ABSo x CSF

Parameter	Units	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Soil (CS)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Soil (IR)	mg/day	400	400	200	400
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	64	6	64
Conversion Factor (CF)	kg/mg	1.00E-06	1.00E-06	1.00E-06	1.00E-06
Body Weight (BW)	kg	16	70	16	70
Averaging Time (non-cancer) (ATnc)	days	2190	23360	2190	23360
Averaging Time (cancer) (ATc)	days	25550	25550	25,550	25,550
SIFnc = (IR*EF*ED*CF)/(BW*ATnc)	$(day)^{-1}$	2.50E-05	5.71E-06	1.25E-05	5.71E-06
IngFadj (Ingestion Adjusted Factor)= (IRch*EDch/BWch)+(IRa*EDa/BWa)	mg-yr/day-kg	515.71		440.71	
SIFc = (IngFadj*EF*CF)/ATc	$(day)^{-1}$	7.37E-06		6.30E-06	

Chemical	RfD-O (mg/kg-d)	CSF-O $(mg/kg\text{-}d)^{-1}$	ABSo unitless
Thallium	7.0E-05	--*	1

Chemical	CS (mg/kg)	Umatilla						Yakama					
		Intake nc Child (mg/kg-d)	Intake nc Adult (mg/kg-d)	Intake c Child/Adult Lifetime (mg/kg-d)	HQ Child	HQ Adult	Risk Child/Adult Lifetime	Intake nc Child (mg/kg-d)	Intake nc Adult (mg/kg-d)	Intake c Child/Adult Lifetime (mg/kg-d)	HQ Child	HQ Adult	Risk Child/Adult Lifetime
Thallium *	0.83	2.1E-05	4.74E-06	6.11E-06	0.296	0.068	--	1.0E-05	4.74E-06	5.23E-06	0.148	0.068	--
Total					0.296	0.068	--				0.148	0.068	--

* The cancer slope factor is not available for this chemical to quantify cancer risks.

Table 6-21. Native American Exposures (Nonradioactive Chemicals) Ingestion of Plant Tissue.

Future

Exposure Medium: Garden Soil
Exposure Point: Fruits and Vegetables
Receptor Population: Native American
Receptor Age: Children and Adults

Non-Cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla child	Umatilla adult	Yakama child	Yakama adult
Chemical Concentration in Tissue (CTi)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/kg-day	--*	9.64	9.77	10.14
Fraction of Plant from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	9.64E-03	9.77E-03	1.01E-02
SIFc = (FC*EF*CF/ATc)*(IRc*EDc+IRa*EDa)	$(day)^{-1}$	9.64E-03		1.01E-02	

* No plant ingestion rate is provided for Umatilla child exposures.

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Thallium	7.0E-05	--

Chemical	CTi (mg/kg)	Umatilla Intake$_{nc}$ child (mg/kg-d)	Umatilla Intake$_{nc}$ adult (mg/kg-d)	Umatilla Intake$_{c}$ child/adult lifetime (mg/kg-d)	Umatilla HQ child	Umatilla HQ adult	Umatilla Cancer Risk child/adult lifetime	Yakama Intake$_{nc}$ child (mg/kg-d)	Yakama Intake$_{nc}$ adult (mg/kg-d)	Yakama Intake$_{c}$ child/adult lifetime (mg/kg-d)	Yakama HQ child	Yakama HQ adult	Yakama Cancer Risk child/adult lifetime
A-8 Crib Soil													
Thallium	0.216	--	2.08E-03	2.08E-03	--	29.75	--	2.1E-03	2.19E-03	2.18E-03	30.15	31.29	--
Total					--	29.75	--				30.15	31.29	--

APPENDIX G

ATTACHMENT 7

SOIL RESRAD RISK SUMMARY TABLES

APPENDIX G

ATTACHMENT 7

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Table 7-1. Summary of Risks for the Umatilla from Soil – 150 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	2E-08	2E-08	1E-12	2E-09	2E-09
Am-241	1E+00	5E-01	4E-04	3E-01	6E-01
Np-237	2E-03	1E-03	2E-08	4E-04	4E-05
Pa-231	1E-08	4E-09	1E-12	7E-09	2E-09
Pu-239	1E+00	5E-02	6E-03	1E+00	1E+00
Pu-240	1E+00	4E-03	1E-03	6E-01	9E-01
Ra-228	4E-12	2E-12	7E-18	2E-12	1E-13
Th-228	2E-12	2E-12	2E-17	2E-14	4E-14
Th-229	8E-10	6E-10	6E-14	4E-11	1E-10
Th-232	2E-14	2E-16	9E-18	7E-15	2E-14
U-233	1E-08	3E-10	3E-12	7E-09	7E-09
U-235	2E-05	2E-05	5E-10	1E-06	1E-06
U-236	1E-05	4E-08	3E-09	7E-06	7E-06
Total	1E+00	5E-01	7E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

Table 7-2. Summary of Risks for the Umatilla from Soil – 500 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	1E-06	9E-07	6E-11	1E-07	1E-07
Am-241	3E-01	9E-02	6E-05	5E-02	1E-01
Np-237	3E-03	3E-03	4E-08	7E-04	8E-05
Pa-231	3E-07	1E-07	2E-11	2E-07	4E-08
Pu-239	1E+00	4E-02	6E-03	1E+00	1E+00
Pu-240	1E+00	3E-03	1E-03	6E-01	9E-01
Ra-228	1E-10	6E-11	3E-16	8E-11	5E-12
Th-228	9E-11	9E-11	9E-16	9E-13	1E-12
Th-229	2E-07	1E-07	1E-11	1E-08	2E-08
Th-232	7E-13	5E-15	3E-16	2E-13	5E-13
U-233	3E-07	5E-09	7E-11	1E-07	1E-07
U-235	7E-05	6E-05	1E-09	3E-06	3E-06
U-236	4E-05	1E-07	9E-09	2E-05	2E-05
Total	1E+00	1E-01	7E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

Table 7-3. Summary of Risks for the Umatilla from Soil - 1,000 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	3E-06	2E-06	1E-10	3E-07	3E-07
Am-241	4E-02	1E-02	8E-06	7E-03	2E-02
Np-237	3E-03	3E-03	4E-08	7E-04	8E-05
Pa-231	7E-07	2E-07	6E-11	4E-07	1E-07
Pu-239	1E+00	4E-02	5E-03	1E+00	1E+00
Pu-240	1E+00	3E-03	1E-03	6E-01	9E-01
Ra-228	4E-10	1E-10	7E-16	2E-10	1E-11
Th-228	2E-10	2E-10	2E-15	2E-12	4E-12
Th-229	6E-07	5E-07	5E-11	4E-08	9E-08
Th-232	2E-12	1E-14	7E-16	5E-13	1E-12
U-233	5E-07	9E-09	1E-10	2E-07	2E-07
U-235	1E-04	9E-05	2E-09	4E-06	4E-06
U-236	5E-05	1E-07	1E-08	3E-05	2E-05
Total	1E+00	6E-02	6E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

Table 7-4. Summary of Risks for the Umatilla from Radon – 150 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	5E-14
Po-216	8E-16
Pb-212	3E-14
Bi-212	1E-14
Total	9E-14

Table 7-5. Summary of Risks for the Umatilla from Radon – 500 Years. 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-12
Po-216	3E-14
Pb-212	1E-12
Bi-212	6E-13
Total	4E-12

Table 7-6. Summary of Risks for the Umatilla from Radon –1,000 Year, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	5E-12
Po-216	8E-14
Pb-212	3E-12
Bi-212	2E-12
Total	1E-11

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Table 7-7. Summary of Risks for the Yakama Nation from Soil – 150 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	2E-08	2E-08	1E-12	3E-09	2E-09
Am-241	1E+00	5E-01	4E-04	4E-01	6E-01
Np-237	2E-03	1E-03	2E-08	5E-04	4E-05
Pa-231	1E-08	4E-09	8E-13	9E-09	2E-09
Pu-239	1E+00	5E-02	5E-03	1E+00	1E+00
Pu-240	1E+00	4E-03	1E-03	7E-01	9E-01
Ra-228	5E-12	2E-12	6E-18	3E-12	1E-13
Th-228	2E-12	2E-12	2E-17	3E-14	4E-14
Th-229	8E-10	6E-10	5E-14	6E-11	1E-10
Th-232	2E-14	2E-16	8E-18	9E-15	2E-14
U-233	2E-08	3E-10	3E-12	9E-09	7E-09
U-235	3E-05	2E-05	4E-10	1E-06	1E-06
U-236	2E-05	4E-08	3E-09	9E-06	7E-06
Total	1E+00	5E-01	6E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

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Table 7-8. Summary of Risks for the Yakama Nation from Soil – 500 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	1E-06	9E-07	5E-11	1E-07	1E-07
Am-241	3E-01	9E-02	5E-05	7E-02	1E-01
Np-237	4E-03	3E-03	4E-08	8E-04	8E-05
Pa-231	4E-07	1E-07	2E-11	2E-07	4E-08
Pu-239	1E+00	4E-02	5E-03	1E+00	1E+00
Pu-240	1E+00	3E-03	1E-03	7E-01	9E-01
Ra-228	2E-10	6E-11	2E-16	1E-10	5E-12
Th-228	9E-11	9E-11	7E-16	1E-12	1E-12
Th-229	2E-07	1E-07	1E-11	1E-08	2E-08
Th-232	7E-13	5E-15	2E-16	3E-13	5E-13
U-233	3E-07	5E-09	6E-11	2E-07	1E-07
U-235	7E-05	6E-05	1E-09	4E-06	3E-06
U-236	4E-05	1E-07	7E-09	2E-05	2E-05
Total	1E+00	1E-01	6E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

Table 7-9. Summary of Risks for the Yakama Nation from Soil – 1,000 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	3E-06	2E-06	1E-10	3E-07	3E-07
Am-241	4E-02	1E-02	7E-06	9E-03	2E-02
Np-237	3E-03	3E-03	4E-08	8E-04	8E-05
Pa-231	8E-07	2E-07	5E-11	5E-07	1E-07
Pu-239	1E+00	4E-02	5E-03	1E+00	1E+00
Pu-240	1E+00	3E-03	9E-04	7E-01	9E-01
Ra-228	4E-10	1E-10	6E-16	3E-10	1E-11
Th-228	3E-10	2E-10	2E-15	3E-12	4E-12
Th-229	6E-07	5E-07	4E-11	5E-08	9E-08
Th-232	2E-12	1E-14	6E-16	7E-13	1E-12
U-233	5E-07	9E-09	1E-10	3E-07	2E-07
U-235	1E-04	9E-05	2E-09	5E-06	4E-06
U-236	6E-05	1E-07	1E-08	3E-05	2E-05
Total	1E+00	6E-02	6E-03	1E+00	1E+00

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk). The shaded total values sum greater than 1, but risks are reported only to 1.

Table 7-10. Summary of Risks for the Yakama Nation from Radon – 150 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	4E-14
Po-216	7E-16
Pb-212	2E-14
Bi-212	1E-14
Total	8E-14

Table 7-11. Summary of Risks for the Yakama Nation from Radon – 500 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-12
Po-216	3E-14
Pb-212	9E-13
Bi-212	5E-13
Total	3E-12

Table 7-12. Summary of Risks for the Yakama Nation from Radon – 1,000 Years, 216-Z-1A Tile Field.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	5E-12
Po-216	7E-14
Pb-212	2E-12
Bi-212	1E-12
Total	9E-12

Table 7-13. Summary of Risks for the Umatilla from Soil – 150 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	5E-15	4E-15	3E-19	5E-16	5E-16
C-14	4E-31	0E+00	0E+00	4E-31	0E+00
Cs-137	3E-01	3E-01	7E-09	2E-02	1E-03
Np-237	4E-05	3E-05	5E-10	7E-06	8E-07
Pa-231	3E-15	1E-15	2E-19	2E-15	4E-16
Pu-239	3E-05	9E-08	1E-08	9E-06	2E-05
Pu-240	6E-06	7E-09	2E-09	2E-06	5E-06
Ra-228	2E-13	8E-14	3E-19	1E-13	7E-15
Tc-99	1E-05	4E-10	8E-14	1E-05	5E-09
Th-228	2E-13	2E-13	2E-18	2E-15	3E-15
Th-229	2E-11	1E-11	1E-15	9E-13	2E-12
Th-232	6E-21	4E-23	2E-24	2E-21	4E-21
U-233	3E-10	5E-12	7E-14	1E-10	1E-10
U-235	9E-12	8E-12	2E-16	4E-13	4E-13
U-236	5E-12	1E-14	1E-15	3E-12	2E-12
Total	3E-01	3E-01	2E-08	2E-02	1E-03

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk).

Table 7-14. Summary of Risks for the Umatilla from Soil – 500 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	1E-12	1E-12	8E-17	1E-13	1E-13
C-14	0E+00	0E+00	0E+00	0E+00	0E+00
Cs-137	3E-06	3E-06	6E-14	2E-07	1E-08
Np-237	3E-05	3E-05	4E-10	6E-06	8E-07
Pa-231	4E-13	1E-13	3E-17	2E-13	6E-14
Pu-239	3E-05	9E-08	1E-08	8E-06	2E-05
Pu-240	6E-06	7E-09	2E-09	2E-06	4E-06
Ra-228	2E-16	7E-17	3E-22	1E-16	6E-18
Tc-99	0E+00	0E+00	0E+00	0E+00	0E+00
Th-228	1E-16	1E-16	1E-21	1E-18	2E-18
Th-229	2E-09	2E-09	2E-13	1E-10	3E-10
Th-232	9E-19	6E-21	3E-22	3E-19	6E-19
U-233	3E-09	6E-11	8E-13	2E-09	2E-09
U-235	1E-10	1E-10	2E-15	5E-12	5E-12
U-236	6E-11	2E-13	1E-14	3E-11	3E-11
Total	7E-05	3E-05	1E-08	2E-05	2E-05

Table 7-15. Summary of Risks for the Umatilla from Soil – 1,000 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	4E-12	3E-12	2E-16	4E-13	4E-13
C-14	0E+00	0E+00	0E+00	0E+00	0E+00
Cs-137	3E-11	3E-11	6E-19	2E-12	1E-13
Np-237	3E-05	2E-05	4E-10	6E-06	7E-07
Pa-231	1E-12	4E-13	9E-17	7E-13	2E-13
Pu-239	3E-05	8E-08	1E-08	8E-06	2E-05
Pu-240	6E-06	6E-09	2E-09	2E-06	4E-06
Ra-228	6E-16	2E-16	1E-21	3E-16	2E-17
Tc-99	0E+00	0E+00	0E+00	0E+00	0E+00
Th-228	4E-16	4E-16	4E-21	4E-18	6E-18
Th-229	7E-09	6E-09	5E-13	4E-10	1E-09
Th-232	3E-18	2E-20	1E-21	8E-19	2E-18
U-233	5E-09	9E-11	1E-12	3E-09	2E-09
U-235	2E-10	2E-10	3E-15	8E-12	7E-12
U-236	9E-11	2E-13	2E-14	5E-11	4E-11
Total	6E-05	2E-05	1E-08	2E-05	2E-05

Table 7-16. Summary of Risks for the Umatilla from Radon – 150 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	4E-15
Po-216	6E-17
Pb-212	2E-15
Bi-212	1E-15
Total	7E-15

Table 7-17. Summary of Risks for the Umatilla from Radon – 500 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	3E-18
Po-216	4E-20
Pb-212	1E-18
Bi-212	7E-19
Total	5E-18

Table 7-18. Summary of Risks for the Umatilla from Radon – 1,000 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	8E-18
Po-216	1E-19
Pb-212	4E-18
Bi-212	2E-18
Total	2E-17

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Table 7-19. Summary of Risks for the Yakama Nation from Soil – 150 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	5E-15	4E-15	2E-19	6E-16	5E-16
C-14	5E-31	0E+00	0E+00	5E-31	0E+00
Cs-137	3E-01	3E-01	6E-09	3E-02	1E-03
Np-237	4E-05	3E-05	4E-10	9E-06	8E-07
Pa-231	4E-15	1E-15	2E-19	2E-15	4E-16
Pu-239	3E-05	9E-08	9E-09	1E-05	2E-05
Pu-240	7E-06	7E-09	2E-09	2E-06	5E-06
Ra-228	2E-13	8E-14	3E-19	1E-13	7E-15
Tc-99	1E-05	4E-10	7E-14	1E-05	5E-09
Th-228	2E-13	2E-13	1E-18	2E-15	3E-15
Th-229	2E-11	1E-11	1E-15	1E-12	2E-12
Th-232	6E-21	4E-23	2E-24	2E-21	4E-21
U-233	3E-10	5E-12	6E-14	2E-10	1E-10
U-235	9E-12	8E-12	1E-16	5E-13	4E-13
U-236	6E-12	1E-14	1E-15	3E-12	2E-12
Total	3E-01	3E-01	2E-08	3E-02	1E-03

Note: Shaded values exceed 1 x 10^{-1} and the following equation for high carcinogenic risk levels from RAGS Part A (EPA, 1989) was used: risk = 1 - exp (- reported RESRAD risk).

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Table 7-20. Summary of Risks for the Yakama Nation from Soil - 500 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	1E-12	1E-12	7E-17	2E-13	1E-13
C-14	0E+00	0E+00	0E+00	0E+00	0E+00
Cs-137	3E-06	3E-06	6E-14	3E-07	1E-08
Np-237	3E-05	3E-05	4E-10	8E-06	8E-07
Pa-231	5E-13	1E-13	3E-17	3E-13	6E-14
Pu-239	3E-05	9E-08	9E-09	1E-05	2E-05
Pu-240	7E-06	7E-09	2E-09	2E-06	4E-06
Ra-228	2E-16	7E-17	3E-22	1E-16	6E-18
Tc-99	0E+00	0E+00	0E+00	0E+00	0E+00
Th-228	1E-16	1E-16	9E-22	1E-18	2E-18
Th-229	2E-09	2E-09	2E-13	2E-10	3E-10
Th-232	9E-19	6E-21	3E-22	3E-19	6E-19
U-233	4E-09	6E-11	7E-13	2E-09	2E-09
U-235	1E-10	1E-10	2E-15	6E-12	5E-12
U-236	7E-11	2E-13	1E-14	4E-11	3E-11
Total	7E-05	3E-05	1E-08	2E-05	2E-05

Table 7-21. Summary of Risks for the Yakama Nation from Soil – 1,000 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Total	External Radiation	Inhalation	Produce	Ingestion
Ac-227	4E-12	3E-12	2E-16	5E-13	4E-13
C-14	0E+00	0E+00	0E+00	0E+00	0E+00
Cs-137	3E-11	3E-11	5E-19	3E-12	1E-13
Np-237	3E-05	2E-05	3E-10	7E-06	7E-07
Pa-231	1E-12	4E-13	8E-17	8E-13	2E-13
Pu-239	3E-05	8E-08	9E-09	1E-05	2E-05
Pu-240	6E-06	6E-09	2E-09	2E-06	4E-06
Ra-228	7E-16	2E-16	9E-22	4E-16	2E-17
Tc-99	0E+00	0E+00	0E+00	0E+00	0E+00
Th-228	4E-16	4E-16	3E-21	4E-18	6E-18
Th-229	8E-09	6E-09	5E-13	5E-10	1E-09
Th-232	3E-18	2E-20	9E-22	1E-18	2E-18
U-233	6E-09	9E-11	1E-12	3E-09	2E-09
U-235	2E-10	2E-10	3E-15	1E-11	7E-12
U-236	1E-10	2E-13	2E-14	6E-11	4E-11
Total	7E-05	2E-05	1E-08	2E-05	2E-05

Table 7-22. Summary of Risks for the Yakama Nation from Radon – 150 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	4E-15
Po-216	5E-17
Pb-212	2E-15
Bi-212	1E-15
Total	6E-15

Table 7-23. Summary of Risks for the Yakama Nation from Radon – 500 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	2E-18
Po-216	3E-20
Pb-212	1E-18
Bi-212	6E-19
Total	4E-18

Table 7-24. Summary of Risks for the Yakama Nation from Radon – 1,000 Years, 216-A-8 Crib.

Radionuclide (Parent and Decay)	Inhalation
Rn-220	7E-18
Po-216	1E-19
Pb-212	4E-18
Bi-212	2E-18
Total	1E-17

APPENDIX G

ATTACHMENT 8

RESIDUAL RISK CALCULATIONS FOR GROUNDWATER

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APPENDIX G

ATTACHMENT 8

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NATIVE AMERICAN EXPOSURES TO GROUNDWATER AT PROPOSED CLEANUP LEVELS –Radioactive Chemicals

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Table 8-1. Native American Exposures (Nonradioactive Chemicals) Ingestion of Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence
Receptor Age: Children and Adults

Non-cancer Hazard = CW x SIFnc / RfD
Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Umatilla Child	Umatilla Adult	Yakama Child	Yakama Adult
Chemical Concentration in Water (CW)	µg/L	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Water (IR)	L/day	1.5	4	2	4
Exposure frequency (EF)	days/year	365	365	365	365
Exposure duration (ED)	years	6	64	6	64
Body weight (BW)	kg	16	70	16	70
Conversion Factor (CF)	mg/µg	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging time (non-cancer) (ATnc)	days	2,190	23,360	2,190	23,360
Averaging time (cancer) (ATc)	days	25,550	25,550	25,550	25,550
SIFnc = (IR*EF*ED*CF)/(BW*ATnc)	L-mg/µg-kg-d	9.38E-05	5.71E-05	1.25E-04	5.71E-05
IngFadj (Ingestion Adjusted Factor) =	L-year/hr-kg				
(IRch*EDch/BWch)+ (IRa*EDa/BWa)		4.22	4.22	4.41	4.41
SIFc = (IngFadj*EF*CF)/ATc	L-mg/µg-kg-d	6.03E-05	6.03E-05	6.30E-05	6.30E-05

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.00E-04	1.30E-01
Chloroform	1.00E-02	--
Chromium III	1.50E+00	--
Chromium VI (GW)	3.00E-03	--
Methylene Chloride	6.00E-02	7.50E-03
Nitrate	1.60E+00	--
PCE	1.00E-02	5.40E-01
TCE	3.00E-04	1.30E-02
Uranium	3.00E-03	--

Total Inorganics Chemical	90th Percentile CW (µg/L)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_{c}$ Lifetime (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Lifetime	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_{c}$ Lifetime (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Lifetime
TCE @ 5 ppb	5.00	4.69E-04	2.86E-04	3.01E-04	1.563	0.952	3.9E-06	6.25E-04	2.86E-04	3.15E-04	2.08E+00	0.952	4.1E-06
TCE @ 1.1 ppb	1.10	1.03E-04	6.29E-05	6.63E-05	0.344	0.210	8.6E-07	1.38E-04	6.29E-05	6.93E-05	4.58E-01	0.210	9.0E-07
Nitrate	10,000.00	9.38E-01	5.71E-01	6.03E-01	0.586	0.357	--	1.25E+00	5.71E-01	6.30E-01	7.81E-01	0.357	--
Chromium, Total	100.00	9.38E-03	5.71E-03	6.03E-03	0.006	0.004	--	1.25E-02	5.71E-03	6.30E-03	8.33E-03	0.004	--
Carbon Tetrachloride	3.40	3.19E-04	1.94E-04	2.05E-04	0.455	0.278	2.7E-05	4.25E-04	1.94E-04	2.14E-04	6.07E-01	0.278	2.8E-05
Chromium VI	48.00	4.50E-03	2.74E-03	2.89E-03	1.500	0.914	--	6.00E-03	2.74E-03	3.02E-03	2.00E+00	0.914	--
Total					**4.5**	**2.7**	**3.1E-05**				**5.9**	**2.7**	**3.3E-05**

Table 8-2. Native American Exposures (Nonradioactive Chemicals) Inhalation of Vapor.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence
Receptor Age: Children and Adults

Non-cancer Hazard = CA x SIFnc x VFw / RfD
Cancer Risk = CA x SIFc x VFw x CSF

Parameter	Unit	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Water (CW)	µg/L	chem-specific	chem-specific	chem-specific	chem-specific
Inhalation Rate (InhR)	m^3/day	8.2	30	16	26
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	64	6	64
Body Weight (BW)	kg	16	70	16	70
Conversion Factor (CF)	mg/µg	1.0E-03	1.0E-03	1.0E-03	1.0E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	23,360	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550	25,550	25,550	25,550
SIFnc = (InhR*EF*ED*CF)/(BW*ATnc)	m^3-mg/µg-kg-day	5.13E-04	4.29E-04	1.00E-03	3.71E-04
InhFadj (Inhalation Adjusted Factor) = (InhRch*EDch/BWch) + (InhRa*EDa/BWa)	m^3-yr/hr-kg	3.05E+01	3.05E+01	2.98E+01	2.98E+01
SIFc = (InhFadj*EF*CF)/ATc	m^3-mg/µg-kg-day	4.36E-04	4.36E-04	4.25E-04	4.25E-04

Chemical	RfDi (mg/kg-d)	CSFi $(mg/kg\text{-}d)^{-1}$	VFw* (L/m^3)
Carbon Tetrachloride	--	5.3E-02	5.0E-01
Chloroform	1.3E-02	8.1E-02	5.0E-01
Chromium III	--	--	--
Chromium VI (GW)	2.9E-05	2.9E+02	--
Methylene Chloride	8.6E-01	1.6E-03	5.0E-01
Nitrate	--	--	--
PCE	1.1E-01	2.1E-02	5.0E-01
TCE	1.1E-02	7.0E-03	5.0E-01
Uranium	--	--	--

*A volatilization factor (VFw) of 0.5 is only applicable for volatile chemicals.

