



7.2 Vadose Zone Characterization, Monitoring, and Technology Demonstrations

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The vadose zone is the region between the ground surface and the top of the water table. Current waste management practices are approved by state and federal regulators and strive to protect to protect groundwater. However, radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, unplanned leaks, solid waste burial grounds, and underground tanks at the Hanford Site are potential sources of continuing and future vadose zone and groundwater

contamination. Subsurface source characterization and vadose zone monitoring, soil-vapor monitoring, sediment sampling and characterization, and vadose zone remediation were conducted in 2000 to better understand and characterize the spread of subsurface contamination. This section summarizes major findings from these efforts, focused primarily on vadose zone soil contamination associated with past operations including reactor operations, single-shell tank leaks, and liquid disposal to ground.

7.2.1 Vadose Zone Characterization

During 2000, one new characterization borehole was drilled and sampled in the SX single-shell tank farm, 200-West Area, to better understand sediment properties, contaminant distribution, and transport mechanisms operating in the vadose zone. Baseline spectral gamma logging of selected wells in single-shell tank farms also was completed. The logging was follow-up to the baseline characterization effort that occurred in all single-shell tank farms between 1995 and 1999.

Semi-quantitative mineral analyses were completed of samples from one borehole in the SX tank farm and four samples designed to be “standards” for the Hanford and Ringold Formations at the Hanford Site. Such analyses have not been done previously at the Hanford Site and will help interpret mechanisms of contaminant transport in the vadose zone.

In 2000, DOE’s Environmental Management Science Program began a 3-year study of clastic dikes

and their influence on movement of subsurface contamination. The study is designed to describe the geometric and hydrologic properties of clastic dikes and extrapolate those properties to the subsurface of waste disposal and storage sites.

Vadose zone characterization activities were conducted at four sites in the 200 Areas to support remediation of sites that received cooling water waste (200-CW-1 Operable Unit) and at one site in the 100-DR Area to support chromate remediation using in situ gaseous reduction technology.

Finally, four comprehensive data packages were published in 2000 to support the 2005 Immobilized Low-Activity Waste Performance Assessment. Those data packages describe the current knowledge about the vadose zone geology, geochemistry, hydrology, and recharge at the proposed Immobilized Low-Activity Waste Disposal Facility site in south-central 200-East Area.



7.2.1.1 River Protection Project Vadose Zone Characterization Activities at Single-Shell Tanks

D. A. Myers

The River Protection Project operated by CH2M HILL Hanford Group conducted a series of investigations at the S and SX tank farms in the 200-West Area during the year 2000.

In January and February, a cone penetrometer was used adjacent to tanks S-102 and S-104. In addition to standard measurements, the cone penetrometer tools included a sodium-iodide spectral gamma detector. Samples were obtained and analyzed from zones identified by the spectral gamma detector as containing significant contamination. The cone penetrometer work identified a gamma peak above the base of tank S-104 and below the

elevation of several spare inlet ports that had been built in the tank. Tank S-104 had been overfilled during its operating history, and the possibility exists that losses from this tank may have been through the spare inlet ports. The cone penetrometer work lends support to this hypothesis, though it does not eliminate the possibility that the tank itself may have developed a leak.

The major activity conducted in and near the Waste Management Area S-SX was the construction of two slant boreholes that were extended into the lower Hanford formation or Plio-Pleistocene Unit. Both boreholes were drilled 30 degrees from vertical. The first of these boreholes was constructed south of the SX tank farm as a demonstration of the new drilling and sampling approach and to train tank farm personnel before deploying the system inside the farm. Upon completion of the demonstration and training effort, the rig was set up inside the farm for the second hole (Figure 7.2.1). During the test



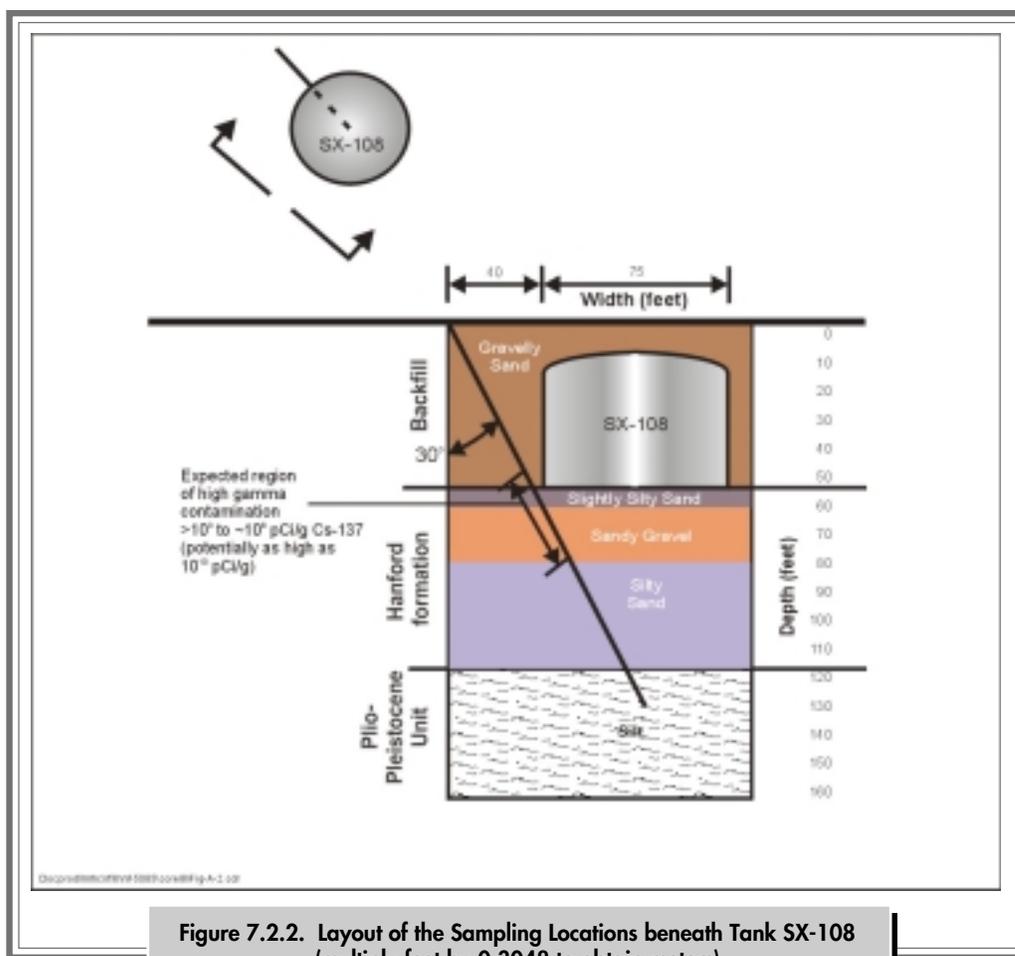
Figure 7.2.1. Slant Borehole Drilling Rig Set Up in the 200-West Area SX Tank Farm

and demonstration, ground acceleration measurements were taken to provide data for analysis of the drilling technique's impact on the sidewalls and bases of the tanks.

The second borehole was aligned to pass beneath tank SX-108, through a zone of highly contaminated soil and "bottom-out" in the Plio-Pleistocene Unit at a vertical depth of 45 meters (148 feet), ~3 meters (10 feet) due south of the tank center. Figure 7.2.2 shows the projection of the borehole relative to the geologic formations and the tank. Samples were successfully collected from 16 of 17 preselected locations. One sample was lost, probably due to the coarse nature and dryness of the soil that allowed it to

fall from the sampler. All other samples were sent for laboratory analysis; the complete results of those analyses will be available in 2001 and will be summarized in the next annual report.

Upon completion, the borehole was geophysically logged and then decommissioned by extracting the casing and filling the borehole with bentonite. Both spectral gamma and downhole temperature logs were obtained, and Figure 7.2.3 shows the logging results. The figure shows good correlation between the available laboratory results and the geophysical logs. Samples from this borehole have provided the highest levels of soil contaminant concentrations recovered from Hanford Site tank farms to date.



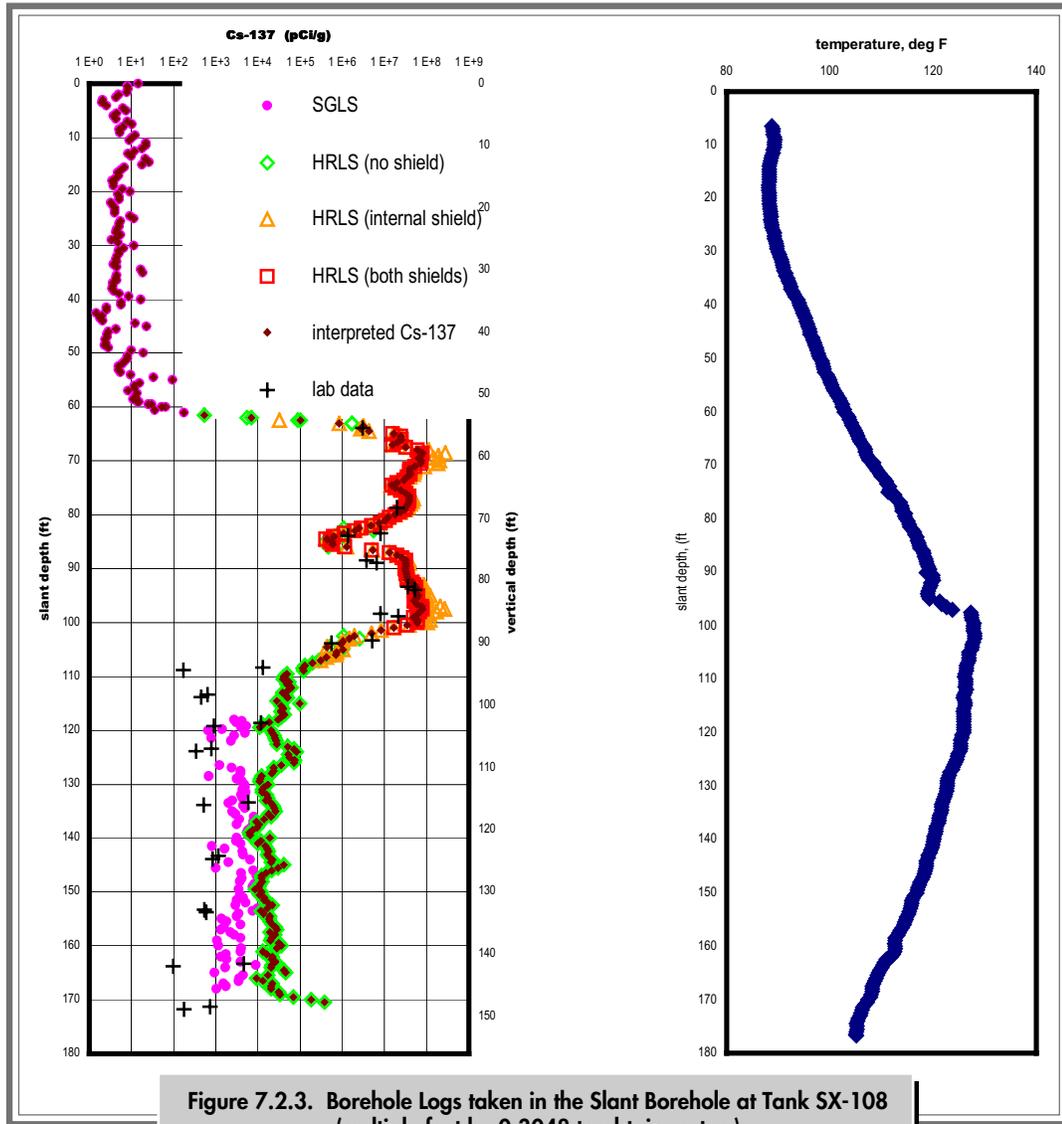


Figure 7.2.3. Borehole Logs taken in the Slant Borehole at Tank SX-108 (multiply feet by 0.3048 to obtain meters)

7.2.1.2 Mineral Characterization of Borehole 41-09-39 at Single-Shell Tank SX-109

H. T. Schaef, D. G. Horton, and D. A. Myers

Borehole 41-09-39 is located adjacent to single-shell tank SX-109 in the SX tank farm in the Hanford Site's 200-West Area. The borehole was originally constructed in 1996 to determine the distribution of

cesium-137 at depths of 24 to 40 meters (79 to 131 feet) below ground surface. The borehole was deepened in 1997 and decommissioned in 1999. As part of the decommissioning effort, sidewall samples were collected at previously unsampled portions of the borehole and submitted for chemical, radiological, and mineralogical analyses.

Summaries of the results of chemical and radiological testing on samples from borehole 41-09-39 were reported in PNNL-13230. This section summarizes the results of mineralogical testing conducted in

2000. These analyses are the first reported semi-quantitative mineral abundances from radionuclide contaminated sediment at the Hanford Site. The results will help interpret chemical reactions between the sediment and contaminants and will help understand the distribution of radiocontaminants in the subsurface. X-ray diffraction analyses were done on five samples from the Hanford formation. Semi-quantitative mineral abundances were determined for both the bulk sample and the $<2\ \mu\text{m}$ (8×10^{-5} in.) size fraction.

Results for bulk samples show that the sediment is about 35 to 50 wt.% quartz and about 25 to 55 wt.% feldspars with lesser amounts of mica and chlorite. Plagioclase feldspar is 2 to 10 times more abundant than is potassium feldspar. Minor amounts of amphibole and calcite also were detected in the bulk sediment. The bulk mineralogy determined by this study is similar to that determined by Tallman et al. (RHO-ST-23) for uncontaminated samples from the southern part of 200-West Area.

The $<2\ \mu\text{m}$ (8×10^{-5} in.) size fractions are dominated by four clay minerals: illite, smectite, chlorite, and kaolinite. Minor amounts of quartz and feldspar and trace amounts of amphibole were identified in some samples (abundances of amphibole were not determined). Overall, illite is the dominant mineral in the $<2\ \mu\text{m}$ fraction ranging from 20 to 35 wt.% of the samples. Smectite ranged from 5 wt.% to as much as 20 wt.% of the samples and chlorite made up between about 10 and 30 wt.% of the samples. Minor amounts of kaolinite (<10 wt.%) were detected in all samples and quartz and feldspars made up about 5 to 20 wt.%.

7.2.1.3 Baseline Spectral Gamma-Ray Logging at Tank Farms

P. D. Henwood and R. G. McCain

Since 1995, baseline vadose zone characterization in single-shell tank farms has been conducted by

the DOE Grand Junction Office (DOE-GJO) and its subcontractor, MACTEC-ERS. By the end of fiscal year 1999, the baseline data had been reported in tank summary data reports for all 133 single-shell tanks with capacities of 2 million liters (528,344 gallons) or greater (100-series tanks), and in reports for each of the 12 single-shell tank farms. Since the original baseline data were acquired, additional data have been collected, new analysis techniques have been developed, and additional insights into the nature and distribution of contamination in the vadose zone have been gained. An addendum to each tank farm report was prepared during fiscal year 2000 to present these additional data and to report revised interpretations of subsurface contaminant distribution. With submittal of these reports, the baseline characterization was completed. Results of the Tank Farms Vadose Zone Characterization Program are posted on the Internet at <http://www.doegjpo.com/programs/hanf/HTFVZ.html>.

Spectral Gamma Logging Methods

Log data in the form of gamma spectra were collected using a high-purity germanium semiconductor detector. This combination of detector and logging truck is referred to as the spectral gamma logging system and is able to quantify radionuclide concentrations from background levels up to several thousand picocuries per gram. Frequently, zones of more intense radiation are encountered in which the detector becomes saturated and ineffective. In order to provide data in these highly contaminated zones, the high-rate logging system, was developed and deployed.

The high-rate logging system uses the same logging trucks and electronics system as the spectral gamma logging system but has a much smaller detector and two optional shields that allow measurement of cesium-137 concentrations up to about 100 million pCi/g. High-rate logging operations were completed in 2000. The spectral gamma logging system and high-rate logging system data were collected in accordance with procedures documented in





MAC-VZCP 1.7.10-1 and analyzed in accordance with MAC-VZCP 1.7.9.

Additional Data and Analysis

Logging was conducted using the high-rate logging system in all borehole intervals where the original baseline spectral gamma logging system indicated zones of detector saturation resulting from very high gamma contamination levels. Data from both the spectral gamma logging system and the high-rate logging system were used together so that the final logs were a composite of the two.

Other data collected since the original tank farm reports were issued include repeat logging measurements acquired up to 4 years after the initial baseline data were collected. Boreholes were selected for repeat logging primarily to check for possible contaminant movement over time. To compare the original baseline and the repeat logging data, baseline data were adjusted for radionuclide decay. Continued movement of radionuclides was detected in some boreholes.

A data analysis method known as shape factor analysis has been in use since the first tank farm report was issued. This method is used to discriminate among contamination on the inside or outside of the borehole casing, uniformly distributed contamination in the formation, or a discrete contaminant source at a distance from a borehole. Depth intervals in which contamination was localized to the borehole were removed from the data sets used to create visualizations of subsurface contamination. Removal of these intervals led to significant modifications to the original visualizations of contaminant distribution presented in the tank farm reports. Addenda were issued during 2000 for each tank farm report that presented revised visualizations based on results of shape factor analysis, repeat logging, high-rate logging, and other information.

Antimony-125, cesium-137, cobalt-60, europium-152, europium-154, uranium-235, uranium-238, and possibly strontium-90 have been detected in tank

farms using the spectral gamma logging systems. The visualizations illustrate how gamma-emitting contaminants that have leaked from tanks may be distributed in the vadose zone sediment. A valuable attribute of the visualizations is that they can be used to define areas of concern in which to focus future characterization, monitoring, and remediation efforts. Figure 7.2.4 presents an example of a revised data visualization that includes high-rate logging data and excludes contamination localized to a borehole.

Results

Results of baseline logging conducted from 1995 to 1999 for single-shell tanks were reported in prior Hanford Site Environmental Reports (e.g., PNNL-13230 and PNNL-12088). Results also were reported in individual tank summary data reports and tank farm reports (<http://www.doegipo.com/programs/hanf/HTFVZ.html>). Conclusions reported in those documents have not changed substantially as a result of incorporating shape factor analysis and high-rate logging data. Inclusion of the high-rate logging data in creating the three-dimensional visualizations had a relatively minor impact on the interpreted spatial distribution of contaminant plumes, but had a substantial impact on the estimated total curie activity within the plume volume. Although evaluation of shape factor results and other data provided a justification for eliminating many contamination intervals in some boreholes, most intervals of significant contamination remain and only relatively low-concentration “ghost” plumes were eliminated from the visualizations. Table 7.2.1 summarizes the results of the tank farm baseline characterization effort.

