
6.2 Vadose Zone Characterization and Monitoring

6.2.1 Tank Farms Vadose Zone Baseline Characterization Project

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Contamination was released to the near-surface and subsurface sediment at 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. Airborne releases and surface spills created contamination plumes in the vadose zone that are generally confined to the near surface but, in some cases, surface contamination is known to have migrated deeper into the vadose zone. Pipeline leaks have also occurred either near the surface or at a maximum depth of 6.1 m (20 ft). In some cases, contamination from pipeline leaks has also migrated deeper into the vadose zone; however, tank leaks created the deepest contamination plumes. Tank leaks occurred most often at the base of the tank or at the footing, where the base and sidewall are joined.

The Resource Conservation and Recovery Act specifies 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 begun to perform an initial baseline characterization of the vadose zone gamma-emitting contamination at Hanford Site tank farms and to satisfy Resource Conservation and Recovery Act requirements in a limited way. The technical plan for this baseline characterization is documented in P-GJPO-1786.

Under the baseline characterization project, approximately 800 preexisting monitoring boreholes surrounding the single-shell tanks are being logged with passive spectral gamma-ray logging methods. Passive spectral gamma-ray logging 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 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-year 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 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 tank summary data report for each tank, a more comprehensive tank farm report is prepared. Each tank farm report provides a correlation of the

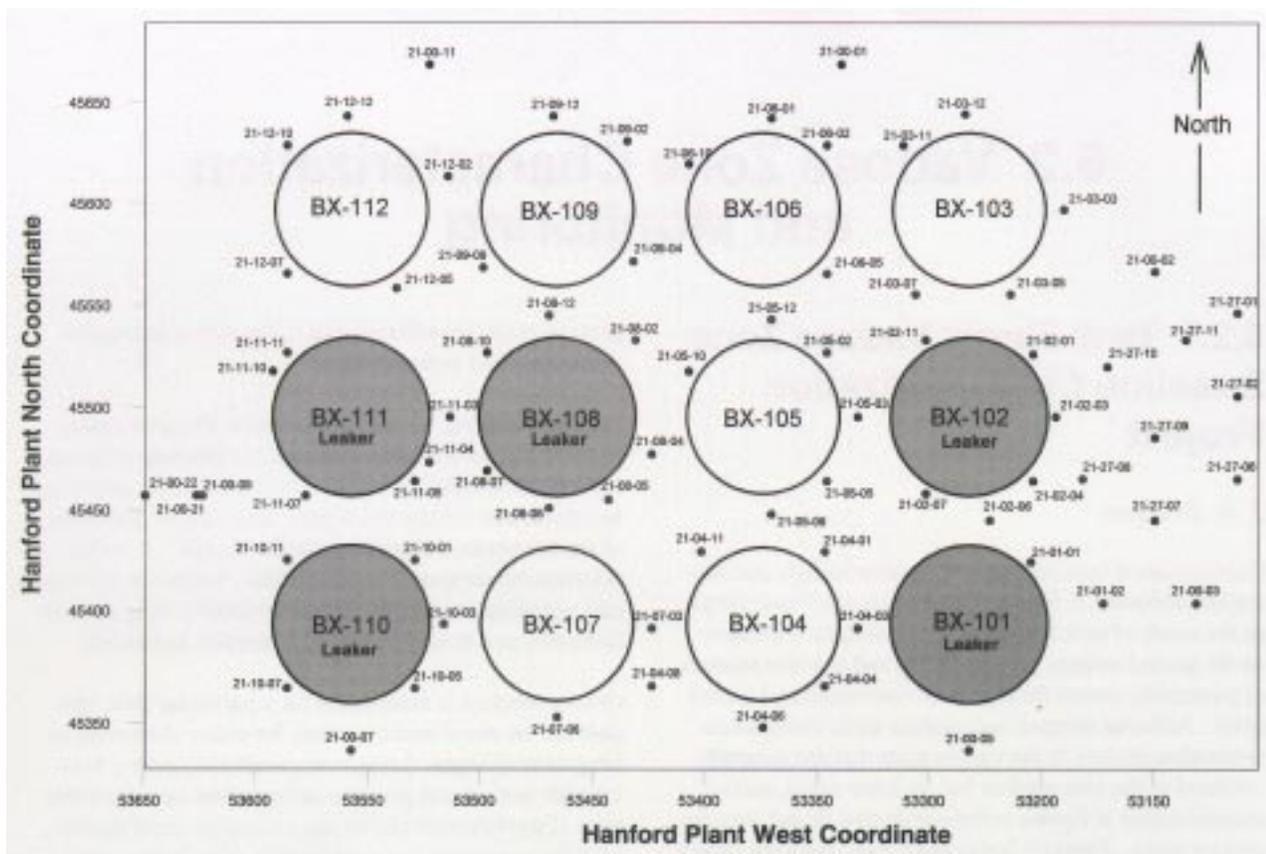


Figure 6.2.1. Plan View of BX Tank Farm with Monitoring Boreholes

contamination across the farm and includes computer-generated 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 completed to develop more realistic and quantitative contamination distribution models.

6.2.2 Data Collection and Analysis

All data acquisition is accomplished with spectral gamma-ray logging systems that are automated 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 *General Administrative Procedures Manual* MAC-1000.

The spectral gamma-ray logging system equipment was calibrated by conducting a comprehensive base calibration and biannual field calibrations as specified in a calibration plan (MAC-VZCP-1.7.3, Rev. 1). The base calibration was conducted using borehole model standards constructed at the DOE Grand Junction Office specifically for borehole logging. The results of the base 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 third biannual recalibration are documented in GJO-HAN-13.

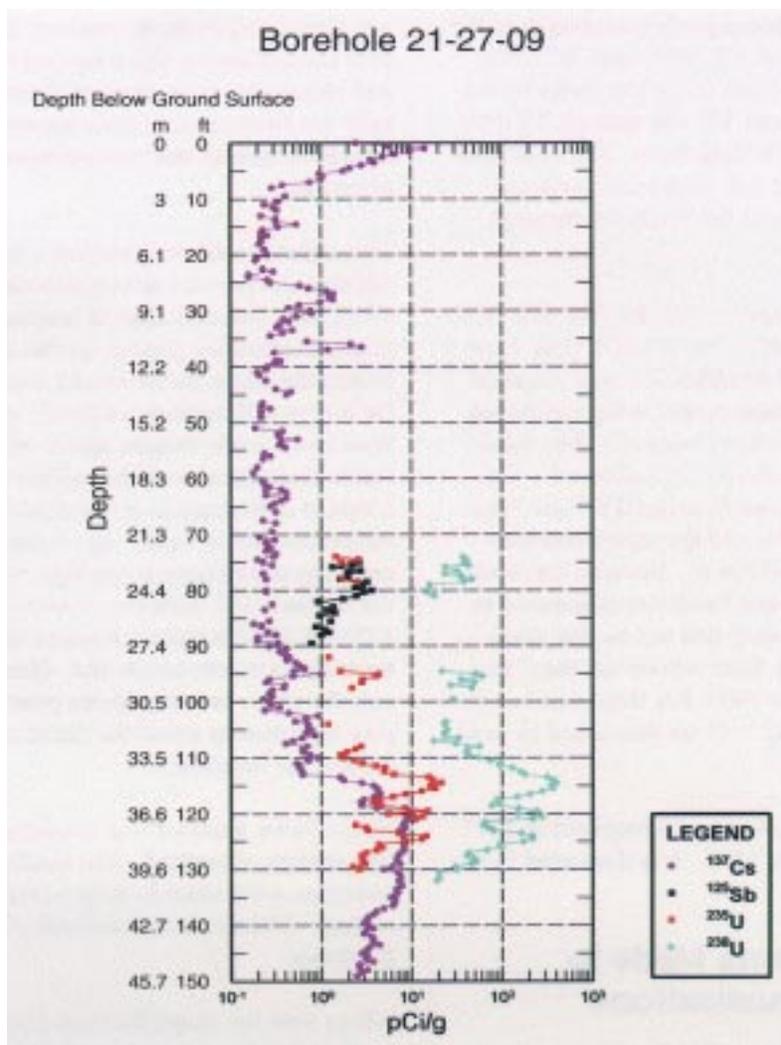


Figure 6.2.2. Example of a Radionuclide Concentration Log

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 a data analysis manual (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.

6.2.3 Activities for 1997

6.2.3.1 Baseline Logging, Tank Summary Data Reports, and Tank Farm Reports

Logging data acquisition was completed for 211 boreholes surrounding tanks at the A, B, BX, and C Tank Farms during 1997.

In addition, tank summary data reports were prepared for tanks AX-102, AX-103, and AX-104; tank BX-102; tanks C-101 through C-110; all 12 of the tanks in the S Tank Farm; tanks TX-106 and TX-108 through TX-118; and all 6 of the tanks in the TY Tank Farm. The individual borehole logs are reported in individual tank summary data reports (GJ-HAN-47 and GJ-HAN-49 through GJ-HAN-92).

Tank farm reports were prepared for the AX, BY, TX, TY, and U Tank Farms in 1997. For the AX Tank Farm, a preliminary farm report (GJO-HAN-10) was prepared to support a tank characterization project being conducted by the Hanford Tanks Initiative Program. The final AX Tank Farm report (GJ-HAN-12) followed a few months later. The bulk of the work on the BY Tank Farm report was completed in 1996, and the report was published in January 1997 (GJO-HAN-6). Because the results of the logging in the BY Tank Farm are discussed in PNNL-11472 (Section 3.3), they will not be discussed here. Preparation of the tank farm reports for the C and S Tank Farms was begun in 1997 but they will not be published until 1998 so they will be discussed in next year's environmental report.

The TY farm report (GJ-HAN-16) was prepared in 1997 and was published in January 1998. It is discussed in the following sections.

6.2.3.2 Improvements Made to Contamination Visualizations

During 1996 and 1997, a significant effort went into developing the spectrum analysis technique called shape factor analysis. This method allows a log analyst to interpret the gamma-ray spectra within vertically continuous zones of contamination to assess the radial distribution of contamination at a depth location in a borehole. The shape factor analysis method can help an analyst differentiate between the following contamination distributions: contamination located on the inside of a borehole casing, contamination located on the outside of a borehole casing, contamination distributed uniformly in the formation in the radial direction, and contamination that is located remote to the borehole. The details regarding spectral shape factor analyses are provided in GJO-HAN-7 and GJO-HAN-15.

The primary utility of the shape factor analysis method is that it often identifies conditions where contamination was carried down during the drilling of a borehole and is

not distributed in the formation. If there has been borehole contamination, this condition needs to be recognized and eliminated from the visualization database, so that false contamination plumes are not generated and a false interpretation of the contaminant distribution is not presented.

Shape factor analysis provides a useful interpretation tool but does not provide an unequivocal interpretation. Quite often, the contamination of interest is not found in a vertically continuous region. In this instance, a unique solution to the shape factor results does not exist and there is no way to differentiate vertically remote source effects from horizontally remote source effects. In addition, shape factor analysis can only be applied over a limited dynamic range of radionuclide concentrations. If the cesium-137 concentration is below approximately 1.5 pCi/g, the counting uncertainty is too high to yield valid results; if the cesium-137 concentration is above approximately 3,000 pCi/g, the spectra become distorted and shape factor analysis results are invalid. However, more often than not, the shape factor analysis provides relatively conclusive information about the distribution of contamination around the boreholes.

Shape factor analysis was implemented in 1997 as a routine analytical method. The results of the shape factor analyses were used to help justify the elimination of regions of borehole contamination from the visualization databases.

Along with the shape factor analysis, the log data were reviewed to identify areas of very low concentrations of discontinuous contamination. Regions with this type of contamination distribution can often be attributed to contamination that was carried down during the borehole drilling operations or particulate matter that fell down into the boreholes. Unless the contamination data can be correlated between several boreholes or the contamination can be otherwise demonstrated to exist within the formation, it is removed from the visualization database.

6.2.3.3 Activities Related to Vadose Zone Characterization at the AX Tank Farm

Thirty boreholes surrounding the four tanks in the AX Tank Farm in the 200-East Area were logged with the spectral gamma logging systems in August and September 1996, with the data reported in GJ-HAN-49 through GJ-HAN-52. A preliminary AX Tank Farm report

(GJO-HAN-10) was published in April 1997; the final (GJ-HAN-12) was published in August 1997.

Cesium-137 was the main gamma-emitting radionuclide detected in the vadose zone at the AX Tank Farm. The highest cesium-137 concentrations (<8,000 pCi/g) and most extensive vertical distributions were detected on the north side of the AX Tank Farm in 2 boreholes that are adjacent to tanks AX-101 and AX-103. Those tanks are designated as sound tanks, whereas tanks AX-102 and AX-104 are designated as leakers. The contamination between tanks AX-101 and AX-103 (shown in Figure 6.2.3) was attributed to a surface source that migrated to depths of more than 30.5 m (100 ft). The historical gross gamma log record shows contamination was present when the borehole was drilled, and there is a high probability that some contamination was carried down during drilling and is not actually present in the formation.

Evaluation of the spectral gamma log data indicates there has been significant near-surface contamination at the AX Tank Farm. Data acquired from virtually all of the boreholes show near-surface contamination is present.

Sources of this contamination include surface spills, airborne releases, and pipeline leaks. Other gamma-emitting radionuclides such as cobalt-60, antimony-125, and europium-154 were detected in several boreholes near the ground surface. Occurrences of these radionuclides were associated with the near-surface cesium-137 contamination.

