



6.2 Vadose Zone Characterization and Monitoring

The vadose zone is the region in the subsurface between the ground surface and the top of the water table. In the Hanford 200 Areas, the vadose zone is >61 m (200 ft) thick. As a result of past Hanford Site operations, the vadose zone has become contaminated from spills, leaks, and intentional discharges.

There are three programs/projects involved in vadose zone characterization and monitoring. This section provides descriptions of each and summarizes the 1998 results.

6.2.1 Tank Farms Vadose Zone Baseline Characterization Project

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Contamination was released to the near-surface and subsurface environment at the Hanford Site single-shell tank farms as the result of tank leaks, spills of radioactive effluent on the ground surface, pipeline leaks, and airborne releases of particulate matter through tank ventilation and access ports.

RCRA specifies the requirements to identify sources of contamination and to determine the nature and extent of the contamination that has leaked from the single-shell tanks. In 1994, the Tank Farms Vadose Zone Baseline Characterization Project was initiated to perform a baseline characterization of the gamma-emitting contamination in the vadose zone under the tank farms and to satisfy RCRA requirements in a limited way. The technical plan for this baseline characterization is documented in P-GJPO-1786.

Under this project, approximately 800 preexisting monitoring boreholes surrounding the Hanford Site single-shell tanks are being logged with passive spectral gamma-ray logging methods. These methods were developed at the Hanford Site in the late 1980s and early 1990s to identify specific gamma-emitting radionuclides in the subsurface and to determine their concentrations.

Borehole logging is used for the initial characterization because it is an economical means of obtaining information about conditions in the subsurface, using existing boreholes, and it helps to identify the locations and sizes of the contamination plumes. For comprehensive characterizations or special investigations, follow-up drilling and sampling must be conducted to identify specific contaminants, to better define observed contaminant distributions, and to collect geologic samples as needed.

Once a baseline is established for a particular tank, that tank can be monitored over time for either short-term or long-term changes. Long-term monitoring over a 5- to 10-yr period can provide information on migration rates of gamma emitters that can be used to verify models used for predictive risk assessments. Short-term monitoring is useful for identifying recent changes in the vadose zone that result from current operations or tank leaks.

A plan view of a typical tank farm is presented in Figure 6.2.1. Each tank farm consists of a collection of between 2 and 18 underground waste storage tanks. Most of the tanks are surrounded by monitoring boreholes that provide access to the subsurface with

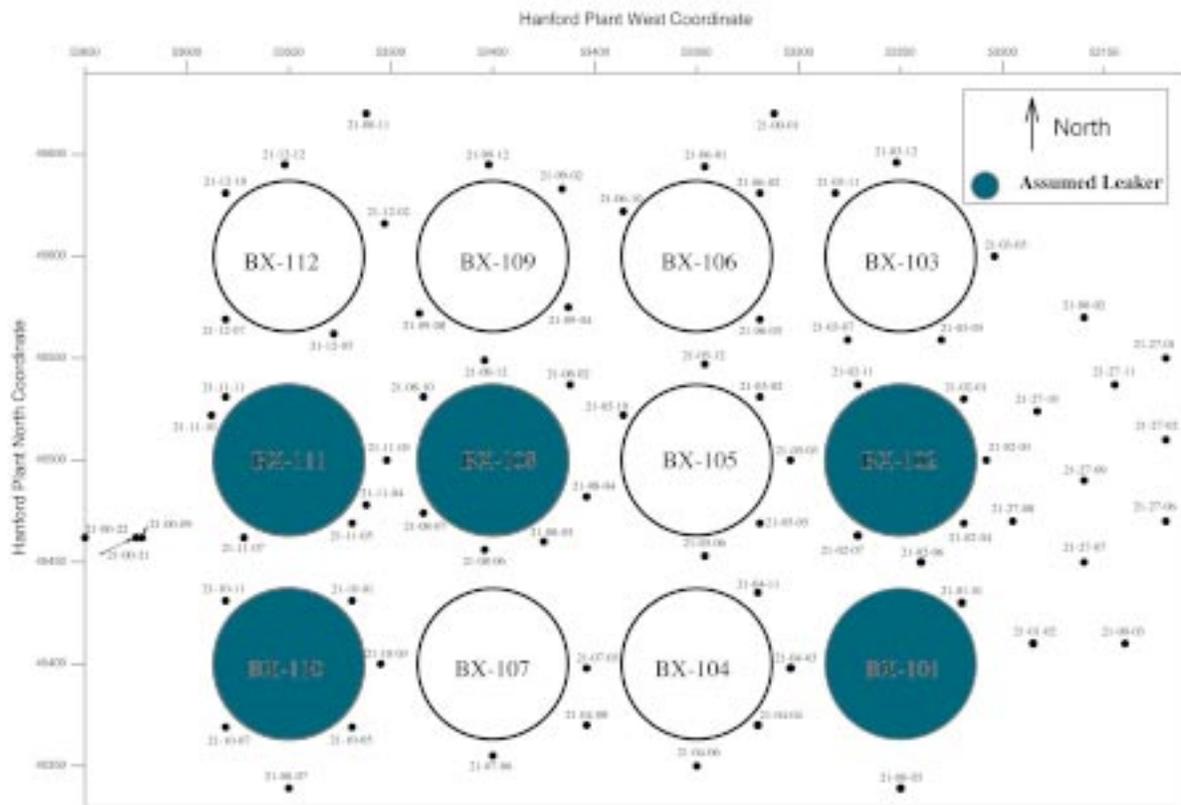


Figure 6.2.1. Plan View of BX Tank Farm with Monitoring Boreholes

geophysical logging probes. There are 12 single-shell tank farms at Hanford that contain a total of 149 tanks.

The baseline characterization project involves logging the boreholes surrounding the single-shell tanks and analyzing the data to produce logs of the radionuclide concentrations. Figure 6.2.2 presents an example of a radionuclide concentration log. The logs for all of the boreholes surrounding a tank are interpreted and reported in a tank summary data report for each tank. The reports also provide summaries of the tank histories and any other tank-specific information.

After completion of a summary data report for each tank, a more comprehensive tank farm report is prepared. Each tank farm report provides a correlation of the contamination across the farm and includes

computer-generated, three-dimensional visualizations of the contamination. Correlations between boreholes help to determine contamination sources and define the three-dimensional contamination distributions. The visualizations are based strictly on an empirical geostatistical correlation of the data and are used to help identify the general location and distribution of the contamination so that more complete analyses can be assembled to develop more realistic and quantitative contamination distribution models. The visualizations are an effective means of identifying regions in specific tank farms where additional characterization is necessary.

6.2.1.1 Data Collection and Analysis

All data acquisition is accomplished with spectral gamma-ray logging systems that are automated

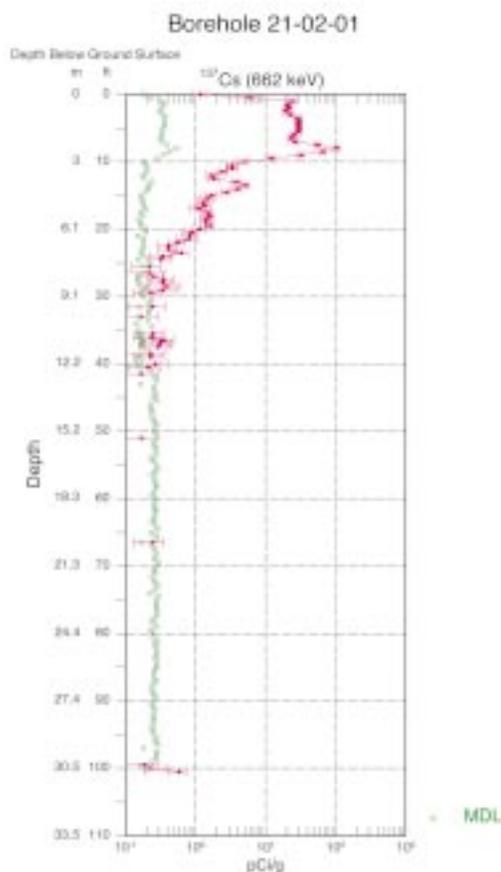


Figure 6.2.2. Example of a Radionuclide Concentration Log (MDL = minimum detection level)

and configured to deliver a germanium detector down a borehole. Data acquisition operations are specified by logging procedures provided in MAC-VZCP-1.7.10-1 (Rev. 2) and governed by quality assurance procedures specified in a project management plan MAC-VZCP-1.7.2 (Rev. 1). All data are managed as quality records governed by the current revision of the Hanford Tank Farms Vadose Zone Working File Index, which is used in conjunction with Section 3.0, “Records Management,” of the *General Administrative Procedures Manual* (MAC-1000).

The spectral gamma-ray logging system equipment was calibrated by conducting a comprehensive

baseline calibration and biannual field calibrations as specified in a calibration plan (MAC-VZCP-1.7.3, Rev. 1). The baseline calibration was conducted using borehole model standards constructed at the DOE Grand Junction Office specifically for borehole logging. The results of the calibration are reported in GJPO-HAN-1. Biannual field calibrations were conducted using borehole calibration models installed at the Hanford Site, and the results were reported in biannual calibration reports. The results of the fifth and most current recalibration report are presented in GJO-98-41-TAR, GJO-HAN-20. Based on the observed stability of the logging system from the biannual recalibrations, a



decision was made in 1998 to revise the calibration frequency from biannually to annually.

Data analysis involves identifying the specific isotopes detected in the gamma-ray spectra and then calculating the concentrations of those isotopes. Once the isotope concentrations are determined, the data are collated into isotope-specific logs of the radionuclide concentration versus depth, and the data are plotted as logs. Logs of man-made and naturally occurring radionuclides are produced routinely. Details of the data analysis process are documented in MAC-VZCP-1.7.9 (Rev. 1).

Data are interpreted by reviewing all of the spectral gamma logs from a single borehole and correlating the data with information on the geology, tank history, and historical gross gamma-ray logs. The intent of the individual borehole interpretations is to quantify contamination plumes, identify potential contamination sources, and relate contamination distribution patterns to the geology or tanks.

6.2.1.2 Activities for 1998

Baseline Logging, Tank Summary Data Reports, and Tank Farm Reports. During 1998, spectral gamma data were acquired from 79 boreholes surrounding tanks in the B and T Tank Farms in the 200-East and 200-West Area, respectively.

Tank summary data reports were completed for 25 tanks in the A, B, BX, C, and T Tank Farms. The tank summary data reports that were completed are tanks A-101 through A-106; tanks B-101 and B-103; tank BX-101 and tanks BX-103 through BX-112; tanks C-222 and C-112; and tanks T-108, T-109, T-111, and T-112. The borehole log plots and interpretation of results are presented in each of the tank summary data reports (GJ-HAN-93 through GJ-HAN-112, GJ-HAN-114, and GJ-HAN-121 through GJ-HAN-124).

During 1998, tank farm reports were prepared for the BX, C, and S Tank Farms (GJO-98-40-TAR,

GJO-HAN-19; GJO-98-39-TAR, GJO-HAN-18; and GJO-97-31-TAR, GJO-HAN-17, respectively). Much of the preparation of the A Tank Farm Report was conducted in 1998, and the report was published in 1999 (GJO-98-64-TAR, GJO-HAN-23). The results of the A Tank Farm vadose zone characterization will be reported in next year's environmental report.

Enhancements to Spectral Shape Factor Analysis. At the recommendation of the independent SX Tank Farm expert panel, activities were conducted in 1998 to enhance the applicability of shape factor analysis. Shape factor analysis is a data analysis method that provides insights into the distribution of gamma-emitting radionuclides relative to the detector based on the ratio of count rates in various portions of the gamma-ray spectrum (GJO-96-13-TAR, GJO-HAN-7; GJO-97-25-TAR, GJO-HAN-15). To provide these insights, spectral shape factor analysis takes advantage of 1) the spectral gamma-ray logging system's ability to record the specific energies of detected gamma rays and 2) the Compton downscattering caused by the interaction of gamma rays with matter between the gamma-ray source and the detector. The enhancement activities conducted in 1998 were based on a combination of computer and physical modeling to simulate the effects of various contaminants.

The computer modeling expanded on work previously performed (GJO-97-25-TAR, GJO-HAN-15) and modeled three types of cesium-137 distributions that had not been performed previously. The three types of distributions modeled were 1) cesium-137 distributed uniformly in a cylindrical configuration of various diameters around a central borehole coincident with the cylinder's axis; 2) a cesium-137 source distributed uniformly in a thick, horizontal tabular zone; and 3) a cesium-137 source distributed uniformly in a thin, horizontal tabular zone. The results of the modeling are provided in GJO-99-80-TAR, GJO-HAN-24.



The physical modeling activities also expanded on previous work (GJO-97-25-TAR, GJO-HAN-15). The physical modeling was performed using a sand-filled tank with a central, steel-cased borehole (15-cm [6-in.] diameter). Tubes were provided in the sand-filled tank at various radii from the central borehole to allow the placement of cobalt-60 and cesium-137 point sources. The borehole was logged with the point sources located at various distances from the borehole to examine the effect of source distance on the shape factor analysis results. Examination of the data from the physical modeling is ongoing, and the results are scheduled to be reported in next year's environmental report.

Reassessment of Vadose Zone Contamination at Tank SX-104. In late 1997, moisture measurements acquired from the liquid observation well in tank SX-104 indicated a possible decrease in the tank's liquid level. At the request of DOE, Richland Operations Office, MACTEC-ERS relogged the boreholes surrounding tank SX-104 to identify regions of increased gamma-ray activity that would indicate increasing contaminant concentration in the sediments surrounding the boreholes. The boreholes were relogged with a spectral gamma logging system in January 1998, and the data were compared to those acquired during the baseline logging conducted between April and June 1995. Each borehole was also logged with a neutron-neutron logging system to evaluate the moisture content in the sediments surrounding tank SX-104.

The results of the 1998 relogging of the SX-104 monitoring boreholes indicated there was no increase or other changes in the concentrations and distributions of contaminants observed in the baseline logging. The moisture data showed variations in volumetric moisture content that were related to soil properties and not to specific contamination intervals that were detected in the boreholes. Consequently, there was no evidence from the log data acquired in 1998 in the SX-104 boreholes that indicated the tank had leaked. The results of the 1998

spectral gamma and neutron-neutron logging and comparisons between the 1998 and the baseline data are presented in GJO-98-48-TAR, GJO-HAN-21.

