

## 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. Radioactive and hazardous wastes in the soil column from past intentional liquid waste disposals, unplanned leaks, solid waste burial grounds, and underground tanks at the Hanford Site are potential sources of continuing and future vadose zone and groundwater contamination. Subsurface source characterization and vadose zone monitoring,

soil-vapor monitoring, sediment sampling and characterization, and vadose zone remediation were conducted in 1999 to better understand and alleviate the spread of subsurface contamination. This section summarizes major findings from these efforts, focused primarily on vadose zone soil contamination associated with reactor operations, past single-shell tank leaks, and liquid disposal to ground as a result of spent fuel processing.

### 6.2.1 Vadose Zone Characterization and Monitoring at Tank Farms

Several vadose zone characterization activities occurred at the single-shell tank farms in 1999. At tank farm SX, in the 200-West Area, samples were collected and characterized from the decommissioning of one borehole drilled to characterize deep vadose zone contamination and from a second, new borehole adjacent to tank SX-115. Tank SX-115 was selected because it is the source of the largest measured leak in the SX tank farm. Also, in the SX tank farm, preliminary temperature and neutron capture borehole logging was accomplished. During 1999, baseline spectral gamma-ray logging at two single-shell tank farms (tank farms T and B in the 200-West and 200-East Areas, respectively) was completed and relogging of the highest count rate zones at the SX tank farm was initiated.

#### 6.2.1.1 Borehole Characterization at the SX Tank Farm

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**Decommissioning of Borehole 41-09-39.** Borehole 41-09-39 is located adjacent to single-shell tank SX-109 in the SX tank farm in the Hanford

Site's 200-West Area. This borehole was originally constructed in 1996 to a depth of 40 meters (131 feet). The primary purpose of the borehole was to determine the presence of cesium-137 at depths of 24 to 40 meters (79 to 131 feet) below ground surface. The borehole was deepened in 1997 and temporarily used as a monitoring well for collecting groundwater samples.

In 1999, the borehole was decommissioned (taken apart and backfilled) to eliminate it as a potential pathway for contaminants to reach the groundwater. As part of the decommissioning effort, sidewall samples were collected from the previously unsampled portion of the hole and submitted for chemical and radiological analysis of contaminants to supplement the data collected in previous years.

Two or three sediment samples were obtained from each of 15 selected depths. One of the samples obtained at 19.8 to 20.1 meters (64.9 to 65.9 feet) was 10 times more radioactive than the other two samples from that depth, so the higher activity sample was kept separate. All samples from each depth interval, except those from 19.8 to 20.1 meters (64.9 to 65.9 feet), were mixed together to form one composite sample for each depth.



Analytical results showed very high concentrations of cesium-137. Levels were the highest obtained from under leaking tanks in the past 35 years. Table 6.2.1 lists the descriptive lithology of the borehole and the results of measurements made directly on the sediment. There appeared to be some correlation between the particle size of the sediment and the cesium-137 content between depths of 18.6 and 33.2 meters (61 and 109 feet). Generally, finer grained sediment has more surface area for greater cesium-137 sorption. The region between depths of 18.6 and 25.3 meters (61 and 83 feet) had the highest concentration of cesium-137. A smaller region with high cesium-137 concentration existed between depths of 31.1 and 33.2 meters (102 and 109 feet).

Several of the samples obtained from borehole 41-09-39 contained insufficient pore water to obtain enough for chemical analyses. Therefore, a water

extract, using 1 part water to 1 part dry sediment (by weight), was done on those samples to obtain sufficient leachate for analysis. The water extract gives an indication of which contaminants are readily leached and, therefore, fairly mobile. Table 6.2.2 lists the analytical results of water extracts from the sediment.

The data in Table 6.2.2 show large amounts of water leachable chromium (presumably hexavalent chromium), nitrate, sodium, and technetium-99 in the sediment. Some selenium and cesium-137 were also leached from some samples in concentrations greater than background concentrations. (See DOE/RL-92-24, Rev. 3 and DOE/RL-96-12, Rev. 0 for background values.) The pH of the water extract was elevated slightly above natural pH values of 8.0 to 8.5 for samples from 18.6 to 25.3 meters (61 to 83 feet) below ground surface. The original tank fluids had pH values above 14 and free hydroxide concentrations perhaps as large as 1 molar or higher. The water

