APPENDIX E

RESIDUAL RADIOACTIVITY ANALYSIS FOR RADIONUCLIDE HUMAN HEALTH RISK CHARACTERIZATION AND THE GROUNDWATER PROTECTION EVALUATION

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APPENDIX E

RESIDUAL RADIOACTIVITY ANALYSIS FOR RADIONUCLIDE HUMAN HEALTH RISK CHARACTERIZATION AND THE GROUNDWATER PROTECTION EVALUATION

E1.0 INTRODUCTION

RESRAD Version 6.3 was used to estimate the peak groundwater concentration and corresponding year from existing concentrations of radiological contaminants in the soil column from each representative waste site. RESRAD was also used to estimate the annual radiation dose and excess lifetime cancer risk (ELCR) from direct contact with radiological contaminants for an industrial/commercial exposure scenario. A 10,000 year time frame was selected for all analyses to capture the peak groundwater concentration for radiological contaminants in each representative waste site.

The analysis proceeds in two steps. First, the results of soil characterization are used to construct a simplified model of radionuclide distributions in the soil at each representative waste site. Second, the soil model is input to the RESRAD software to calculate groundwater concentrations and to estimate annual radiation dose and ELCR from direct contact exposure to contamination.

E2.0 DESCRIPTION OF THE 200-CS-1 CONTAMINATED SOIL SITES

The first chemical sewer operable unit for the 200 Areas (200-CS-1) includes 216-A-29 Ditch, 216-B-63 Trench, 216-S-10 Ditch, and the 216-S-10 and 216-S-11 Ponds. The general characteristics of each site are listed in Table E-1. This information is from the DOE Waste Information Data System (WIDS) database.

E3.0 RADIONUCLIDE DISTRIBUTIONS IN THE SOIL

The objective of this section is to establish the distribution of radionuclide contaminants of potential concern (COPC) in soil at each of the representative waste sites. This information will be used in the RESRAD software. The contaminated soil model specifies the concentration of radionuclide COPCs in the surface and subsurface soil at the 200-CS-1 waste sites. In this simplified approach, the soil contamination is assumed to be present in layers below the surface with each layer having a uniform concentration of the contaminants.

In this section, the entire list of radionuclides that were detected in the soil samples is evaluated and used in a RESRAD calculation of groundwater concentration. No detectable radionuclides were eliminated from consideration.

E3.1 RADIONUCLIDE SAMPLE RESULTS FOR 200-CS-1 REPRESENTATIVE WASTE SITES

The sample data includes various radionuclides that are naturally occurring in the soil. The

naturally occurring radionuclides are K-40, U-238 with progeny, U-235 with progeny, and Th-232 with progeny. The measured ranges for these radionuclides are listed in Table E-2. Soil concentrations in this table are from DOE/RL-96-12, *Hanford Site Background: Part 2: Soil Background for Radionuclides*. The radioactive decay information is from the National Nuclear Data Center web site (www.nndc.bnl.gov/index.jsp).

In Table E-2 the short half-life progeny, namely, those with half-lives less than 1 year, are identified in the wide cell preceding the rows listing the long half-life nuclides. The short half-life progeny come to equilibrium with the long-lived parent nuclides rather quickly because the half-lives are less than 30 days. Thus, there is no need to list the short half-life nuclides explicitly. In some cases, the activity of the parent is measured by radiation emitted from a short-lived daughter. An example is the use of Tl-208, a strong photon emitter, to determine the activity of Th-228. It should be noted that RESRAD automatically includes the entire decay chain for every radionuclide that is selected.

The background soil concentrations are compared to the measured soil concentrations to evaluate if a measured quantity is within the observed range for natural background. If it is then the measured quantity is not of concern. If the measured concentration exceeds the expected range, then it will be evaluated for its potential impact on human health risk.

The radionuclides that are commonly analyzed for in soil samples are listed in Table E-3. Also shown in Table E-3 are the radioactive decay half-life, the isotopic mass, and the specific activity of the pure isotope. The isotope mass and decay half-life for each isotope is from the USDOE's National Nuclear Data Center web site (www.nndc.bnl.gov/index.jsp). The specific activity is the number of curies that are present in one gram of the pure isotope. It is calculated using the formula below.

$$\text{Specific Activity} = \frac{(\text{Unit Conversion})}{(\text{Isotopic Mass})(\text{Half Life})}$$

$$\text{Unit Conversion} = \left(\frac{1\,\text{Curie}}{3.7 \times 10^{10}\ \text{atoms/s}}\right) \frac{(6.02214199 \times 10^{23}\ \text{atoms/mole})}{(365.24219\ \text{d/y})(24\ \text{h/d})(3600\ \text{s/h})}\ \ln(2)$$

The largest measured activity concentrations in soil at the five sites are shown in Tables E-4 to E-8. The measured results and depths at which the sample was collected were obtained from the Hanford Environmental Information System (HEIS) database. Sample results below detection limits (those having the "U" flag) were assumed to be zero (or not detected) to facilitate the modeling of doses and risks from the various exposure scenarios.

The data in Tables E-4 through E-8 are arranged by sample location along the ditches. The soil concentrations at each sample location are the actual measured values without consideration of natural background levels. The columns on the right side of each table (under the "Worst Case" heading) have evaluated the relationship to natural background. The "Worst Case" columns show the largest man-made addition to the soil concentration and the depth at which it was found. Most of the activity is confined to the upper 6.1-9.1 m (20 to 30) feet of the soil column. The main exceptions were H-3 (tritium) and Ni-63.

Some of the alpha-emitting radionuclides are difficult to distinguish due to similar radiations as well as similar chemistry. This is the case for Pu-239 and Pu-240, as well as for U-233 and U-234. The two plutonium isotopes are both synthetic and have nearly identical radiological characteristics. It is customary in risk assessments to conservatively treat the duo as simply Pu-239 because this isotope has the longer half life and is normally present in greater amounts. The two uranium isotopes are quite different in origin. The U-233 is produced by decay of Np-237 (a synthetic nuclide) as well as neutron bombardment of Th-232. U-233 is entirely of synthetic origin. The U-234 is naturally occurring, being produced by the decay of U-238.

The measured concentrations of the naturally occurring radionuclides are generally consistent with background. However, at 216-A-29 a high reading for U-238 and U-233/234 was interpreted as a synthetic addition. In particular, the absence of Np-237 and normal levels of Th-232 indicates the U-233/234 should be interpreted as U-234. Note that there is no corresponding increase in Th-230 or Ra-226 at that depth (2.3 to 2.6 m [7.5-8.5 ft]) as would be expected if it were of natural origin. The synthetic contribution was calculated as the largest value observed at any sample location. The background levels of naturally occurring radionuclides were not subtracted from the detected site concentrations.

At the 216-A-29 Ditch there is also a higher than expected concentration of Th-230 in the sample at 15.2 to 16 m (50 to 52.5 feet) below the surface. This higher result (1.6 pCi/g) is just 6% above the estimated background soil concentration from Table E-2. Thus, the Th-230 concentration will be treated as background.

At the 216-B-63 Trench there is also a higher than expected concentration of Th-230 in the sample at 8.5 to 9.1 m (28 to 30 feet) below the surface. This higher result (1.73 pCi/g) is just 15% above the estimated background soil concentration from Table E-2. Thus, the Th-230 concentration will be treated as background.

In Table E-5a the sample results for borehole 299-E33-333 were not included. However, because the 216-B-63, 216-B-2-1, and 216-B-2-2 Ditches overflowed into one another, it is reasonable to consider the effect of including the E33-333 sample results (shown in Table E-5b).

In Table E-5b the effect of including the sample results from E33-333 are shown. The E33-333 results add a large concentration of Sr-90 as well as Eu-154 and Th-230 to the inventory of the shallow soil zone. It also increases the maximum expected concentration for Am-241, Cs-137, and Pu-239. The Th-230 concentration measured at E33-333 will be treated as man-made because it is nearly twice the maximum observed for natural background. The man made contribution of Th-230 is the largest measured value listed in Table E-2.

The high value for Th-228 at the 216-S-10 Ditch shown in Table E-6 can be interpreted as an anomalous result due to inconsistencies with other members of the thorium decay chain. Th-228 has a half-life of 1.9116 years and thus should be near equilibrium with its long-lived parent nuclides (Ra-228 and Th-232). The Th-228 was measured two ways; “IX/AEA” gave

5.9 pCi/g while "GEA" gave 0.352 pCi/g. Both Ra-228 and Th-232 measured 0.625 pCi/g using "GEA". The high Th-228 value is far enough away from where it should be that it was rejected. It should be noted that Th-228 may also be produced by the decay of U-232 (68.9 y half-life). U-232 is present in wastes at Hanford in trace amounts due to decay of Pu-236 (2.858 y half-life). The presence of measurable U-232 would be accompanied by significant amounts of the other uranium and plutonium isotopes. Since this is not the case, the high value for Th-228 must be an anomalous result.

The deepest locations where detected soil concentrations were found are listed in Table E-9. Note that two of the waste sites southwest of REDOX, namely, 216-S-10 Pond and 216-S-11 Pond, were combined into one waste site due to their proximity to one another. The borehole from that area is near both waste sites as observed in Figure 2-4. Additionally, the 216-S-11 Pond is an analgous waste site to the representative 216-S-10 Pond.

E3.2 SIMPLIFIED SOIL CONTAMINATION MODEL FOR RADIONUCLIDES

A simplified model of the sample data will be used to represent the waste sites. The soil column to ground water is divided into a few layers. Each layer is assumed to have a uniform activity concentration at the maximum value found in the layer. The simplified model is summarized in Table E-10.

The uncontaminated cover thickness is based on the 200-CS-1 Remedial Investigation report with the exception of the cover thickness for the 216-S-10 Ditch. Currently, the 216-S-10 Ditch is partially uncovered. The northern two-thirds of the length of the ditch was dredged and placed into the southern third. This makes the northern two-thirds wider and deeper. The northern two-thirds of 216-S-10 Ditch was removed during dredging. The ditch is typically filled with tumbleweeds that have blown into the ditch.

At the 216-A-29 Ditch essentially all of the measured activity (with the exception of tritium) appears to be in the top 6.1 m (20 ft) of soil. Samples taken at 5.8 to 6.7 m (19.5-22 ft) showed no man-made activity. The tritium concentrations were not measured down to the sample at 45.7 – 46.3 m (150-152 ft.) Measurable contamination was found in the sample taken at 61 m 61.6 m (200-202 ft.) Thus, the tritium appears to be confined to a thin layer deep in the vadose zone. However, in the RESRAD soil model the tritium will be represented as uniform throughout a thicker layer extending from 53.3 m (175 ft) below the surface down to the aquifer at 82.3 m (270 ft.) The tritium concentration in this layer is the maximum found, namely 7.05 pCi/g. Thus, the soil model for 216-A-29 Ditch has two contaminated layers, the upper layer is from 1.2 to 6.1 m (4 to 20 ft) and the deeper layer is from 53.3 82.3 m (175 ft to 270 ft.) The activity concentration in each layer is listed in Table E-10.

At the 216-B-63 Trench essentially all of the measured activity appears to be in the top 7.6 m (25 ft) of soil. Samples taken at 7.3 to 7.6 m (24 to 25 ft) and below showed no man-made activity with the exception of Ni-63. However, soil samples were only taken to a depth of 31.4 m (103 ft.) and the soil column extends to 74.7 (245 ft.) The Ni-63 concentrations were greatest in the upper 7.6 m (25 ft), but lower concentrations of Ni-63 were measured all the

way to the lowest depth sampled. By simple extrapolation, the missing Ni-63 concentration between 31.4 m (103 ft) and the ground water (31.4 m [245 ft]) will be represented by the maximum value found between 7.6 m and 31.4 m (25 and 103 ft), namely 5.68 pCi/g. Thus, the soil model for the 216-B-63 Trench has two contaminated layers, the upper layer is from 1.5 to 7.6 m (5 to 25 ft) and the deeper layer is from 1.5 m to 74.7 m (25 ft to 245 ft.) The activity concentration in each layer is listed in Table E-10.

At the 216-S-10 Ditch essentially all of the measured activity appears to be in the top 9.1 m (30 ft) of soil. Samples taken below 8.2 m (27 ft) showed no man-made activity, with the exception of Ni-63. The Ni-63 concentration is not detected in the 15.2-15.8 m (50-52 ft), 30.5-31.1 m (100-102 ft), 41.1-41.8 m (135-137 ft), and 67.1-68 m (220-222 ft) samples. Measurable concentrations were observed in the 45.7-46.3 m (150-152 ft), 56.4-57 m (185-187 ft), and 61-61.6 m (200-202) ft samples. Hence, the Ni-63 contaminated deep zone will be represented by a soil layer ranging from 140 ft to 210 ft below the surface. The activity concentration in this layer is the maximum observed, namely 10.7 pCi/g. Thus, the soil model for 216-S-10 Ditch has two contaminated layers, the upper layer is from .6 to 9.1 m (2 to 30 ft) and the deeper layer is from 42.7-64 m (140 ft to 210 ft.) The activity concentration in each layer is listed in Table E-10.

In accordance with the *Remedial Investigation Report for the 200-CS-1 Chemical Sewer Group Operable Unit* (DOE/RL-2004-17) (hereinafter referred to as the RI Report), a cover thickness of 0.6 m (2 ft) was selected to represent the uncontaminated soil cover in the 216-S-10 Ditch. At present, about 2/3 of the length of the ditch is still a ditch with side slopes approximately 1:2 and depth approximately 2.4 to 3 m (8 to 10 feet). The bottom of the ditch is believed to be uncontaminated due to the dredging. Human activity in the vicinity of the ditch is expected to result in little human proximity to the waste due to the steep sides of the ditch and the presence of dried tumbleweeds. In the future, it is possible the ditch may be burned every few years, which would temporarily make the bottom of the ditch accessible for human exposure. The ditch also will be collecting wind-borne dust on a continual basis. Thus the bottom of the ditch is continually acquiring a non-radioactive cover. Therefore, a .6 m (2 ft) thick cover is used in the RESRAD model to represent both the reduced human occupancy at the bottom of the ditch as well as the ever thickening soil cover.

At the 216-S-10 Pond all of the samples are from depths above 7.9 m (26 ft) or from depths below 10.7 m (35 ft.) Essentially all of the measured activity (except for Ni-63, Sr-90, and Pu-239) appears to be in the top 9.1 m (30 ft) of soil based on the supposition that 216-S-10 Ditch and 216-S-10 Pond are connected and should have similar activity distributions. The sample taken at 15.2-15.8 m (50-52 ft) contained some Ni-63 and Sr-90. Also, the sample at 30.3-30.9 m (99.5-101.5 ft) showed a small Pu-239 contamination. However, samples at 10.7-11.3 m (35-37 ft), 41.1-41.8 m (135-137 ft), 45.7-46.3 m (150-152 ft), 54.9-5.5 m (180-182 ft), and 60-61 m (197-199 ft) had no man-made radionuclide contamination. Hence, the Ni-63 and Sr-90 contamination is represented as extending from 44 ft to 76 ft below the surface. The Pu-239 contamination is represented as extending from 76 ft to 118 ft below the surface.

In summary, the soil model for the 216-S-10 Pond has three contaminated soil layers, the

upper layer is from 1.8 to 9.1 m (6 to 30 ft), the first deep layer is from 13.4 to 23.1 m (44 ft to 76 ft), and the second deep layer is from 23.1 to 36 m (76 ft to 118 ft.) The activity concentration in each layer was listed in Table E-10. The soil model presented in Table E-9 was input to the RESRAD software using the parameter values listed in Tables E-13 and E-14. RESRAD allows the user to input information from only one contaminated layer at a time, so it was necessary to construct two or three runs for each site and add the results.