SX Tank Farm Borehole 41-09-39 Extension. Borehole 41-09-39 was installed to evaluate deep cesium-137 contamination that was detected around tank SX-109 during the initial spectral gamma logging in the SX Tank Farm in 1995. The borehole was terminated at a depth of 40 m (130 ft), and log data collected during installation were analyzed. The results were reported in GJO-97-4-TAR, GJO-HAN-9. The borehole was deepened in the fall of 1997, and the spectral gamma-ray system was used to log borehole 41-09-39 periodically during extension activities. The purposes of the logging were to estimate gamma-emitting radionuclide concentrations and to assess whether contamination was being dragged down during drilling operations. The spectral gamma-ray logging system was operated in both the spectral and total gamma modes during these logging operations.

Drag down relates to the contamination, generally cesium-137, that adheres to the outside of the casing and is carried down as the casing is advanced (i.e., the casing becomes contaminated as it passes through a contaminated zone). The drag-down contamination is later detected by the spectral gamma logging system, and every effort is made to identify and eliminate the drag-down data from the interpretation.

The spectral data from certain depths showed contaminant concentration changes from one log run to the next (Figure 6.2.3). On the basis of these data, and corroboration by the results of a spectral shape factor analysis process where applicable, it was shown that drag-down contamination was occurring during the deepening of borehole 41-09-39. Because of this drag-down contamination, it was not possible to determine to what depth contamination plumes exist. If an actual contaminant plume exists in the interval from approximately 40 to 49 m (133 to

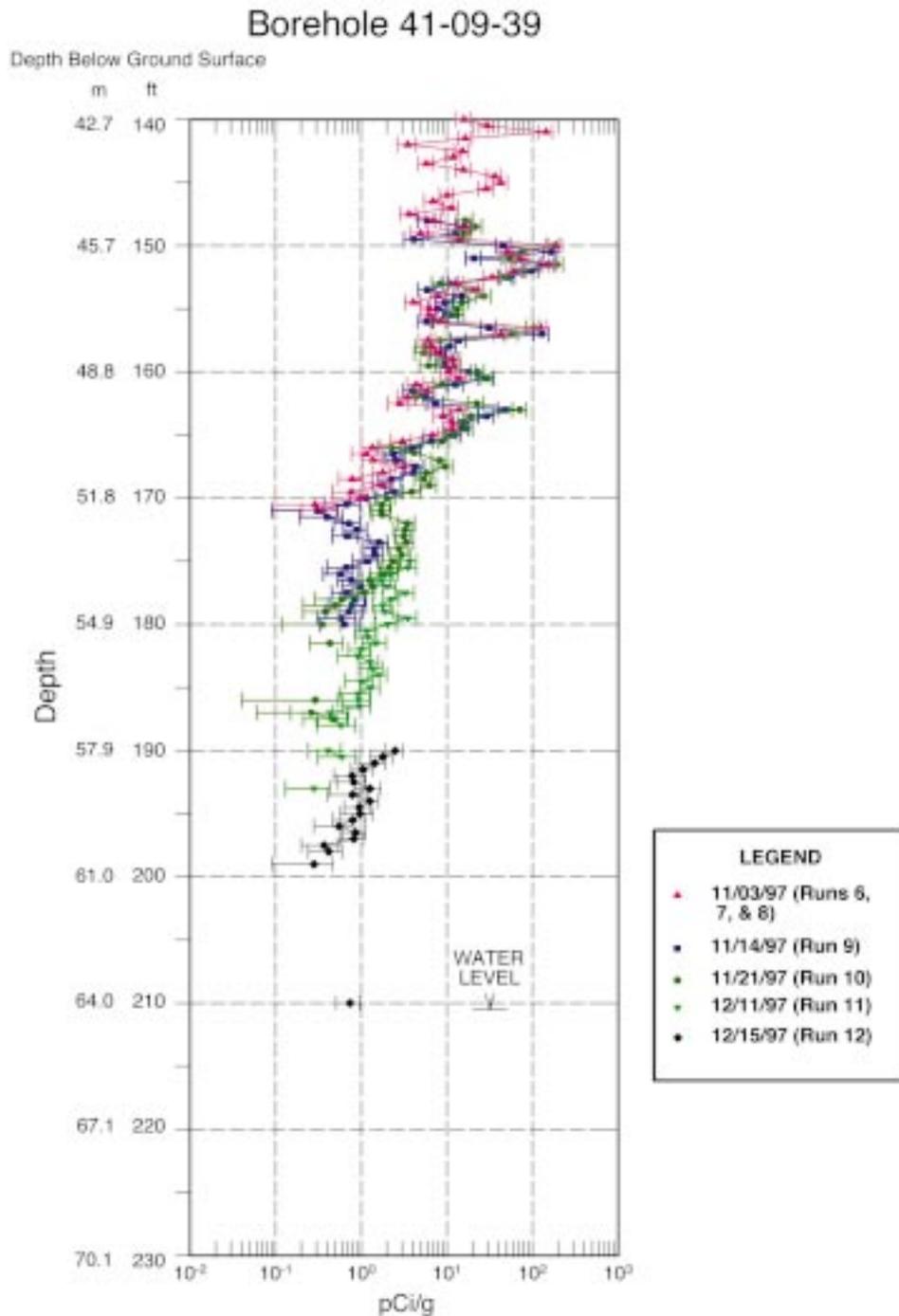


Figure 6.2.3. Comparison of Cesium-137 Concentrations from Log Runs 6 through 12 in Borehole 41-09-39, 200-West Area



160 ft), it could be masked by a false plume caused by contamination dragged down from higher in the borehole. Below approximately 49 m (160 ft), no zones of highly elevated activity were detected during the first log run in those intervals, suggesting that the existence of contaminant plumes in those intervals is very unlikely. On the basis of a comparison of the driller's logs and the gamma logs, it was postulated that the one mechanism of the drag down was that contamination had been smeared on the inside of the outer borehole casing and was being knocked loose and collected at the bottom of the borehole during drilling, logging, and sampling activities.

In addition to the spectral and total gamma logging, neutron-neutron moisture log data were collected at the conclusion of borehole drilling. Increases in moisture content identified in the neutron-neutron moisture log data correlated to water additions during drilling.

BX Tank Farm Vadose Zone Characterization. Details of the results of the spectral gamma logging in boreholes surrounding tank BX-102, where most of the vadose zone contamination in the BX Tank Farm was found, were presented in PNNL-11795 (Section 6.2.3.4). Some of the information discussed in that report are presented again in this section, along with the information for the rest of the tank farm, to provide a complete description of the BX Tank Farm vadose zone contamination.

The 74 existing boreholes surrounding the 12 single-shell tanks in the BX Tank Farm were logged with the spectral gamma logging system from May to August 1997. Figure 6.2.1 is a plan view of the BX Tank Farm, showing the locations of the monitoring boreholes. The final tank summary data report for the BX Tank Farm was completed in May 1998, and the BX Tank Farm report (GJO-98-40-TAR, GJO-HAN-19) was completed in August 1998.

Cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and

uranium-238 were the major gamma-emitting contaminants detected in the BX Tank Farm vadose zone. Occurrence of these radionuclides was detected around and below all tanks that are designated as leakers (BX-101, -102, -108, -110, and -111); however, the vadose zone contamination in the tank farm was not limited to these tanks. Figure 6.2.4 shows the vadose zone contamination at the BX Tank Farm that was detected with spectral gamma logging. The contamination shown in the figure is limited to the depth extent of the existing monitoring boreholes.

Cesium-137 was detected at ground surface throughout most of the BX Tank Farm area, and most of this contamination is associated with surface spill and/or piping leaks. This contamination decreased below the detection limits of the logging equipment at depths of approximately 3 m (10 ft).

The majority of the contamination in the BX Tank Farm was detected in its eastern area, where cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were detected throughout the 46-m (150-ft) depths of the monitoring boreholes (the majority of the monitoring boreholes surrounding the tanks are 30 m [100 ft] deep). This contamination is associated with leakage from tanks BX-101 and -102, which are designated as leakers, and the plumes originating from these tanks have commingled to create a complex distribution of contamination in this region of the tank farm. Because the monitoring boreholes surrounding tanks BX-101 and -102 are only 30 m (100 ft) deep, the presence of these radionuclides below the tanks, as well as the westward extent of the contaminant plumes, could not be determined.

Monitoring of groundwater in the well network surrounding the B, BX, and BY Tank Farms indicates contamination of groundwater has occurred. Remobilization of waste leaked from tanks BX-101 and -102 has been identified as the source of contamination in monitoring well 299-E33-41, which is located approximately 46 m (150 ft) northeast of

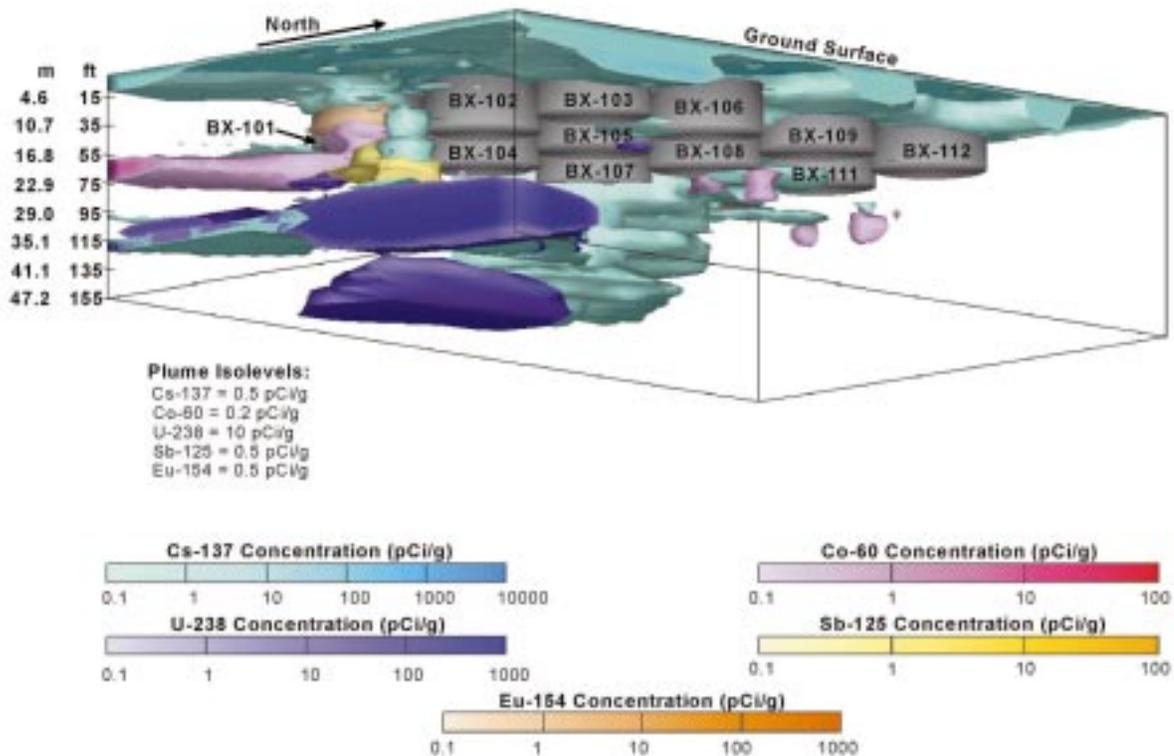


Figure 6.2.4. Vadose Zone Contamination at the BX Tank Farm, 200-East Area

tank BX-102 (PNNL 11826). Man-made uranium was detected in sediments at the depth of groundwater (which is approximately 78 m [255 ft]) and at the capillary fringe in this well.

An isolated plume of antimony-125, cesium-137, uranium-235, and uranium-238 occurs along the side of tank BX-106, which is designated as sound. The isolated nature of this plume and its spatial position relative to the tank location suggest that tank BX-106 may have leaked.

A thick accumulation of cesium-137 contamination occurs along the southern side of tank BX-107 and in the area between tanks BX-107 and -110 (see Figure 6.2.4). Several boreholes in this area have high-cesium-137 concentrations along most of their lengths. There are no documented spills and/or leaks for this area of the BX Tank Farm to account for the

contamination that was detected with the spectral gamma logging systems.

C Tank Farm Vadose Zone Characterization. The 70 existing boreholes surrounding the 12 single-shell tanks in the C Tank Farm, 200-East Area, were logged with the spectral gamma logging system from January to April 1997. The final tank summary data report was completed in January 1998, and the C Tank Farm report (GJO-98-39-TAR, GJO-HAN-18) was completed in July 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the vadose zone at the C Tank Farm; europium-152, europium-154, and uranium-235 were also detected, but their occurrences were limited to thin zones or single encounters near ground surface. Three-dimensional visualizations were created only for the cobalt-60 and cesium-137



distributions, and the plumes of these radionuclides are shown in Figure 6.2.5. The contamination detected in the C Tank Farm is limited to the depths of the existing C Tank Farm monitoring boreholes.

The majority of the contamination detected by the spectral gamma logging in the C Tank Farm cannot be directly associated to documented leaks from tanks or subsurface pipelines. The contamination distributions in some cases appear to indicate that tanks designated as sound (C-104, -105, -106, -107, and -108) may, in fact, have leaked. Conversely, there was minimal evidence of contamination detected in boreholes surrounding tanks that are designated as leakers (C-110 and -111). Contamination leaking from these tanks may not have migrated laterally to the extent to reach the vadose zone penetrated by the monitoring boreholes.

The contamination detected beneath tanks C-104, -105, and -106 may have resulted from leakage from cascade lines between these tanks as a result of overfilling tank C-105 or possible leakage from the tank itself. A 91-cm (36-in.) liquid-level drop in tank C-105 between 1963 and 1967 may be indicative of tank leakage. An investigation of this liquid-level drop identified evaporation as the cause; however, there was no positive support to this conclusion.