Some small, isolated occurrences of cesium were identified in several boreholes. These boreholes did not show significant contamination above the deeper isolated zones of contamination other than at the ground surface; therefore, it is unlikely that contamination was carried down during drilling.

Borehole log plots of concentrations of the naturally occurring radionuclides potassium-40, thorium-232, and uranium-238 were prepared and evaluated to determine if lithologic features may have contributed to the distribution of cesium-137 contamination in the AX Tank Farm. Interpretations of three-dimensional visualizations of the potassium-40 concentration data indicate an extensive region of coarse and more permeable sediments may be

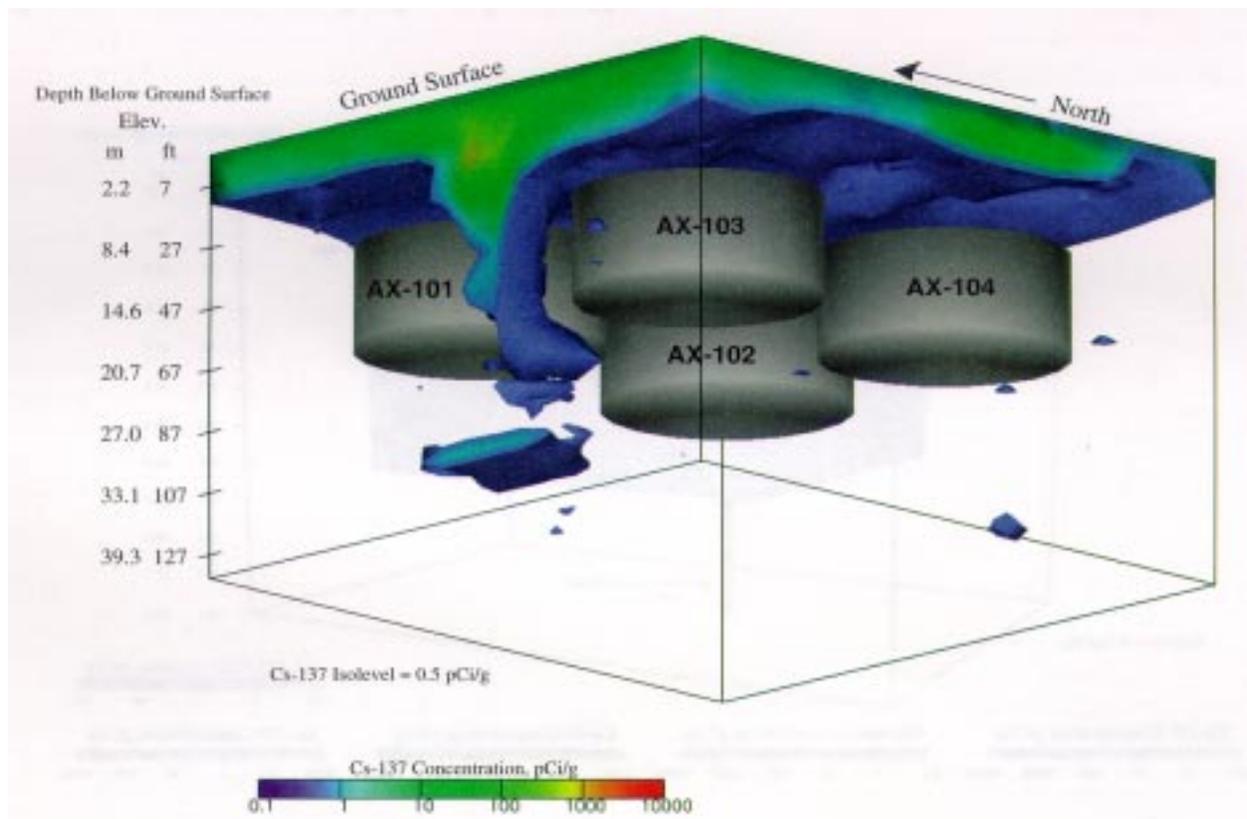


Figure 6.2.3. Vadose Zone Contamination at the AX Tank Farm

present in the north and northeast portions of this tank farm. These sediments may have provided a vertical pathway that enhanced cesium-137 migration in this region of the tank farm.

6.2.3.4 Activities Related to Vadose Zone Characterization at the BX Tank Farm

Seventy-six boreholes surrounding the 12 tanks in the BX Tank Farm in the 200-East Area were logged with the spectral gamma logging systems from May to August 1997. The tank summary data report for tank BX-102 (GJ-HAN-89) was the only report issued for the BX Tank Farm in 1997. The BX Tank Farm report is planned for completion in mid-1998.

Because tank BX-102 was the source of an extensive, well-documented, contamination plume (Figure 6.2.4), the tank summary data report contained visualizations and was more comprehensive than other such reports.

Spectral gamma log data acquired from the BX-102 boreholes showed significant and deep contamination east

and northeast of the tank that resulted from leakage of tanks BX-101 and BX-102. Contamination from these tanks created deep and laterally extensive plumes of cobalt-60, antimony-125, cesium-137, europium-154, uranium-235, and uranium-238.

Cesium-137 contamination was detected throughout the length of borehole 21-02-04, which is located adjacent to the southeast side of tank BX-102. This borehole, which was 77.7 m (255 ft) deep when the borehole was first drilled, was the deepest borehole in the BX Tank Farm. Contamination was detected from ground surface to the groundwater at approximately 73.2 m (240 ft), but it is probable that some contamination was carried down the borehole when it was drilled. The highest concentration of cesium from this borehole is located at the base of the tank, implicating this region as the source of the contamination. If borehole contamination occurred, it is probable that cesium-137 is present in the formation at a depth of 65.8 m (150 ft) because cesium that cannot be explained as borehole contamination was detected in several adjacent boreholes at the 65.8-m (150-ft) depth region.

An extensive uranium plume with concentrations approaching 1,000 pCi/g was also detected in the region

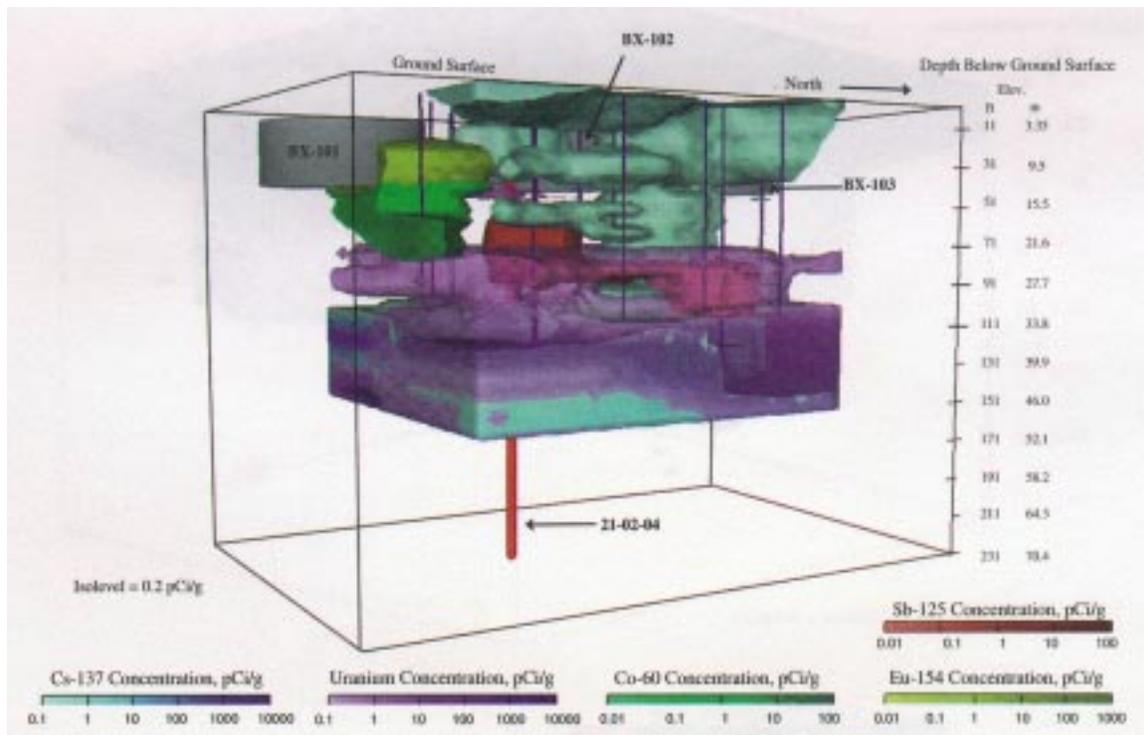


Figure 6.2.4. Vadose Zone Contamination at the BX Tank Farm

of this cesium plume from depths of 30.7 to 65.8 m (70 to 150 ft). Because no uranium was detected near the ground surface, it is not probable that the uranium was carried down during drilling. The total depth extent of the uranium is not known because it was detected as continuous plumes at the bottoms of several 65.8-m (150-ft) boreholes. Uranium was also identified in the sediment at the depths of the groundwater and the capillary fringe in well 299-E33-41, a groundwater monitoring well drilled in 1991 just northwest of tank BX-102. The strong correlation with the uranium plume from tank BX-102 makes it highly probable that uranium from the tank migrated down and into the groundwater. Slightly anomalous levels of uranium have been detected in the groundwater from well 299-E33-41.

Cobalt-60 and europium-154 contamination plumes were detected as relatively isolated plumes next to tank BX-101 (see Figure 6.2.4). These plumes appear to have originated from a leak from tank BX-101. A separate antimony-125 contamination plume was also identified and is associated with the leak from tank BX-102.

6.2.3.5 Activities Related to Vadose Zone Characterization at the TX Tank Farm

Ninety-four boreholes surrounding the 18 tanks in the TX Tank Farm in the 200-West Area were logged with the spectral gamma logging systems, and the logging was completed in May 1996. The last tank summary data report (GJ-HAN-63) was issued in April 1997; the TX Tank Farm report (GJ-HAN-11) was issued in September 1997.

Cesium-137 is the most abundant and highest concentration man-made gamma-emitting radionuclide that was detected, and concentrations $>8,000$ pCi/g were identified. Other gamma-emitting radionuclides detected were cobalt-60, europium-154, uranium-235, uranium-238 from processed uranium, and minor amounts of antimony-125. Visualizations of the spectral log data showing the distribution of these contaminants (with the exception of antimony, which occurred as a minor, isolated occurrence) in the vadose zone surrounding the TX tanks were prepared. Figure 6.2.5 is an example of the visualizations that were

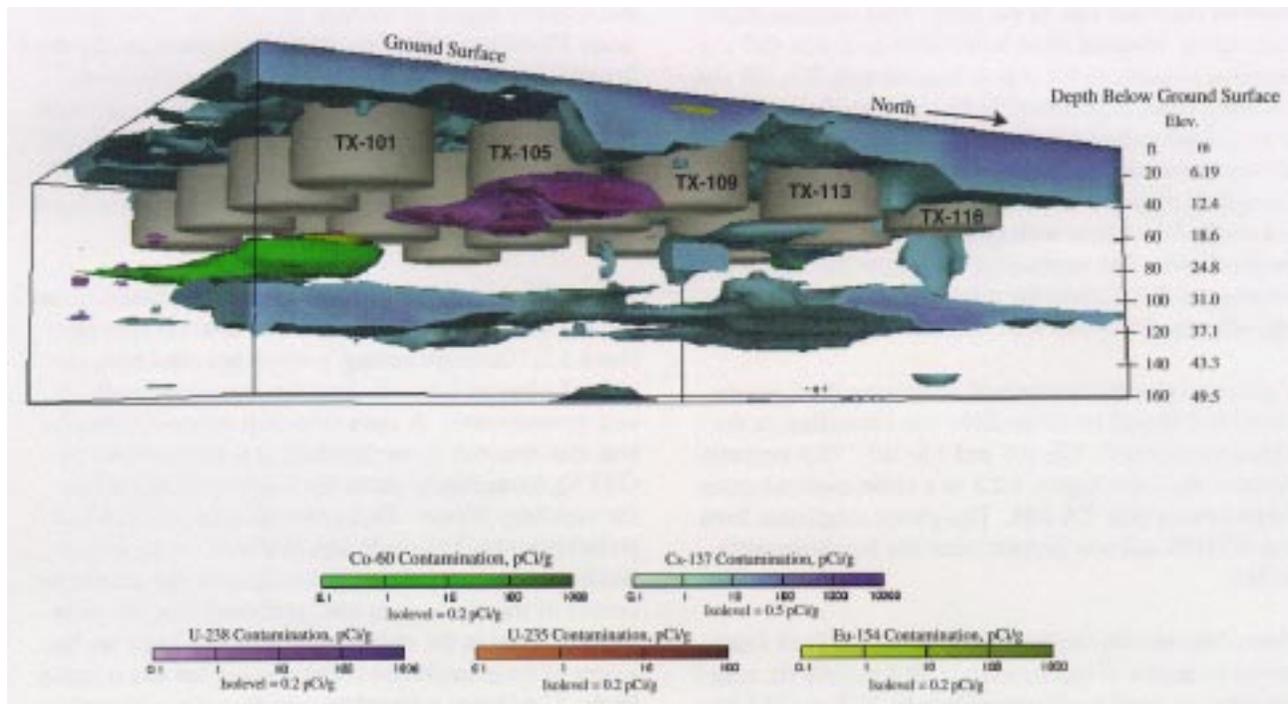


Figure 6.2.5. Vadose Zone Contamination at the TX Tank Farm

prepared to show the distribution of these contaminants in the vadose zone at the TX Tank Farm.