This completes the discussion of the distribution of radioactivity in the soil column at each waste site. The next step is to describe how the hydraulic and geochemical properties will be represented for each of the soil columns suitable for input to RESRAD.

E4.0 SOIL MODEL FOR INPUT TO RESRAD

The soil column from surface to groundwater has been characterized at numerous locations around the Hanford Site. There are also boreholes at each of the 200-CS-1 waste sites that have been analyzed for various soil properties. The physical architecture (e.g. geology, hydraulic properties, and geochemical properties) beneath the 200-CS-1 waste sites varies by location. The geometry and configuration of hydrostratigraphic facies and heterogeneities can be quite complex at small scales. However, for the purposes of simulating release of mobile contaminants from the vadose zone to the groundwater on a large scale, the vadose zone can be simulated in a fairly simple manner. This is accomplished with the small-scale stratifications and variations in texture represented in the context of larger hydrostratigraphic units. The omission of small-scale heterogeneities and anisotropy is expected to lead to an underestimation of lateral spreading, and enhanced downward transport.

For the purposes of this analysis, the soil column beneath each waste site can be represented by a one-dimensional soil column. RESRAD allows the soil column to be divided into four layers: uncontaminated cover, contaminated, unsaturated, and saturated. RESRAD requires several parameters related to the hydraulic and geochemical properties of each layer, which is summarized in Table E-11. The 216-A-29 Ditch is long enough (1219.2 m [approximately 4,000 ft]) that two soil columns were prepared. The hydrostratigraphic layers represented on this table were defined based on the geologic and hydrogeologic data described in the RI Report (DOE/RL-2004-17) and other pertinent site-specific documents such as the *Groundwater Monitoring Plan for the 216-A-29 Ditch* (PNNL-13047).

Hydraulic properties (and input parameters) were assigned to each of these hydrostratigraphic layers by matching them to the soil hydraulic property classes described in the *Vadose Zone Hydrogeology Data Package for Hanford Assessments* (PNNL-14702). Some minor differences were noted for two of the soil classes (Hg-2W and Rg-2W) between Table 4.9 in PNNL-14702 and those in Appendix B of PNNL-14702. The values from Appendix B (PNNL-14702) were used in the present analysis. The selected hydraulic properties are listed in Table E-12.

In PNNL-14702, the distribution coefficient (Kd) values depend on the type of waste liquid and the soil class. The Kd classes that were chosen for 200-CS-1 are shown in Table E-12. The waste stream that best fits the 200-CS-1 is Category 4, Low Organic/Low Salt/Near

Neutral. The "H" or "I" refer to high or intermediate impact of the waste stream on the Kd values. For intermediate impacted soil the Kd also depends on the gravel content. Gravel in the soil lowers the Kd. Thus, in Table E-12 the Kd class notation "4I2" refers to category 4 liquid waste with intermediate impact, and gravel that comprises 90% by volume of the soil. The notation "4I1" refers to category 4 liquid waste with intermediate impact in sand.

The RESRAD "b" parameter was determined from the soil textures listed in the RESRAD Version 6 manual. The Hydrogeologic units have little of the finer material (silt and clay). Hence the "b" parameters are all near 4.05 for sand. The soil class Hss was given the sandy loam value of 4.90. The soil class Hfs was given the loamy sand value of 4.38.

With the information in Tables E-11 and E-12 along with the radionuclide distribution model from Table E-10, the soil properties needed for input to RESRAD can be determined. The RESRAD software requires the soil column to groundwater to be represented using four layers. The top layer is uncontaminated cover soil. The only hydraulic property needed for the cover soil is its bulk density. The second layer is contaminated soil. The radioactive contaminants are represented as uniformly distributed throughout the layer. The third layer is the unsaturated, or vadose zone. The vadose zone can be divided into as many as five sublayers. The fourth layer is the saturated zone, or aquifer. The thickness of the saturated zone is not a RESRAD input parameter.

Because RESRAD works with only one layer of contaminated soil at a time, it is necessary to model different contaminated soil layers separately and later combine the results. Thus, each waste site has separate models for the upper and lower contamination layers.

The soil model dimensions used for input to RESRAD are shown in Figures E-1 to E-5. The column on the left shows the hydrologic units for the waste site. The other columns show the RESRAD input to represent the site. The layer of contaminated soil is shaded a rose color. The aquifer is shaded blue. The notes below each figure summarize the grouping of hydrologic units where necessary to make reasonable RESRAD input.

In Figure E-1 the upper layer of contaminated soil includes some of the backfill layer and some of the Hanford gravelly sand layer. Because RESRAD requires the hydraulic properties in a layer to be the same everywhere in that layer, the different properties of B and Hg were combined using a thickness-weighted average. To illustrate the calculation, the upper contamination layer at 216-A-29 head end (Figure E-1) is comprised of 1.8m (6 ft) of backfill (B) and 4.5 m (15 ft) of Hanford gravelly sand (Hgs). The hydraulic conductivity (Ksat) of backfill is 188.6 m/y (Table E-12) and the hydraulic conductivity of Hgs is 209.7 m/y. The thickness-weighted average hydraulic conductivity is calculated as shown below.

$$\text{Average Ksat} = \frac{(6\text{ ft})(188.6\text{ m/y}) + (10\text{ ft})(209.7\text{ m/y})}{16\text{ ft}} = 201.8\text{ m/y}$$

The average values for the other hydraulic parameters are calculated in the same manner as the hydraulic conductivity.

In Figure E-1, note that the two Hgs layers above and below the 16.8 m (55 ft) thick Hcs layer were combined into one layer. This was necessary because RESRAD allows only 5 layers in the unsaturated zone.

In Figure E-5, the 216-S-10 Pond have three RESRAD soil models because there are two deeper layers of contamination, one for Ni and Sr, the other for Pu.

The parameter lists shown in Tables E-13 and E-14 are used as input to RESRAD Version 6.3. The lengths parallel to the aquifer flow in Table E-13 were chosen to be the full length of the ditch or waste site. Although it is highly unlikely that groundwater flow will exactly match the long axis of each waste site throughout the entire the simulation time period, this construct is used to represent a worst case condition. Under this construct, not only does the aquifer flow along the long dimension of the waste site, the well that represents the point of calculation is located immediately downgradient from the site.

The RESRAD code Version 6.3, has met the Software QA requirement in HNF-PRO-309 (*Computer Software Management*) as documented in HNF-33271 (*RESRAD Version 6.3 Requirements and Management Plan*).

The hydraulic parameters for the saturated zone were obtained from several reports by George Last. The remaining hydraulic parameters for the saturated zone are the same as those for the lowest layer of the vadose zone.

The field capacities in the saturated zone are equated with the specific yields listed in Table 5.2 of the *Groundwater Data Package for Hanford Assessments* (PNNL-14753). The 216-A-29 Ditch and 216-B-63 Trench field capacities are the numbers for Unit 1 and the 216-S-10 Ditch and Pond numbers come from Unit 5.

The porosity and hydraulic gradient of the saturated zone for the 216-A-29 Ditch and 216-B-63 Trench are from the *Hanford Site Groundwater Monitoring for Fiscal Year 1998 (*PNNL-12086). The saturated zone porosity and hydraulic gradient for 216-S-10 Ditch and Pond is from the *Post-Closure RCRA Groundwater Monitoring Plan for the 216-S-10 Pond and Ditch* (PNNL-15731).

E5.0 OTHER INPUT PARAMETERS FOR RESRAD

Parameters selected to represent conditions at the Hanford Site include the annual average relative humidity (54.6%), the average wind speed (3.40 m/s), and the average annual precipitation (0.177 m/y). These numbers come from PNNL-15160, *Hanford Site Climatological Summary for 2004 with Historical Data*. The monthly average relative humidities were converted to an airborne mass concentration of water using the average monthly temperatures given in PNNL-15160. The average mass concentration of water for input to RESRAD is then 5.5 g/m^3.

The RESRAD surface erosion rate was set to 1×10^{-5} m/y. This erosion rate was selected to prevent any future erosion from the cover that is currently present over the representative

waste site. In addition, the irrigation rate is set to zero that crops are not irrigated above the waste site. Only natural precipitation drives contaminants into the groundwater.

Values used for recharge depend on the location on the Hanford Site and the likely ground cover as discussed in PNNL-14702. The values used in these calculations are from Table 4.15 of that reference. Owing to revegetation efforts after backfilling, the sites are expected to evolve to a young shrub-steppe plant community that is present over the entire period of simulation. Thus the annual recharge for 216-A-29 Ditch and 216-S-10 Ditch and Pond was chosen to be 0.8 cm/y and the annual recharge for the 216-B-63 Trench was chosen to be 0.3 cm/y.

The RESRAD input for recharge is carried out indirectly through the inputs for the amount of irrigation and precipitation as well as the runoff coefficient and evapotranspiration coefficient. The annual precipitation at the Hanford Site is 0.177 m/y. The runoff coefficient is set to zero so that all the precipitation soaks into the ground. The evapotranspiration coefficient was assigned values that would lead to the desired recharge rates (0.8 and 0.3 cm/y). The formula used by RESRAD is described in Appendix E to the RESRAD Version 6 User's Manualand is also shown below. Also shown are the two evapotranspiration coefficients.

$$\text{Infiltration} = (\text{irrigation} + \text{precipitation})(1 - \text{runoff})(1 - \text{evapotranspiration})$$

$$(\text{A-29 \& S-10}) = (0.0 + 17.7\,\text{cm/y})(1 - 0.0)(1 - 0.955) = 0.80\,\text{cm/y}$$

$$(\text{216-B-63}) = (0.0 + 17.7\,\text{cm/y})(1 - 0.0)(1 - 0.983) = 0.30\,\text{cm/y}$$

Note that the RI Report (DOE/RL-2004-17) used a precipitation rate of 0.16 cm/y with a runoff coefficient of 0.2 and an evapotranspiration of 0.91. With these inputs the annual water infiltration in the absence of irrigation was 1.15 cm/y for all of the 200-CS-1 waste sites. What impact does this have on the present analysis?

Other RESRAD input parameters that are common to all the waste sites are first the "water table drop rate" which is set to 1 x 10^{-4} m/y. With this input the depth of the groundwater changes little during the time period of interest. The second parameter is the "well pump intake depth" which is set to 4.6 m (15 ft) into the aquifer. The third parameter is the "well pumping rate" which is set to 90 m^3/y based on representative household use (*Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments*, HNF-SD-WM-TI-707). In RESRAD, the groundwater concentration is inversely related to the well pumping rate, so the default pumping rate (250 m^3/y) was reduced to represent a worst case scenario indicative of a well used for household needs rather than irrigation.

A final parameter used by RESRAD is the Kd value for each radionuclide. In the simple approach used here, the sandy soil types have one set of Kd values while a second set of Kd values is used for gravel dominated sediments. Since significant gravel content is known to decrease Kd values, the gravel Kd numbers are generally reduced by a factor of 10. This represents a 90% reduction in sorption sites, which most likely underestimates the Kd values, since most gravel dominated sediments generally range from about 22 to 80% gravel. RESRAD allows a different Kd value for each layer of soil and for each radiological

contaminant. Note that RESRAD has default values that are inserted automatically when new soil concentrations are added. The user needs to verify and possibly re-enter site specific values for Kd whenever radionuclides are added or deleted from the contaminated soil layer.

The distribution coefficients assumed for radionuclides in the present report are shown in Table E-15. The numbers shown in the table are the best estimate values from PNNL-14702. For gravel, these Kd values were reduced as described in PNNL-14702 Section 4.3.

The Kd values for lead (Pb), nickel (Ni), and protactinium (Pa) were derived by G. Last and K. Cantrell using soil data from *Hanford Contaminant Distribution Coefficient Database and Users Guide* (PNNL-13895) and "The Apsorption of Thorium and Protactinium onto Different Particle Types: Experimental Findings" (Geibert and Usbeck [2004]). They are considered best estimate values.

E6.0 HUMAN HEALTH EXPOSURE SCENARIOS

The waste sites located within the Central Plateau are currently under the control of the U.S. Department of Energy (DOE). Once the sites are acceptably remediated the land may be available for limited public use. Based on these assumptions, the current and reasonably anticipated future land use within the Central Plateau is industrial/commercial use. This restricted land use assumes that an industrial worker is working directly over the waste site for their entire career duration of 25 years. Because the individual's residence is some distance from the waste, the exposure time is limited to 40 hours per week and 50 weeks per year. Complete exposure pathways are based on direct contact with the waste site and includes direct exposure to gamma radiation, incidental soil ingestion, and inhalation of dust particulates. The doses that are calculated are for the year with the largest dose, while the cancer risks are for the entire 25 years of exposure.

In the unlikely event that the waste disposal sites become available for unrestricted public use, there may be individuals residing directly over the contaminated soil. Under this scenario, the individual is assumed to drill a well through the waste to obtain water for domestic uses. The well construction is plausible in the 200 Areas due to the distance between the waste site and the nearest surface water. The water obtained from the well is used for drinking, cooking, showering, irrigating a garden and a pasture that supports a cow. The garden is typical of ones found near the Hanford Site. Such gardens produce vegetables and fruits, but no grains. The cow produces both milk and beef. It is slaughtered periodically and another cow obtained to ensure a continuous supply of locally produced milk. The exposure duration for this scenario is 30 years. The doses that are calculated are for the year with the largest dose, while the cancer risks are for the entire 30 years of exposure.

The annual radiation doses and ELCRs are calculated for various time periods after site closure. For comparative purposes, radiation dose and risk estimates are discussed relative to the following exposure times.

- 0 y represents current waste site conditions
- 50 y is the estimated time that DOE will have an on-site presence

- 150 y is the estimated time that institution controls are assumed to be effective
- 500 y is the estimated time that passive institution controls are assumed to be effective
- 1000 y is the estimated time frame in which peak radiation dose and risk estimates should be within
- The year in which the target radiation dose limit of 15 mrem/y is achieved.

In this report site closure is assumed to have occurred when the samples were analyzed, i.e., no radioactive decay of the sample results prior to closure is included in the calculations.

E6.1 INDUSTRIAL EXPOSURE SCENARIO DETAILS

Under an industrial/commercial land use scenario, the site owner permits limited use of the land directly over the waste sites. Any facilities constructed would be single-story and have footing depths no more than 0.6 m (2 feet). Because all of the 200-CS-1 sites have a cover depth at least 0.6 m (2 feet thick, there is no intrusion into the contaminated soil layer near the surface.

The worker is exposed to the buried waste daily during a normal work year (250 days per year) for a total of 25 years. Exposure pathways include (1) direct exposure to penetrating photon radiation, (2) inhalation of dust particulates that become airborne, and (3) incidental ingestion of trace amounts of soil due to unintentional acts such as licking the lips. Because the buried waste is not brought to the surface, the only complete exposure pathway is from direct exposure to gamma radiation that penetrates the cover soil. The internal pathways (inhalation and ingestion) are considered incomplete and result in zero dose. Nevertheless, the internal pathways will be discussed here to completely define the RESRAD inputs.

The various parameters to represent the exposure pathways were initially provided in the *Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual* (EPA-540/R92/003), hereinafter referred to as RAGS-B. These have been updated in the *Exposure Factors Handbook* (EPA/600/P-95/002Fa) and the *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA-540/R-00/006), hereinafter referred to as SSG-R.