High-rate logging data were collected in 51 boreholes in the Hanford Site tank farms. Of these 51 boreholes, 39 exhibited high gamma contamination zones below the operating level of the tanks. Contamination in the remaining 12 boreholes was at depths above the tank operating level and was typically associated with contamination related to tank farm infrastructure, such as buried transfer lines, that are not related to tank leaks. The maximum

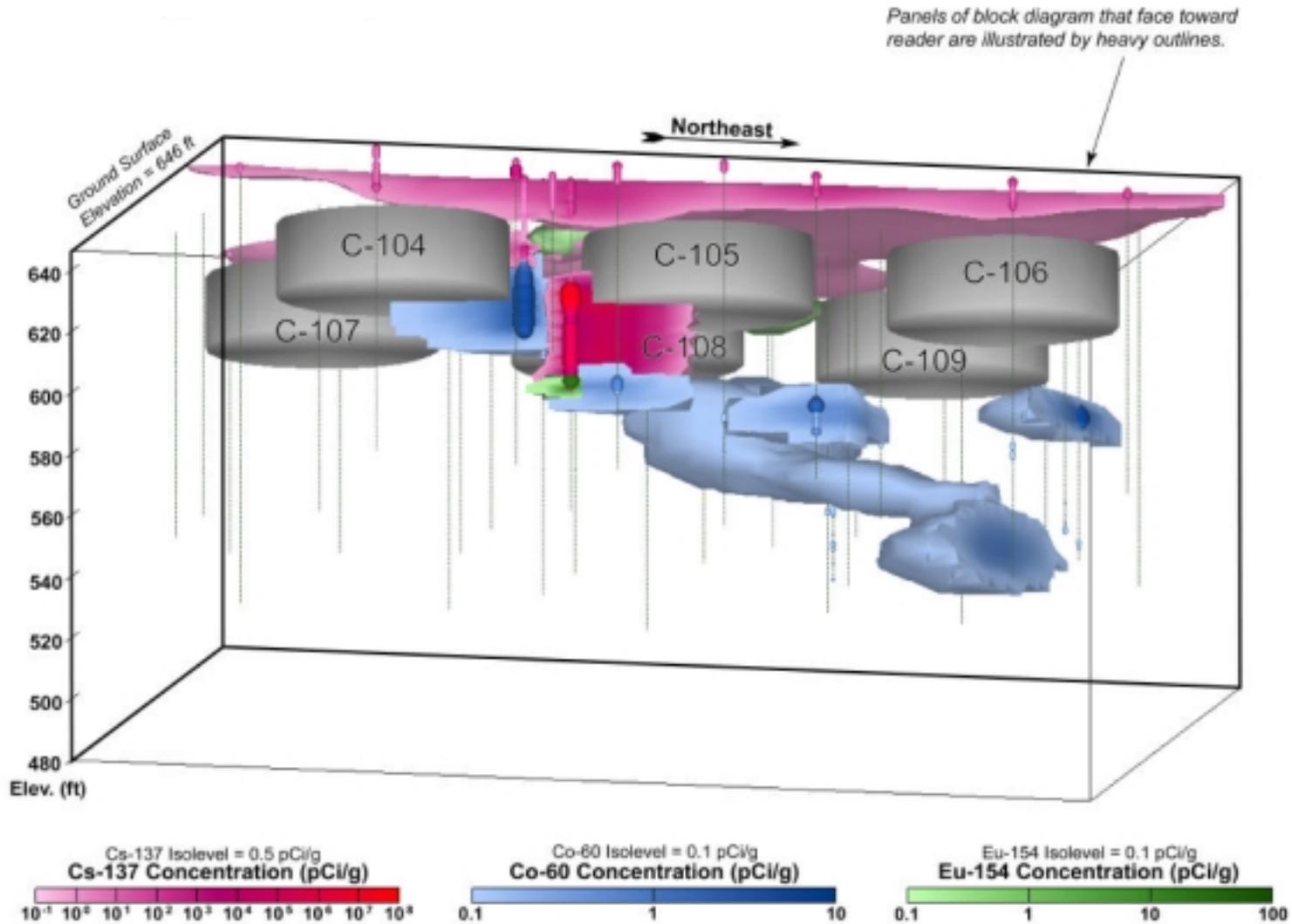


Figure 7.2.4. Example of a Revised Visualization from the C Tank Farm in the 200-East Area (multiply feet by 0.3048 to obtain meters)



Table 7.2.1. Summary of Hanford Site Tank Farm Baseline Geophysical Logging Characterization Results

Farm	Plumes Detected^(a)	Predominant Gamma-Emitting Radionuclides	Maximum Concentration (pCi/g)^(b)	Maximum Depth (m)^(c)	Movement Detected	Comment
A	1	⁶⁰ Co, ¹⁵⁴ Eu, ¹³⁷ Cs	10 ² (⁶⁰ Co)	25.9	No	Historical plumes identified at 24.4 m.
AX	1	¹³⁷ Cs	10 ² (¹³⁷ Cs)	12.2	No	Historical plumes identified at 21.3 m.
B	6	⁶⁰ Co, ¹⁵⁴ Eu, ¹³⁷ Cs	10 ⁷ (¹³⁷ Cs)	32.6	No	Possible ⁹⁰ Sr plume identified.
BX	5	⁶⁰ Co, ¹³⁷ Cs, ¹⁵⁴ Eu, ¹²⁵ Sb, ²³⁵ U, ²³⁸ U	10 ⁷ (¹³⁷ Cs)	45.7	Yes	Plume may reach groundwater (70.1 m).
BY	5	⁶⁰ Co, ¹³⁷ Cs, ¹²⁵ Sb	20 (⁶⁰ Co)	42.7	Yes	Plume may reach groundwater (76.2 m).
C	5	⁶⁰ Co, ¹⁵⁴ Eu, ¹³⁷ Cs	10 ⁷ (¹³⁷ Cs)	38.1	Yes	Boreholes by assumed leakers C-101, -110, and -111 show no current contamination. Downward ⁶⁰ Co movement detected near C-106.
S	3	⁶⁰ Co, ¹³⁷ Cs	10 ⁶ (¹³⁷ Cs)	21.3	No	⁹⁹ Tc detected in groundwater (PNNL-12114).
SX	5	⁶⁰ Co, ¹³⁷ Cs	10 ⁸ (¹³⁷ Cs)	41.1	Yes	Tank SX-102 may be a leaker; possible ⁹⁰ Sr plume identified. ⁹⁹ Tc detected in groundwater (PNNL-12114).
T	6	⁶⁰ Co, ¹⁵⁴ Eu, ⁹⁴ Nb, ¹³⁷ Cs, ¹²⁶ Sn, ¹²⁵ Sb	10 ⁷ (¹³⁷ Cs)	37.5	Yes	Plumes from tank waste and adjacent waste sites may have commingled.
TX	4	⁶⁰ Co, ¹⁵⁴ Eu, ¹³⁷ Cs, ²³⁵ U, ²³⁸ U, ¹²⁵ Sb	10 ⁴ (¹³⁷ Cs)	30.5	Yes	Possible ⁹⁰ Sr plume identified.
TY	3	⁶⁰ Co, ¹³⁷ Cs	10 ⁷ (¹³⁷ Cs)	45.1	Yes	Plume may reach groundwater (67.1 m).
U	4	⁶⁰ Co, ¹³⁷ Cs, ²³⁵ U, ²³⁸ U	10 ⁷ (¹³⁷ Cs)	30.5	Yes	Infiltrating surface H ₂ O may be remobilizing tank waste (PNNL-13282).

(a) Approximate number of plumes identified below the operating level of a tank.

(b) Approximate highest concentration observed of all measured radionuclides and may not be the radionuclide that is most pervasive.

(c) In some cases, the maximum depth is limited by the depth of the borehole and the vertical extent of contamination is not fully defined.



concentration measured in any zone was about 100 million pCi/g. The acquisition of high-rate logging data completed the baseline characterization of tank farms and allowed determination of maximum concentrations in contamination plumes. This capability provides a basis on which to estimate the volume of contaminated soil and contaminant inventory in the vadose zone. It also provides a method for future quantitative comparisons of contaminant movement in high gamma contamination zones by repeated logging through time.

Repeat log data were collected with the spectral gamma logging system in all tank farms from selected depth intervals in 88 boreholes. The log intervals measured in 80 of the boreholes were below the operating level of the tanks. Data acquired in 22 borehole intervals below the operating levels of the tanks indicated possible concentration increases that would suggest the possibility of continued contaminant movement through the vadose zone from tanks that had leaked in the past.

7.2.1.4 Hydrologic Influence of Clastic Dikes on Vadose Zone Transport

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A 3-year study of clastic dikes and their influence on vertical movement of moisture and contaminants in the vadose zone began in fiscal year 2000. The goal is to describe the geometry and hydrologic properties of clastic dikes and dike networks and extrapolate those properties to the vadose zone beneath waste storage and disposal facilities. Clastic dikes are potentially important subsurface features because, depending on their features, they may enhance or inhibit movement of contaminants to groundwater.

Clastic dikes are common sedimentary structures in the vadose zone at the Hanford Site (BHI-01103). The dikes consist of vertical to subvertical

structures that are often contorted and irregular, and cross-cut the normal subhorizontal sand and silt beds of the Hanford formation (Figure 7.2.5). The dikes vary in width from less than 1 centimeter (0.4 inch) to more than 2 meters (6.6 feet) and have vertical extents that range from less than 1 meter (3.3 feet) to more than 50 meters (164 feet), with a large number greater than 20 meters (66 feet). Previous investigators have proposed that the dikes may provide a preferential path for contaminated water leaking from waste tanks to move through the thick unsaturated zone to the unconfined aquifer. However, there is insufficient evidence to determine if that speculation is accurate.

In 2000, the project used remote sensing and ground-penetrating radar surveys to describe the large-scale distribution of the clastic dikes along Army Loop Road in the 600 Area and at the 216-S-16 pond near the 200-West Area. Figure 7.2.6 shows the dikes at the two sites as mapped into a Geographic Information System from air photographs. The Geographic Information System then was used to extract the lengths, area of the polygons, and azimuth of the dikes and simple statistical analyses were made. The mean length of 3,835 dikes is 62 meters (203 feet), and the average width of the surface expression of 58 dikes is just over 2 meters (6.6 feet). Spatial analysis of 3835 dikes shows a slight preferential orientation to the dikes in the network, with many of the dikes occurring in two conjugate sets.

Surface ground-penetrating radar surveys were conducted at three areas: square grid surveys at the Army Loop Road site and at the 216-S-16 pond, and a 6.9-kilometer (4.3-mile) traverse in the 600 Area (see Figure 7.2.6). The surveys were to aid mapping the dikes and to detect smaller dikes not visible on air photos or the ground surface. Figures 7.2.7 and 7.2.8 show examples from the ground-penetrating radar survey at Army Loop Road. Figure 7.2.7 shows four northeast-southwest profiles. The white area at ~30 meters (98 feet) distance in the northeast-southwest direction on each traverse is a clastic dike;

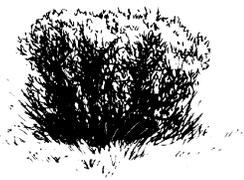




Figure 7.2.5. Photograph of Clastic Dikes in the Hanford Formation at the Environmental Restoration Disposal Facility, 200-West Area (from BHI-00230)



Figure 7.2.6. Distribution of Clastic Dikes at the Army Loop Road Site and the 216-S-16 Pond



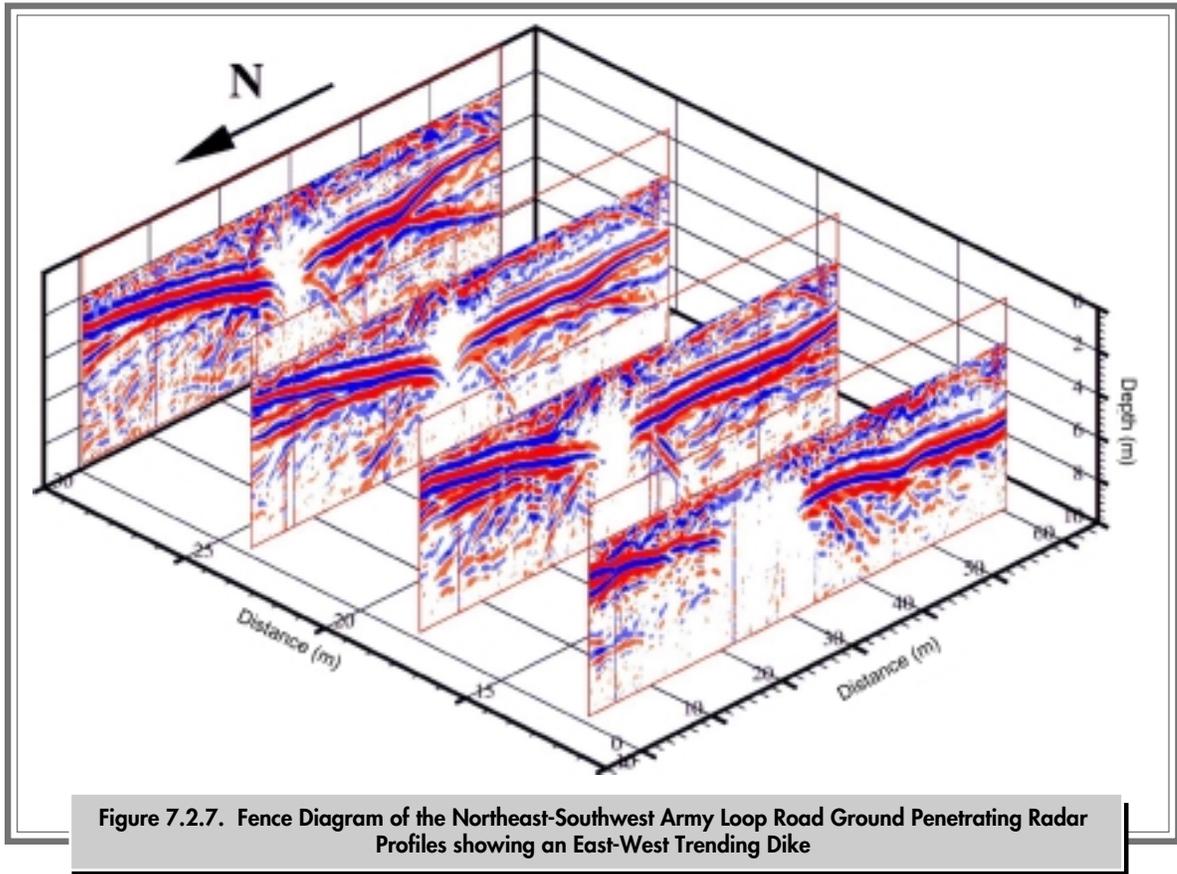


Figure 7.2.7. Fence Diagram of the Northeast-Southwest Army Loop Road Ground Penetrating Radar Profiles showing an East-West Trending Dike

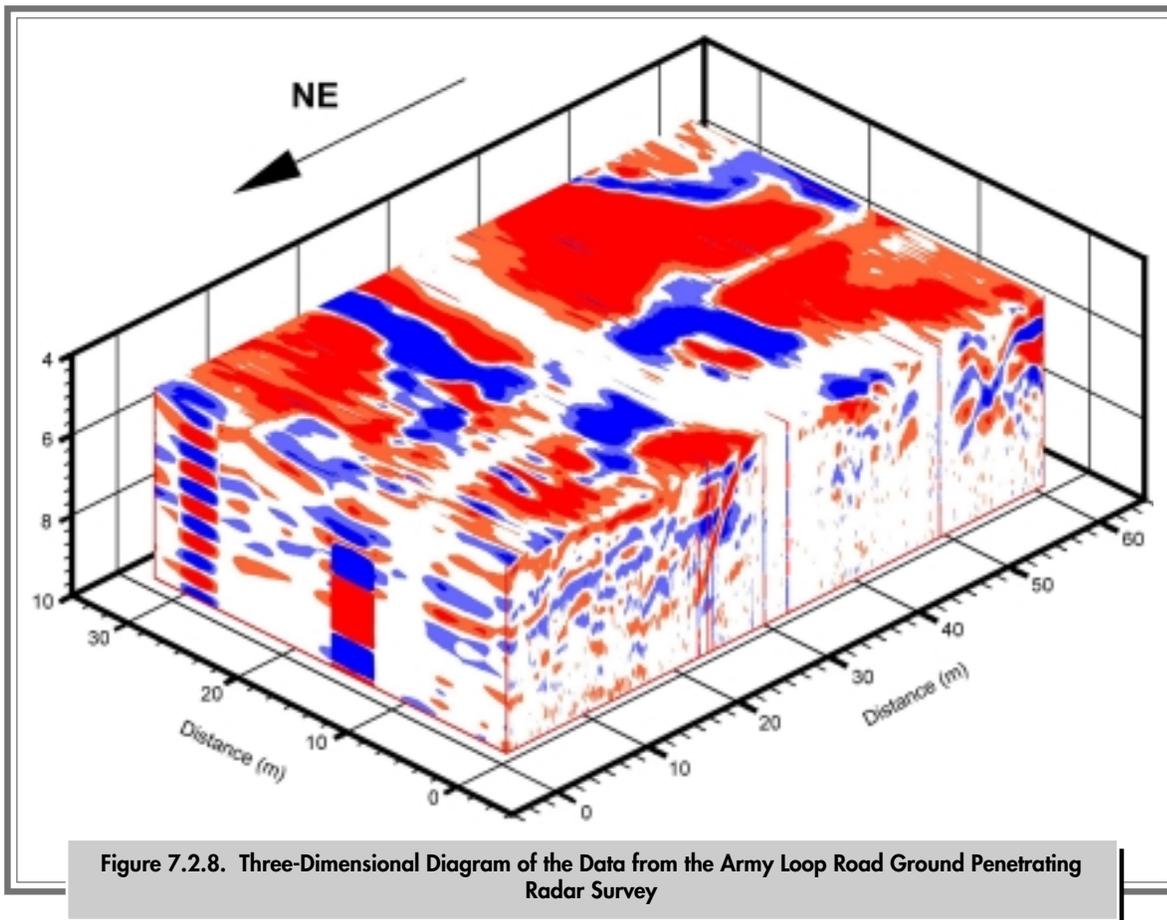
Figure 7.2.8 is a three-dimensional view of the same area. The white area along the plot's surface corresponds to the subsurface expression of a clastic dike. A second dike can be seen at ~10 meters (33 feet) on the east-west face of the plot. The second dike intersects the first dike near the center of the diagram.

The ground-penetrating radar survey and the air photo and field mapping were used to select a site to trench across a clastic dike. In August 2000, a clastic dike at the 216-S-16 pond was trenched with a backhoe to a depth of ~3.5 meters (11.5 feet) (Figure 7.2.9). The exposed clastic dike is in the sand-dominated facies of the Hanford formation. The dike is ~0.7 meter (2.3 feet) thick at the bottom of the trench but becomes extremely narrow (~8 to 10 centimeters [3.2 to 3.9 inches]) within ~1 meter (3.3 feet) of the surface.