Cesium-137 contamination was detected in all of the boreholes. Plumes originating from tank leaks were detected between tanks TX-103 and TX-107, near tanks TX-113 and TX-114, and between tanks TX-117 and TX-118. Other areas showed low levels of contamination that could not be spatially correlated, and it is suspected that drilling may be responsible for much of this low-level contamination. Because the TX Tank Farm log data were not analyzed with the shape factor analysis method, the influence of contamination carried down during drilling was not evaluated. A future priority task will be to perform shape factor analysis on the data from farms that were logged before shape factor analysis was developed.

The contamination shown in Figure 6.2.5 as a widespread cesium plume near an elevation of 175.3 m (575 ft) may not actually exist within the vadose zone and may be caused by contamination that has fallen down the inside of the borehole casings.

Spatially continuous cobalt-60 contamination identified in the vicinity of tanks TX-103 and TX-107 is shown in Figure 6.2.5 as a green contamination plume below the tanks on the south side of the farm. This contamination most likely resulted from leakage of tank TX-107 that migrated laterally to the region beneath tank TX-103 and reached a depth of 30.5 m (100 ft); however, the maximum depth of the cobalt-60 plume could not be determined because it was detected at the bottoms of the boreholes. The cobalt migrated laterally at least 36.6 m (120 ft), and was tracked over time with gross gamma monitoring of the boreholes. The monitoring data show that cobalt did not migrate down along the outside of the borehole casings after the boreholes were drilled.

A plume of processed uranium, containing the isotopes uranium-235 and uranium-238, was identified in the region around tanks TX-101 and TX-105. This contamination is shown in Figure 6.2.5 as a violet contamination plume next to tank TX-105. This plume originated from tank TX-105 and was present when the boreholes were drilled.

Most of the monitoring boreholes in the TX Tank Farm extend to depths of approximately 30.5 m (100 ft); only 7 extended to depths of approximately 76.2 m (250 ft). Therefore, the maximum depth of the contamination plumes in this tank farm is not known.

6.2.3.6 Activities Related to Vadose Zone Characterization at the TY Tank Farm

The TY Tank Farm in the 200-West Area consists of six single-shell tanks, five of which are designated as leakers. Twenty-two monitoring boreholes surrounding the six TY tanks were logged with the spectral gamma logging systems. The logging was completed in May 1996, and the last tank summary data report (GJ-HAN-69) was issued in May 1997. The TY Tank Farm report (GJ-HAN-16) was issued in early 1998.

Cobalt-60 and cesium-137 were the major gamma-emitting contaminants detected in the TY Tank Farm. Borehole log data from this farm were subjected to shape factor analysis, and regions of known borehole contamination as well as isolated or discontinuous regions of low-level cesium contamination were removed from the visualization database prior to developing three-dimensional visualizations. The resulting "interpreted data set" was used to create visualization of the cesium and cobalt plumes, as shown in Figure 6.2.6.

Figure 6.2.6 shows the most extensive contamination in the southern region of the tank farm below the bases of tanks TY-105 and TY-106. Both tanks are presently designated as leakers; the deep contamination beneath these tanks is primarily cobalt-60. Cobalt plumes are as much as 15.2 m (50 ft) thick, and because cobalt was detected at the bottom of several boreholes, with a pattern of increasing concentration with depth, the maximum depth of the cobalt is not known.

Some of the cobalt-60 contamination was detected below the Early Palouse/Plio-Pleistocene interval (see Section 6.1.1, "Geologic Setting"), which has often been considered a barrier between downwardly migrating fluids and groundwater. A zone of cobalt-60 contamination was also detected in one borehole at a depth of 64.9 m (213 ft), immediately above the water table and within the capillary fringe. This contamination, which has probably reached groundwater, is shown on the visualization as an isolated pod down deep in the southwest corner of the farm. It is not confirmed that the deep cobalt plumes in the vadose zone from the tanks are the source of the groundwater contamination, but this is highly likely. Cobalt was released into nearby cribs and trenches, and it is probable that those cribs contributed cobalt to the groundwater.

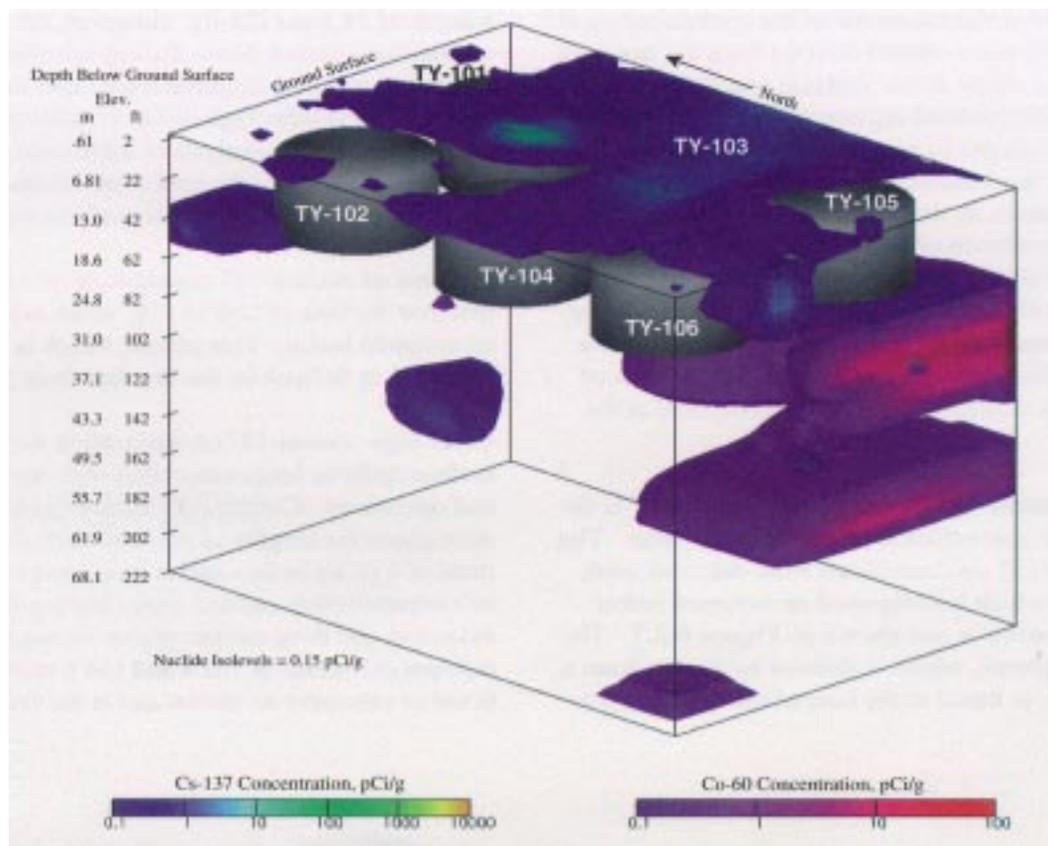


Figure 6.2.6. Vadose Zone Contamination at the TY Tank Farm

Cesium-137 detected near the ground surface over a widespread area of the TY Tank Farm resulted from surface spills and/or pipeline leaks. This contamination migrated as deep as 4.6 m (15 ft) in the southern portion of the tank farm.

An interval of cesium-137 contamination of approximately 100 pCi/g was also detected near the base of tank TY-102, indicating that this tank may have leaked, though the tank is presently designated as sound. This contamination was detected in a borehole outside the northwest quarter of the tank that is isolated from tanks that are known to have leaked; therefore, it could not have originated from another tank. This contamination was shown in Figure 6.2.6 as a plume in the northwest corner of the farm at the base of tank TY-102. Historical gross gamma-ray log data acquired in the borehole indicated increased activity in 1980 at the depth cesium-137 was detected with the spectral gamma logging system. It is possible that this contamination originated from either a surface spill or a leak from the near-surface tank condenser tower (the above-ground portion of the tower was removed) and then

migrated down the tank side. However, no contamination was detected in the upper portion of the borehole, which would be expected for this scenario.

6.2.3.7 Activities Related to Vadose Zone Characterization at the U Tank Farm

Fifty-nine boreholes surrounding the 12 tanks in the U Tank Farm in the 200-West Area were logged with the spectral gamma logging system from September to December 1995. The final tank summary data report for the U Tank Farm (GJ-HAN-41) was completed in September 1996. The U Tank Farm report (GJ-HAN-8) was issued in May 1997.

Cobalt-60, cesium-137, europium-154, uranium-235, and uranium-238 were detected in the U Tank Farm boreholes. Plots of the radionuclide concentrations as a function of depth are included in the individual tank summary data reports.

Three-dimensional visualizations of the contamination at the U Tank Farm were created directly from the borehole log data because shape factor analysis was not yet developed. In addition, isolated regions of low-level contamination that is thought to result from drilling were not removed from the visualization database. The cross-borehole correlation is, therefore, based on the empirical geostatistical correlation of data that is biased, in that suspected borehole contamination is not removed, and the visualizations may show contamination plumes in the vadose zone that may not actually be present. Figure 6.2.7 is a visualization showing the interpreted distribution of cesium-137 and uranium-238 in the vadose zone at the U Tank Farm.

The spectral gamma log data indicated cesium-137 is the most extensive contaminant in the U Tank Farm. The highest cesium-137 concentrations were detected north of tank U-112, which is designated an assumed leaker. This contamination is not shown in Figure 6.2.7. The contamination plume, which is defined by the log from a single borehole, is found at the base of the tank down to

a depth of 38.1 m (125 ft). However, the amount of contamination carried down during borehole drilling is unknown, and data acquired from other nearby boreholes do not show similar high levels of contamination. As a result, shape factor analysis or additional drilling will be required to determine the total depth of this plume. Tasks are planned to do shape factor analysis on these logs.

A plume of cesium-137 contamination was also identified near the base of tank U-110, which is also designated an assumed leaker. This plume, which is shown in Figure 6.2.7, is defined by the log data from two boreholes.

Other high cesium-137 contamination is related to near-surface spills or leaks associated with equipment failures and operations. Cesium-137 contamination was detected throughout the lengths of several boreholes at concentrations of 1 pCi/g or less and is suspected to be the result of contamination carried down during drilling. The extensive and deep cesium plume shown in Figure 6.2.7 between elevations of 152.4 and 164.6 m (500 and 540 ft) is not as extensive as shown and is the result of borehole

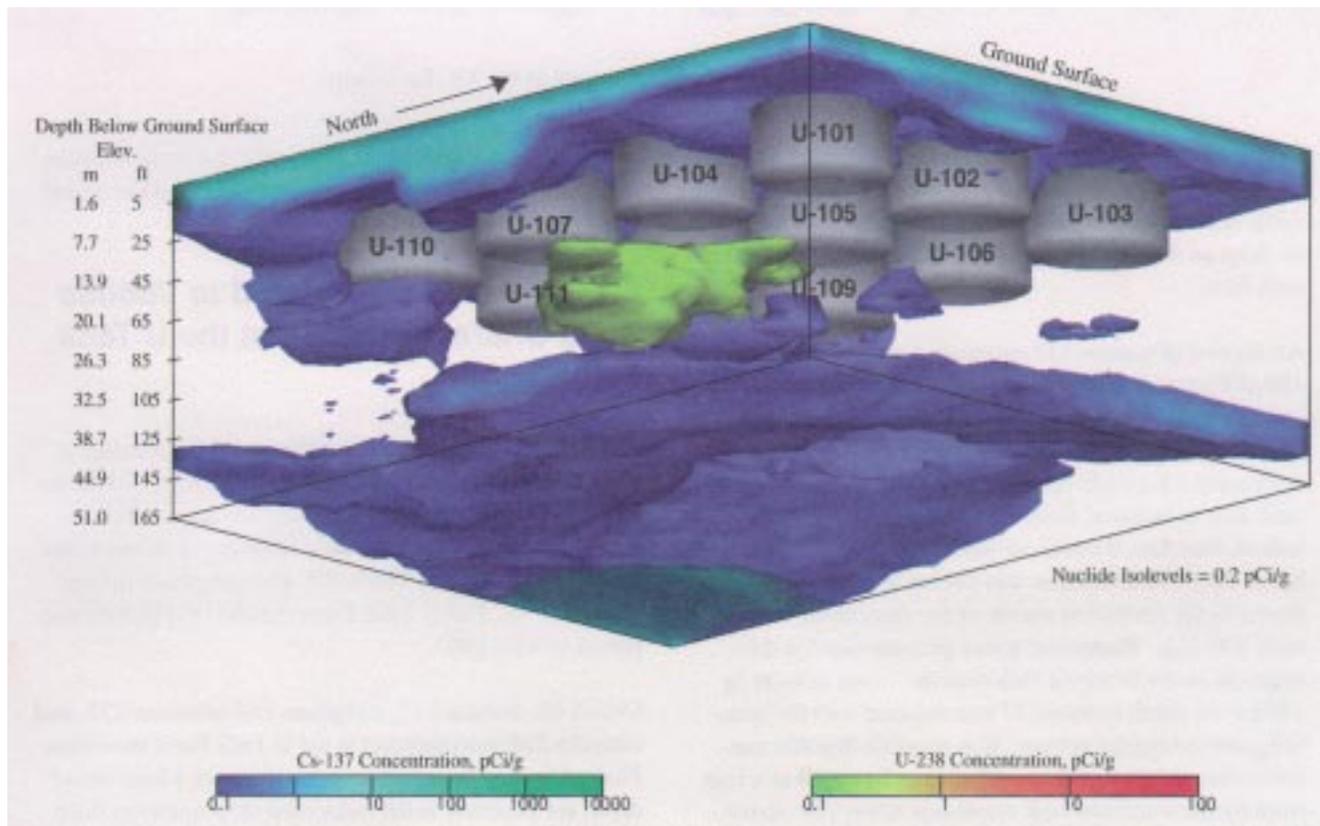


Figure 6.2.7. Vadose Zone Contamination at the U Tank Farm

contamination in some places. In some boreholes, however, the contamination was not carried down during drilling, as determined by the fact that little contamination was detected in the upper portion of the borehole, while the lower portion of the borehole showed relatively higher concentrations.