External Exposure – Industrial Scenario

Direct exposure to penetrating photon radiation occurs because the individual is located on or near the contaminated soil. The unit dose factors used in the calculation of external dose were derived for slabs of various thicknesses, but very large in horizontal extent. For this reason, the doses are adjusted downward to correct for smaller areas. In addition, the presence of cover soil reduces the dose rate and thus the annual dose. RESRAD carries out both of these adjustments.

External exposures must also be reduced to account for occupancy at the work location. The various occupancy parameters are listed in Table E-16. The time at work is 40 hours per week for 250 days per year, or 2000 hours per year. Since there are 8760 hours in a year, there must be a factor (2000 h)/(8760 h) = 0.2283. Note that the annual exposure time (8760

h/y) is hard-coded into RESRAD. To include the occupancy factor, it must be incorporated into other inputs.

There is an external dose rate reduction factor in RESRAD to account for reduced exposure during the time spent indoors as well as the occupancy time. It has three parts, the "outdoor time fraction", the "indoor time fraction", and the "external gamma shielding factor". The occupancy factor will be included with the indoor and outdoor time fractions.

The generic worker is located indoors 3 minutes for every minute spent outdoors. This is intended to represent that indoor tasks are more likely than outdoor tasks in an occupational setting. Thus during the time at work, the indoor time fraction is 75% while the outdoor time fraction is 25%. For input to RESRAD, the indoor time fraction is 0.2283*0.75=0.1712 while the outdoor time fraction is 0.2283*0.25=0.0571. The sum of these two is the desired occupancy factor, 0.2283. The ratio of indoor to outdoor dose rates (i.e., the "external gamma shielding factor") is 0.4 as discussed in the SSG-R (page 2-18).

In the 200-CS-1 RI Report (DOE/RL-2004-17), a different parameter set was used in the industrial scenario. The indoor shielding factor for gamma exposure was 0.8. Also, the indoor time fraction was 0.137, while the outdoor time fraction was 0.091. The time fractions are 60% indoors and 40% outdoors. With these inputs RESRAD calculates the effective annual exposure time as 1760 h/y as shown below and in Table E-16.

Effective External Exposure Time = (8760 h/y) (0.091 + 0.137*0.8) = 1760 h/y

Parameters used to represent external exposures in the industrial scenario are listed in Table E-16. If the present risk assessment were to use the same 60-40 split as in the RI Report (DOE/RL-2004-17), the effective annual external exposure time would increase from 1100 h/y to 1280 h/y, or 16%. The main difference with the RI Report (DOE/RL-2004-17) is the indoor shielding factor. The RI Report (DOE/RL-2004-17) used the earlier value from RAGS-B, while the present risk assessment uses the current EPA recommendation found in SSG-R.

Inhalation Exposure – Industrial Scenario

The individual is assumed to inhale 10 m^3 of air each day during the 8 hours at work. Over the course of a work year (250 d) he would inhale 2500 m^3. For comparison, the *Exposure Factors Handbook* (EPA/600/P-95/002Fa) recommends a total daily inhalation rate of 15.2 m^3/d for the average adult male, and 1.3 m^3/h for the outdoor worker. In an 8-hour working day the average outdoor worker would inhale 10.4 m^3. Thus the inhalation rate while at work of 10 m^3/d is consistent with EPA recommendations.

The calculation of inhalation dose also requires an estimate for the mass of contaminated soil that is inhaled during the year. RESRAD calculates this using the surface area of the waste site, the average wind speed, the average airborne mass loading, the annual inhalation rate, and a reduction factor based on indoor and outdoor time fractions. The reduction factor is also known as an occupancy factor. It takes into account lower air concentrations indoors. The various parameters that contribute to the final amount are listed in Table E-17. The total mass inhaled is listed in the last row of this table.

The average dust loading of the air during the day has used the RESRAD default, 100 $\mu g/m^3$. This is the respirable portion of the dust and represents a high value. The annual average dust loading near the Hanford Site is about 20 $\mu g/m^3$, based on air quality information available from the EPA AirData website (http://www.epa.gov/air/data/) for Benton County. This more realistic value will be used as the average contaminated dust loading of the air during the work day. The total dust loading is likely larger, but the total dust loading includes dust from uncontaminated sources nearby.

The occupancy factor has three parts, the "outdoor time fraction", the "indoor time fraction", and the "indoor dust filtration factor". As with the external dose, it will be assumed that the generic worker is located indoors three minutes for every minute spent outdoors. Thus the indoor time fraction is 75% while the outdoor time fraction is 25%. The airborne dust concentration is lower indoors largely due to filtration by the building ventilation system. The ratio of indoor to outdoor air concentrations (i.e., the "indoor dust filtration factor") is 0.4 as discussed in the SSG-R. The occupancy factor is calculated as shown below.

$$\text{Occupancy Factor} = (\text{Outdoor Fraction}) + (\text{Indoor Fraction})*(\text{Filtration})$$

The actual occupancy factor computed by RESRAD can be found in the detailed report (DETAILED.REP) by searching for "FO2". The values found in the RESRAD output are shown in Table E-17.

It happens that RESRAD uses the same indoor and outdoor time fractions for both the external dose calculation and the inhalation dose calculation. Thus, the time fractions used for the external dose must also be used here for inhalation dose. These time fractions were reduced by the factor of 0.2283 to adjust the external dose calculation. To account for this adjustment, the inhalation rate was increased to (2500 m^3/y)/(0.2283) = 10,950 m^3/y.

One additional factor is used in RESRAD to adjust the air concentration based on the average wind speed and the surface area of the contamination is called the "Area Factor". The values calculated by RESRAD are available in the detailed report (DETAILED.REP). They can be found by searching for "FA2". The values found in the RESRAD output are shown in Table E-17.

With these inputs the RESRAD output can be examined to find the mass of contaminated soil inhaled during a year. This is found in the DETAILED.REP output file. The line with the total inhaled mass can be found by searching for "FO2 * F12". With the above inputs, the result in the output file is stated as, "FA2 * FO2 * F12 * ASR2: 2.9567E-03 g/yr", or 2.96 mg/y. The terms in the formula are listed below.

"FA2" is the area factor
"FO2" is the occupancy factor
"F12" is the volume of air inhaled annually
"ASR2" is the mass loading of the air inhaled.

As a check on how RESRAD works, the inhaled mass was also calculated using an inhalation

rate of 2500 m^3/y with indoor and outdoor time fractions of 0.75 and 0.25. The result in the output file was stated as, "FA2 * FO2 * F12 * ASR2: 2.9565E-03 g/yr", or 2.96 mg/y. The area factor and mass loading are unchanged. The changes to occupancy and volume exactly offset one another.

In contrast to the method used by RESRAD, EPA uses a particulate emission factor (PEF) to represent the air concentrations. The PEF is the inverse of the airborne concentration of contaminated soil. In RAGS-B (chapter 4 pg 39), the default PEF was 4.63×10^9 m^3/kg. This number can be fine-tuned using local wind data and the actual waste site area. The method for calculating the PEF was updated in the SSG-R (pg 2-13 to 2-17) to yield a new default value of 1.32×10^9 m^3/kg. The SSG-R value for PEF includes a vegetation cover factor of 50%. This factor will be eliminated to account for the reduced vegetative ground cover at the Hanford Site. Note that reduced ground cover means more airborne dust. Thus, the default PEF becomes 6.60×10^8 m^3/kg.

Using this adjusted PEF, the total mass of contaminated soil that is inhaled in a year is calculated as shown below. The additional parameters shown in the numerator adjust the soil inhalation to account for building filtration as discussed in the paragraphs above for RESRAD.

$$\text{Waste Soil Inhaled} = \frac{\left(2500\ \text{m}^3/\text{y}\right)\left(0.25 + 0.75 * 0.4\right)}{\left(6.60\text{x}10^8\ \text{m}^3/\text{kg}\right)\left(1\text{x}10^{-6}\ \text{kg/mg}\right)} = 2.08\ \text{mg/y}$$

In the 200-CS-1 RI Report (DOE/RL-2004-17) a different parameter set was used in the industrial scenario. The dust loading was 1×10^{-4} g/m^3 and the annual volume of air inhaled was 7300 m^3. Also, the indoor time fraction was 0.137, while the outdoor time fraction was 0.091. With these inputs RESRAD calculates the total mass inhaled as 11.6 mg/y as shown in Table E-17. The present method better represents the EPA method.

Note that exact agreement will not be pursued because of other model differences. For example, the horizontal area of the waste sites is different. RESRAD corrects for this using a different method than EPA. The approximate agreement shown in Table E-17 is considered adequate.

<u>Incidental Soil Ingestion Exposure – Industrial Scenario</u>

Trace amounts of soil are ingested as a result of unintentional actions such as licking the lips. The EPA RAGS B value of 50 mg/d was selected as the incidental ingestion rate for the industrial worker. The total annual ingestion is (250 d)(50 mg/d) = 12,500 mg/y or 12.5 g/y. This value will be used as input to RESRAD. For comparison, the 200-CS-1 RI uses a contaminated soil ingestion rate of 36.5 g/y for the Industrial scenario, which is based on 100 mg/d for 365 days per year.

E6.2 RESRAD INPUTS FOR THE INDUSTRIAL SCENARIO

All of the input parameters that define the industrial/commercial scenario in RESRAD are

listed in Table E-18. The order of presentation is that used when entering input values to RESRAD Version 6.30. The soil concentration and location parameters are unique to each site and were shown in previous tables.

Note that the Industrial scenario includes no drinking water pathways. The worker is present onsite during the work week, but any water is brought in from elsewhere. This is part of the limited use of the Hanford Site that is assumed to occur relatively soon after site closure.

For the industrial scenario, the surface mixing layer was entered as 0.3 m. Any contaminated soil within 0.3 m of the surface is evenly mixed in a layer this thick. Thus as the uncontaminated cover erodes and becomes thinner than 0.3 m, the surface layer acquires contamination. Owing to the very small surface erosion rate assumed ($1x10^{-5}$ m/y), this thickness is unimportant.

E7.0 RESRAD DOSE AND RISK RESULTS FOR THE INDUSTRIAL SCENARIO

For the purposes of this risk assessment, the radiation dose limit for the industrial exposure scenario is 15 mrem/y (10 CFR 835, "Occupational Radiation Protection"). This dose limit is developed for members of the public who are unknowingly exposed to radiation and is approximately equivalent to an ELCR of 1×10^{-4}.

The EPA generally considers action to be warranted at a site when cancer risks exceed 1×10^{-4} based on a reasonable maximum exposure scenario. Action generally is not required for risks falling within 1×10^{-4} to 1×10^{-6}; however, this is judged on a case-by-case basis. Risks less than 1×10^{-6} generally are not of concern to regulatory agencies (OSWER Directive 9285.6-03).

Since each waste site currently has a clean soil cover and minimal cover erosion is assumed, the resulting doses and risk estimates are small. The industrial worker is not directly exposed to the contaminated soil beneath the cover, therefore the inhalation and ingestion exposure routes are incomplete resulting in doses and risks that are zero. The external dose is small due to shielding by the soil cover. The annual radiation doses and ELCR for each year evaluated are summarized in Table E-19 for each waste site. The total radiation dose for each representative waste site evaluated does not exceed the target radiation dose level of 15 mrem/y at any of the exposure times evaluated. Similarly, the ELCR for each representative waste site does not exceed 1.0×10^{-6} at any of the exposure times evaluated.

Doses and risks are calculated for a hypothetical scenario in which the soil cover is removed from each waste site. This exposes the contaminated soil under the covers. In this situation, the same commercial/industrial exposure assumptions will be used. Note that even with the covers removed, the industrial scenario does not include a drinking water well to groundwater.

The annual doses and lifetime excess cancer risks from RESRAD are summarized in Table E-20. Note that both ends of the 216-A-29 Ditch have the essentially the same doses and cancer

risks. They are the same because the soil concentrations are the same. There is a small difference in soil density, but this has little effect.

E8.0 RESRAD GROUNDWATER CONCENTRATIONS

Each contaminated soil layer was run as a separate case in RESRAD. Although RESRAD allows a maximum simulation time of 100,000 y, the maximum time period was limited to 10,000 y. The principle reason for this limit is the uncertainty associated with future climate. Global warming and cooling cycles will alter the annual recharge. Return of glaciers could lead to a repeat of the glacial lake outburst floods responsible for the peculiar sediments at the Hanford Site.

Extra RESRAD cases were run to find the maximum groundwater concentration during the first 10,000 y. Peak concentrations for those contaminants that reached groundwater in 10,000 y are listed in Table E-21. Contaminants that did not reach groundwater and small contributions from progeny nuclides such as U-233 that are produced by the decay of the parent are not shown.

216-A-29 Ditch.

The graphical output for the H-3 groundwater concentrations at the head of the 216-A-29 Ditch is shown in Figure E-6. Tritium is the only contaminant predicted to reach groundwater based on soil properties observed near the head of the 216-A-29 Ditch. Tritium was only analyzed in the B8826 borehole with the highest concentrations measured from 79.2 to 79.9 m (260 to 262 ft) bgs (7.05 pCi/g) and from 82.9 to 83.5 m (272 to 274 ft) bgs (1.63 pCi/g). The peak tritium concentration of 1,300 pCi/L is predicted to reach groundwater in 20 years (A.D. 2027) and is below the federal maximum contaminant level (MCL) of 20,000 pCi/L.

The graphical output for U-234 and U-238 groundwater concentrations are shown in Figures E-7 through E-8, respectively. The U-234 and U-238 isotopes are predicted to reach groundwater in 5,174 years based on soil properties near the outlet of the ditch while the isotopes are not predicted to reach groundwater using the soil properties at the head of the ditch. Since the EPA drinking water standard (MCL) for uranium is given as a mass concentration, the activity concentrations of the main isotopes of uranium were converted from activity to mass using the specific activities listed in Table E-3. As shown, the total uranium concentration of 1,129 µg/L is considerably above the federal drinking water MCL of 30 µg/L.

U-234 was detected in all four samples with concentrations ranging from 0.33 pCi/g to 2.3 pCi/g. The maximum U-234 concentration of 2.3 pCi/g was measured at test pit AD-2 from 7.5 to 8.5 ft bgs. All remaining U-234 concentrations were less than the 90th percentile Hanford Site background level of 1.1 pCi/g. Although U-234 is present at one location above the 90th percentile background level, it contributes an insignificant amount to the total uranium concentrations predicted to reach groundwater.

U-235 was detected in three of 28 samples with concentrations ranging from 0.061 pCi/g to 0.44 pCi/g. The maximum U-235 concentration of 0.44 pCi/g was measured at test pit AD-1

from1.2 to 1.5 m (4 to 5 ft) bgs. All remaining concentrations were less than the 90th percentile Hanford Site background level of 0.11 pCi/g, so is not considered a contaminant at the outlet of the Ditch.

U-238 was detected in six of 36 samples with concentrations ranging from 0.5 pCi/g to 1.8 pCi/g. The maximum U-238 concentration of 1.8 pCi/g was measured at test pit AD-2 from 2.3 to 2.6 m (7.5 to 8.5 ft) bgs. All remaining U-238 concentrations were less than the 90th percentile Hanford Site background level of 1.1 pCi/g.

No other contaminants measured at the 216-A-29 Ditch were predicted to reach groundwater within the 10,000 year time period.

216-B-63 Trench.

The graphical output for Tc-99 groundwater concentrations are shown in Figure E-9. Tc-99 is the only contaminant predicted to reach groundwater at the 216-B-63 Trench. The peak Tc-99 concentration of 185 pCi/L is predicted to reach groundwater in 2,273 years (A.D. 4280) and is below the federal MCL of 900 pCi/L. Tc-99 was detected in only one of 25 samples analyzed. Tc-99 was detected at a concentration of 0.41 pCi/g in borehole B8827 from 5.3 to 5.8 m (17.5 to 19 feet) bgs.