In the exposure of the bottom half of the trench, the host material is very different on each side of the

dike (see Figure 7.2.9). The material to the west of the dike (to the left in Figure 7.2.9) is medium to coarse-grained plane laminated sand containing some silt and sand rip-up clasts. The material to the east of the dike consists of finer grained, silty fine to medium sand. In addition, a clastic sill (a structure similar to a clastic dike but concordant with horizontal bedding) is exposed east of the dike, near the base of the trench. The sill is seen in Figure 7.2.9 as the ~8-centimeters-thick (3.2-inches-thick), fine-grained unit to the right of the dike in the lower part of the trench. The heterogeneities within both the host sediment and within the dike complicate comparison of physical property data from samples of dike and host.

The trench was terraced at four levels. The dike and host sediment were characterized by air permeability measurements and infrared imaging on each level except the first. In addition, samples



were taken for moisture analyses, grain size distribution, and mineralogy (x-ray diffraction).

Moisture content was determined from several samples collected in the trench. As expected, the moisture content was higher in the dike than in the host sediment. The average moisture content of dike samples was about 15 volume percent whereas that for the sediment was about 2.5 volume percent. Nineteen samples were submitted for analysis of particle size distribution. In general, the samples from the dike tended to be much finer grained than did samples of host sediment.

Figure 7.2.10 shows two composite photographs of the lowest level in the trench. The lower photo is a normal photograph and the upper photo is an infrared photograph. The contrast in the infrared photo is due to variation in the moisture content of

the sediment; darker colors indicate more moisture. The dark vertical band on the left side of the infrared photo is the clastic dike and the dark horizontal band is the clastic sill. The photo shows that clastic dikes tend to hold more moisture than the surrounding host sediment.

Several hundred air permeability measurements were obtained from the exposures in the trench. Air permeability of the dike ranged from about 0.025 to 0.6 darcy and averaged about 0.2 darcy. (A darcy is a unit of permeability and is defined as the permeability that will lead to a discharge of 1 cm/sec.) The host sediment had a slightly higher permeability ranging from about 0.7 to 1.12 darcies with an average of 0.9 darcy. The dike and sill exposed in the trench tend to be finer-grained than the host material and, therefore, have a higher moisture content and lower permeability than the host material.



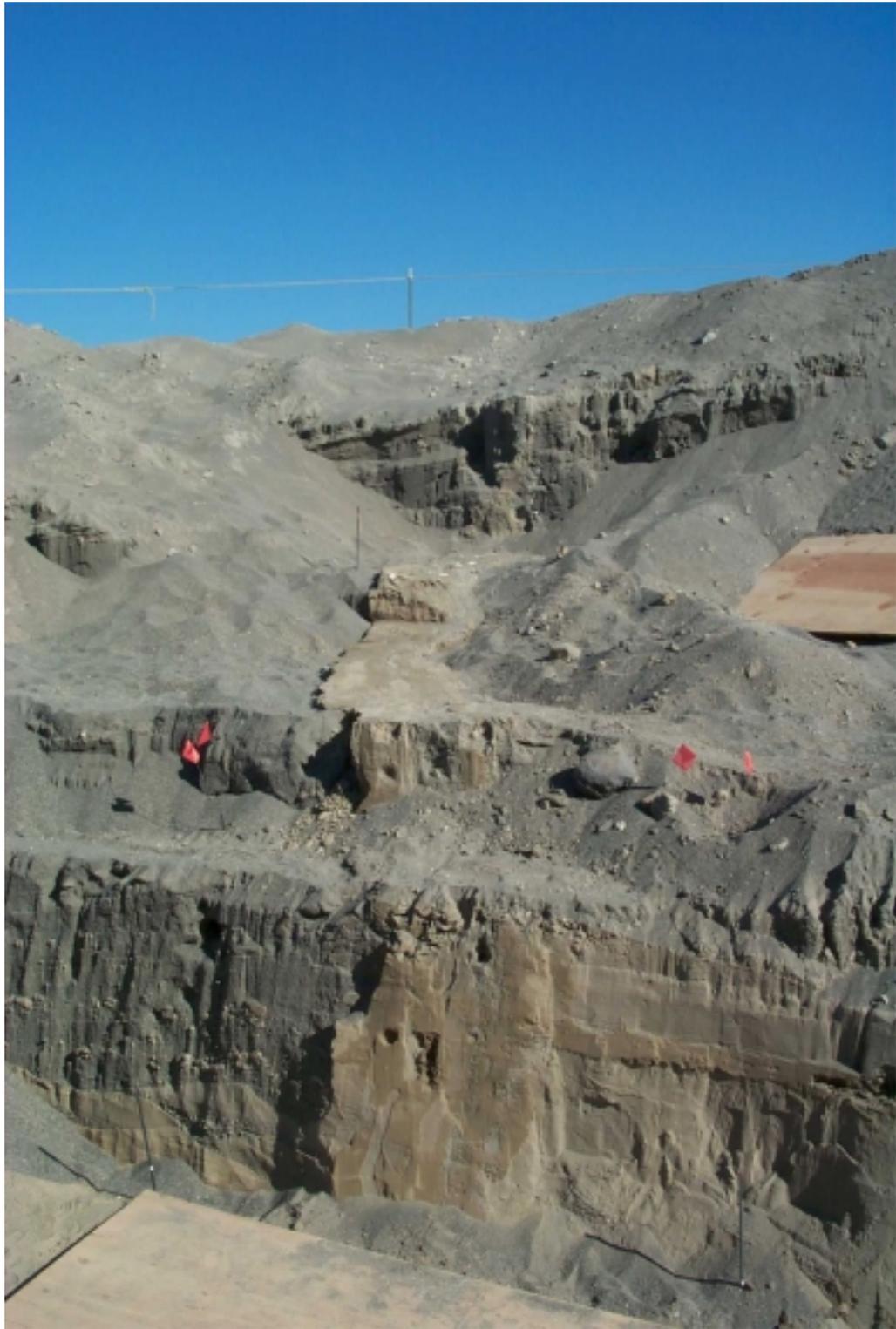


Figure 7.2.9. Clastic Dike Exposed in Trench at 216-S-16 Pond. The dike is approximately 0.7 meter (2.3 feet) wide at the bottom of the trench.

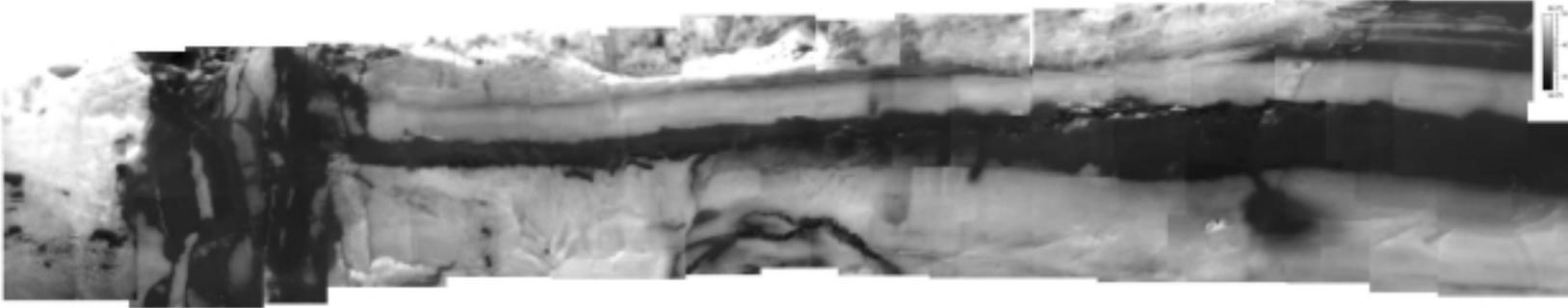


Figure 7.2.10. Composite Photograph of the Lower Part of the Trench at the 216-S-Pond. The upper photo is an infrared image and the lower photo is a normal photograph.



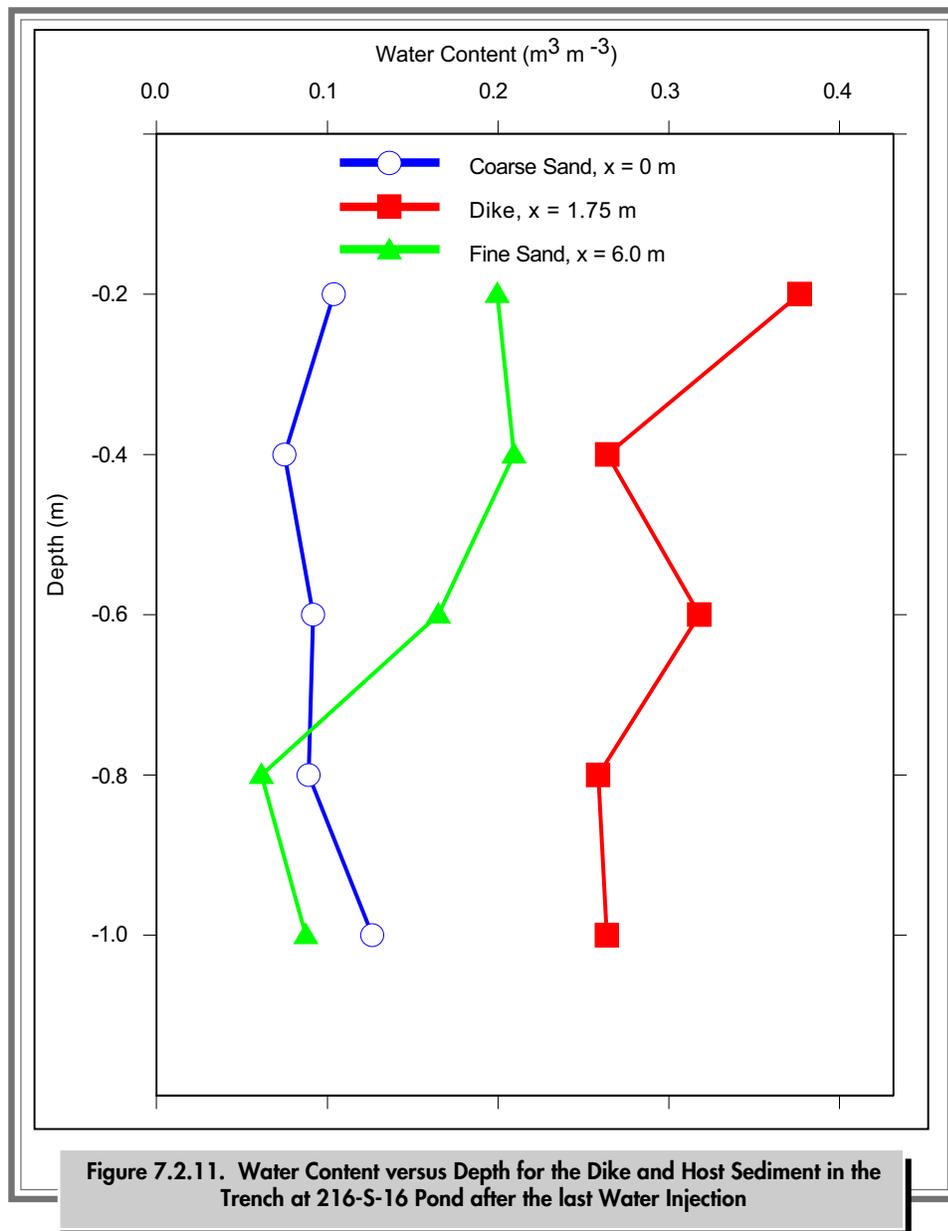


Samples were collected from the dike and host sediment to compare the mineralogy and grain size distribution between the dike and host sediment. Qualitative x-ray diffraction analysis of 21 samples showed that the mineral composition of both the dike and the host sediment were similar.

In addition to the above tests, drip-irrigation and dye-tracer studies were done at the excavation. A drip irrigation system with lines spaced ~5 centimeters (2 inches) apart was used to uniformly deliver known

amounts of water. A vertical and horizontal array of probes was used to measure moisture flow. Also, soil-water pressure head and field-saturated conductivity were monitored.

Figure 7.2.11 shows an example of the water content for three different sediment materials. The data show that the fine-grained material of the dike had the highest water content whereas the coarse-grained host sediment west of the dike (to the left on Figure 7.2.9) had the lowest water content.



The finer-grained host material, to the east of the dike, had intermediate water content.

There were five injections of water during the experiment totaling 738 liters (195 gallons). Figure 7.2.12 shows the distribution of soil moisture three days after the first injection. The figure shows that the wetting front appears deeper in the dike than in the relatively coarser grained host sediment. This is, in part, due to capillary wicking of the finer sediment in the dike. The water was applied so that the soil remained unsaturated; therefore, capillary wicking was quite important. After nearly a week, the entire exposed face on the west of the dike (to the left on Figure 7.2.12) was visibly wet to a depth of greater than 1 meter (3.3 feet), whereas on the east side, the sediment appeared to be uniformly wet to a depth of ~75 centimeters (30 inches), or ~20 centimeters (8 inches) below the bottom of the horizontal clastic sill. This suggests that clastic sills retard vertical movement of moisture.

Brilliant Blue dye was mixed with the water for the last injection. Figure 7.2.13 shows the distribution of dye 1 day after the dye injection and 8 days after the start of the first injection. The dye injection preferentially infiltrates the coarser-grained parts of the dike and the coarse-grained host sediment. The dye trace results suggest that clastic dikes containing fine sediment may actually retard vertical flow rather than act as conduits to fluids applied at the upper surface of the dike. Also, it suggests that such features may act as cutoff walls, limiting the spread of fluids, which otherwise could move significant distances laterally in response to large scale features such as graded horizontal layering, typical of most Hanford sediment.

The trench and dike studies completed in fiscal year 2000 are preliminary tests to prepare for larger scale studies to be done in fiscal year 2001. The main test to be done in the future is a large-scale infiltration test. The infiltration test and geostatistical



Figure 7.2.12. Distribution of Soil Moisture Three Days after the First Injection of Water for the Infiltration Experiment at the 216-S-16 Pond

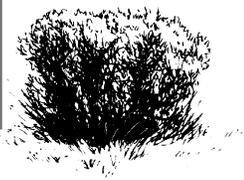




Figure 7.2.13. Dye and Water Distribution in Clastic Dike and Adjacent Host Sediment 1 Day after Dye Injection and 8 Days after the Start of the First Injection

techniques will be used to integrate all data and construct quantitative hydrologic models of the dike and enclosing sediment.

7.2.15 Characterization of the 183-DR Site to Support In Situ Gaseous Reduction Demonstration

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In 2000, both field and laboratory investigations were conducted to support an in situ gaseous reduction technology demonstration in the 100-DR Area. In situ gaseous reduction technology is being developed for remediation of hexavalent chromium at soil

waste sites. The technology involves injecting a mixture of hydrogen sulfide gas mixed with nitrogen or air into chromate contaminated soil through a borehole. The mixture is drawn through the soil by a vacuum applied to extraction wells located around the injection well. Hexavalent chromium is reduced to the trivalent oxidation state as the gas mixture contacts the contaminated soil. The result is immobilization and detoxification of the chromium.

A large plume of groundwater contaminated with chromate exists at the former 183-DR water treatment facility in the 100-DR Area. The shape of the plume suggests that the source is the 183-DR site. If a vadose zone source of hexavalent chromium can be identified and treated, the groundwater plume will eventually dissipate.

Two trenches were excavated and two boreholes drilled to evaluate the distribution of hexavalent chromium in the vadose zone at the former 183-DR water treatment facility. One borehole was drilled to a depth of 30.7 meters (100 feet) and the second to 26.3 meters (86 feet). The deeper borehole was completed as a groundwater monitoring well. Essentially no significant chromium contamination was found in samples from the two boreholes.

In addition to the borehole samples, fifty samples were collected from the trenches and were analyzed for hexavalent chromium. Generally, no significant chromium concentrations were detected.

Laboratory Treatment Testing

Because field characterization at the 183-DR site did not locate a vadose zone source of hexavalent chromium, it is not possible to proceed with an in situ gaseous reduction demonstration at this time. Such a demonstration awaits the discovery of a vadose zone source of hexavalent chromium contamination in the Hanford Site 100 Areas.

7.2.1.6 Characterization at 200-CW-1 Operable Unit

C. S. Cearlock, K. M. Singleton, M. E. Todd, and D. B. Barnett

Bechtel Hanford, Inc. and CH2MHILL Hanford, Inc. characterized the contaminant distribution at four inactive waste sites in 2000 as part of the remedial investigation for the 200-CW-1 Operable Unit (BHI-01367). The waste sites were 216-B-2-2 ditch, 216-B-3-3 ditch, 216-B-3 pond (Main B Pond), and 216-A-25 pond (Gable Mountain Pond), which are all in or near the 200-East Area. All four ditches and ponds are no longer used and have been backfilled. Characterization was accomplished by geologic and geophysical logging, analysis of soil physical properties, and sampling and analysis for chemical and radiochemical constituents. The data collected will

be used to evaluate remedial actions for 24 other analogous sites. This section summarizes the results of the study, which showed no immediate threat to groundwater. A complete description of characterization activities can be found in BHI-01367.

Samples were collected for laboratory analyses from 29 test pits and two boreholes. Two hundred and ten samples were collected from the test pits including 38 quality control samples.

Boreholes were drilled by cable tool and sampled by split spoon methods. Twenty-five samples were collected from the boreholes including eight quality control samples.

Borehole geophysical logging was performed on two new boreholes (B8757 and 699-43-44) and three existing groundwater monitoring wells (699-53-47A, 699-54-49, and 699-55-50) adjacent to Gable Mountain Pond. Spectral gamma and neutron-neutron moisture surveys were conducted in new boreholes drilled through B Pond and Gable Mountain Pond. Only spectral gamma surveys were performed in existing wells. Small-diameter geophysical logging was also conducted at B Pond and the 216-B-2-2 Ditch using the Geoprobe™.^(a) Details of this investigation are presented in BHI-01352 and summarized in Section 7.2.3.2 of this report.

Several metals and anions were found to exceed background levels but most were well below *Model Toxics Control Act* (WAC 173-340) cleanup levels for direct contact. With several exceptions, there were variations in spatial distributions of contaminants with respect to position in the ponds and ditches. As might be expected, higher concentrations tended to be found in the interior of ponds and at the head end of ditches. Also, the highest concentrations of contaminants were in the pond and ditch bottom sediment and concentrations tended to decrease rapidly with depth. Details are provided in BHI-01367 and summarized in the following sections.

(a) Geoprobe is a registered trademark of Geoprobe Systems, Salinas, Kansas.





Gable Mountain Pond

Gable Mountain Pond was a 28.7-hectare (70-acre) natural depression south of Gable Mountain. Gable Mountain Pond routinely received cooling water and other low-level radioactive effluent from several facilities between 1957 and 1987 (DOE/RL-99-07). The pond received 307 billion liters (81 billion gallons) of liquid waste.

Figure 7.2.14 shows the location of the 16 test pits and one borehole (B8757) used for characterization at Gable Mountain Pond. Beneath the pond is basalt overlain by up to ~4 meters (13 feet) of sediment typical of the Hanford formation. Overlying the Hanford formation are 1.5 meters (5 feet) or less of pond sediment. This zone also contains plant material, red and yellow staining, and elevated beta-gamma activity (BHI-01367). Overlying the pond sediment, and extending to the surface, are backfill materials.