Dissolved Inorganics Chemical	90th Percentile CW (µg/L)	Umatilla $Intake_{nc}$ Child (mg/kg-d)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_c$ Lifetime (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Cancer Risk Lifetime	Yakama $Intake_{nc}$ Child (mg/kg-d)	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_c$ Lifetime (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Cancer Risk Lifetime
TCE @ 5 ppb	5.00	1.28E-03	1.07E-03	1.09E-03	0.116	0.097	7.6E-06	2.50E-03	9.29E-04	1.06E-03	0.23	0.08	7.4E-06
TCE @ 1.1 ppb	1.10	2.82E-04	2.36E-04	2.40E-04	0.026	0.021	1.7E-06	5.50E-04	2.04E-04	2.34E-04	0.05	0.02	1.6E-06
Nitrate	10,000.00	--	--	--	--	--	--	--	--	--	--	--	--
Chromium, Total	100.00	--	--	--	--	--	--	--	--	--	--	--	--
Carbon Tetrachloride	3.40	8.71E-04	7.29E-04	7.41E-04	--	--	3.9E-05	1.70E-03	6.31E-04	7.23E-04	--	--	3.8E-05
Chromium VI	48.00	--	--	--	--	--	--	--	--	--	--	--	--
Total					**0.14**	**0.12**	**4.7E-05**				**0.28**	**0.10**	**4.7E-05**

Table 8-3a. Native American Exposures (Nonradioactive Chemicals) Intermediate Dermal Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence
Receptor Age: Children and Adults

Exposure Parameters		Units
Fraction absorbed	FA	unitless
Dermal permeability coefficient	PC	cm/hour
Concentration in surface water	CW	mg/m^3
Lag time per event	T event	hour/event
Time to reach steady state	t*	hours
Event duration	t event	hour/event
Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis.	B	unitless
Absorbed dose per event	DA event	mg/cm^2-event

Formulas Used to Calculate Absorbed Dose per Event (DAevent):

ORGANIC CHEMICALS:

If $t_{event} \leq t^*$, then $DA_{event} = 2\ FA \times PC \times Cw\ (6 \times T_{event} \times t_{event}/Pi)^{0.5}$

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

INORGANIC CHEMICALS:

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

Chemical	FA	PC	Cw	T_{event}	t*	t_{event} hr/event		Pi	B	DAevent mg/cm^2-event	
	Unitless	cm/hr	mg/cm^3	hr/event	Hours	Adult	Child	Unitless	Unitless	Adult	Child
TCE @ 5 ppb	1	1.20E-02	5.00E-06	0.58	1.39	0.58	1	3.14	0.1	9.62E-08	1.26E-07
TCE @ 1.1 ppb	1	1.20E-02	1.10E-06	0.58	1.39	0.58	1	3.14	0.1	2.12E-08	2.78E-08
Nitrate	--	--	1.00E-02	--	--	0.58	1	3.14	--	--	--
Chromium, Total	--	0.001	1.00E-04	--	--	0.58	1	3.14	--	5.80E-08	1.00E-07
Carbon Tetrachloride	1	1.60E-02	3.40E-06	0.78	1.86	0.58	1	3.14	0.1	1.01E-07	1.33E-07
Chromium VI	--	2.00E-03	4.80E-05	--	--	0.58	1	3.14	--	5.57E-08	9.60E-08

Table 8-3b. Native American Exposures (Nonradioactive Chemicals) Dermal Contact with Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence
Receptor Age: Children and Adults

Non-cancer HQ = DAevent x SIFnc / RfD
Cancer Risk = DAevent x SIFc x CSF

Parameter	Units	Umatilla Adult	Umatilla Child	Yakama Adult	Yakama Child
Absorbed dose per event (DAevent)	(mg/cm^2-event)	chem-specific	chem-specific	chem-specific	chem-specific
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	64	6	64	6
Event Frequency (EV)	events/day	1	1	1	1
Surface Area Available for Contact (SA)	cm^2	18,000	6,600	18,000	6,600
Body Weight (BW)	kilograms	70	16.6	70	16.6
Averaging Time (non-cancer) (ATnc)	days	23,360	2,190	23,360	2,190
Averaging Time (cancer) (ATc)		25,550	25,550	25,550	25,550
SIFnc(child) = ((EF*EDc*SAc)/(BWc*ATnc-c))	ev-cm^2/kg-d	2.57E+02	3.98E+02	2.57E+02	3.98E+02
DFadj (Dermal Adjusted Factor) = (EDc*EFc*EVc*SAc/BWc)+(EDa*EFa*EVa*SAa/BWa)	ev-cm^2/kg	6.88E+06		6.88E+06	
SIFc(child/adult) = DFadj/ATc	ev-cm^2/kg-d	2.69E+02		2.69E+02	

Chemical	RfD-D (mg/kg-d)	CSF-D (mg/kg-d)$^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	2.0E-02	--
Chromium VI (GW)	7.5E-05	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	--	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	Umatilla DA event (mg/cm^2-event) Child	Umatilla DA event (mg/cm^2-event) Adult	Umatilla Intake$_{nc}$ Child (mg/kg-d)	Umatilla Intake$_{nc}$ Adult (mg/kg-d)	Umatilla Intake$_c$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla HQ Adult	Umatilla Risk Child/Adult	Yakama Intake$_{nc}$ Child (mg/kg-d)	Yakama Intake$_{nc}$ Adult (mg/kg-d)	Yakama Intake$_c$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama HQ Adult	Yakama Risk Child/Adult
TCE @ 5 ppb	1.26E-07	9.62E-08	5.02E-05	2.47E-05	2.59E-05	0.167	0.082	3.37E-07	5.02E-05	2.47E-05	2.59E-05	0.167	0.082	3.37E-07
TCE @ 1.1 ppb	2.78E-08	2.12E-08	1.11E-05	5.44E-06	5.70E-06	0.037	0.018	7.41E-08	1.11E-05	5.44E-06	5.70E-06	0.037	0.018	7.41E-08
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chromium, Total	1.00E-07	5.80E-08	3.98E-05	1.49E-05	1.56E-05	0.002	0.00076	--	3.98E-05	1.49E-05	1.56E-05	0.0020	0.00076	--
Carbon Tetrachloride	1.33E-07	1.01E-07	5.28E-05	2.60E-05	2.72E-05	0.075	0.037	3.54E-06	5.28E-05	2.60E-05	2.72E-05	0.075	0.037	3.54E-06
Chromium VI	9.60E-08	5.57E-08	3.81687E-05	1.43E-05	1.50E-05	0.51	0.19	--	3.81687E-05	1.43E-05	1.50E-05	0.51	0.19	--
Total						**0.79**	**0.33**	**4.0E-06**				**0.79**	**0.33**	**4.0E-06**

Table 8-4a. Native American Exposures (Nonradioactive Chemicals) Intermediate Sweatlodge Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Sweatlodge Vapor
Receptor Population: Tribal Subsistence
Receptor Age: Adults

Formula for Volatile and Semi-volatile Organic Compounds:

$$C_v = C_w * VF_{org}$$

where,

$$VF_{org} = \frac{V_{w,total}}{2 * 2/3 * pi * r^3}$$

Formula for Nonvolatile and Chemicals and Radionuclides (except Tritium):

$$C_v = C_w * VF_{m,r}$$

where,

$$VF_{m,r} = \frac{MW_w * p^*}{R * T * \rho_w}$$

and, $p^* = EXP(18.3036-3816.44/(T-46.13))$

Parameter	Definition (units)	Value
C_v	Concentration in sweatlodge vapor (mg/m^3)	chem.-specific
C_w	Concentration in groundwater (mg/L or pCi/L)	chem.-specific
$V_{w,total}$	total volume of water used to create steam (L)	4
r	radius of sweatlodge (m)	1
MW_w	molecular weight of water (g/gmole)	18
R	ideal gas law constant (mmHg*m^3/gmole*K)	0.06237
T	temperature of sweatlodge (K)	339
ρ_w	density of liquid water (g/L)	1000
p^*	partial pressure of water at temp K (mmHg)	194.89
VF_{org}	**Vaporization factor, organic chemicals (L/m^3)**	**0.955**
$VF_{m,r}$	**Vaporization factor, metals and radionuclides (L/m^3)**	**0.166**

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Table 8-4b. Native American Exposures (Nonradioactive Chemicals) Inhalation of Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater
Exposure Point: Sweatlodge
Receptor Population: Tribal Subsistence
Receptor Age: Children and Adults

Non-cancer Hazard = CW x $VF_{(org)}$ x SIFnc / RfD
Cancer Risk = CW x $VF_{(org)}$ x SIFc x CSF

Parameter	Unit	Umatilla Adult	Yakama Adult
Chemical Concentration in Water (CW)	mg/L	chem-specific	chem-specific
Inhalation Rate (InhR)	m^3/day	30	26
Exposure Frequency (EF)	days/year	365	260
Event Time (ET)	hours/event	1	2
Event frequency (EvF)	events/day	1	1
Exposure Duration (ED)	years	68	68
Body Weight (BW)	kg	70	70
Conversion Factor (CF)	days/hour	4.2E-02	4.2E-02
Averaging Time (non-cancer) (ATnc)	days	24,820	24,820
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc = (InhR*EF*ED*ET*EvF*CF)/(BW*ATnc)	m^3/kg-day	1.79E-02	2.20E-02
SIFc = (InhR*EF*ED*ET*EvF*CF)/(BW*ATc)	m^3/kg-day	1.73E-02	2.14E-02

Chemical	RfDi (mg/kg-d)	CSFi $(mg/kg\text{-}d)^{-1}$	VForg (L/m^3)
Carbon Tetrachloride	--	5.3E-02	0.955
Chloroform	1.3E-02	8.1E-02	0.955
Chromium III	--	--	--*
Chromium VI (aerosols)	2.3E-06	2.9E+02	--*
Methylene Chloride	8.6E-01	1.6E-03	0.955
Nitrate	--	--	--*
PCE	1.1E-01	2.1E-02	0.955
TCE	1.1E-02	7.0E-03	0.955
Uranium	--	--	--*

Dissolved Inorganics Chemical	90th Percentile CW (mg/L)	Umatilla $Intake_{nc}$ Adult (mg/kg-d)	Umatilla $Intake_c$ Lifetime (mg/kg-d)	Umatilla HQ Adult	Umatilla Cancer Risk Lifetime	Yakama $Intake_{nc}$ Adult (mg/kg-d)	Yakama $Intake_c$ Lifetime (mg/kg-d)	Yakama HQ Adult	Yakama Cancer Risk Lifetime
TCE @ 5 ppb	0.00500	8.93E-05	8.67E-05	0.008	5.8E-07	1.10E-04	1.07E-04	0.0096	7.2E-07
TCE @ 1.1 ppb	0.00110	1.96E-05	1.91E-05	0.002	1.3E-07	2.43E-05	2.36E-05	0.0021	1.6E-07
Nitrate	10.00000	--*	--*	--*	--*	--*	--*	--*	--*
Chromium, Total	0.10000	--*	--*	--*	--*	--*	--*	--*	--*
Carbon Tetrachloride	0.00340	6.07E-05	5.90E-05	--	3.0E-06	7.50E-05	7.28E-05	--	3.7E-06
Chromium VI	0.048	--*	--*	--*	--*	--*	--*	--*	--*
Total				**0.0095**	**3.7E-06**			**0.012**	**4.6E-06**

* At the direction of the U.S. Department of Energy, inhalation of non-volatile chemicals from the sweatlodge was not evaluated.

Table 8-4c. Native American Exposures (Nonradioactive Chemicals) Dermal Contact with Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater	**Non-cancer Hazard (non-VOCs) = PC x [(SIFnc$_{(dissolved)}$ x Cw)] / RfD**
Exposure Point: Sweatlodge	**Cancer Risk (non-VOCs) = PC x [(SIFca$_{(dissolved)}$ x Cw)] x CSF**
Receptor Population: Tribal Subsistence	**Non-cancer Hazard (VOCs and SVOCs) = PC x SIFnc$_{(vapor)}$ x Cv / RfD**
Receptor Age: Children and Adults	**Cancer Risk (VOCs and SVOCs) = PC x SIFca$_{(vapor)}$ x Cvx CSF**

Parameter	Units	RME Umatilla	RME Yakama
Permeability Constant (PC)	(cm/hour)	chem-specific	chem-specific
Exposure Frequency (EF)	days/year	365	260
Exposure Duration (ED)	years	68	68
Event Frequency (EV)	events/day	1	1
Exposure Time (ET)	hours/event	1	2
Surface Area Available for Contact (SA)	cm^2	18,000	18,000
Conversion Factor 1 (CF1)	m^3/cm^3	0.000001	0.000001
Conversion Factor 2 (CF2)	L/cm3	0.001	0.001
Body Weight (BW)	kilograms	70	70
Averaging Time (non-cancer) (ATnc)	days	24,820	24,820
Averaging Time (cancer) (ATc)	days	25,550	25,550
SIFnc(dissolved) = SA*ET*EV*EF*ED*CF2/(BW*ATnc)	hour-L/cm-kg-day	2.6E-01	3.7E-01
SIFnc(vapor) = SA*ET*EV*EF*ED*CF1/(BW*ATnc)	hour-m^3/cm-kg-day	2.6E-04	3.7E-04
SIFca(dissolved) = SA*ET*EV*EF*ED*CF2/(BW*ATca)	hour-L/cm-kg-day	2.5E-01	3.6E-01
SIFca(vapor) = SA*ET*EV*EF*ED*CF1/(BW*ATca)	hour-m^3/cm-kg-day	2.5E-04	3.6E-04

Chemical	RfD-D (mg/kg-d)	CSF-D $(mg/kg\text{-}d)^{-1}$	PC (cm/hr)	VF_{org} (L/m^3)	VOC or SVOC?
Carbon Tetrachloride	7.0E-04	1.3E-01	1.6E-02	0.95541401	Y
Chloroform	1.0E-02	--	6.8E-03	0.95541401	Y
Chromium III	2.0E-02	--	1.0E-03	--*	N
Chromium VI (GW)	7.5E-05	--	2.0E-03	--*	N
Methylene Chloride	6.0E-02	7.5E-03	3.5E-03	0.95541401	Y
Nitrate	--	--	--	0.95541401	N
PCE	1.0E-02	5.4E-01	3.3E-02	0.95541401	Y
TCE	3.0E-04	1.3E-02	1.2E-02	0.95541401	Y
Uranium	3.0E-03	--	2.0E-03	--*	N

Chemical	90th Percentile Dissolved GW Concentration Cw (mg/L)	90th Percentile Vapor Phase Concentration Cv (mg/m^3)	Umatilla Intake$_{nc}$ Child/Adult (mg/kg-d)	Umatilla Intake$_c$ Child/Adult (mg/kg-d)	Umatilla HQ Child	Umatilla Risk Child/Adult	Yakama Intake$_{nc}$ Child/Adult (mg/kg-d)	Yakama Intake$_c$ Child/Adult (mg/kg-d)	Yakama HQ Child	Yakama Risk Child/Adult
TCE @ 5 ppb	5.00E-03	4.78E-03	1.47E-08	1.43E-08	0.000049	1.86E-10	2.10E-08	2.04E-08	0.000070	2.65E-10
TCE @ 1.1 ppb	1.10E-03	1.05E-03	3.24E-09	3.15E-09	0.000011	4.10E-11	4.62E-09	4.49E-09	0.000015	5.83E-11
Nitrate	1.00E+01	a	--	--	--	--	--	--	--	--
Chromium, Total	1.00E-01	a	2.57E-05	2.50E-05	0.0013	--	3.66E-05	3.56E-05	0.002	--
Carbon Tetrachloride	3.40E-03	3.25E-03	1.34E-08	1.30E-08	0.000019	1.69E-09	1.90E-08	1.85E-08	0.000027	2.40E-09
Chromium VI	4.80E-02	a	2.47E-05	2.40E-05	0.33	--	3.52E-05	3.42E-05	0.469	--
Total					**0.33**	**1.9E-09**			**0.47**	**2.7E-09**

* At the direction of the U.S. Department of Energy, vapor phase concentrations of non-volatile chemicals were not calculated.

Table 8-5. Native American Agricultural Exposures (Nonradioactive Chemicals) Ingestion of Plant Tissue.

Future

Exposure Medium: Groundwater (used for irrigation)
Exposure Point: Fruits and Vegetables
Receptor Population: Tribal Subsistence
Receptor Age: Adults

Non-cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Tissue (CTi)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/kg-day	--*	9.64	9.77	10.4
Fraction of Plant from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	9.64E-03	9.77E-03	1.04E-02
SIFc = (FC*EF*CF/ATc)*(IRc*Edc+IRa*Eda)	$(day)^{-1}$	9.64E-03		1.03E-02	

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (GW)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

* No plant ingestion rate is provided for Umatilla child exposures.

Chemical	90th Percentile	Umatilla						Yakama					
	CTi (mg/kg)	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult
TCE @ 5 ppb	1.19E-01	--	1.15E-03	1.15E-03	--	3.82	1.5E-05	1.2E-03	1.24E-03	1.23E-03	3.88	4.13	1.6E-05
TCE @ 1.1 ppb	2.62E-02	--	2.52E-04	2.52E-04	--	0.84	3.3E-06	2.6E-04	2.72E-04	2.71E-04	0.85	0.91	3.5E-06
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
Chromium, Total	1.29436364	--	1.25E-02	1.25E-02	--	0.0083	--	1.26E-02	1.35E-02	1.34E-02	0.0084	0.00897	--
Carbon Tetrachloride	6.59E-02	--	6.35E-04	6.35E-04	--	0.91	8.3E-05	6.4E-04	6.85E-04	6.81E-04	0.92	0.98	8.9E-05
Chromium VI	6.21E-01	--	5.99E-03	5.99E-03	--	2.00	--	6.1E-03	6.46E-03	6.43E-03	2.0	2.2	--
Total					**--**	**7.58**	**1.0E-04**				**7.7**	**8.2**	**1.1E-04**

Table 8-6. Native American Exposures (Nonradioactive Chemicals) Ingestion of Beef Tissue.

Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Beef Cattle
Receptor Population: Tribal Subsistence
Receptor Age: Adults

Non-cancer Hazard = CTi x SIFnc / RfD
Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Tissue (CTi)	mg/kg	chem-specific	chem-specific	chem-specific	chem-specific
Ingestion Rate of Beef Tissue (IR)	g/kg-day	--*	1.07	7.95	6.03
Fraction of Beef from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	1.07E-03	7.95E-03	6.03E-03
SIFc = (FC*EF*CF/ATc)*(IRc*Edc+IRa*Eda)	$(day)^{-1}$	1.07E-03		6.20E-03	

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (GW)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

* No beef ingestion rate is provided for Umatilla child exposures.

Chemical	90th Percentile	Umatilla						Yakama					
	CTi (mg/kg)	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult
TCE @ 5 ppb	1.10E-05	--	1.17E-08	1.17E-08	--	0.000039	1.5E-10	8.7E-08	6.61E-08	6.79E-08	0.00029	0.00022	8.8E-10
TCE @ 1.1 ppb	2.41E-06	--	2.58E-09	2.58E-09	--	0.0000086	3.4E-11	1.9E-08	1.46E-08	1.49E-08	0.000064	0.000049	1.9E-10
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
Chromium, Total	1.85E-01	--	1.98E-04	1.98E-04	--	0.000132	--	1.5E-03	1.12E-03	1.15E-03	0.00098	0.00074	--
Carbon Tetrachloride	1.61E-05	--	1.73E-08	1.73E-08	--	0.000025	2.2E-09	1.3E-07	9.74E-08	1.00E-07	0.00018	0.00014	1.3E-08
Chromium VI	8.87E-02	--	9.50E-05	9.50E-05	--	0.032	--	7.1E-04	5.35E-04	5.50E-04	0.235	0.178	--
Total					**--**	**0.032**	**2.4E-09**				**0.237**	**0.17958**	**1.4E-08**

Table 8-7. Native American Agricultural Exposures (Nonradioactive Chemicals) Ingestion of Dairy Products.

Future

Exposure Medium: Groundwater (used for watering livestock)
Exposure Point: Dairy Cattle
Receptor Population: Tribal Subsistence
Receptor Age: Adults

Non-cancer Hazard = CMi x SIFnc / RfD
Cancer Risk = CMi x SIFc x CSF

Parameter	Unit	Umatilla		Yakama	
		Child	Adult	Child	Adult
Chemical Concentration in Milk (CM)	mg/kg	chem-specific		chem-specific	
Ingestion Rate of Milk Products (IR)	g/kg-day	--*	--*	32.19	17.66
Fraction of Dairy Cattle from Contaminated Source (FC)	unitless	1	1	1	1
Exposure Frequency (EF)	days/year	365	365	365	365
Exposure Duration (ED)	years	6	70	6	64
Conversion Factor (CF)	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Averaging Time (non-cancer) (ATnc)	days	2,190	25,550	2,190	23,360
Averaging Time (cancer) (ATc)	days	25,550		25,550	
SIFnc = (IR*FC*EF*ED*CF)/(ATnc)	$(day)^{-1}$	--	--	3.22E-02	1.77E-02
SIFc = (FC*EF*CF/ATc)*(IRc*EDc+IRa*EDa)	$(day)^{-1}$	--		1.89E-02	

* No milk ingestion rate is provided for Umatilla.