No other contaminants measured at the 216-B-63 Trench were predicted to reach groundwater within the 10,000 year time period.

216-S-10 Ditch.

No contaminants measured at the 216-S-10 ditch were predicted to reach groundwater within the 10,000 year time period.

216-S-10 Pond.

The graphical output for the C-14 groundwater concentration near the 216-S-10 Pond is shown in Figure E-10. C-14 is the only contaminant predicted to reach groundwater at the 216-S-10 Pond. The peak C-14 concentration of 8,260 pCi/L is predicted to reach groundwater in 1,323 years (A.D. 3330). As shown in Table E-18, the peak concentration of 8,260 pCi/L is above the federal MCL of 2,000 pCi/L. C-14 was only detected at test pit SP-2 at a concentration of 12.2 pCi/g from 2 to 2.3 (6.5 to 7.5 feet) bgs.

E9.0 CONCLUSIONS

There are only a handful of radionuclides that may exceed drinking water standards according to the simple (and conservative) models used in this analysis. Table E-22 shows the summary for radionuclides. Only the uranium isotopes at 216-A-29 Ditch and the C-14 at the 216-S-10 Pond exceed the drinking water limits within 10,000 y.

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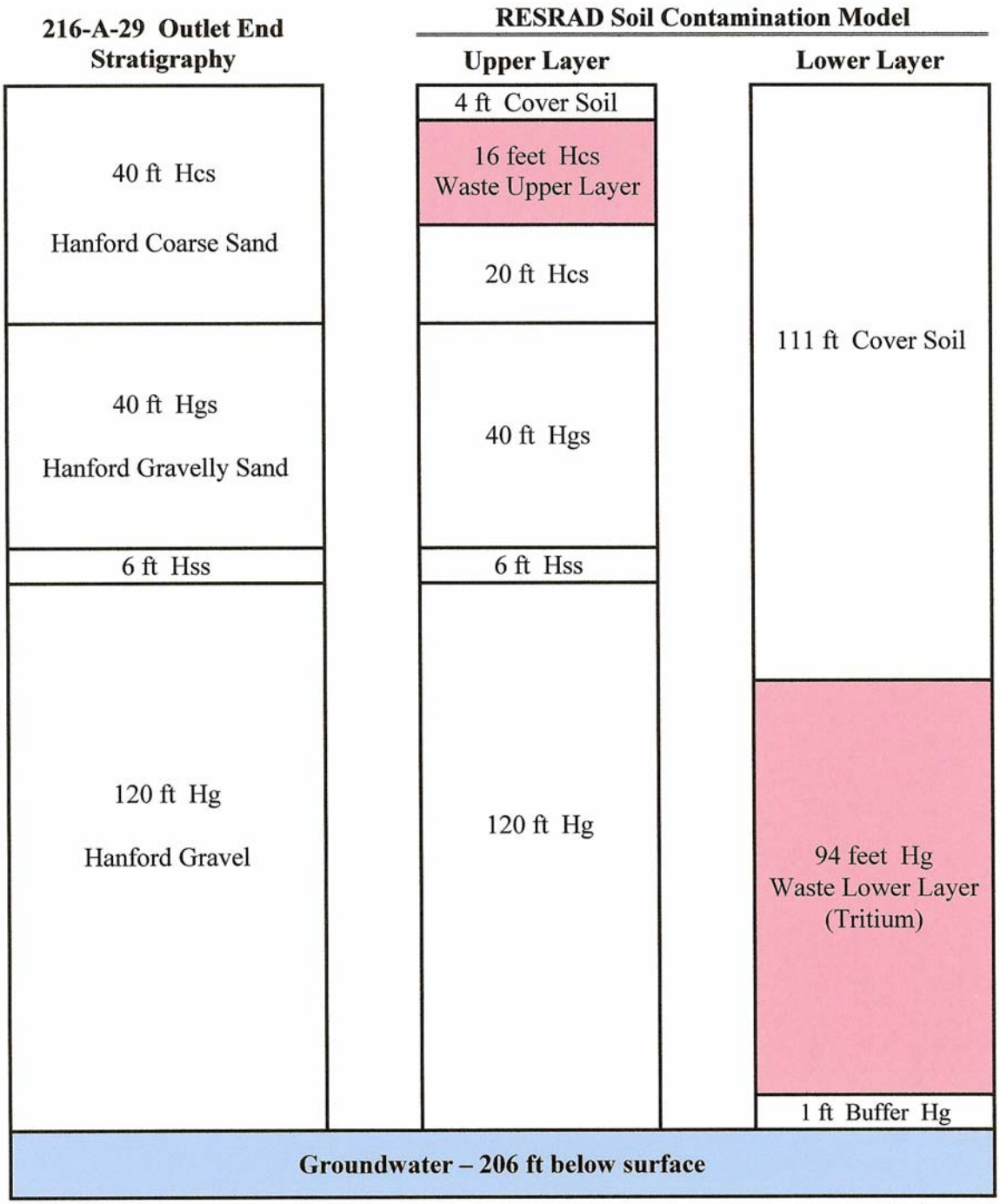
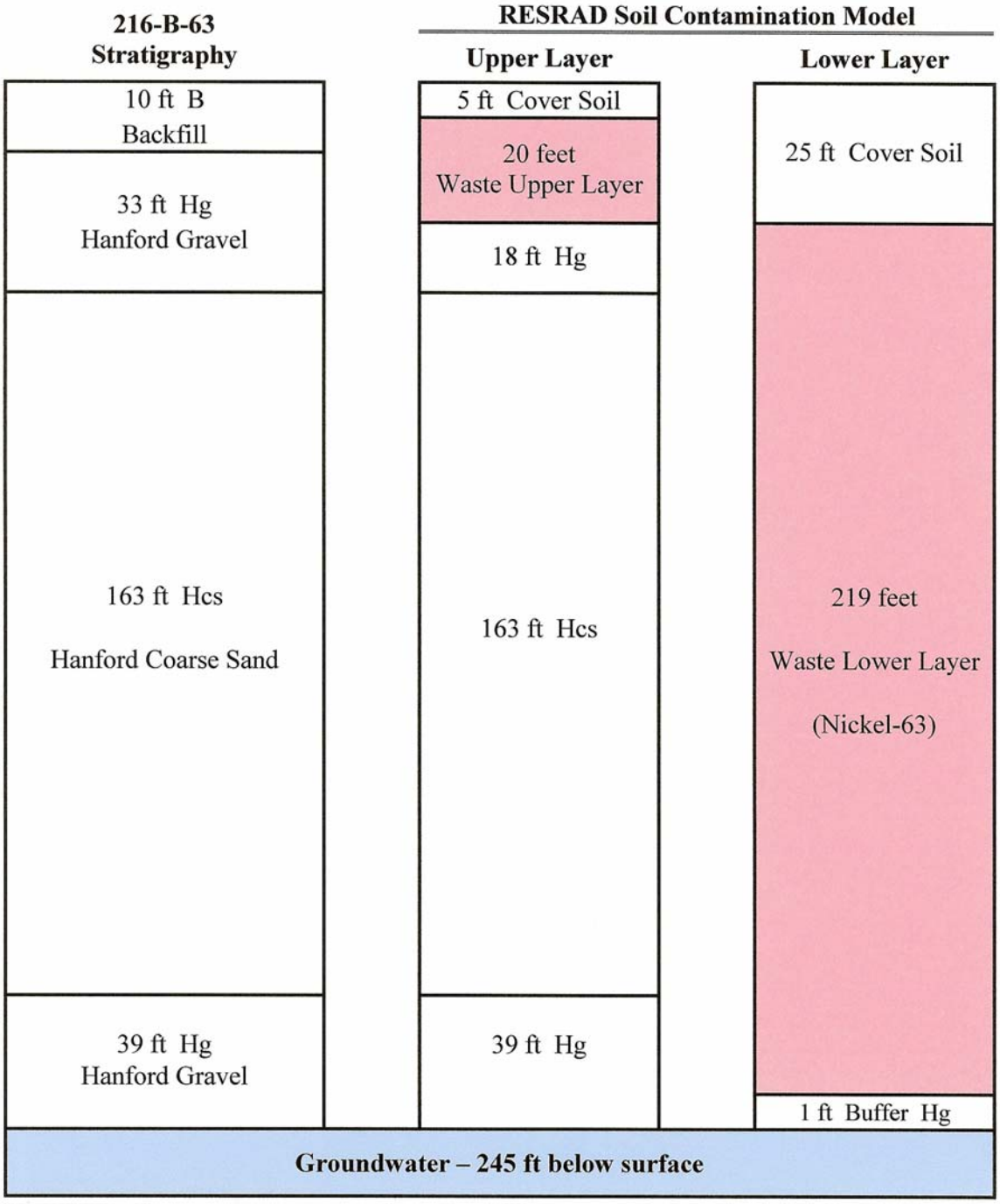
Figure E-1. RESRAD Soil Contamination Model - 216-A-29 Ditch - Outlet End.



At 216-A-29 ditch (outlet end) the only mixture for RESRAD was the cover over the lower waste layer. The mixture consists of 40 ft Hcs, 40 ft Hgs, 6 ft Hss, and 25 ft Hg.

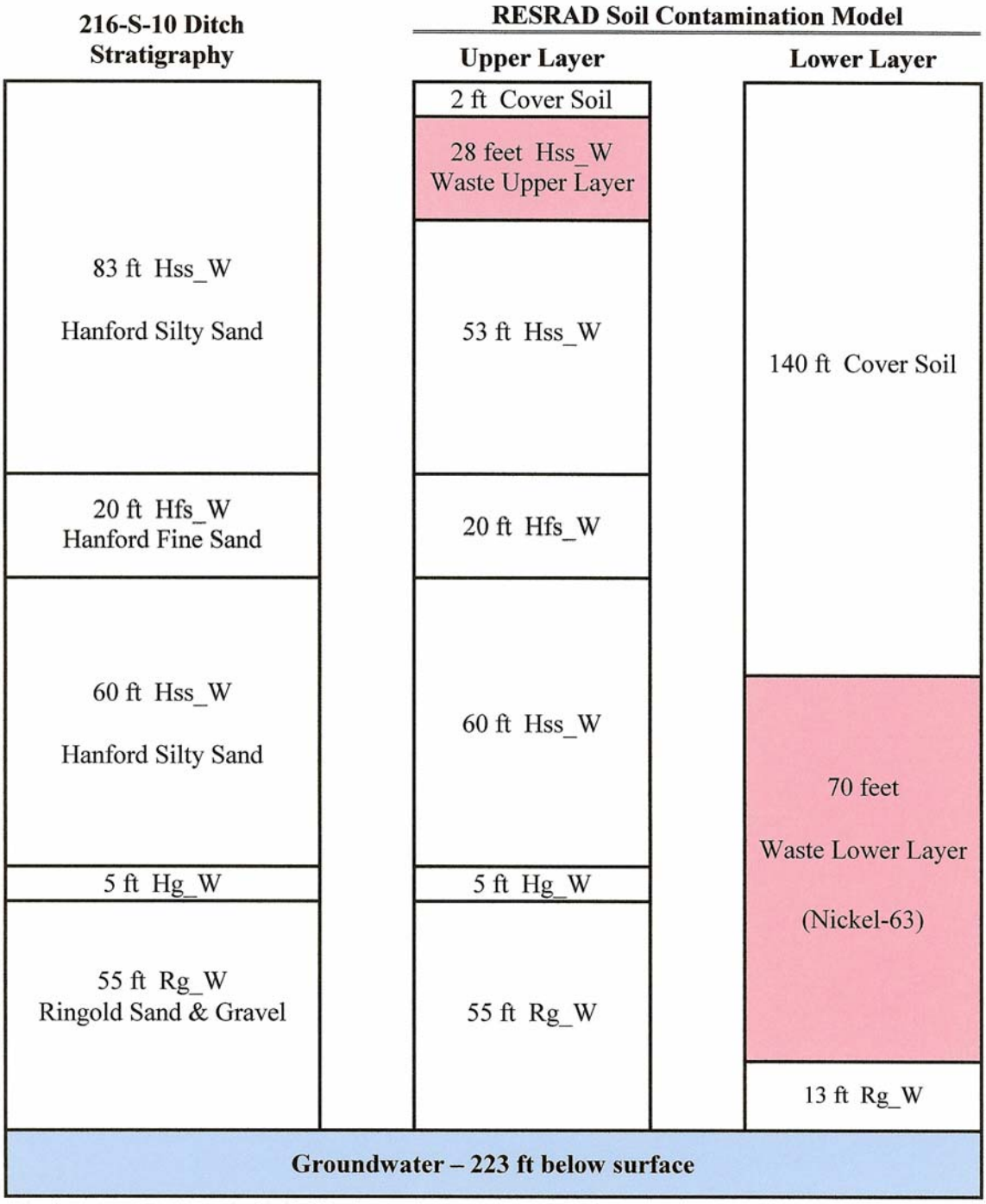
Figure E-2. RESRAD Soil Contamination Model - 216-B-63 Trench.



For input to RESRAD the following mixtures are used for 216-B-63 Trench:

- The upper waste layer is a mixture of 5 ft backfill (B) and 15 ft Hanford gravel (Hg).
- The lower layer of waste is a mixture of 56 ft Hg and 163 ft Hcs.
- The cover above the lower layer is a mixture of 10 ft backfill (B) and 15 ft Hg.

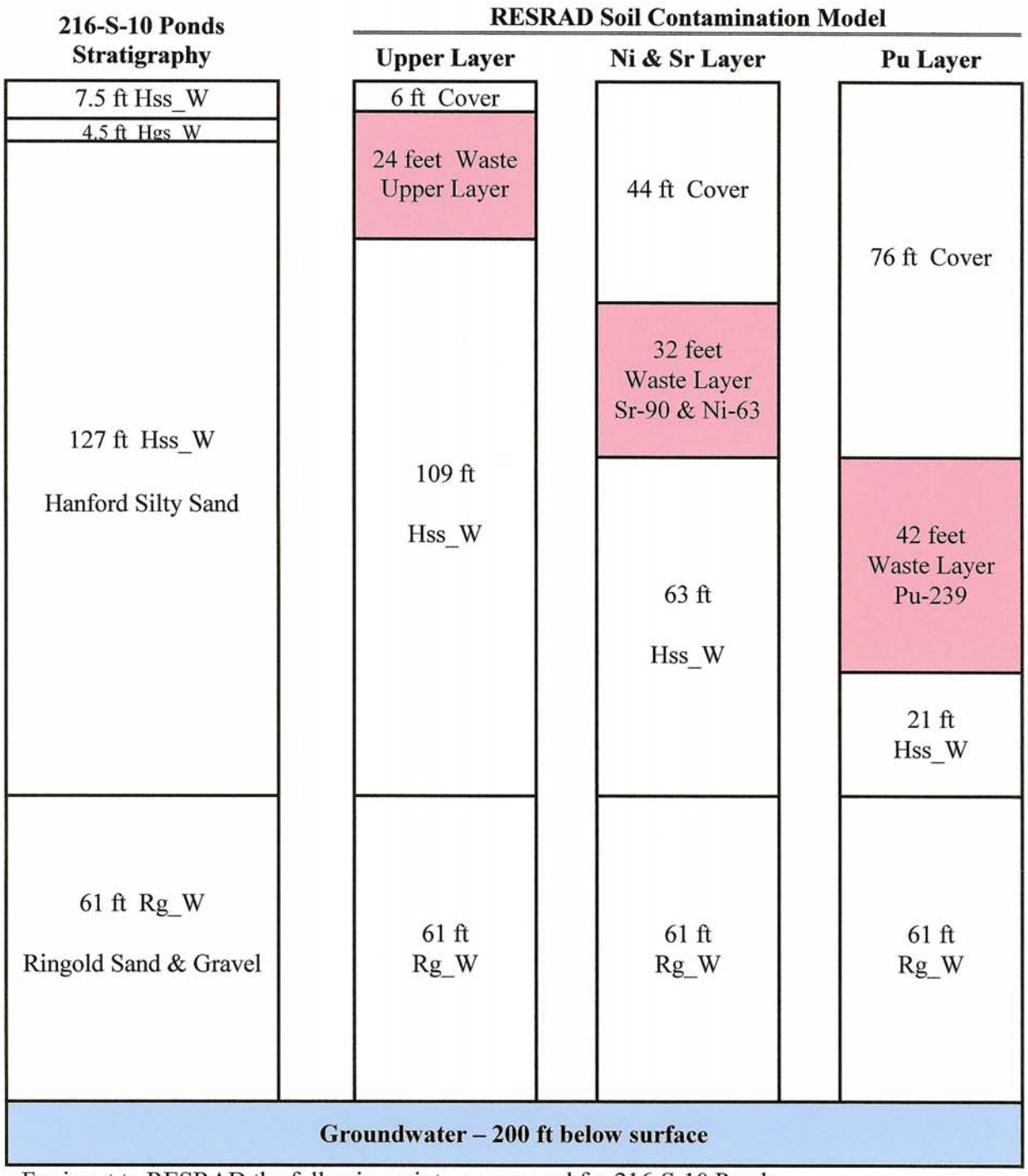
Figure E-3. RESRAD Soil Contamination Model - 216-S-10 Ditch.