Barium, beryllium, nickel, and vanadium were detected in most samples from Gable Mountain Pond near or below the Hanford Site background concentrations (see DOE/RL-92-24 for background values of non-radionuclide constituents). Total chromium, copper, lead, and zinc were detected at concentrations above Hanford Site background but less than the *Model Toxics Control Act* (WAC-173-340) Method B cleanup levels for direct contact (BHI-01367). Four samples contained cadmium at concentrations up to 1.7 mg/kg exceeding the state background level of 1.0 mg/kg. Twelve samples contained arsenic at greater than the Hanford Site background value of 6.5 mg/kg with a maximum concentration of 33.8 mg/kg.

The anions ammonia, chloride, nitrate, and sulfate were detected in most samples. Although the elevated concentrations in several samples were above Hanford Site background levels, all concentrations were less than 25% of the *Model Toxics Control Act* Method B cleanup levels for direct contact (BHI-01367). The maximum anion

concentrations were found typically in the pond bottom samples and concentrations decreased with depth.

No semi-volatile compound or volatile organic compound exceeded the *Model Toxics Control Act* Method B cleanup level for direct contact.

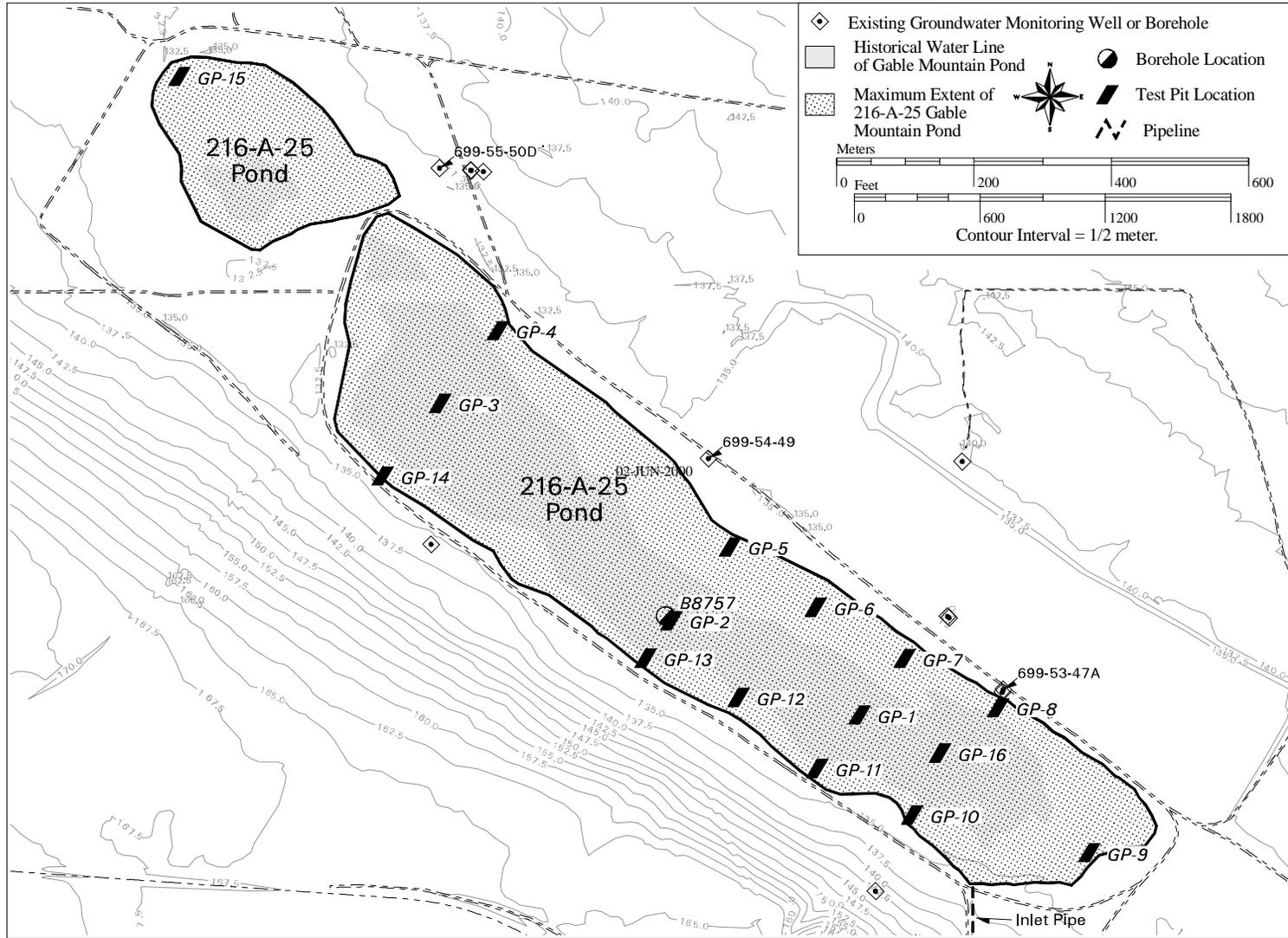
Strontium-90 and cesium-137 were the predominant manmade radionuclides detected in samples from Gable Mountain Pond with maximum concentrations of 58.8 and 7,180 pCi/g, respectively. Figure 7.2.15 shows the distribution of these radionuclides. High concentrations of cesium-137 generally were associated with sediment from the pond bottom and were one to two orders of magnitude higher than concentrations 0.3 to 0.6 meter (1 to 2 feet) deeper. Strontium-90 concentrations tended to increase with depth, and the greatest concentrations were found in the deepest sample from some test pits (7.6 meters or 25 feet). Also, strontium-90 concentrations tended to be higher in the interior of the pond than near the edges.

In addition to cesium-137 and strontium-90, europium-154 was identified in three test pits at a maximum concentration of 3.37 pCi/g and americium-241 was identified in two test pits at a maximum concentration of 1.28 pCi/g. Technetium-99 was identified in one sample at an estimated concentration of 0.458 pCi/g (BHI-01367).

The only manmade radionuclide identified by spectral gamma-ray logging of borehole B8757 at Gable Mountain Pond was cesium-137. The main zone of contamination was relatively thin, between a depth of 3.5 and 3.8 meters (11.5 and 12.5 feet) below ground surface with a maximum concentration of 573 pCi/g.

B Pond (216-B-3 Pond)

B Pond was located adjacent to the northeast corner of the 200-East Area. Throughout its operational lifetime, B Pond varied in size from about 5.7 to 18.6 hectares (14 to 45 acres) (DOE/RL-99-07).

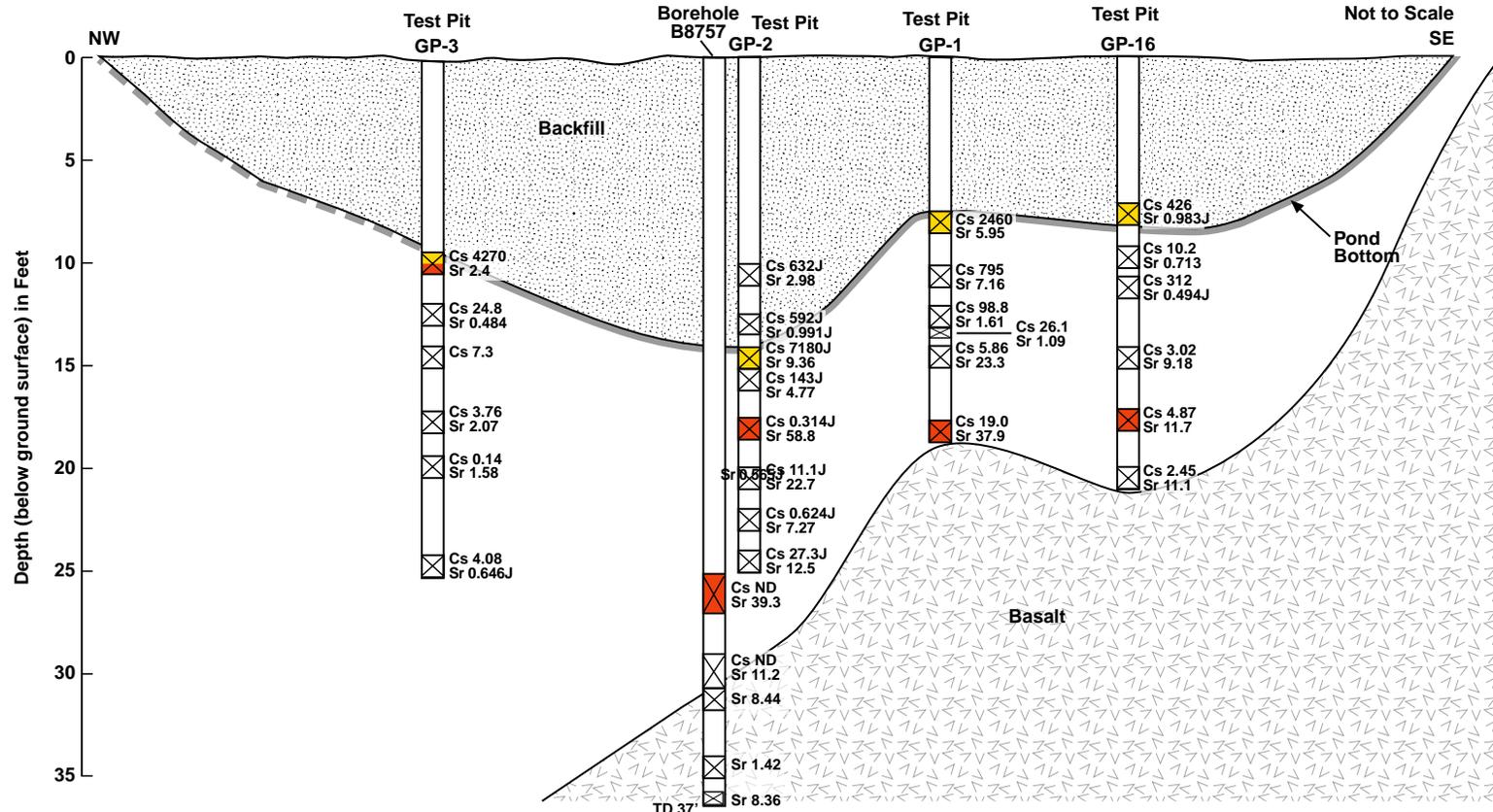


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Figure 7.2.14. Location of the Test Pits and Borehole B8757 at the Former Gable Mountain Pond (from BHI-01367)



Gable Mountain Pond



E0001028_2

Figure 7.2.15. Cross Section of Former Gable Mountain Pond showing the Distribution of Cesium-137 and Strontium-90 (from BHI-01367)

B Pond received an estimated 240 billion liters (63.4 billion gallons) of effluent between 1945 and 1991. The effluent consisted mostly of cooling water and steam condensate.

Figure 7.2.16 shows the location of the five test pits and one borehole (699-43-44, B8758) at B Pond. Beneath the pond is basalt overlain by the lower mud unit of the Ringold Formation. Overlying the Ringold Formation is sandy gravel, gravelly sand, and sand of the Hanford formation. Overlying the Hanford formation are 0.6 to 1.5 meters (2 to 5 feet) of pond sediment and overlying the pond sediment, and extending to the surface, are 1.7 to 3.7 meters (5.5 to 12 feet) of backfill material.

Arsenic, barium, beryllium, chromium, nickel, and vanadium were detected in most samples from B Pond near or below the Hanford Site background concentrations. Copper and zinc were detected at concentrations above Hanford Site background but less than the *Model Toxics Control Act* (WAC 173-340) Method B cleanup levels for direct contact (BHI-01367). Seven samples contained cadmium at concentrations up to 7.3 mg/kg and exceeding the state background level of 1.0 mg/kg. Lead concentrations ranged from 2 to 573 mg/kg of which only the highest concentration exceeded the *Model Toxics Control Act* cleanup level of 253 mg/kg. Four samples contained silver between 0.29 and 9.6 mg/kg with only the highest concentration exceeding the 8 mg/kg *Model Toxics Control Act* cleanup level. Eleven samples contained mercury between 0.05 and 11.9 mg/kg. The maximum concentrations of cadmium, lead, silver, and mercury were in samples of the pond bottom sediments.

The anions chloride, nitrate, and sulfate were detected in most samples. Although the elevated concentrations in several samples were above Hanford Site background levels, all concentrations were less than 10% of the *Model Toxics Control Act* Method B cleanup levels for direct contact (BHI-01367). The maximum anion concentrations were

found typically in the pond bottom samples and concentrations decreased with depth.

No semi-volatile compound or volatile organic compound exceeded the *Model Toxics Control Act* Method B cleanup levels for direct contact.

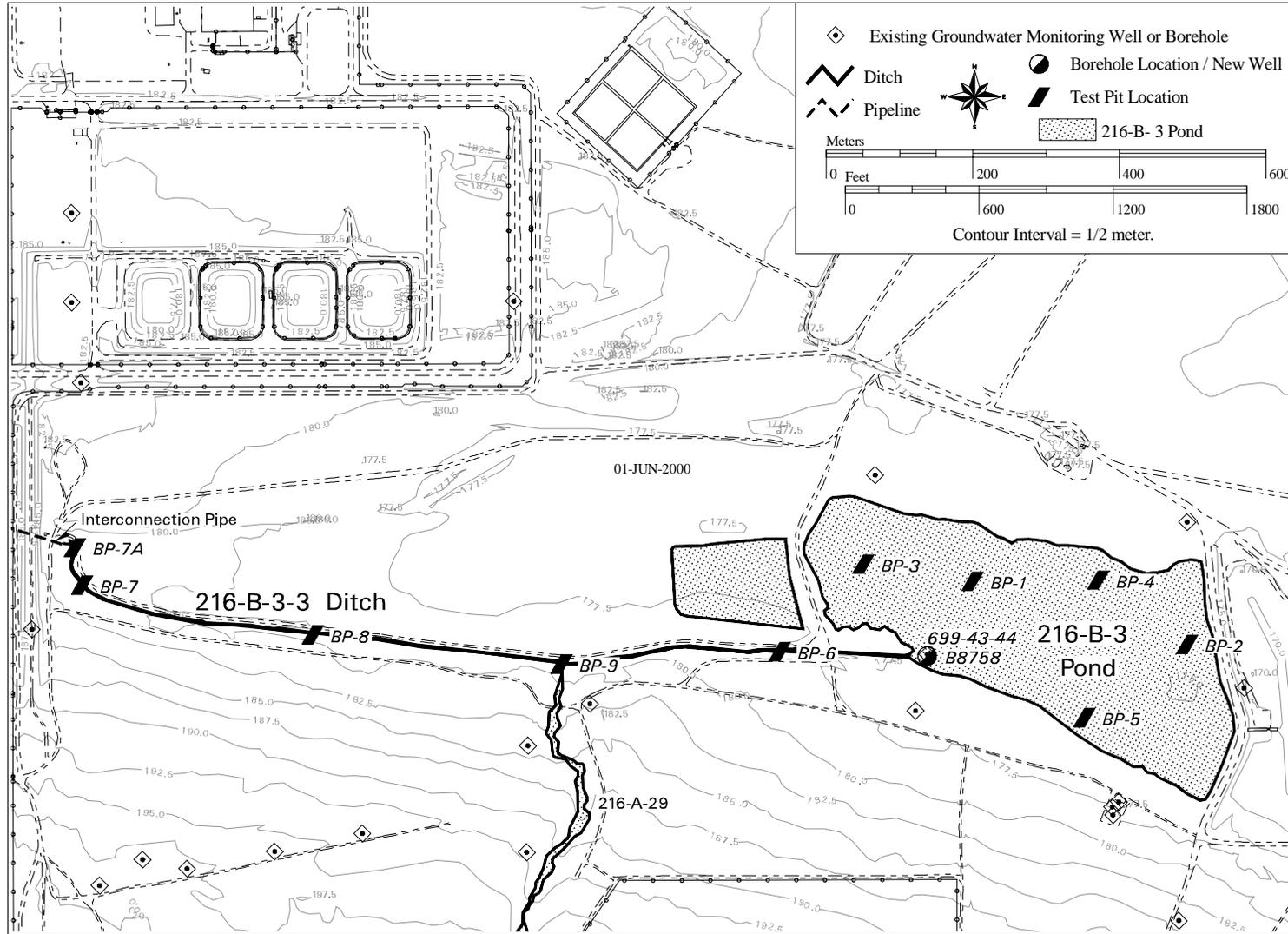
Cesium-137, plutonium-239/240, and strontium-90 were the predominant manmade radionuclides detected in samples from B Pond. The maximum concentration of strontium-90 was 99.9 pCi/g, the maximum cesium-137 was 1,000 pCi/g, and the maximum plutonium-239/240 was 27.5 pCi/g. Americium-241 was found in three test pits with concentrations between 0.083 and 4.96 pCi/g. Figure 7.2.17 shows the distribution of these radioisotopes. The maximum concentrations of americium-241, cesium-137, and plutonium-239/240 generally were associated with the sediment from the bottom of B Pond and were one to two orders of magnitude higher than concentrations 1.5 to 1.8 meters (5 to 6 feet) deeper. Strontium-90 concentrations tend to increase with depth in the test pits, and the maximum strontium-90 concentration was at the bottom of test pit BP-1. In borehole 699-43-44, strontium-90 was not detected below 15.2 meters (50 feet). As at Gable Mountain Pond, concentrations of radioisotopes in B Pond samples tended to be higher in the interior of the pond than near the edges (BHI-01367).

The only manmade radionuclide identified by spectral gamma-ray logging of borehole 699-43-44 at B Pond was cesium-137. Concentrations ranged between 0.9 and 21 pCi/g.