Chemical	RfDo (mg/kg-d)	CSFo $(mg/kg\text{-}d)^{-1}$
Carbon Tetrachloride	7.0E-04	1.3E-01
Chloroform	1.0E-02	--
Chromium III	1.5E+00	--
Chromium VI (GW)	3.0E-03	--
Methylene Chloride	6.0E-02	7.5E-03
Nitrate	1.6E+00	--
PCE	1.0E-02	5.4E-01
TCE	3.0E-04	1.3E-02
Uranium	3.0E-03	--

Chemical	90th Percentile	Umatilla						Yakama					
	CM (mg/kg)	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult	$Intake_{nc}$ Child (mg/kg-d)	$Intake_{nc}$ Adult (mg/kg-d)	$Intake_{c}$ Child/Adult (mg/kg-d)	HQ Child	HQ Adult	Cancer Risk Child/Adult
TCE @ 5 ppb	5.14E-06	--	--	--	--	--	--	1.7E-07	9.08E-08	9.72E-08	0.00055	0.000303	1.3E-09
TCE @ 1.1 ppb	1.13E-06	--	--	--	--	--	--	3.6E-08	2.00E-08	2.14E-08	0.00012	0.000067	2.8E-10
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--
Chromium, Total	3.11E-04	--	--	--	--	--	--	1.0E-05	5.49E-06	5.87E-06	0.0000067	0.0000037	--
Carbon Tetrachloride	7.61E-06	--	--	--	--	--	--	2.5E-07	1.34E-07	1.44E-07	0.00035	0.0002	1.9E-08
Chromium VI	1.49E-04	--	--	--	--	--	--	4.8E-06	2.63E-06	2.82E-06	0.0016	0.0009	--
Total					--	--	--				**0.0026**	**0.0014**	**2.0E-08**

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Table 8-8. Summary of Umatilla Cancer Risks at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat Ingestion	Plant Ingestion	Milk Ingestion
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total			
TCE	5	3.9E-06	7.6E-06	3.4E-07	1.2E-05	5.8E-07	1.9E-10	5.8E-07	1.5E-10	1.5E-05	c
TCE	1.1	8.6E-07	1.7E-06	7.4E-08	2.6E-06	1.3E-07	4.1E-11	1.3E-07	3.4E-11	3.3E-06	c
Nitrate	10,000	b	b	b	--	b	b	--	b	b	c
Chromium, total	100	b	b	b	--	b	b	--	b	b	c
Carbon tetrachloride	3.4	2.7E-05	3.9E-05	3.5E-06	6.9E-05	3.0E-06	1.7E-09	3.0E-06	2.2E-09	8.3E-05	c
Chromium VI (GW)	48	b	a	b	--	d	b	--	b	b	c
	TOTAL	**3.1E-05**	**4.7E-05**	**3.9E-06**	**8.1E-05**	**3.6E-06**	**1.9E-09**	**3.6E-06**	**2.4E-09**	**9.7E-05**	**c**

Notes:

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = Chemical not associated with carcinogenic effects through this pathway from groundwater.
c = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
d = Inhalation of non-volatile chemicals from the sweatlodge was not evaluated.
Totals include the risks for TCE based on a CUL of 5 µg/L.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
TCE = trichloroethylene

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Table 8-9. Summary of Umatilla Non-Cancer Hazards at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat Ingestion		Plant Ingestion		Milk Ingestion	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total						
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
TCE	5	1.6	0.95	0.12	0.10	0.167	0.082	1.8	1.1	0.0078	0.000049	0.0078	c	0.000039	c	3.8	d	d
TCE	1.1	0.34	0.21	0.026	0.021	0.037	0.018	0.41	0.25	0.0017	0.000011	0.0017	c	0.000009	c	0.84	d	d
Nitrate	10,000	0.59	0.36	a	a	b	b	0.59	0.36	e	b	--	c	f	c	--	d	d
Chromium, total	100	0.0063	0.0038	a	a	0.0020	0.00076	0.0083	0.0046	e	0.0013	0.0013	c	0.00013	c	0.0083	d	d
Carbon tetrachloride	3.40	0.46	0.28	b	b	0.075	0.037	0.53	0.31	b	0.000019	0.000019	c	0.000025	c	0.91	d	d
Chromium VI (GW)	48.00	1.5	0.91	a	a	0.51	0.19	2.0	1.1	e	0.33	0.33	c	0.032	c	2.0	d	d
TOTAL		**4.1**	**2.51**	**0.12**	**0.10**	**0.75**	**0.31**	**5.0**	**2.9**	**0.0078**	**0.33**	**0.34**	**--**	**0.032**	**--**	**6.7**	**--**	**--**

Notes:

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = No toxicity criteria are available for this chemical to quantify non-cancer hazards through this pathway of exposure.
c = The Umatilla do not provide child-specific ingestion rates.
d = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
e = Inhalation of non-volatile chemicals from the sweatlodge was not evaluated.
f = Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
Totals include the hazards calculated for TCE based on a CUL of 5 µg/L.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
TCE = trichloroethylene

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Table 8-10. Summary of Yakama Cancer Risks at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (µg/L)	Tap Water				Sweatlodge			Meat Ingestion	Plant Ingestion	Milk Ingestion
		Ingestion	Inhalation	Dermal	Total	Inhalation	Dermal	Total			
TCE	5	4.1E-06	7.4E-06	3.4E-07	1.2E-05	7.2E-07	2.7E-10	7.2E-07	8.8E-10	1.6E-05	1.3E-09
TCE	1.1	9.0E-07	1.6E-06	7.4E-08	2.6E-06	1.6E-07	5.8E-11	1.6E-07	1.9E-10	3.5E-06	2.8E-10
Nitrate	10,000	b	b	b	--	b	b	--	b	b	b
Chromium, total	100	b	b	b	--	b	b	--	b	b	b
Carbon tetrachloride	3.4	2.8E-05	3.8E-05	3.5E-06	7.0E-05	3.7E-06	2.4E-09	3.7E-06	1.3E-08	8.9E-05	1.9E-08
Chromium VI (GW)	48	b	a	b	--	c	b	--	b	b	b
	TOTAL	**3.2E-05**	**4.6E-05**	**3.9E-06**	**8.2E-05**	**4.4E-06**	**2.7E-09**	**4.4E-06**	**1.4E-08**	**1.0E-04**	**2.0E-08**

Notes:

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = Chemical not associated with carcinogenic effects through this pathway from groundwater.
c = Inhalation of non-volatile chemicals from the sweatlodge was not evaluated.
Totals include the risks for TCE based on a CUL of 5 µg/L.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
TCE = trichloroethylene

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Table 8-11. Summary of Yakama Non-Cancer Hazards at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (µg/L)	Tap Water								Sweatlodge			Meat Ingestion		Plant Ingestion		Milk Ingestion	
		Ingestion		Inhalation		Dermal		Total		Inhalation	Dermal	Total						
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult
TCE	5	2.08	0.95	0.227	0.084	0.17	0.082	2.48	1.12	0.0096	0.000070	0.0096	0.00029	0.00022	3.9	4.1	0.00055	0.00030
TCE	1.1	0.46	0.21	0.050	0.019	0.037	0.018	0.55	0.25	0.0021	0.000015	0.002122	0.000064	0.000049	0.85	0.91	0.00012	0.00007
Nitrate	10,000	0.78	0.36	a	a	b	b	0.78	0.36	c	b	--	d	d	d	d	d	d
Chromium, total	100	0.0083	0.0038	a	a	0.0020	0.00076	0.010	0.0046	c	0.0019	0.0019	0.0010	0.00074	0.0084	0.0090	0.0000067	0.0000037
Carbon tetrachloride	3.40	0.61	0.28	b	b	0.075	0.037	0.68	0.31	b	0.000027	0.000027	0.00018	0.00014	0.92	0.98	0.00035	0.00019
Chromium VI (GW)	48.00	2.0	0.91	a	a	0.51	0.19	2.5	1.1	c	0.47	0.47	0.24	0.18	2.0	2.2	0.0016	0.00088
	TOTAL [e]	**5.5**	**2.5**	**0.23**	**0.084**	**0.75**	**0.31**	**6.5**	**2.9**	**0.010**	**0.47**	**0.48**	**0.24**	**0.18**	**6.8**	**7.3**	**0.0025**	**0.0014**

Notes:

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = No toxicity criteria are available for this chemical to quantify non-cancer hazards through this pathway of exposure.
c = Inhalation of non-volatile chemicals from the sweatlodge was not evaluated.
d = Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
Totals include the hazards calculated for TCE based on a CUL of 5 µg/L.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
TCE = trichloroethylene

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Table 8-12. Summary of Umatilla Cancer Risks for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water		Sweatlodge		Meat		Plant		Milk Ingestion
	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	
TCE (based on 5 ppb)	2.6E-05	1.2E-05	1.3E-05	5.8E-07	3.3E-10	1.5E-10	3.3E-05	1.5E-05	c
Nitrate	b	b	b	b	b	b	b	b	c
Chromium, total	b	b	b	b	b	b	b	b	c
Carbon tetrachloride	5.8E-02	6.9E-05	2.5E-03	3.0E-06	1.9E-06	2.2E-09	6.8E-02	8.3E-05	c
Chromium VI (GW)	a	a	a	a	b	b	b	b	c
TOTAL	**5.8E-02**	**8.1E-05**	**2.6E-03**	**3.6E-06**	**1.9E-06**	**2.4E-09**	**6.8E-02**	**9.7E-05**	--

Notes:

a = Chromium VI is only carcinogenic through the inhalation pathway. Chromium VI is not volatile, and the inhalation from groundwater as tap water pathway is incomplete for non-volatiles. Although inhalation of non-volatiles from the sweatlodge pathway is complete, this pathway was not quantified due to the uncertainty associated with estimating concentrations in sweatlodge vapor.
b = Chemical not associated with carcinogenic effects through this pathway from groundwater.
c = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
ppb = parts per billion
TCE = trichloroethylene

Table 8-13. Summary of Umatilla Non-Cancer Hazards for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water				Sweatlodge		Meat				Plant				Milk Ingestion	
	Total - 90th Percentile		Total - CUL		Total - 90th Percentile	Total - CUL	Total - 90th Percentile		Total - CUL		Total - 90th Percentile		Total - CUL			
	Child	Adult	Child	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
TCE (based on 5 ppb)	4.0	2.5	1.85	1.13	0.017	0.0078	b	0.000085	b	0.000039	b	8.3	b	3.824	c	c
Nitrate	4.7	2.9	0.59	0.36	a	a	d	d	d	d	d	d	d	d	c	c
Chromium, total	0.011	0.0059	0.0083	0.0046	0.0017	0.0013	b	0.00017	b	0.00013	b	0.011	b	0.0083	c	c
Carbon tetrachloride	453	268	0.53	0.31	0.016	0.000019	b	0.021	b	0.000025	b	774	b	0.907	c	c
Chromium VI (GW)	8.5	4.7	2.0	1.1	1.4	0.33	b	0.13	b	0.032	b	8.5	b	2.0	c	c
TOTAL	**470**	**278**	**5.0**	**2.9**	**1.4**	**0.34**	**--**	**0.16**	**--**	**0.032**	**--**	**790**	**--**	**6.7**	**--**	**--**

Notes:

a = Toxicity criteria are not available to quantify exposures from this pathway for this chemical.
b = The Umatilla do not provide child-specific ingestion rates.
c = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
d = Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
ppb = parts per billion
TCE = trichloroethylene

Table 8-14. Summary of Yakama Cancer Risks for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water		Sweatlodge		Meat		Plant		Milk	
	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL
TCE (based on 5 ppb)	2.6E-05	1.2E-05	1.6E-06	7.2E-07	1.9E-09	8.8E-10	3.5E-05	1.6E-05	2.8E-09	1.3E-09
Nitrate	a	a	a	a	a	a	a	a	a	a
Chromium, total	a	a	a	a	a	a	a	a	a	a
Carbon tetrachloride	5.9E-02	7.0E-05	3.1E-03	3.7E-06	1.1E-05	1.3E-08	7.3E-02	8.9E-05	1.6E-05	1.9E-08
Chromium VI (GW)	b	b	b	b	a	a	a	a	a	a
TOTAL	**5.9E-02**	**8.2E-05**	**3.1E-03**	**4.4E-06**	**1.1E-05**	**1.4E-08**	**7.3E-02**	**1.0E-04**	**1.6E-05**	**2.0E-08**

Notes:

a = Chemical not associated with carcinogenic effects through this pathway from groundwater.
b = Chromium VI is only carcinogenic through the inhalation pathway. Chromium VI is not volatile, and the inhalation from groundwater as tap water pathway is incomplete for non-volatiles. Although inhalation of non-volatiles from the sweatlodge pathway is complete, this pathway was not quantified due to the uncertainty associated with estimating concentrations in sweatlodge vapor.
-- = not evaluated
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
ppb = parts per billion
TCE = trichloroethylene

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Table 8-15. Summary of Yakama Non-Cancer Hazards for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water				Sweatlodge		Meat				Plant				Milk			
	Total - 90th Percentile		Total - CUL		Total - 90th Percentile	Total - CUL	Total - 90th Percentile		Total - CUL		Total - 90th Percentile		Total - CUL		Total - 90th Percentile		Total - CUL	
	Child	Adult	Child	Adult	Adult	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
TCE (based on 5 ppb)	5	2	2.48	1.12	0.021	0.0096	0.00063	0.00048	0.00029	0.00022	8.4	9.0	3.9	4.1	0.0012	0.00066	0.00055	0.00030
Nitrate	6	3	0.78	0.36	a	a	b	b	b	b	b	b	b	b	b	b	b	b
Chromium, total	0.013	0.0059	0.010	0.0046	0.0024	0.0019	0.0013	0.0010	0.00098	0.00074	0.011	0.012	0.0084	0.0090	0.0000087	0.0000048	0.0000067	0.0000037
Carbon tetrachloride	582	268	0.68	0.31	0.023	0.000027	0.16	0.12	0.00018	0.00014	784	835	0.92	0.98	0.30	0.16	0.00035	0.00019
Chromium VI (GW)	10.6	4.7	2.5	1.1	2.0	0.47	1.0	0.76	0.24	0.18	8.6	9.1	2.0	2.2	0.0068	0.0037	0.0016	0.00088
TOTAL	**605**	**278**	**6.5**	**2.9**	**2.0**	**0.48**	**1.2**	**0.88**	**0.24**	**0.18**	**801**	**853**	**6.8**	**7.3**	**0.31**	**0.17**	**0.0025**	**0.0014**

Notes:

a = Toxicity criteria are not available to quantify exposures from this pathway for this chemical.
b = Transfer factors are not readily available for nitrate. Therefore, nitrate in the food chain cannot be reliably quantified.
-- = not evaluated
COPC = contaminant of potential concern
CUL = proposed cleanup level
GW = groundwater
ppb = parts per billion
TCE = trichloroethylene

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Table 8-16. Native American Exposures (Radioactive Chemicals) Ingestion of Groundwater.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence **Cancer Risk = CW x SIFc x CSF**
Receptor Age: Lifetime

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Ingestion Rate of Water (IR)	L/day	4	4
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*EF*ED)	L	1.02E+05	1.02E+05

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.5E-10
Tc-99	2.75E-12
Tritium	5.07E-14

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1	1.5E-05	1.5E-05
Tc-99	900	2.5E-04	2.5E-04
Tritium	20,000	1.0E-04	1.0E-04
TOTAL		**3.7E-04**	**3.7E-04**

Table 8-17. Native American Exposures (Radioactive Chemicals) Inhalation of Vapor.

Future

Exposure Medium: Groundwater
Exposure Point: Drinking Water
Receptor Population: Tribal Subsistence
Receptor Age: Lifetime

Cancer Risk = CA x SIFc x VF x CSF

Parameter	Units	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Inhalation Rate of Air (InhR)	m^3/day	30	26
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (InhR*EF*ED*VF)	m^3	7.7E+05	6.6E+05

Chemical	CSFi (risk/pCi)	VF (L/m^3)
I-129 (non-dairy)	1.60E-10	--
Tc-99	--	--
Tritium	5.62E-14	0.011675

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1	--	--
Tc-99	900	--	--
Tritium	20,000	1.0E-05	8.7E-06
Total		**1.0E-05**	**8.7E-06**

Table 8-18a. Native American Exposures (Radioactive Chemicals) Intermediate Sweatlodge Spreadsheet.

Exposure Medium: Groundwater
Exposure Point: Sweatlodge Vapor
Receptor Population: Tribal Subsistence
Receptor Age: Adults

Formula for Volatile and Semi-Volatile Organic Compounds (including tritium):

$$C_v = C_w * VF_{org}$$

where,

$$VF_{org} = \frac{V_{w,total}}{2 * 2/3 * pi * r^3}$$

Parameter	Definition (units)	Value
C_v	Concentration in sweatlodge vapor (mg/m^3)	Chem-specific
C_w	Concentration in groundwater (mg/L or pCi/L)	Chem-specific
$V_{w,total}$	total volume of water used to create steam (L)	4
r	radius of sweatlodge (m)	1
MW_w	molecular weight of water (g/gmole)	18
R	ideal gas law constant ($mmHg*m^3/gmole*K$)	0.06237
T	temperature of sweatlodge (K)	339
ρ_w	density of liquid water (g/L)	1,000
p^*	partial pressure of water at temp K (mmHg)	194.89
VF_{org}	**Vaporization factor, organic chemicals (L/m^3)**	**0.955**

Table 8-18b. Tribal Exposures (Radioactive Chemicals) Inhalation of Vapor in Sweatlodge.

Future

Exposure Medium: Groundwater
Exposure Point: Sweatlodge
Receptor Population: Tribal Subsistence
Receptor Age: Lifetime

Cancer Risk = CA x $VF_{(org\ or\ m,r)}$ x SIFc x CSF

Parameter	Units	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Water (CW)	pCi/L	chem-specific	chem-specific
Inhalation Rate of Air (InhR)	m^3/day	30	26
Event Time (ET)	hours/event	1	2
Event frequency (EvF)	events/day	1	1
Exposure Frequency (EF)	days/year	365	260
Exposure Duration (ED)	years	68	68
Conversion Factor (CF)	days/hour	4.2E-02	4.2E-02
SIFc = (InhR*EF*ED*ET*EvF*CF)	m^3	3.1E+04	3.8E+04

Chemical	CSFi (risk/pCi)	VF_{org} (L/m^3)
I-129 (non-dairy)	1.60E-10	*
Tc-99	1.41E-11	*
Tritium	5.62E-14	0.955

Chemical	90th Percentile CW (pCi/L)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1	*	*
Tc-99	900	*	*
Tritium	20,000	3.3E-05	4.1E-05
Total		**3.3E-05**	**4.1E-05**

* At the direction of the U.S. Department of Energy, inhalation of non-volatile constituents in the sweatlodge was not evaluated.

Table 8-19. Native American Exposures (Radioactive Chemicals) Ingestion of Plant Tissue.

Current/Future

Exposure Medium: Plant Tissue
Exposure Point: Plants
Receptor Population: Tribal Subsistence
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Tissue (CTi)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Plant Tissue (IR)	g/day	675	709
Fraction of Plant from Contaminated Source (FC)	unitless	1	1
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*FC*EF*ED)	g	1.72E+07	1.81E+07

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
Tc-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	1.31E-02	3.6E-05	3.8E-05
Tc-99	1.22E+02	8.4E-03	8.8E-03
Tritium	5.25E+02	1.3E-03	1.4E-03
Total		**9.7E-03**	**1.0E-02**

Table 8-20. Native American Exposures (Radioactive Chemicals) Ingestion of Livestock Animal Tissue.

Future

Exposure Medium: Animal Tissue
Exposure Point: Livestock
Receptor Population: Tribal Subsistence
Receptor Age: Lifetime

Cancer Risk = CTi x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Tissue (CTi)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Animal Tissue (IR)	g/day	75	422.4
Fraction of Tissue from Contaminated Source (FC)	unitless	1	1
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*FC*EF*ED)	g	1.92E+06	1.08E+07

Chemical	CSFo (risk/pCi)
I-129 (non-dairy)	1.61E-10
Tc-99	4E-12
Tritium	1.44E-13

Chemical	90th Percentile CTi (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	8.40E-03	2.6E-06	1.5E-05
Tc-99	1.52E+00	1.2E-05	6.6E-05
Tritium	2.00E+01	5.5E-06	3.1E-05
Total		**2.0E-05**	**1.1E-04**

Table 8-21. Native American Exposures (Radioactive Chemicals) Ingestion of Milk.

Future

Exposure Medium: Milk
Exposure Point: Milk
Receptor Population: Tribal Subsistence
Receptor Age: Lifetime

Cancer Risk = CW x SIFc x CSF

Parameter	Unit	Umatilla Lifetime	Yakama Lifetime
Chemical Concentration in Milk (CM)	pCi/g	chem-specific	chem-specific
Ingestion Rate of Milk (IR)	g/day	*	1,236
Exposure Frequency (EF)	days/year	365	365
Exposure Duration (ED)	years	70	70
SIFc = (IR*EF*ED)	g	--	3.16E+07

* No milk ingestion rate is provided for Umatilla.

Chemical	CSFo (risk/pCi)
I-129 (dairy)	3.22E-10
Tc-99	4.0E-12
Tritium	1.44E-13

Chemical	90th Percentile CM (pCi/g)	Umatilla Cancer Risk Lifetime	Yakama Cancer Risk Lifetime
Iodine-129	0.004	--	3.9E-05
Tc-99	3.050	--	3.9E-04
Tritium	20	--	9.1E-05
Total		--	**5.1E-04**

Table 8-22. Summary of Umatilla Cancer Risks at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (pCi/L)	Tap Water			Sweatlodge Inhalation	Meat Ingestion	Plant Ingestion	Milk Ingestion
		Ingestion	Inhalation	Total				
90th Percentile Groundwater Concentration								
Iodine-129	1	1.5E-05	a	1.5E-05	b	2.6E-06	3.6E-05	c
Tc-99	900	2.5E-04	a	2.5E-04	b	1.2E-05	8.4E-03	c
Tritium	20,000	1.0E-04	1.0E-05	1.1E-04	3.3E-05	5.5E-06	1.3E-03	c
	TOTAL	**3.7E-04**	**1.0E-05**	**3.8E-04**	**3.3E-05**	**2.0E-05**	**9.7E-03**	--

Notes:

a = Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.
b = Inhalation of non-volatile constituents in the sweatlodge was not evaluated.
c = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
COPC = contaminant of potential concern

Table 8-23. Summary of Yakama Cancer Risks at the Proposed Cleanup Level Groundwater Concentration.

COPC	Groundwater Concentration (pCi/L)	Tap Water			Sweatlodge Inhalation	Meat Ingestion	Plant Ingestion	Milk Ingestion
		Ingestion	Inhalation	Total				
90th Percentile Groundwater Concentration								
Iodine-129	1	1.5E-05	a	1.5E-05	b	1.5E-05	3.8E-05	3.9E-05
Tc-99	900	2.5E-04	a	2.5E-04	b	6.6E-05	8.8E-03	3.9E-04
Tritium	20,000	1.0E-04	8.7E-06	1.1E-04	4.1E-05	3.1E-05	1.4E-03	9.1E-05
	TOTAL	**3.7E-04**	**8.7E-06**	**3.8E-04**	**4.1E-05**	**1.1E-04**	**1.0E-02**	**5.1E-04**

Notes:

a = Radionuclide not volatile. Inhalation from groundwater pathway incomplete for this radionuclide.
b = Inhalation of non-volatile constituents in the sweatlodge was not evaluated.
COPC = contaminant of potential concern

Table 8-24. Summary of Umatilla Cancer Risks for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water		Sweatlodge		Meat		Plant		Milk Ingestion
	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	
Iodine-129	1.8E-05	1.5E-05	a	a	3.0E-06	2.6E-06	4.3E-05	3.6E-05	b
Tc-99	4.1E-04	2.5E-04	a	a	1.9E-05	1.2E-05	1.3E-02	8.4E-03	b
Tritium	2.1E-04	1.1E-04	6.0E-05	3.3E-05	1.0E-05	5.5E-06	2.4E-03	1.3E-03	b
TOTAL	**6.3E-04**	**3.8E-04**	**6.0E-05**	**3.3E-05**	**3.2E-05**	**2.0E-05**	**1.6E-02**	**9.7E-03**	--

Notes:

a = Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
b = The Umatilla do not have default milk ingestion rates to evaluate risks from exposure by this pathway.
-- = no value to sum
COPC = contaminant of potential concern
CUL = proposed cleanup level

Table 8-25. Summary of Yakama Cancer Risks for the 90th Percentile and Proposed Cleanup Level Groundwater Concentration.

COPC	Tap Water		Sweatlodge		Meat		Plant		Milk	
	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL	Total - 90th Percentile	Total - CUL
Iodine-129	1.8E-05	1.5E-05	*	*	1.7E-05	1.5E-05	4.5E-05	3.8E-05	4.5E-05	3.9E-05
Tc-99	4.1E-04	2.5E-04	*	*	1.0E-04	6.6E-05	1.4E-02	8.8E-03	6.2E-04	3.9E-04
Tritium	2.0E-04	1.1E-04	7.4E-05	4.1E-05	5.6E-05	3.1E-05	2.5E-03	1.4E-03	1.6E-04	9.1E-05
TOTAL	**6.3E-04**	**3.8E-04**	**7.4E-05**	**4.1E-05**	**1.8E-04**	**1.1E-04**	**1.7E-02**	**1.0E-02**	**8.3E-04**	**5.1E-04**

* Chemical not volatile. Inhalation from groundwater pathway incomplete for this chemical.
-- = not evaluated
COPC = contaminant of potential concern
CUL = proposed cleanup level

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Appendix H

Pipelines Remedial Evaluation

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Terms

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BRA	baseline risk assessment
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	Code of Federal Regulations
COC	contaminant of concern
COPC	contaminant of potential concern
CS	carbon steel
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FS	feasibility study
GRA	general response action
IC	institutional controls
IDMS	Integrated Document Management System
ISS	in situ stabilization
MCL	maximum contaminant level
NCP	National Contingency Plan
NPH	normal paraffin hydrocarbon
O&M	operations and maintenance
OU	operable unit
PFP	Plutonium Finishing Plant
PRG	preliminary remediation goal
RAO	remedial action objective
RCRA	*Resource Conservation and Recovery Act of 1976*
RI	remedial investigation

ROD	record of decision
RTD	removal, treatment, and disposal
SS	stainless steel
SVE	soil vapor extraction
TBD	to be determined
TBP	tributyl phosphate
TEDF	Treated effluent disposal facility
TRU	transuranic
TSD	treatment, storage, and disposal
UPR	unplanned release
VCP or VC	vitrified clay piping
WAC	*Washington Administrative Code*
WIDS	Waste Information Data System

H1 Introduction

This appendix describes the inactive subsurface pipelines associated with the feasibility study (FS) addressing the 200-PW-1, 200-PW-3, and 200-PW-6 operable unit (OU) waste sites, and the 200-CW-5 OU waste sites. The 200-PW-1, 200-PW-6, and 200-CW-5 OUs are located in the 200 West Area of the Hanford Central Plateau. Pipelines 200-W-174-PL, 200-W-205-PL, 200-W-206-PL, 200-W-207-PL, 200-W-208-PL, 200-W-210-PL, and 200-W-220-PL are located near the Plutonium Finishing Plant (PFP) (Figure H2-1, at the end of Appendix H). All pipelines were used to transport and convey process liquid waste or cooling water and steam condensate liquids from the PFP to the respective OU waste sites.