**Table 6.2.1. Composition of Sediment from Borehole 41-09-39 in SX Tank Farm**

Depth (m) <sup>(a)</sup>	Lithology	Direct Measures on Dry Sediment					
		Moisture Content (wt. %)	Total Carbon (wt. %)	Organic Carbon (wt. %)	Cesium-137 (pCi/g)	Europium-152 (pCi/g) <sup>(b)</sup>	Cobalt-60 (pCi/g) <sup>(b)</sup>
7.6-7.9	Very fine- to medium-grained sand	8.12	0.16	0.06	6.059E+02	<0.217	0.66 ± 0.27
13.4-13.7	Medium-grained sand	8.57	0.13	0.03	1.113E+03	<0.103	<0.0262
17.1-17.4	Very fine-grained sandy, clayey silt	16.27	0.18	0.03	2.600E+04	<1.03	<0.229
18.6-18.9	Silty, very fine- to medium-grained sand	12.84	0.25	0.14	1.246E+05	<1.73	<1.79
19.8-20.1	Fine- to medium-grained sand	4.71	0.27	0.13	6.258E+05	<39.2	<10.1
19.8-20.1	Fine-grained sand	5.29	0.19	0.08	4.092E+06	<153	<41
21.0-21.3	Fine- to coarse-grained sand	4.36	0.23	0.07	9.493E+03	<0.148	<0.0349
22.6-22.9	Fine- to medium-grained sand	5.17	0.25	0.08	2.342E+06	<65.4	<17.1
24.0-24.4	Silty, clayey sand	10.71	0.30	0.06	2.557E+06	<145	<25.6
25.0-25.3	Fine- to medium-grained sand	8.41	0.31	0.03	1.759E+07	<2660	<1240
27.4	Fine-grained sand	10.25	0.27	0.04	4.378E+04	<0.15	<0.041
29.0-29.3	Fine-grained sandy silt	8.12	0.28	0.06	3.825E+04	<1.03	<0.263
31.1-31.4	Clayey silt	10.40	0.30	0.12	1.619E+06	<117	<28.2
32.9-33.2	Very fine- to fine-grained sand and silt	12.01	0.45	0.28	3.374E+05	<7.19	<2.2
34.1	Very fine- to medium-grained sand	8.17	0.27	0.04	1.492E+03	<0.0965	<0.0202
38.8	Very fine- to fine-grained silty sand	12.66	0.44	0.08	4.199E+03	<0.123	<0.0271

(a) Below ground surface.

(b) Less than values are below the analytical detection limit.



**Table 6.2.2. Water Leachable Chemicals in Sediment from Borehole 41-09-39 in SX Tank Farm**

Depth (m) <sup>(a)</sup>	1:1 Water Extracts							
	pH	Specific Conductance ( $\mu\text{S}/\text{cm}$ )	Nitrate ( $\mu\text{g}/\text{g}$ soil)	Sodium ( $\mu\text{g}/\text{g}$ soil)	Technetium-99 (pCi/g soil)	Cesium-137 (pCi/g soil)	Chromium ( $\mu\text{g}/\text{g}$ soil)	Selenium ( $\mu\text{g}/\text{g}$ soil) <sup>(b)</sup>
7.6-7.9	8.4	188	13	32	0	ND <sup>(c)</sup>	5.0E-04	<5.00E-03
13.4-13.7	8.5	226	13	44	1	ND	2.9E-03	<5.00E-03
17.1-17.4	8.3	287	13	44	1	6.9	3.4E-03	<5.05E-03
18.6-18.9	8.6	355	13	90	1	9.6	8.1E-03	<5.00E-03
19.8-20.1	9.2	899	29	131	4	245	3.4E-01	<5.00E-03
19.8-20.1	9.8	504	18	232	8	3,974	3.4E-01	<5.00E-03
21.0-21.3	9.2	752	33	201	6	75	5.1E+00	<5.00E-03
22.6-22.9	9.6	719	44	201	8	261	4.1E+00	<5.00E-03
24.0-24.4	9.6	1,722	371	432	18	267	7.2E-01	<5.00E-03
25.0-25.3	8.7	8,293	2,838	2,343	393	38,150	7.5E+02	8.6E-02
27.4	8.3	41,820	28,036	12,515	2,749	221	7.1E+02	1.4E-01
29.0-29.3	7.9	41,010	32,770	11,899	7,076	747	2.6E+02	2.2E-01
31.1-31.4	8.0	41,910	31,656	12,581	6,140	9,665	5.3E+02	2.3E-01
32.9-33.2	8.1	56,480	42,488	19,095	11,897	1,636	4.8E+02	3.9E-01
34.1	8.1	42,770	32,822	12,600	8,560	6.3	1.8E+02	2.9E-01
38.8	7.9	16,550	12,813	1,889	334	6.3	1.1E-02	3.1E-02

(a) Below ground surface.

(b) Less than values indicate an analytical result less than method detection limit.