An extensive plume of cobalt-60 and cesium-137 was detected in boreholes between and around tanks C-108 and -109, which are designated as sound. This contamination may have resulted from leaks from tanks C-108 and/or -109, from a leak in the cascade line between these tanks, or from a leak over the dome of either tank. The leak over the dome may

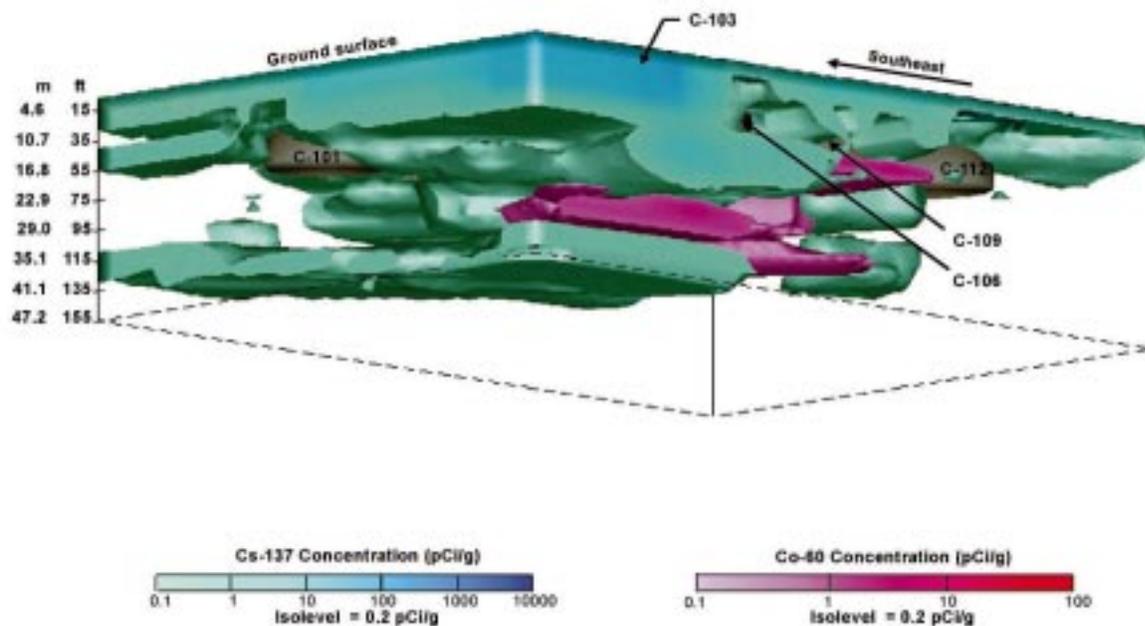


Figure 6.2.5. Vadose Zone Contamination at the C Tank Farm, 200-East Area



have migrated downward along the tank sides and may have accumulated at the interface of the backfill materials and undisturbed Hanford formation sediments. The source(s) of this contamination was not positively identified.

Tanks C-201, -202, -203, and -204 are designated as leakers. There are no monitoring boreholes around these tanks; therefore, the vadose zone in this region of the C Tank Farm cannot be characterized. The contamination from the relatively small volume of leakage (6,624 L [1,750 gal]) from these tanks is probably minimal.

There is no indication from published groundwater monitoring data that waste from tanks in the C Tank Farm has reached groundwater.

S Tank Farm Vadose Zone Characterization. The 68 existing boreholes surrounding the 12 single-shell tanks in the S Tank Farm, 200-West

Area, were logged with the spectral gamma logging system from May to June 1996. The final tank summary data report was completed in August 1997, and the S Tank Farm report (GJO-97-31-TAR, GJO-HAN-17) was completed in February 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the S Tank Farm vadose zone monitoring boreholes. Europium-154 was detected in one borehole in a thin interval near ground surface. Because of the limited occurrence of cobalt-60 contamination relative to the distribution of cesium-137, three-dimensional visualizations of only the cesium-137 contamination were prepared. Figure 6.2.6 shows the cesium-137 contamination in the S Tank Farm that was detected with spectral gamma logging; the characterization of the S Tank Farm vadose zone contamination is limited to the depths of the tank monitoring boreholes.

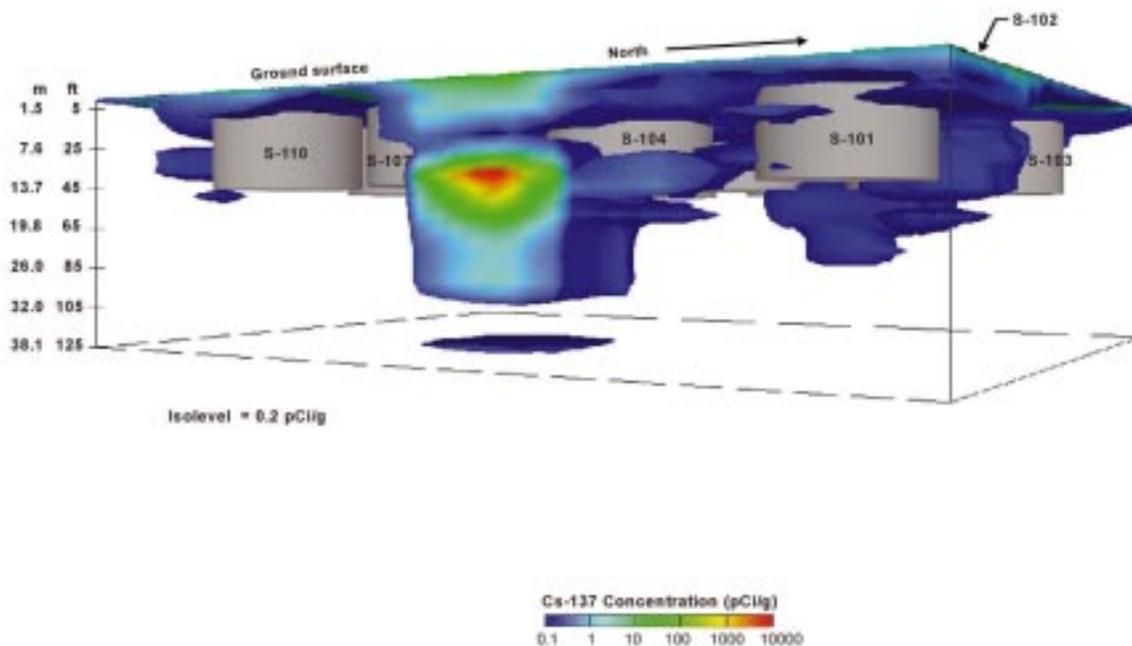


Figure 6.2.6. Vadose Zone Contamination at the S Tank Farm, 200-West Area



Two major regions of contamination were detected in the S Tank Farm: one beneath and to the east of tank S-104 and the other around tanks S-101, -102, and -103. Cesium-137 contamination beneath tank S-104 resulted from leakage from that tank and extends to a depth of approximately 29 m (95 ft) (approximately 17 m [55 ft] beneath the tank base).

Cobalt-60 and cesium-137 contamination was detected around tanks S-101, -102, and -103. This plume of contamination resulted from a large surface spill that occurred in this region of the tank farm in 1973. The surface spill appears to have migrated

through the backfill materials, cascaded over tank domes, and collected at the base of the tank farm excavation to depths of approximately 22 m (73 ft).

Data indicate that contaminants may be entering the groundwater beneath the S Tank Farm; however, a positive source of the contamination could not be determined from this initial vadose zone characterization. Waste disposal facilities adjacent to the S Tank Farm, as well as the S Tank Farm itself, may be sources of the groundwater contamination (WHC-SD-EN-AP-191).

6.2.2 Vadose Zone Monitoring at Waste Disposal Facilities

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Radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, accidental spills, and leachate from solid waste burial grounds at the Hanford Site are potential sources of groundwater contamination. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring were conducted during 1998. Also in 1998, physical, chemical, and hydraulic properties were measured from samples obtained from characterization boreholes at the Immobilized Low-Activity Waste site in the 200-East Area, which is the site for activities associated with retrieval and processing of tank waste, to support performance assessment modeling; at the borehole 41-09-39 extension site in the 200-West Area, to support SX Tank Farm remediation/closure; and at the 216-B-2-2 ditch in the 200-East Area to support 200 Areas soils remediation. Further, soil-vapor monitoring in the 200-West Area continued in 1998, and the summary of those activities is provided in this section.

6.2.2.1 Subsurface Characterization and Vadose Zone Monitoring

During 1998, in situ spectral gamma logging was performed by Waste Management Federal Services, Inc., Northwest Operations in support of Pacific Northwest National Laboratory RCRA groundwater monitoring in 21 boreholes (Figure 6.2.7) at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, all associated with the Plutonium Finishing Plant in the 200-West Area. These facilities were logged to determine whether recent movement of transuranic radionuclides had occurred beneath the facilities as a result, in part, of infiltration of precipitation. The surface of the 216-Z-1A facility is approximately 2 m (6.6 ft) below the surrounding grade and is covered with gravel. Thus, infiltration at this facility could be expected to be enhanced.

Spectral Gamma Logging Results. All borehole logs and a full discussion of the logging results at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib can be found in PNNL-11978.

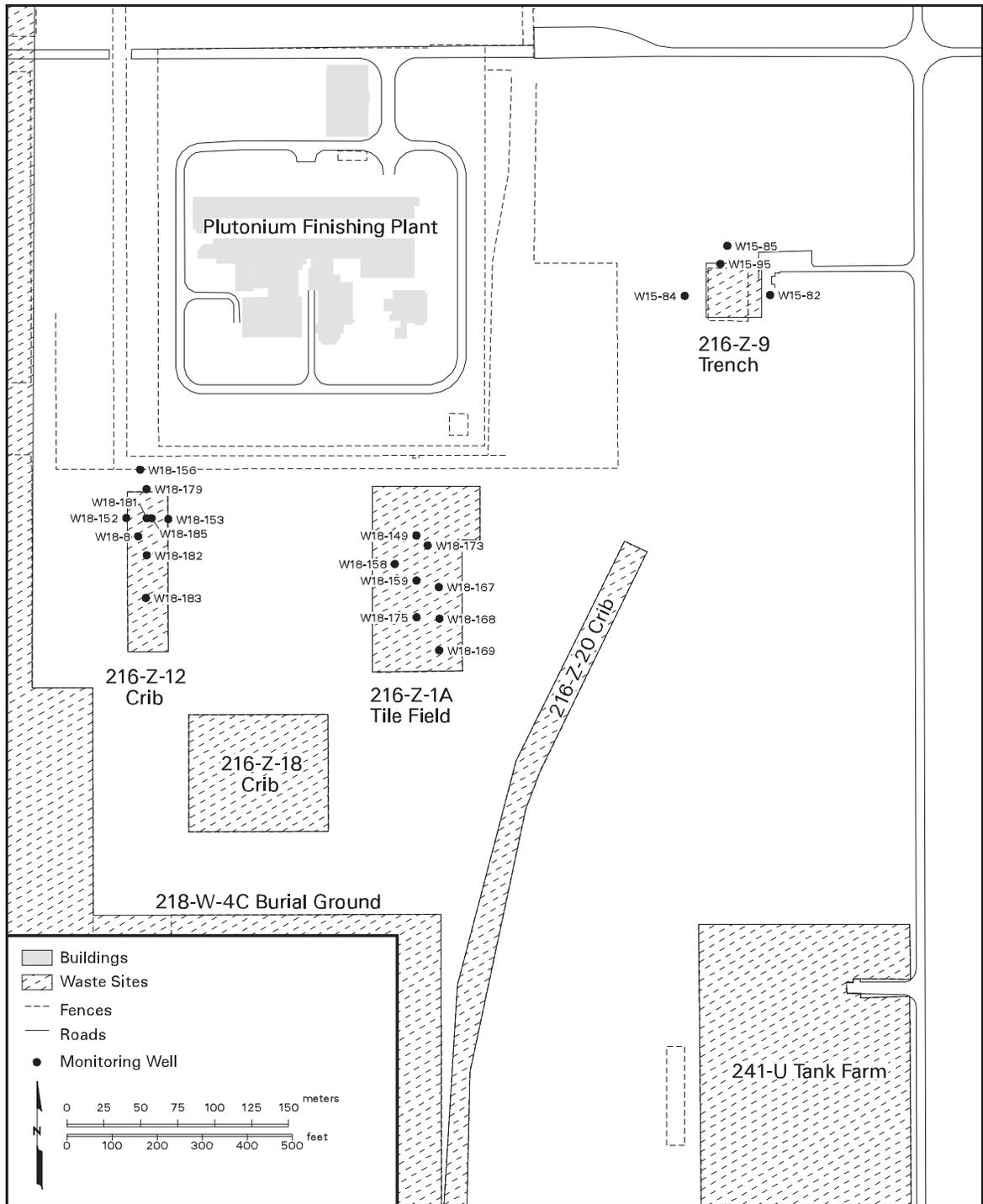


Figure 6.2.7. Location of Boreholes Logged at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, 200-West Area



The discussion below summarizes those results. All depths referred to in this section are relative to ground surface.

Cesium-137, protactinium-233, plutonium-239, and americium-241 were identified in the logs from the tile field and the crib. The maximum activities found at the tile field were in borehole 299-W18-159, which is located along the centerline/central distributor pipe of the tile field (cesium-137, 23 pCi/g at 3.3 m [10.8 ft]; protactinium-233, 63 pCi/g at 16.5 m [54.1 ft]; plutonium-239, 25,000,000 pCi/g at 3.3 m [10.8 ft]; americium-241, 2,500,000 pCi/g at 4.3 m [14.1 ft]). The distributor pipes are at the approximate 4.6-m (15-ft) depth (RHO-ST-17). This high-activity, shallow zone has been attributed to particulate plutonium dioxide that was filtered out of the liquid effluent by the sediments. Grab samples obtained in 1979 during drilling of borehole 299-W18-159 were found to contain a maximum of 1,500,000 pCi/g plutonium-239,240 at 4 m (13.1 ft) (RHO-ST-17). The difference between the maximum activities found from the 1979 laboratory results and the 1998 logging results probably reflects differences in the two analytical methods, coupled with the potential for discrete particulate plutonium dioxide at the level of the distributor pipe.

The deepest depth at which contamination was found at the 216-Z-1A Tile Field was approximately 30 m (98.4 ft) in borehole 299-W18-175, which is located along the centerline/central distributor pipe, where protactinium-233 was ~21 pCi/g, plutonium-239 was near 28,000 pCi/g, and americium-241 was near 80,000 pCi/g. Significant activities ($\geq 100,000$ pCi/g) of plutonium-239 were found as deep as 16 m (52.3 ft) in one borehole and approximately 14 m (46 ft) in another. Significant activities ($\geq 100,000$ pCi/g) of americium-241 were found as deep as 15 to 18 m (49 to 59 ft) in two boreholes. Whereas the shallow, high-activity zone can be attributed, in part, to particulate plutonium dioxide that was filtered out of the effluent by the sediments, the deeper, more widely distributed zones of

contamination probably resulted from dissolved transuranics in aqueous and/or organic phases.

The only man-made radionuclide identified at the 216-Z-9 Trench was cesium-137, at < 1 pCi/g near the surface in borehole 299-W15-95. However, only four wells were logged, and radionuclide contamination almost certainly exists beneath the trench.