The 200-PW-3 OU is located in the 200 East Area of the Hanford Central Plateau. Although 200-PW-3 is mentioned in this section, its associated waste sites and pipelines will be addressed in the 200-IS-1 OU (DOE/RL-2002-14, Rev. 1, *Tanks/Lines/Pits/Boxes/Septic Tank and Drain Fields Waste Group Operable Unit RI/FS/Work Plan and RCRA TSD Unit Sampling Plan; Includes 200-IS-1 and 200-ST-1 Operable Units*). 200-PW-3 is described in this section for information only.

To identify the pipelines included in the decision for these OUs, a rules set was developed as follows:

1. The pipeline had a classification status of "Accepted" or "Accepted (Proposed)" in Waste Information Data System (WIDS).
2. The pipeline had an OU assignment of "to be determined" (TBD) meaning it is not associated with an OU.
3. The pipeline had conveyed liquid waste to a 200-PW-1, 200-PW-3, 200-PW-6, or 200-CW-5 waste site for disposal.
4. Segments of pipelines that are still in active use are excluded from the 200-PW-1, 200-PW-3, 200-PW-6 OU, and 200-CW-5 remedial alternative decision.
5. Systems and equipment regulated under *the Resource Conservation and Recovery Act of 1976* (RCRA) are excluded from the 200-PW-1, 200-PW-3, 200-PW-6 OU, and 200-CW-5 remedial alternative decision.
6. Geographic logistics (i.e., overlapping pipelines) will be considered on a pipeline-specific basis, which may alter the selection.

Pipelines within the footprint of the remedial action for an individual waste site would be remedied according to the decisions in the respective feasibility study (FS) for each OU waste site, and therefore are not included in this evaluation.

For a brief history of the waste sites, refer to Chapter 1.0 of DOE/RL-2007-27 for 200-PW-1, 200-PW-3, and 200-PW-6 OUs, and Chapter 1.0 of DOE/RL-2004-24, *Feasibility Study for the 200-CW-5 (U Pond/Z Ditches Cooling Water Waste Group), 200-CW-2 (S Pond and Ditches Cooling Water Waste Group), 200-CW-4 (T Pond and Ditches Cooling Water Waste Group), and 200-SC-1 (Steam Condensate Waste Group) Operable Units*, for 200-CW-5.

The waste site pipelines of interest were investigated using a variety of research tools including Arc Geographic Information System (ArcGIS), WIDS, Query Map (Qmap), and the Integrated Document Management System (IDMS). These tools provided limited histories of each pipeline and waste site as well as historical engineering drawings. The researched documents were compared and verified amongst themselves for engineering and historical consistency. The documents were not field-verified. One unplanned release (UPR) has been identified for these pipelines. No information is available regarding any additional pipeline leaks.

H1.1 Purpose

The purpose of this assessment is to develop and evaluate alternatives for remediation of the pipelines connected to waste sites in the 200-PW-1, 200-PW-3, 200-PW-6, and 200-CW-5 OUs. Because some of the pipelines in whole or part are already addressed in the 200-IS-1 OU, this document identifies which pipelines will be remediated under the decision for these OUs, and provides remedial alternatives with analysis, as appropriate. The format of the waste site FS (DOE/RL-2007-27, Rev. 0) is followed to maintain consistency. The pipelines are categorized under the following waste types:

- High-Salt Pipeline(s): 200-W-174-PL, 200-W-206-PL
- Low-Salt Pipeline(s): 200-W-205-PL, 200-W-208-PL, 200-W-210-PL, and 200-W-220-PL
- Z-Ditch Pipeline(s): 200-W-207-PL

H1.2 Scope

This assessment evaluated existing information and data for the pipelines associated with the 200-PW-1, 200-PW-3, 200-PW-6, and 200-CW-5 OU waste sites. The scope includes all or portions of the following pipelines: 200-W-174-PL, 200-W-205-PL, 200-W-206-PL, 200-W-207-PL, 200-W-208-PL, 200-W-210-PL, and 200-W-220-PL. Specifically, each pipeline's boundary is described in detail in Chapter 2. The scope involves waste piping and the surrounding soil deemed necessary to evaluate in order to meet remediation goals. In some cases, the remediation activity may need to terminate at a particular junction—building wall/slab, diversion box, or tank. The ancillary equipment may not be included in the pipeline scope, and is described as follows.

The scope does not include tanks, vessels, valve pits, diversion boxes, French drains, and/or equipment that are RCRA-regulated units. Nor does it evaluate pipelines associated with water, utilities, inert gases, sanitary sewers, sanitary water, stormwater, aboveground pipelines, or active pipelines. Some pipelines will be addressed in the 200-IS-1 OU and are not included in this remedial evaluation. These pipelines include the following:

- Pipelines associated with 200-PW-3 including 200-E-164-PL, 200-E-165-PL, 200-E-182-PL, 200-E-183-PL, and 200-E-186-PL
- Pipeline 200-W-204-PL to 216-Z-10
- Pipelines 200-W-202-PL to 216-Z-5
- Pipeline 200-W-209-PL

The one known UPR (UPR-200-W-103) has been documented. This release is associated with the 200-W-174-PL pipeline and the remediation of this release is being addressed under the 200-MG-2 OU.

In order to properly assess the pipelines, the following assumptions were made:

- Pipelines were installed per historical record drawings, unless noted otherwise.
- Pipelines are intact and are not currently leaking at fittings (joints, welds, elbows, and/or valves) or anywhere else along the pipeline.
- Pipelines were properly cleaned and flushed per operational history and, therefore, do not contain significant inventories of liquid or sludge that would cause plugging.
- Pipelines are assumed to have little or no residual volume and transuranic (TRU) waste is not anticipated to be present (less than 100 nCi/g).

H1.2.1 Document Content and Relationship to 200-PW-1, 200-PW-3, 200-PW-6 Operable Unit Feasibility Study, and 200-CW-5 Operable Unit Feasibility Study

Historically, the pipelines were constructed in conjunction with and for the purposes of conveying the same materials that were disposed in the OU waste sites. Therefore, much of the background information (i.e., physical setting, land use) associated with these pipelines has already been discussed in the applicable FS for each OU and will not be repeated in this assessment. Table H1-1 provides a cross-walk showing the location in the OU FS where the particular FS component can be found.

Table H1-1. Crosswalk for Feasibility Study Components in 200-PW-1, 200-PW-3, 200-PW-6 Operable Unit, and 200-CW-5 Operable Unit

Feasibility Study Component	200-PW-1, 200-PW-3, and 200-PW-6 OU Locations (DOE/RL-2007-27)	200-CW-5 Location (DOE/RL-2004-24)
Physical Setting	Section 2.1	Section 2.2
Natural Resources	Section 2.3	Section 2.3
Plutonium Fate and Transport	Section 2.5	N/A
Land Use	Section 3.1	Section 3.1
Baseline Risk Assessment	Section 3.2	Section 3.2
Contaminants of Concern	Section 3.5	Section 3.3
ARARs	Section 3.6	Section 3.4
Remedial Action Objectives	Section 3.7	Section 3.6
Preliminary Remediation Goals	Section 3.8	Section 3.7

Notes:

ARARs = applicable or relevant and appropriate requirements

N/A = Not applicable

DOE/RL-2004-24, *Feasibility Study for the 200-CW-5 (U Pond/Z Ditches Cooling Water Waste Group), 200-CW-2 (S Pond and Ditches Cooling Water Waste Group), 200-CW-4 (T Pond and Ditches Cooling Water Waste Group), and 200-SC-1 (Steam Condensate Waste Group) Operable Units.*

This appendix contains the following chapters:

- Chapter H1 Introduction: Introduces OU scope, purpose, assumptions, and document content.
- Chapter H2 Pipeline Background and Description: Discusses the pipeline locations, description, and access issues.
- Chapter H3 Identification and Screening of Remedial Technologies: Discusses general response actions, and technologies.
- Chapter H4 Remedial Action Alternatives: Develops and describes the remedial technology.
- Chapter H5 Detailed Analysis of Alternatives: Describes evaluation criteria, and analyzes each of the alternatives in detail.
- Chapter H6 Comparative Analysis of Alternatives: Compares the alternatives per the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) evaluation criteria.
- Chapter H7 Uncertainties Related to Decision-making: Discusses uncertainties and their potential impacts.
- Chapter H8 References: Summarizes the reference documents.

H2 200-PW-1, 200-PW-6, and 200-CW-5 Pipeline Descriptions and Considerations

This section describes each waste pipeline associated with the 200-PW-1, 200-PW-6, and 200-CW-5 OUs. In general, most of the 200-PW-1, 200-PW-6, and 200-CW-5 pipelines are buried underground, except where a pipeline may enter a building or building slab. The proximity of the pipelines to one another and to other waste sites is depicted in Figure H2-1 (at the end of Appendix H). All piping is considered unpressurized and flows downhill towards the waste sites—typical of gravity drains with slopes between one-half to 3 percent. The piping usually consists of a mix-match of the following materials: carbon steel (CS), stainless steel (SS), and vitrified clay pipe (VCP, or VC).

H2.1 Pipeline Descriptions

Descriptions of each pipeline are presented in the following subsections. For ease of review, the pipelines have been grouped according to the materials conveyed by each pipeline: High-Salt waste, Low-Salt waste, or the cooling water and steam condensate discharged to the Z-Ditches. The groups consist of the following:

- High-Salt – in general, this acidic aqueous waste was a concentrated nitrate solution containing dissolved metal (aluminum, calcium, sodium, and magnesium) nitrates, plutonium, and other TRU elements. At times, significant volumes of organics (principally carbon tetrachloride, tributyl phosphate [TBP], and lard oil), both entrained in the aqueous phase waste streams and as separate, nonaqueous phase waste streams were conveyed in the same pipeline with the High-Salt waste stream.

- Low-Salt – this waste stream included neutral to basic aqueous materials that contained plutonium and americium, with negligible amounts of organics and no nonaqueous phase liquids. This aqueous waste was primarily a dilute sodium fluoride and sodium nitrate solution when discharged.

- Cooling Water/Steam Condensate (Z-Ditches) – this aqueous waste stream typically consisted of process cooling water and steam condensate water from PFP processes, but known to show similarities in characterization to the Low-Salt materials. The Z-Ditches are associated with the 200-CW-5 OU. However, they are included as part of the FS for 200-PW-1/3/6 because there is only one pipeline (200-W-207-PL) of concern that is connected to 216-Z-19. Since 200-CW-5 OU is being combined with the 200-PW-1/3/6 in the Proposed Plan and the record of decision (ROD), it is more efficient to evaluate that Z-ditch pipeline along with the other 200-PW-1/3/6 pipelines.

In addition, each pipeline discussion has an assessment of the aboveground and underground features that may present unique challenges during remedial action implementation.

H2.1.1 High-Salt Pipelines

The High-Salt pipelines (200-W-174-PL and 200-W-206-PL) are presented in this section.

Pipeline 200-W-174-PL: This pipeline connects to the 200-PW-1 OU waste site 216-Z-18 Crib and 216-Z-1A Tile Field. Figure H2-2 shows this pipeline and associated waste units. Pipeline 200-W-174-PL consists of two parallel pipelines designated 1035 and 1036. Pipeline 200-W-174-PL begins as two 5 cm (2 in.) diameter SS pipelines (1035 and 1036) that run underground heading south from the south wall of Building 234-5Z near Building 2727-Z, and underneath the 241-ZB Structure. The pipeline continues bypassing the 241-Z-361 Settling Tank, 216-Z-1, 216-Z-2, and 216-Z-3 Cribs into the 216-Z-1A Tile Field area where it turns and heads southwest. The pipelines then merge and enlarge to an 8 cm (3 in.)

diameter common SS header. The combined single 8 cm (3 in.) pipeline runs the length of the 216-Z-18 pipeline and separates into several discharge headers.

The 216-Z-1A Tile Field was once fed by pipelines 200-W-174-PL (1035) and 200-W-174-PL (1036). Pipeline 200-W-174-PL (1036) extends into the 216-Z-1A Crib area where it terminates inside a 20 cm (8 in.) VCP line. Pipeline 200-W-174-PL remediation scope consists of the same piping as described previously, including the portion running back to its point of origin in the 234-5Z Building, with the exception of the section of piping that exists within the waste site boundaries. Most of this pipeline consists of two parallel pipes of SS. Pipeline 200-W-174 (1036) that connects to the 234-5Z Building, with the exception of the section of piping that exists within the waste site boundaries. Most of this pipeline consists of two parallel pipes of SS.

The 200-W-174-PL consists of two segments, each having a different depth and slope. The pipeline 200-W-174-PL (1036) that connects to the 216-Z-1A Tile Field appears to be a maximum 2.6 m (8.5 ft) below surface with a slope between 0.57 to 2.0 percent. The pipeline 200-W-174-PL (1035) that connects to the 216-Z-18 Crib appears to be a maximum 4.6m (15 ft) below surface with a slope between 0.5 to 2 percent.

Aboveground access to this pipeline may be restricted by fences, roads, and buildings. Belowground access to this pipeline may be restricted by electrical utilities, RCRA pipelines, and sanitary water pipelines.

Pipeline 200-W-174-PL has the following aboveground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 216-Z-1A Tile Field and the 216-Z-18 Crib:

- The pipeline crosses underneath Cispus Loop Road and another unnamed service road near the 216-Z-18 Crib.
- The pipeline runs underground alongside the 2727-Z Building, the 243-ZB Structure, and the 243-ZA Structure.
- The pipeline runs underneath the 241-ZB Structure.
- The pipeline runs underground near the 241-Z Building's asphalt walkway and tank vault.
- Security fences are located near each of the destination 216-Z-18 Crib and 216-Z-1A Tile Field.

Pipeline 200-W-174-PL has the following belowground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 216-Z-1A Tile Field and the 216-Z-18 Crib:

- The pipeline runs near electrical power lines near the south side of the 234-5Z Building.
- The pipeline crosses a sanitary water pipeline after crossing Cispus Loop Road.
- The pipeline crosses RCRA Pipeline 200-W-178-PL. It is unclear whether the pipeline runs over or under RCRA Pipeline 200-W-178-PL.
- No known waste units are associated with the 241-Z Building and structures (UPR-200-74, UPR-200-W-75, and UPR-200-W-79).
- The pipeline runs near the 241-Z-361 Settling Tank and 200-W-58 Z-Plant Diversion Box No. 1.
- The pipeline crosses the 200-W-208-PL pipeline and then the 200-W-207-PL pipeline before entering the 216-Z-1A Tile Field. It continues on, crossing under another unnamed service road, and enters into the 216-Z-18 Crib.

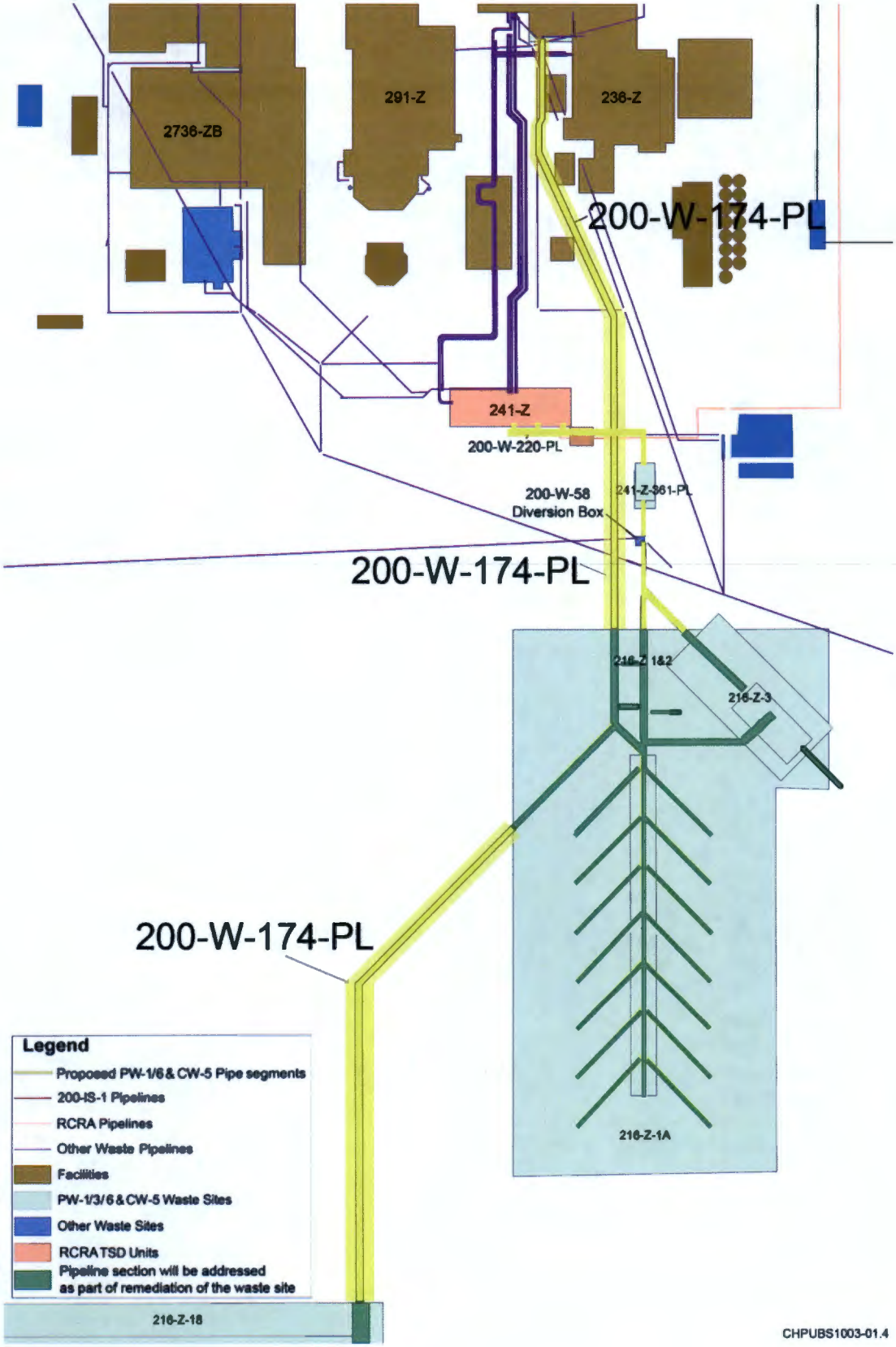

Figure H2-2. Pipeline 200-W-174-PL

Pipeline 200-W-206-PL: This pipeline connects to the 200-PW-1 OU waste site 216-Z-9 Crib. Figure H2-3 shows this pipeline and associated waste units. The 200-W-206-PL pipeline consists of two 3.8 cm (1.5 in.) diameter SS pipelines that run underground heading east from the east wall of Building 234-5Z and underneath Building 2725-Z to 216-Z-9 Crib. The lines run in the same soil trench as the 200-W-205-PL pipeline lines for the first 61 m (200 ft) before diverging. The remediation scope of the 200-W-206-PL pipeline would include the piping described previously, except the piping within the 216-Z-9 Crib back to its point of origin at the Building 234-5Z wall. The pipeline consists of two parallel SS pipes. The section of the pipeline 200-W-206-PL that connects to the 216-Z-9 Crib appears to be a maximum 1.8 m (6 ft) below surface with a slope between 1 to 2 percent.

Aboveground access to this pipeline may be restricted by fences, roads, and buildings. Belowground access to this pipeline may be restricted by electrical utilities, RCRA pipelines, sanitary water pipelines, and sewer pipelines.

Pipeline 200-W-206-PL pipeline has the following aboveground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 216-Z-9 Crib:

- The pipeline runs underneath Building 234-5ZA (east of Building 234-5Z) and near Storage Building 2725-Z.
- The pipeline crosses underneath Cispus Loop Road.
- Security fences are located near the destination 216-Z-9 Crib.

Pipeline 200-W-206-PL has the following belowground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 216-Z-9 Crib:

- The pipeline runs near electrical power lines near the east side of Building 234-5Z.
- The pipeline crosses sanitary water pipeline near the east side of Building 234-5Z.
- The pipeline crosses sewer water pipeline just east of Cispus Loop Road.
- The pipeline crosses RCRA Pipeline 200-W-178-PL.
- The pipeline crosses a sanitary water pipeline for a second time before making its way near and passing by the 241-Z-8 Settling Tank and then the 216-Z-8 French Drain.
- The pipeline crosses pipeline 200-W-125-PL.
- The pipeline crosses the 216-Z-1D Ditch.
- The pipeline runs in parallel with the 200-W-205-PL pipeline up to the 241-Z-8 Settling Tank.

H2.1.2 Low-Salt Pipelines

The Low-Salt pipelines (200-W-205-PL, 200-W-208-PL, 200-W-210-PL, and 200-W-220-PL) are discussed as follows.

Pipeline 200-W-205-PL: This pipeline connects to the 200-PW-6 OU waste site's 241-Z-8 Settling Tank and 216-Z-8 Crib. Figure H2-3 shows this pipeline and associated waste units. The 200-W-205-PL pipeline consists of two parts. One is the inlet to the 241-Z-8 Settling Tank; the other is the outlet of the 241-Z-8 Settling Tank that discharges to the 216-Z-8 French Drain. The first part is two 3.8 cm (1.5 in.) diameter SS pipelines heading east from the east wall of Building 234-5Z underneath Building 2725-Z to

the 241-Z-8 Settling Tank (inlet). The second part is a 10 cm (4 in.) diameter CS pipeline that runs between the overflow of the 241-Z-8 Settling Tank and the 216-Z-8 French Drain. The lines run in the same soil trench as the 200-W-206-PL pipelines for the first 61 m (200 ft) before diverging. The remediation scope of the 200-W-205-PL pipeline would be the piping described previously back to the point of origin at the Building wall. The pipeline consists of two parallel SS pipes. The section of pipeline 200-W-205-PL that connects to the 241-Z-8 Settling Tank and the 216-Z-8 Crib appears to be a maximum of 1.8 m (6 ft) below surface with a slope between 1 to 2 percent.

Aboveground access to this pipeline may be restricted by fences, roads, and buildings. Belowground access to this pipeline may be restricted by electrical utilities, RCRA pipelines, sanitary water pipelines, and sewer pipelines.

Pipeline 200-W-205-PL has the following aboveground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 216-Z-8 French Drain:

- The pipeline runs underneath Building 234-5ZA (east of Building 234-5Z) and near Storage Building 2725-Z.
- The pipeline crosses underneath Cispus Loop Road.
- Security fences are located near the destination 241-Z-8 Settling Tank and the 216-Z-8 French Drain.

Pipeline 200-W-205-PL has the following belowground restrictions/obstructions listed in order, starting at the 234-5Z Building and ending at the 241-Z-8 French Drain:

- The pipeline runs near electrical power lines near the east side of Building 234-5Z.
- The pipeline crosses the sanitary water pipeline near the east side of Building 234-5Z.
- The pipeline crosses the sewer water pipeline just east of Cispus Loop Road.
- The pipeline crosses RCRA pipeline 200-W-178-PL.
- The pipeline crosses a sanitary water pipeline for a second time before making its way to the 241-Z-8 Settling Tank and then the 216-Z-8 French Drain.
- The pipeline runs parallel with the 200-W-206-PL pipeline for the full extent of the run.