(c) ND = Not detected.

extract pH values showed that the sediments had substantially buffered the pH of leaked fluids.

Analytical results of a strong acid (8 molar nitric acid) leach of the sediment samples are shown in Table 6.2.3. These results approximate the total amount of contaminant in the sediment that would be environmentally available per EPA suggestions in SW-846. The data show that greater than background levels of chromium, molybdenum, selenium, and technetium-99 are leached from the sediment. Concentrations of americium-241, neptunium-237, plutonium-239/240, and strontium-90 were not present in the sediment at levels above 1 pCi/g and are not included in the table. Concentrations of aluminum and iron (also not shown in Table 6.2.3) appear to be slightly elevated in samples where cesium-137, chromium, nitrate, and sodium are definitely present.

Table 6.2.4 shows the percent of cesium-137 that was leached from the sediment by the water extraction procedure compared to the total cesium-137 present in the sediment (from Table 6.2.1). The table also shows the percentages of chromium and technetium-99 that were leached by water compared to the amounts leached by the strong acid extract. The latter is an approximation of the total technetium-99 and chromium in the sediment.

Very little cesium-137 was leached by the water extraction procedure, indicating that most cesium-137 in the sediment from borehole 41-09-39 is not soluble and is bound to the sediment. Conversely, significant percentages of the chromium and technetium-99 were leached by the water extraction. These data can be used to estimate in situ distribution coefficients ( $K_d$ ) for each chemical in each sediment sample.  $K_d$  is a measure of the relative concentration



**Table 6.2.3. Acid Extractable Chemicals in Sediment from Borehole 41-09-39 in SX Tank Farm**

Depth (m) <sup>(a)</sup>	Acid Extract					
	Technetium-99 (pCi/g) ICP/MS <sup>(b)</sup>	Technetium-99 (pCi/g) Radiolog- ical Analysis	Uranium-238 (pCi/g) ICP/MS <sup>(b)</sup>	Chromium (µg/g)	Molybdenum (µg/g)	Selenium (µg/g)
7.6-7.9	<19.95	-47	0.14	6.5	7.89E-02	9.73E-02
13.4-13.7	<5.94	-5	0.23	6.0	4.01E-01	1.23E-01
17.1-17.4	28	292	0.20	24.1	6.01E-01	9.39E-02
18.6-18.9	11	-18	0.21	130.3	2.00E-01	6.85E-02
19.8-20.1	26	-12	0.13	80.3	1.03E+00	1.21E-01
19.8-20.1	13 ± 4	0 ± 22	0.13	69.5	3.99E-01	7.91E-02
21.0-21.3	<25.3	96	0.15	42.3	9.72E-01	1.09E-01
22.6-22.9	<35.3	12	0.15	122.0	1.50E+00	7.83E-02
24.0-24.4	2,400	3,006	0.15	597.4	1.08E+01	8.29E-02
25.0-25.3	1,088 ± 336	1,160 ± 280	0.21	1,458.6	1.28E+01	1.66E-01
27.4	3,241	3,586	0.15	1,277.8	5.23E+00	1.14E-01
29.0-29.3	7,618	7,468	0.16	710.7	1.71E+00	1.61E-01
31.1-31.4	12,979	13,036	0.21	1,169.6	4.39E+00	1.56E-01
32.9-33.2	13,766	13,877	0.19	783.9	2.29E+00	2.59E-01
34.1	9,840	9,906	0.12	298.5	4.39E-01	2.16E-01
38.8	405	405	0.16	15.8	2.26E+00	5.10E-02

(a) Below ground surface.

(b) ICP = Inductively coupled plasma emission mass spectroscopy.

of contaminant sorbed on the sediment to that dissolved in solution; the smaller the  $K_d$ , the more contaminant is in solution. The calculated  $K_d$ s are shown in Table 6.2.5.

The apparent large in situ  $K_d$  values for technetium-99, and perhaps chromium, in selected samples merit additional, more detailed investigations to determine whether the sediment contains adsorbed or co-precipitated technetium-99 and chromium. The chromium  $K_d$  values for some of the samples that did not contain elevated total chromium concentrations represent native trivalent chromium in the sediment. The  $K_d$  values for the samples from 7.6, 13.4, 17.1, and 38.8 meters (24.9, 44.3, 56.1, and 127.3 feet), in Table 6.2.5 may represent immobile native trivalent chromium. Large in situ  $K_d$  values for chromium in samples from other depths are unexplained at this time. Also, the reason for the large

variation in cesium-137  $K_d$  values is unknown and will require further work.