At the 216-Z-12 Crib, boreholes 299-W18-179, -181, -182, and -185 showed the highest activities of man-made radionuclides. The maximum plutonium-239 activity was 3,000,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-181. The maximum americium-241 activity was 2,100,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-182. The maximum cesium-137 activity was 900 pCi/g at 5.8 m (19 ft) in borehole 299-W18-179. The distributor pipe is ~5.2 m (17 ft) below ground surface at this facility. The deepest contamination was found ~10 to 11 m (32.8 to 36 ft) at borehole 299-W18-181, where plutonium-239 was ~110,000 pCi/g, americium-241 was ~40,000 pCi/g, and cesium-137 was ~6 pCi/g. These boreholes all lie along the central distributor pipe near the headend of the crib. Protactinium-233 was the only man-made radionuclide found in boreholes near the crib boundary.

Comparisons of log data collected in 1998 with past logging event data suggest that some changes have occurred in radionuclide activity around two boreholes in the 216-Z-1A Tile Field and around one borehole in the 216-Z-12 Crib.

In borehole 299-W18-159 at the 216-Z-1A Tile Field, there was an apparent decrease in protactinium-233 activity to approximately one-third of 1991 values between 13.4 and 15 m (43.9 to 49.2 ft), with no apparent change above or below that zone. This suggests a lateral, not a vertical, change in protactinium-233 activity. Also, between 13 and 16 m (42.6 and 52.5 ft), cesium-137 activity decreased by a factor of approximately three, compared to the 1991 log.



In borehole 299-W18-175 at the 216-Z-1A Tile Field, a 51% increase in protactinium-233 activity was found between 6 and 16 m (19.7 and 52.5 ft) and a 22% increase between 28 and 29 m (91.9 and 95.1 ft), compared to activities from a 1993 log. Also in this borehole, there was an increase in the intensity of the americium-241 60-keV photopeak but no change in the intensity of the americium-241 208-keV photopeak at the 12.5-m depth, which compared with the 1993 log data. This suggests either a decrease in the casing thickness, such as from corrosion, leading to less attenuation of the less-energetic photon, or small amounts of americium-241 inside the borehole casing.

Only borehole 299-W18-179 at the 216-Z-12 Crib suggested that there were changes in subsurface distribution of radionuclides at that facility. Protactinium-233 showed an apparent 16% increase, and plutonium-239 showed an apparent 123% increase over the 4.6- to 5.5-m (15- to 18-ft) depth interval since the last logging in 1993. This depth is within the crib backfill material.

There is significance to the occurrence and the changes in protactinium-233 activity found in the three boreholes. Protactinium-233 has a 27-d half-life, so its occurrence must be supported by a long-lived parent isotope. Alpha decay of neptunium-237, with a half-life of 2.2 million years, is the most probable parent for protactinium-233. One probable origin for the neptunium-237 is alpha decay of americium-241, which was a significant contaminant in the waste stream sent to the Plutonium Finishing Plant cribs. A second possible origin for neptunium-237 is uranium-238 (n,2n) uranium-237, which beta decays to neptunium-237. Regardless of the origin of the neptunium-237, it is considered to be rather mobile in oxidizing environments (see PNL-10379, SUP. 1). Thus, the changes in activity of protactinium-233 probably reflect movement of neptunium-237, and the distribution of protactinium-233 can be considered a surrogate for neptunium-237.

Finally, the 1998 logging found large amounts of transuranics around boreholes 299-W18-149 and -159 that produced a large neutron flux, resulting in activation of elements in the soil column and in the borehole casing. This phenomenon was not investigated further.

Migration of Transuranics. The mobility of transuranics that are complexed with organic molecules in acidic waste streams discharged to past-practice disposal facilities near the Plutonium Finishing Plant were discussed in Section 4.4.5 of PNNL-11793 and by Johnson and Hodges (1997). The mechanism suggested by Johnson and Hodges might account for the distribution of high-activity transuranics to the 20- to 30-m (65.6- to 98.4-ft) depth in the 216-Z-1A Tile Field as found in earlier soil-column characterizations (RHO-ST-17). It is also suggested that transuranics could be adsorbed by the soil column after degradation of the organic complexing agents, resulting in stabilization of the contaminants. Alternatively, other soil-chemical reactions may have occurred (RHO-ST-17, NUREG/CR-6124).

In 1993, a logging team produced prompt fission neutron logs of four boreholes at the 216-Z-1A Tile Field and one each at the 216-Z-9 Trench and 216-Z-12 Crib. The prompt fission neutron tool measures undifferentiated, fissionable isotopes (primarily uranium-235, plutonium-239, and plutonium-241). The results of the prompt fission neutron logging were not published, but a draft report states that all the boreholes at the 216-Z-1A Tile Field and one borehole at the 216-Z-12 Crib showed large activities of fissionable isotopes. Two of the boreholes at the tile field had been logged previously with the prompt fission neutron tool in 1978 and again in 1984. The distribution of contaminants, as seen from the 1993 log, agreed well with the previous logs, indicating that fissionable radionuclides, including plutonium, had not moved substantially over the span of 15 yr at the two boreholes. The general



conclusion is that transuranics were relatively mobile at the time of discharge to the tile field but have been fairly stable since.

The 1998 logging found that the subsurface distribution of plutonium had changed around only one borehole at the 216-Z-12 Crib. “Particulate” plutonium, with discrete 2- to 24-micron particle sizes (>79 wt% plutonium dioxide) at and immediately below the distribution pipe at the 216-Z-1A Tile Field was documented in Price and Ames (1976). Although it is possible that particulate plutonium has been remobilized at the 5-m (16.4-ft) depth at the crib, further investigation is needed to determine both the nature and the reasons for plutonium remobilization.

Comparing the distribution of transuranics beneath the 216-Z-1A Tile Field and the 216-Z-12 Crib shows a much deeper penetration of transuranics beneath the tile field. This agrees with past characterizations at the two facilities (RHO-ST-17, RHO-ST-44) and can be explained by the processes described in Section 4.4.5 of PNNL-11793 or in Johnson and Hodges (1997). Unlike the acidic, organics-containing waste stream disposed to the tile field, the waste stream sent to the crib was neutral to basic and contained little organic-complexing agents (though sufficient carbon tetrachloride was found beneath the crib to include it in the vapor-extraction project). The initial mobility of transuranics is expected to be greater in the former waste stream than in the latter. After the disposal occurred, both the acidic and organic complexes are expected to have diminished via soil pH neutralization and biodegradation processes, and transuranics, especially americium and plutonium, would be expected to adsorb strongly to the sediments. There has been no obvious increased americium or plutonium migration deeper into the sediment profile at these facilities, but the protactinium-233 distribution may be interpreted as showing some migration of neptunium-237.

6.2.2.2 Immobilized Low-Activity Waste Site

The Tank Waste Remediation System program is focusing on resolving tank safety issues, planning for waste retrieval, developing waste pretreatment and treatment facilities, and evaluating waste storage and disposal needs for single-shell tank wastes. Vitrification and onsite disposal of low-activity waste from single-shell tanks are embodied in the strategy described in the Hanford Site federal facility agreement and consent order (commonly known as the Tri-Party Agreement; Ecology et al. 1989). The pretreatment and immobilization operations for both the low-activity and high-level wastes have been contracted to private organizations. The current plan is to dispose of immobilized, low-activity, tank waste in new facilities in the south-central part of the 200-East Area and in four existing vaults (unused, reinforced concrete structures remaining at the former Grout Treatment Facility) along the eastern side of the 200-East Area (DOE/RL-97-69).

Boreholes 299-E17-21, B8501, and B8502 were drilled in April 1998 at the southwestern corner of the Immobilized Low-Activity Waste disposal site (Figure 6.2.8) in support of the performance assessment activities for the disposal options. The boreholes were drilled using an air-lift, driven-casing method, and continuous soil samples were collected through the vadose zone. A complete description of the drilling project is presented in PNNL-11957.

Geologic logging of the drill cores showed that the vadose zone beneath the southwestern portion of the Immobilized Low-Activity Waste disposal site consists of the upper few meters (feet) of Ringold Formation Unit E gravels overlain by the Hanford formation (PNNL-11957). The careful drilling and near-continuous core recovery allowed geologists to identify for the first time three paleosols (layers) in a single borehole (299-E17-21). The three paleosols represent significant time intervals when soil development took place and are interpreted to be the tops

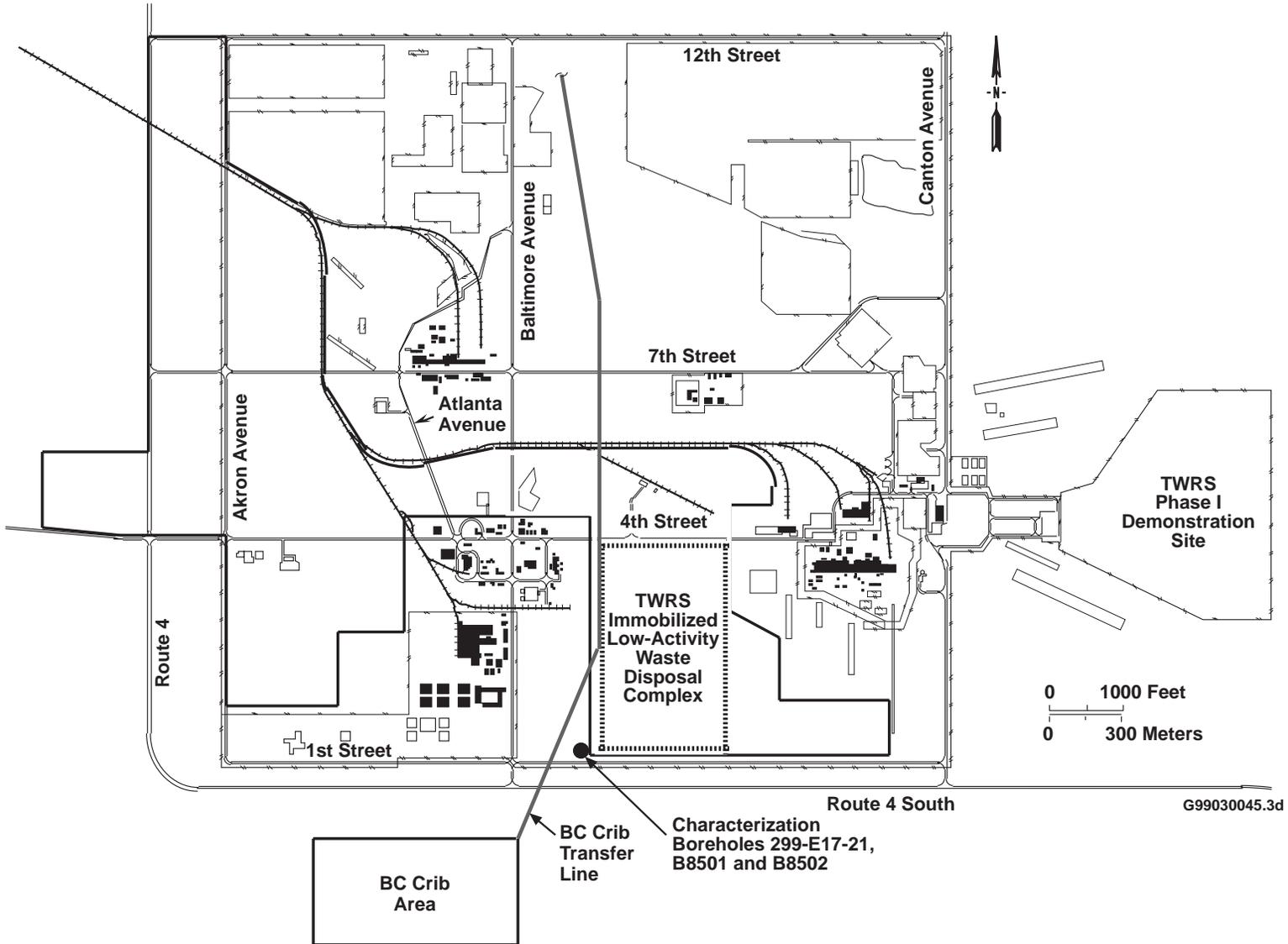


Figure 6.2.8. Locations of the Immobilized Low-Activity Waste Site and Characterization Boreholes 299-E17-21, B8501, and B8502, 200-East Area



of three Missoula flood deposits. The three flood events have been mapped at the Hanford Site (Reidel and Fecht 1994a, 1994b) but they have not been encountered in a single borehole. The detailed stratigraphy from the borehole sets a good background for the subsequent chemical transport, physical properties, and estimation of recharge tests.

All three boreholes were logged with a high-purity germanium detector to determine whether man-made, gamma-emitting radionuclides were present and to provide analyses of naturally occurring isotopes for stratigraphic purposes. No man-made radionuclides were identified. The boreholes were also logged with a neutron probe to determine moisture content. The moisture logging showed higher moisture content in the upper part of the borehole, consistent with higher-than-normal precipitation over the past several years. Comparison of the neutron probe moisture data with the stratigraphy indicated good agreement between high-moisture zones and fine-grained stratigraphic units.

Twenty intact cores from borehole 299-E17-21 were analyzed for physical and hydraulic properties. The 20 cores are from the Hanford formation sandy sequence. The cores were found to be fairly uniform as were the data generated, reflecting the high percentage of medium to fine sand. The variability among the hydrologic and physical data collected was within the range reported by WHC-EP-0883 for sediments of the 200 Areas. This increases confidence that existing data sets are representative of the range of physical and hydrologic properties present in the uncontaminated portions of the 200 Areas and may be representative of many of the contaminated portions of the 200 Areas. The data represent the most complete set of physical properties (i.e., particle size, particle density, bulk density, porosity) and hydrologic properties (i.e., saturated and unsaturated hydraulic conductivity, water retention) measured on undisturbed cores (split-spoon samples) at the Hanford Site.

In two samples, thin zones were observed with finer texture and lower hydraulic conductivities than were seen in the other 18 samples. These two thin zones could impact flow and contaminant transport by increasing lateral spreading. These observations, in concert with others, will be used to formulate a vadose zone conceptual model for the Immobilized Low-Activity Waste disposal site. Additional boreholes are planned in future years to help verify whether the two, thin, fine-textured layers are continuous across the disposal site. An unexpected feature found during coring activities was a relatively thick, open-framework, gravel sequence below 76.2 m (250 ft). No physical or hydrologic data are available for this sequence. Plans are in place to gather samples that are as undisturbed as possible during the future drilling activities.