A processed uranium plume, consisting of the isotopes uranium-235 and uranium-238, was identified near tanks U-104 and U-108. This plume, located between tanks U-104, U-105, U-107, and U-108, is well defined in Figure 6.2.7. This plume was associated with leakage from tank U-104.

Only small amounts of cobalt-60 and europium-154 were detected at the U Tank Farm. These radionuclides, which were limited in distribution and detected as isolated occurrences near the ground surface, are clearly the result of surface spills.

No contamination plume was identified for the region around tank U-101, the only other assumed leaker in the U Tank Farm. It is probable that the leak from the tank was relatively small and that the boreholes around this tank did not intercept the contamination plume.

Concentrations of the naturally occurring radionuclides potassium-40, thorium-232, and uranium-238 were correlated with the lithologic information to determine if distinguishable features were present beneath the U Tank Farm and to determine how these features correlate with the distribution of contaminants. The potassium-40 concentration plots showed distinct increases at the interface between the backfill sediments and undisturbed Hanford formation fine-grained unit at the base of the tank farm excavation. Although few of the monitoring boreholes were deep enough to intercept the Plio-Pleistocene unit, those that did showed a very distinct low activity response on the potassium-40 log that is correlated to the caliche zone of the Plio-Pleistocene unit.

6.2.4 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 current and future

groundwater contamination. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring were conducted during 1997. This section summarizes major findings from these efforts. The 1997 efforts focused primarily on vadose zone soil contamination associated with past liquid disposals to cribs, trenches, drain fields, and injection wells at the B-BX-BY Waste Management Area in the 200-East Area, the Plutonium Finishing Plant liquid waste disposal sites in the 200-West Area, and the Non-radioactive Dangerous Waste Landfill at the Central Landfill in the 600 Area. The interpretation of monitoring and characterization results is presented in the sections that follow.

6.2.4.1 In Situ Monitoring

The objectives of vadose zone monitoring are to document contamination location and to determine moisture and radionuclide movement in the soil column. Spectral gamma logging is an in situ (meaning in place) measurement of subsurface gamma-emitting radionuclides obtained through cased monitoring wells that are completed in the vadose zone or extend into the saturated zone. The detector or sensor is generally a crystal of germanium and associated electronics. Photons emitted from radionuclides in the formation interact with the detector material, resulting in electronic pulses transmitted to the surface via electrical cables to a digital data storage system. By periodically recording detector response at various depths, changes over time can be documented. This general type of logging (in particular gross gamma screening as opposed to spectral gamma) has been conducted at the Hanford Site for over 25 years by slowly raising and lowering the detector inside existing cased monitoring wells in the vicinity of disposal facilities and single-shell tanks. During 1997, in situ spectral gamma logging was performed by Waste Management Federal Services, Inc., Northwest Operations personnel in support of Pacific Northwest National Laboratory Resource Conservation and Recovery Act assessment (PNNL-11826) in selected groundwater monitoring wells outside the B-BX-BY Waste Management Area.

Sixteen wells were successfully surveyed from the ground surface to the water table. The well numbers and location description are given in Table 6.2.1 and can be seen on Figure 6.2.8. The technique is capable of probing the sediment around the well casing to a radius of a few to several tens of centimeters (0.5 to 2 ft), depending on the casing thickness and sediment bulk density. Corrections for varying well diameters and presence of sealants around

Table 6.2.1. Location of Spectral Gamma Logged Boreholes at the B-BX-BY Waste Management Area, 200-East Area

Well Number	Closest Disposal Facility
299-E33-04	Just northwest of the 216-B-46 Crib in the BY Cribs
299-E33-05	Located just southwest of 216-B-47 cribs in the BY Cribs
299-E33-13	~100 m east of the BY Cribs and northeast of the BY Tank Farm
299-E33-15	At the end of the last spur line of the 216-B-8TF Tile Field
299-E33-16	At the front end of the 216-B-8 Crib and 216-B-8TF Tile Field
299-E33-17	East of the 216-B-8TF Tile Field and north of the 216-B-11 Injection Wells
299-E33-18	Just north of the northwestern edge of the B Tank Farm and just southwest of the 216-B-7B Crib
299-E33-19	Just north of the 216-B-11B Injection Well
299-E33-20	Just south of the 216-B-11A Injection Well
299-E33-21	Near the eastern end of the 216-B-36 Trench and west of the BX Tank Farm
299-E33-31	West of the fence line surrounding the BX-BY Tank Farms
299-E33-32	Along the fence line of the BX-BY Tank Farms; 135 m directly south of well 299-E33-31
299-E33-38	Midway between the 216-B-47 Crib and north fence line of BY Tank Farm; inside BY Cribs fence
299-E33-41	On east fence line of BX Tank Farm
299-E33-42	Approximately midway between wells 299-E33-31 and 299-E33-32
299-E33-43	30 m south of well 299-E33-31

the annulus of the casing should be taken into account prior to interpreting the raw counts obtained as a function of depth in monitoring wells. In addition, a concern with any well is the degree to which contaminants may have migrated down the inside or outside of the well casing. A technique called shape factor analysis discussed in Section 6.2.3.2, "Improvements Made to Contamination Visualizations," can help address this latter issue. Shape

factor analysis was not used to aid the interpretation of the spectral gamma logging presented in the next section.

Spectral Gamma Logging Results. Four of the 16 gamma logs obtained outside the B-BX-BY Waste Management Area suggest that gamma-emitting radionuclides may have been redistributed in sediments surrounding 4 wells in the last 10 years (299-E33-05, 299-E33-18, 299-E33-38, and 299-E33-41). The evidence for redistribution is not above question for some of these wells, and the significance of redistribution varies. An attempt was made to capture the uncertainties and significance in the discussion that follows.

Movement of cobalt-60 at well 299-E33-05 between September 1991 and December 1994 was documented in a small zone between 33.2 and 34.7 m (109 and 114 ft) but the logging in September 1997 showed no measurable change since 1994. The 1994 logging showed apparent horizontal migration of cobalt-60 away from the well based on a slight decrease (above that expected from natural radioactive decay) in cobalt activity. Because there was no difference between the spectral gamma logs at shallower or deeper depths, one can speculate that the cobalt moved laterally. Geologic data from a nearby well suggested that there is a fine-grained sand lens at the 33.5-m (110-ft) level that is bounded above and below by coarser material that would act as a barrier that limits water flow to occur only in the fine-grained sand. See Hillel (1980) or Guymon (1994) for descriptions of unsaturated flow in vadose zone sediments and Richards-type barriers. Several Hanford scientists are concerned that the small change in cobalt-60 may be within the uncertainty in calibration of the detectors and slight procedural changes from one logging event to another. These logging activities found no change in the cobalt-60, antimony-125, or cesium-137 in the rest of the vadose zone profile.

Cobalt was found in the September 1997 log between 15.2 and 50.3 m (50 and 165 ft) and trace amounts were found close to the water table at 68.6 to 71.3 m (225 to 234 ft). The higher levels of cobalt-60 are between 25.9 and 38.1 m (85 and 125 ft). The maximum cobalt-60 activity is 50 pCi/g at 29.9 m (98 ft). Antimony-125 and cesium-137 and are also found in the gamma logs at well 299-E33-05. The cesium-137 was between the depths of 15.2 and 19.8 m (50 and 65 ft) with a trace amount (approximately 3 pCi/g) just above the water table. Groundwater taken from this well show cobalt-60 has been present since samples have been collected (October 1956), and the concentration has ranged between 10 to 30 pCi/L over the past 2 years. The groundwater data,

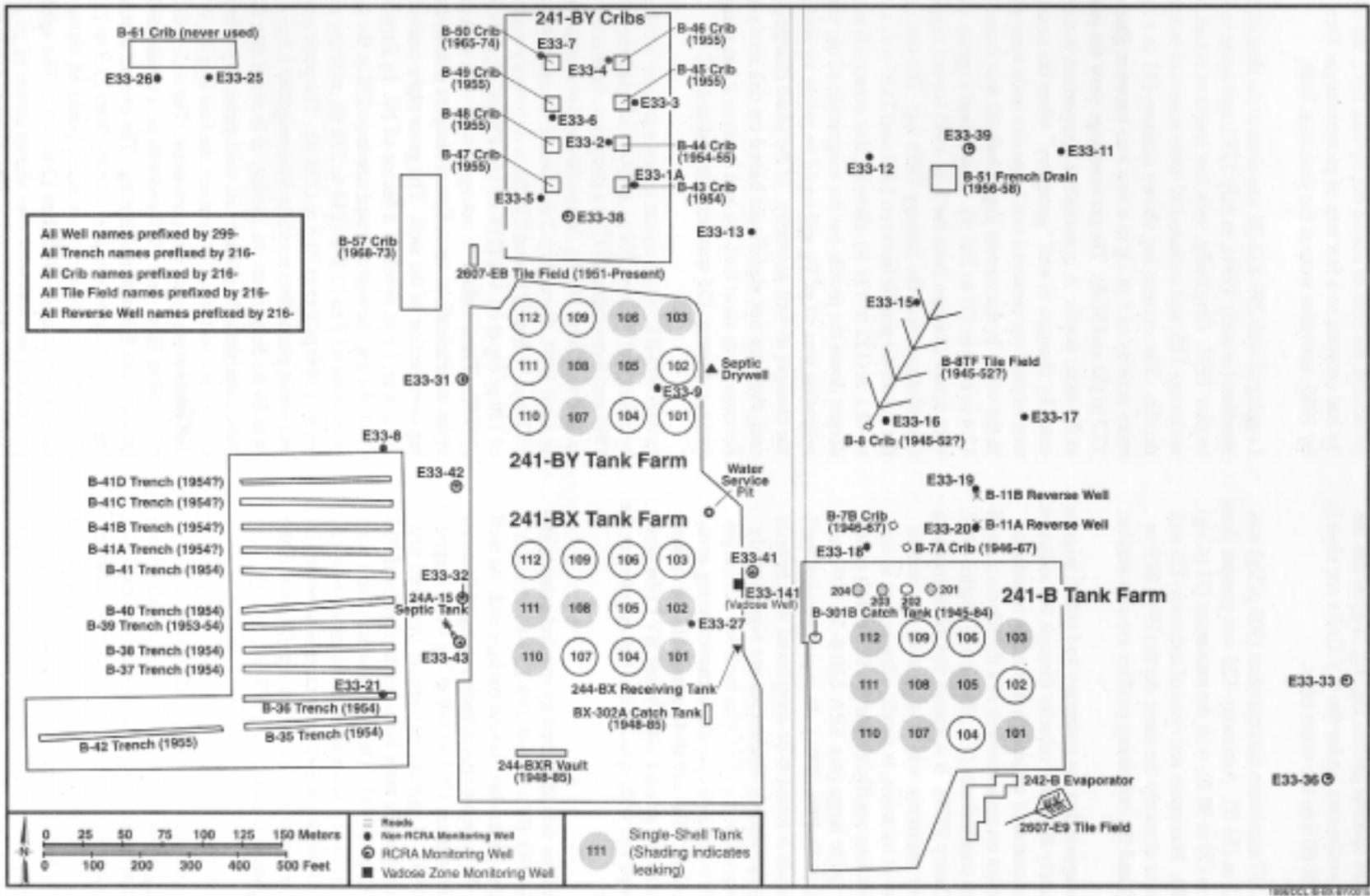


Figure 6.2.8. Diagram of Waste Management Area B-BX-BY

more so than the spectral gamma logging, suggest that the vadose zone sediments under the BY Cribs are slowly draining cobalt-60 into the water table.

The cesium-137 maximum concentration (900 pCi/g) was found at 16.2 m (53 ft). Antimony-125 was present from 15.2 to 29.9 m (50 to 98 ft), with the maximum (33 pCi/g) at 29 m (95 ft). Maximum activities of antimony-125 and cobalt-60 occur at nearly the same depth (29 to 29.9 m [95 to 98 ft]) and the remaining profiles are also similar.

These facts suggest that the antimony and cobalt migrate at approximately the same velocity through the sediment. A common measure of migration rate is the retardation factor that relies on measurement of a distribution coefficient for each contaminant (e.g., Serne and Muller 1987, Freeze and Cherry 1979). It is known that the distribution coefficient for antimony, which is generally present in groundwaters as an anion, is small; often as low as zero, yet the distribution coefficient for the free cobalt cation is generally quite large (see EPA 520/6-78-007 and NUREG/CR-1322, PNL-2901). In some chemical environments, cobalt is found to be complexed with ligands such that its adsorption tendencies are significantly reduced. Disposal at the BY Cribs included discharges of liquids that contained cyanide, a known strong complexant for cobalt. The cobalt-60 present in the vadose zone sediments and groundwater below BY Cribs probably has complexed with cyanide and has migrated to the groundwater.