**New Borehole at Single-Shell Tank SX-115.** A new characterization borehole (299-W23-19) was completed at tank farm SX adjacent to tank SX-115 in 1999. This tank was selected for investigation because it is the source of the largest measured leak in the SX tank farm. The tank had a measured loss of 189,000 liters (49,890 gallons) during a sodium nitrate retrieval effort in the mid-1960s; this volume contained a significant amount of technetium-99. Groundwater monitoring wells to the southeast of the tank were some of the first to show increased technetium-99 concentrations at this site. The new borehole was located near the tank adjacent to a zone of high, subsurface gamma flux reported in BNWL-CC-701. Near-continuous samples were collected through the Hanford formation by driving a split-spoon sampler ahead of a



**Table 6.2.4. Estimates of Mobility of Cesium, Technetium, and Chromium in Samples from Borehole 41-09-39 in the SX Tank Farm, Based on the Percent of the Constituent Leached by Water**

Depth (m) <sup>(a)</sup>	% Cesium-137 Leached by Water Versus Total Cesium in the Sediment	% Technetium-99 Leached by Water Versus Total Acid Extractable Technetium <sup>(b)</sup>	% Chromium Leached by Water Versus Total Acid Extractable Chromium
7.6-7.9	NA	>81	0.01
13.4-13.7	NA	>16	0.05
17.1-17.4	0.03	1.8	0.01
18.6-18.9	0.01	6.5	0.01
19.8-20.1	0.04	15.8	0.43
19.8-20.1	0.10	60.1	0.50
21.0-21.3	0.79	>22	11.97
22.6-22.9	0.01	>22	3.35
24.0-24.4	0.01	0.8	0.12
25.0-25.3	0.22	36.1	51.09
27.4	0.50	84.8	55.71
29.0-29.3	1.95	92.9	36.63
31.1-31.4	0.60	47.3	45.14
32.9-33.2	0.48	86.4	61.34
34.1	0.42	87.0	58.73
38.8	0.15	82.4	0.07

(a) Below ground surface.

(b) Greater than values indicate an acid extract value that is less than method detection limit.

casing string. The borehole was drilled into the groundwater (at 69 meters [226 feet]) to allow sampling for the RCRA monitoring program. Analysis of the groundwater samples revealed technetium-99 concentrations up to 48,000 pCi/L, the highest levels found to date on the Hanford Site. Because of this finding, the well is to be completed as a RCRA assessment well rather than decommissioned as originally planned.

**Geophysical Logging at Boreholes 41-09-39 and 299-W23-19.** Geophysical logging was conducted in both the 41-09-39 and 299-W23-19 boreholes. Logging consisted of spectral gamma-ray, moisture, temperature, and neutron capture gamma spectroscopy logs. A neutron moisture probe was used to assess the distribution of water throughout the vadose zone in both boreholes. Water in the

vadose zone provides the mobilizing force to transport contaminants to the groundwater. Temperature logs were obtained in single-cased portions of both boreholes, and borehole wall temperatures (no casing) were logged in 41-09-39 as the borehole was decommissioned. Temperatures were taken using a side-looking infrared instrument so that the temperatures represent the casing or borehole wall conditions and not the air inside the borehole. The results of the temperature log of borehole 41-09-39 are presented in Figure 6.2.1. The temperature distribution corresponds to an increase in gamma activity as seen on the gross gamma-ray log and to the distribution of radionuclides as determined by laboratory measurements. For comparison, subsurface temperatures measured at similar depths in uncontaminated boreholes at the Hanford Site are near 17 to 19° Celsius (62 to 66° Fahrenheit).



**Table 6.2.5. Calculated In Situ Distribution Coefficients ( $K_d$ )<sup>(a)</sup> for Samples from Borehole 41-09-39 in SX Tank Farm**

Depth (m) <sup>(b)</sup>	Cesium In Situ $K_d$ (mL/g)	Technetium In Situ $K_d$ (mL/g)	Chromium In Situ $K_d$ (mL/g)
7.6-7.9	ND <sup>(c)</sup>	<130 <sup>(d)</sup>	13,059
13.4-13.7	ND <sup>(c)</sup>	5.17	2,090
17.1-17.4	3,772	54.97	7,047
18.6-18.9	13,017	14.44	15,994
19.8-20.1	2,554	5.33	234
19.8-20.1	1,030	0.66	201
21.0-21.3	127	3.58	7.4
22.6-22.9	8,989	3.58	28.8
24.0-24.4	9,589	131.22	832
25.0-25.3	461	1.77	1.0
27.4	199	0.18	0.8
29.0-29.3	51	0.08	1.7
31.1-31.4	168	1.11	1.2
32.9-33.2	206	0.16	0.6
34.1	237	0.15	0.7
38.8	53,262	0.21	1,377

- (a) A measure of the relative concentration of contaminant sorbed on the sediment to that dissolved in solution. The smaller the  $K_d$ , the more contaminant is in solution.
- (b) Below ground surface.
- (c) ND = Not detected.
- (d) Less than value indicates a water leach result that is less than method detection limit.