Specific Distribution Coefficient Data. Radionuclide distribution coefficients (K_d) are a measure of the ratio of the amount of radionuclide adsorbed onto soil or rock and the amount remaining in solution (i.e., groundwater). K_d s are usually obtained by contacting soil with groundwater that has been spiked with a known amount of a specific radionuclide. The quantity of radionuclide adsorbed on the soil and the quantity remaining in the water are then measured. The higher the K_d , the greater the amount of contaminant on the soil relative to the amount remaining in the groundwater.

Radionuclide K_d measurements for cesium, iodine, selenium, strontium, technetium, and uranium were made on 20 samples from borehole 299-E17-21. Results of the measurements are summarized below. A more complete description of the tests is given in PNNL-12086 (Section 4.4). The results of the testing serve as input to performance assessment modeling of the Immobilized Low-Activity Waste Site.

Two sets of K_d values were calculated: conservative and best estimate. The conservative and best estimates of K_d values are given in Table 6.2.1,



Table 6.2.1. Conservative and Best Estimates of Distribution Coefficient (K_d) Values of Units 1, 2, and 3^(a,b) at Borehole 299-E17-21, 200-East Area

Radionuclide	Units 3 and 2 K_d, mL/g		Unit 1 K_d, mL/g	
	Conservative^(c)	Best^(d)	Conservative^(c)	Best^(d)
Cesium	1,370	2,050 ± 440	1,370	2,050 ± 440
Iodine	0	0 ± 0	0	0.1 ± 0.1
Selenium	3.8	6.7 ± 1.9	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6	12.0	16.5 ± 1.9
Technetium	0	0 ± 0	0	0 ± 0
Uranium	0.5	0.6 ± 0.1	0.5	0.6 ± 0.1

- (a) Different K_d values were assigned to each unit when statistical analyses determined that they differed at the 5% level of confidence. Otherwise, the same K_d values were assigned for all three units.
- (b) Units represent depths within the Hanford formation: unit 3, 1.5 to 17.7 m (5 to 58 ft); unit 2, 17.7 to 49.7 m (58 to 163 ft); and unit 1, 49.7 to 75.3 m (163 to 247 ft).
- (c) Conservative estimates were based on the minimum value.
- (d) Best estimates were based on the median ± standard deviation.

assuming that performance assessment modeling will divide the Hanford formation into three geologic units separated by the paleosols described above, and in Table 6.2.2, assuming that the Hanford formation will be treated as a single modeling unit. Which of these two conceptual models will ultimately be used in future performance assessments will depend on these as well as other characterization data. Presumably, if significant differences in other parameter values such as hydraulic conductivity are observed among the three units, then it may be decided that introducing the added complexity of three units is warranted. Otherwise, the most conservative estimate of the combined units may be used for the performance assessment.

Overall, the estimates appearing in Tables 6.2.1 and 6.2.2 are consistent with those used for past performance assessments, with some notable exceptions. The older, conservative values for cesium, selenium, and strontium used in past calculations

were 100, 0, and 5 mL/g, respectively, and were appreciably more conservative than necessary. The new K_d estimates for technetium and uranium in Tables 6.2.1 and 6.2.2 are approximately the same as those used for past calculations. The iodine K_d value from this new work is appreciably less than that used in the most recent performance assessment (3 mL/g) (DOE/RL-97-69), which was based on a literature review of K_d values measured using generic Hanford Site sediments (PNL-10379, SUP. 1). The cause for the new, measured, lower, iodine K_d values is not known, though the sediments used in this study clearly had appreciably lower amounts of fine-grained material than the previously used Hanford Site sediments. These differences in values underscore the importance of basing K_d estimates for the more-mobile major dose contributors on measurements using site-specific sediments.

Ideally, all K_d experiments should be conducted using site-specific sediments because the science of



Table 6.2.2. Conservative and Best Estimates of Distribution Coefficient (K_d) Values for the Hanford Formation at Borehole 299-E17-21, 200-East Area

<u>Radionuclide</u>	<u>Conservative K_d Value,^(a) mL/g</u>	<u>Best K_d Value,^(b) mL/g</u>
Cesium	1,370	2,030 ± 597
Iodine	0	0 ± 0
Selenium	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6
Technetium	0	0 ± 0
Uranium	0.5	0.6 ± 0.1

(a) Conservative K_d value estimates are based on the lowest value for each radionuclide (except uranium, which used the second-lowest measured K_d value.

(b) Best K_d value estimates are the median ± standard deviation from the 20 samples studied.

geochemistry is not yet advanced enough to permit estimating the geochemical behavior of a radionuclide in one sediment based on its behavior in another. However, site-specific sediments are generally expensive to collect, and the volume of material available usually is limited. The newly determined iodine K_d data suggest that the most technically defensible way to quantify radionuclide sorption is through experiments conducted with site-specific sediments and pore water or waste leachate, but the new results for the other contaminants studied are quite similar to past results using generic Hanford Site sediments not proximal to the proposed Immobilized Low-Activity Waste disposal complex.

6.2.2.3 Borehole 41-09-39 Extension to Groundwater

Borehole 41-09-39 was drilled in 1996 in the SX Tank Farm, 200-West Area, to a depth of 40 m (131 ft) in response to the determination that cesium-137 might reside in the soil column at depths >30.4 m (100 ft). Closed-end casing was driven to ascertain whether the contamination was an artifact of transport

down the outside of an adjacent borehole or was disseminated in the soil formation. Geophysical logging of this borehole in late 1996 confirmed that cesium-137 dissemination within the formation was plausible and that contamination was still present at a depth of 40 m (131 ft).

Concern was raised that if relatively immobile cesium-137 was present at that depth, then more-mobile, long-lived, tank-waste constituents such as technetium-99 might be at or near the water table at approximately 64 m (210 ft). In response to a recommendation of the independent expert panel brought together to address these early findings (DOE/RL-97-49), borehole 41-09-39 was extended to groundwater in 1998 and samples were collected for laboratory analysis of tank waste components.

The closed-end casing was removed by milling with a rotary drilling machine, and the borehole was extended by sequentially driving a split-spoon sampler into the formation ahead of the drill casing, then cleaning the bore to the depth sampled, driving the drill casing to that depth, and finally cleaning out the drill casing again. This process was then repeated for



subsequent samples. Geologic conditions resulted in excessive friction against the drill pipe, effectively stopping progress. The drill casing was removed from the bore, and the drill shoe was replaced to over-ream the hole, reducing friction and allowing the casing to be advanced. The over-reaming drill shoe created a small annular space that may have contributed to drag down of contamination.

Sediment samples were collected in a near-continuous manner throughout the vadose zone, except where geologic conditions required use of a drilling method that resulted in unrepresentative samples. All sediment returned to the surface was preserved for potential analysis. Samples from seven selected locations within the borehole were analyzed for radionuclides, chemical constituents, cation-exchange capacity, and particle-size distribution.

Periodic geophysical logging of the borehole was used to indicate the occurrence of contaminant drag down and to provide additional data used to select sample locations. Gamma logging techniques were used throughout the drilling effort. On completion of the borehole, a neutron-neutron moisture log was run. Geophysical logging indicated that some contaminated material was following the casing as it was advanced. It should be noted that the indicated contaminant levels were low.

Screening analyses of the samples showed that the upper portion of the split-spoon sampler often exhibited low levels of contamination while the lower portion did not. The regularity of this occurrence resulted in its being interpreted as cross-contamination, either from material dragged along the outside of the casing or from material smeared along the inside of the casing that was deposited as the drill tools and samplers were inserted or extracted from the bore. Samples from the upper split-spoon sleeves were excluded from analysis when there was evidence of such possible cross-contamination.

Detailed geochemical analyses of the seven samples from this borehole showed that tank waste

constituents are predominantly held within or above the Plio-Pleistocene sediments. Nonradiological constituents (calcium, nitrate, sodium) point to the leading edge of tank waste components being at a depth of approximately 47 m (154 ft) in borehole 41-09-39. This leading edge may be from natural percolation or drag down; however, the determination of which process is most likely cannot be made at this time.

Analyses for cesium-137, the radionuclide originally recognized as being deeper than expected in the vadose zone, were conducted on all samples via gamma energy analysis. Cesium-137 activity in the soils of the extended borehole was highest in the Plio-Pleistocene sediments at the 40-m (131-ft) depth. Activity dropped off rapidly and was at or below detection levels from 48.8 m (160 ft) to the water table at 64.3 m (210 ft).

Distribution of technetium-99, the most mobile of the long-lived radionuclides found in tank wastes, was sporadic, with most occurrences above the method detection level being above the Plio-Pleistocene unit. A single, deep occurrence was noted at 56.3 m (185 ft); this is the location postulated to be the highest level reached by groundwater during operation of U Pond (now decommissioned) located west of the SX Tank Farm. It is possible that technetium-99 was brought to this sediment sample by horizontal migration from disposal facilities outside the tank farm boundaries. If the technetium source was the SX tanks, it would have been expected that near-continual detection would have been noted throughout the shallower sediments. Figure 6.2.9 shows the distribution of cesium-137, technetium-99, and water extractable nitrate concentrations in the vadose zone sediments from borehole 41-09-39.

K_d tests were run on sediment samples for both technetium-99 and cesium-137. These tests showed that cesium-137 is strongly bound to the fine-grained sediments. The tests for technetium-99 showed positive K_d values, but the uncertainty associated with those values was significant.

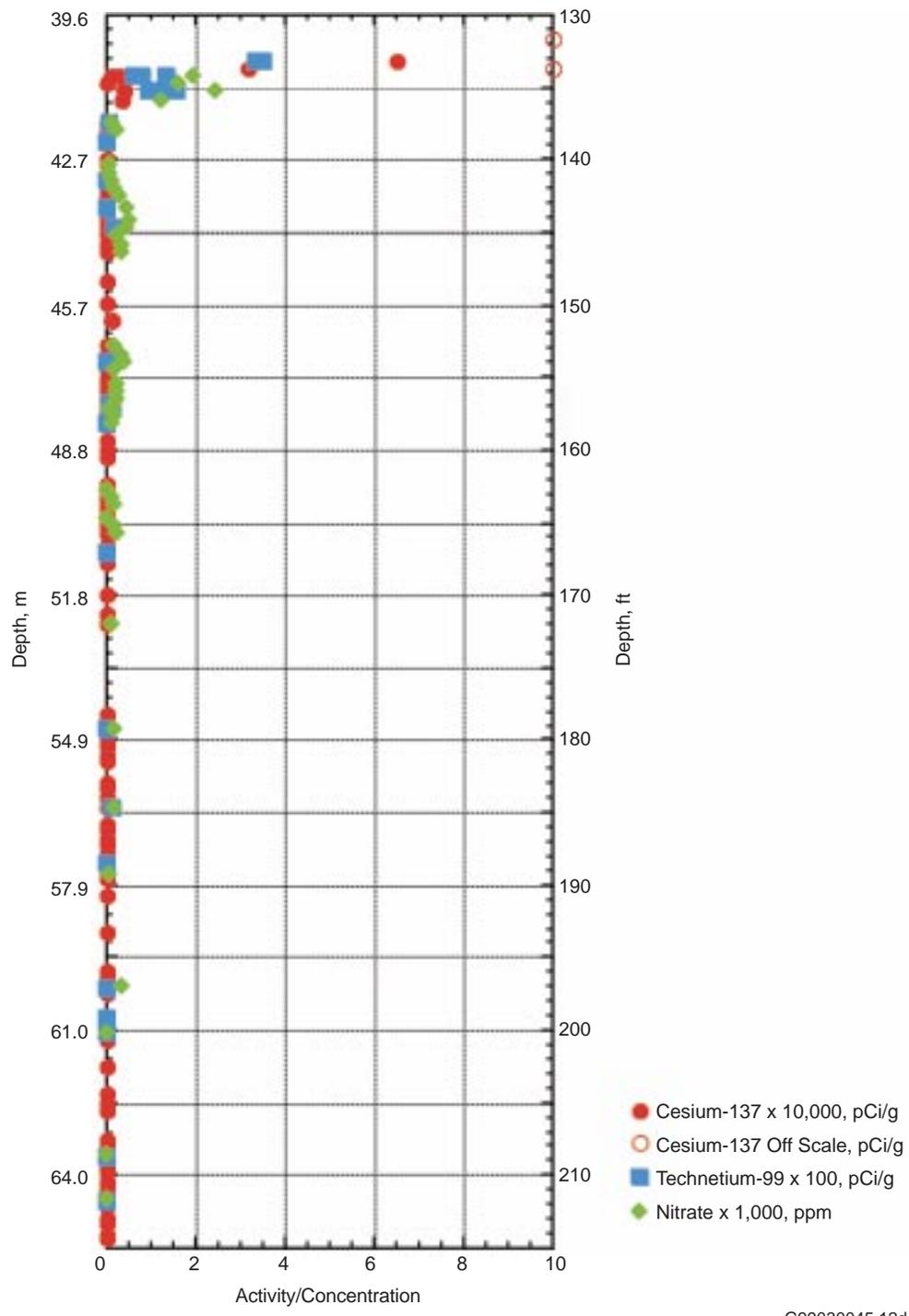


Figure 6.2.9. Distribution of Technetium-99 and Cesium-137 in the Vadose Zone Sediments from Depth and the Water Extractable Nitrate Concentrations from Borehole 41-09-39, SX Tank Farm, 200-West Area



Groundwater samples were collected from 0.02, 0.6, and 3 m (0.06, 2, and 10 ft) below the water table. Analyses of these samples showed technetium-99 and tritium activities indicative of an upgradient source. Analytical results for chromium were consistently below the method detection limit. These analyses indicate that groundwater contamination at this specific location is due to non-tank farm sources. More sampling of vadose zone sediments under the SX Tank Farm at additional locations is needed to determine whether the contaminants in downgradient monitoring wells may have originated from the single-shell tanks or from non-tank-related liquid discharge facilities nearby.

The results of the investigation of the borehole 41-09-39 extension point to a need to ascertain the disposition and distribution of the mobile, long-lived, waste constituents in the vadose zone. Complete details of the borehole extension findings can be found in HNF-2855. The geochemistry of tank wastes and the possible interactions of mobile species with sediments of the vadose zone are major gaps in the Hanford Site vadose zone information base for addressing tank remediation/closure.