Elevated uranium was identified by spectral gamma logging in wells 299-E33-18 and 299-E33-41 at much higher concentrations than natural background. At well 299-E33-18, the uranium concentration changed from not detected in September 1992 to 400 pCi/g when logged in September 1997. Uranium movement occurred just above the groundwater table between the depths of 70.7 to 75.9 m (232 to 249 ft). The groundwater at this well started showing rising uranium concentrations between February 1993 and April 1994 and ranged between 100 to 200 µg/L in the past 2 years. The significance of the uranium migration is under study (PNNL-11826).

At well 299-E33-18, there is a minor amount (maximum <2 pCi/g) of cesium-137 between the ground surface and 3.05-m (10-ft) depth. There is also some cobalt-60 deep in the formation between 70.1 and 81.4 m (230 and 267 ft), with a maximum activity of 3 pCi/g in a zone between 70.1 and 74.7 m (230 and 245 ft), just above the current water table. In the 1960s, groundwater at this well contained several thousand to a few tens of thousands of

picocuries per liter of cobalt-60; by late 1977, the activity had dropped to a few tens of picocuries per liter; and by 1985, activities were at the detection limit.

Logging of well 299-E33-38 was done at the time of construction (in early 1991), in July 1995, and again in September 1997. Originally, very low levels of cobalt-60, antimony-125, and cesium-137 were observed at several depths. The current log shows cesium-137 at a maximum activity of 3 pCi/g in a thin lens between 15.8 and 17.7 m (52 and 58 ft). The previous logs show the cesium at the same depth. A quantitative comparison is complicated by changes in well "geometry" when the construction casing was removed and bentonite seals were placed in the void. In the current log, cobalt-60 was found from 17.4 to 61.9 m (57 to 203 ft). This recent logging shows very minor changes from the July 1995 log but significant changes from the January 1991 log. The change in the cobalt-60 profile between 1991 and 1995 was at 37.2 to 42.1 m (122 to 138 ft), showing that cobalt-60 moved deeper down the profile but the magnitude of the vertical migration was <1 pCi/g and could be solely an artifact of the changes in well geometry. If the small changes are real, they are not significant based on risk analyses. Because of its short half-life and because it has decayed away, antimony-125 was not detected in 1997.

In well 299-E33-41, uranium appears to have increased by a factor of 5 (from 200 to 1,000 pCi/g) between April 1991 and September 1997 in a deep zone between 67.1 to 73.2 m (220 to 240 ft). When this well was constructed in April 1991, there were 2 uranium-238 peaks between 65.2 and 71.6 m (214 and 235 ft), with activity maxima of 190 pCi/g at 66.4 m (218 ft) and 160 pCi/g at 71.3 m (234 ft). These values do not agree very well with gross alpha determinations on sediment samples obtained during construction of the well. The gross alpha activities are lower, by as much as a factor of 10. In September 1997, the log showed elevated uranium-238 in the sediment from 65.2 to 71.9 m (214 to 236 ft), with the maximum (1,000 pCi/g) at 72.5 m (238 ft). The peak activity and whole plume thus seems to have migrated 1.2 to 6.1 m (4 to 20 ft) deeper into the profile. It is noted that there were considerable changes in well geometry (changed casings and added seals) between the two logging events that could complicate interpretations. The well will be relogged in fiscal year 1998 and will be a candidate for future, more frequent monitoring. The overall uranium log for 1997 shows elevated activity from 22.9 to 73.2 m (75 to 240 ft), with numerous minor peaks all above the current water table at 75.1 m (246.5 ft). The spectral gamma log for this well also shows minor (2 pCi/g) cesium-137 surface contamination down to 1.5 m (5 ft).

The groundwater at well 299-E33-41 showed a small increase in uranium concentrations between June 1993 and March 1994. The uranium concentration in the groundwater has ranged from 8 to 81 $\mu\text{g/L}$. No water analyses for uranium were performed in 1995 to May 1997. A November 1997 analysis shows a significant increase from 1994 (81 versus 8 $\mu\text{g/L}$). The most recent uranium analysis (December 1997) was 23 $\mu\text{g/L}$. As discussed in Section 6.2.3.4, "Activities Related to Vadose Zone Characterization at the BX Tank Farm," single-shell tank BX-102 is the likely source of the uranium.

The following is a summary of the gamma logs for wells that do not show any signs that gamma-emitting radionuclides have moved in the sediments surrounding the casings over the last 20 years.

Well 299-E33-04 showed high levels of cesium-137 and some cobalt-60 in the profile. Significant cesium-137 activity is found between 6.1 and 21.3 m (20 and 70 ft), and the detector saturates between 6.1 and 8.2 m (20 and 27 ft) because of very high signal. Using a less sensitive detector, the region between 6.1 and 8.2 m (20 and 27 ft) shows the maximum activity is 1,400,000 pCi/g at 7.5 m (24.75 ft). Cesium-137 is not found in the log below 27.4 m (90 ft), suggesting that it is less mobile than cobalt-60. Cobalt-60 is observed from 16.8 m (55 ft) to the bottom of the well at 68.6 m (225 ft). There are 2 maxima, both 36 pCi/g at 27.4 and 70.4 m (90 and 231 ft). It is known that cobalt-60 has reached the groundwater under the BY Cribs, and the gamma logging seems to corroborate this finding. The water table in 1997 was at 69.3 m (227.4 ft) at this location but was higher in the past. In the 1950s to the mid 1960s, groundwater at this well contained 100,000 pCi/L cobalt-60 and, at present, there may be a small amount above the detection limit. There may also have been some cesium-137 in unfiltered groundwater in the late 1950s but because more accurate methods have been used, starting in the 1970s, there has been no detectable cesium-137 in groundwater.

Well 299-E33-13 shows cesium-137 in 2 zones: one very shallow (ground surface to 9.1 m [30 ft] deep), with a maximum of 16 pCi/g at 0.3 m (1 ft) and the second between 62.5 to 71.3 m (205 to 234 ft), with 16 pCi/g found 3 times between 62.5 and 67.1 m (212 and 220 ft). Cesium-137 has never been measured above detection limits in the groundwater in this well.

Cobalt-60 is also observed at this well at very low activities, from 30.5 to 67.1 m (100 to 220 ft), and at moderate levels between 67.1 and 73.2 m (220 and 234 ft), with a

maximum of 8 pCi/g at the bottom (73.2 m [234 ft]) of the well. Cobalt-60 was present in the groundwater from 1956 to 1971. Sampling was restarted in 1991, and no cobalt-60 has been detected in the groundwater to the present time.

The log for well 299-E33-15 showed no cobalt-60 and cesium-137 in the profile until 67 m (220 ft) was reached. From 67.1 to 72.5 m (220 to 238 ft), cobalt-60 was found at a maximum of 30 pCi/g at the well bottom (72.5 m [238 ft]). Cobalt-60 was measured in the groundwater from 1956 through 1965, when the sampling ceased. Cesium-137 was present in the groundwater briefly in 1956. Starting in 1991, groundwater sampling resumed but no cobalt-60 or cesium-137 has been found above the detection limit.

The log for well 299-E33-16 showed very high cesium-137 activity between 8.5 and 10.1 m (28 and 33 ft) and high activity between 10.1 and 15.8 m (33 and 52 ft). There is also some cesium-137 at 0.3 m (1 ft) below the ground surface and between 6.7 and 50.3 m (22 and 165 ft). Using a less sensitive detector, the maximum cesium-137 was found to be 62,000 pCi/g at the 9.4-m (31-ft) level. The maximum cobalt-60 activity (20 pCi/g) was observed at 76.2 m (250 ft), with the overall zone found between 68.6 and 76.2 m (225 and 250 ft). The gamma log at the head end of the 216-B-8TF Tile Field shows much more radioactivity than the back end well (299-E33-15). Very little liquid waste may have reached the end of the tile field prior to percolating into the sediments. The brief occurrence of cesium-137 in the groundwater at well 299-E33-15 may have reached the water table closer to well 299-E33-16 and migrated toward well 299-E33-15.

Analyses of unfiltered water from well 299-E33-16 occurred from 1956 to 1962 and then resumed in late 1997. During the first period, cobalt-60 was readily detected in the water but the current sampling shows activity very near the detection limit. Early water analysis for cesium-137 ended in May 1959 and restarted in August 1997. It is not certain whether cesium-137 reached the water table at this location.

Well 299-E33-17 showed very low levels of cesium-137 near the surface and just above the water table (now at 67.8 m [229 ft]). The cesium-137 activity is always below 2 pCi/g. Cobalt-60 is observed deep in the profile between 68.6 and 73.5 m (225 and 241 ft), the bottom of the well. The cobalt-60 activity in this zone is 23 pCi/g. It would appear that the cobalt-60 reached this location via horizontal migration in the aquifer. Cobalt-60 was present in

the groundwater in the mid-1950s through the mid-1960s but currently, there is no detectable cobalt-60 in the groundwater. The very low cesium-137 activity near the ground surface and deep in the sediment at this location is difficult to explain. The well is approximately 100 m (328 ft) away from any disposal facility.

Well 299-E33-19 showed 3 zones of cesium-137 with decreasing activity with depth. The 216-B-11 Injection Wells were 10-cm (4-in.) dia. cased holes that extended 12.2 m (40 ft) below grade. The first zone was from the ground surface to 3.05 m (10 ft), with a maximum activity of 50 pCi/g. The second zone is a lens between 32 and 33.5 m (105 and 110 ft), with an activity of 10 pCi/g. The deepest zone is at 70.7 to 74.4 m (232 to 244 ft) at the bottom of the well, and the maximum cesium-137 concentration is <2 pCi/g. The two latter zones are well below the depth of the injection wells, suggesting cesium-137 migration through the vadose zone sediments. Cobalt-60 was detected between 69.2 and 71.3 m (227 and 234 ft) but the activities are rather low (<0.4 pCi/g). Groundwater at this well was monitored for a brief time (1957 to 1962) and never showed measurable cesium-137 but did show the presence of cobalt-60 at several thousand to a few tens of thousands of picocuries per liter.

The log for well 299-E33-20 was very similar to the log for well 299-E33-19. Again, there are 3 zones of cesium-137 contamination: ground surface to 3.05 m (10 ft), 26.8 to 28.3 m (88 to 93 ft), and 57.3 to 60.4 (188 to 198 ft). The maximum cesium-137 activities in these zones are 40, 35, and 23 pCi/g, respectively. The values for the 2 deeper depths are higher than those at well 299-E33-19. This well also shows the deep (74.7- to 79.9-m [245- to 262-ft]) zone of very low cobalt-60 (<1 pCi/g). Groundwater from this well was analyzed from 1957 to 1963, briefly in 1987, and then again in 1997. Cesium-137 was never detected. Cobalt-60 was present through 1963 but had decayed away by 1987. In 1997, there were no gamma emitters present in the groundwater.

Well 299-E33-21 showed a significant cesium-137 plume, stretching from 3.7 m (12 ft) below ground surface (the depth of the trench bottom is 3.05 m [10 ft]) to the bottom of the well at 85.3 m (280 ft). Between 4.6 and 7.0 m (15 and 23 ft), the cesium-137 activity saturates the detector and also causes distortion in the detector readings down to 13.7 m (45 ft). A less sensitive detector was used to quantify the activity in this high-count-rate zone. The cesium-137 activity peaks at 5.5 m (18 ft) at a value of 120,000 pCi/g. The elevated cesium-137 at the bottom of the well (30 pCi/g) could be sediment adhering to

the drive shoe that is the terminus of the casing. The 216-B-36 Trench received scavenged waste in 1954, the product of trying to reprocess bismuth phosphate waste to extract uranium. One would expect to see high activities of cesium-137 in the remaining fluid from extracting uranium. In the late 1970s, there may have been some (5 to 15 pCi/L) cesium-137 detected in unfiltered groundwater from this well but the quality assurance for these early results is difficult to ascertain. Since 1985, when better quality assurance documentation had been entered into the database, no cesium-137 was found above the detection limit in groundwater from this well. This trench appears to be a good candidate for more detailed study on cesium distribution and migration potential within the vadose zone.

There is also a very minor (<1-pCi/g) cobalt-60 signal at the very bottom of the casing in well 299-E33-21. In 1958, a few hundred picocuries per liter of cobalt-60 were observed in groundwater from this well. From 1975 through 1980, the cobalt-60 in the groundwater was between 10 and 20 pCi/L. By 1983, the cobalt-60 activity dropped to a few picocuries per liter, where it remains today.

Well 299-E33-31 showed no anthropogenic radionuclides at depth. There are minor amounts of cesium-137 from the surface to 3.05 m (10 ft). This undoubtedly reflects a surface spill in the past. Well 299-E33-32 has a spectral gamma log with no anthropogenic radionuclides measured. Well 299-E33-42 is approximately midway between wells 219-E33-31 and 299-E33-32. The spectral gamma log for well 299-E33-42 showed only minor cesium-137 contamination (<1 pCi/g) from the ground surface to 3.05 m (10 ft). Well 299-E33-43 showed no anthropogenic radionuclides at any depth. The logs for these four wells suggest that no man-made radionuclides have been transported from the 216-B-35 to 216-B-42 Trenches away in an easterly direction. Conversely, the data also suggest that no gamma-emitting radionuclides from tank leaks have traveled in a westerly direction. PNNL-11826, however, shows that concentrations of technetium-99, specific conductance, and nitrate have been increasing in groundwater well 299-E33-32 in the recent past such that there may be migration of some contaminants in the groundwater between the B Trenches and BX-BY Tank Farms.