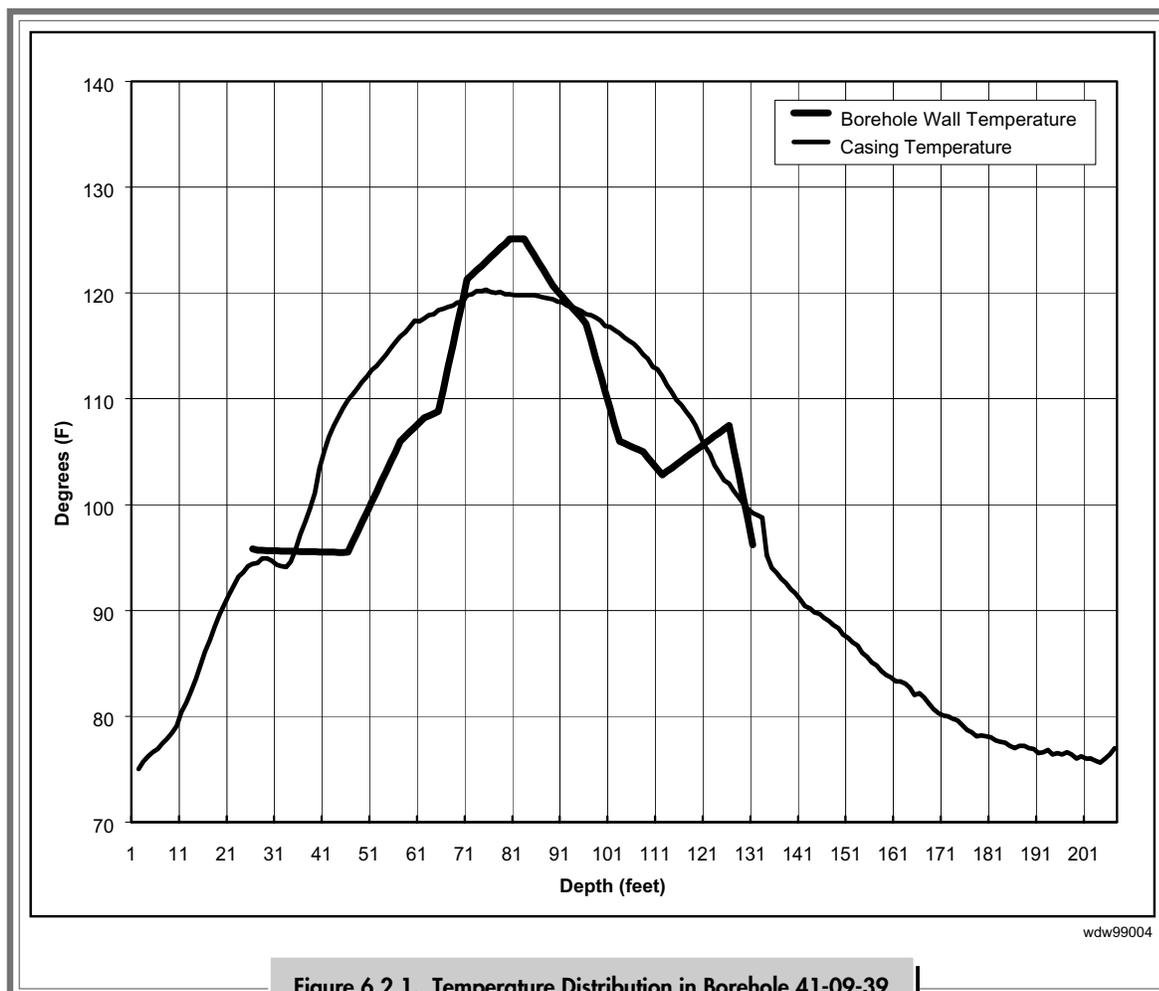
Neutron capture spectroscopy logs were run in both boreholes. These logs were generated by exciting elements within the sediments with neutrons from a radioactive source and measuring gamma-ray energies emitted following excitation. The resulting spectra were then analyzed to determine a distribution of specific elements. However, the instrument used for this work was calibrated for chlorine only and provided only a relative abundance of other elements.

Both the temperature log and the neutron gamma-capture log represent new analytical tools for Hanford and the initial results illustrate their potential usefulness.