6.2.2.4 200 Areas Assessment

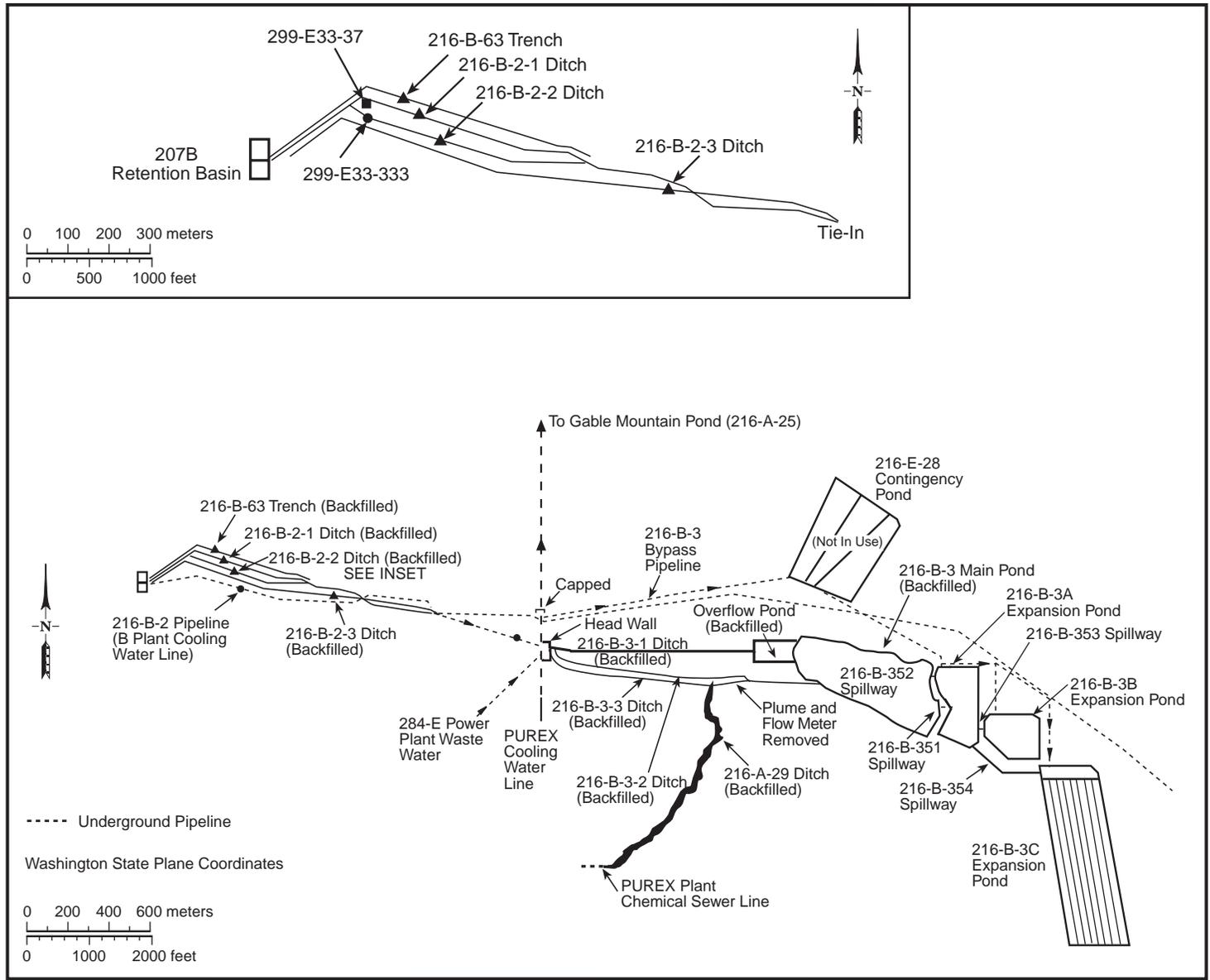
A characterization borehole (299-E33-333) was drilled through the 216-B-2-2 Ditch, 200-East Area, (Figure 6.2.10) to groundwater during late December 1997 and early January 1998. This ditch was selected for characterization based on the criteria in DOE/RL-96-81, which identified this ditch as a representative site for the 200-CW-1 Gable Mountain Pond/B Pond and Ditches Cooling Water Group (formerly the 200-BP-11 Operable Unit). The 216-B-2-2 Ditch was selected as a representative site because 1) it was operationally typical of a ditch and contains a representative inventory of contaminants; 2) it is expected to contain typical to higher levels of contamination at the headend of the ditch system; and 3) it lies in the middle of the 216-B-2 Ditch system, providing composite data for all three 216-B-2 ditches at depth.

The 216-B-2-2 Ditch received 49,700,000 L (13,100,000 gal) of effluent containing 147 Ci of strontium-90 as the major contaminant (DOE/RL-96-81). The purpose of drilling the borehole was to refine the preliminary physical conceptual models of contaminant distribution and hydrogeology, to assess the nature and extent of subsurface contaminants, and to support remedial action/closure decisions for the 200-CW-1 group (BHI-01052). The characterization activities, sampling and analysis plan, and data quality objectives are described in the description of work (BHI-01052). The characterization results are found in the borehole summary report (BHI-01177).

Characterization borehole 299-E33-333 was drilled at the influent end of the 216-B-2-2 Ditch because it was the location considered the most likely to have the highest concentration of contaminants along the ditch. The borehole was extended to a depth of 77.4 m (254 ft), which is below the water table, to investigate the extent of contamination throughout the vadose zone. The borehole was drilled using cable-tool techniques and was abandoned following characterization. Soil samples for chemical and radiological analyses and/or physical property testing were collected at 13 depths using a split-spoon sampler.

Geophysical surveys of borehole 299-E33-333 included both spectral gamma logging and neutron-neutron logging (BHI-01177). Spectral gamma logging was conducted to characterize the vertical profile of gamma-emitting radionuclides in the vadose zone. Neutron-neutron logging was conducted to characterize the vertical profile of the moisture content of the vadose zone.

Volatile organic analyses were conducted on all chemical samples, with the exception of the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) below ground surface, which had insufficient sample volume. Three target volatile organic contaminants (acetone, methylene chloride, toluene) were detected at



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Figure 6.2.10. Location of the 216-B-2 Ditch System, 200-East Area



concentrations below the limit of quantification. One nontarget volatile organic (total xylenes) was detected at 8 $\mu\text{g}/\text{kg}$ in the 45.7- to 46.5-m (150- to 152.5-ft) interval.

Semivolatile organic analyses were conducted on all chemical samples. The only polychlorinated biphenyl detected was aroclor-1260, which was found in the 2.4- to 4.7-m (8- to 15.5-ft) interval, with a maximum concentration of 9,200 $\mu\text{g}/\text{kg}$ between 2.4- and 3.2-m (8 and 10.5 ft). Two nontarget semivolatile organic contaminants (butyl benzyl phthalate, di-n-octylphthalate) were detected at concentrations below the limit of quantification.

Chemical analyses for ammonia, cyanide, nitrate, nitrite, and sulfate were conducted on all samples, with one exception: cyanide was not analyzed in the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) because a sufficient sample volume was not available. Cyanide was not detected in any sample. The maximum ammonia, nitrate, nitrite, and sulfate concentrations were 0.553, 35.8, 0.38, and 43.3 mg/kg , respectively, and all were detected in the 1.2- to 3.2-m (4- to 10.5-ft) interval. Ammonia and elevated nitrate were detected in only the uppermost sample from 1.2 to 1.8 m (4 to 6 ft).

Inorganic (metal) analyses were conducted on all chemical samples. For 12 of the 17 target metals detected, the maximum concentration was found in the 2.4- to 4.7-m (7.9- to 15.4-ft) interval. Cadmium and tin were the only 2 of the 17 target metals not detected in any samples.

Radiochemical analyses were conducted on all samples for both man-made and naturally occurring radionuclides. The primary man-made radionuclides detected were strontium-90, cesium-137, and europium-154 at maximum activities of 4,710, 100, and 1.29 pCi/g , respectively. The activities were one to two orders of magnitude higher in the intervals from 2.4 to 3.0 and 4.0 to 4.6 m (8 to 10 and 13 to 15 ft) than in the intervening sample interval from

3.2 to 4.0 m (10 to 13 ft). No man-made radionuclides were detected below 4.6 m (15 ft).

Cobalt-60, cesium-137, and europium-154 were detected in borehole 299-E33-333 by spectral gamma-ray logging methods. Cesium-137 was detected from the ground surface to a depth of 0.7 m (2.3 ft) and at depths between 1.8 and 3.3 m (6 and 11 ft). The maximum cesium-137 activity was approximately 400 pCi/g measured at 2.7 m (8.8 ft). Analysis of the data indicates that, within the zone of highest cesium-137 activity, the contamination is uniformly distributed in the formation as a thin, 0.15- to 0.3-m-thick (0.5- to 1-ft) layer (BHI-01177). Cobalt-60 was detected at the ground surface and at a depth of 0.15 m (0.5 ft). The maximum cobalt-60 activity was approximately 0.15 pCi/g . Europium-154 was detected at three points at depths between 2.6 and 2.9 m (8.5 and 9.5 ft) within the interval of highest cesium-137 activity. The maximum europium-154 activity was 2.0 pCi/g . The spectral gamma logging and sediment radiochemical analyses agree, except that the spectral gamma logging estimates the maximum cesium-137 activity at 400 versus 100 pCi/g for the laboratory analyses. Strontium-90, a beta emitter, was not detectable using the spectral gamma logging instrument.

For both data sets, man-made radionuclides are found within the upper 4.6 m (15 ft) of the soil column. One zone of high activity was found at a depth of 2.4 to 3.2 m (7.9 to 10.5 ft) in both data sets. The laboratory analytical data also indicated a zone of high activity from 4.0 to 4.6 m (13.1 to 15.1 ft). The distribution of man-made radionuclides underlying the 216-B-2-2 Ditch is consistent with the conceptual model developed for the 200-CW-1 group (DOE/RL-96-81). The conceptual model for this group is that the highest activity of the primary contaminants of concern (e.g., strontium-90) will be directly underlying the headend of the ditch. Furthermore, according to the conceptual model, most of the contaminants were expected to be within the



uppermost gravel unit, which at this site extends to a depth of 9.1 m (29.8 ft). The data indicate that, in fact, the radionuclide contamination does not extend below 4.6 m (15.1 ft).

6.2.2.5 Soil-Vapor Monitoring

Soil-vapor extraction is being used to remove the carbon tetrachloride from the vadose zone as part of the 200-West Area expedited response action being conducted by Bechtel Hanford, Inc. This section summarizes 1998 activities. For a more complete description of 1998 activities, see Section 4.5 of PNNL-12086. For descriptions of past work, see BHI-00720 (Rev. 2) and Section 4.4 in PNNL-11793.

To track the effectiveness of the remediation effort, measurements of soil-vapor concentrations of chlorinated hydrocarbons were made at the inlet to the soil-vapor-extraction system, at individual, on-line (i.e., operating), extraction wells, and at individual, off-line (i.e., standby), wells and probes throughout the soil-vapor-extraction sites during 1998. One soil-vapor-extraction system was operated from April through September 1998. Soil-vapor monitoring at off-line wells and probes was conducted from October 1997 through September 1998.

Soil-vapor samples were collected from approximately 25 off-line wells and probes once per month. Soil-vapor samples were analyzed primarily to monitor for carbon tetrachloride; however, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor.

In 1998, 46 drilled wells were available for on-line extraction or monitoring (BHI-00720, Rev. 2) (Figure 6.2.11). Thirteen of these wells were drilled during 1992 and 1993 and were completed as vapor-extraction wells with stainless-steel casing and screens; one well was drilled at a 45-degree incline. Thirty-three wells, drilled between 1954 and 1978 and completed with carbon steel casing, were adapted for

vapor extraction by perforating the well casing using mechanical or jet perforators. Of the 46 wells, 17 have two, separated open intervals in the well. The soil-vapor-extraction system extracts simultaneously from multiple wells open either above and/or below the Plio-Pleistocene unit. The mix of on-line wells is adjusted periodically to optimize contaminant removal.

There are 125 subsurface monitoring probes at >2 m (6.6 ft) below ground surface. A cone penetrometer was used to install 11 extraction, or monitoring, wells (denoted by + on Figure 6.2.11) and 104 subsurface monitoring probes at 33 locations (denoted by D on Figure 6.2.11). Up to five monitoring probes were installed per location at various depths. The deepest monitoring probe installed at the vapor-extraction sites is 36 m (118 ft) below ground surface. Ten stainless-steel tubes were strapped to the outside of the casing of 4 of the 13 wells during installation to enable monitoring above and below the screened intervals.

There are up to 73 shallow, soil-vapor probes at depths ranging from 1.2 to 1.8 m (4 to 6 ft) (Figure 6.2.12). The network was installed between 1991 and 1995. Some of the probes have since been destroyed, primarily as a result of other near-surface construction activities or prolonged exposure to weather conditions.