For input to RESRAD the following mixtures are used for 216-S-10 Ditch:

- The lower layer of waste is a mixture of 23 ft Hss_W, 5 ft Hg_W, and 42 ft Rg_W.
- The cover above the lower layer is a mixture of 120 ft Hss_W and 20 ft Hfs_W.

Figure E-4. RESRAD Soil Contamination Model - 216-S-10 Pond.



For input to RESRAD the following mixtures are used for 216-S-10 Ponds:

- The upper layer of waste is a mixture of 19.5 ft Hss_W and 4.5 ft Hgs_W.
- The cover above the Ni & Sr waste layer is a mixture of 39.5 ft Hss_W and 4.5 ft Hgs_W.
- The cover above the Pu waste layer is a mixture of 71.5 ft Hss_W and 4.5 ft Hgs_W.

Figure E-5. H-3 Concentrations in Groundwater from Head of 216-A-29 Ditch.

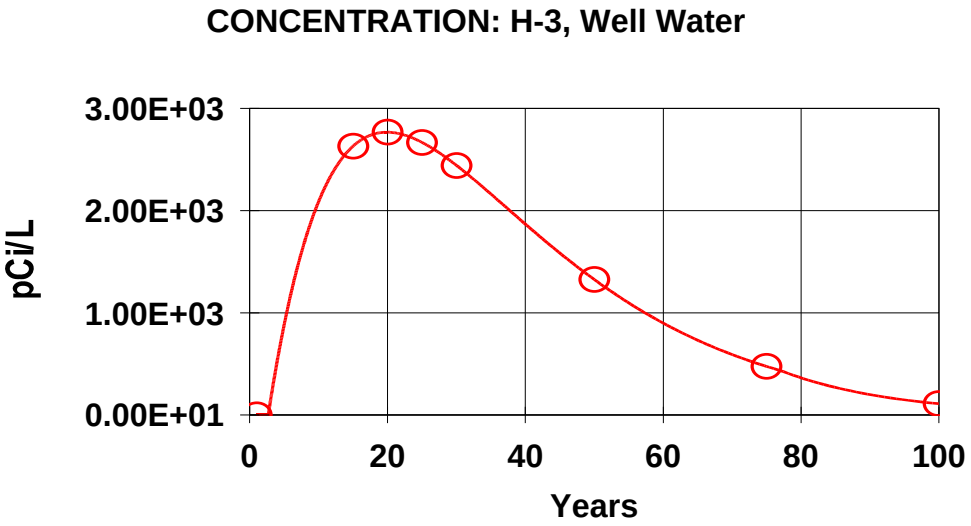


Figure E-6. U-234 Concentrations in Groundwater from Outlet of 216-A-29 Ditch.

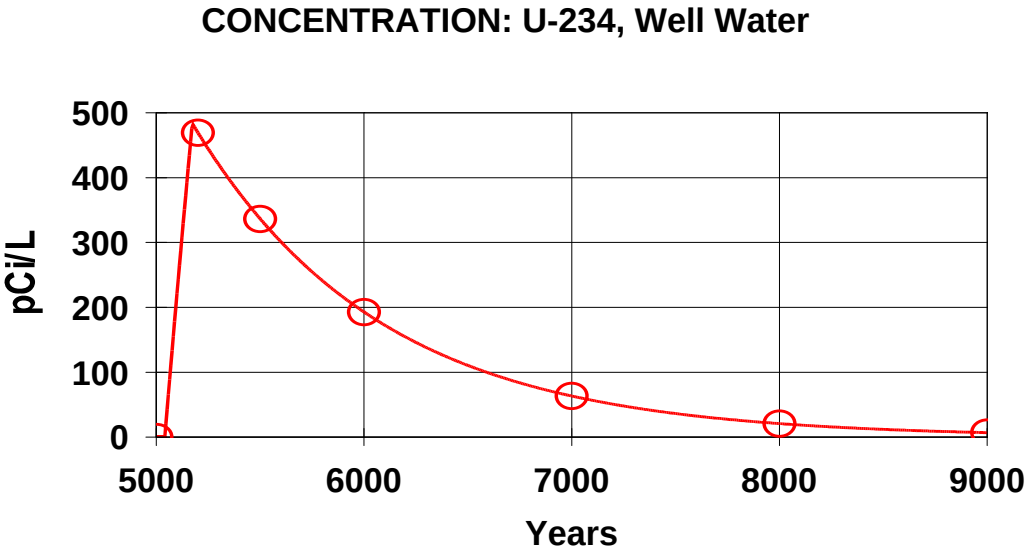


Figure E-7. U-238 Concentrations in Groundwater from Outlet of 216-A-29 Ditch.

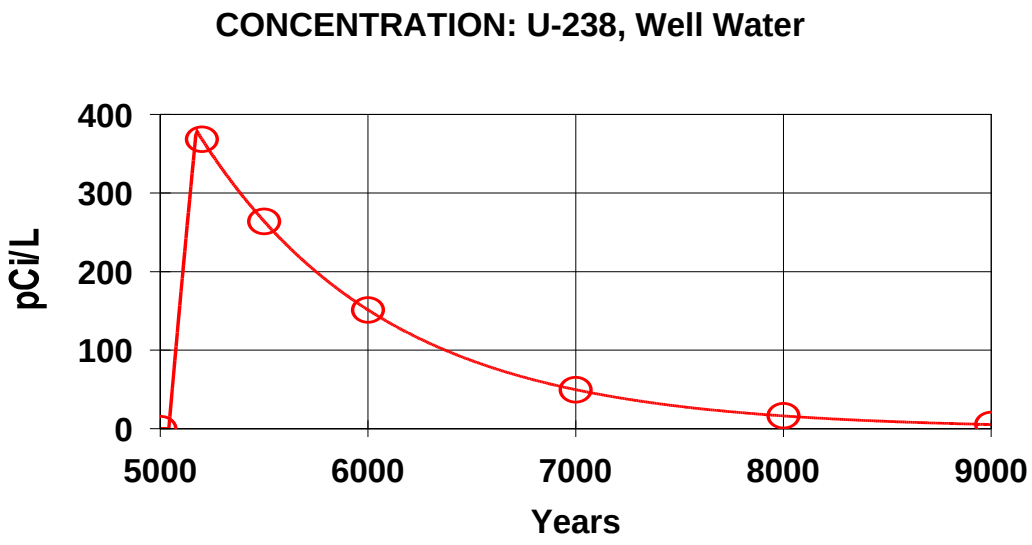


Figure E-8. Tc-99 Concentrations in Groundwater from 216-B-63 Trench.

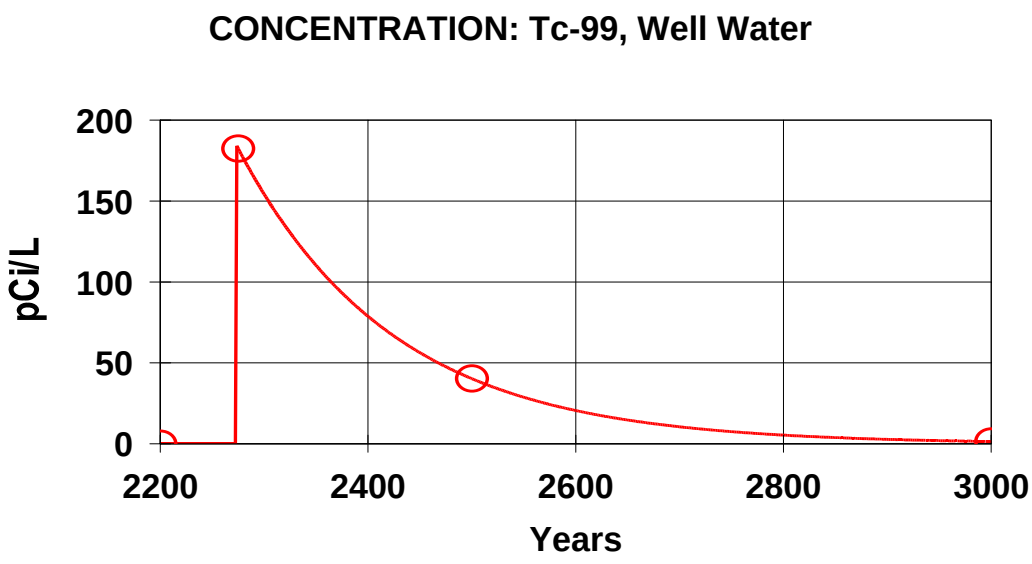


Figure E-9. C-14 Concentrations in Groundwater from 216-S-10 Pond.

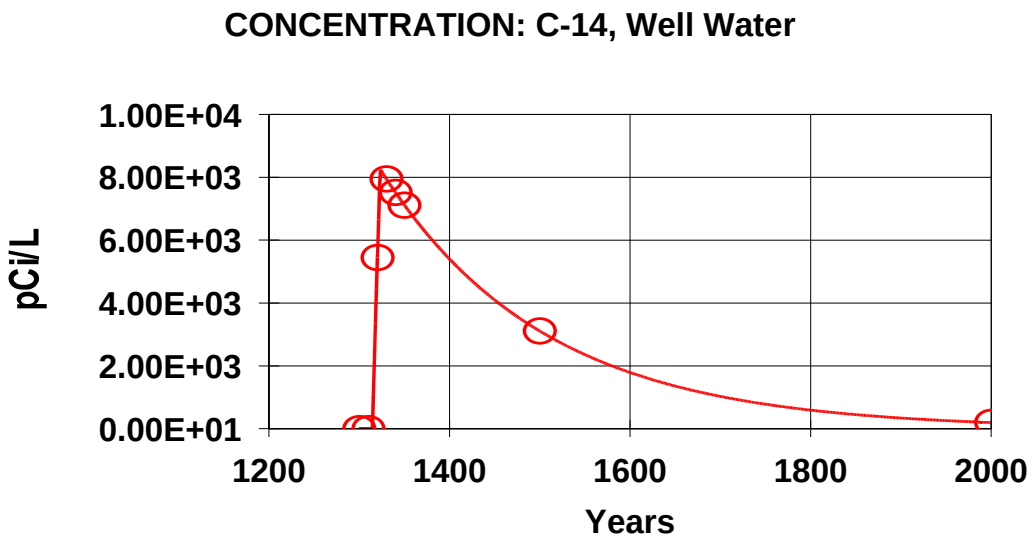


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Table E-1. Waste Site Dimensions and Aquifer Depth.

Parameter	216-A-29 Ditch	216-B-63 Trench	216-S-10 Ditch	216-S-10 Pond	216-S-11 Pond
Contaminated length	4000 ft (1220 m)	1400 ft (427 m)	2250 ft (686 m)	1040 ft (317 m)	500 ft (152 m)
Contaminated width	6 ft (1.83 m)	4 ft (1.22 m)	4 ft (1.22 m)	85 ft (25.9 m)	200 ft (61.0 m)
Horizontal area	0.55 acre (2230 m^2)	0.13 acre (520 m^2)	0.21 acre (836 m^2)	2.03 acre (8210 m^2)	2.3 acre (9290 m^2)
Depth to groundwater	270.2 ft (82.4 m)	245 ft (74.7 m)	223 ft (68.0 m)	200.5 ft (61.1 m)	200.5 ft (61.1 m)

Notes:

- 216-A-29 Ditch was meandering ditch carrying water from the 284-E powerhouse and later PUREX. Some water entered the soil column, but most of the water reached the 216-B-3 Pond. It was backfilled in 1991.
- 216-B-63 Trench was constructed to accept B-Plant water. It was never connected to the B-Pond system and was backfilled in 1994. Known to have overflowed into or received overflow from adjacent ditches.
- 216-S-10 Ditch was constructed to accept water from REDOX facilities. It drained into the 216-S-10 Pond. In 1984 the pond and the southern two-thirds of the ditch was backfilled using material dredged from the northern third. Clean cover soil was added. The northern 2/3 of 216-S-10 Ditch is still a ditch.
- 216-S-11 Pond was constructed to accept overflow from 216-S-10 Pond. It was backfilled in stages before the 216-S-10 Pond was backfilled.

Table E-2. Background Soil Concentrations.

Radionuclide	Half-life	Soil Concentration, pCi/g		
		Minimum	**Maximum**	**Lognormal 50th percentile**
K-40	1.265E+09 y	9.29	19.7	12.8
U-238 and its long half-life progeny are shown below. Short half-life progeny include Th-234, Pa-234, Pa-234, Rn-222, Po-218, Pb-214, Bi-214, and Po-214				
U-238	4.468E+09 y	0.354	1.21	0.733
U-234	245,500 y	0.399	1.51	0.762
Th-230*	75,380 y	0.399	1.51	0.762
Ra-226*	1600 y	0.399	1.51	0.762
Pb-210*	22.2 y	0.399	1.51	0.762
U-235 and its long half-life progeny are shown below. Short half-life progeny include Th-231, Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207, and Po-211				
U-235	7.040E+08 y	0.00462	0.386	0.0327
Pa-231*	32,760 y	0.00462	0.386	0.0327
Ac-227*	21.772 y	0.00462	0.386	0.0327
Th-232 and its long half-life progeny are shown below. Short half-life progeny include Ac-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, and Tl-208				
Th-232	1.405E+10 y	0.468	1.58	0.909
Ra-228*	5.75 y	0.468	1.58	0.909
Th-228*	1.9116 y	0.468	1.58	0.909

Notes:

- All of the nuclides are in approximate secular equilibrium with the long-lived parent (i.e., U-238, U-235, or Th-232). This means the soil concentrations of the progeny are nearly the same as the parent.
- Background soil concentration values are from DOE/RL-96-12. Radionuclides marked with an asterisk are not listed in DOE/RL-96-12. The numbers shown assume secular equilibrium with the long-lived parent nuclide.
- Half-life values are from the USDOE's National Nuclear Data web site (www.nndc.bnl.gov/index.jsp).