216-B-2-2 Ditch

The 216-B-2-2 ditch carried effluent to B Pond between 1963 and 1970. The ditch has since been backfilled. Three test pits were excavated at the 216-B-2-2 ditch for characterization. Figure 7.2.18 shows the location of the pits. Excavation of the test pits showed that fill material, consisting of silty sandy gravel with minor sand layers, extends from



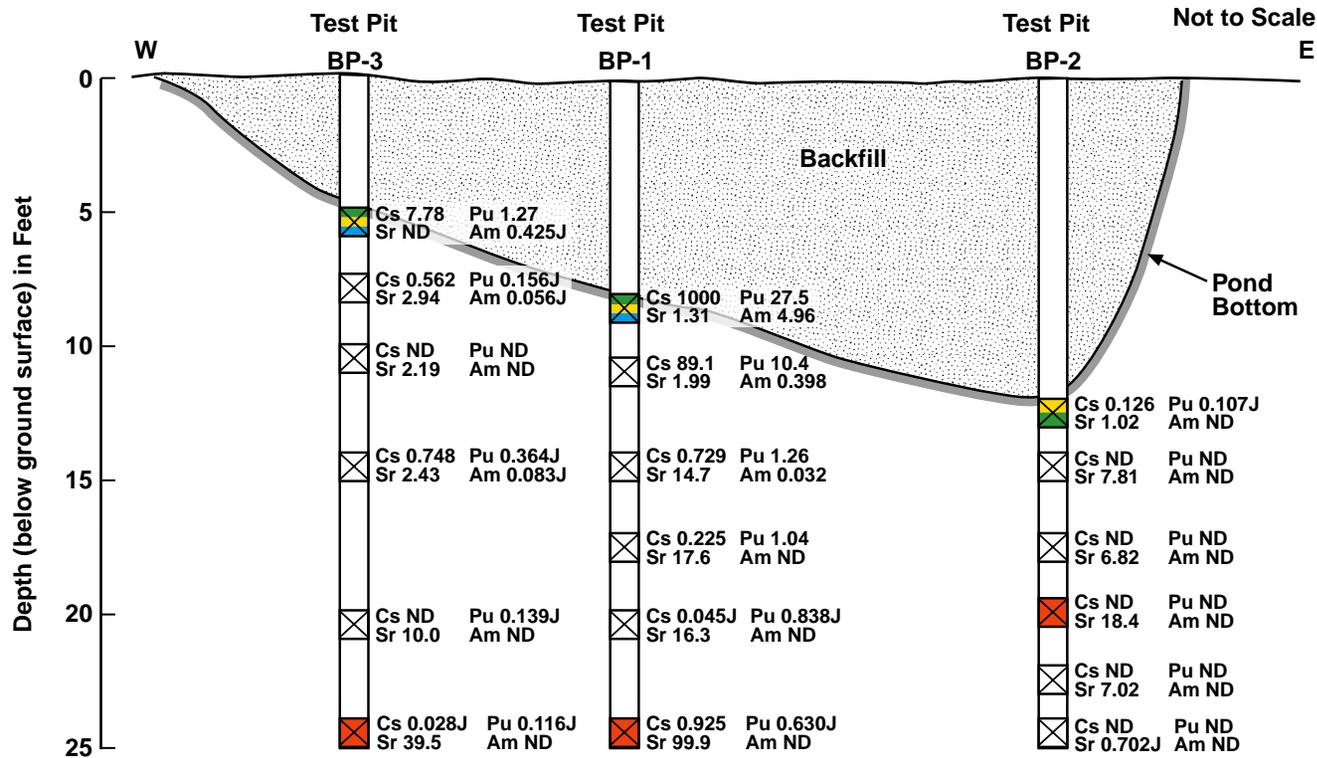


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Figure 7.2.16. Location of Test Pits and Borehole 699-43-44 (B8758) at the Former B Pond and Test Pits at 216-B-3-3 Ditch (from BHI-01367)



216-B-3 Pond



- Cs – Cesium 137
- Sr – Total Strontium
- Pu – Plutonium 239/240
- Am – Americium 241
- ND – Not Detected
- J – Estimated Quantity
- Highest Cesium Concentration in pCi/g for each location
- Highest Strontium Concentration in pCi/g for each location
- Highest Plutonium Concentration in pCi/g for each location
- Highest Americium Concentration in pCi/g for each location
- X Sample Interval

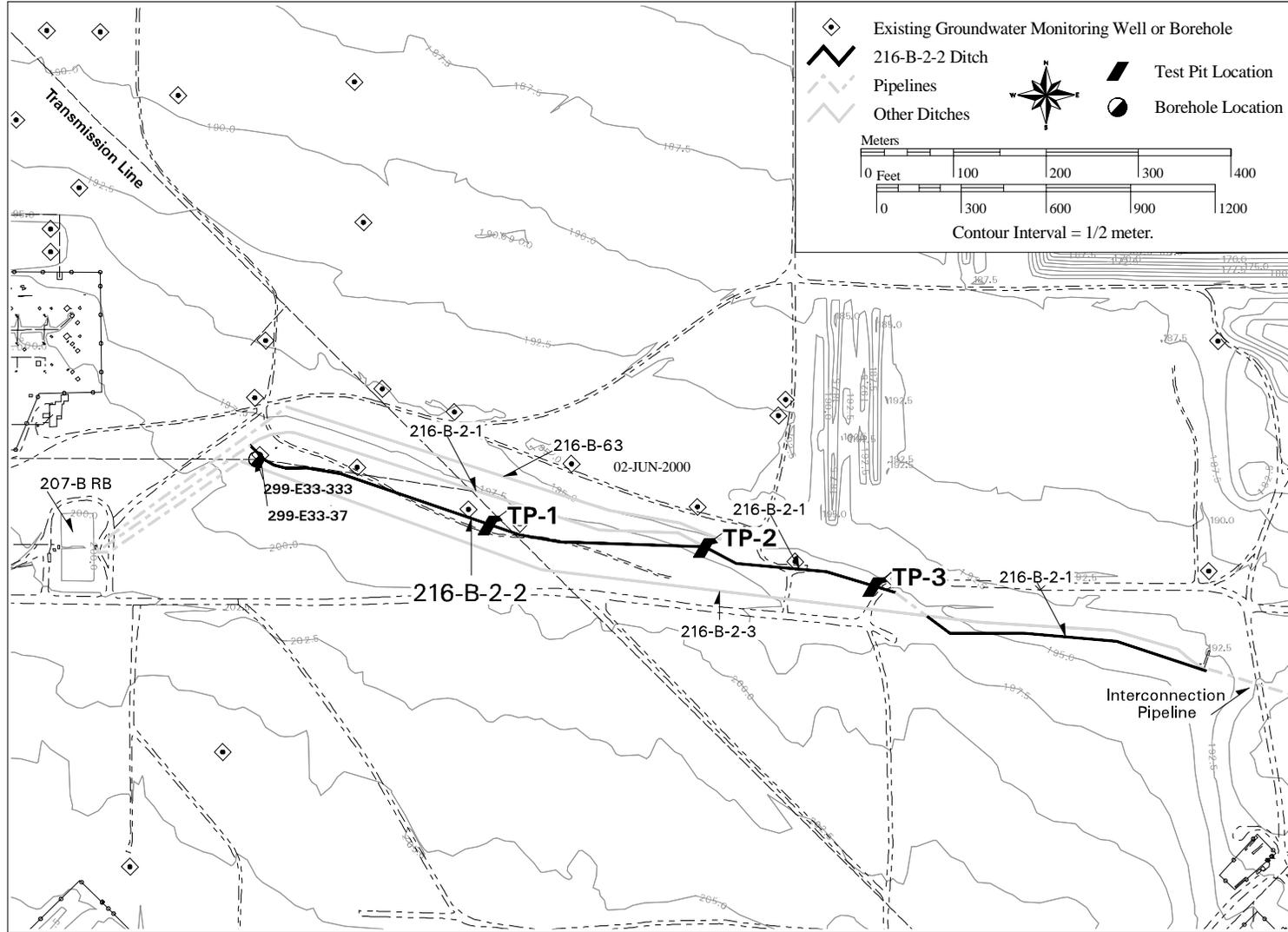
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Figure 7.2.17. Cross Section of the Former B Pond showing the Distribution of Radionuclides beneath the Pond (from BHI-01367)

7.99

Vadose Zone Characterization





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Figure 7.2.18. Location of the 216-B-2-2 Ditch Test Pits (from BHI-01367)



the surface to a depth of 1.8 to 2.7 meters (6 to 9 feet). The bottom of the ditch is represented by less than 1.8 meters (6 feet) of silty sandy gravel and silty sand with localized reddish stains. Hanford formation sediment extends from the ditch bottom to the base of the test pits (BHI-01367).

Arsenic, barium, beryllium, cadmium, chromium, copper, and vanadium were detected in most samples from the test pits near or below the Hanford Site background concentrations. Lead and zinc were detected at concentrations above Hanford Site background but less than the *Model Toxics Control Act* (WAC 173-340) Method B cleanup levels for direct contact. Mercury and silver were detected in bottom sediment from the ditch in test pit TP-1 (see Figure 7.2.18 for location) at 0.93 and 8.4 mg/kg, respectively (less than cleanup levels). Nickel was found at the slightly elevated concentration of 44.8 mg/kg at 0.6 meter (2 feet) below the ditch bottom in test pit TP-1.

The anions ammonia, chloride, nitrate, and sulfate were detected in most samples. Although the elevated concentrations in several samples were above Hanford Site background levels, all concentrations were less than 10% of the *Model Toxics Control Act* Method B cleanup levels for direct contact (BHI-01367).

No semi-volatile compound or volatile organic compound exceeded the *Model Toxics Control Act* Method B cleanup level for direct contact.

The polychlorinated biphenyl (PCB) Aroclor-1260 was identified between 2.4 and 4.6 meters (8 and 15 feet) below ground surface and between 1.3 and 33 mg/kg in test pit TP-1. Also, 6.5 mg/kg of diesel organics were found in a sample from the ditch bottom in pit TP-1, and waste oil constituents were found at three locations between concentrations of 78 and 1,100 mg/kg.

Cesium-137 and strontium-90 were the predominant manmade radionuclides detected in samples from 216-B-2-2 ditch with maximum

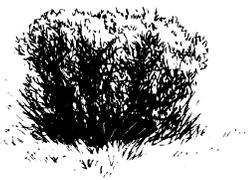
concentrations of 721 and 12,100 pCi/g, respectively. The highest concentrations of cesium-137 and strontium-90 were in a sample of the ditch bottom in test pit TP-1 and were one to two orders of magnitude greater than concentrations 0.3 to 0.6 meter (1 to 2 feet) deeper. Small amounts of americium-241 and europium-154 were found in test pit TP-1 and 0.064 pCi/g plutonium-238 was in one sample from pit TP-3 (BHI-01367). Test pit TP-1 is the nearest pit to the head end of the 216-B-2-2 ditch. The distribution of radionuclides among the three test pits suggests that most contamination remains at the head end of the ditch.

216-B-3-3 Ditch

The 216-B-3-3 ditch began carrying effluent to B Pond in 1970. The ditch has since been backfilled. Five test pits were excavated at the 216-B-3-3 ditch. Figure 7.2.16 shows the location of the pits. Excavation of the test pits showed that fill material, consisting mostly of silty sandy gravel, extends from the surface to a depth of ~1.8 meters (6 feet). The bottom of the ditch is represented by the contact of fill material with up to 3 meters (10 feet) of gravel, sand, and silt. A layer of plant debris was found in this zone. Sediment typical of the Hanford formation extends from a depth of ~3 meters (10 feet) to the base of the pits (BHI-01367).

Barium, beryllium, cadmium, chromium, nickel, vanadium, and zinc were detected near or below the Hanford Site background concentrations in most samples from the 216-B-3-3 ditch. Lead, copper, and silver were found above Hanford Site background levels but less than *Model Toxics Control Act* (WAC 173-340) Method B cleanup levels for direct contact. The highest concentration of mercury was 0.51 mg/kg in test pit BP-9, and arsenic was 14.7 mg/kg in pit BP-6.

The anions ammonia, chloride, nitrate, and sulfate were detected in most samples. Although the elevated concentrations in several samples were above Hanford Site background levels, all





concentrations were less than 5% of the *Model Toxics Control Act* Method B cleanup levels for direct contact (BHI-01367).

No semi-volatile compound or volatile organic compound exceeded the *Model Toxics Control Act* Method B cleanup level for direct contact.

The PCBs Aroclor-1254 and Aroclor-1260 were identified in three of five test pits. Aroclor-1254, up to 38 $\mu\text{g}/\text{kg}$, was in samples from pit BP-9 and Aroclor-1260, between 35 and 440 $\mu\text{g}/\text{kg}$, was identified in pits BP-6 and BP-7A. At all three locations, the highest concentrations of PCBs were found in the ditch bottom sediment. Waste oil was found in pit BP-9 with the maximum concentration of 78 mg/kg in ditch bottom sediment.

Cesium-137 and strontium-90 were the predominant manmade radionuclides detected in samples from 216-B-3-3 ditch with maximum concentrations of 188 and 9.79 pCi/g , respectively, in test pit BP-7A. The highest concentrations of cesium-137 and strontium-90 were in samples of ditch bottom sediment (except in pit BP-9) and were one to two orders of magnitude greater than concentrations 0.3 to 0.6 meter (1 to 2 feet) deeper. Plutonium-239/240 was found in all test pits with concentration between 0.032 to 5.73 pCi/g . There were no significant concentrations of manmade radionuclides found deeper than 4.6 meters (15 feet) below the ground surface (BHI-01367).

7.2.1.7 Immobilized Low-Activity Waste

D. G. Horton

The DOE Office of River Protection is responsible for safely disposing of the portion of single- and double-shell tank waste that is classified as low-activity waste. The current plan is to vitrify the waste and bury the low activity portion as solid waste in shallow, near-surface facilities. The Hanford Immobilized Low-Activity Tank Waste Performance

Assessment is currently underway to assess the performance of the disposal facilities. The goal is to provide a reasonable expectation that the disposal of the waste protects the general public and environmental resources. Fifteen data packages were issued in fiscal year 2000 to support the 2001 Immobilized Low-Activity Waste Performance Assessment (HNF-5636). This section summarizes four of those data packages that pertain directly to the vadose zone:

- *Geologic Data Package for 2001 Immobilized Low-Activity Waste Performance Assessment* (PNNL-12257)
- *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment* (PNNL-13033)
- *Geochemistry Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment* (PNNL-13037)
- *Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment* (HNF-4769).

Geology

Geologic information was compiled for two proposed immobilized low-activity waste disposal sites. The first site is the area of the former grout treatment facility east of the 200-East Area. The second is an area in the south-central part of the 200-East Area. Data were compiled from both surface and subsurface sources including published geologic maps, driller's and geologist's logs, archived samples, and geophysical logs. Uncertainty in the data is mainly related to borehole information. Variations in sampling and drilling techniques cause some correlation uncertainties across the sites.

The information consists of tables of geologic contacts from all wells and boreholes associated with the two sites. From this information, cross sections, structure contour maps, and fence diagrams were made depicting the subsurface lithology, stratigraphy and structure. The seismicity of the areas was

also discussed. Few earthquakes have occurred in the area and most were less than coda magnitude 3.0 (coda magnitude is a local magnitude that approximates the Richter magnitude).

The data supplied in the geology data package are used to construct conceptual models considered in the remaining three data packages.

Recharge

Estimates of recharge rates were made for both current conditions and long-term scenarios involving the shallow land disposal of immobilized low-activity waste to support the 2001 Performance Assessment. The Performance Assessment requires recharge estimates for the surface cover, the cover sideslope, the immediately surrounding soil, and a degraded cover. The following discussion is from PNNL-13033.

Table 7.2.2 gives the recharge estimates for the best estimate case and upper and lower bounding cases. The best estimate case is the situation for

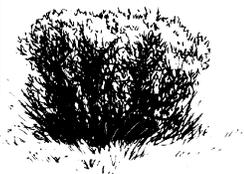
which all disposal facility features function as expected, a shrub-steppe plant community surrounds the site, the climate is the same as today, and no irrigated farming occurs at the site. The lower bounding case assumes the same conditions as the best estimate case but with the lowest possible recharge. The upper bounding case assumed the best estimate case conditions with the exception of either erosion of part of the surface cover or sand deposition on the surface cover and a sparse shrub-steppe cover on the surround soil. The recharge estimates for each case were derived from lysimeter and tracer data and from modeling analyses.

The most important feature of the disposal facility is expected to be a modified RCRA Subtitle C cover. This uses a 1-meter-thick (3.3-foot-thick) silt loam over sand and gravel layers to create a capillary break. A 0.15-meter-thick (0.5-foot-thick) asphalt layer underlies the sand and gravel to promote lateral drainage. Sideslopes are expected to be sandy gravel at a 1:10 (vertical to horizontal) slope.

Table 7.2.2. Recharge Estimates for the Best Estimate Case and Reasonable Bounding Cases during each Period of Interest to the Immobilized Low-Activity Waste Performance Assessment (from PNNL-13033)

Surface Feature	Estimated Recharge Rates for the Best Estimated Case (and Reasonable Bounding Cases) (mm/yr)			
	Time Period of Recharge Evaluation			
	Pre-Hanford Site	During Disposal Operations	During Surface Cover Design Life	After Surface Cover Design Life
Modified RCRA Subtitle C Cover	NA	NA	0.1 (0.01, 4.0)	0.1 (0.01, 4.0)
Cover Sideslope	NA	NA	50 (4.2, 86.4)	50 (4.2, 86.4)
Rupert Sand	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)	0.9 (0.16, 4.0)
Burbank Loamy Sand	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)	4.2 (2.8, 5.5)
Hanford formation	NA	55.4 (50, 86.4)	NA	NA

NA = Not applicable.





A recharge rate of 0.1 mm/yr (0.004 in./yr) is estimated for the surface cover (PNNL-13033). Although the cover design goal is 0.05 mm/yr (0.02 in./yr), the rate of 0.1 mm/yr is used because it is closer to actual rates measured with lysimeters. Modeling results showed that erosion of the top 20% of the cover or deposition of 20 centimeters (8 inches) of sand on the cover did not impair performance.

A recharge rate of 50 mm/yr (2 in./yr) is estimated for the sideslope, which is lower than the 75 mm/yr (3 in./yr) used in the 1998 Performance Assessment. For a soil type known as the Rupert sand with shrub-steppe plant community, an estimate of 0.9 mm/yr (0.04 in./yr) is given, which is lower than the 3 mm/yr (0.12 in./yr) rate used in the 1998 Performance Assessment. For a soil type known as the Burbank loamy sand with the same plant community, an estimated rate of 4.2 mm/yr (0.16 in./yr) is given. Finally, a recharge rate of 55.4 mm/yr (2.2 in./yr) is given for Hanford formation sediment during construction. Neither the Burbank loamy sand or the Hanford formation were considered in the 1998 Performance Assessment.

Modeling sensitivity tests showed that the cover limited recharge to less than 0.1 mm/yr (0.004 in./yr) regardless of plant type, the presence of plants, or any reasonable climate change. However, recharge rates into the Rupert sand and the Burbank loamy sand increased when the vegetation type or the climate were changed. A complete description of the work can be found in PNNL-13033.

Geochemistry

The geochemical properties of the materials comprising the Immobilized Low-Activity Waste Disposal Facility, the disturbed region around the facility, and the physically undisturbed sediments below the facility were estimated to support the Immobilized Low-Activity Waste 2001 Performance Assessment. The geochemical parameters that were estimated are the distribution coefficient (K_d), which is used to quantify adsorption, and the solution concentration limit, used to quantify solubility. A

complete discussion of the estimates and their sources can be found in PNNL-13037 from which the following summary was taken.

Best estimates were made for K_d s and solution concentration limits for each of five expected environments in the disposal system. One of the five environments was a concrete vault. The current design for the disposal facility does not include the vault. The five environments and the geochemical characteristics used to evaluate K_d s are shown in Table 7.2.3.

Most probable “empirical” K_d values and/or solubility values, reasonable lower-bounding estimates, and a likely range of values are given in PNNL-13037 for each radionuclide considered in the 1998 Performance Assessment in each geochemical environment. Where possible, estimates were based on specific Hanford Site experiments. Literature or offsite data were used where no site-specific data were available. Attempts were made to choose literature values that were appropriate for the Hanford Site. In a few cases, no data were available and estimates were based on “expert judgement.”