Pipeline 200-W-208-PL: This pipeline connects to the 200-PW-1 OU waste site 216-Z-12 Crib. Figure H2-4 shows this pipeline and associated waste units. This pipeline is discussed as part of the 200-IS-1 OU. This pipeline will be remediated to the isolation valve inside the 200-W-59 (Diversion Box No. 2), and the remainder of the pipeline will be handled through the 200-IS-1 OU. Pipeline 200-W-208-PL is a 15 cm (6 in.) SS pipeline that originates at the 200-W-58 (Diversion Box No. 1) and connects to 200-W-59 (Diversion Box No. 2). It transitions to a 30 cm (12 in.) VCP pipeline at the 216-Z-12 Crib. Both diversion boxes should be addressed with the 200-IS-1 OU. Inside of 200-W-59 (Diversion Box No. 2), 200-W-208-PL splits into two segments to feed the 216-Z-12 Crib. The original segment comes in at the north end of the crib and the other segment bypasses the north side of the crib and extends to just short of half the distance of the west side of the crib. The original segment transitions from 15 cm (6 in.) SS to 30 cm (12 in.) VCP at the 200-W-59 (Diversion Box No. 2). The bypass section, which was installed to resolve plugging, transitions from 15 cm (6 in.) SS to 30 cm (12 in.) VCP inside the crib. The remediation of the 200-W-208-PL pipeline would include a segment of the piping described

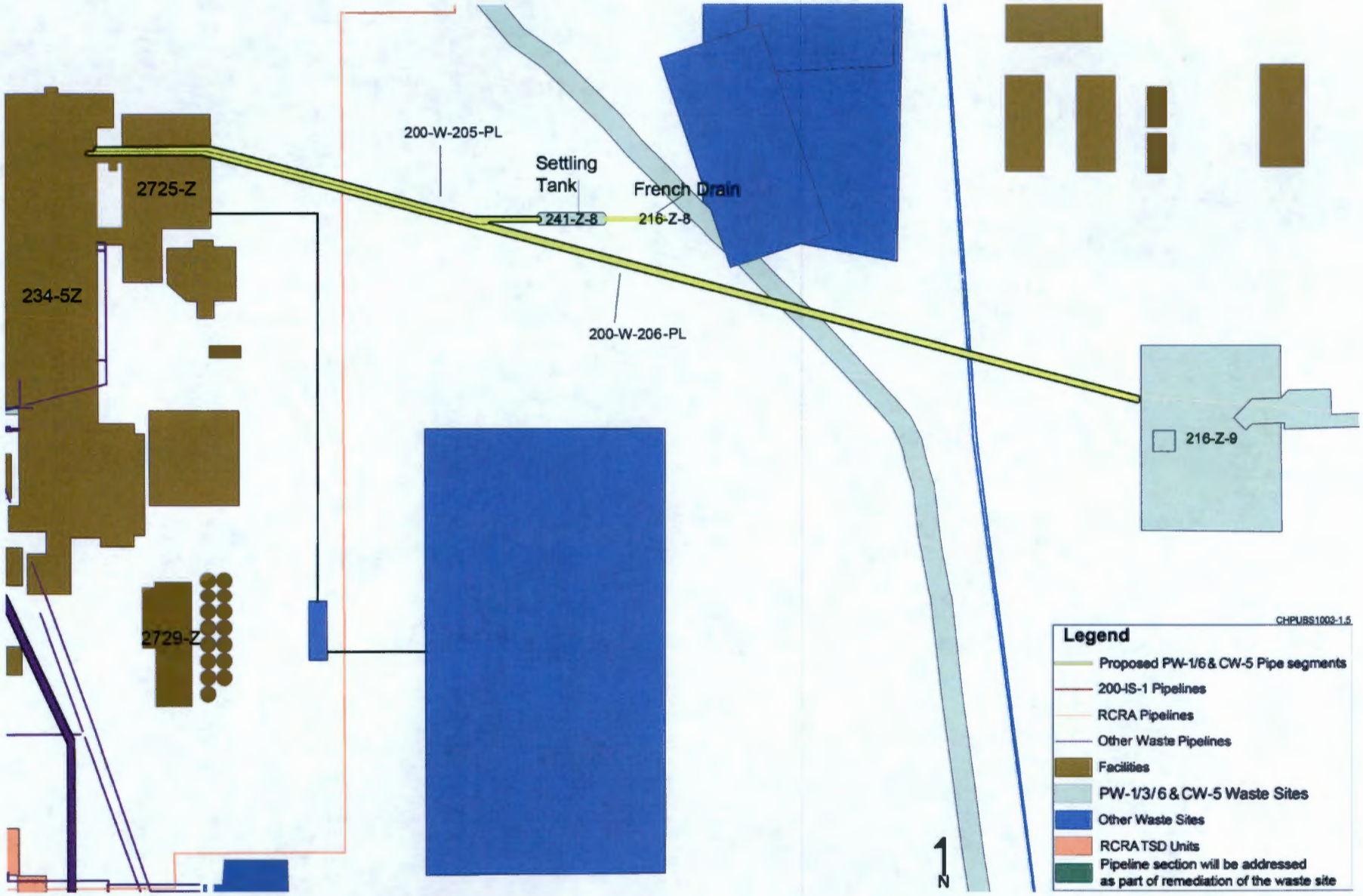

Figure H2-3. Pipeline 200-W-205-PL and 200-W-206-PL

previously. Piping within the footprint of the remedy selected for the 216-Z-12 Crib would be addressed as part of the remedy for the crib. The pipe will be remediated between the 216-Z-12 Crib and the 200-W-59 (Diversion Box No. 2) up to the isolation valves inside 200-W-59 (Diversion Box No. 2). The pipeline consists of one SS pipe. Pipeline 200-W-208-PL that connects to the 216-Z-12 Crib appears to be a maximum of 4.6 m (15 ft) below surface with unknown slope. Aboveground access to this pipeline may be restricted by fences. Belowground access to this pipeline is not restricted.

Pipeline 200-W-208-PL has the following aboveground restrictions/obstructions listed in order, starting at the 200-W-59 Z-Plant Diversion Box No. 2 and ending at the 216-Z-12 Crib:

- Security fences are located near the destination 216-Z-12 Crib.

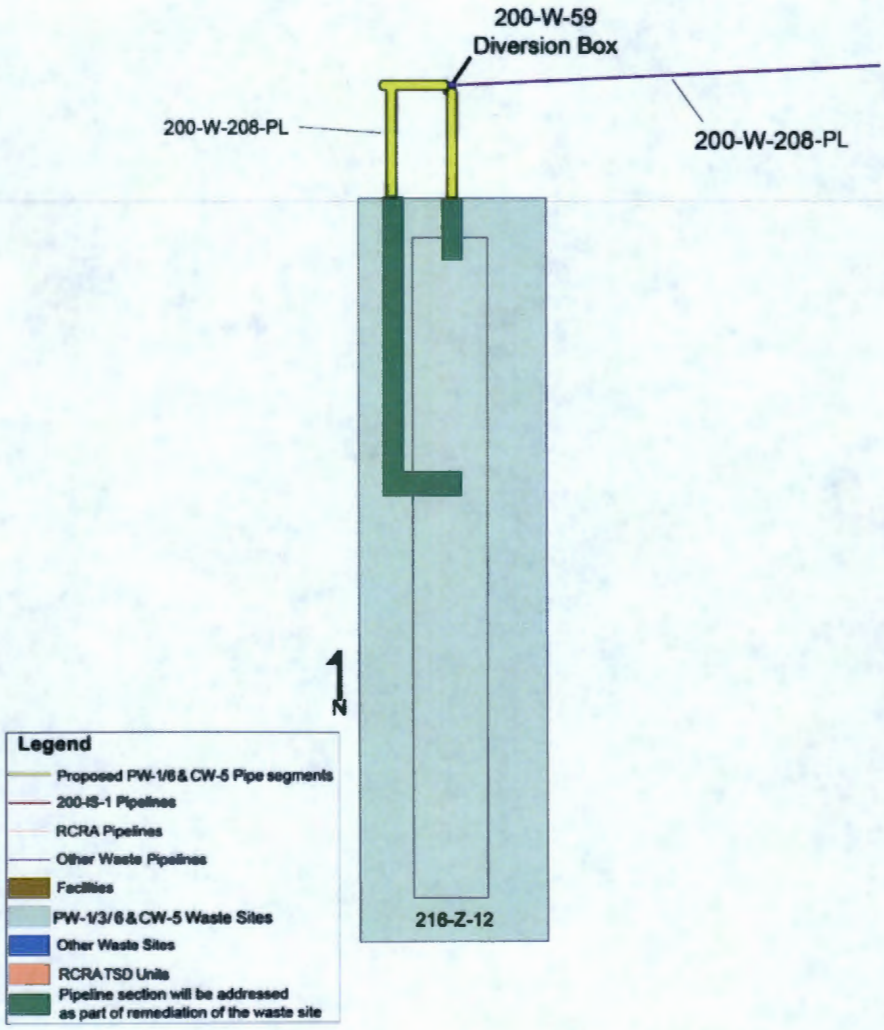

Figure H2-4. Pipeline 200-W-208-PL

Pipeline 200-W-210-PL: This pipeline connects to the 200-PW-1 OU waste sites 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and the 216-Z-1A Tile Field. Figure H2-5 shows this pipeline and associated waste units. This pipeline is discussed as part of the 200-IS-1 OU. This pipeline feeds the 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and 216-Z-1A Tile Field by way of the 241-Z-361 Settling Tank, and through the 200-W-58 Diversion box (Diversion Box No. 1). Pipeline 200-W-210-PL is a 20 cm (8 in.) diameter SS pipeline that originates at the 241-Z-361 Settling Tank and splits to the 216-Z-1Crib and 216-Z-2 Crib, and then to the 216-Z-3 Crib. For each crib, the line transitions to a 20 cm (8 in.) VCP pipeline. A second 20 cm (8 in.) VCP line exits the 216-Z-3 Crib and overflows to the 216-Z-1A Tile Field.

Given the proximity to the 216-Z-1A site and the 241-Z-361 Settling Tank, the section of the 200-W-210-PL pipeline from the cribs to 200-W-58 (Diversion Box No. 1) is included. Care should be taken when in proximity to the 200-W-207-PL pipeline, as it is active and is part of the Treated Effluent Disposal Facility (TEDF) system. From the data available in the PFP subgrade Engineering Evaluation/Cost Analysis (EE/CA) (HNF-30862, *Engineering Evaluation/Cost Analysis for the Plutonium Finishing Plant Sub-Grade Structures and Installations*) it appears as if the 200-W-210-PL pipeline is below the 200-W-207-PL pipeline. The remediation of pipeline 200-W-206-PL would include the piping described previously, except piping within the 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and 216-Z-1A Tile Field, back to its point of origin at the 241-Z-361 Settling Tank. The pipeline consists of several pipe segments of SS and VCP. Pipeline 200-W-210-PL to the 216-Z-1, 216-Z-2, and 216-Z-3 cribs and 216-Z-1A Tile Field appears to be between 6.75 and 3 m (22 and 10 ft) below surface with unknown slope.

Aboveground access to this pipeline may be restricted by fences. Belowground access to this pipeline may be restricted by process pipelines in the vicinity, particularly the active portion of pipeline 200-W-207-PL.

Pipeline 200-W-210-PL has the following aboveground restrictions/obstructions listed in order, starting at the 241-Z-361 Settling Tank and ending at the 200-W-210-PL to 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and the 216-Z-1A Tile Field:

- Security fences are located near the destination 200-W-210-PL to 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and 216-Z-1A Tile Field.

Pipeline 200-W-210-PL has the following belowground restrictions/obstructions listed in order, starting at the 241-Z-361 Settling Tank and ending at the 200-W-210-PL to 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and the 216-Z-1A Tile Field:

- The pipeline begins and runs near the 241-Z-361 Settling Tank.
- The pipeline runs through the 200-W-58 (Diversion Box No. 1).
- The pipeline crosses the active portion of Pipeline 200-W-207-PL. It is unclear whether the pipeline runs over or under pipeline 200-W-207-PL.

Pipeline 200-W-220-PL: This pipeline connects to the 200-PW-1 OU waste site 241-Z-361 Settling Tank. Figure H2-5 shows this pipeline and associated waste units. 200-W-220-PL is a 15 cm (6 in.) diameter SS pipeline that originates at the 241-Z Building as three outlets that are connected with a manifold and run to the 241-Z-361 Settling Tank. Care should be taken when in proximity to the 200-W-178-PL pipeline, as it is an inactive RCRA pipeline. Remediation of 200-W-220-PL would include piping described previously, starting at the 241-Z-361 Settling Tank, back to its point of origin at the 241-Z Building. The pipeline consists of several SS pipe segments. Pipeline 200-W-220-PL to the 241-Z-361 Settling Tank appears to be between 2.06 and 3 m (6.75 and 10 ft) below surface with unknown slope.

Aboveground access to this pipeline may be restricted by fences. Belowground access to this pipeline may be restricted by process pipelines in vicinity, particularly the inactive portion of RCRA-regulated pipeline 200-W-178-PL.

Pipeline 200-W-220-PL has the following aboveground restrictions/obstructions listed in order, starting at the 241-Z Building and ending at the 241-Z-361 Settling Tank:

- Security fences are located near Building 241-Z.

Pipeline runs underground near the 241-Z Building's asphalt walkway and tank vault.

Pipeline 200-W-220-PL has the following belowground restrictions/obstructions listed in order, starting at the 241-Z Building and ending at the 241-Z-361 Settling Tank:

- The pipeline starts and runs near Building 241-Z.
- The pipeline runs near and parallel to the inactive RCRA-regulated pipeline 200-W-178-PL.

The pipeline ends and runs near the 241-Z-361 Settling Tank.

H2.1.3 Z-Ditch Pipeline

The Z-Ditch pipeline 200-W-207-PL, which is associated with 200-CW-5 OU, is discussed below.

Pipeline 200-W-207-PL: This pipeline connects to the 200-CW-5 OU waste sites 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 Ditches (Z-Ditch system). Figure H2-6 shows this pipeline and associated waste units. The Z-Ditch system was fed by two pipelines: 200-W-207-PL and 200-W-125-PL. The 200-W-125-PL pipeline should be addressed by the 200-IS-1 OU.

Pipeline 200-W-207-PL is still an active piece of the TEDF system. It is connected to the 600-291 drainline to the TEDF. The active portion is not considered for remediation. The portion of 200-W-207-PL considered in this location is the downstream, inactive, capped portion of the junction at the 600-291 pipeline in the C-1 manhole. From this point, the 200-W-207-PL is a 38 cm (15 in.) diameter VCP that runs underground and splits amongst the 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditches. The remediation scope of the 200-W-207-PL would be all the piping downstream of the manhole to the waste site boundaries. The pipeline consists of one VCP pipe. Pipeline 200-W-207-PL to the Z-Ditch system appears to be 1.5 m (5 ft) below surface with a slope between 2 to 3 percent.

Aboveground access to this pipeline may be restricted by fences and roads. Belowground access to this pipeline may be restricted by process pipelines in the vicinity.

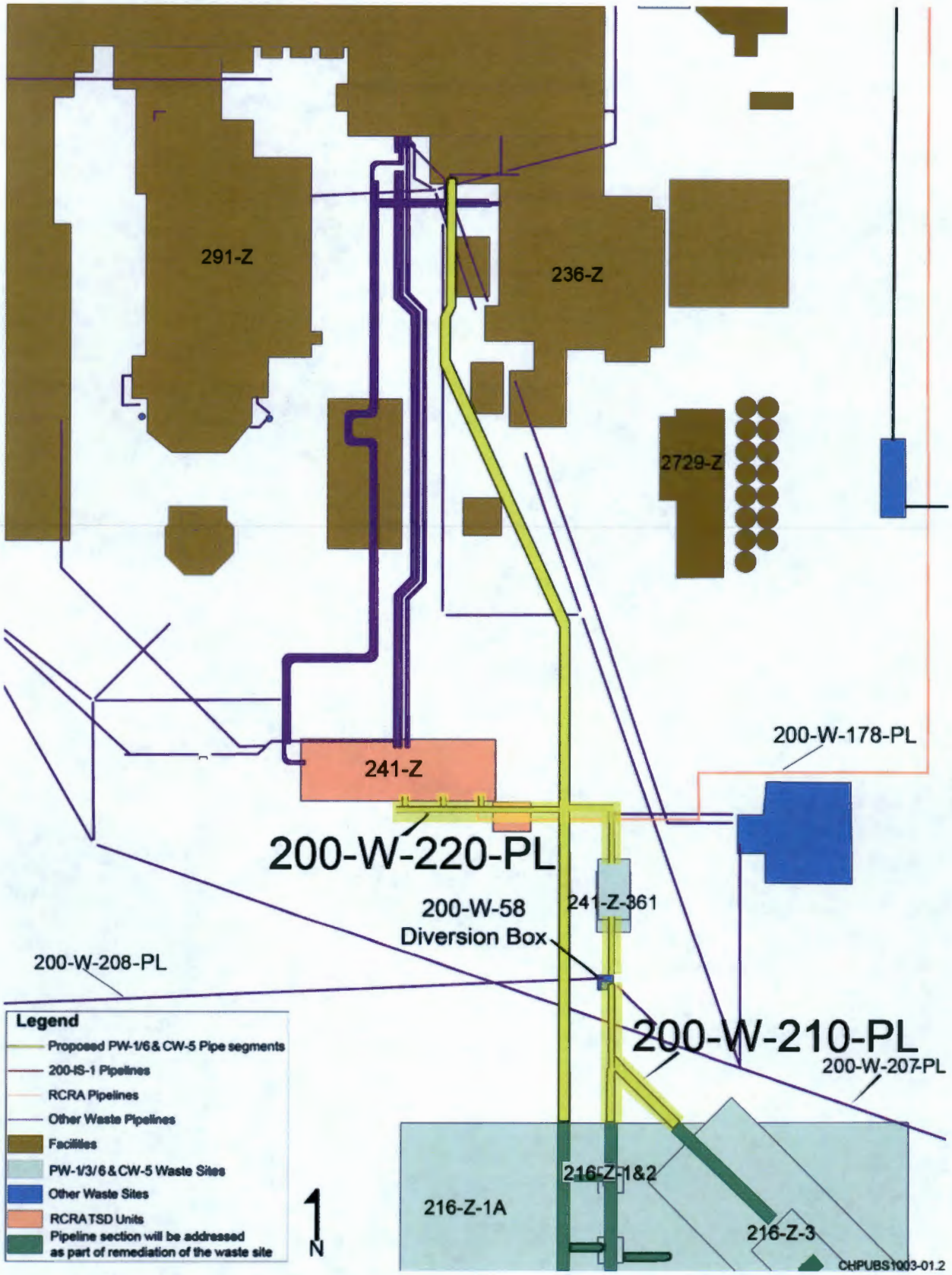

Figure H2-5. Pipeline 200-W-210 and 200-W-220-PL

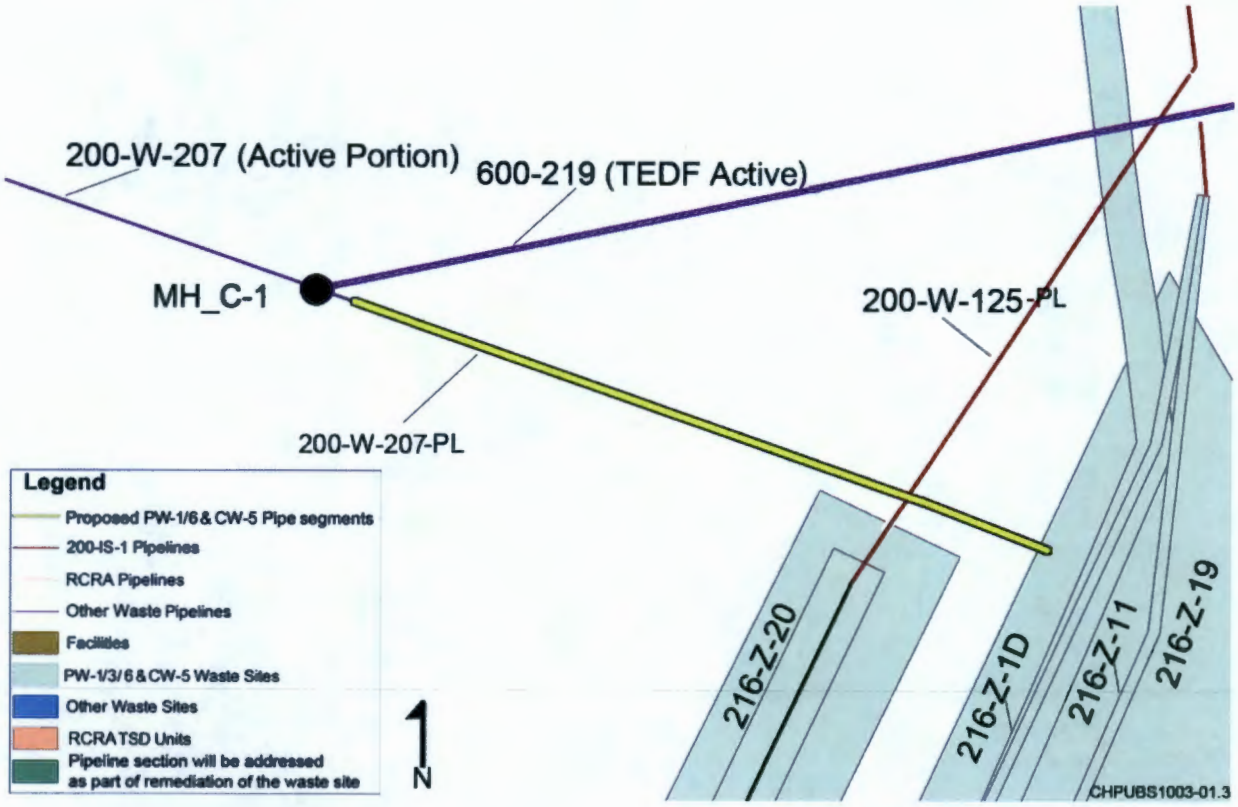

Figure H2-6. Pipeline 200-W-207-PL

Pipeline 200-W-207-PL has the following aboveground restrictions/obstructions listed in order, starting near the C-1 manhole and ending at the 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditches:

- The pipeline begins and runs near the C-1 manhole and associated active TEDF pipeline 600-291.

Pipeline 200-W-207-PL has the following belowground restrictions/obstructions listed in order, starting near the C-1 manhole and ending at the 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 ditches:

- The pipeline crosses pipeline 200-W-125-PL.

Table H2-1 summarizes the pipelines and the length, diameter, and material composition of each pipeline.

H2.2 Human and Ecological Risk Consideration

The 200-PW-1, 200-PW-6, and 200-CW-5 OU pipelines contain radioactive isotopes, heavy metals, and regulated organic compounds. The human health and ecological risks associated with the 200-PW-1, 200-PW-6, and 200-CW-5 OU pipelines have not been quantified in detail. Limited characterization data exist for contaminants remaining inside of the pipes, or for undocumented releases due to leaks. It is important to note that the potential for an undocumented release is greater for the VCP than for SS or CS pipe. For qualitative purposes, it is assumed that each pipeline contains the same contamination species and concentration levels of each of their respective destination waste sites. In general, the primary contaminant of potential concerns (COPCs) and human health risk associated with a release from the 200-PW-1, 200-PW-6, and 200-CW-5 OU pipelines is assumed to be no higher than those of the baseline risk evaluation completed for each pipeline's destination waste site (see crosswalk in Section H1).

Table H2-1. 200-PW-1, 200-PW-6, and 200-CW-5 Operable Unit Remediation Pipelines

Site	Length (ft)	Pipe Diameter/ Material	Reference Documents	Use	Maximum Depth
200-W-174-PL — Parallel pipelines to 216-Z-18 Crib and 216-Z-1A	500 x 2* 430 15	2" SS 3" SS 8" VCP	H-2-16459 Rev. 8 H-2-24923 Rev. 5 H-2-24924 Sh. 1 Rev. 3 H-2-24924 Sh. 2 Rev. 5 H-2-26093 Rev. 5 H-2-27503 Rev. 0 H-2-26094 Rev. 3	PW-1 High-Salt Drain	9 ft 15 ft
200-W-206-PL — Pipeline to 216-Z-9 Crib	690 x 2*	1-1/2" SS	H-2-15492 Rev. 5 H-2-16653 Rev. 7 H-2-31732 Rev. 3 H-2-32528 Rev. 6 H-2-71679 Rev. 1	PW-1 High-Salt Drain	6 ft
200-W-205-PL — Pipeline to 241-Z-8 Tank and 216-Z-8 Crib	820x2* 4 33	1-1/2" SS 2" CS 4" CS	H-2-15492 Rev. 5 H-2-16653 Rev. 7 H-2-32528 Rev. 6 H-2-71679 Rev. 1	PW-6 Low-Salt Drain	6 ft
200-W-208-PL — Pipeline to 216-Z-12 Crib	115 50	6" SS 12" VCP	H-2-20986, Rev. 6 H-2-20987, Rev. 3	PW-1 Low-Salt Process Sewer	15 ft
200-W-210-PL — Pipeline to 216-Z-1, 216-Z-2, and 216-Z-3 Cribs, and 216-Z-1A Tile Field	36 30 46 72	*2" SS* *8" CS* *8" SS* *8" VCP*	H-2-32528 Rev. 6 H-2-16459 Rev. 8 H-2-16421 Rev. 21 H-2-24924 Sh. 2 Rev. 5 H-2-12292 Rev. 13 H-2-27503 Rev. 0 H-2-20987 Rev. 3 H-2-24923 Rev. 5	PW-1 Low-Salt Process Sewer	8 ft
200-W-220-PL — Pipeline to 241-Z-361 Settling Tank	143	6" SS	H-2-16419 Rev. 14	PW-1 Low-Salt Process Sewer	10 ft

Table H2-1. 200-PW-1, 200-PW-6, and 200-CW-5 Operable Unit Remediation Pipelines

Site	Length (ft)	Pipe Diameter/ Material	Reference Documents	Use	Maximum Depth
200-W-207-PL — Pipeline to 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20 Ditches (Z-Ditch system)	270	15" VCP	H-2-16421 Rev. 21 H-2-27151 Sh. 1 Rev. 1 H-2-817992 Sh. 1 Rev. 1 H-2-817992 Sh. 2 Rev. 1 M-2904-W Sh. 15 Rev. 4[x] H-2-140336 Rev. 2[u]	CW-5 Z-Ditch System Process Sewer	5 ft

Notes:

*The length represents two pipelines running parallel. For example, 200-W-174-PL is two 154 m (500 ft) stainless steel pipes. These pipelines are analyzed as side-by-side for cost estimate purposes.