Table E-3. List of Long-Lived Radioactive Analytes.

Nuclide	Half-life (years)	Isotopic Mass (g/mole)	Specific Activity (Ci/g)
Am-241	432.2	241.05682	3.431E+00
C-14	5,700	14.00324	4.479E+00
Cs-137	30.07	136.90708	8.684E+01
Eu-154	8.593	153.92298	2.703E+02
Eu-155	4.7611	154.92289	4.847E+02
H-3	12.32	3.01605	9.621E+03
K-40	1.265E+09	39.96400	7.072E-06
Np-237	2,144,000	237.04817	7.034E-04
Ni-63	100.1	62.92967	5.675E+01
Pu-238	87.7	238.04955	1.712E+01
Pu-239	24,110	239.05216	6.203E-02
Ra-226	1,600	226.02540	9.886E-01
Ra-228	5.75	228.03106	2.727E+02
Sr-90	28.79	89.90774	1.381E+02
Sb-125	2.75856	124.90525	1.038E+03
Tc-99	211,096	98.90625	1.712E-02
Th-228	1.9116	228.02873	8.202E+02
Th-230	75,380	230.03313	2.062E-02
Th-232	1.405E+10	232.03805	1.097E-07
U-233	159,200	233.03963	9.636E-03
U-234	245,500	234.04095	6.222E-03
U-235	7.040E+08	235.04392	2.161E-06
U-238	4.468E+09	238.05078	3.361E-07

Notes:

- Numbers for half-life and isotopic mass are from the National Nuclear Data web site (www.nndc.bnl.gov/index.jsp).
- Specific Activity is calculated using the half-life and isotopic mass. One year is 365.24219 days when converting time units to seconds.

Table E-4. Maximum Sample Results (pCi/g) for 216-A-29 Ditch.

Nuclide	Sample Location							Worst Case	
	AD-1	B8826	AD-3	Pos 9	Pos 8	AD-2	Crib	Maximum	Depth
Am-241	2.22	145	--	--	0.096	0.772	--	145	4 - 6.5 ft 1.2 – 2 m
Cs-137	98.4	12.9	--	0.6	2	4.94	--	98.4	4 – 5 ft 1.2 – 1.5 m
Eu-155	--	--	--	--	0.05	--	--	0.05	10 ft 3 m
H-3	--	7.05	--	--	--	--	--	7.05	260 – 262 ft 72 – 80 m
K-40	13	13.9	16	14	15	14	9.92	bkgd	na
Np-237	0.124	--	--	--	--	--	--	0.124	11.5-12.5 ft 3.5 – 3.7 m
Pu-238	0.303	15.7	--	--	--	0.056	--	15.7	4 - 6.5 ft 1.2 – 2 m
Pu-239/240	25.8	667	--	--	--	5.07	--	667	4 - 6.5 ft 1.2 – 2 m
Ra-226	0.788	0.514	0.895	0.55	0.7	0.667	0.334	bkgd	Na
Ra-228	0.858	1.04	1.11	0.83	0.89	0.89	0.488	bkgd	na
Sb-125	1.67	--	--	--	--	--	--	1.67	4 – 5 ft 1.2 – 1.5 m
Sr-90	0.739	0.516	--	0.32	0.27	0.779	--	0.779	10 – 11 ft 3 – 3.4 m
Th-228	1	1.04	0.969	0.74	1.1	1.14	0.48	bkgd	na
Th-230	0.688	1.6*	0.66	--	--	0.883	--	bkgd	na
Th-232	0.858	1.07	1.11	0.83	0.89	1.22	0.488	bkgd	na
U-233/234	1.19	--	0.774	--	--	2.31	--	2.31	7.5 – 8.5 ft 2.3 – 2.6 m
U-234	--	--	--	--	--	0.964	--	Bkgd	na
U-235	0.439	0.083	--	--	--	0.0614	--	0.439	na
U-238	0.726	--	0.495	--	--	1.81	--	1.81	7.5 – 8.5 ft 2.3 – 2.6 m

*The Th-230 result at B8826 is only slightly above the maximum background value of 1.51 pCi/g. Because the Th-230 accumulates slowly from the decay of U-234, and because it is not a significant part of the waste at Hanford, it will be treated as a background result. Note also that thorium is less mobile than uranium, but the high value for Th-230 is at 15.2 to 16 m (50 to 52.5) feet while the high values for uranium are at depths less than 3 m (10 feet).

Table E-5a. Maximum Sample Results (pCi/g) for 216-B-63 Trench.

Nuclide	Sample Location			Worst Case	
	B8827	**BT-1**	**BT-2**	**Maximum**	**Depth**
Am-241	--	0.0345	--	0.0345	9.5 - 10.5 ft 2.9 – 3.2 m
Cs-137	1.32	3.56	0.817	3.56	9.5 - 10.5 ft 2.9 – 3.2 m
H-3	0.044	0.33	--	0.33	10 – 11 ft 3 – 3.4 m
K-40	13.7	12.9	13.2	bkgd	na
Np-237	0.035	0.054	--	0.054	9.5 - 10.5 ft 2.9 – 3.2
Ni-63	23	--	--	23	17.5 – 19 ft 5.3 – 5.8 m
Pu-238	0.081	--	--	0.081	17.5 – 19ft 5.3 – 5.8 m
Pu-239/240	0.026	--	--	0.026	17.5 – 19 ft 5.3 – 5.8 m
Ra-226	0.454	0.606	0.544	bkgd	na
Ra-228	0.635	0.827	0.777	bkgd	na
Sr-90	7.1	3.21	29.5	29.5	7.5 - 8.5
Tc-99	0.406	--	--	0.406	17.5 – 19 ft 5.3 – 5.8 m
Th-228	0.905	0.975	0.831	bkgd	na
Th-230	1.73*	0.786	1.33	bkgd	na
Th-232	0.748	0.856	0.88	bkgd	na
U-234	--	0.533	0.748	bkgd	na
U-238	--	0.455	0.93	bkgd	na

The samples taken from the 299-E33-333 borehole were not included in this table.

*The Th-230 result at B8827 is only slightly above the maximum background value and will be treated as a background result.

Table E-5b. Maximum Sample Results (pCi/g) for 216-B-63 Trench Including E33-333.

Nuclide	Sample Location				Worst Case	
	B8827	**BT-1**	**BT-2**	**E33-333**	**Maximum**	**Depth**
Am-241	--	0.0345	--	0.589	0.589	8 - 10.5 ft 2.4 -3.2 m
Cs-137	1.32	3.56	0.817	100	100	13 - 15.5 ft 4 - 4.7 m
Eu-154	--	--	--	1.29	1.29	8 - 10.5 ft 2.4 – 3.2 m
H-3	0.044	0.33	--	--	0.33	10 - 11 ft 3 - 3.4 m
K-40	13.7	12.9	13.2	18.4	bkgd	na
Np-237	0.035	0.054	--	--	0.054	9.5 - 10.5 ft 2.9 – 3.2 m
Ni-63	23	--	--	--	23	17.5 – 19 ft 5.3 – 5.8 m
Pu-238	0.081	--	--	--	0.081	17.5 – 19 ft 5.3 – 5.8 m
Pu-239/240	0.026	--	--	4.97	4.97	13 - 15.5 ft 4 – 4.7 m
Ra-226	0.454	0.606	0.544	0.762	bkgd	na
Ra-228	0.635	0.827	0.777	0.917	bkgd	na
Sr-90	7.1	3.21	29.5	4710	4710	13 - 15.5 ft 4 – 4.7 m
Tc-99	0.406	--	--	--	0.406	17.5 – 19 ft 5.3 – 5.8 m
Th-228	0.905	0.975	0.831	1.47	bkgd	na
Th-230	1.73*	0.786	1.33	2.67**	2.67	8 – 10.5 ft 2.4 – 3.2 m
Th-232	0.748	0.856	0.88	1.03	bkgd	na
U-234	--	0.533	0.748	--	bkgd	na
U-238	--	0.455	0.93	0.653	bkgd	na

The samples taken from the 299-E33-333 borehole were included in this table to quantify the effect it would have on the model for the 216-B-63 Trench.

*The Th-230 result at B8827 is only slightly above the maximum background value from Table E-2 and will be treated as a background result.

**The Th-230 result at E33-333 is nearly twice the background and will therefore be included as a manmade contaminant even though Th-230 is a minor port of the waste at Hanford.

Table E-6. Maximum Sample Results (pCi/g) for 216-S-10 Ditch.

Nuclide	Sample Location				Worst Case	
	SD-2	SD-3	W26-14	SD-1	Maximum	Depth
Am-241	0.412	--	1.84	0.253	1.84	6.5 – 9 ft 2 – 2.7 m
Cs-137	9.13	0.046	0.307	0.155	9.13	0 - 1.5 ft 0 - .5 m
H-3	--	--	0.061	--	0.061	25 – 27 ft 7.6 – 8.2 m
K-40	12	13.3	14.3	12.8	bkgd	na
Ni-63	--	--	38.4	--	38.4	25 – 27 ft 7.6 – 8.2 m
Pu-239/240	3.24	--	5.33	0.223	5.33	6.5 – 9 ft 2 – 2.7 m
Ra-226	0.526	0.603	0.922	0.513	bkgd	na
Ra-228	0.757	0.939	1.1	0.778	bkgd	na
Sr-90	--	0.462	0.318	--	0.462	3 - 4 ft .9 – 1.2 m
Th-228	0.632	0.903	5.9 *	0.752	bkgd	na
Th-230	0.515	0.612	1.38	0.481	bkgd	na
Th-232	0.757	0.939	1.41	0.778	bkgd	na
U-234	--	--	--	0.524	bkgd	na
U-238	--	--	--	0.536	bkgd	na

The northern 2/3 of 216-S-10 Ditch was dredged and used to fill the southern 1/3. The northern 2/3 is still a ditch that accumulates wind-blown tumbleweeds.

* The high value for Th-228 at well W26-14 at a depth of 67.1 to 67.7 m (220 to 222 feet) was rejected as anomalous. Th-228 has a half-life of 1.9116 years and thus comes to equilibrium with Ra-228 and Th-232 in a decade. The Th-228 was measured two ways; "IX/AEA" gave 5.9 pCi/g while "GEA" gave 0.352 pCi/g. Both Ra-228 and Th-232 measured 0.625 pCi/g using "GEA". The high Th-228 value is far enough away from where it should be that it was rejected.

Table E-7. Maximum Sample Results (pCi/g) for 216-S-10 Pond.

Nuclide	Sample Location				Worst Case	
	SP-1	SP-2	SP-3	SP-4	Maximum	Depth
Am-241	0.199	0.395	--	--	0.395	5 – 6 ft 1.5 – 1.8 m
C-14	--	12.2*	--	--	12.2	1 ft .3 m
Cs-137	0.336	1.77	0.428	--	1.77	5 – 6 ft 1.5 – 1.8 m
H-3	--	--	1.53	--	1.53	10 – 11 ft 3 m
K-40	11.6	13	13.2	13.6	bkgd	na
Np-237	0.062	--	--	--	0.062	10 – 11 ft 3 – 3.4 m
Pu-239/240	0.831	2.33	--	--	2.33	5 – 6 ft 1.5 – 1.8 m
Ra-226	0.504	0.498	0.739	0.537	bkgd	na
Ra-228	0.749	0.761	0.938	0.878	bkgd	na
Sr-90	1.26	1.43	0.293	0.829	1.43	25 – 26 ft 7.6-7.9 m
Th-228	1.45	0.711	0.979	0.73	bkgd	na
Th-230	0.776	1.12	1.59**	0.61	bkgd	na
Th-232	0.831	0.761	0.938	0.878	bkgd	na
U-233/234	0.577	--	--	--	bkgd	na
U-234	0.563	--	--	--	bkgd	na
U-235	--	--	--	--	bkgd	na
U-238	0.568	--	--	--	bkgd	na

* The background level of C-14 in living matter is 13.56 dpm/g carbon, or 6.11 pCi/g carbon. The sample result at SP-2 has twice the concentration found in pure carbon.

**The Th-230 result at SP-3 is only slightly above the maximum background value (1.51 pCi/g) and will be treated as a background result.

Table E-8. Sample Results (pCi/g) for 216-S-10/216-S-11 Pond.

Nuclide	Sample W26-13	Worst Case	
		Maximum	Depth, ft
K-40	13.9	bkgd	na
Ni-63	2.46	2.46	50 – 52 ft 15.2 – 15.8 m
Pu-239/240	0.117	0.117	99.5 - 101.5 ft 30.2 – 30.9 m
Ra-226	0.589	bkgd	na
Ra-228	0.907	bkgd	na
Sr-90	1.57	1.57	50 – 52 ft 15.2 – 15.8 m
Th-228	0.883	bkgd	na
Th-230	1.06	bkgd	na
Th-232	0.907	bkgd	na

Table E-9. Maximum Depth for Non-Zero Soil Concentrations.

Nuclide	216-A-29 Ditch	216-B-63 Trench	216-B-63 + E33-333 Trench	216-S-10 Ditch	216-S-10 Pond
Am-241	13 ft 4 m	10.5 ft 3 m	22.5 ft 6.9 m	9 ft 2.7 m	8.5 ft 2.6 m
C-14	na	na	na	na	1 ft .3 m
Cs-137	14.5 ft 4.4 m	13 ft 4 m	15.5 ft 4.7 m	9 ft 2.7 m	11 ft 3.4 m
Eu-154	na	na	15.5 ft 4.7 m	na	na
Eu-155	10 ft 3 m	na	na	na	na
H-3	274 ft 83.5 m	19 ft 5.8 m	19 ft 5.8 m	27 ft 8.2 m	25 ft 7.6 m
Ni-63	na	103 ft 31.4 m	103 ft 31.4 m	202 ft 61.6 m	52 ft 15.8 m
Np-237	12.5 ft 3.8 m	14.5 ft 4.4 m	14.5 ft 4.4 m	na	11 ft 3.4 m
Pu-238	6.5 ft 2 m	19 ft 5.8 m	19 ft 5.8 m	na	na
Pu-239	17 ft 5.1 m	19 ft 5.8 m	19 ft 5.8 m	27 ft 8.2 m	101.5 ft 30.9 m
Sb-125	5 ft 1.5 m	na	na	na	na
Sr-90	17 ft 5.1 m	21.5 ft 6.6 m	21.5 ft 6.6 m	9 ft 2.7 m	52 ft 15.8 m
Tc-99	na	19 ft 5.8 m	19 ft 5.8 m	na	na
U-234	8.5 ft 2.6 m	na	na	na	na
U-235	5 ft 1.5 m	na	na	na	na
U-238	8.5 ft 2.6 m	na	na	na	na

Notes:

- Depth units are feet below ground surface.
- Maximum sample depth at 216-A-29 Ditch is 83.5 m (274 ft) below the surface.
- Maximum sample depth at 216-B-63 Trench is 31.4 m (103 ft) below the surface. E33-333 went to 77.4 m (254 ft).
- Maximum sample depth at 216-S-10 Ditch is 67.7 m (222 ft) below the surface.
- Maximum sample depth at 216-S-10 Pond is 60.7 m (199 ft) below the surface..