Based on the results of the 1997 rebound study (BHI-01105) and the declining rate of carbon tetrachloride removal during continuous extraction operations (BHI-00720, Rev. 2), the operating strategy for 1998 was modified. Rather than operating all three soil-vapor-extraction systems continuously, only the 14.2-m³/min (500-ft³/min) system was used for carbon tetrachloride removal during 1998. The 14.2-m³/min (500-ft³/min) system was modified so that it could be moved between the well fields surrounding the 216-Z-1A Tile Field, 216-Z-9 Trench, 216-Z-12 Crib, and 216-Z-18 Crib. The 28.3- and

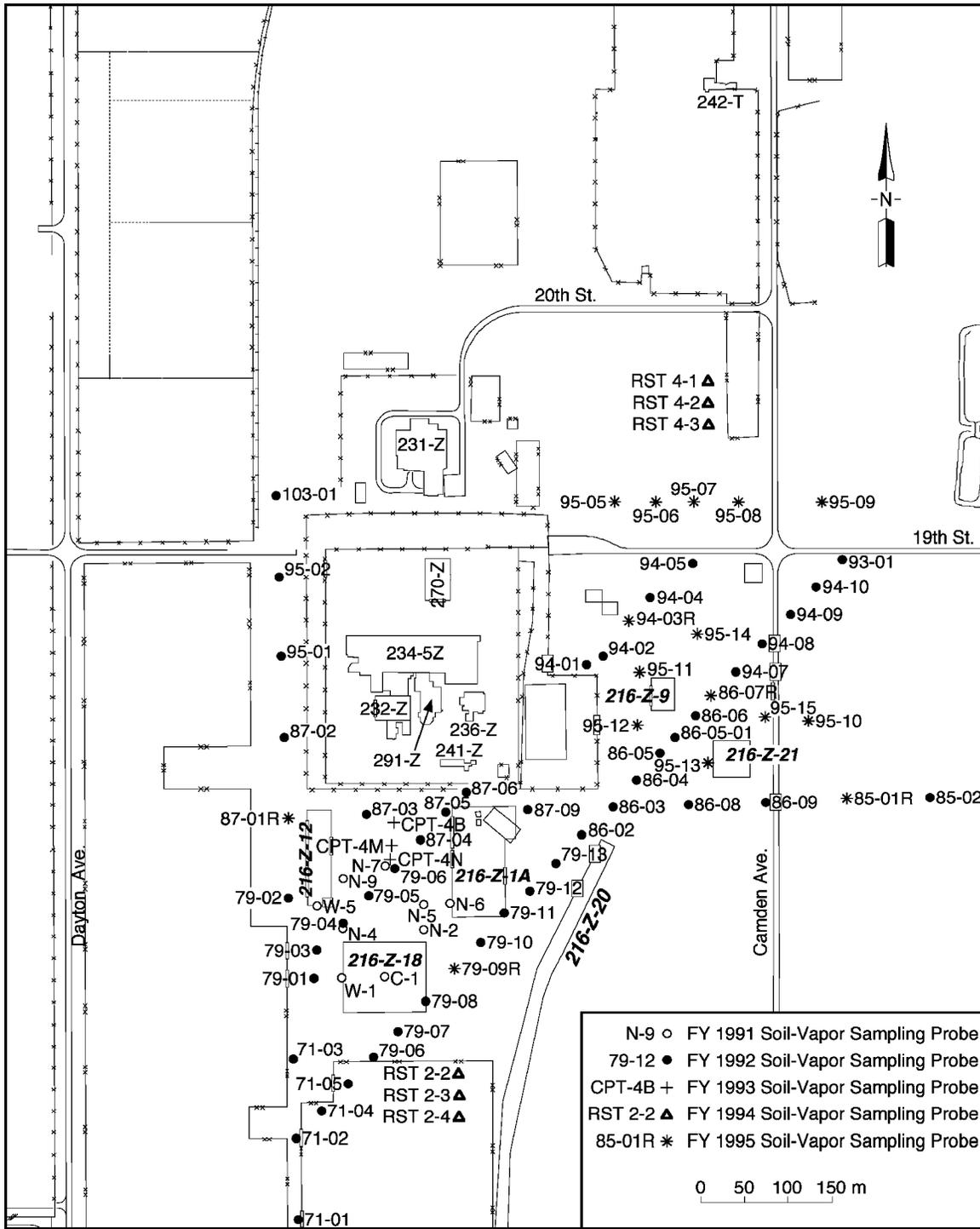


Figure 6.2.12. Locations of Shallow Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area



42.5-m³/min (1,000- and 1,500-ft³/min) soil-vapor-extraction systems were maintained in standby mode during 1998.

The 14.2-m³/min (500-ft³/min) soil-vapor-extraction system was operated from March 30 through June 30, 1998 at the combined 216-Z-1A/-12/-18 well field and from July 7 through September 30, 1998 at the 216-Z-9 well field. The system was shut down for the winter (October 1, 1997 through March 29, 1998).

For the 6 mo that the system was shut down, the rebound in carbon tetrachloride concentrations was monitored at 25 wells and probes at both well fields. For the 3 mo that the system was operated at 216-Z-1A/-12/-18, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-9 well field; for the 3 mo that the system was operated at the 216-Z-9 well field, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-1A/-12/-18 well field.

Soil-Vapor Remediation. Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on March 30, 1998 at the 216-Z-1A/-12/-18 well field, using the 14.2-m³/min (500-ft³/min) system, which is on the northern side of the 216-Z-18 Crib. Fifteen extraction wells distributed throughout the well field were selected to optimize both protection of groundwater and mass removal of contaminant. Initial characterization of the 15 on-line wells indicated that the system was extracting soil vapor effectively from only the closest wells and that the applied vacuum at the distant wells was insufficient to produce flow. Tests showed that the system could, however, extract soil vapor effectively from isolated, distant wells. Therefore, the mix of on-line extraction wells was periodically switched among one set of seven relatively nearby wells and various sets of four relatively distant wells. Each set included wells open near the groundwater and wells open near the less-permeable Plio-Pleistocene unit. As a result, the system was extracting from wells primarily

associated with the 216-Z-18 Crib for the first 7 wk (March 30 through May 17) and from wells primarily associated with the 216-Z-1A Tile Field for the following 6 wk (May 18 through June 30). Comparison of the changes in inlet concentrations to the changes in the sets of on-line wells indicated that the higher concentrations observed from May 18 through June 30 tended to be associated with the 216-Z-1A wells (Figure 6.2.13).

Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on July 7, 1998 at the 216-Z-9 well field, using the 14.2-m³/min (500-ft³/min) system. Initial on-line wells were selected close to the 216-Z-9 Trench. As extraction continued, wells farther away from the trench were brought on line. Each selection of on-line wells included those with openings near the groundwater and those with openings near the less-permeable Plio-Pleistocene unit. The daily mass-removal rate increased significantly twice during the 3 mo of extraction as a result of changes in extraction wells: two additional wells were brought on line on July 29, 1998 (the mass-removal rate increased, despite a continued decline in concentrations, because the flow rate increased [see Figure 6.2.13]); and the mix of on-line wells was changed again on September 1, 1998 (the mass-removal rate increased, despite a constant flow rate, because the inlet concentrations increased [see Figure 6.2.13]).

During a total of 178 d of soil-vapor extraction in 1998, 777 kg (1,700 lb) of carbon tetrachloride were removed from the vadose zone. Of this total, 254 kg (560 lb) were removed from the 216-Z-1A/-12/-18 well field during 91 d of operation and 523 kg (1,150 lb) were removed from the 216-Z-9 well field during 86 d of operation.

As of September 1998, approximately 75,000 kg (165,000 lb) of carbon tetrachloride had been removed from the subsurface since extraction operations started in 1992 (Table 6.2.3). Since initiation, the extraction systems are estimated to

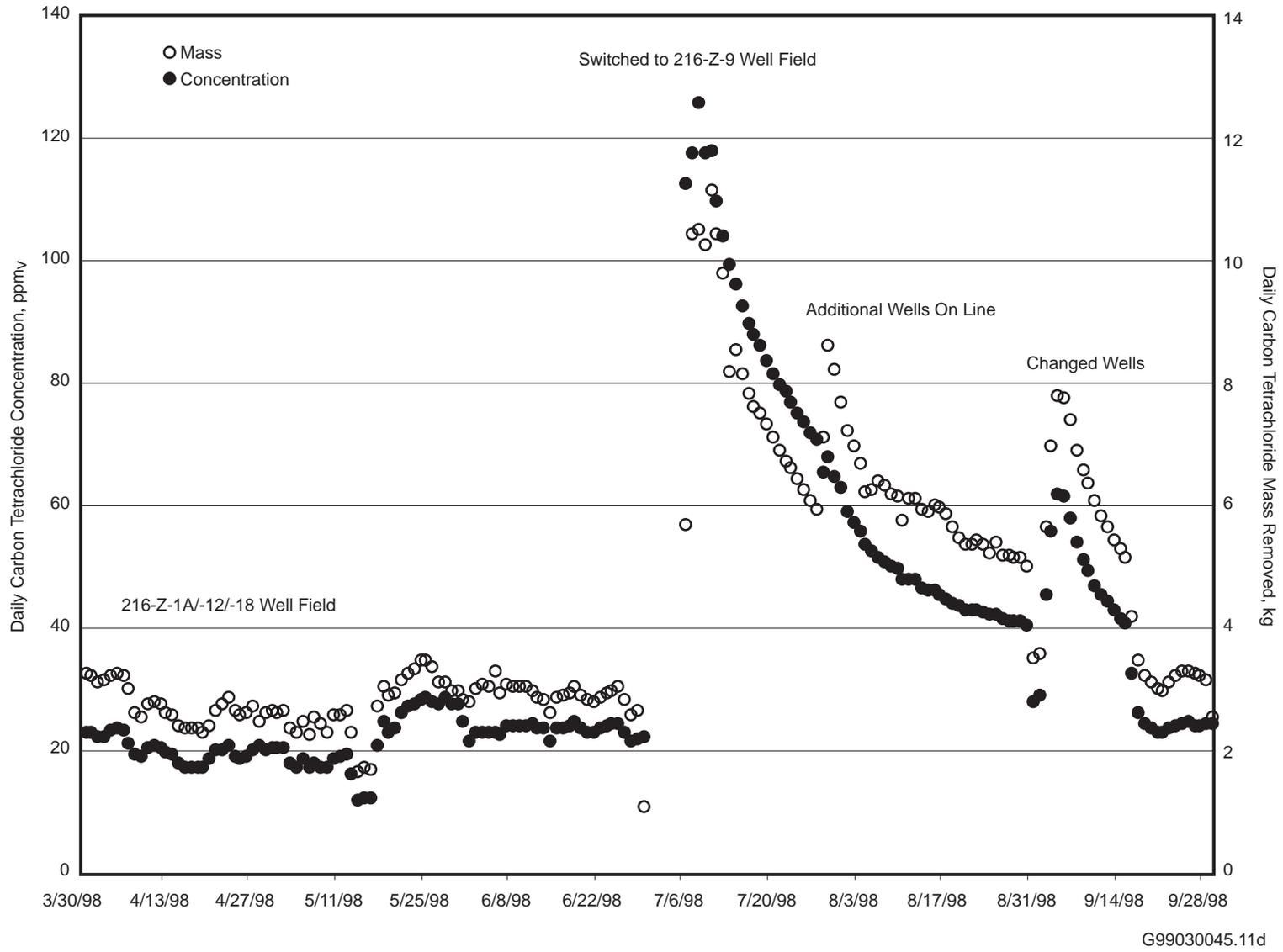


Figure 6.2.13. Time-Series Concentration of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-1A/-12/-18 Well Fields, 200-West Area



Table 6.2.3. Carbon Tetrachloride Inventory in Primary Disposal Sites, 200-West Area

Well Field	Estimated Mass Discharged, 1955 to 1973,^(a) kg (lb)	Estimated Mass Lost to Atmosphere, 1955 to 1990,^(b) kg (lb)	Mass Removed Using Soil-Vapor Extraction, 1992 to 1998,^(c) kg (lb)
216-Z-1A	270,000 (595,000)	56,700 (125,000)	22,983 ^(d) (50,500)
216-Z-18	170,000 (375,000)	35,700 (78,700)	
216-Z-9	130,000 to 480,000 (287,000 to 1,060,000)	27,300 to 100,800 (60,200 to 222,000)	52,507 (115,500)
Total	570,000 to 920,000 (1,260,000 to 2,030,000)	119,700 to 196,800 (264,000 to 434,000)	75,490 (166,000)

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

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

(c) Based on BHI-00720 (Rev. 2).

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

have removed 7% of the residual mass at the 216-Z-1A/-12/-18 well field and 22% of the mass at the 216-Z-9 well field. This estimate assumes that all of the mass that has not been lost to the atmosphere (21% of the original inventory) or dissolved in groundwater (2% of the original inventory) is still available in the vadose zone as "residual" mass (BHI-00720, Rev. 2; WHC-SD-EN-TI-101).

Soil-Vapor Monitoring. During October 1997 through March 1998, soil-vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the soil-vapor-extraction system was allowing carbon tetrachloride to migrate out of the vadose zone. The maximum concentration detected between 1.5 and 4.5 m (5 and 15 ft) below ground surface was 1 ppm (by volume); the maximum concentration detected between 7.6 and 18.3 m (25 and 60 ft) was 43 ppm (by volume). Near the groundwater, at depths ranging from 56.0 to 63.4 m (184 to 208 ft), maximum concentrations ranged from 14.6 to 31.3 ppm (by

volume). These results, after 6 mo of rebound, are similar to those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During April through June 1998, soil-vapor monitoring was continued at the shallow and deep locations at the 216-Z-9 well field. Monitoring locations were added near the less-permeable Plio-Pleistocene unit at 216-Z-9 to provide an indication of concentrations that could be expected during restart of soil-vapor extraction in July 1998. Concentrations detected in the near-surface and near-groundwater zones during these additional 3 mo of rebound were similar to those observed during the previous 6 mo. Nearer the Plio-Pleistocene layer, at depths ranging from 18.3 and 36.0 m (60 and 118 ft), maximum concentrations ranged from 0 to 630 ppm (by volume). The highest concentration was detected in well 299-W15-217 (35.1 m [115 ft] deep), the well at which the highest concentration was detected during the 1997 rebound study. These results were obtained after 9 mo of rebound and are similar to



those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During July through September 1998, soil-vapor monitoring was resumed at the 216-Z-1A and -18 sites. Monitoring was conducted in the near-surface, near-Plio-Pleistocene, and near-groundwater zones. The maximum concentration detected was 143 ppm (by volume) in well 299-W18-158L (37.5 m [123 ft] deep) in the 216-Z-1A Tile Field. This result was obtained after only 3 mo of rebound.

Samples were collected initially from well 299-W15-217 at the wellhead before the downhole sampling tube was installed to evaluate the effect of an installed sampling tube. In March and April, these wellhead samples contained 65 and 25 ppm (by volume) of carbon tetrachloride, respectively. Samples collected in May and June, using the downhole sampling tube, contained 630 and 504 ppm (by volume) of carbon tetrachloride, respectively. Other wells sampled without the sampling tube had anomalously low to nondetectable carbon tetrachloride concentrations.

Because carbon tetrachloride concentrations did not increase significantly at the shallow probes monitored in 1998, temporarily suspending operation of the soil-vapor-extraction system for 6 to 9 mo appears to have caused minimal, detectable, vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the soil-vapor-extraction system appears to have had no negative impact on groundwater quality.

Carbon Tetrachloride Migration. A schematic representation, or conceptual model, of the subsurface behavior of carbon tetrachloride beneath the 216-Z-9 Trench is shown in Figure 6.2.14. A numerical model was developed (BHI-00459) to simulate the primary transport processes shown in Figure 6.2.14, using local stratigraphy and published parameters for the source term and soil properties.

Results of initial simulations suggested that over two-thirds of the discharged carbon tetrachloride would have been retained in the soil column and that a dense, nonaqueous-phase liquid would continue to drain slowly through the vadose zone into the underlying aquifer for years into the future. Although additional modeling is needed to assess the influence of effective porosity and groundwater velocity, the modeling results support the liquid-phase transport concept illustrated on the model in Figure 6.2.14. The vapor-phase results were less definitive but suggested that vapor-phase transport is secondary to dense, nonaqueous-phase liquid transport as a groundwater contamination pathway.