In summary, the spectral gamma surveys in 16 wells within the B-BX-BY Waste Management Area found indications of small changes (a few picocuries per gram) in cobalt-60 concentrations in the sediment profiles in

two wells (299-E33-05 and 299-E33-38). The changes occurred between 1991 and 1994 in the first well and between 1991 and 1995 in the second well. As discussed, changes in casing construction, addition of sealants, and changes in logging procedures may have compromised the interpretation of whether the movement actually occurred. There has been little indication of further movement based on the September 1997 logs in these two wells. The cobalt-60 movement in well 299-E33-04 was horizontal (migration away from the casing) in a fine-grained zone between 33.2 and 34.7 m (109 and 114 ft). The cobalt-60 migration at well 299-E33-38 may have been down the profile between 37.2 and 42.1 m (122 and 138 ft), but amounts are insignificant (1 pCi/g). Uranium appears to have migrated deeper in wells 299-E33-18 and 299-E33-41, but the data for the latter well is being reevaluated. The zones in the two wells where the uranium may be migrating are near their respective water tables. There may not be a common source of uranium for these wells. The uranium activity increases in the gamma logs for these wells are 400 and 800 pCi/g, respectively. Groundwater in both wells has shown significant increases in uranium over the past 2 years such that the spectral gamma results corroborate the groundwater monitoring results. These 2 wells are approximately 100 m (328.1 ft) apart and are located to the east of the BX Tank Farm and just north of the B Tank Farm. The uranium concentration in the groundwater at well 299-E33-18 is higher than the uranium concentration in well 299-E33-41, perhaps suggesting that, if there is a common source, it is closer to well 299-E33-18. Spectral gamma logging from wells inside the BX Tank Farm suggest that a leak from tank BX-102 is the source of the uranium observed in well 299-E33-41. Thus, the higher uranium observed in groundwater at well 299-E33-18 may be from a different source. Well 299-E33-18 is 50 m (164 ft) north of tank B-112, a known leaker, and in the past, groundwater flow was in a north-northwesterly direction at this waste management area. The hydraulic gradient is almost level today; so it is difficult to be certain how the uranium reached well 299-E33-18. See PNNL-11826 for further discussion on the possible sources of recent elevated levels of uranium, technetium, specific conductance, and nitrates in groundwaters under this waste management area.

6.2.4.2 Soil-Gas Monitoring

Soil-vapor extraction is being used to remove the carbon tetrachloride source from the vadose zone as part of the 200-West Area carbon tetrachloride expedited response action being conducted by Bechtel Hanford, Inc. For descriptions of past work, see BHI-00720 (Rev. 1) and

Section 4.2.2 in PNNL-11470. To track the effectiveness of the remediation effort, measurements of soil-gas concentrations of chlorinated hydrocarbons were made at individual, on-line, extraction wells; at soil-gas probes throughout the vadose zone; and at the inlets to three soil-vapor extraction systems during 1997. While the extraction systems were shut down from November 1996 through June 1997, a study was conducted to evaluate the magnitude and rate of chlorinated hydrocarbon concentration rebound by measuring soil-gas concentrations in samples collected from wells and probes throughout the extraction sites (BHI-01105). At the carbon tetrachloride extraction site (Figure 6.2.9), there are currently 46 drilled wells available for on-line extraction or monitoring (BHI-00720, Rev. 1; BHI-01105). Each of the soil-vapor extraction systems extracts simultaneously from multiple wells. The mix of on-line wells is adjusted periodically to optimize contaminant removal.

There are 125 subsurface monitoring probes at depths greater than 2 m (6.6 ft) as shown in Figure 6.2.10. The network was installed between 1991 and 1995. In 1997, a soil-gas study was also performed at the Nonradioactive Dangerous Waste Landfill, and results/observations are included in this section.

Soil-Vapor Remediation and Monitoring Results. The soil-vapor extraction systems were operated from October 1 through November 3, 1996 and from July 18 through September 30, 1997. From November 4, 1996 through July 17, 1997, the extraction systems were shut down and the rebound in carbon tetrachloride concentrations was monitored at 90 wells and soil-gas probes in the extraction well field sites.

During October and November 1996, carbon tetrachloride concentrations in extracted soil vapor continued to decline, as they have since operation of the extraction systems began in 1992 (BHI-00720, Rev. 1; BHI-01105). This is typical and represents removal of the readily available vapor phase of the contaminant in vadose zone sediment pore spaces. The most dramatic vapor-phase decrease was at the 216-Z-9 Well Field, where carbon tetrachloride concentrations measured at the system inlet declined from ~30,000 parts per million by volume (ppmv) in 1993 to 25 ppmv in early November 1996 (Figure 6.2.11). In comparison, carbon tetrachloride concentrations in soil vapor extracted from the 216-Z-1A Well Field declined from ~1,500 ppmv in 1992 to 16 ppmv in November 1996 (Figure 6.2.12) and in soil vapor extracted from the 216-Z-18 Well Field declined from ~275 ppmv in 1994 to 10 ppmv in November 1996 (Figure 6.2.13).

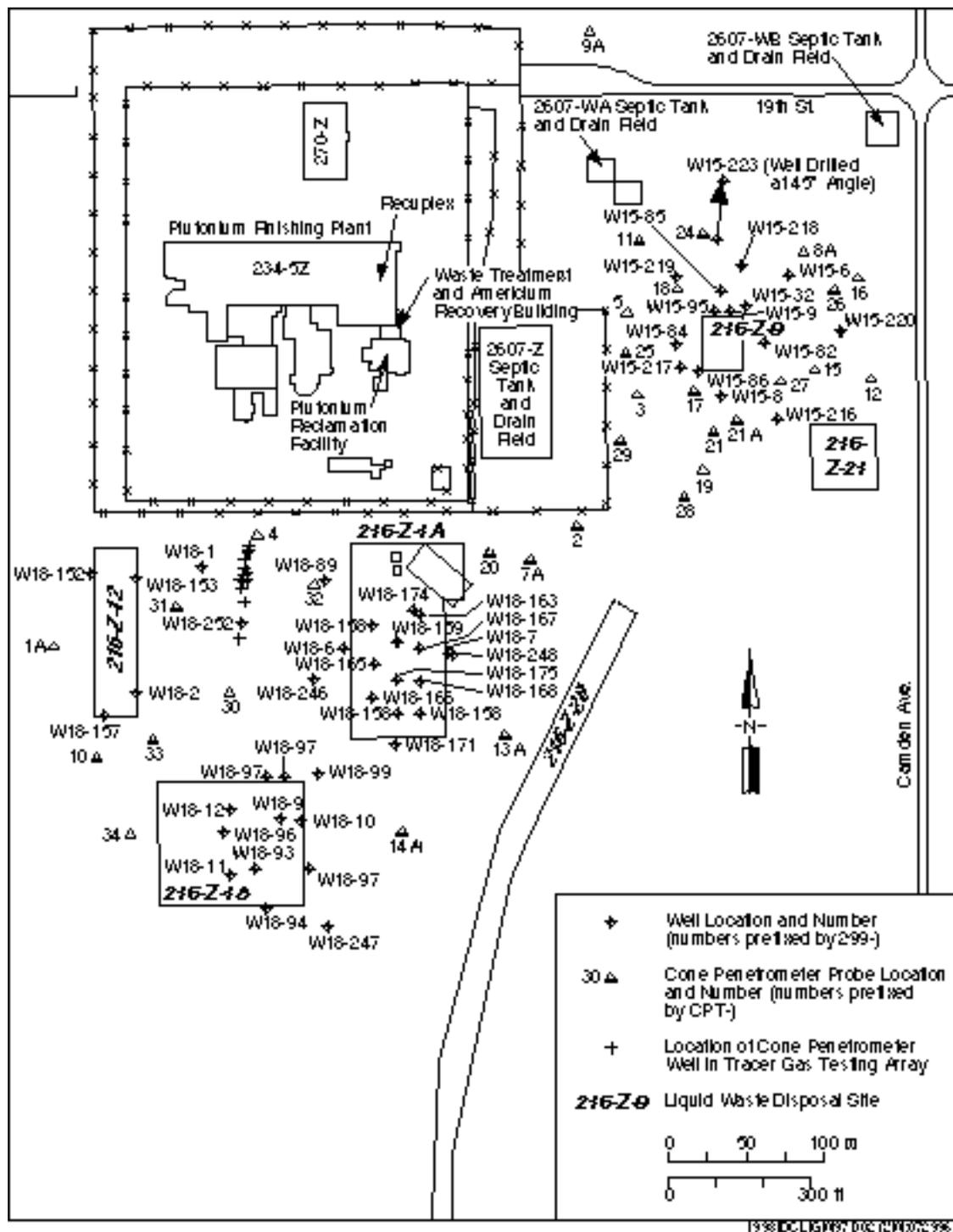


Figure 6.2.9. Wells and Deep Monitoring Probes at the Carbon Tetrachloride Vapor Extraction Site

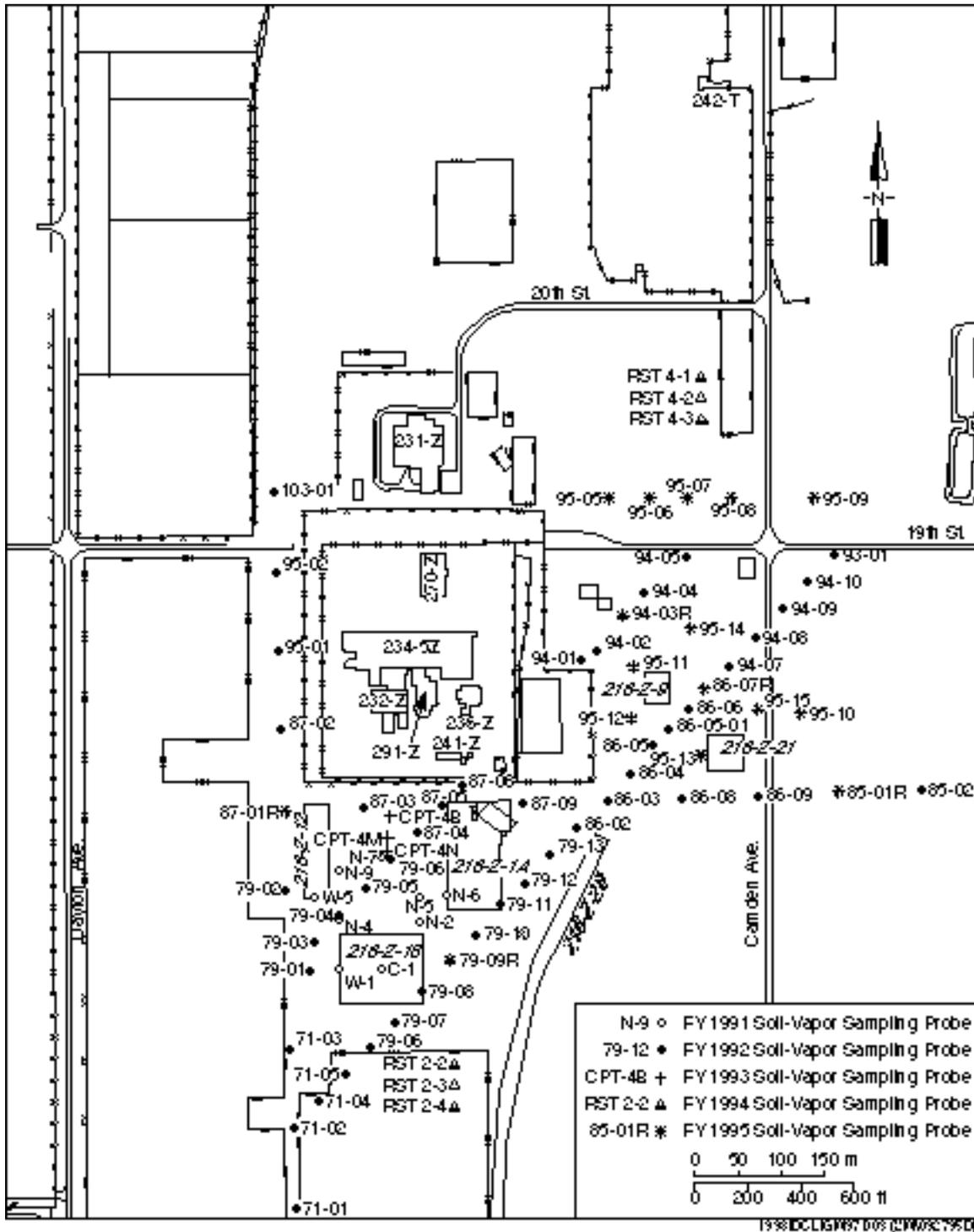


Figure 6.2.10. Shallow Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor Extraction Site