## 6.2.1.2 Tank Farms Baseline Vadose Zone Characterization Project

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In 1994, the Tank Farms Vadose Zone Baseline Characterization Project was initiated by the Department of Energy Grand Junction Office at the request of the DOE Richland Operations Office. The purpose, as documented in technical plan P-GJPO-1786, was to perform a baseline characterization of gamma-emitting radionuclides in the vadose zone under the single-shell tank farms.



**Figure 6.2.1. Temperature Distribution in Borehole 41-09-39**

By the end of 1999, the baseline characterization program was essentially complete. During 1999, tank summary data reports were completed for the remaining tanks in tank farms T and B and the tank farm report for tank farm T (GJO-99-101-TAR, GJO-HAN-27) was completed. Tank summary data reports had been issued for a total of 133 single-shell tanks; the 16 smaller 208,000 liter (55,000-gallon) tanks were not addressed because of lack of available boreholes from which spectral gamma data could be collected. Also by the end of 1999, 11 of 12 tank farm reports had been issued; only the B tank farm report remains to be completed. During 1999, repeat logging of selected boreholes was completed and a high count rate logging system was deployed to measure

radionuclide concentrations in borehole intervals where high gamma flux led to saturation of the spectral gamma logging system. It is anticipated that the final tank farm report will be issued by the end of March 2000. Work is underway to prepare a series of addenda for earlier tank farm reports that will present additional data from high rate and repeat logging, as well as modifications to the visualizations based on re-evaluation of existing data, including shape factor analysis where appropriate. The addenda will also include estimates of contaminant inventories in the vadose zone. Project reports and data are posted on the DOE's Grand Junction Office web page at: <http://www.doegjpo.com/programs/hanf/HTFVZ.html>



The baseline project has provided valuable information regarding the nature and extent of vadose zone contamination associated with gamma-emitting radionuclides in the vicinity of the single-shell tanks. Specific contaminant plumes have been delineated and it is possible to identify locations for more detailed investigative and sampling efforts. Borehole logging in existing boreholes represents an effective means to identify subsurface contamination plumes. Spectral gamma logging also allows specific gamma-emitting radionuclides to be identified and quantified. However, gamma logging in boreholes is unable to detect radionuclides such as tritium, strontium-90, or technetium-99, which do not emit significant gamma rays. Drilling and sampling are required to detect and quantify these contaminants.

The baseline data also provide the basis for selection of borehole intervals for future monitoring. Routine monitoring of gross gamma levels in dry wells surrounding the single-shell tank farms has been performed since the 1940s. Numerous additional dry wells were installed around individual tanks in the 1970s to monitor for leaks. Gross gamma logs are available in electronic format from 1974 through 1994, when routine monitoring was discontinued.

Individual dry wells can be monitored over time and compared to the baseline to detect and quantify short-term or long-term changes. Long-term monitoring data over a 5- to 10-year period can be used to estimate contaminant migration rates and to provide supporting data necessary to verify predictive models. Short-term monitoring is useful for identifying recent changes associated with tank farms operations and/or tank leaks.

A plan view of a typical single-shell tank farm is shown in Figure 6.2.2. Each single-shell tank farm consists of between 4 and 18 underground waste storage tanks. There are 149 single-shell tanks organized into 12 tank farms. Individual tank capacities are 208,000 liters (55,000 gallons), 2,017,405 liters (533,000 gallons), 2,869,030 liters (758,000 gallons),

or 3,785,000 liters (1,000,000 gallons). The 208,000 liter (55,000-gallon) tanks are 6.1 meters (20 feet) in diameter and all other tanks are 22.9 meters (75 feet) in diameter. The larger tanks are surrounded by monitoring boreholes or dry wells that provide access to the subsurface for geophysical logging probes.

The baseline characterization project involves logging the boreholes surrounding the single-shell tanks with a high resolution spectral gamma logging system and analyzing the resulting spectra to produce logs of both natural and man-made gamma-emitting radionuclides showing concentration (in terms of specific activity) as a function of depth. Figure 6.2.3 presents an example of a typical log plot for man-made and natural radionuclide concentrations, as well as total gamma activity and the latest available historical gross gamma log.

Data from individual logs surrounding a tank are incorporated into a tank summary data report. The tank summary data report also includes a discussion of geologic conditions, as well as tank construction and operational history. When appropriate, the tank summary data report may also include a limited analysis of historical gross gamma logs or other available data. Each tank summary data report provides an assessment of the implications of the spectral gamma logging data, including recommendations regarding future data needs and/or any corrective action that may be required.