Field measurements of carbon tetrachloride vapor concentrations are not completely consistent with numerical modeling results. Soil-vapor monitoring of rebound carbon tetrachloride concentrations conducted in 1997 and 1998 within the vadose zone at the 216-Z-9 Trench did not exceed 60 ppm (by volume). Vapor-extraction concentrations >12,000 ppm (by volume) of carbon tetrachloride are needed to indicate that the soil near the extraction well is saturated with nonaqueous-phase liquid. The low, measured, vapor concentrations indicate less nonaqueous-phase liquid remaining in the vadose zone below the Plio-Pleistocene unit than predicted; however, these measurements were not taken directly under the 216-Z-9 Trench or at depth-discrete, narrow zones above the water table. Although carbon tetrachloride volatilizing from a residual, nonaqueous-phase, liquid source may have been diluted by the time the vapor reached the sampling locations, the data suggest that soil-vapor extraction may have removed much of the remaining source in the area of the 216-Z-9 Trench and that the continuing groundwater source may now be within the aquifer (BHI-01105).

Vertical and areal distribution of dissolved carbon tetrachloride in groundwater is consistent with a dense, nonaqueous-phase, liquid transport mechanism for transport of carbon tetrachloride to groundwater. Maps and profiles of carbon tetrachloride

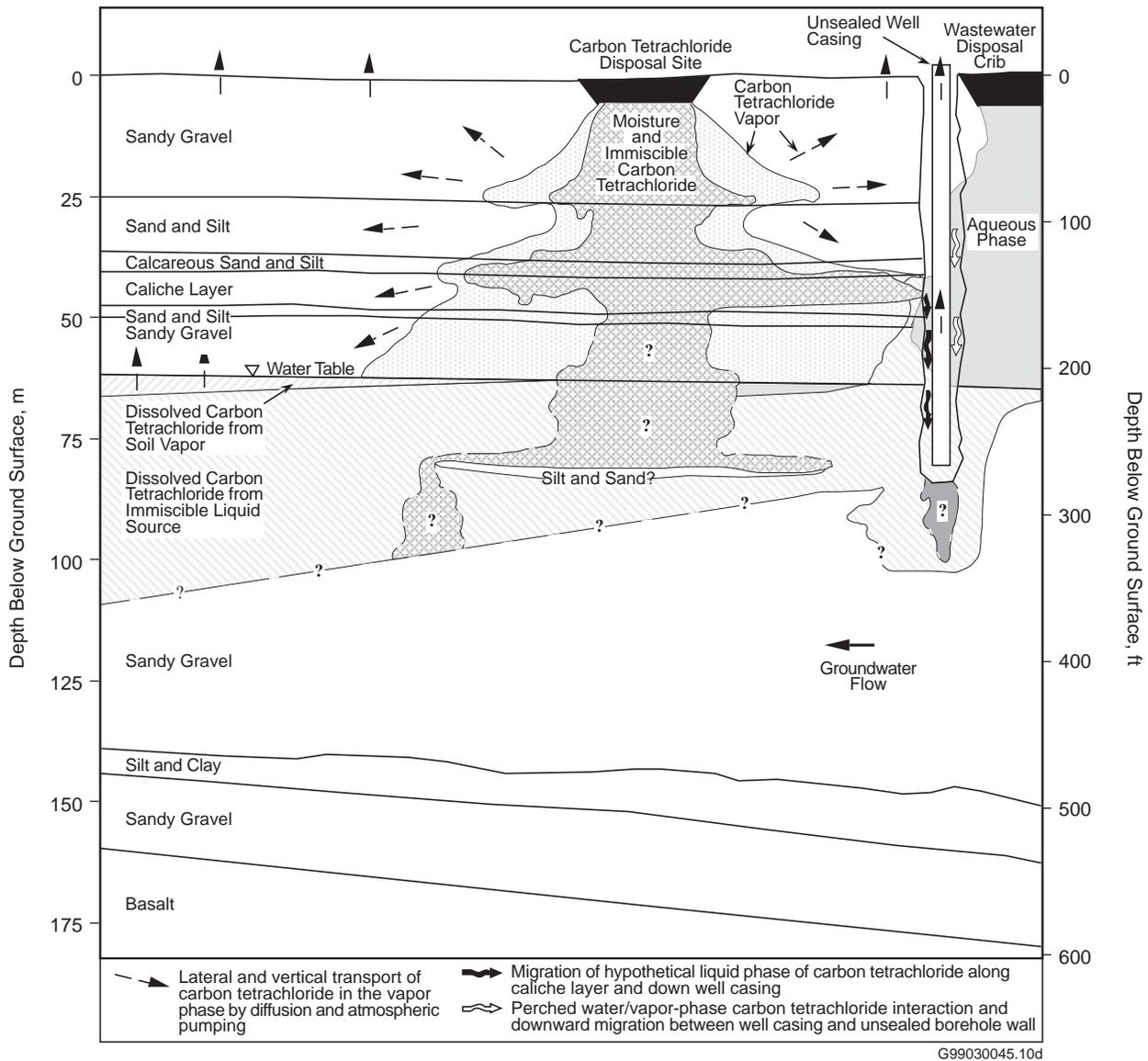


Figure 6.2.14. Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench, 200-West Area

distribution in groundwater suggest there is a continuing groundwater source that produces somewhat uniform carbon tetrachloride concentrations with depth in the aquifer. A dense, nonaqueous-phase liquid that drained from the vadose zone into the aquifer and is slowly dissolving could produce such a pattern. An alternative explanation for the depth-distribution pattern is that a secondary source of water passing near or through an area containing a

dense, nonaqueous-phase liquid and soil-vapor carbon tetrachloride could absorb this slightly soluble, chlorinated hydrocarbon and carry it into the aquifer under saturated flow conditions.

The continuing presence of relatively high, dissolved, carbon tetrachloride concentrations in groundwater in the immediate vicinity of the 216-Z-9 Trench, 35 yr after termination of disposal operations, suggests that a dense, nonaqueous-phase liquid is



slowly dissolving within the aquifer. Although this liquid phase may be slowly draining from the vadose zone to groundwater, the soil-vapor concentrations monitored deep within the vadose zone during 1997 and 1998 suggest that soil-vapor-extraction remediation may have removed much of the vadose-zone source and that the continuing groundwater source resides within the aquifer. Carbon tetrachloride concentrations in the soil vapor and underlying groundwater do not appear to be in equilibrium, and the expected direction of carbon tetrachloride migration is from the groundwater to the vadose zone (BHI-01105).

Carbon tetrachloride rebound concentrations indicate that in many areas much of the readily accessible mass has been removed during soil-vapor-extraction operations and that the supply of additional carbon tetrachloride is limited by desorption and/or diffusion from contaminant sources (e.g., lower-permeability zones such as the lower Hanford formation silt and/or Plio-Pleistocene unit). Under these conditions, the removal rate of the additional carbon tetrachloride using soil-vapor extraction is controlled by the desorption and diffusion rates of the contaminant.

6.2.3 Historical Gross Gamma-Ray Log-Time Series

R. R. Randall, D. A. Myers, D. G. Horton

The single-shell tank farm borehole logging surveillance program was established as one of several methods used to identify leaking tanks and operated until 1994. In 1975, borehole logging within this program was upgraded to a digital system. Under the upgraded program, gross gamma-ray logs were captured in digital form and reviewed to identify large leaks of radioactive liquid from the underground tanks. In 1998, Waste Management Federal Services, Inc., Northwest Operations and Three Rivers Scientific reanalyzed the January 1975 through 1993/1994 gross gamma-ray logs to look for mobile changes in subsurface contamination not found under the original program. During 1998, the tank data for the BX, BY, SX, and TY Tank Farms were reanalyzed. The results of these analyses were available in 1998, but only those for the SX Tank Farm were published (WMNW/TRS-ES-VZMA-002). The remaining results are scheduled to be published in 1999.

This section summarizes the methods of analysis and the general observations for the borehole data analyzed during 1998. A more-complete description of this work is found in PNNL-12086 (Section 4.3) and in WMNW/TRS-ES-VZMA-002.

The strategy for analysis of the surveillance log data was to preserve as much of the raw data as possible by limiting the amount of processing. All historical log surveys for one borehole were analyzed as a group for each radioactive zone in a well, allowing statements to be made about the stability of any given contaminated interval.

Integral to the analysis of the gross gamma-ray data was the use of information provided by the spectral gamma logging system (DOE/ID/12584-268, GJPO-HAN-4). The spectral gamma logging system employs a high-resolution germanium detector to obtain data that lead to the identity and depth of radionuclides. Knowledge of the isotopes present in the subsurface was invaluable in the interpretation of the tank farm surveillance logs. By integrating the spectral gamma logging data with historical surveillance data, the behavior of radionuclides in the vadose zone over time was examined. The analysis performed on the gross gamma-ray data makes evident the usefulness of the historical data for the purpose of evaluating the presence of gamma-emitting radionuclides in the vadose zone beneath the tank farms.



Data were represented graphically to illustrate trends in subsurface contamination. Figure 6.2.15 shows an example analysis for borehole 41-00-08 in the SX Tank Farm, 200 West Area. The plot shows gamma-ray data by depth over the period for which data were available. The log profiles in Figure 6.2.15 represent quarterly logging events selected from more frequently collected data for most years between 1975 and 1994. Between 1980 and 1984, log data were collected approximately once per year. This example illustrates zones of anthropogenic gamma-ray activity at 20.7 and 23.8 m (68 and 78 ft). The activity at 23.8 m (78 ft) is first identifiable around 1985 and increases with survey date from that time to the end of data collection in 1993. The zone at 20.7 m (68 ft) is a clear case of lateral contaminant migration into the region surrounding the borehole.

The analysis of the 98 SX Tank Farm boreholes indicates that 45 were free of identifiable contamination, 31 exhibited zones of contamination interpreted to have been stable over the period of records analyzed, 9 exhibited zones that are interpreted to have increasing activity at the end of the period of records analyzed, and 13 exhibited zones of contamination that could not be readily interpreted. A total of 37,210 records were analyzed.

The analysis of the 74 BX Tank Farm boreholes indicates that 25 were free of identifiable contamination, 27 exhibited zones of contamination interpreted to have been stable over the period of the records analyzed, 8 exhibited zones interpreted to have been increasing at the end of the record period, 8 had contamination interpreted to be from tank

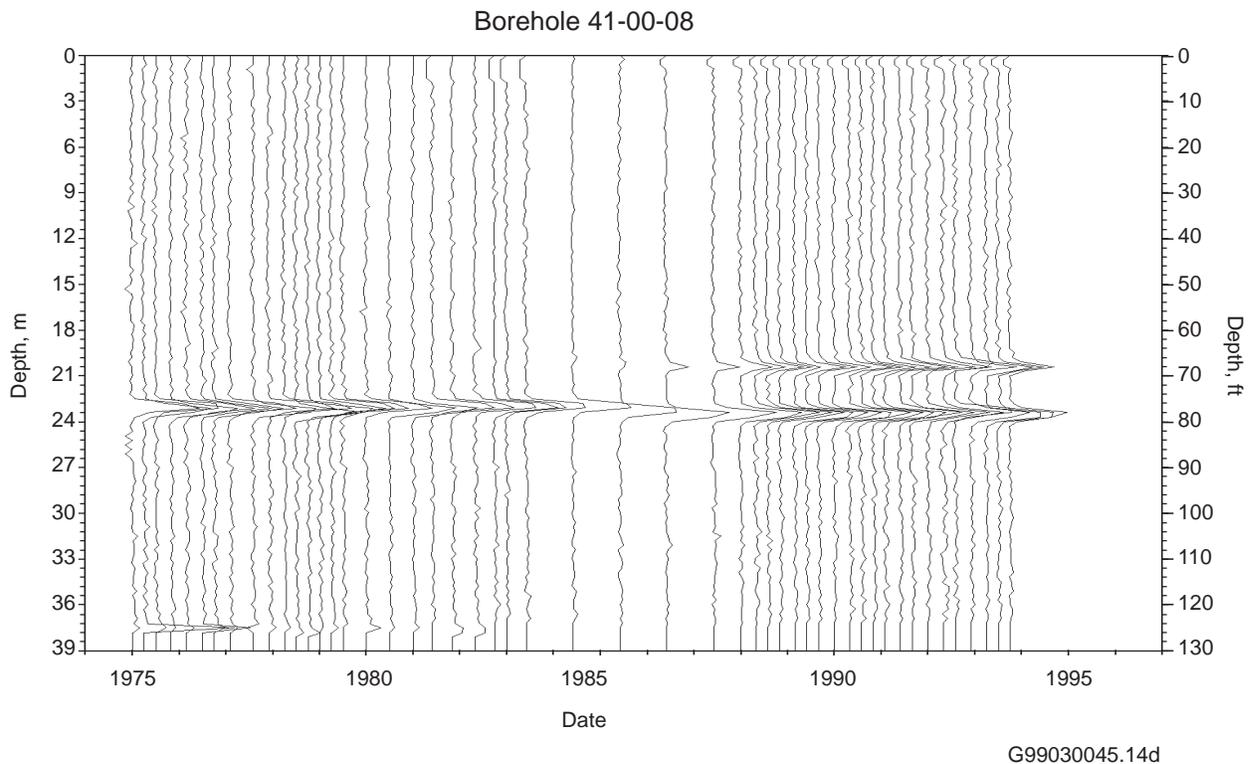


Figure 6.2.15. Example Analysis of Historical Gross Gamma-Ray Logs from Borehole 41-00-08 in the SX Tank Farm



farm activities such as waste transfers, and 6 exhibited zones of contamination that could not be readily interpreted. A total of 20,021 records were analyzed.

The analysis of the 71 BY Tank Farm boreholes indicates that 5 were free of identifiable contamination, 8 were interpreted to be stable at the end of the period of record analyzed, 10 were interpreted to be unstable or increasing at the end of the record period, 43 had contamination interpreted to be from tank farm activities such as waste transfers, and 4 exhibited zones of contamination that could not

be readily interpreted. There was one borehole for which there were no available data. A total of 30,882 records were analyzed.

Boreholes may exhibit one or more characteristics, so the above summations reflect the most conservative status.

The results of these analyses show that detailed examination of historical gross gamma-ray logs can reveal changes in subsurface contamination at the tank farms that was not previously identified.