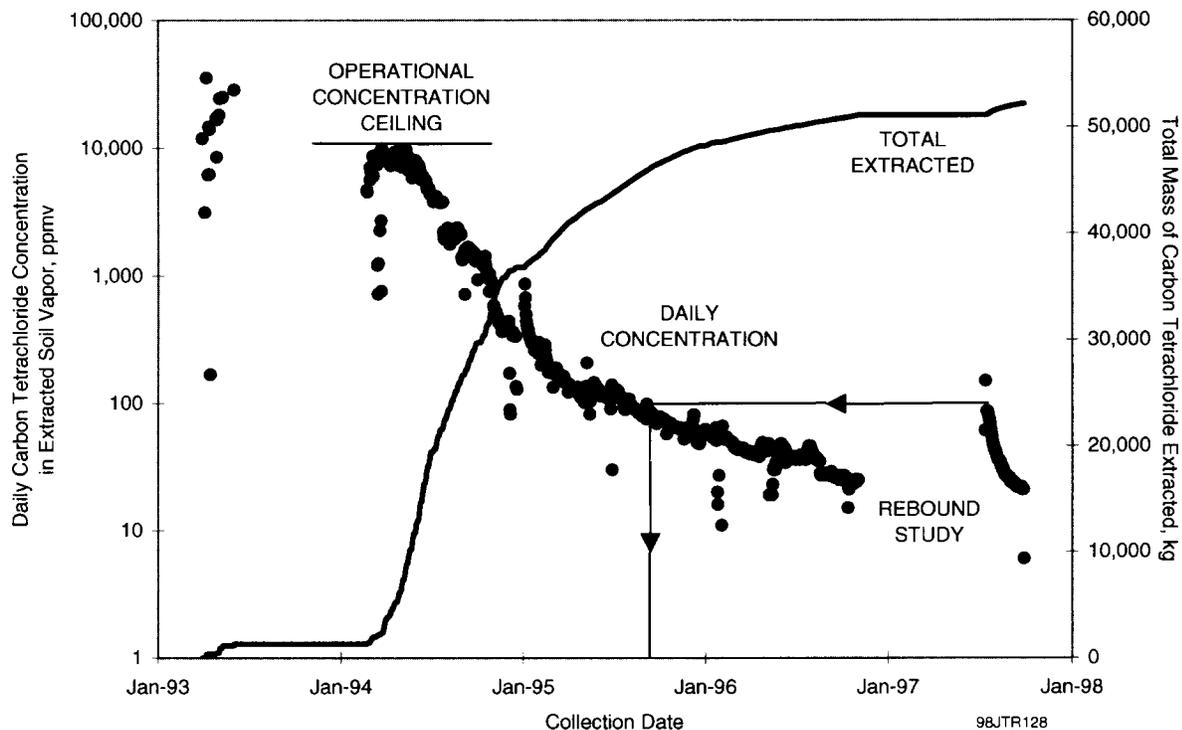


Figure 6.2.11. Daily Carbon Tetrachloride Concentrations in Soil Vapor Extracted from 216-Z-9 Well Field (after BHI-00720, Rev. 1)

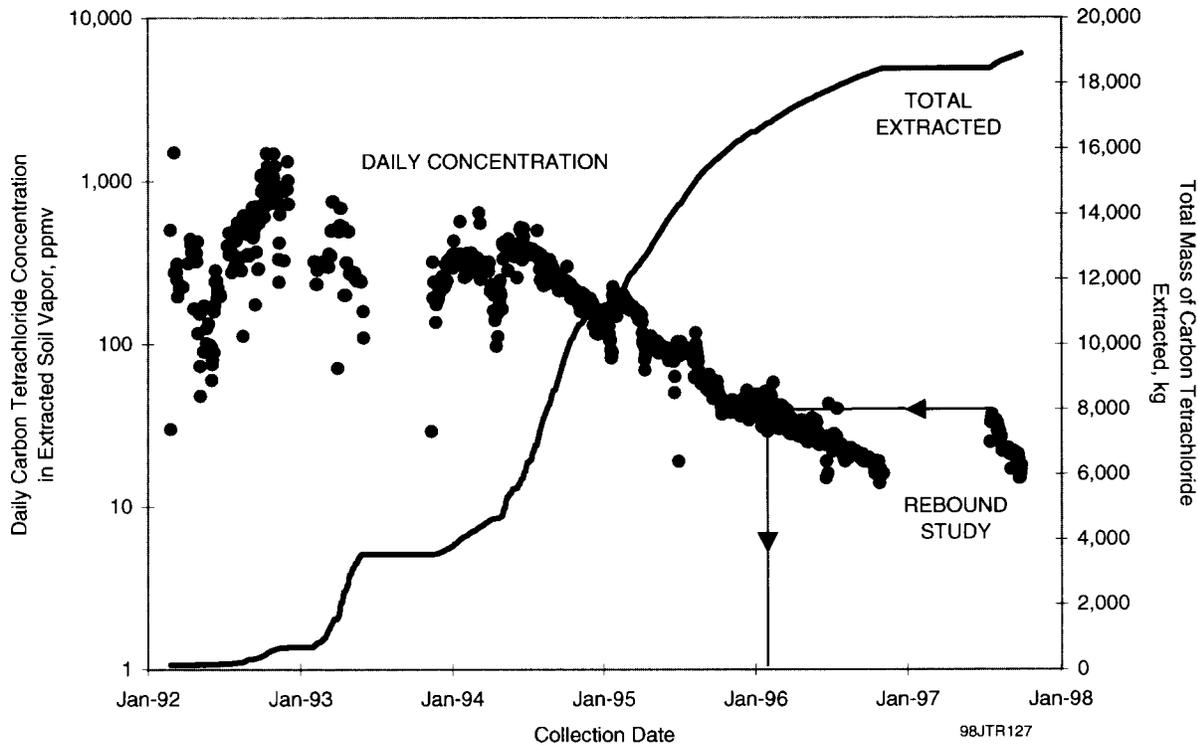


Figure 6.2.12. Daily Carbon Tetrachloride Concentrations in Soil Vapor Extracted from 216-Z-1A Well Field (after BHI-00720, Rev. 1)

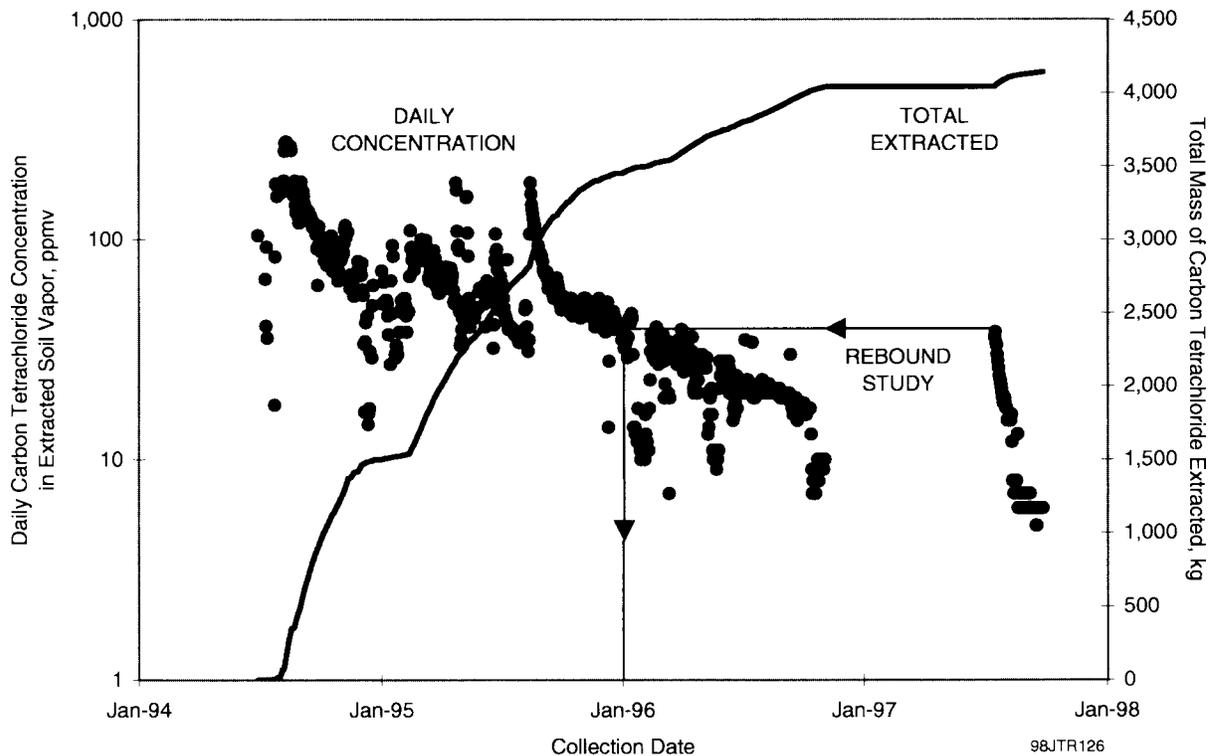


Figure 6.2.13. Daily Carbon Tetrachloride Concentrations in Soil Vapor Extracted from 216-Z-18 Well Field (after BHI-00720, Rev. 1)

Wells in the 216-Z-18 Well Field were included in the 216-Z-1A Well Field from 1992 to 1994.

When the extraction systems were restarted in July 1997 after the 8-month shutdown for the rebound study, carbon tetrachloride concentrations in the soil vapor had increased, as expected, at each of the three extraction systems (BHI-01105). After restart, daily concentrations at the three systems were equivalent to concentrations measured previously (at times ranging from September 1995 to February 1996) as indicated by arrows on Figures 6.2.11 to 6.2.13. However, the July 1997 concentrations decreased at a faster rate than the equivalent concentrations did in the past.

During the last 3 weeks of extraction operations (October-November 1996) before the 8-month shutdown for the rebound study, the 3 systems combined were extracting carbon tetrachloride at an average of 102 kg/wk (224.9 lb/wk). During the first 3 weeks of operations following the shutdown (July-August 1997), the 3 systems combined were extracting an average of 178 kg/wk (392 lb/wk) (BHI-01105). With continued operation in 1997, the mass removal rates continued to decline toward the October-November 1996 rates.

As of September 1997, ~75,000 kg (165,000 lb) of carbon tetrachloride had been removed from the subsurface since extraction operations started in 1992 (see Table 6.2.2 and BHI-01105 for additional details). Of this total, 1,824 kg (4,022 lb) were removed during 15 weeks of operation in 1997. Since its initiation in 1992, the extraction systems are estimated to have removed 6% of the residual carbon tetrachloride at the 216-Z-1A/216-Z-18 Well Fields and 21% of the residual carbon tetrachloride at the 216-Z-9 Well Field (BHI-00720, Rev. 1). 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 for extraction from the vadose zone (BHI-00720, Rev. 1; BHI-01105; WHC-SD-EN-TI-101).

Rebound Study Results. The rebound study was conducted at the 200-ZP-2 Operable Unit carbon tetrachloride soil-vapor extraction site from November 1996 through July 1997 (BHI-01105). The purpose of the study was to determine the increase in carbon tetrachloride vapor concentrations in vadose zone pores following shutdown of the extraction systems. During the time when the systems were off-line, carbon tetrachloride concentrations were

Table 6.2.2. 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 1997, ^(c) kg (lb)
216-Z-1A	270,000 (595,250)	56,700 (125,000)	22,729 ^(d) (50,110)
216-Z-18	170,000 (374,790)	35,700 (78,700)	
216-Z-9	130,000 to 480,000 (286,600 to 1,058,220)	27,300 to 100,800 (60,190 to 222,230)	51,984 (114,610)
Total	570,000 to 920,000 (1,256,630 to 2,028,250)	119,700 to 196,800 (263,890 to 433,870)	74,713 (164,720)

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

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

(c) Based on BHI-01105.

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

monitored at 90 subsurface locations. The magnitude and rate of rebound can be used to indicate the distribution of remaining carbon tetrachloride sources and the transfer rate of additional carbon tetrachloride to the vapor phase that can be remediated using soil-vapor extraction.

The maximum carbon tetrachloride concentration measured at each sampling location is plotted with depth in Figure 6.2.14. This vertical profile indicates that the remaining carbon tetrachloride available for removal using soil-vapor extraction is primarily associated with the lower Hanford formation silt and underlying Plio-Pleistocene layers. The location of remaining carbon tetrachloride sources in the various strata is a result of its initial accumulation in the finer grained, lower permeability layers observed during characterization in 1991-1993 (WHC-SD-EN-TI-248) and the relative inability of the extraction system to induce airflow through this lower permeability zone to remove soil vapor effectively.

Additional carbon tetrachloride may be slowly migrating from the micropores of soil particles within the higher permeability zones also. Although rebound concentrations in these zones appear to be low, the large volume of high permeability soil represents a potentially significant mass of carbon tetrachloride. The continuing rebound at many locations indicates that the supply of additional carbon tetrachloride for soil-vapor extraction is limited

by diffusion of the contaminant from the micropores and/or the lower permeability zones.

Carbon tetrachloride concentrations measured in soil vapor near the water table increased relatively slowly during the rebound study and remained relatively constant during restart in July 1997. These relatively slow changes during the rebound study suggest that the volatilization of dissolved carbon tetrachloride from groundwater into the unsaturated zone and/or the downward migration of carbon tetrachloride from the lower permeability zone toward the groundwater was occurring slowly relative to the 8-month-long rebound study.