Table E-10. Contaminated Soil Dimensions for Each Waste Site. (2 pages)

Parameter	216-A-29 Ditch	216-B-63 Trench	216-B-63 + E33-333 Trench	216-S-10 Ditch	216-S-10 Pond
Contaminated length	4000 ft (1220 m)	1400 ft (427 m)	1400 ft (427 m)	2250 ft (686 m)	1000 ft (305 m)
Contaminated width	6 ft (1.83 m)	4 ft (1.22 m)	4 ft (1.22 m)	4 ft (1.22 m)	188 ft (57.4 m)
Horizontal area	0.55 acre (2230 m^2)	0.13 acre (520 m^2)	0.13 acre (520 m^2)	0.21 acre (836 m^2)	4.32 acre (17,500 m^2)
Uncontaminated cover soil thickness	4 ft (1.22 m)	5 ft (1.52 m)	5 ft (1.52 m)	2 ft (0.61 m)	6 ft (1.83 m)
Depth to bottom of the upper contaminated soil layer	20 ft (6.10 m)	25 ft (7.62 m)	25 ft (7.62 m)	30 ft (9.14 m)	30 ft (9.14 m)
Upper Layer Soil Concentrations	**216-A-29 Ditch**	**216-B-63 Trench**	**216-B-63 + E33-333 Trench**	**216-S-10 Ditch**	**216-S-10 Pond**
Am-241	145 pCi/g	0.0345 pCi/g	0.589 pCi/g	1.84 pCi/g	0.395 pCi/g
C-14	0	0	0	0	12.2 pCi/g
Cs-137	98.4 pCi/g	3.56 pCi/g	100 pCi/g	9.13 pCi/g	1.77 pCi/g
Eu-154	0	0	1.29 pCi/g	0	0
Eu-155	0.05 pCi/g	0	0	0	0
H-3	0	0.33 pCi/g	0.33 pCi/g	0.061 pCi/g	1.53 pCi/g
Ni-63	0	23 pCi/g	23 pCi/g	38.4 pCi/g	0
Np-237	0.124 pCi/g	0.054 pCi/g	0.054 pCi/g	0	0.062 pCi/g
Pu-238	15.7 pCi/g	0.081 pCi/g	0.081 pCi/g	0	0
Pu-239	667 pCi/g	0.026 pCi/g	4.97 pCi/g	5.33 pCi/g	2.33 pCi/g
Sb-125	1.67 pCi/g	0	0	0	0
Sr-90	0.779 pCi/g	29.5 pCi/g	4710 pCi/g	0.462 pCi/g	1.43 pCi/g
Tc-99	0	0.406	0.406	0	0
Th-230	0	0	2.67 pCi/g	0	0
U-233/234	2.34 pCi/g	0	0	0	0
U-235	0.439 pCi/g	0	0	0	0
U-238	1.81 pCi/g	0	0	0	0

Table E-10. Contaminated Soil Dimensions for Each Waste Site. (2 pages)

Deeper Layer Soil Concentrations	**216-A-29 Ditch**	**216-B-63 Trench**	**216-B-63 + E33-333 Trench**	**216-S-10 Ditch**	**216-S-10 Pond**
Depth to top of layer	175 ft (53.3 m)	25 ft (7.62 m)	25 ft (7.62 m)	140 ft (42.7 m)	44 ft (13.4 m)
Depth to bottom of soil layer	270 ft (82.4 m)	245 ft (74.7 m)	245 ft (74.7 m)	210 ft (64.0 m)	76 ft (23.2 m)
Radionuclide	H-3	Ni-63	Ni-63	Ni-63	Ni-63 & Sr-90
Activity Concentration	7.05 pCi/g	5.68 pCi/g	5.68 pCi/g	10.7 pCi/g	2.46 pCi/g & 1.57 pCi/g

Note:

- There is a third layer of contamination for the 216-S-10 Pond. This layer extends from 23.2 m to 36 m (76 ft to 118 ft)below the surface and contains Pu-239 at a concentration of 0.117 pCi/g.

Table E-11. Hydrostratigraphic Thicknesses and Associated Soil Classes.
(2 pages)

216-A-29 Ditch Head End (B8826)

Hydrogeologic Unit	Thick	Depth	Soil Class
Backfill	3 m 10 ft	3 m 10 ft	B
Hanford Gravelly Sand	4.5 m 15ft	7.6 m 25 ft	Hgs
Hanford Coarse Sand	16.8 m 55 ft	24.4 m 80 ft	Hcs
Hanford Gravelly Sand	3 m 10 ft	27.4 m 90 ft	Hgs
Hanford Silty Sand	39.6 m 130 ft	67.1 m 220ft	Hss
Hanford Gravel	6.1m 20 ft	73.2 m 240 ft	Hg
Ringold Sand and Gravel	9.1 m 30 ft	82.3 m 270 ft	Rg

216-A-29 Ditch Outlet End (299-E26-13)

Hydrogeologic Unit	Thick	Depth	Soil Class
Hanford Coarse Sand	12.2 m 40 ft	12.2 m 40 ft	Hcs
Hanford Gravelly Sand	12.2 m 40 ft	24.4 m 80 ft	Hgs
Hanford Silty Sand	1.8 m 6 ft	26.2 m 86 ft	Hss
Hanford Gravel	36.6 m 120 ft	61.9 m 206ft	Hg

216-B-63 Trench (DOE/RL-2004-17)

Hydrogeologic Unit	Thick	Depth	Soil Class
Backfill	3 m 10 ft	3 m 10 ft	B
Hanford Gravel	10.1 m 33 ft	13.1 m 43 ft	Hg
Hanford Coarse Sand	49.7 m 163 ft	61.9 m 206 ft	Hcs
Hanford Gravel	11.9 m 39ft	74.7 m 245 ft	Hg

Table E-11. Hydrostratigraphic Thicknesses and Associated Soil Classes.
(2 pages)

216-S-10 Ditch (DOE/RL-2004-17)

Hydrogeologic Unit	Thick	Depth	Soil Class
Hanford Silty Sand	25.3 m 83 ft	25.3 m 83 ft	Hss_W
Hanford Fine Sand	6.1 m 20 ft	31.4 m 103 ft	Hfs_W
Hanford Silty Sand	18.3 m 60 ft	49.7 m 163 ft	Hss_W
Cold Creek Sandy Gravel	1.5 m 5 ft	51.2 m 168 ft	Hg_W
Ringold Sand and Gravel	16.8 m 55 ft	68 m 223 ft	Rg_W

216-S-10 Pond (DOE/RL-2004-17)

Hydrogeologic Unit	Thick	Depth	Soil Class
Hanford Silty Sand	2.3 m 7.5 ft	2.3 m 7.5 ft	Hss_W
Hanford Gravelly Sand	1.4 m 4.5 ft	3.7 m 12 ft	Hgs_W
Hanford Silty Sand	38.7 m 127 ft	42.4 m 139 ft	Hss_W
Ringold Sand and Gravel	2.7 m 9 ft	45.1 m 148 ft	Rg_W
Ringold Sandy Gravel	15.8 m 52 ft	61 m 200 ft	Rg_W

Table E-12. Hydraulic Properties of Soil Classes from PNNL-14702.

Hydraulic Property	Bulk Density (kg/L)	Porosity	Residual Moisture	Ksat	Kd Class	RESRAD "b"
Hanford Site Average						
B – Backfill	1.94	0.262	0.030	188.6	4H	4.05
Hss – Hanford Silty Sand	1.61	0.445	0.072	27.06	4H	4.90
Hcs – Hanford Coarse to Medium Sand	1.67	0.349	0.027	715.9	4I1	4.05
Hgs – Hanford Gravelly Sand	1.94	0.238	0.033	209.7	4I1	4.05
Hg – Hanford Gravel	1.93	0.167	0.022	104.1	4I2	4.05
Rg – Ringold Sand and Gravel	1.90	0.177	0.026	130.2	4I2	4.05
200 West Average						
Hss_W – Hanford Silty Sand	1.668	0.398	0.057	6.023	4H	4.90
Hfs_W – Hanford Fine Sand	1.700	0.356	0.042	11.57	4I1	4.38
Hgs_W – Hanford Gravelly Sand	1.810	0.273	0.030	74.11	4I1	4.05
Hg_W – Hanford Gravel	1.891	0.154	0.024	441.5	4I2	4.05
Rg_W – Ringold Sand and Gravel	1.838	0.294	0.041	33.43	4I2	4.05

The RESRAD "b" parameter was assigned based on soil texture. The other information is from PNNL-14702 Appendix B.

Table E-13. Upper Layer Soil Parameters Input to RESRAD. (2 pages)

Parameter Name	216-A-29 Ditch		216-B-63 Trench	216-S-10 Ditch	216-S-10 Pond
	Head End	Outlet End			
Area of contaminated zone	2230 m^2	2230 m^2	520 m^2	836 m^2	17,500 m^2
Thickness of contaminated zone	4.88 m	4.88 m	6.10 m	8.53 m	7.32 m
Length parallel to aquifer flow	1220 m	1220 m	427 m	686 m	305 m
Cover depth	1.22 m	1.22 m	1.52 m	0.61 m	1.83 m
Density of cover material	1.94 g/cm^3	1.67 g/cm^3	1.94 g/cm^3	1.668 g/cm^3	1.668 g/cm^3
Cover erosion rate	0.00001 m/y	0.00001 m/y	0.00001 m/y	0.00001 m/y	0.00001 m/y
Density of contaminated zone	1.94 g/cm^3	1.67 g/cm^3	1.933 g/cm^3	1.668 g/cm^3	1.695 g/cm^3
Contaminated zone erosion rate	0.00001 m/y	0.00001 m/y	0.00001 m/y	0.00001 m/y	0.00001 m/y
Contaminated zone total porosity	0.247	0.349	0.1908	0.398	0.3746
Contaminated zone field capacity	0.0319	0.027	0.024	0.057	0.0519
Contaminated zone hydraulic conductivity	202 m/y	716 m/y	125 m/y	6.02 m/y	18.8 m/y
Contaminated zone “b” parameter	4.05	4.05	4.05	4.90	4.741
Density of saturated zone	1.90 g/cm^3	1.93 g/cm^3	1.93 g/cm^3	1.838 g/cm^3	1.838 g/cm^3
Saturated zone total porosity	0.20	0.20	0.20	0.15	0.15
Saturated zone effective porosity	0.20	0.20	0.20	0.15	0.15
Saturated zone field capacity	0.10	0.10	0.10	0.11	0.11
Saturated zone hydraulic conductivity	6570 m/y	6570 m/y	18980 m/y	3650 m/y	3650 m/y
Saturated zone hydraulic gradient	0.0005	0.0005	5.0×10^{-5}	0.0015	0.0015
Saturated zone “b” parameter	4.05	4.05	4.05	4.05	4.05

Table E-13. Upper Layer Soil Parameters Input to RESRAD. (2 pages)

Parameter Name	216-A-29 Ditch		216-B-63 Trench	216-S-10 Ditch	216-S-10 Pond
	Head End	Outlet End			
Water table drop rate	0.0001	0.0001	0.0001	0.0001	0.0001
Well pump intake depth	4.6	4.6	4.6	4.6	4.6
Model for water transport	Non-dispersion	Non-dispersion	Mass balance	Non-dispersion	Non-dispersion
Well pumping rate	90 m^3/y	90 m^3/y	90 m^3/y	90 m^3/y	90 m^3/y
Number of unsaturated strata	5	4	3	5	2
Thickness of each layer	4.57, 16.76, 39.62, 6.10, 9.14 m	6.10, 12.19, 1.83, 36.58 m	5.49, 49.68, 11.89 m	16.15, 6.10, 18.29, 1.52, 16.76 m	33.22, 18.59 m
Density of each layer	1.94, 1.67, 1.61, 1.93, 1.90 g/cm^3	1.67, 1.94, 1.61, 1.93 g/cm^3	1.93, 1.67, 1.93 g/cm^3	1.668, 1.70, 1.668, 1.891, 1.838 g/cm^3	1.668, 1.838 g/cm^3
Total porosity of each layer	0.238, 0.349, 0.445, 0.167, 0.177	0.349, 0.238, 0.445, 0.167	0.167, 0.349, 0.167	0.398, 0.356, 0.398, 0.154, 0.294	0.398, 0.294
Effective porosity of each layer	0.238, 0.349, 0.445, 0.167, 0.177	0.349, 0.238, 0.445, 0.167	0.167, 0.349, 0.167	0.398, 0.356, 0.398, 0.154, 0.294	0.398, 0.294
Field capacity of each layer	0.027, 0.033, 0.072, 0.022, 0.026	0.027, 0.033, 0.072, 0.022	0.022. 0.027, 0.022	0.057, 0.042, 0.057, 0.024, 0.041	0.057, 0.041
Hydraulic conductivity of each layer	210, 716, 27.1, 104, 130 m/y	716, 210, 27.1, 104 m/y	104, 716, 104 m/y	6.02, 11.6, 6.02, 442, 33.4 m/y	6.02, 33.4 m/y
"b" parameter of each layer	4.05, 4.05, 4.90, 4.05, 4.05	4.05, 4.05, 4.90, 4.05	4.05, 4.05, 4.05	4.90, 4.38, 4.90, 4.05, 4.05	4.90, 4.05

Note:
- RESRAD parameter values are from PNNL-14702 Rev 1 as described in the text.

Table E-14. Lower Layer Soil Parameters Input to RESRAD.

Parameter Name	216-A-29 Ditch		216-B-63 Trench	216-S-10 Ditch	216-S-10 Pond	
	Head End	Outlet End			Ni & Sr	Pu Layer
Cover depth	53.34 m	33.83 m	7.62 m	42.67 m	13.41 m	23.16 m
Density of cover material	1.695 g/cm^3	1.823 g/cm^3	1.934 g/cm^3	1.673 g/cm^3	1.683 g/cm^3	1.676 g/cm^3
Thickness of contaminated zone	28.65 m	28.65 m	66.75 m	21.34 m	9.75 m	12.8 m
Density of contaminated zone	1.768 g/cm^3	1.93 g/cm^3	1.736 g/cm^3	1.786 g/cm^3	1.668 g/cm^3	1.668 g/cm^3
Contaminated zone total porosity	0.3032	0.167	0.3025	0.3182	0.398	0.398
Contaminated zone field capacity	0.0472	0.022	0.0257	0.045	0.057	0.057
Cont. zone hydraulic conductivity	75.3 m/y	104 m/y	559 m/y	53.6 m/y	6.02 m/y	6.02 m/y
Contaminated zone "b" parameter	4.457	4.05	4.05	4.329	4.90	4.90
Number of unsaturated strata	1	1	1	1	2	2
Thickness of each layer	0.30 m	0.30 m	0.30 m	3.96 m	19.2, 18.59m	6.4, 18.59 m
Density of each layer	1.90 g/cm^3	1.93 g/cm^3	1.93 g/cm^3	1.838 g/cm^3	1.668, 1.838 g/cm^3	1.668, 1.838 g/cm^3
Total porosity of each layer	0.177	0.167	0.167	0.294	0.398, 0.294	0.398, 0.294
Effective porosity of each layer	0.177	0.167	0.167	0.294	0.398, 0.294	0.398, 0.294
Field capacity of each layer	0.026	0.022	0.022	0.041	0.057, 0.041	0.057, 0.041
Hydraulic conduct. of each layer	130 m/y	104 m/y	104 m/y	33.4 m/y	6.02, 33.4 m/y	6.02, 33.4 m/y
"b" parameter of each layer	4.05	4.05	4.05	4.05	4.90, 4.05	4.90, 4.05

Note:

- Parameter values are based on weighted averages of numbers shown in Table E-13. As before the weighting factors are the thickness of the soil layer. Parameters for the saturated zone are shown in Table E-13.

Table E-15. Distribution Coefficients for Radionuclides.