K_d s for the radionuclides in the gravel-dominated environment were corrected for gravel content. The correction was based on the assumption that the gravel fraction had no sorption capacity and was made according to $K_{dgc} = (1-g)K_d$ where K_{dgc} is the gravel-corrected distribution coefficient, g is the weight fraction of gravel in the sample, and K_d is the measured or literature value from samples containing no gravel. The correction provides more conservative K_d s for the Immobilized Low-Activity Waste Performance Assessment than do uncorrected values.

The conservative K_d s are reasonable lower-bounding values that consider conditions that may enhance radionuclide transport. The lower value from the range of values was usually taken as the reasonable conservative K_d . The best estimates were selected as the central value of the available data

Table 7.2.3. Five Conceptual Geochemical Environments Associated with the Immobilized Low-Activity Waste Disposal Facility (from PNNL-13037)

<u>Zone</u>	<u>Solid Phases</u>	<u>Aqueous Phase</u>	<u>Appropriate Geochemical Parameters</u>
Near field	Glass, secondary phases from glass degradation, backfill, engineered barrier materials	Glass leachate: high pH, high ionic strength, high radionuclide concentrations	K_d Solubility constraints
Degraded concrete vault	Three assemblages based on concrete age: fresh concrete with pH = 12.5, moderately aged concrete with pH ~10.5, and completely aged concrete with pH ~8.5	Three leachate chemistries controlled by different aged concrete: pH values of 12.5, 10.5, and 8.5 to match solid phases; generally high ionic strength and high radionuclide concentration	K_d Solubility constraints
Chemically impacted far field in Hanford formation sand sequence	Sand-dominated sequence altered because of contact with moderately caustic aqueous phase	pH 8 to 11, ionic strength 0.01 to 0.1, low radionuclide concentration	K_d
Chemically impacted far field in Hanford formation gravel sequence	Gravel-dominated sequence altered because of contact with moderately caustic aqueous phase	pH 8 to 11, ionic strength 0.01 to 0.1, low radionuclide concentration	K_{dgc}
Far field in a Hanford formation gravel sequence	Unaltered Hanford formation gravel sequence	Unaltered Hanford Site groundwater with trace of radionuclides	K_{dgc}

and on expert judgement. Supporting references for the selection of all values are given in PNNL-13037.

Hydrology

The hydrologic data needed to perform far-field vadose zone flow and transport modeling for the Immobilized Low-Activity Waste Performance Assessment were compiled in fiscal year 2000. This section summarizes the content of the material in the data package. The actual data along with discussions of the data are presented in HNF-4769.

The hydrologic data package presented results of previously determined laboratory measurements of physical and hydraulic properties measured from core samples of the Hanford formation sand-dominated sequence obtained at the Immobilized Low-Activity Waste Disposal Facility in south-central 200-East Area and samples of the Hanford formation gravel-dominated sequence obtained from the 100 Areas and extrapolated to the disposal site. Laboratory measurements were compiled for moisture retention,

particle-size distribution, saturated and unsaturated hydraulic conductivity, and bulk density.

The numerical models of flow and transport of fluids and contaminants in the unsaturated zone require hydraulic properties scaled to discrete grid blocks (scales on the order of meters). The laboratory measured hydraulic properties were obtained from core samples and are applicable to scales of a few centimeters. Therefore, hydraulic parameter estimates need to be extrapolated from the laboratory scale to the field scale. The hydrologic data package presents the methodology and results of extrapolating the flow parameters of moisture retention and saturated and unsaturated hydraulic conductivity and the transport parameters of bulk density, diffusivity, and macrodispersivity. Extrapolated parameters are presented for both the sand-dominated and the gravel-dominated sediment of the Hanford formation.





The data package presents a method to estimate uncertainties in model predictions of far-field hydrologic behavior. Uncertainty estimates on model predictions include 1) variations in model configurations, 2) uncertainties in the calculated mean solution for concentration, and 3) variance around the calculated mean solution for concentration. Variations in model configuration include variations in stratigraphy, presence of discontinuities such as clastic dikes, the degree of homogeneity in the stratigraphy, and the orientation of the sedimentary layers (dip). Uncertainties in the calculated mean solution for concentration include the variations in the conceptual model mentioned above and sensitivity of the model predictions due to variations in extrapolated input parameters.

Uncertainties in far-field hydrologic behavior predicted by the numerical models will be calculated as part of the Immobilized Low-Activity Waste Performance Assessment.

7.2.1.8 Characterization of Standard Hanford and Ringold Formation Samples

H. T. Schaefer and D. G. Horton

Pacific Northwest National Laboratory, Bechtel Hanford Inc., and CH2M HILL Hanford Group collected large quantities of Ringold and Hanford Formation sediment in fiscal year 1999. The purpose of the samples was to establish well characterized “standards” to be made available to researchers throughout the Hanford Site, the DOE complex, and academia that wish to study problems associated with the cleanup of the Hanford Site.

Characterization was conducted throughout the year 2000 and included determinations of

- water content
- particle size distribution

- particle density
- calcium carbonate and organic carbon content
- bulk chemical composition
- cation exchange capacity
- pore water composition
- 1:1 water extract pH and cation, anion, and trace element compositions
- nitric acid extract compositions
- mineralogy of the bulk sample and the silt and clay fractions.

This section summarizes the mineralogy results available in 2000.

The Samples

Three areas were sampled on or adjacent to the Hanford Site: the 218-E-12B burial ground (submarine pit) in 200-East Area, the Environmental Restoration Disposal Facility near 200-West Area, and the White Bluffs located east of the Columbia River in Franklin County. Only samples from the 218-E-12B burial ground and the White Bluffs were characterized in 2000. The White Bluffs’ sample consisted of silt from the Upper Ringold Formation. Samples from the 218-E-12B burial ground were 1) pebbly sand (hereafter termed Hanford coarse sand) representing the sand-dominated facies of the Hanford formation and 2) silty, fine sand (called the Hanford fine sand) representing the silt-dominated facies of the Hanford formation.

A fourth sample was a composite of sediment from drill cores obtained from borehole 299-W22-50 located east of the SX tank farm in 200-West Area. The borehole sample was a slightly silty medium to fine sand (called the borehole fine sand in this description) of the Hanford formation and represents the fine-grained strata underlying many of the single-shell tanks in 200-West Area.

All samples were air dried and homogenized prior to any testing.

Semi-quantitative mineralogy of the four “standard” samples was determined by x-ray diffraction on both the bulk sediment samples and on the separated $\leq 2 \mu\text{m}$ size fractions (clay fractions) of the samples.

Summary of Results

X-ray diffraction analysis of the bulk sediment shows that the samples are mostly quartz (30 to 80 wt.%) and plagioclase feldspar (5 to 20 wt.%), with minor amounts of potassium feldspar (<10 wt.%) and amphibole. Calcite was identified in the Ringold Formation sediment at <5 wt.%. Mica and/or clay minerals are evident in the bulk sample but were not quantified. Mica and chlorite are more abundant in the Ringold Formation silt than in the Hanford formation sediment.

The $< 2 \mu\text{m}$ size fraction of all four samples is dominated by four clay minerals: illite (15 to 40 wt.%), smectite (30 to 40 wt.%), chlorite (~15 to 20 wt.%), and minor kaolinite. Minor amounts of quartz, feldspars, and amphibole are also present.

In addition to the x-ray diffraction analyses, some transmission electron microscopy was done on the samples. The analyses show that the mineral illite and not just detrital muscovite occurs in the clay size fraction. This distinction is important when considering the nature and types of cation exchange sites available for contaminant sorption. The cation exchange capacity of muscovite mica can be 75% less than that of illite; thus, illite has a greater capacity to sorb some contaminants.

7.2.2 Vadose Zone Monitoring

D. G. Horton

Vadose zone monitoring occurred at four sites at the Hanford Site in the year 2000. Leachate and soil gas monitoring continued at the Solid Waste Landfill and the Environmental Restoration Disposal Facility and historical results from the 3-year period 1996 to 1999 were summarized for the Environmental Restoration Disposal Facility. Also, soil gas monitoring at the carbon tetrachloride expedited response action site continued during 2000. Finally, soil gas monitoring was done at the 618-11 burial ground in response to elevated levels of tritium discovered during 2000. This section summarizes the vadose zone monitoring efforts that occurred during the past year.

7.2.2.1 Helium-3/Helium-4 Ratios in Soil Gas as an Indicator of Subsurface Tritium Contamination at the 618-11 Burial Ground Site

K. B. Olsen, P. E. Dresel, J. C. Evans, G. W. Patton, J. V. Borghese, R. W. Ovink, and J. M. Faurote

A groundwater sample collected in January 2000 from well 699-13-3A (see Figure 7.1.17 for location), located along the eastern fence line of the 618-11 burial ground, contained 8.1 million pCi/L of tritium. This is the highest concentration of tritium detected at the Hanford Site in recent years. An investigation to determine the extent of the groundwater contamination was begun in 2000. As part of the investigation, a soil gas survey was begun at the burial ground during the summer to determine the





distribution of tritium. Section 7.1.6 discusses the results of the groundwater investigation at the 618-11 burial ground. This section summarizes the soil gas investigation.

Samples of soil gas collected at the 618-11 burial ground were analyzed for helium-3 concentrations in an effort to locate tritium contamination in the subsurface. The technique is based on the decay of tritium, with a half-life of 12.32 years. Tritium decays to the stable, inert isotope helium-3. As tritium decays, its daughter isotope, helium-3, begins to build up in the vadose zone and groundwater at the rate of tritium decay. The helium-3 then diffuses away from the source and toward the surface. Throughout this process, helium-3 acts as a non-reactive tracer moving through the vadose zone. The soil gas monitoring at the 618-11 burial ground was based on the detection of helium-3 in the soil gas to identify vadose or groundwater sources of tritium in the subsurface environment.

Soil Gas Sampling and Analysis

Fifty-four soil gas sampling points were installed north and east of the 618-11 burial ground and up to 120 meters (395 feet) to the east of well 699-13-3A (Figure 7.2.19). All sampling points were completed at 6 meters (20 feet) below ground surface. Soil gas sampling points were installed using a truck mounted Geoprobe™ system equipped with a 1.25-inch-diameter probe and a detachable steel tip. Each sampling location was allowed to equilibrate for at least 24 hours before soil gas samples were collected. All samples were collected with a flexible diaphragm pump.

Fifty-milliliter (1.7-ounce) samples were collected for analysis of helium-3/helium-4 ratios from each sampling location near 618-11 burial ground. Helium-4 is the natural form of helium and does not change, whereas helium-3 increases as tritium decays. Thus, an increase in the helium-3/helium-4 ratio indicates an increase in tritium. After collection, soil gas samples were sent to the University of Rochester for helium isotope analysis. All

helium-3/helium-4 ratios were reported relative to the atmospheric ratio (R_A), using air helium as the absolute standard.

Two groundwater samples also were collected to determine tritium concentrations; one sample was collected from the area with the highest helium-3/helium-4 ratio on the north side of the burial ground, and the second was collected ~60 meters to the east of well 699-13-3A (see Figure 7.2.19).

Results and Discussion

The results of soil gas analyses of samples from the west and south sides of the 618-11 burial ground were near background (that is, near the value of ambient air normalized to 1.0). Helium-3/helium-4 ratios from samples from the north and east sides of the burial ground, however, were larger than ambient air indicating tritium decay. The largest value was 62.5 times greater than the atmospheric ratio (see Figure 7.2.19). The largest values were about midway between the east and west ends of the burial ground, north of a series of disposal caissons. A groundwater grab sample collected from a well near the maximum helium-3/helium-4 value contained only 6,500 pCi/L tritium, however. This suggests that the helium-3 enrichment resulted from a vadose zone source of tritium in the area. The area of high helium-3/helium-4 may represent a “halo” of elevated helium-3 in the vadose zone surrounding the tritium source within the burial ground.

A second area of elevated helium-3/helium-4 occurs at the northeastern corner of the burial ground with a maximum ratio of 10.9. A groundwater sample has not been collected at this location. If the helium-3 at this location is from tritium in groundwater, then the concentration of tritium in groundwater can be estimated to be about 24 million pCi/L based on scaling the concentration of tritium in groundwater at well 699-13-3A (~8 million pCi/L) and the helium-3/helium-4 (3.69) directly adjacent to the well.

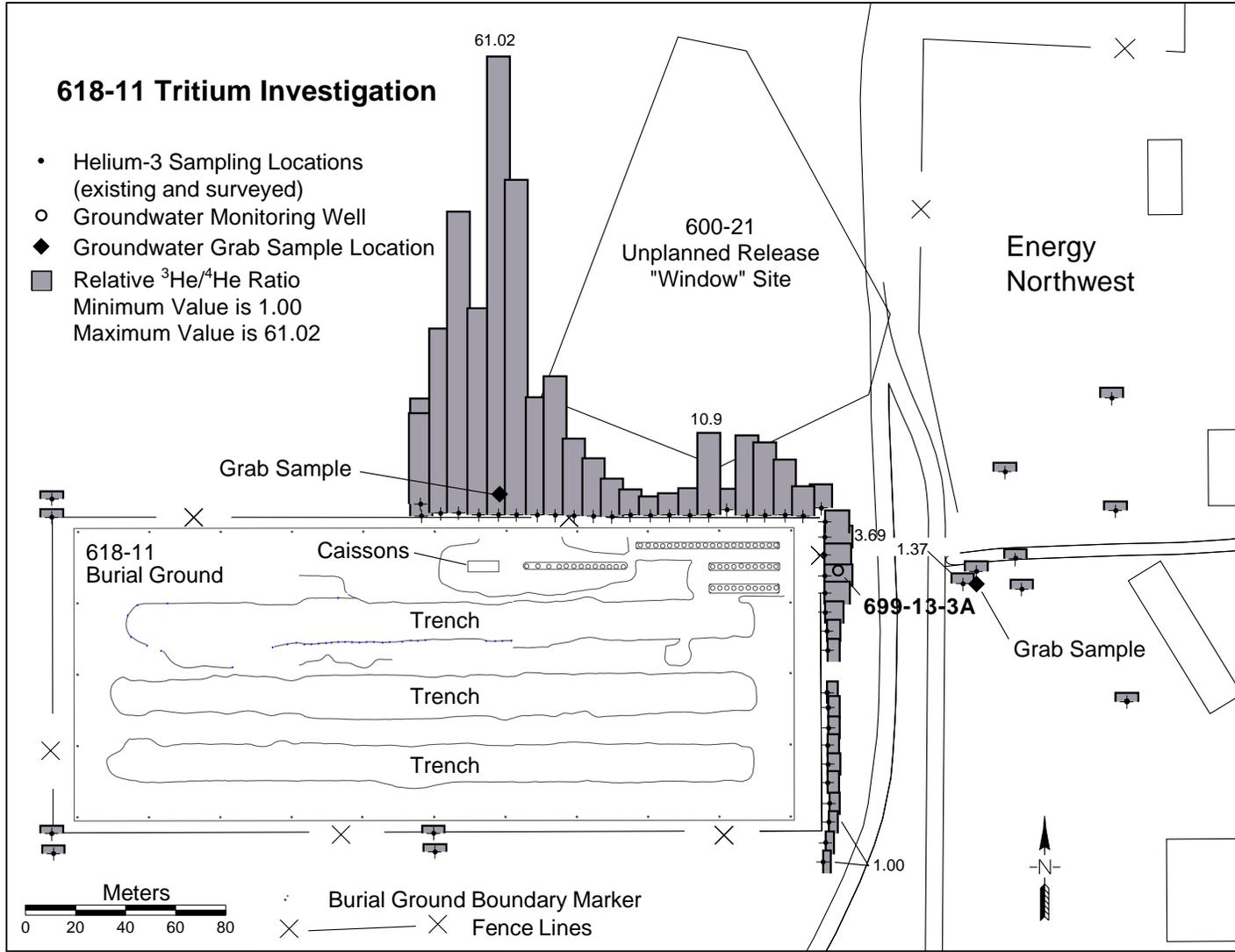


Figure 7.2.19. Relative Helium-3/Helium-4 Ratios at Soil Gas Sampling Locations around the 618-11 Burial Ground





A tritium concentration of 1.5 million pCi/L was measured in a groundwater sample collected from a borehole ~80 meters (260 feet) east of well 699-13-3A. This value is consistent with the helium-3/helium-4 ratio (1.37) that would be predicted by scaling the values given in the above paragraph.

Year 2001 studies are planned to further define the extent of the groundwater tritium plume. Helium-3/helium-4 ratios from additional soil gas monitoring points will be used to determine locations for collection of groundwater samples.

7.2.2.2 Leachate Monitoring at the Environmental Restoration Disposal Facility

J. M. Faurote

Bechtel Hanford, Inc. operates the Environmental Restoration Disposal Facility to dispose of radioactive, hazardous or dangerous, and mixed waste generated during waste management and remediation activities at the Hanford Site. In 2000, Bechtel Hanford, Inc. published the results of groundwater monitoring and sampling at the Environmental Restoration Disposal Facility during the first four years of operation (BHI-01382). Part of the published results contains laboratory analyses of leachate collected from beneath the facility. This section discusses those results.

The Environmental Restoration Disposal Facility began operation in July 1996. Located between the 200-East and 200-West Areas (see Figure 7.1.1), the facility is currently operating two trenches covering 10.3 hectares (25 acres). Each trench is lined to collect leachate resulting from water added as a dust suppressant and precipitation. The liner is sloped to a sump and the leachate is pumped from the sump to tanks. After about 757,080 liters (200,000 gallons) of leachate are collected, samples are taken and

analyzed. Analyses are made for 41 volatile organics, 64 semi-volatile organics, 23 metals, and 9 radionuclides. Gross alpha and gross beta analyses are also done. The number of samples depends on the amount of leachate collected.

The purposes of the data are to provide an inventory to the Effluent Treatment Facility, where the leachate is disposed, and to determine whether additional analytes should be added to the groundwater-monitoring list.

Analyses of leachate collected from the Environmental Restoration Disposal Facility show that the liquid collected so far contains no elevated levels of contaminants of concern (BHI-01382). Small levels of common laboratory organics used during analyses are present. A few analytes showed statistically significant increases in groundwater samples since operations began. However, leachate samples contain no constituents of concern for groundwater and no leachate has been released to the soil column at the Environmental Restoration Disposal Facility.

7.2.2.3 Leachate and Soil Gas Monitoring at the Solid Waste Landfill

R. A. Del Mar and D. G. Horton

The Solid Waste Landfill is a land disposal facility in the center of the Hanford Site (labeled as Central Landfill on Figure 7.1.1). The Solid Waste Landfill began operation in 1973; it received non-hazardous, non-radioactive sanitary waste generated from site operations. The Solid Waste Landfill stopped receiving waste in 1996 and an “interim cover” was placed over all trenches. Current monitoring at the Solid Waste Landfill includes leachate, soil gas, and groundwater. Recent groundwater monitoring results are discussed in Section 7.1.6. This section summarizes the leachate and soil gas

results reported by DynCorp Environmental Programs and Compliance to the U.S. Department of Energy (DOE).^(b,c)

One of the double trenches in the Solid Waste Landfill overlies a lined, basin lysimeter designed to collect leachate generated by infiltration through the overlying refuse. The lysimeter covers an area of about 88 square meters (947 square feet). A discharge pipe continuously drains leachate by gravity flow from the basin to a nearby collection pump (BHI-01063). Leachate is only collected from under two of more than 90 buried trenches and the two trenches are newer trenches built after implementation of regulations restricting land disposal practices.