H-2-12292, *Waste Effluent Disposal Facilities Plot Plan & Crib Details*, Rev. 13.

H-2-15492, *Architectural Waste Disposal Facility Details*, Rev. 5.

H-2-16419, *Waste Disposal Facilities – Waste Sumps & Storage Tank Pit Arrg't.*, Rev. 14.

H-2-16421, *Underground Services Sewer & Water*, Rev. 21.

H-2-16459, *216-Z-1A Tile Field 216-Z-1 & 216-Z-2 Cribs*, Rev. 8.

H-2-16653, *Silica Waste Storage Tank & French Drain 216-Z-8*, Rev. 7.

H-2-20986, *Crib & Test Wells for 234-5 Building Wastes*, Rev. 6.

H-2-20987, *Crib 216-Z-12 Plan, Section & Details*, Rev. 3.

H-2-24923, *216-Z-1A Modifications – Process Waste Disposal Plan*, Rev. 5.

H-2-24924, *Plan & Profile Process Waste Disposal Facility*, Sh. 1, Rev. 3.

H-2-24924, *Plan & Profile Process Waste Disposal to 216-Z-18 Crib*, Sh. 2, Rev. 5.

H-2-26093, *Civil 216-Z-18 Crib Plot Plan & General Notes*, Rev. 5.

H-2-26094, *Civil Profile, Section & Details 216-Z-18 Crib*, Rev. 3.

H-2-27151, 1976, *Composite Drain EFD 232-Z & 291-Z & Outside Routing to 216-Z-19 Outfall*, Sh. 1, Rev. 1.

H-2-27503, *216-Z-1A File Field & Vicinity*, Rev. 0.

H-2-31732, *Civil – Outside Lines Plot Plan Fire-Sanitary Modifications Z-Plant Area*, Rev. 3.

H-2-32528, *"Z" Plant Liquid Waste Disposal Sites 216-Z Series*, Rev. 6.

H-2-71679, *Piping Plans & Elevations 241-Z-8 & 241-Z-361*, Rev. 1.

H-2-140336, *Civil Line C Sta 0-34.22 to Sta 8+52.54*, Rev. 2.

H-2-817992, *Civil PFP Effluent Stream Manhole Locations*, Sh 1, Rev. 1.

H-2-817992, *Civil PFP Effluent Stream MH Upgrades & Pipe Lining*, Sh. 2, Rev. 1.

M-2904-W, Sh. 15, Rev. 4.

Pipeline 200-W-174-PL is buried to a maximum depth of 2.7 m (9 ft) and had one known release (designated UPR-200-W-103) near the PFP Building. This release has been designated as a separate waste site and has been assigned to the 200-MG-2 OU and will be addressed under the decisions for that OU.

Segments of the pipelines do fall within the depth range of mammal burrows and plant roots (DOE/RL-2007-27, Appendix B, "Screening Level Ecological Risk Assessment"). Therefore, ecological risks associated with the pipelines may exist. In considering the subsurface extent of plant roots or animal burrows, it is important to realize that burrow and root density are not continuous from the soil surface to the maximum reported depths; biotic activity decreases with depth. It should be noted that only two segments of the pipelines (see Table H2-1) presented in this assessment reside at a depth below 4.6 m (15 ft).

The *Washington Administrative Code* (WAC) allows for a conditional point of compliance to be set at the terminus of the biologically active zone (WAC-173-340-7490[4][a], "Model Toxics Control Act--Cleanup," "Terrestrial Ecological Evaluation Procedures"). The depths to which insects, animals (burrows), and plants (roots) are likely to occur define the biologically active zone. The working hypothesis is that biological activity is limited largely to the top 3 m (10 ft).

H2.3 Evaluation of Groundwater Protection Consideration

A fate and transport evaluation of all soil contaminants at the waste sites indicated that carbon tetrachloride is the only contaminant that could potentially migrate through the soil beneath the High-Salt waste sites and affect groundwater above the drinking water level within 1,000 years (DOE/RL-2007-27, Appendix E, "Evaluation of Groundwater Protection"). The groundwater protection assessment can be extended to the pipelines, as a result of the shallower depth of the pipelines. Therefore, only carbon tetrachloride at the High-Salt pipelines would have had the potential to affect the groundwater. However, because of limited characterization data for carbon tetrachloride residing outside of the High-Salt pipelines (through a release), a data gap exists that will must be resolved during remedial activities, should previously undocumented releases be identified.

In addition, technetium-99 and nitrate are potential threats to groundwater. Technetium-99 and nitrate were detected in three wells (two at 216-Z-9 and one at 216-A-8) during routine RI sampling. However, there is some uncertainty associated with the data. The analytical results are considered to be spatially biased because the samples were collected from preferential boreholes in more contaminated areas. Therefore, the potential nature and extent of the technetium-99 and nitrate contamination needs to be confirmed. Additional sampling is proposed after the ROD has been issued for these potential non-volatile mobile contaminants.

H3 Identification and Screening of Remedial Technologies

The remedial action technologies for the 200-PW and 200-CW pipelines included in this assessment must be protective of human health and the environment and must not inhibit future implementation of remedial action operations. The potential risks to be addressed in the selection of a remedial action technology are the same as the 200-PW-1, 200-PW-6, and CW-5 OU waste sites. Radioactive and/or nonradioactive hazardous substances are contained in and potentially around the pipelines due to unidentified releases.

H3.1 General Response Actions

The general response actions (GRA) describe those actions that will satisfy the remedial action objectives (RAOs). The RAOs for the 200-PW-1, 200-PW-6, and 200-CW-5 pipelines are the same as the RAOs associated with the waste sites. Refer to the crosswalk in Section 1 of this appendix for the location of further discussion of GRAs and RAOs in each FS.

The three RAOs identified for these pipelines are:

- Prevent or mitigate unacceptable risk to human health and ecological receptors associated with radiological exposure to waste or soils contaminated above risk-based criteria by removing the source or eliminating the pathway. Unacceptable risks are (1) an incremental lifetime cancer risk greater than 10^{-4}, or (2) a hazard index greater than 1.
- Prevent or mitigate unacceptable risk to human and ecological receptors associated with nonradiological exposure to wastes or soil contaminated above risk-based criteria by removing the source or eliminating the pathway. The risk would be mitigated to human health and ecological receptors by eliminating exposure to wastes or soils contaminated above risk-based criteria to a depth of 4.6 m (15 ft) bgs.
- Control the sources of potential groundwater contamination to support the Central Plateau groundwater goal of restoring and protecting the beneficial uses of groundwater, including protecting the Columbia River from adverse impacts. This would be accomplished by preventing migration of carbon tetrachloride from soil to groundwater in concentrations that exceed final cleanup levels in the 200-ZP-1 Groundwater OU ROD (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

The following four GRAs were selected to implement the RAOs:

- No action: baseline GRA required by CERCLA
- Institutional Controls/Monitored Natural Attenuation (IC/MNA): to mitigate risks by prohibiting certain activities, thereby limiting direct contact with contaminants and controlling migration of contaminants while contaminants are allowed to remediate through natural conditions
- Removal of contaminated media, treatment as necessary, and disposal: to mitigate risks by excavating contaminated media, treating it as necessary, and disposing of it in an appropriate onsite or offsite disposal facility
- In situ treatment or stabilization of contaminated media: to mitigate risks by treating contaminated media in place to reduce contaminant toxicity, mobility, or volume

H3.2 Technologies

The GRA and potential implementing technologies were first addressed in the Implementation Plan (DOE/RL-98-28, *200 Areas Remedial Investigation/Feasibility Study Implementation Plan-Environmental Restoration Program*). That document provided an initial framework to guide the remedial investigations (RIs) in the 200 Areas and documented a preliminary screening of remedial technologies appropriate to the contaminants, media, and conditions found in the arid environment in the 200 Areas (Appendix D, Sections D5 to D5.6, and Table D-1 of the Implementation Plan).

The PW-1/3/6 and CW-5 OU FSs used these technologies from the Implementation Plan to develop remedial technologies, which focused more specifically on the final contaminants of potential concern (COPCs) and conditions encountered at the 200-PW-1, 200-PW-6, and 200-CW-5 OU waste sites. Because the final COPCs and RAOs are consistent between the waste site and the pipelines, the technologies that were screened in the respective FS reports would apply to the pipelines as well. For this reason, the technology screening will not be performed again. Only potential screening technologies not evaluated in the respective FS documents, will be included in the discussion.

H3.2.1 Screening of Remedial Technologies

The technologies outlined in the respective FS documents were screened based on their effectiveness, implementability, and relative cost, in accordance with CERCLA guidance and will not be repeated in this section. Two remedial options (grout fill and grout injection) were not assessed during the respective FSs. These in situ treatment and stabilization technologies are discussed below as follows.

H3.2.1.1 In Situ Treatment and Stabilization

The in situ technologies of grout filling and grout injection are viable in situ technologies that were not discussed previously, and are outlined as follows.

Grout Fill

Grout fill addresses the pipeline contamination by applying a grout flow through the pipeline with sufficient pressure to force any residual contamination that may be left in the elbows and joints of the pipeline to move through the pipeline and be flushed out of the pipe, stabilized, and disposed accordingly. The grout then hardens inside the pipeline, effectively solidifying any other contamination in the pipeline.

This methodology would entail digging to the depth of the pipeline, cutting the pipeline open at two ends (the length to be determined in the remedial action plan), and adding grout to the pipeline until grout emerges at the other end. Because this process only allows observation of two points along the pipeline, uncertainty exists as to whether or not there might be contamination that was released from the pipeline. Therefore, confirmation soil sampling may need to be accomplished along the length of the unopened pipeline to verify that contaminants have not been released from the pipeline. With filling complete, ICs will be used to prevent access to the pipeline and contaminants. Controls will include site fencing or other physical access restriction, site land use controls, and groundwater use restrictions.

Grout Isolation

Grout isolation plugs the pipeline by only injecting grout at the open ends or discharge points of the pipeline, and where else it is deemed appropriate during remedial design. The plugs prevent entrained waste from exiting the pipe and prevent water and ecology from entering the pipe from the surrounding soil. The methodology would be the same as grouting stabilization, but only grouting the openings as necessary. With plugging complete, ICs will be used to prevent access to the pipeline and contaminants. Controls will include site fencing or other physical access restriction, site land use controls, and groundwater use restrictions.

The retained remedial technologies and associated process options are listed in Table H3-1 and discussed in the following sections.

Table H3-1. Retained Remedial Technologies

General-Response Action	Technology Type	Remediation Technology	Target Contaminants
No Action	No Action	No Action	IMRO
Institutional Controls	Land Use Management	Deed Restrictions	IMRO
		Deed Notices	IMRO
		Declaration of Environmental Restrictions	IMRO
		Information Distribution	IMRO
		Restrictive Covenants	IMRO
		Federal/state/county/local registries	IMRO
		Signs/Fences	IMRO
	Warning Notices and Entry Restrictions	Entry Control	IMRO
	Monitoring	Surveillance/Monitoring	IMRO
Removal	Excavation	Conventional Excavation	IMRO
		Remote Excavation	IMRO
		Soil Vacuum Excavation	IMR
Disposal	Landfill Disposal	Onsite Landfill	IMRO
In Situ Stabilization	Chemical/ Physical Stabilization	Grout Isolation	IMRO
		Grout Fill	IMRO
Attenuation Processes	Natural Attenuation*	Monitored Natural Attenuation	RO

Notes:

*Not a treatment process

I = inorganic, nonmetallic contaminants

M = heavy metal contaminants

R = radionuclide contaminants

O = organic contaminants

H4 Remedial Action Alternatives

The alternatives presented in this chapter were developed by combining the representative process options identified in Chapter H3 into an appropriate range of remedial alternatives that will be more fully analyzed in the detailed analysis in Chapter H5. The development of remedial alternatives followed U.S. Environmental Protection Agency (EPA) guidance (EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, OSWER Directive 9355.3-01) and considered the nature of contamination at each pipeline from Chapter H2 of this appendix.

H4.1 Development of Remedial Alternatives

The purpose of the overall remedy selection process is to identify remedial actions that eliminate, reduce, or control risks to human health and the environment. The pipeline remedial alternatives will be similar to each respective waste site regarding implementability and contamination history. Similar to the waste sites, the range of alternatives will reduce the toxicity, mobility, or volume of the hazardous substances, pollutants, or contaminants. One or more alternatives that involve little or no treatment, but provide protection of human health and the environment primarily by preventing or controlling exposure to hazardous substances, pollutants, or contaminants, through engineering controls, for example, containment, and, as necessary, ICs to protect human health and the environment and to ensure continued effectiveness of the response action. The No Action Alternative, which may be no further action if some removal or remedial action has already occurred at the site and pipeline, shall be developed.

The following sections outline the alternatives developed to satisfy these requirements.

H4.2 Description of Remedial Alternatives

The representative process options identified in Chapter H3 were combined to formulate a range of remedial alternatives to satisfy the RAOs for the 200-PW-1, 200-PW-6, and 200-CW-5 OUs. Preliminary technical and functional requirements for the elements of each alternative are identified based on the RAOs and potential applicable or relevant and appropriate requirements (ARARs), as well as other considerations.

Table H4-1 summarizes the remedial alternatives as well as the GRA, technology type, representative process option, and the area or volume for each option. The remedial alternatives include the following:

- No Action Alternative. The National Contingency Plan (NCP) requires consideration of a No Action Alternative. This alternative would leave a waste site "as-is" in its current state, with no additional remedial activities or access restrictions. This alternative is only acceptable if current waste site conditions are protective of human health and the environment. This alternative is not discussed further in this section; however, the alternative is carried into the detailed analysis (see Chapter H5 of this appendix).

- Alternative One – Removal, Treatment, and Disposal (RTD). For this technology, the action would be to remove the pipeline and any contaminated soil from leaks and dispose as appropriate down to 3 m (10 ft). For pipelines greater than 3 m (10 ft), the soil data will be reviewed to determine the potential threat to groundwater. Excavations will be backfilled with clean compacted fill. Sampling to show that the selected (or appropriate) risk-based standards are met will be completed prior to backfilling.

- Alternative Two
  - In Situ Stabilization Grout Fill (ISS Grout Fill). In this technology, a pipeline will be injected with grout effectively removing and stabilizing entrained waste inside the pipe. Filling the void space inside of the pipe with grout would stabilize the pipe—the walls of the pipe would act as a physical barrier. The pipeline would be provided with institutional or administrative control to eliminate its use in the future.
  - In Situ Stabilization Grout Isolation (ISS Grout Isolation). In this technology, a pipeline will be injected with grout and plugged at the inlet and outlet to demobilize and contain the contaminants—the walls of the pipe would act as a physical barrier. The pipeline would be provided with institutional or administrative control to eliminate its use in the future.
  - This alternative may require ICs/MNA as part of the remedy.

Table H4-1. Remedial Alternatives for 200-PW-1, 200-PW-6, and 200-CW-5 Operable Unit Pipelines

Medium	General Response Action	Technology Type	Representative Process Option	Area or Volume	No Action	1 RTD	2 ISS
Soil	Institutional Controls	Land Use Management	Deed Restrictions/ Covenants/Notices	All pipelines with residual contamination above acceptable risk levels		X	X
		Warning Notices and Entry Restrictions	Signs/Fences			X	X
			Entry Control			X	X
		Monitoring	Surveillance/Monitoring			X	X
	Removal	Excavation	Conventional Excavation	Soil above risk levels		X	
	Disposal	Landfill Disposal	Onsite Landfill	All 200-PW-1, 200-PW-6, and 200-CW-5 piping		X	
	ISS	Chemical/ Physical Treatment and Stabilization	Grout Fill/Cap	All 200-PW-1, 200-PW-6, and 200-CW-5 piping			X

The details of these alternatives with regard to representative process options and specific waste sites are described as follows.

H4.2.1 Common Components of Remedial Alternatives

Several common components are included in more than one remedial alternative (see Table H4-1). To limit redundancy, they are discussed in this section and referenced in the discussion of each alternative.

H4.2.1.1 Institutional Controls

The Site-wide ICs plan (DOE/RL-2001-41, *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions*) identifies the ICs for the current Hanford Site. It also describes how ICs are implemented and maintained, and it serves as a reference for the selection of ICs in the future. ICs work in conjunction with the more active cleanup measures to protect human health and the environment during the cleanup process, as well as following the completion of cleanup for areas containing residual contamination above risk levels. Therefore, existing ICs will continue as long as risks remain that make the site unsuitable for unrestricted use. Institutional controls include the following:

- Administrative controls
  - Maintain the site listings and updates in the 200-PW-1, 200-PW-6, and 200-CW-5 OUs facility and land use plan; update changes or terminations agreed to by the agencies.
  - Provide public notices to stakeholders of changes in ICs.
  - Control the use of groundwater via use restrictions, easements for monitoring, restrictive covenants, or land withdrawal documentation that would be deemed necessary to further protect the public and the environment if land use or ownership changes.
  - Maintain work control process in accordance with the *Code of Federal Regulations* (CFR), 10 CFR 835, "Occupational Radiation Protection," and DOE G 441.1-1BC, 2008, *Radiation Protection Programs Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection.*
  - Restrict and/or control soil disturbances to eliminate the potential spread of contamination.
  - Access restrictions: Post and maintain visible access restrictions.
- Control access
  - Maintain Hanford Site access controls in accordance with DOE O 470.4A, *Safeguards and Security Program.*
  - Maintain restrictions on leasing or transferring property.
  - Maintain notification requirements in response to failed controls/corrective action.

As long as contaminants remain within the 200-PW-1, 200-PW-6, and 200-CW-5 OU pipelines at concentrations that exceed protective risk levels, a 5-year site review is required by the NCP (40 CFR 300.430(f)(4)(ii), "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of Federal Regulations*. (300.430. "Remedial Investigation/Feasibility Study and Selection of Remedy.") The 5-year reviews will be conducted to evaluate the effectiveness of the existing ICs, to evaluate the need for continued ICs, or to consider a supplemental action.

H4.2.2 Alternative 1–Removal, Treatment, and Disposal

This alternative involves removing pipeline soil, sludge, and/or debris, treating it as necessary to meet ARARs, and disposing of it in an onsite (Environmental Restoration Disposal Facility [ERDF]) disposal facility as appropriate. Refer to the waste site RTD description in the waste site FS.

The pipelines will be removed and disposed of as an extension of the respective waste site. Therefore, the same conventional excavation technologies, methods, and personnel would be used for the pipelines as they would be used for the waste site. Minimum soil volume surrounding each pipeline will be removed and disposed along with the pipe. The actual amount, excavation methods, and details will be developed during remedial design. At this time, 0.6 m (2 ft) of surrounding peripheral soil will be removed along with the pipeline for cost estimate purposes.

Conceptually, the RTD process for this alternative consists of the following five steps:

1. Remove and stockpile clean overburden for use in backfilling.
2. Remove contaminated pipelines and limited amount of soil to a depth of 3 m (10 ft), and place in waste containers.
3. If evidence of a leak or other release of contamination is identified, then soil will be removed and verification sampling will be conducted to ensure the soil meets preliminary remediation goals (PRGs) both laterally and to a depth of 4.6 m (15 ft).
4. Haul waste containers to assay/screening station and then to the ERDF for disposal.
5. Backfill excavation with clean fill and compact.
6. Replant surface with native vegetation.

Each of the 200-PW-1, 200-PW-6, and 200-CW-5 pipelines contains an unspecified amount of waste inventory, or residue entrained inside the pipe. Because all the pipelines potentially contain inventories of plutonium and americium (which emit alpha radiation) special conditions apply when disturbing or handling the pipelines. Special care will be needed when removing the pipelines for further disposal, as entrained liquid could pour out of the pipeline, creating a release scenario to the surrounding soil surface. In addition, the excavation may create dust. Therefore, control of airborne contamination will require engineering controls such as water misting and appropriate personal protective equipment for remedial action workers. For the 200-PW-1, 200-PW-6, and 200-CW-5 pipelines, this assessment assumes the excavation and waste container packaging will be performed per waste site methodology. Figure H4-1 depicts the conceptual configuration of the RTD alternative at the pipelines.

H4.2.3 Alternative 2– In Situ Stabilization

This alternative consists of two potential alternatives: grout capping and grout filling.

H4.2.3.1 Grout Fill/Cap

This option utilizes grout to temporarily reduce the mobility of hazardous substances as a principal element. ISS uses strategically placed grout injection to physically fill the pipe and fill the pipe's void space. Pipelines would be filled with flowable, self-leveling, and self-compacting grout. Radionuclides and other pollutants are immobilized within the pipe. The method would involve filling the entire volume inside the pipe with grout. This operation will pressure flush the pipeline of some contaminant materials, while filling the pipeline void space to stabilize the pipeline. Any material flushed through the pipeline ideally would be observed and collected at the other open pipeline end, assuming the pipeline was not broken. The pipeline would be provided with ICs or administrative controls to eliminate its use in the future.

Institutional controls are also a component of this option at pipelines where the ISS fill process leaves residual contamination at a pipeline that will require long-term controls.

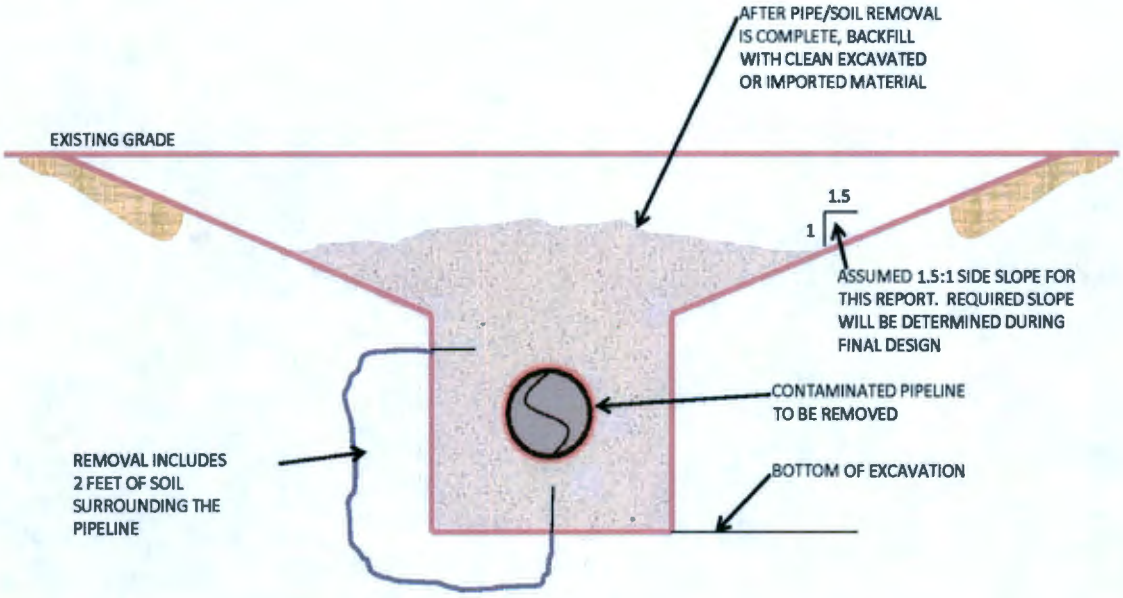

Figure H4-1. Conceptual Design of Alternative 1 - Removal, Treatment, and Disposal

Alternatively, this option utilizes grout plugs to temporarily reduce the mobility of hazardous substances as a principal element. ISS uses strategically placed grout injection to physically cap or plug the pipe at the inlet and outlet of the pipe. Pipelines would be plugged with flowable, self-leveling, and self-compacting grout. Radionuclides and other pollutants are demobilized within the pipe walls. The method would involve exposing each end of a pipeline and pouring non-shrink grout plugs or other appropriate plugs. In this technology, a pipeline will be filled with grout only at the inlet, and discharge where engineered appropriate. This operation will effectively plug or cap the pipelines at each end, trapping and containing entrained liquid residue. The pipeline would be provided with institutional or administrative controls to eliminate its use in the future. Institutional controls are also a component of this option at pipelines where the ISS process leaves residual contamination at a pipeline that will require long-term controls.