After the tank summary data reports are completed for a tank farm, the information from each report is incorporated into a tank farm report. The tank farm report provides an integrated summary of available information for the tank farm. The log data from individual boreholes are incorporated into a geostatistical model that is used to estimate the spatial distribution of contaminants. Commercially available three-dimensional visualization software is used to provide views of contaminant plumes within the vadose zone. The tank farm report provides a discussion of the nature and extent of subsurface

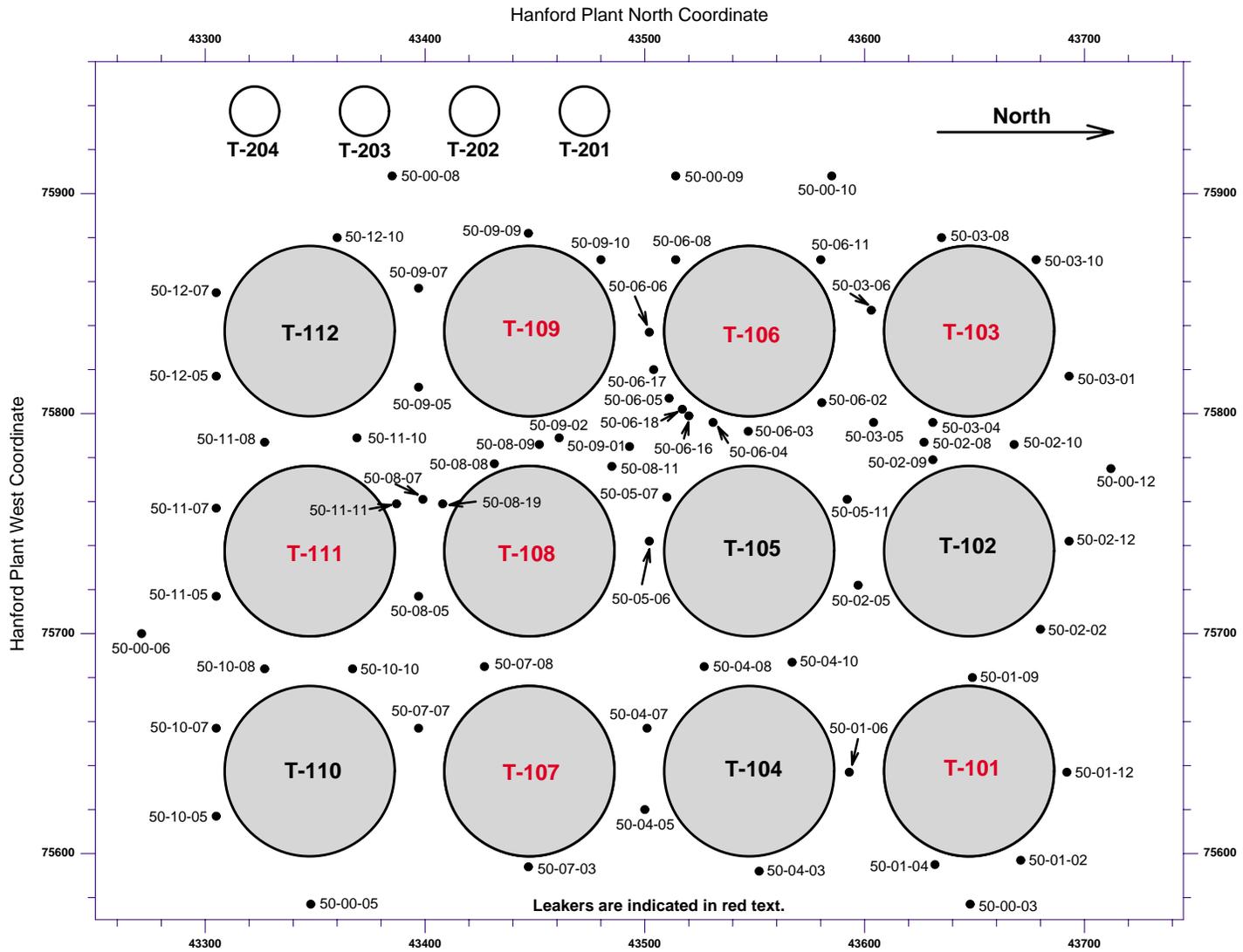
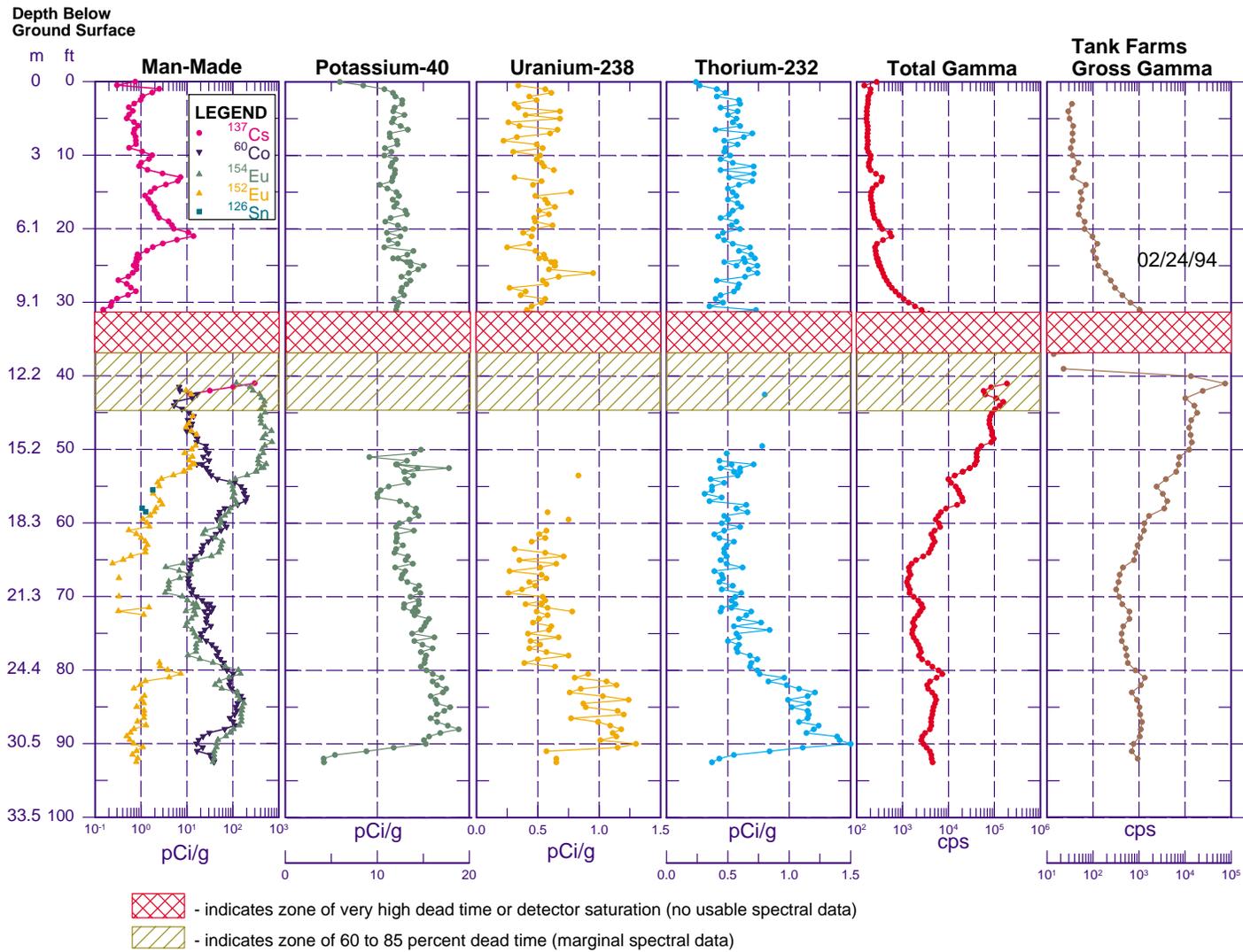