Element	Symbol	Kd, ml/g		Reference
		Sand+	Gravel	
Actinium	Ac	200	62	same as Europium
Americium	Am	200	62	same as Europium
Antimony	Sb	1.4	0.14	Ames & Rai (1978)
Carbon	C	0	0	PNNL-14702 Best Estimate
Cesium	Cs	2000	620	PNNL-14702 Best Estimate
Europium	Eu	200	62	PNNL-14702 Best Estimate
Hydrogen (as tritiated water)	H	0	0	PNNL-14702 Best Estimate
Lead	Pb	70,000	7000	PNNL-13895
Neptunium	Np	10	1	PNNL-14702 Best Estimate
Nickel	Ni	200	20	PNNL-13895
Protactinium	Pa	200,000	20,000	Geibert & Usbeck (2004)
Plutonium	Pu	600	190	PNNL-14702 Best Estimate
Radium	Ra	22	7	same as Strontium
Strontium	Sr	22	7	PNNL-14702 Best Estimate
Technetium	Tc	0	0	PNNL-14702 Best Estimate
Thorium	Th	20	2	EPA (1999)
Uranium	U	0.8	0.08	PNNL-14702 Best Estimate

Notes:

- The gravel soil classes are Hanford Gravel (Hg) and Ringold Sand and Gravel (Rg).
- The Kd numbers from PNNL-14702 are the best estimate values. Similarly, the Kd values for Pb, Ni, and Pa were derived as best estimates (emails from G. Last and K. Cantrell).
- Kd values for gravel were reduced as described in PNNL-14702 Section 4.3. In general, a factor of 10% is applied to the Kd for sandy soils.
- The Kd for Hydrogen is for tritiated water.

Table E-16. Comparison of External Dose Methods for Industrial Scenarios.

RESRAD Parameter	Remedial Investigation (2004)	Present Risk Assessment	EPA RAGS-B (1991)	EPA SSG-R (2000)
Facility horizontal area	2500 m^2	2230 m^2	2023 m^2 (0.5 a.)	2023 m^2 (0.5 a.)
Annual time at work	8760 h/y	8760 h/y	8760 h/y	2000 h/y
Indoor shielding factor for gamma	0.8	0.4	0.8	0.4
Indoor time fraction	0.137	0.1712	not used	0.75 *
Outdoor time fraction	0.091	0.0571	not used	0.25 *
Effective annual external exposure time	1760 h/y	1100 h/y	7008 h/y	1100 h/y

Notes:

- "Remedial Investigation" is DOE/RL-2004-17. Values shown above are from Table 4-19 for the 216-A-29 Ditch. The RESRAD annual exposure time of 8760 h/y cannot be altered by the user. RESRAD adjustments for density, area, and depth are omitted.
- "RAGS-B" is EPA-540/R92/003. The method for a commercial/industrial land use risk assessment is described in section 4.2.
- "SSG-R" is EPA-540/R-00/008. The revised method for external exposure is presented on pages 2-17 and 2-18 for a residential scenario. The time fractions (marked with an asterisk) have been assumed for an industrial scenario. The adjustment for horizontal area of the source has been omitted because RESRAD calculations include a similar adjustment.

Table E-17. Comparison Inhalation Dose Methods for Industrial Scenarios.

RESRAD Parameter	Remedial Investigation (2004)	Present Risk Assessment	EPA RAGS-B (1991)	EPA SSG-R (2000)
Facility horizontal area	2500 m^2	2230 m^2	2023 m^2 (0.5 acre)	2023 m^2 (0.5 acre)
Air inhaled annually	7300 m^3/y	10,950 m^3/y	5000 m^3/y	2500 m^3/y *
Mass loading for inhalation	0.0001 g/m^3	2 x 10^{-5} g/m^3	not used	not used
Indoor dust filtration factor	0.4	0.4	not used	0.4
Indoor time fraction	0.137	0.1712	not used	0.75 *
Outdoor time fraction	0.091	0.0571	not used	0.25 *
Average wind speed	3.4 m/s	3.4 m/s	not used	not used
Particulate emission factor	not used	not used	4.63x10^9 m^3/kg	6.60x10^8 m^3/kg
Occupancy Factor	0.2006	0.1256	1	0.5500
Area Factor	0.1088	0.1075	1	1
Mass of contaminated dust inhaled annually	11.6 mg/y	2.96 mg/y	1.08 mg/y	2.08 mg/y

Notes:

- "Remedial Investigation" is DOE/RL-2004-17. Values shown above are from Table 4-19 for the 216-A-29 Ditch. The "Particulate emission factor" is not a RESRAD input.
- "RAGS-B" is EPA-540/R92/003. The method for a commercial/industrial land use risk assessment is described in section 4.2. Annual inhalation is based on 250 d/y and 20 m^3/d. The particulate emission factor shown is the EPA default.
- "SSG-R" is EPA-540/R-00/006. The revised method for fugitive dust emissions is presented on pages 2-13 to 2-17 for a residential scenario. The annual inhalation and time fractions (marked with an asterisk) have been assumed for an industrial scenario.
- Values for Occupancy Factor and Area Factor are calculated as described in the text.

Table E-18. RESRAD Input Parameters for the Industrial Exposure Scenario.

Parameter Name	Parameter Value	Rationale for Value
Inhalation rate	10,950 m^3/y	RAGS-B industrial scenario inhalation rate scaled up to account for reduced occupancy fractions
Mass loading for inhalation	$2x10^{-5}$ g/m^3	Annual average air concentration in Benton County Washington
Exposure duration	25 y	RAGS-B Chapter 4
Indoor dust filtration factor	0.4	RAGS-B Chapter 4
External gamma shielding factor	0.4	SSG-R Part 2, Section 2.4
Indoor time fraction	0.1712	75% indoor time fraction while at work; reduced for worker occupancy of 2000 h/y
Outdoor time fraction	0.0571	25% outdoor time fraction while at work; reduced for worker occupancy of 2000 h/y
Shape of contaminated zone	Circular	Simplifies calculation
Soil ingestion rate	12.5 g/y	RAGS-B Chapter 4
Drinking water ingestion rate	0 L/y	RAGS-B Chapter 4

Table E-19. Doses and Cancer Risks for the Industrial Scenario – with Cover.

Time After Site Closure	216-A-29 Ditch		216-B-63 Trench		216-S-10 Ditch	216-S-10 Pond
	Head End	Outlet End	without	with E33-333		
Radiation Dose, mrem/y						
0 y	6.69E-09	1.53E-07	9.54E-13	5.25E-11	2.28E-04	1.77E-13
50 y	2.13E-09	4.85E-08	3.03E-13	2.53E-11	7.22E-05	5.63E-14
100 y	6.87E-10	1.56E-08	9.64E-14	3.49E-11	2.29E-05	1.79E-14
150 y	2.29E-10	5.14E-09	3.07E-14	4.89E-11	7.28E-06	5.67E-15
300 y	2.70E-11	4.70E-10	9.93E-16	9.47E-11	2.33E-07	1.84E-16
500 y	3.12E-11	4.23E-10	2.53E-17	1.55E-10	2.72E-09	6.87E-18
1000 y	7.75E-11	8.99E-10	4.95E-17	2.98E-10	4.61E-10	1.39E-17
2000 y	2.11E-10	2.24E-09	2.03E-16	5.59E-10	6.09E-10	4.41E-17
5000 y	6.35E-10	5.92E-09	1.64E-15	1.25E-09	1.04E-09	1.94E-16
10000 y	1.26E-09	1.01E-08	1.07E-14	2.59E-09	2.44E-09	5.71E-16
Excess Lifetime Cancer Risk						
0 y	9.58E-14	2.19E-12	1.37E-17	6.83E-16	3.27E-09	2.55E-18
50 y	3.06E-14	6.98E-13	4.36E-18	5.10E-16	1.04E-09	8.08E-19
100 y	9.93E-15	2.25E-13	1.39E-18	7.25E-16	3.29E-10	2.57E-19
150 y	3.37E-15	7.51E-14	4.40E-19	9.99E-16	1.05E-10	8.15E-20
300 y	4.91E-16	8.31E-15	1.43E-20	1.88E-15	3.35E-12	2.66E-21
500 y	6.10E-16	8.21E-15	4.41E-22	3.02E-15	4.02E-14	1.24E-22
1000 y	1.50E-15	1.74E-14	9.59E-22	5.75E-15	8.18E-15	2.68E-22
2000 y	4.06E-15	4.30E-14	3.91E-21	1.07E-14	1.08E-14	8.44E-22
5000 y	1.21E-14	1.13E-13	3.13E-20	2.38E-14	1.84E-14	3.71E-21
10000 y	2.41E-14	1.93E-13	2.05E-19	4.96E-14	4.30E-14	1.09E-20

Notes:

- Radiation dose is the total effective dose equivalent for one year at the elapsed times indicated in the left column. These times are measured from Hanford Site closure.
- Lifetime incremental cancer risk is calculated for a 25-year exposure period using cancer morbidity factors derived for population exposures in Federal Guidance Report Number 13.

Table E-20. Doses and Cancer Risks for the Industrial Scenario – without Cover.

Time After Site Closure	216-A-29 Ditch		216-B-63 Trench		216-S-10 Ditch	216-S-10 Pond
	Head End	Outlet End	without	with E33-333		
Radiation Dose, mrem/y						
0 y	4.83E+01	4.83E+01	1.41E+00	5.17E+01	3.49E+00	7.56E-01
50 y	2.19E+01	2.19E+01	4.48E-01	1.59E+01	1.15E+00	2.67E-01
100 y	1.35E+01	1.35E+01	1.46E-01	5.12E+00	4.13E-01	1.13E-01
150 y	1.08E+01	1.08E+01	5.12E-02	1.80E+00	1.79E-01	6.37E-02
300 y	9.17E+00	9.17E+00	8.83E-03	4.99E-01	7.11E-02	4.09E-02
500 y	8.66E+00	8.65E+00	7.36E-03	6.91E-01	6.29E-02	3.87E-02
1000 y	7.92E+00	7.92E+00	7.15E-03	1.20E+00	5.53E-02	3.64E-02
2000 y	7.30E+00	7.29E+00	6.91E-03	1.91E+00	4.95E-02	3.40E-02
5000 y	6.58E+00	6.57E+00	6.40E-03	2.73E+00	4.43E-02	3.01E-02
10000 y	5.65E+00	5.64E+00	5.66E-03	2.74E+00	3.81E-02	2.51E-02
Lifetime Excess Cancer Risk						
0 y	5.66E-04	5.66E-04	2.03E-05	7.43E-04	4.92E-05	1.05E-05
50 y	1.95E-04	1.95E-04	6.45E-06	2.31E-04	1.56E-05	3.44E-06
100 y	7.76E-05	7.76E-05	2.11E-06	7.46E-05	5.07E-06	1.23E-06
150 y	4.01E-05	4.00E-05	7.48E-07	2.68E-05	1.74E-06	5.37E-07
300 y	2.13E-05	2.13E-05	1.42E-07	8.84E-06	2.26E-07	2.21E-07
500 y	1.83E-05	1.82E-05	1.21E-07	1.27E-05	1.50E-07	2.02E-07
1000 y	1.46E-05	1.45E-05	1.19E-07	2.22E-05	1.09E-07	1.88E-07
2000 y	1.19E-05	1.19E-05	1.15E-07	3.56E-05	8.07E-08	1.72E-07
5000 y	1.04E-05	1.03E-05	1.07E-07	5.11E-05	6.79E-08	1.45E-07
10000 y	8.93E-06	8.83E-06	9.47E-08	5.14E-05	5.84E-08	1.10E-07

Notes:

- The Artificial Industrial Scenario assumes the cover soil at each site is excavated and hauled away leaving a smooth layer of contamination exposed to the air. The scenario also assumes no well to groundwater.
- Radiation dose is the total effective dose equivalent for one year at the elapsed times indicated in the left column.
- Lifetime excess cancer risk is calculated for a 25-year exposure period using cancer morbidity factors derived for population exposures in Federal Guidance Report Number 13.

Table E-21. Peak Radionuclide Groundwater Concentrations.

Groundwater Concentration for 216-A-29 Ditch Head End				
		Peak Concentration		
Upper Layer	**Nuclide**	**Activity**	**Mass**	**EPA MCL**
	na	na	na	na
Lower Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	H-3	1,300	20 y	20,000 pCi/L
Groundwater Concentration for 216-A-29 Ditch Outlet End				
		Peak Concentration		
Upper Layer	**Nuclide**	**Activity**	**Mass**	**EPA MCL**
	U-234	483 pCi/L	0.078 µg/L	
	U-238	380 pCi/L	1,129 µg/L	
		Total U:	**1,129 µg/L**	**30 µg/L**
Peak Uranium Concentration is at 5174 y				
	Nuclide	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Np-237	na	na	na
Lower Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	H-3	2,800	20 y	20,000 pCi/L
Groundwater Concentration for 216-B-63 Trench				
Upper Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Tc-99	185	2,273 y	900 pCi/L
Lower Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Ni-63	na	na	na
Groundwater Concentration for 216-S-10 Ditch				
Upper Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	na	na	na	na
Lower Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Ni-63	na	na	na
Groundwater Concentration for 216-S-10 Pond				
Upper Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	C-14	8,260	1,323	2,000 pCi/L
Lower Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Ni-63 & Sr-90	na	na	na
Bottom Layer	**Nuclide**	**Peak pCi/L**	**Peak Year**	**EPA MCL**
	Pu-239	na	na	na
"na" means the contaminants did not reach groundwater within 10,000 y.				

Table E-22. Summary of Radionuclides at 200-CS-1 Waste Sites.

Nuclide	216-A-29 Ditch		216-B-63 Trench	216-B-63 & E33-333 Trench	216-S-10 Ditch	216-S-10 Pond
	Head	Outlet				
Am-241	ok	ok	ok	ok	ok	ok
C-14	non	non	non	non	non	*** GW ***
Cs-137	ok	ok	ok	ok	ok	ok
Eu-154	non	non	non	ok	non	non
Eu-155	ok	ok	non	non	non	non
H-3	ok	ok	ok	ok	ok	ok
K-40	bkgd	bkgd	bkgd	bkgd	bkgd	bkgd
Np-237	ok	ok	ok	ok	non	ok
Ni-63	non	non	ok	ok	ok	ok
Pu-238	ok	ok	ok	ok	non	non
Pu-239/240	ok	ok	ok	ok	ok	ok
Ra-226	bkgd	bkgd	bkgd	bkgd	bkgd	bkgd
Ra-228	bkgd	bkgd	bkgd	bkgd	bkgd	bkgd
Total Sr	ok	ok	ok	ok	ok	ok
Sr-90	non	non	non	ok	non	non
Sb-125	ok	ok	non	non	non	non
Tc-99	non	non	ok	ok	non	non
Th-228	bkgd	bkgd	bkgd	bkgd	ok	bkgd
Th-230	ok	ok	ok	ok	bkgd	ok
Th-232	bkgd	bkgd	bkgd	bkgd	bkgd	bkgd
U-233/234	ok	***GW***	bkgd	bkgd	non	bkgd
U-234	bkgd	bkgd	bkgd	bkgd	bkgd	bkgd
U-235	ok	ok	non	non	non	bkgd
U-238	ok	*** GW ***	bkgd	bkgd	bkgd	bkgd

The abbreviations used in this table are defined as
"non" – the radionuclide was not detected.
"bkgd" – the radionuclide was measured, but values are within the range of natural background concentrations.
"ok" – the radionuclide was detected above natural levels, but did not exceed drinking water limits within 10,000 y
"* GW *" – radionuclide exceeds drinking water standards in the groundwater within 10,000 y.

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