Some of the advantages of the ISS alternative include the following:

- The ISS process generates a relatively small volume of regulated waste, very little waste would require offsite disposal because most of the waste would be generated by tools and/or equipment being exposed to the contaminated pipelines and surrounding soil.
- The surrounding soil and ecology would be left undisturbed, except for strategic areas where digging is required to access and inject grout.

A disadvantage of this alternative is that the grout material used to seal the pipeline does not have an infinite lifetime. The grout material will breakdown slowly over time. In addition, the process of flushing the pipeline cannot guarantee a complete mixing/stabilization of the materials that may remain inside the pipeline.

Figure H4-2 depicts the conceptual configuration of the ISS Grout Fill/Isolation alternative at the pipelines.

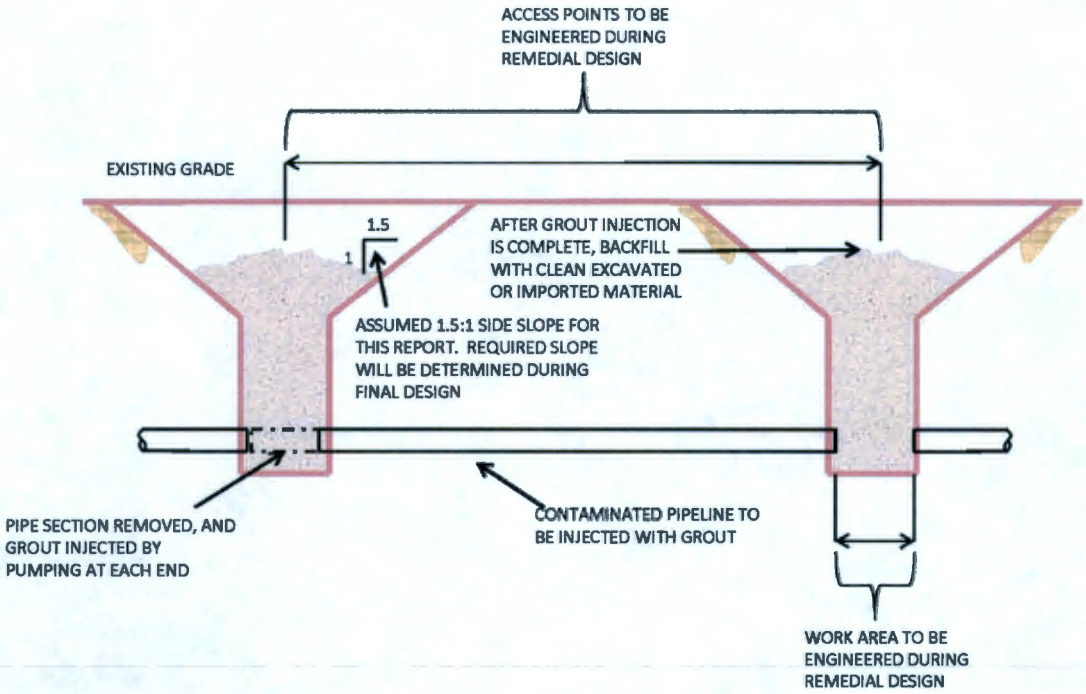

Figure H4-2. Conceptual Design of Alternative 2- In Situ Stabilization Grout Fill/Isolation

Each of these alternatives is examined in more detail in Chapters H5 and H6 of this appendix.

H5 Detailed Analysis of Alternatives

Each of the remedial alternatives described in Section H4 is evaluated in this chapter with respect to specific CERCLA evaluation criteria, as required by 40 CFR 300.430(e)(9), "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of Federal Regulations*. (300.400) "Investigation/ Feasibility Study and Selection of Remedy," "Detailed Analysis of Alternatives." The CERCLA criteria are grouped into two Threshold Criteria (Overall protection of human health and the environment and Compliance with ARARs), five Balancing Criteria (Long-term effectiveness and permanence, Reduction of toxicity, mobility, or volume through treatment, Short-term effectiveness, Implementability, and Cost) and two Modifying Criteria (State acceptance and Community acceptance). These criteria have been explained extensively in Sections 6.1.1 through 6.1.9 of the PW1/3/6 FS and will not be repeated in this section.

H5.1 Detailed Analysis of No Action Alternative

The NCP requires consideration of a No Action Alternative. This alternative would leave a waste site pipeline "as-is" in its current state, with no additional remedial activities or access restrictions. This alternative is only acceptable if current waste pipeline conditions are protective of human health and the environment.

H5.1.1 Overall Protection of Human Health and the Environment

The baseline risk assessment (BRA) (Appendix A of the PW1/3/6 FS) concluded the risks from exposure to soils at the 216-Z-8 French Drain are below levels that are a health concern for all three populations evaluated (construction worker, driller, and subsistence farmer). Since the 241-Z-8 Settling Tank overflow pipeline to the 216-Z-8 French Drain would contain the same contaminant history as the soil and French drain, it is assumed that the contamination levels of this segment of pipe (200-W-205-PL) are the same. A No Action Alternative is deemed protective of human health and the environment for the soil and French drain, and therefore deemed protective for the overflow pipeline segment.

For the other six pipelines and the remaining portion of the 200-W-205-PL (similar to the respective waste sites), this alternative does not eliminate, reduce, or control potential risks; thus, it is not protective of human health and the environment and fails to meet this threshold criterion. Therefore, the discussion of the remaining evaluation criteria for this alternative is limited to its application for the overflow segment of the 200-W-205-PL pipeline to the 216-Z-8 French Drain.

H5.1.2 Compliance with ARARs

The only chemical-specific ARARs for the No Action Alternative are the requirements to protect the environment via the migration to groundwater pathway. The No Action Alternative at the 216-Z-8 French Drain and therefore the overflow segment of the 200-W-205-PL pipeline would comply with federal maximum contaminant levels (MCLs) from 40 CFR 141, "National Primary Drinking Water Regulations," because no groundwater impacts were identified in the fate and transport modeling of radionuclides in the 200 West Area (see Appendix E).

The WAC defines the soil cleanup depth (the standard point of compliance) as extending from the ground surface to 4.6 m (15 ft) bgs (WAC 173-340-7490[4][b]). However, WAC-173-340-7492(4)(a) allows for a conditional point of compliance to be used. This assessment proposes a conditional point of compliance of 3 m (10 ft). The rationale for this revised point of compliance is outlined in CHPRC-00651, "*Evaluation of Biointrusion at the Hanford Site for Protection of Ecological Receptors*, February 2010."

H5.1.3 Long-Term Effectiveness and Permanence

Although the No Action Alternative would leave untreated wastes at the overflow segment of the 200-W-205-PL pipeline, the BRA showed that these concentrations are below levels that are a health concern and the fate and transport modeling showed that these radionuclides would not affect groundwater. No controls are required to manage the untreated wastes at this pipeline to ensure long-term protection of human health and the environment. Therefore, the No Action Alternative provides long-term effectiveness and permanence at the overflow segment of 200-W-205-PL pipeline.

H5.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

The No Action Alternative does not need to employ treatment technology, or reduction in toxicity or mobility. It was determined that only the 216-Z-8 French Drain and, by extension, its pipe systems, has no risk and needs no reduction in toxicity or mobility.

H5.1.5 Short-Term Effectiveness

Because no actions are associated with this alternative, the No Action Alternative poses no additional short-term risks to human health or the environment and the response objectives are achieved immediately.

H5.1.6 Implementability

There are no technical or administrative issues that would affect the implementability of the No Action Alternative at the overflow piping leading to the 216-Z-8 French Drain.

H5.1.7 Cost

Costs associated with the No Action Alternative are estimated at $0.

H5.2 Detailed Analysis of Alternative 1–Removal, Treatment, and Disposal

Alternative 1 removes segments of pipeline, surrounding soil, residue, sludge, and/or debris, treating it as necessary to meet ARARs, and then disposing of it in an onsite (ERDF) facility as appropriate. It is expected that if the alternative leaves residual contamination above risk levels, ICs will be implemented as remedy components to protect human health and the environment. However, for the purposes of cost estimating, it has been assumed that ICs will not be needed.

For pipelines 200-W-208-PL and 200-W-174-PL, where these pipelines have portions of the pipe at or just below 4.6 m (15 ft), the excavation observations will continue to a depth of 3 m (10 ft). In addition, observations from the area associated with the waste site footprint will be used to assess if additional excavation depth is required for the pipelines. If additional excavation is required, a 1.5 m (5 ft) lift will be removed and verification samples will be collected. In any case, 0.6 m (2 ft) of peripheral soil will be excavated and removed for these pipe segments. All remaining pipelines fall within the 4.6 m (15 ft) depth range, and would be removed accordingly.

H5.2.1 Overall Protection of Human Health and the Environment

Alternative 1 achieves adequate protection of human health and the environment using the soil removal criteria outlined previously for the associated pipelines. Alternative 1 poses the greatest short-term risks to remedial action workers and the environment, which can be mitigated by engineering and radiological controls but at significant costs. Compliance with this criterion, by pipeline group, is summarized as follows.

- High-salt pipelines: The potential direct contact risk to the representative industrial worker at the 200-W-174-PL, and 200-W-206-PL pipelines would be eliminated by Alternative 1, assuming the pipeline is intact because the walls of the piping act as a physical barrier, thereby encasing the residual contamination. The current direct contact risks at the 216-Z-9 Trench and the toe outlet of associated pipeline 200-W-206-PL are limited by the soil overburden and pipe encasement. However, if the piping leaks, future direct contact risks to the representative industrial worker, human health would not be eliminated by Alternative 1 unless contaminated soil around the leak was removed. There is no current direct contact risk at the 216-Z-18 Crib's associated pipeline 200-W-174-PL, and Alternative 1would further reduce this risk; however, this is based on limited data and the assumption the pipeline has not leaked. There is a potential that the pipelines have leaked, although this possibility varies greatly depending on pipeline material.

- Low-salt pipelines: Currently, there are no direct contact risks at the pipelines 200-W-208-PL and 200-W-210-PL (Cribs 216-Z-1, 216-Z-2, and 216-Z-3), and 200-W-220-PL due to the current depth of the pipes with soil overburden. However, it is unclear if leaks occurred in the past, thereby contaminating the surrounding soil. RTD for the pipelines would reduce risk along the reasoning explained for the respective waste sites at various depths within the 3 m (10 ft) depth.

- Z-Ditch pipelines: Currently, there are no known direct contact risks at the 200-W-207-PL (Z-Ditches 216-Z-1D, 216-Z-11, 216-Z-19, and 216-Z-20) pipeline due to the current depth of the pipes with soil overburden. The potential risks to a well driller, which currently are already below health-based levels, would be further reduced by Alternative 1. However, it is unclear if leaks occurred in the past, thereby contaminating surrounding soil. RTD for the pipelines would reduce risk along the reasoning explained for the respective waste sites at various depths.

- No action pipelines: Alternative 1 is not necessary for the 200-W-205-PL overflow pipe segment because a determination has already been made that this segment is protective of human health and the environment.

H5.2.2 Compliance with ARARs

The only chemical-specific ARARs for Alternative 1 include the requirements to protect the environment via the migration to groundwater pathway. Alternative 1 would comply with federal MCLs from 40 CFR 141, "National Primary Drinking Water Regulations" because the potential groundwater impacts from carbon tetrachloride underneath the High-Salt waste pipelines will be mitigated by the current soil vapor extraction (SVE) system at component of the respective High-Salt waste sites, as discussed in per the 200-PW1/3/6 OU Waste Site FS.

No archeological, historic, cultural, or Native American artifacts, or threatened or endangered species have been identified at any of the waste site areas in previous characterization activities; therefore, it is assumed the same condition applies to the pipelines and their surrounding soil. State surveys will be conducted as required prior to soil disturbance.

Designation, handling, and disposal of the excavated pipelines and associated soils will comply with WAC 173-303, "Dangerous Waste Regulations;" WAC 173-304, "Minimum Functional Standards for Solid Waste Handling;" and WAC 173-350, "Solid Waste Handling Standards." Alternative 1 will also comply with potential action-specific ARARs (WAC 173-400, "General Regulations for Air Pollution Sources" [WAC 173-400]; WAC 173-460, "Controls for New Sources of Toxic Air Pollutants" [WAC 173 -460]; WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides" [WAC 173-480]; and WAC 246-247, "Radiation Protection—Air Emissions" [WAC 246-247]), because the SVE system will treat extracted vapors for known plumes associated with the waste sites near the pipelines prior to release and engineering controls will be used to reduce and control airborne dust during the RTD process.

H5.2.3 Long-Term Effectiveness and Permanence

Compliance with this criterion, considering the magnitude of residual risk and the adequacy and reliability of controls, is discussed by pipeline group and their associated waste sites as follows.

- High-salt pipelines: The SVE component for known plumes associated with the waste sites near the pipelines would remove carbon tetrachloride from the vadose zone to prevent residual concentrations from migrating and affecting the groundwater. However, this is an interim remediation. Alternative 1 reduces the radioactive contamination at these pipelines through RTD of soil surrounding the pipelines, making this alternative a permanent remedial solution.

- Long-term monitoring, maintenance, and enforcement of ICs will not be required for contaminated soil removed to 3 m (10 ft). If ICs are required to ensure Alternative 1 remains effective and permanent, the controls will become associated with any controls required for the waste sites. Required CERCLA reviews every 5 years will reexamine and ensure this alternative remains effective and permanent in the long-term.

- Low-salt pipelines: There are no direct contact risks due to the soil overburden and physical barrier characteristic of the pipelines at the Low-Salt waste sites. Therefore, the associated pipelines (200-W-208-PL, 200-W-210-PL, and 200-W-220-PL) have no direct contact risk. The potential risks to a well driller, which currently are already below health-based levels for each waste site, and are expected as such for the associated pipelines (200-W-208-PL, 200-W-210-PL, and 200-W-220-PL), would be further reduced by the RTD Alternative 1.

- Z-Ditch pipelines–There are no direct contact risks at the Z-Ditch waste sites and it is expected that the associated pipeline 200-W-207-PL has no direct contact risk. The potential risks to a well driller, which currently are already below health-based levels for each Z-Ditch, and are expected as such for the associated pipeline 200-W-207-PL, would be further reduced by the RTD Alternative 1.

Long-term monitoring, maintenance, and enforcement of ICs will not be required for contaminated soil removed to 3 m (10 ft). If ICs are required to ensure Alternative 1 remains effective and permanent, the controls will become associated with any controls required for the waste sites. Required CERCLA reviews every 5 years will reexamine and ensure this alternative remains effective and permanent in the long-term.

H5.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 1 reduces the radioactive contamination at the High-Salt waste sites, Low-Salt waste sites, and Z-Ditch pipelines by the physical removal of contaminated pipes and soil surrounding the pipes. However, the RTD component of Alternative 1 does not incorporate a treatment component.

H5.2.5 Short-Term Effectiveness

The remedial action workers will have risks from potential exposure to final COPCs and exposure to radionuclides during the RTD process. These risks can be reliably mitigated with standard and site-specific radiation and industrial safety practices. For example, the High-Salt and Low-Salt waste sites and pipelines RTD cases could be conducted inside a portable enclosure to mitigate the potential for airborne contamination, dust suppression controls would be used, and workers likely would use respiratory protection. All of these controls can effectively mitigate the short-term risks to workers, but they also limit RTD productivity and significantly increase costs.

Fugitive dust during RTD excavation and backfilling with clean soil will be controlled using standard dust-suppression measures. Alternative 1 disturbs an area about twice the size of the excavated pipeline and waste site because of soil stockpiles and RTD operations areas, in addition to the borrow source areas needed for backfill. However, no significant adverse environmental impacts are related to implementation of Alternative 1 (see Section H6). RTD is estimated to achieve the RAOs at the pipelines within 1 to 2 years, from the start of the remedial action.

H5.2.6 Implementability

Although the technical feasibility of RTD is proven and is a commercially available technology, several site-specific issues may affect the implementability of Alternative 1. The nature and extent of contamination is generally determined using available data. However, RTD activities may encounter previously unknown leaks, releases, or contamination. This would affect the estimated RTD excavation volumes, costs, and schedules used in the FS. Additional RTD activities could be undertaken to manage these uncertainties, similar to the methods used for the respective waste sites.

For Alternative 1, there is an additional risk due to potential drainage of entrained liquid residue from inside the pipelines as the pipelines are removed, crushed, and prepared for the ERDF. The uncertainty regarding the residual waste inventory is high, but drainage is expected as an occurrence that could be controlled and isolated to the ground surface, or onsite collection. Any discharge to the soil or collection would be followed by immediate soil removal or disposal to the ERDF.

The technical and administrative feasibility of Alternative 1 is the result of the proximity of several pipelines and respective waste sites to facilities and infrastructure. The High-Salt and Low-Salt pipelines are located adjacent to the PFP and associated structures. Decontamination and decommissioning (D&D) of the PFP is currently ongoing and coordination of Alternative 1 with that project will be necessary. Some of these pipelines overlap and affect other pipelines and utilities. The 216-Z-1, 216-Z-2, 216-Z-3, and 216-Z-1A waste sites' pipelines (200-W-174-PL, 200-W-210-PL, and 200-W-220-PL) are co-located and near the RCRA 241-Z Building, the inactive RCRA pipeline 200-W-178-PL, the active portion of pipeline 200-W-207-PL, and the 241-Z-361 Settling Tank. Therefore, the selection and implementation of the remedies for these pipelines will require careful planning and coordination. The same careful planning would be needed for the remainder of the pipelines because most of the pipelines have aboveground and belowground obstructions that may hinder accessibility during RTD.

The conventional excavation technology considered as part of Alternative 1 is readily available through many contractors. Alternative 1 will require onsite disposal services and capacity at the ERDF. All of these services and disposal capacities are assumed to be available.

H5.2.7 Cost

Table H5-1 summarizes the estimated costs for Alternative 1 at the High-Salt, Low-Salt, and Z-Ditch waste sites' associated piping. The period of analysis for the present value cost is 1 year for the High-Salt, Low-Salt, and Z-Ditch pipelines.

H5.3 Detailed Analysis of Alternative 2– In Situ Stabilization Grout Fill/Capping

Alternative 2, ISS Grout Fill provides no treatment, but prevents and controls exposure to hazardous substances through injection grouting, engineering controls, and ICs to protect human health and the environment. This alternative consists of a grout injection (either cap or fill). The grout injection would consist of excavating access points along each pipeline (such as the inlet and outlet or where dictated from the remedial design), and injecting grout at the ends of the pipe to successfully isolate and plug the pipe. Grout can also be injected to fill the pipeline void space, leaving the pipelines in the ground. Contaminated material generated as part of this technology would be disposed of to the ERDF.

In addition, Alternative 2 includes common components already provided by the respective waste sites. These components include ICs for sites with residual risks above acceptable levels (1,000 years for sites with long-lived radionuclides).

H5.3.1 Overall Protection of Human Health and the Environment

Alternative 2 has the potential to achieve adequate protection of human health and the environment by eliminating, reducing, or controlling potential risks. Compliance with this criterion, by waste site and pipeline group, is summarized as follows:

- High-Salt pipelines: Given that the walls of the piping act as a physical barrier encasing residual contamination, there is no direct contact risk assuming the pipeline has not leaked. If the pipeline has leaked, Alternative 2 does not eliminate a potential direct contact risk to the representative industrial worker at any of the waste sites' associated pipelines. Lastly, the ICs component will help control potential risks by controlling site access and preventing land use that is not compatible with this alternative.

- Low-Salt pipelines: Compliance is the same as for the High-Salt pipelines, except there are no direct contact risks at these waste sites due to the physical barrier characteristic of the pipelines unless the pipeline has been leaking. There is no carbon tetrachloride characterized for the Low-Salt waste sites and expected for the pipelines so the SVE system is not part of Alternative 2 for these sites.

- Z-Ditch pipeline: There are no direct contact risks at the Z-Ditch waste sites and it is expected that the proposed segment of pipeline 200-W-207-PL has no direct contact risks. The potential risks to a well driller, which currently are already below health-based levels for each Z-Ditch, and expected as such for the associated pipeline 200-W-207-PL, would be further reduced by the RTD Alternative 2.

- 216-Z-8 French Drain's associated overflow pipe segment from the 241-Z-8 Settling Tank: Alternative 2 is not applicable to this pipeline.

Although the pipe contents can be filled/remediated using this methodology, any releases from the pipelines would not be protective of human health or the environment. Because there is limited characterization data for the pipelines and collecting soil samples to attempt to characterize pipeline releases cannot be performed without a substantial soil sampling effort, this alternative does not meet this overall protection of human health and the environment criterion and will not be evaluated further. Table H5-1summarizes the alternative assessment for the High-Salt, Low-Salt, and Z-Ditch pipelines, including costs.

Table H5-1. Summary of Detailed Analysis of Alternatives

Criteria	No Action Alternative	Alternative 1– Removal, Treatment, and Disposal	Alternative 2–ISS Grout Injection
Overall Protection of Human Health and the Environment	The No Action Alternative is only evaluated for the pipelines where this alternative meets both threshold criteria.	Alternative 1 is evaluated for all of the pipelines except the pipelines evaluated under the No Action Alternative.	Alternative 2 is evaluated for all of the pipelines except the pipelines evaluated under the No Action Alternative.
Representative Industrial Worker	Final COPCs are below risk levels at the 216-Z-8 French Drain overflow pipeline so this alternative is protective and the remaining criteria are only evaluated for this pipeline.	RTD eliminates potential direct contact risk at pipelines.	Grout injection eliminates potential direct contact risk at pipelines. However, any releases present from the pipelines would not be protective of human health and the environment. Therefore, this alternative has not been retained for further evaluation.
Well Driller	At the other pipelines, there is no elimination, reduction, or control of potential risks, so this alternative fails this threshold criterion.	Current risks below health concerns – RTD further reduces these risks.	
Future Subsistence Farmer		None.	
Protection of Groundwater		SVE component of waste sites removes impact from carbon tetrachloride underneath High-Salt pipelines.	
Environmental Protection		Ecological risks at pipelines unknown – RTD reduces risk.	
Compliance with ARARs			
Chemical-specific ARARs	Would comply with MCLs to protect groundwater.	Would comply with MCLs to protect groundwater.	
Location-specific ARARs	There are no location-specific ARARs.	Excavation activities would comply with archeological, historic, cultural, Native American, and threatened and endangered species ARARs. After excavation, waste soil and debris would be handled and disposed of to comply with ARARs regarding dangerous waste, solid waste, and disposal criteria at ERDF.	
Action-specific ARARs	There are no action-specific ARARs.	Would comply with air pollution ARARs.	
Long-term Effectiveness and Permanence			
Magnitude of Residual Risk	Residual risks are below health concerns with no groundwater impacts.	RTD reduces risk at High-Salt, and Low-Salt pipelines as described previously for the overall protection criterion.	
Adequacy and Reliability of Controls	Not needed.	Not needed.	
Need for 5-Year Reviews	Not needed.	Required at High-Salt, and Low-Salt pipelines to ensure alternative remains protective as long as risks exceed acceptable levels.	
Reduction of Toxicity, Mobility, or Volume Through Treatment			
Treatment Process Used	None.	None.	
Amount Destroyed or Treated	None.	None.	
Expected Reduction in Toxicity, Mobility, or Volume	None.	None.	
Irreversible Treatment	None.	None.	