The carbon tetrachloride vapor concentrations observed between the Plio-Pleistocene layers and the groundwater were similar at the 216-Z-1A and 216-Z-9 Well Fields despite the underlying groundwater plumes of different concentrations (3,000 µg/L in the water below 216-Z-1A and 6,000 µg/L in the water below 216-Z-9). The measured vapor concentrations are an order of magnitude lower than the equilibrium vapor concentrations predicted for these groundwater concentrations using Henry's Law (450 ppmv predicted at 216-Z-1A and 900 ppmv predicted at 216-Z-9). The vapor concentrations are also much lower than saturated vapor concentrations in equilibrium with a carbon tetrachloride nonaqueous-phase liquid (120,000 ppmv), suggesting that the continuous carbon

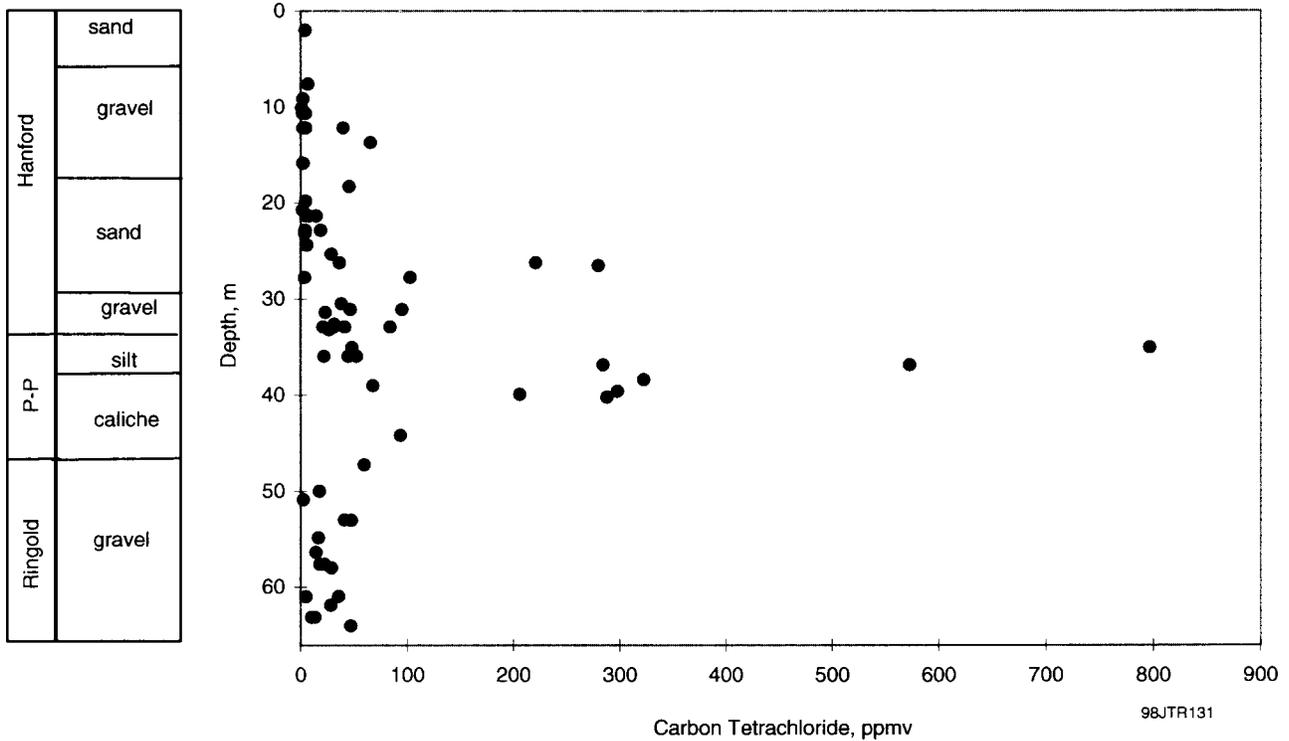


Figure 6.2.14. Vertical Profile of Maximum Carbon Tetrachloride Rebound Concentrations (after BHI-01105)

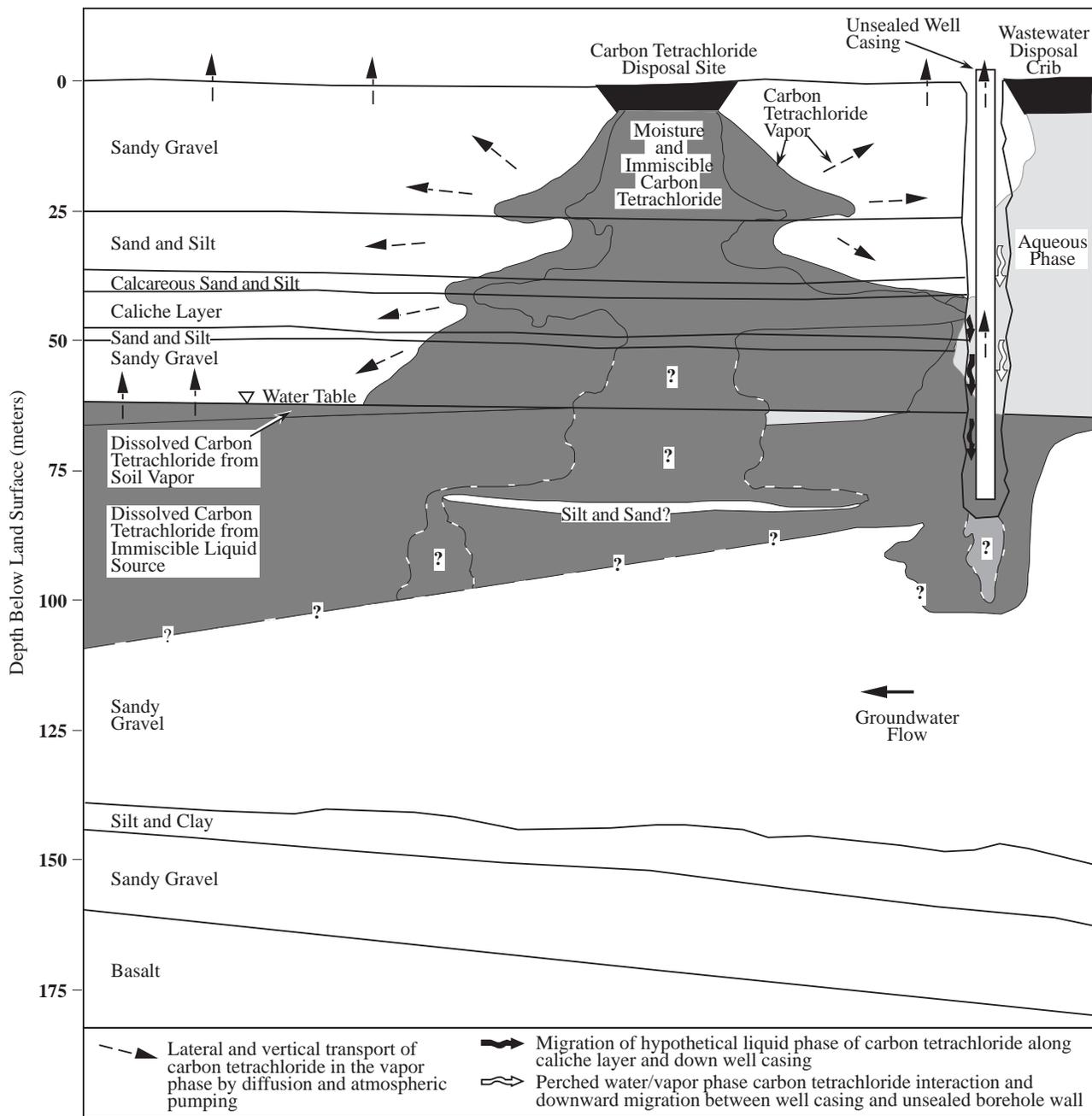
tetrachloride contamination source indicated for groundwater at the 216-Z-9 Well Field may be within the aquifer rather than draining from the vadose zone sediments (BHI-01105).

Carbon Tetrachloride Migration. Three major pathways for transport of carbon tetrachloride in the vadose zone to groundwater are possible: 1) sinking and lateral spreading of a heavier than air vapor phase down to the top of the aquifer; 2) transport of a liquid phase or dense nonaqueous-phase liquid down through the vadose zone over time, which eventually reaches the water column, dissolves, and settles through the saturated zone to an unknown depth; and 3) transport of carbon tetrachloride dissolved in the aqueous phase either through disposal of aqueous waste or by contact between infiltrating recharge and residual dense nonaqueous-phase liquid (WHC-SD-EN-TI-248). A schematic representation, or conceptual model, of the subsurface behavior of carbon tetrachloride beneath the 216-Z-9 Trench is shown in Figure 6.2.15.

The vapor phase results obtained to date suggest that vapor-phase transport is secondary to dense nonaqueous-phase liquid as a groundwater contamination pathway, but field measurements of carbon tetrachloride vapor

concentrations are not completely consistent with numerical modeling results. If a major fraction of the carbon tetrachloride originally discharged to the 216-Z-9 Trench were still present in the soil column as a nonaqueous phase, a relatively high soil-vapor concentration would be expected. For example, vapor extraction concentrations >12,000 ppmv of carbon tetrachloride would indicate that the soil near the extraction well was saturated with nonaqueous carbon tetrachloride liquid.

During initial soil-vapor extraction operations at the 216-Z-9 Trench, soil-vapor concentrations extracted from wells open above the Plio-Pleistocene layer were in excess of 12,000 ppmv, suggesting the presence of a nonaqueous carbon tetrachloride phase (see Figure 6.2.11). Soil vapor extracted from wells open below the Plio-Pleistocene layer were an order of magnitude lower and, based on the rule of thumb, would not suggest the presence of a nonaqueous-phase liquid. However, the depths and locations of the extraction wells below the Plio-Pleistocene layer may not have been optimal to detect the presence of a nonuniformly distributed contaminant, and the presence of a nonaqueous-phase liquid cannot be ruled out.



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Figure 6.2.15. Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench

During the 1997 rebound study, the carbon tetrachloride vapor concentrations monitored deep within the vadose zone at the 216-Z-9 Trench did not exceed 60 ppmv. These low vapor concentrations do not indicate the presence of a nonaqueous-phase liquid remaining in the vadose zone below the Plio-Pleistocene layer; however, these measurements were not taken directly under the 216-Z-9 Trench. The data suggest that soil-vapor extraction may have removed much of the remaining deep vadose zone nonaqueous-phase liquid source in the 216-Z-9 area and that the continuing groundwater source may now be within the aquifer (BHI-01105).

The apparent discrepancy between the numerical modeling results and the field measurements may be a result of: 1) nonuniform discharge, migration, and distribution of the nonaqueous-phase carbon tetrachloride; 2) nonoptimal locations for monitoring; 3) nonequilibrium partitioning of carbon tetrachloride within the vadose zone; 4) discharge of carbon tetrachloride organic liquid mixtures rather than pure phase liquids; and/or 5) vadose zone geologic heterogeneities and structure.

In summary, groundwater monitoring below the carbon tetrachloride disposal units suggests there is a continuing groundwater source that produces somewhat uniform carbon tetrachloride concentrations with depth in the aquifer. A dense nonaqueous-phase liquid that has drained from the vadose zone into the aquifer and is slowly dissolving could produce such a pattern. The continuing presence of relatively high dissolved carbon tetrachloride concentrations in groundwater in the immediate vicinity of the 216-Z-9 Trench, 35 years after termination of disposal operations, suggests that a dense nonaqueous liquid phase of carbon tetrachloride 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 suggest that soil-vapor extraction remediation may have removed much of the vadose zone source and that the continuing groundwater source is now 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 Plio-Pleistocene layers). 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.

Nonradioactive Dangerous Waste Landfill. The Nonradioactive Dangerous Waste Landfill is a Resource Conservation and Recovery Act land disposal unit located approximately 5.6 km (3.5 mi) southeast of the 200-East Area. This landfill was used to dispose of nonradioactive dangerous waste and asbestos waste from 1975 to 1985. Volatile organic compounds were detected primarily within and south of the eastern third of the landfill trenches during a 1993 shallow (1.5- to 1.8-m [4.9- to 5.9-ft] deep) soil-vapor survey and have been detected during groundwater monitoring of wells near the landfill since 1987 (WHC-SD-EN-TI-199).

A soil-vapor survey was conducted at the landfill during 1997 to 1) collect deep soil-vapor data to assess the vertical extent of volatile organic compound contamination and the potential impacts to groundwater and 2) resample selected shallow vapor probes to assess changes in contaminant distribution that may indicate contaminant movement. The strategy and methods used to sample and analyze the soil vapor within the subsurface at the landfill and a summary of the data quality objectives process are described in BHI-01073.

The sampling locations focused on the eastern half of the landfill based on the results of the 1993 soil-vapor survey (WHC-SD-EN-TI-199). A total of 35 probes were installed during August 1997. Soil-vapor samples were collected from six shallow probes (1.5 to 1.8 m [4.9 to 5.9 ft] deep) and 33 deep probes (8.8 to 29.7 m [28.9 to 97.4 ft] deep) (BHI-01115). The water table under the facility is 36.6 to 38.4 m (120 to 126 ft) below ground surface.

Six volatile organic compounds were detected during the 1997 survey: carbon tetrachloride, chloroform, 1,1-dichloroethane, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene (BHI-01115). Of these contaminants, 1,1,1-trichloroethane was the most widespread and was detected in all but one of the samples from the deep probes at concentrations <1 ppmv; however, 1,1,1-trichloroethane was not detected in the samples from the shallow probes. Carbon tetrachloride and chloroform were the only contaminants detected at concentrations exceeding 1 ppmv. In samples from 2 adjacent

locations (1 shallow and 2 deep probes within and beneath the chemical trenches), concentrations ranged from 20 to 46 ppmv. All of the same contaminants, except 1,1-dichloroethane, were detected in the 1993 survey.

Based on the 1997 results, the soil-vapor contaminants tend to be distributed at low concentration levels within or south of the landfill trenches. The volatile organic compound concentrations detected in deep samples suggest

that vertical migration of carbon tetrachloride occurred directly beneath the chemical trenches within a narrow zone. Comparison of analytical results for 1993 and 1997 soil-vapor samples collected from shallow probes indicates that the maximum carbon tetrachloride concentrations are still within the chemical trenches at the landfill, suggesting that the contaminants have not migrated significantly (BHI-01115).