Therefore, the analytical results from the lysimeter may not reflect leachate draining from most trenches.

Figure 7.2.20 shows the volume of leachate collected since routine monitoring began in 1997. The volume collected is consistent with expected infiltration rates at the Solid Waste Landfill. Table 7.2.4 shows analytical results for several key indicator parameters, metals, anions, and organics in leachate samples during fiscal year 2000. The data show that some indicator parameters and some organic and metal constituents continue to be above the groundwater quality criteria (WAC 173-200) and/or maximum contaminant levels (WAC 246-290).

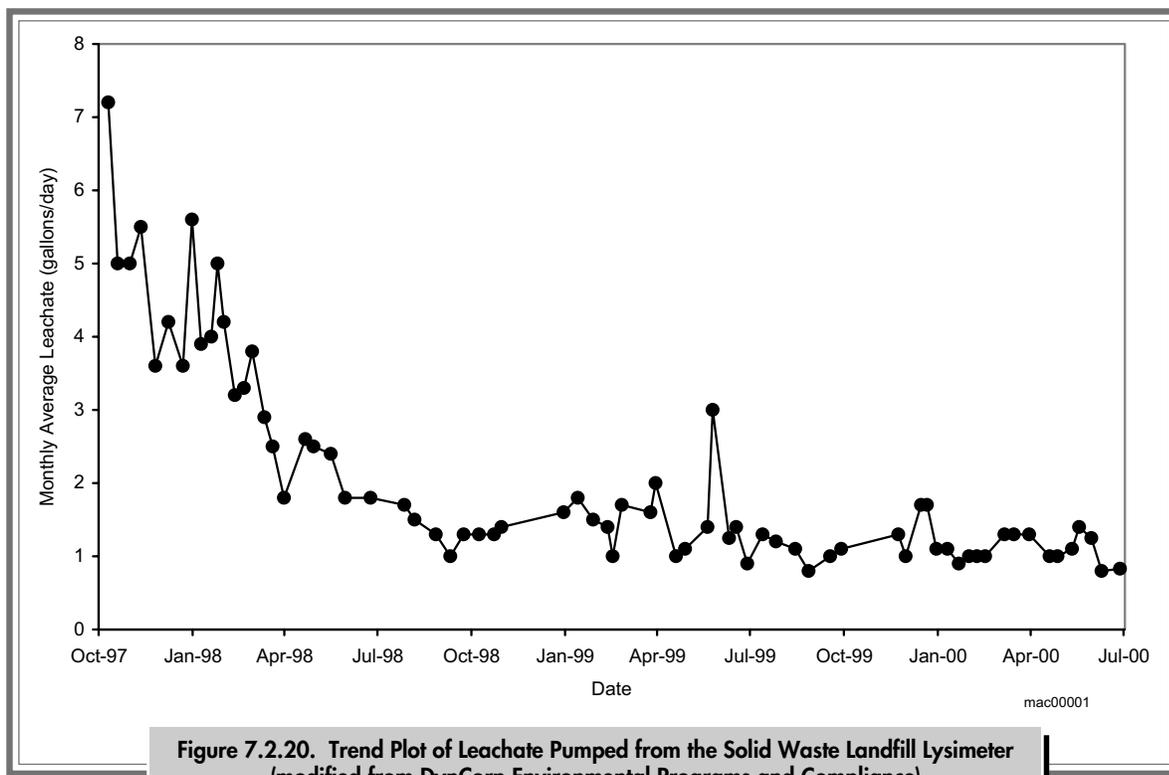


Figure 7.2.20. Trend Plot of Leachate Pumped from the Solid Waste Landfill Lysimeter (modified from DynCorp Environmental Programs and Compliance)

(b) Letter report FH-0001763, *Submittal of Solid Waste Landfill Leachate, Soil Gas, and Groundwater Monitoring Results from Fourth Quarter, Calendar Year 1999*, from D. S. Kelly, Fluor Hanford, Inc. to S. H. Wisness, DOE/RL, Richland, Washington, dated May 3, 2000.

(c) Letter report FH-0002667, *Submittal of Solid Waste Landfill Leachate, Soil Gas, and Groundwater Monitoring Results from First and Second Quarters, Calendar Year 2000*, from D. S. Kelly, Fluor Hanford, Inc. to S. T. Burnum, DOE/RL, Richland, Washington, dated September 20, 2000.

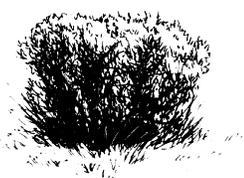




Table 7.2.4. Fiscal Year 2000 Leachate Monitoring Results from the Solid Waste Landfill

Parameter	Results			GWQC ^(a)	MCL ^(b)
	First Quarter	Second Quarter	Third Quarter		
pH	7.6	6.14	7.43	6.5 - 8.5	NA ^(c)
Conductivity (µS/cm)	2,000	1,970	1,943	NA	700
Sulfate (mg/L)	8	8	7.7	250	250
Chloride (mg/L)	238.9	223.5	188.3	250	250
Total dissolved solids (mg/L)	1,300	1,288	1,297	500	NA
Arsenic (µg/L)	19.2	17.5	13	0.05	50
Barium (µg/L)	458	444	384	1,000	2,000
Manganese (µg/L)	2,480	2,480	2,310	50	50
Nickel (µg/L)	208	179	191	NA	100
Cadmium (µg/L)	<0.5	0.45	0.29	10	5
Copper (µg/L)	7.97	4.05	2.78	1,000	NA
Selenium (µg/L)	3.65	2.79	2.48	10	50
Zinc (µg/L)	1,490	649	448	5,000	5,000
1,4-Dioxane (µg/L)	180	150	57	7	NA
1,4-Dichlorobenzene (µg/L)	6	6	4	4	NA
Total organic halides (µg/L)	742	586	945	NA	NA
Acetone (µg/L)	12	8	19	NA	NA
Methyl ethyl ketone (µg/L)	<3.1	<3.1	12	NA	NA
Tetrahydrofuran (µg/L)	22	24	21	NA	NA
Liquid volume (L)	483	398	344	NA	NA

Bold indicates values that exceeded groundwater quality criteria or maximum contaminant level.

(a) Groundwater quality criteria from WAC 173-200.

(b) Maximum contaminant level from WAC 246-290.

(c) NA = Not available.

The most notable change in the leachate between the second and third quarters of fiscal year 2000 was a statistically significant increase in total organic halide from 586 to 945 µg/L. The only specific organic halide detected was 1,4-dichlorobenzene at 6 and 4 µg/L for the first and second quarters, respectively. These small concentrations cannot account for the total organic halide values and the source for the total organic halide is unknown.

The increase in pH from 6.14 during the second quarter of fiscal year 2000, which is below the groundwater quality criteria of 6.5, to 7.43 during the third quarter suggests that the second quarter's pH value was low. A pH of 7.43 is within the normal range for historical measurements.

None of the contaminants of concern thus far detected in the leachate has been detected at significant levels in the groundwater (see Section 7.1.6).

Soil gas monitoring at the Solid Waste Landfill uses eight shallow monitoring stations located around the perimeter of the landfill. Each station consists of two soil gas probes at depths of ~2.7 and 4.6 meters (8.8 and 15 feet). Soil gas is monitored quarterly to determine concentrations of oxygen, carbon dioxide, methane, and several key volatile organic compounds. No contaminants of concern were discovered above reporting limits during the first three quarters of fiscal year 2000.

7.2.2.4 Carbon Tetrachloride Monitoring and Remediation

V. J. Rohay and L. C. Swanson

Soil-vapor extraction is being used to remove carbon tetrachloride from the vadose zone in the 200-West Area. EPA and the Washington State Department of Ecology authorized DOE to initiate this remediation in 1992 as a CERCLA expedited response action. The primary focus in the following discussion is on fiscal year 2000 activities associated with the carbon tetrachloride removal. For descriptions of past work, see BHI-00720 and Section 3.2 in PNNL-13116.

The 14.2 m³/min (18.6 yd³/min) soil-vapor extraction system operated from March 29 through June 28, 1999, at the 216-Z-9 well field and from June 30 through September 30, 1999, at the combined 216-Z-1A/-12/-18 well field (see PNNL-13080 for location maps of the well fields). The system was maintained in standby mode in fiscal year 2000. Soil vapor monitoring during non-operation of the soil-vapor extraction system has been in progress since July 1999. The 28.3 and 42.5 m³/min (37 and 56 yd³/min) soil-vapor extraction systems also were maintained in standby mode during fiscal years 1999 and 2000.

Remediation efforts during the year were directed toward monitoring carbon tetrachloride concentrations during non-operation of the soil-vapor extraction system, passive soil-vapor extraction, and continuation of the carbon tetrachloride innovative technology remediation demonstration program.

Soil-Vapor Extraction

As of September 1999, ~76,500 kilograms (168,872 pounds) of carbon tetrachloride had been removed from the vadose zone since extraction operations started in 1992 (Table 7.2.5). Since initiation, the extraction systems are estimated to have removed 7% of the residual mass at well field 216-Z-1A/-12/-18 and 22% of the mass at well field 216-Z-9. This estimate assumes that all of the mass that has not been lost to the atmosphere (21% of the original inventory), dissolved in groundwater (2% of the original inventory), or biodegraded (1% of the original inventory) is still available in the vadose zone as residual mass (BHI-00720; WHC-SD-EN-TI-101).

Monitoring at Off-Line Wells and Probes

During fiscal year 2000, soil-vapor concentrations of carbon tetrachloride were monitored near the ground surface, near the Plio-Pleistocene Unit (~40 meters (131 feet) below ground surface), and

Table 7.2.5. Carbon Tetrachloride Inventory in Primary Disposal Sites

Well Field	Estimated Mass Discharged 1955 to 1973^(a) (kg)	Estimated Mass Lost to Atmosphere 1955 to 1990^(b) (kg)	Mass Removed Using Soil-Vapor Extraction 1991 to 1999^(c) (kg)
216-Z-1A	270,000	56,700	23,511 ^(d)
216-Z-9	130,000 to 480,000	27,300 to 100,800	52,949
216-Z-18	170,000	35,700	
Total	570,000 to 920,000	119,700 to 196,800	76,460

(a) Based on DOE/RL-91-32.

(b) Based on WHC-SD-EN-TI-101.

(c) Based on BHI-00720.

(d) Includes mass removed from 216-Z-18 site; reported as a combined value because the well fields overlap.





near groundwater (~66 meters [216 feet] below ground surface) (see Figure 7.1.3). Soil-vapor concentrations were monitored near the ground surface and groundwater to assess whether non-operation of the soil-vapor extraction system is allowing carbon tetrachloride to migrate out of the vadose zone. The maximum concentration detected near the ground surface (between 2 and 10 meters [6.5 and 33 feet] below ground surface) was 9.4 ppmv. Near the groundwater, at a depth of 58 meters (190 feet) below ground surface, the maximum concentration was 20.4 ppmv.

Soil-vapor concentrations were also monitored above and within the Plio-Pleistocene Unit to provide an indication of concentrations that could be expected during restart of the soil-vapor extraction system. (The Plio-Pleistocene Unit is a geologic stratum that may be a confining layer to carbon tetrachloride vapors.) The maximum concentration detected near the Plio-Pleistocene Unit (between 25 and 41 meters [82 and 134 feet] below ground surface) was 442 ppmv in well 299-W15-217 (35 meters [115 feet] below ground surface) at the 216-Z-9 site. During monitoring in fiscal years 1997, 1998, and 1999, the highest carbon tetrachloride concentrations also were detected in this well.

At the 216-Z-1A/-12/-18 well field, the maximum carbon tetrachloride concentration detected near the Plio-Pleistocene Unit was 248 ppmv in well 299-W18-167 (37 meters [121 feet] below ground surface) in the 216-Z-1A tile field. The highest concentrations detected during the fiscal years 1998 and 1999 were detected at well 299-W18-158L also within the 216-Z-1A tile field.

The temporary suspension of soil-vapor extraction in fiscal year 2000 appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere. This view is supported because carbon tetrachloride concentrations did not increase significantly at the near-surface probes monitored during the year. In addition, suspending operations of the soil-vapor

extraction system appears to have had no negative impact on groundwater quality, because carbon tetrachloride concentrations have not increased significantly near the water table since that time.

Passive Soil-Vapor Extraction

Passive soil-vapor extraction is a remediation technology that uses naturally-induced pressure gradients between the subsurface and the surface to drive soil vapor to the surface. In general, falling atmospheric pressure causes subsurface vapor to move to the atmosphere through wells, while rising atmospheric pressure causes atmospheric air to move into the subsurface. Passive soil-vapor extraction systems are designed to use this phenomenon to remove carbon tetrachloride from the vadose zone.

Passive soil-vapor extraction systems were installed at the end of fiscal year 1999 at eight boreholes that are open near the vadose-groundwater interface at the 216-Z-1A/-12/-18 well field. The passive systems have a check valve that only allows soil-vapor flow out of the borehole (i.e., one way movement), and a canister holding granular activated carbon that adsorbs carbon tetrachloride before the soil vapor is vented to the atmosphere. The check valve prohibits flow of atmospheric air into the borehole during a reverse barometric pressure gradient, which tends to dilute and spread carbon tetrachloride vapors in the subsurface.

Three of eight boreholes measure hourly air pressure differentials between the ground surface and the bottom of the borehole, carbon tetrachloride concentrations, temperature, and flow rates. These data can be used to calculate an hourly estimate of the amount of mass removed from the well. The granular activated carbon in all eight boreholes is sampled monthly and analyzed quarterly using laboratory analytical services. The granular activated carbon samples provide a passive, time-integrated measure of the amount of mass removed through the well.

At the two instrumented boreholes near 216-Z-1A tile field, 299-W18-6L and 299-W18-252L,

the peak carbon tetrachloride concentration was 69.2 ppmv. Well 299-W18-247L located at the southeastern corner of the 216-Z-18 crib had a peak concentration of 8 ppmv. Flow rates measured at

the wells ranged from 0 to as high as 0.3 m³ (0.4 yd³) per minute. Passive soil-vapor extraction is considered successful at these areas on the Hanford Site.

7.2.3 Technical Demonstrations

D. G. Horton

Technical demonstrations are designed to result in new, innovative methods for cleanup and monitoring at the Hanford Site. This section summarizes three technical demonstrations that occurred at the Hanford Site during 2000.

A small-diameter, passive neutron tool was demonstrated to be able to detect subsurface transuranics in the vadose zone under certain conditions. Also, a small-diameter spectral gamma logging tool was demonstrated at an environmental remediation site in the 100 Areas. Both tools could result in substantial cost savings over conventional methods of characterization and monitoring. In addition, the Vadose Zone Transport Field Study conducted a series of tests in 2000 to evaluate how contaminant plumes move in the vadose zone. Several geophysical methods to monitor moisture movement were tested. The year 2000 tests are the first of four field tests to be conducted at the Hanford Site.

7.2.3.1 Demonstration of a Passive Neutron Tool to Detect Transuranic-Contaminated Soil

R. G. Bauer, R. R. Randall, and R. K. Price

Bechtel Hanford, Inc., CH2M HILL Hanford, Inc., Three Rivers Scientific, and Pacific Northwest Geophysics evaluated the ability of a passive neutron tool to detect transuranic radionuclide contaminated soil in the subsurface during 2000. The demonstration was done in two boreholes that penetrated

transuranic contaminated sediment at the 216-Z-1A tile field in the 200-West Area.

The demonstration had three objectives:

- test a small-diameter, bismuth-germanate gamma-ray detector designed for use with a small-diameter gamma logging system and small-diameter Geoprobe™ hydraulic driver
- determine whether the passive neutron detector could detect transuranic-contaminated soil at or near the 100 nCi/g threshold concentration
- determine whether a relationship exists between different transuranic radionuclides and neutron detector response in soil matrices.

The gamma-logging instrument used in the demonstration was a bismuth-germanate scintillator, housed in a probe 3.8 centimeters (1.5 inches) in diameter and 0.658 meter (2.2 feet) long. The passive neutron-logging instrument was a helium-3 detector, housed in a 3.8 centimeter (1.5 inch) by 0.57-meter (1.9-foot) probe.

Boreholes 299-W18-149 and 299-W18-167 were selected for logging. Borehole 299-W18-149 was chosen because it contains a known passive neutron flux and has a large range of transuranic concentration (PNNL-11978). Borehole 299-W18-167 was chosen because concentrations of transuranic radionuclides were potentially below the detection limit of the small-diameter tools and the ratio of americium-241 to plutonium-239 varies significantly between boreholes 299-W18-167 and 299-W18-149.





Results

The logging results show that the efficiency of the bismuth-germanate detector was sufficient to detect transuranic radionuclides at threshold levels equivalent to the high purity germanium detector used to log the boreholes in 1998 for a gross gamma determination. The electronics associated with the bismuth-germanate detector are faster responding and do not experience as much dead time as the high purity germanium detector. Dead time is the time interval during which a photon is detected and processes. During this time interval, the system cannot respond to another photon.

The range of passive neutron and transuranic radionuclide concentrations were found to be large in borehole 299-W18-149 and the magnitude of the neutron count rate is a function of the concentrations. The neutron measurements in borehole 299-W18-149 indicate an upward biased passive neutron detector response. This is most likely due to neutron streaming in the air-filled borehole. (Neutron streaming is the result of the lack of scattering and attenuation of neutrons in the air, which causes a stream of neutrons up and down the inside of the borehole. The result is a detectable flux of neutrons above and below the zone containing the transuranic radionuclides.)

The neutron count rate measured in borehole 299-W18-167 is much lower than that encountered in borehole 299-W22-149, and the background streaming in the air-filled borehole is lower. The estimated total concentration of transuranic radionuclides in 299-W18-167 is ~150 nCi/g. The passive neutron detector response indicates successful detection of transuranic concentrations just above 100 nCi/g. The vertical depth resolution is less for the neutron signal than for the gross gamma signal due to streaming in the borehole.

The bismuth germanate and high purity germanium data from borehole 299-W18-149 were analyzed to determine the relationship of the passive neutron response to increasing concentrations of

transuranic radionuclides. The least squares fit of the data shows that the neutron count rate is exponentially proportional to the total transuranic concentration. An intercept near 1 count per second for the neutron count rate represents the minimum observable count rate in the data and is not the detection limit. Neutron streaming was found to make the minimum detection limit higher. Thus, when high concentrations of transuranic radionuclides are encountered, higher detection limits will result, as expected.