Table H5-1. Summary of Detailed Analysis of Alternatives

Criteria	No Action Alternative	Alternative 1– Removal, Treatment, and Disposal	Alternative 2–ISS Grout Injection
Type and Quantity of Residuals Following Treatment	None.	None.	
Statutory Preference for Treatment	Does not satisfy.	Does not satisfy.	
Short-term Effectiveness			
Community Protection	No risk to community. Pending confirmatory sampling.	No risk to community for onsite disposal to ERDF.	
Worker Protection	No significant risk to workers.	Protection required from dermal contact, and dust during RTD construction. Engineering and radiological controls needed for worker protection at significant cost.	
Environmental Impacts	No environmental impacts.	Dust emissions will meet air pollution ARARs.	
Time Until Action is Complete	None.	One year.	
Implementability			
Technical Feasibility	No technical issues.	Excavation may have technical difficulties caused by proximity of several pipelines to facilities and infrastructure (roads and utilities).	
Administrative Feasibility	No administrative issues.	Coordinate RTD of High-Salt and Low-Salt pipelines with PFP D&D.	
Availability of Services and Materials	No availability issues.	No availability issues.	
Cost*			
Capital Cost	$0 for 216-Z-8 French Drain.	High-salt $2,620,000 Low-salt $2,260,000	
Total Non-Discounted Costs	$0	High-salt $2,620,000 Low-salt $2,260,000	
Total Present Value Cost	$0	High-salt $2,620,000 Low-salt $2,260,000	

* These cost estimates are based on the best available information for the site-specific anticipated remedial actions. The actual costs are expected to range from -30 percent to +50 percent of these estimated values. Major changes to assumed remedial action scope can result in remedial action costs outside of this range. Net present worth calculations are based on 1,000 years.

H6 Comparative Analysis of Alternatives

The remedial action alternatives for the 200-PW-1, 200-PW-6, and 200-CW-5 OU pipelines that were developed in Chapter H4 and analyzed in detail in Chapter H5 resulted in retention of only Alternative 1. The comparative analysis can only be conducted against the No Action Alternative as follows.

- No Action Alternative
- Alternative 1—RTD
  - Remove contaminated soils and pipelines that could be a direct-contact risk to representative industrial workers and that are less than 3 m (10 ft) below the current ground surface. For the pipelines, removal to include soil within 0.6 m (2 ft) of the pipe. The observational approach will be used to make decisions about the remedy to be applied to those sections of the pipeline that are 3 to 4.6 m (10 to15 ft) bgs.

H6.1 Overall Protection of Human Health

Alternative 1 will provide better overall protection for human health and the environment than the No Action Alternative. The No Action Alternative provides adequate protection of human health and the environment only at the 216-Z-8 French Drain's overflow segment of pipeline 200-W-205-PL because current risk levels at this site are within or below the CERCLA risk range of 10^{-4} to 10^{-6} based on the FS discussion. For the remaining CW-5 OU sites, the No Action Alternative is not protective of human health and the environment. Alternative 1 will utilize the SVE component of the waste sites' FS to eliminate groundwater impacts from carbon tetrachloride at the High-Salt waste sites and pipelines.

H6.2 Compliance with ARARs

The evaluation of the ability of the alternatives to comply with ARARs included a review of chemical-specific, location-specific, and action-specific ARARs that was presented for each alternative in Chapter H5. Alternative 1 will meet the respective ARARs, whereas the No Action Alternative will not meet ARARs.

H6.3 Long-Term Effectiveness and Permanence

Alternative 1 provides better long-term effectiveness at the High-Salt waste pipelines because it will remove contaminants to the ecological exposure depth of 3 m (10 ft) and eliminates the need for long-term ICs. The No Action Alternative provides long-term effectiveness and permanence at the 216-Z-8 French Drain's overflow segment of pipeline 200-W-205-PL because, similar to the waste site assessment, current risk levels at this site's associated pipeline are anticipated to be within or below the CERCLA risk range of 10^{-4} to 10^{-6}.

H6.4 Reduction of Toxicity, Mobility, or Volume through Treatment

There is no treatment component for the pipelines.

H6.5 Short-Term Effectiveness

Alternative 1 is expected to present short-term risks to the community, remedial action workers, and the environment. However, all these risks can be readily addressed. The potential land area impacts, wastes generated, and soil and rock quantities needed for backfill are summarized for the RTD alternative. The RTD alternative at the High-Salt, Low-Salt, and Z-Ditch waste pipelines would result in approximately 4,650 m^3 (6,079 yd^3) of waste transported to the ERDF. These potential risks to the community are mitigated by costly shipping requirements. Workers must be protected from dermal contact, dust, and vapors during SVE and RTD construction and SVE operation. Protecting workers from airborne radiological contamination during excavation at the High-Salt, Low-Salt, and Z-Ditch pipelines will require engineering and radiological controls at significant cost. Alternative 1 will also have the greatest environmental impacts at the pipelines being excavated and will disturb significant land areas. The time required to achieve short-term effectiveness for the pipelines is anticipated to be approximately 1 year from the start of the remedial action. The sequencing and duration of remedy components will be refined during the remedial design.

H6.6 Implementability

Alternative 1 would be less implementable than the No Action Alternative. Alternative 1 is readily implementable using current technology. Coordination will be required to handle any entrained liquid residue, and the known proximity of active RCRA and TEDF facilities, equipment, and pipelines near the excavation zone. The RTD excavations will require significant contaminated material handling requirements for worker safety and environmental protection due to the entrained residual (although perceived to be negligible) material within the pipes. Because the High-Salt and Low-Salt sites' pipelines contain plutonium and americium (which emit alpha radiation) special conditions apply when disturbing, handling, and transporting these contaminated pipelines. Control of airborne contamination will require engineering controls such as water misting and appropriate personal protective equipment for remedial action workers. For the High-Salt, Low-Salt, and Z-Ditch pipelines, the excavation, and waste container packaging could be performed inside a portable enclosure. All contaminated pipelines, soil, and debris are expected to meet the criteria for disposal onsite at the ERDF. In addition, radiation dose rates to workers from the contaminated pipelines and soils in the excavation and from the full waste containers will limit the excavation rate and the amount of contaminated soil that can be placed in each waste container.

Because of the land area required for pipeline excavation, remedial operations, and clean soil stockpiling, Alternative 1 at the High-Salt, Low-Salt, and Z-Ditches must be administratively coordinated with the PFP D&D project. Because the 216-Z-1, 216-Z-2, 216-Z-3, and 216-Z-1A pipelines are co-located and near the 241-Z Building and inactive RCRA pipeline 200-W-178-PL, and 241-Z-361 Settling Tank, the selection and implementation of the remedy(s) for these pipelines will require careful planning and coordination.

A key uncertainty that affects the cost and duration of Alternative 1 is the estimated quantity of contaminated soil at the High-Salt and Low-Salt pipelines that will require disposal at the ERDF. The RTD at each pipeline may need to be expanded if contamination is discovered beyond the pipeline footprint either laterally or with depth. If there is either visual or soil sample data that indicate soil contamination extends below 3 m (10 ft), then an additional 1.5 m (5 ft) lift will be removed and a final soil sample collected at this terminal depth. More information will be presented during the remedial design stage of the project.

H6.7 Cost

The No Action Alternative has no costs for the High-Salt and Low-Salt pipelines. It should be noted that the CW-5-related pipeline has been incorporated into the Low-Salt costs. Alternative 1 has a capital cost, non-discounted cost, and net present value cost of $2,260,000 for the Low-Salt pipeline cost and $2,620,000 for the High-Salt pipeline cost. No operations and maintenance (O&M) costs are associated with Alternative 1, as the soil removal will not require O&M.

H6.8 State Acceptance

State acceptance will be addressed in the ROD.

H6.9 Community Acceptance

Community acceptance will be addressed in the ROD.

H7 Uncertainties Related to Decision Making

The purpose of this chapter is to describe the key uncertainties inherent to the analyses performed as part of this assessment. Uncertainties are propagated throughout any evaluation of technical processes that have a scope as complex as environmental restoration. The uncertainty is a reflection of limited knowledge, engineering, and technical assumptions made during the evaluation. The pipelines analyses will follow the areas of cost, performance, technology, policy, future land use, and human health and ecological risk. This section will focus on the uncertainty related to the inventory and residual contamination, and physicality (size, configuration and integrity) of the pipelines. The following summary presents these uncertainties and their associated potential impacts.

H7.1 Uncertainties in Estimating Pipeline Inventory

Pipeline residual volumes and concentration are important in understanding the risk associated with remediating the pipelines. Because there is no characterization or surveys of the contents of the pipelines, there is uncertainty related to the residual volumes and concentrations of processed waste. The residual concentration cannot be estimated to a confident degree because sample data are not available.

Moving and/or disturbing the pipelines will certainly cause any residual volume entrained in the pipeline to move or flow. The residual volume would most likely flow to the low point of the pipeline during movement or disturbance, resulting in a potential encounter with a worker during construction, and/or a ground surface spill at the outlet of a low-point leak.

Based on previous information, the residual volume associated with pipelines with histories of plugging is a concern. Pipeline 200-W-208-PL is the only pipeline that has shown a history of plugging. This is why a bypass line was installed in 1968. The plugged VCP portion is only 12.2 to 15.2 m (40 to 50 ft long), with only 4.6 m (15 ft) vertical in orientation, and resides near the footprint of the 216-Z-12 Crib. The residual waste volume for 200-W-208-PL could most likely be removed within the scope of work for the 216-Z-12 Crib.

Residual volumes can be estimated per the methodologies developed in RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*. It is assumed that there is minimal waste inventory entrained in several pipelines (200-W-174-PL, 200-W-205-PL, 200-W-206-PL, 200-W-207-PL, and 200-W-210-PL) as per the basis set forth in RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*. That is, the pipelines were typically flushed or drained to a diversion box, before, during, and after being taken out of service. Therefore, the risk is relatively low for this uncertainty. This poses an upper-bound risk and is conservative, given the operational history provided in HNF-30862, *Engineering Evaluation/ Cost Analysis for the Plutonium Finishing Plant Sub-grade Structures and Installations*. HNF-30862 describes the process records, showing that the 200-PW-1 and 200-PW-6 pipelines were flushed and rinsed after each waste discharge and during the shutdown of the facility. It is assumed that these flushes effectively diluted and removed the contents of the pipelines and that the pipelines contain some impregnated residue inside the walls of the pipelines. The concentrations of the residue impregnated in the walls would probably be similar to those concentrations found at the respective waste sites, but would be far less mobile than if it were free flowing, posing a far less risk than the wastes found at each respective pipeline's waste site.

H7.1.1 Potential Impacts

Every aspect of the risk assessment contains multiple sources of uncertainty. Because the exact amount of uncertainty cannot be quantified, the risk assessment is intended to overestimate rather than underestimate probable risk. The pipeline inventory uncertainty impacts will be less than the impacts associated with the waste sites due to the increased dilution (and, therefore, decreased residence time) from the operational flushes. The pipeline inventory uncertainty impacts will be less because the sampling strategies for contaminants in the waste site assessment were, in general, designed to prevent underestimation of media concentrations, thus avoiding an underestimation of the risks to public health. The results of the pipeline assessment, therefore, are likely to be protective of health despite the inherent uncertainties in the process, similar to the waste site evaluation.

H7.2 Uncertainties in Estimating Pipeline Physicality (Size, Configuration, and Integrity)

Although there is quite a bit of information about pipeline locations (maps, surveys, and historical drawings), knowledge is limited concerning the pipelines' current size, configuration, and structural integrity. Some drawings are unclear regarding vertical and horizontal changes in perceived straight sections of pipe. It is unknown how much the pipelines have moved or changed due to soil settling immediately after construction, and to natural shifts in the geology of the soil where they lie. Any settlement of soil underneath the pipelines could naturally affect the slope of the pipelines to some degree.

There are uncertainties as to the structural integrity of each pipeline, i.e., have the pipelines underlying roads and access ways been affected (deformed or broken) by the weight of passing vehicles and heavy equipment aboveground. There is uncertainty as to whether welds in stainless steel and carbon steel have held up and are still intact. Although it is known that VCP is generally prone to cracks, leaks, and split joints, it is uncertain if the piping has significant damage or wear. Most of this type of piping is a part of the 200-W-207-PL pipeline, which conveyed very low-contaminated cooling water to the Z-Ditches (see DOE/RL-2004-24 for Z-Ditch waste characteristics). Pipeline 200-W-207-PL is a larger-diameter pipe, making it prone to collapse and resulting in the potential for infiltration and leaks. Other shorter lengths and portions of VCP are located at the pipeline outlets near or in the waste sites' (cribs and tile field) footprint. For all cases, it is assumed the pipelines were built per the construction drawings in location, size, and configuration, and the pipe structural integrity is still intact as initially designed and constructed.

H7.2.1 Potential Impacts

The uncertainty in estimating the extent of contamination at various pipelines potentially affects the extent of a remedial alternative. This would affect the estimated cost and duration of the remedial alternatives. For example, if a pipe were found to be broken (split-joint), then sampling could be conducted at the target area, and a decision made concerning the path forward. The uncertainty in contamination extent and the potential impacts will be mitigated by pre-remedial design confirmatory investigations.

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Appendix I

Cost Estimate Associated with Post-ROD Sampling for Groundwater Protection

1

I1 Capital Cost Summary

TOTAL COST OF RESPONSE ACTION			
Site:	PW 1/3/6 Post ROD Sampling	Base Year:	2010
Location:	Hanford, WA	Date:	7/16/2010
Phase:	RI/FS		

	PW 1/3/6/ Post ROD Sampling
Total Project Duration (years)	1
Capital Cost	$33,720,000
Total O&M Cost	$0
Total Periodic Cost	$0
Non-Discounted	**$33,720,000**
Total Present Value of Alternative (Discounted)	**$33,720,000**

This is an executive summary of the Environmental Cost Estimate referencing the document ECE-200PW1/3/610-00007, *PW-1/3/6 Post ROD Sampling Cost Estimate*.

I2 Purpose

The purpose of this Estimate for Present Value Costs is to establish an opinion of probable cost based on planning documents and site information.

I3 Background

This document provides a backup of the cost estimate conducted to support the response action for the PW-1/3/6 post record of decision (ROD) sampling according to Appendix D of this document and evaluates the post ROD sampling response action. This response action requires specific inputs and assumptions as discussed in Section I4.2.1.

I4 Methodology

The cost estimate for the PW-1/3/6 post ROD sampling was developed in accordance with EPA/540/R-00/002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER 9355.0-75. The Remedial Action Cost Estimate Requirement (RACER) Cost Estimator software was used in conjunction with Microsoft Excel software and the response action site information presented in Appendix D of this document to develop the cost estimate for the response action.

The cost estimates are based on actual pricing information derived from historical experience. The unit costs associated with each one of the quantity estimates may have been factored or adjusted by the estimator and/or task lead, as appropriate, to reflect influences by the contract, work site, or other

identified special conditions. Historical information from similar Hanford Site planning and reverse well decommissioning efforts was applied to this estimate.

Net present value costs were estimated using the real discount rate published in Appendix C of the Office of Management and Budget (OMB) Circular No. A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," effective through January 2010. Programs with durations longer than 30 years use the 30-year interest rate of 2.7 percent. Net present value costs are discussed for each alternative in the following subsections. Typically the period of analysis for the net present value cost is 1,000 years; however, no present value has been calculated for this estimate as all costs are calculated in year one.

The estimate was also prepared in accordance with the guidelines of the Association for the Advancement of Cost Engineering (AACE) International, AACE International Recommended Practice No. 18R-97, *Cost Estimate Classification System—As Applied in engineering, Procurement, and Construction for the Process Industries*. According to the definitions of AACE International, Recommended Practice No. 8R-97, the Class 5 Estimate is defined as the following:

> *"This estimate is prepared based on limited information, where little more than proposed waste site, its location, and remediation alternatives are known, where preliminary engineering is from 0 percent to 2 percent complete. Strategic planning purposes include but are not limited to, market studies, assessment of viability, evaluation of alternate schemes, project screening, location, and evaluation of resource needs and budgeting, and long-range capital planning. Examples of estimating methods used would include cost/capacity curves and factors, scale-up factors, and parametric and modeling techniques. Typically, little time is expended in the development of this estimate. The expected accuracy ranges for this class of estimate are –20 percent to –50 percent for the low range side and +30 percent to +100 percent on the high range side."*

No sensitivity analyses were performed. The following factors might cause the estimate to change significantly:

- Levels of contamination
- Extended time required for sampling crews to work in personal protective equipment (PPE)
- Number of total samples required and number of analytes per sample

The cost estimates provide a discriminator for deciding between similar protective and implemental alternatives for a specific waste site. Therefore, the costs are relational, not absolute, costs for the evaluation of the response action.

I5 Assumptions and Inputs

There are two different types of assumptions and inputs for cost estimation. The first type is general assumptions and inputs. These general inputs can be applied to cost estimating in general such as labor rates and direct and indirect cost factors. The second type of assumptions and inputs are remedial activity specific such as sampling specific criteria.

I5.1 General Assumptions

I5.1.1 Labor

Fixed-price (FP) construction craft labor rates are those listed in Appendix A of the *Site Stabilization Agreement for All Construction Work for the U.S. Department of Energy at the Hanford Site* (commonly

known as the Hanford Site Stabilization Agreement [HSSA]). The HSSA rates include base wage, fringe benefits, and other compensation as negotiated between CH2M HILL Plateau Remediation Company (CHPRC) and the National Building and Construction Trades Department American Federation of Labor-Congress of Industrial Organizations (AFL-CIO). Other factors that account for additional costs (such as, Workman's Compensation, *Federal Insurance Contributions Act* [FICA {*The Social Security Act of 1935*}], and state and federal unemployment insurance) to develop a fully burdened rate by craft, have been incorporated. The labor rates used are for 2010.

Plateau Remediation Contractor (PRC) labor rates for management, engineering, safety oversight, and technical support are based on the PRC-approved planning rates for fiscal year 2010.

I5.1.2 Direct Cost Factors

The direct cost factor in the cost estimates is the Washington State sales tax, which has been applied to all materials and equipment purchases at 8.3 percent.

I5.1.3 Indirect Cost Factors

The following indirect cost factors are included in the cost estimates:

- Contractor overhead, profit, bond, and insurance costs have been applied at a rate of 26.5 percent on FP labor, materials, and equipment.
- PRC general and administrative (G&A) has been applied at a rate of 14.8 percent to all PRC labor, material, and equipment. G&A is also applied to the FP contractor costs.

I5.1.4 Other

The following general pricing assumptions were included in the cost estimates:

- PRC cost estimating templates for site remediation are used as the basis for each waste site cost estimate.
- Construction labor, material, and equipment units were estimated based on standard commercial estimating resources and databases: Means, 2010a, *Building Construction Cost Data*, and Means, 2010b, *Heavy Construction Cost Data*. The units may have been factored or adjusted by the estimator as appropriate to reflect influences by contract, work site, or other identified project or special conditions.
- Quotes from local commercial sources are used for materials that need to be acquired for the construction of temporary improvements.
- Equipment rates are based on 21 working days per month.
- Equipment operation is based on one shift of 8 hours per day.
- One workweek equals 5 days.
- Work stoppages or shutdowns caused by inclement weather are factored into the estimates or planning schedules. It is assumed that there will be 20 days of delays per calendar year. For projects that are less or greater than one year, the delay time is prorated.
- Work delays or stoppages caused by waiting for laboratory results or approval for backfilling waste site excavations are included in the estimates.

- The cost estimates include costs for design, work plan preparation, and any other preparation costs normally associated with activities occurring before field mobilization.
- Remedial design capital costs are based on EPA/540/R-00/002, Exhibit 5-8. The following guide is used in this study:
  - For projects with construction costs less than $100,000, remedial design is planned at 20 percent of the construction cost.
  - For projects with construction costs from $100,000 to $500,000, remedial design is planned at 15 percent of the construction cost.
  - For projects with construction costs from $500,000 to $2 million, remedial design is planned at 12 percent of the construction cost.
  - For projects with construction costs from $2 million to $10 million, remedial design is planned at 8 percent of the construction cost.
  - For projects with construction costs greater than $10 million, remedial design is planned at 6 percent of the construction cost.
- Escalation has not been included in the calculations. All costs are present day (fiscal year 2010).
- Contingency has been applied to the capital costs and the rates are based on EPA/540/R-00/002, Section 5.4.

I5.2 Remedial Activity-Specific Assumptions

The site-specific assumptions for the post ROD sampling activities are summarized below.

I5.2.1 General Assumptions

The general assumptions for the post ROD sampling response action include:

- Thirteen waste sites requiring five sampling boreholes each was assumed for the Post ROD sampling cost estimate.
- Hollow stem auger equipment and crews were assumed for the five sampling boreholes required for each site.
- One mobilization, demobilization, and 64 moves of the hollow stem auger equipment were assumed for the project.
- A total depth of 23 m (75 ft) with sampling intervals of every 1.5 m (5 ft) starting at a depth of 4.5 m (15 ft) from existing ground surface was assumed for each sampling borehole.
- The analytical suite of tests assumed nitrate+nitrite as nitrogen, radionuclides (technetium-99, plutonium-239/240, americium-241, and uranium isotopes), volatile organic compounds, semivolatile organic compounds, metals, and polychlorinated biphenyls.
- An additional 5 percent, of the total samples required, were assumed for quality assurance.
- It is assumed 40 percent of the sampling boreholes to be highly contaminated; therefore, additional PPE and lower production rates were assumed for this duration of the sampling activities.

- Remedial design has been excluded as it is assumed this sampling plan will be a design item for the overall project.

I6 Software Applications

I6.1 Approved Software

RACER 2010, Version 10.3, has been accredited in accordance with Department of Defense (DOD) Instruction 5000.61, *DOD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A)* (dated July 11, 2001). Each year the RACER software is assessed technically by the RACER DOD technical review group and updated as needed to make sure it complies with the VV&A instruction.

RACER is registered in the Hanford Information System Inventory.

I6.1.1 Description

The software package used in the calculation:

- RACER
- Version 10.3HISI 2440
- CH2M HILL Laptop 31050012

I6.1.2 Software Installation and Checkout

RACER software installation and checkout was performed. Multiple tests were performed on the software comparing a sample project and results provided by Architecture, Engineering, Consulting, Operations, and Maintenance (AECOM) help desk. The test was performed using the RACER 10.3 version software on a government workstation and the results were duplicated.

I6.1.3 Statement of Valid Software Application

RACER is a cost estimating system that was developed under the direction of the U.S. Air Force for estimating environmental investigation and cleanup costs for the annual budgeting and appropriations process. A prime area where RACER is used within the firm is to develop cost estimates for cleanup scenarios on feasibility studies for hazardous waste sites and corrective measures studies under the *Resource Conservation and Recovery Act of 1976* (RCRA). Given the limited data inputs required and the structured estimating process, RACER is an ideal tool for developing cost estimates for multiple cleanup approaches consistent with RCRA, *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, underground storage tank, and other environmental regulatory programs.

I7 References

AACE International Recommended Practice No. 18R-97, 2005, *Cost Estimate Classification System—As Applied in engineering, Procurement, and Construction for the Process Industries*, AACE, Inc., Morgantown, West Virginia. Available at: http://www.aacei.org/technical/rps/18r-97.pdf.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq. Available at: http://uscode.house.gov/download/pls/42C103.txt.

DOD Instruction 5000.61, 2001, *DOD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)*, U.S. Department of Defense, Washington, D.C. Available at: http://www.simval.org/document/DoDI_5000_61/DoDI_5000_61.pdf.

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EPA/540/R-00/002, 2000, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER 9355.0-75, U.S. Environmental Protection Agency, Washington, D.C. Available at: http://epa.gov/superfund/policy/remedy/sfremedy/rifs/costest.htm.

Federal Insurance Contributions Act (FICA, *Social Security Act of 1935*), 26 USC 3101, et seq. Available at: http://www.law.cornell.edu/uscode/26/usc_sup_01_26_10_C_20_21.html.

Means, R.S., 2010a, *Building Construction Cost Data*, 68th Annual Edition, R.S. Means, Company Inc., Kingston, Massachusetts.

Means, R.S., 2010b, *Heavy Construction Cost Data*, 24th Annual Edition, R.S. Means Company Inc., Kingston, Massachusetts.

National Environmental Policy Act of 1969, 42 USC 4321, et seq. Available at: http://www.fhwa.dot.gov/environment/nepatxt.htm.

OMB Circular No. A-94, 2009, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" (memorandum for Heads of Executive Departments and Establishments), Appendix C, "Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses," Office of Management and Budget, Washington, D.C., as revised. Available at: http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/.

Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq. Available at: http://www4.law.cornell.edu/uscode/42/6901.html.

Site Stabilization Agreement for All Construction Work for the U.S. Department of Energy at the Hanford Site, 1984, as amended, commonly known as the Hanford Site Stabilization Agreement (original title, *Site Stabilization Agreement, Hanford Site, between J. A. Jones Construction Services Company and Morrison-Knudsen Company, Inc., and the Building and Construction Trades Department of the AFL-CIO and its affiliated international unions, and the International Brotherhood of Teamsters, Chauffeurs, Warehousemen, and Helpers of America*), Donald Paul Hodel, Secretary of Energy. Available at: http://www.hanford.gov/pmm/page.cfm/HSSA.