Conclusions

The initial evaluation to detect transuranic radionuclides with a small-diameter geophysical logging system gross gamma probe and a passive neutron detector was successful. Two objectives of the evaluation were met:

- a small-diameter geophysical logging system passive gamma probe for detection of transuranic-contaminated soil was demonstrated.
- the passive neutron detector was demonstrated to detect transuranic-contaminated soil at or near the 100 nCi/g concentration during the logging of borehole 299-W18-167.

A third objective to determine whether a relationship exists between different transuranic radionuclide concentrations and neutron detector response was not accomplished because there were significant differences between the two boreholes that were logged. These differences introduced too many variables to support a baseline comparison of neutron responses from americium-241 and plutonium-239.

7.2.3.2 Small-Diameter Geophysical Logging System Demonstration

K. A. Bergstrom, T. H. Mitchell, R. R. Randall, and R. K. Price

The results of a small-diameter geophysical logging system demonstration became available in 2000.

The system was designed to collect information on the distribution of subsurface gamma-emitting radionuclides. The purpose of the demonstration was to collect information to reduce remediation costs by minimizing the amount of excavated soils from the 126-F-1 ash pit in the Hanford Site's 100-F Area. Complete results of the demonstration can be found in BHI-01352. This section summarizes those results.

A truck mounted Geoprobe hydraulic driver was used for the demonstration. The logging tool was 2.12 centimeters (0.8 inch) in diameter, 20.5 centimeters (8 inches) long, and contained a cesium iodide scintillator crystal. The tool was lowered inside the push rods and measurements were taken at intervals of 15 centimeters (6 inches) with a count time of 200 seconds. (Push rods are the part of the system driven into the ground to make the borehole.) The detector was calibrated in the Hanford Site borehole calibration models. The minimum detection limit for cesium-137 was about 4 pCi/g and for cobalt-60 about 0.5 pCi/g.

The small-diameter geophysical logging system was used to geophysically log 42 probe holes at the 216-B-2-2 ditch, 216-B-3 pond (B Pond), and the 126-F-1 ash pit. Holes created during geophysical logging were decommissioned according to Washington State Department of Ecology guidelines (WAC 173-160) by sealing with grout.

Five small-diameter geophysical logging system probe holes were logged at B Pond. The rods were pushed to depths between 4.75 and 7.87 meters (15.6 and 26 feet). Cesium-137 was the only manmade radionuclide identified. Cesium-137 was primarily in a narrow zone ~2.5 to 3.5 meters (8.5 and 11.5 feet) below the ground surface. This agrees with laboratory data collected from another study (see Section 7.2.1.6). The maximum cesium-137 concentration was 488 pCi/g.

Five small-diameter probe holes were logged at the 216-B-2-2 ditch. The ditch had been covered

previously with fill material, and its exact location was not known. The objective was to locate the ditch. The five holes were equally spaced at 3 meters (10 feet) along a line across the projected location of the ditch. Only one probe hole encountered contamination. Cesium-137 was identified at 2.3 meters (7.5 feet) below ground surface with a concentration of 11.53 pCi/g. A test pit was excavated at the site, and subsequent results suggest the pit was located in the ditch (BHI-01367).

The 126-F-1 ash pit is a solid waste site that received large amounts of coal ash sluiced with raw Columbia River water. The coal ash originated from the 100-F Area powerhouse. The initial remedial action for the site was planned to remove and dispose of 287,904 cubic meters (376,564 cubic yards) of contaminated material (BHI-01352). The site was contaminated by leaks from reactor effluent lines in the 1940s. Most of the contamination is believed to be contained north of an earthen dike built in the late 1940s. Forty-two small-diameter geophysical logging system probe holes along seven profiles were made in and adjacent to the ash pit in an attempt to better delineate contamination and potentially reduce the amount of material needing to be removed. All probe holes are believed to have penetrated through the ash and entered native soils. This is based on refusal of the push rods to extend deeper into the soil at approximately the same elevation at most probe holes. Refusal is believed to be due to a horizontally pervasive soil layer.

The small-diameter geophysical logging system demonstration identified cesium-137 and cobalt-60 in the northern part of the ash pit but found no contamination in the southern part. Based on the results of the investigation, a new volume of 148,000 cubic meters (193,575 cubic yards) is estimated to be contaminated. This is a reduction of about 50% and can result in substantial cost savings to the 126-F-1 ash pit remediation project.





7.2.3.3 Vadose Zone Transport Field Studies: Summary of Fiscal Year 2000 Activities

G. W. Gee and A. L. Ward

The scope of the Vadose Zone Transport Field Studies is to conduct a series of tests at the Hanford Site to evaluate how contaminant plumes move in the vadose zone. Planned experiments include two flow and transport tests at an uncontaminated site to simulate a tank leak, followed by two flow and transport tests in deeper Hanford formation sediment. During 2000, the first of the four planned field tests was completed at an uncontaminated site. This section provides a summary of the 2000 field test. Many contractors and individuals from national laboratories collaborated on this study.

The objectives of the Vadose Zone Transport Field Studies are to conduct controlled transport experiments at well-instrumented field sites at the Hanford Site to

- identify mechanisms controlling transport in soil typical of Hanford's waste disposal sites
- reduce uncertainty in conceptual models
- develop a detailed and accurate database of hydraulic and transport parameters for validation of three-dimensional numerical models
- identify and evaluate advanced, cost-effective characterization methods and to assess changing conditions in the vadose zone.

A test site was selected in 2000 at the 299-E24-111 experimental test well (RHO-ST-46P) located in the 200-East Area where an extensive amount of characterization has already been completed (RHO-ST-46P; NUREG/CR-5996; PNNL-10860). Ward and Gee (PNNL-13263) provide details of the site selection process. Figure 7.2.21 shows the test site location in the 200-East Area.

Figure 7.2.22 shows the site during instrument installation and sampling on May 31, 2000. A drill rig was used to place advanced tensiometers and provide core samples. Surface electrodes were placed for geophysical logging measurements.

More than 20 technologies were screened to identify those that could be used alone or in conjunction with others to reduce the uncertainty in plume delineation. With this objective in mind, a short list of possible technologies was identified based on the following criteria:

- the ability to identify key geologic features controlling water movement with a vertical resolution of 0.1 meter (0.3 foot) or better and a horizontal resolution of 1 meter (3.3 feet) or better
- the ability to locate wetting fronts and a change in water content of $0.01 \text{ m}^3/\text{m}^3$ ($0.35 \text{ ft}^3/35 \text{ ft}^3$) or better with a repeatability of at least $0.01 \text{ m}^3/\text{m}^3$
- the ability to determine the shape and extent of non-gamma-emitting contaminant plumes or their surrogates
- the ability to function and produce useful results in culturally noisy environments.

The nine technologies resulting from the screening process included neutron moisture logging, advanced tensiometry/suction lysimetry, electrical resistance tomography, cross hole radar tomography, cross hole seismic tomography, cross hole electromagnetic induction, high-resolution resistivity, and tracers (including isotopes) and coring. The details of each of the nine methods selected and the collaborators who helped deploy the selected methods are listed in the Vadose Zone Transport Field Studies test plan (PNNL-13263).

Neutron probes were used in the past to monitor water content at the Sisson and Lu injection site (RHO-ST-46P; NUREG/CR-5996; PNNL-10860). These probes also are used routinely to monitor water content in the field at the Hanford Site. For the

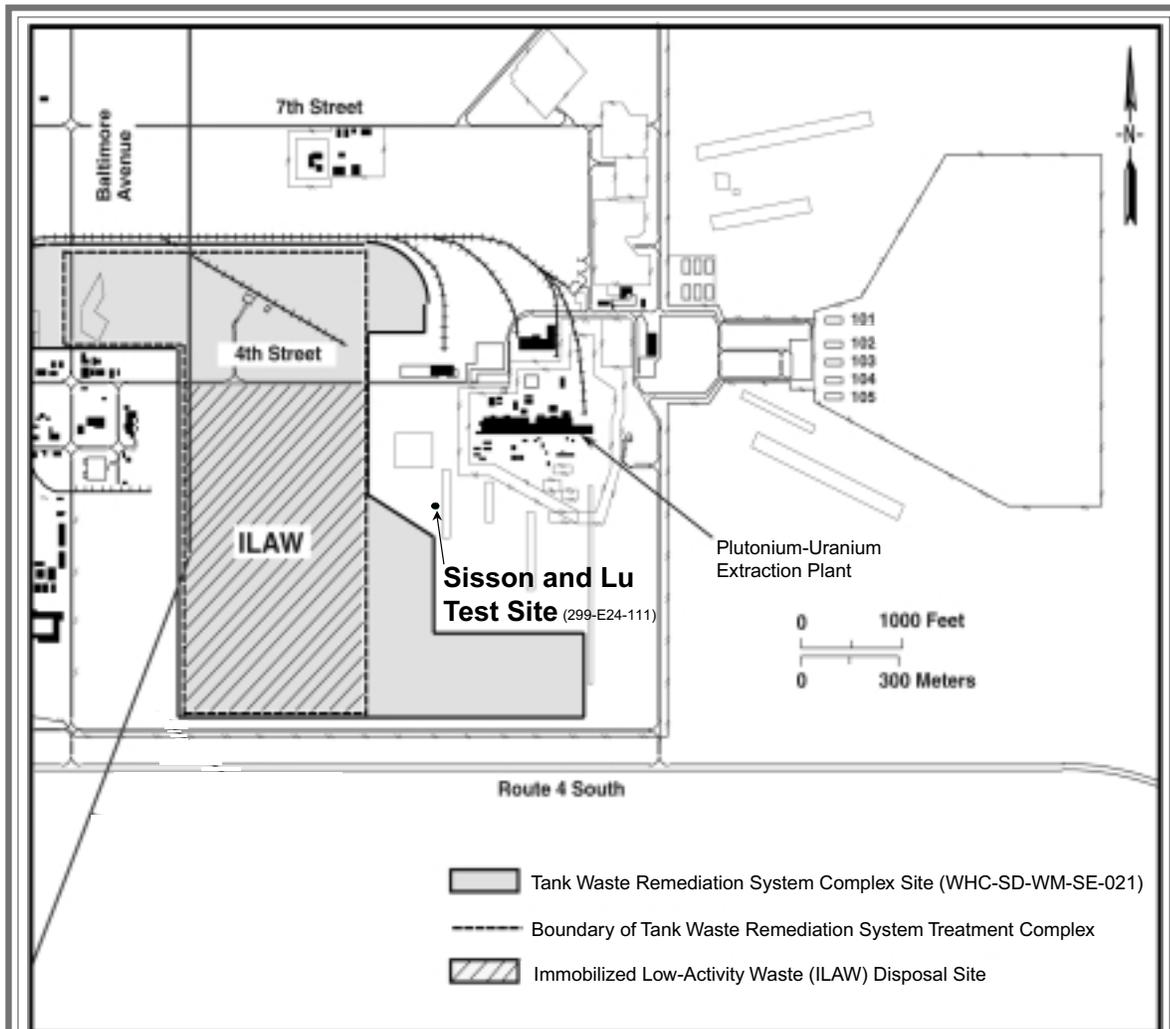


Figure 7.2.21. Schematic of Test Site Location in the 200-East Area. The site was used by Sisson and Lu (RHO-ST-46P) to conduct the first controlled vadose zone transport study at the Hanford Site and is now designated as 299-E24-111, Experimental Test Well Site, in the Hanford Waste Information Data System (WIDS).

2000 study, water content was the primary variable measured. Water content, as determined by neutron probe logging, was also selected as the primary standard against which the other geophysical methods could be compared. Details of the calibration of neutron probes for monitoring water content at the Sisson and Lu site is provided in PNNL-10860.

Water Injection Tests

After baseline data from all methods were obtained, a series of five water injections were

conducted. Injections began on June 1, 2000, when 4,000 liters (1,057 gallons) of water were injected into the 5-meter-deep (16.4-foot-deep) injection well over a 6-hour period. Subsequent injections occurred weekly for a period of 5 weeks. Neutron logging of 32 steel-cased wells (surrounding the injection well) occurred before the initial injection and followed each of the five injections within a day, with the exception of the injection that occurred on June 26, 2000. On that day, a wildfire burned on the Hanford Site so that neutron logging occurred on



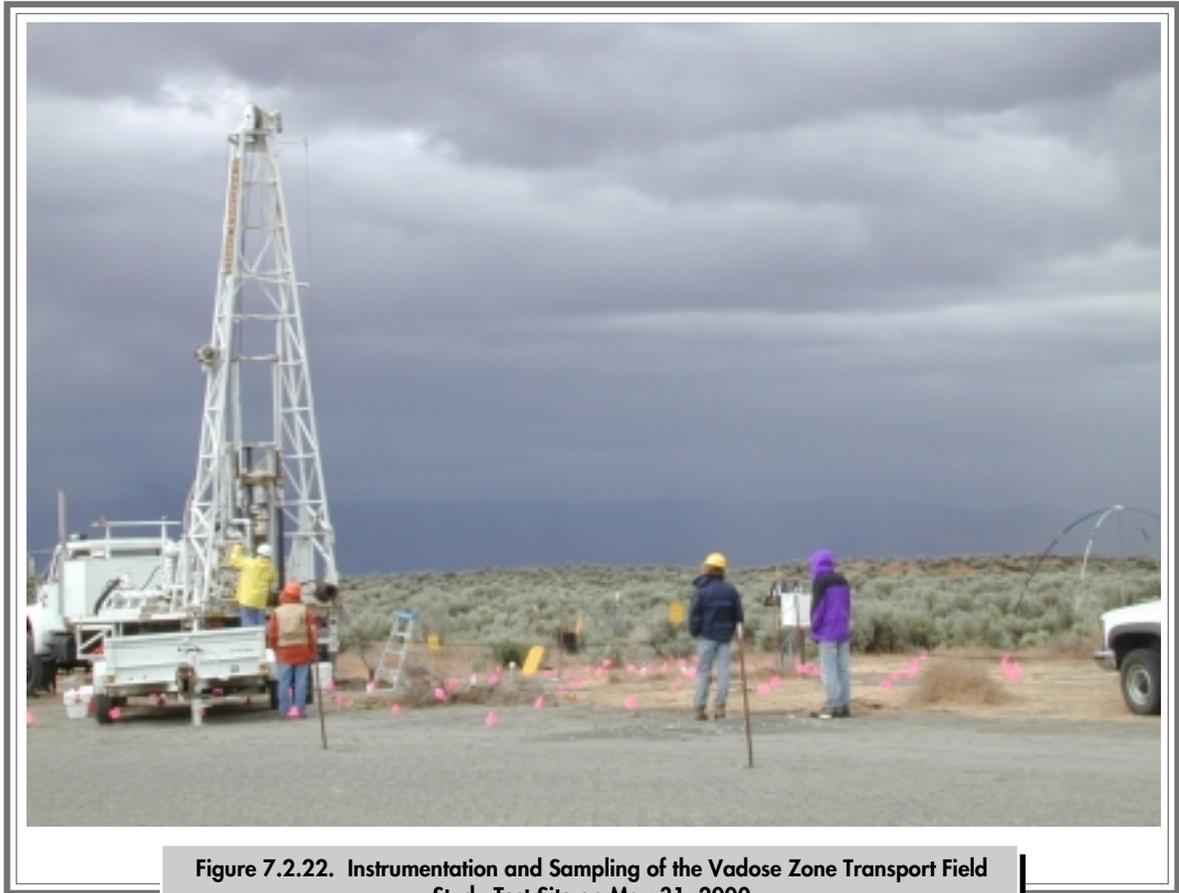


Figure 7.2.22. Instrumentation and Sampling of the Vadose Zone Transport Field Study Test Site on May 31, 2000

July 7, 2000. One additional 4,000-liter (1,057-gallon) injection was made on September 18, 2000. This injection was made to obtain in situ hydrologic properties using a combination of pressure measurements and neutron probe water content measurements at the same depth.

Preliminary Modeling of Fiscal Year 2000 Vadose Zone Transport Field Studies Injection Test

The 2000 test was simulated using STOMP (Sub-surface Transport Over Multiple Phases), a multiphase (unsaturated) flow and transport code developed at Pacific Northwest National Laboratory (PNNL-11217). A conditional simulation of the five injections was made using methods developed by Rockhold et al. (1999). The simulations assumed an initial water content and water retention characteristics of

Hanford Site soils that are similar, but not identical, to the soil found by Sisson and Lu (RHO-ST-46P).

The model results describe the general flow depths and directions of the plume but do not completely describe the extent of the lateral spreading of the plume. The improved and more site-specific hydraulic property data collected during the field test may be helpful in improving the prediction of the lateral spreading.

Summary

Pacific Northwest National Laboratory and collaborators conducted the first of four field tests at the 299-E24-111 injection site in the 200-East Area of the Hanford Site in 2000. Nine methods were tested to document a vadose zone plume produced from injecting a total of 20,000 liters (5,283 gallons) of

Columbia River water into a 5-meter-deep (16.4-foot-deep) injection well, in five increments of 4,000 liters (1,057 gallons) each over a period of 5 weeks. Water contents, obtained by neutron probe logging techniques, were used as baseline measurements upon which other geophysical measurements were compared. Prior to completing the test, the development of the water plume was simulated using conditional simulation techniques (Rockhold et al. 1999). The conditional simulation relied on estimates from hydrologic characterization of a limited number of samples previously taken from the site. While the computational results were in qualitative agreement with field measurements, they did not predict the observed lateral extent of the plume.

All methods were successful to some degree in identifying changes in subsurface water contents (or pressures) resulting from the five injections. Electrical resistance tomography showed promise in delineating the shape of the entire plume. However, the interpretation of signal responses was difficult, mostly because of interference between the electrical signal and the dense “forest” of more than 35 steel-cased wells. Apparent changes in electrical resistivity were observed at depths of 18 meters (59 feet) but on closer inspection, real changes were confined largely to depths of 6 and 12 meters (19.7 and 39.4 feet) in conformance with water content changes observed by neutron probe logging.

Cross-borehole radar was successful in identifying a section of the plume, and provided a good time

lapse of the redistribution of one injection. The results compared well with neutron probe logging; however, the results were limited by the relatively narrow spacing of the plastic access tubes. Tests with electromagnetic induction and high-resolution resistivity were marginally successful in showing changes in electrical properties but the surface measurements were unable to provide sufficient vertical resolution to identify the depth of penetration of the wetting front, an important parameter for plume migration investigations. Seismic monitoring was successful in delineating stratigraphy at the site. Peak concentrations of isotopic tracers (e.g., deuterium) sampled from vertical cores matched well with the bromide tracer data taken from adjacent cores and indicated the peak concentrations of the tracer plume. Isotopic tracer distributions also confirmed that none of the new water injected penetrated the impeding layer at the 12-meter (39.4-foot) depth. Advanced tensiometers were only marginally successful in delineating the pressure profiles due to a series of pressure transducer failures in about half of the units.

The work accomplished in 2000 provides for a more intelligent choice of vadose zone monitoring technology to match a specific monitoring need. Also, the data collected in 2000 further the understanding of vadose zone processes such that contaminated movement can be better predicted.