Figure 6.2.2. Plan View of T Tank Farm with Monitoring Boreholes





**Figure 6.2.3. Example of a Radionuclide Concentration Log**



contamination and provides recommendations for future data collection activities and corrective actions, as appropriate.

**Data Collection and Analysis.** Two borehole logging trucks were specially fabricated for the baseline logging project. Downhole spectra are collected using a high-purity germanium semiconductor detector with 35% relative efficiency. This combination of detector and logging truck is referred to as the spectral gamma logging system.

The spectral gamma logging system is able to quantify radionuclide concentrations from background levels up to several thousand picocuries per gram. Frequently, however, zones of more intense radiation are encountered in which the detector becomes saturated and ineffective. In order to provide data in these intervals, an additional detector was developed and deployed in 1999. The high rate logging system utilizes a 6-millimeter diameter high purity germanium detector. It operates with the same logging trucks and electronics system as the spectral gamma logging system. Two tungsten shields that can be used individually or in combination are available to extend the range of the high rate detector.

Data acquisition is performed in accordance with logging procedures provided in MAC-VZCP-1.7.10-1 (Rev. 2), and governed by quality assurance requirements specified in the project management plan MAC-VZCP-1.7.2 (Rev. 1).

The spectral gamma logging system was initially calibrated using the borehole calibration standards constructed at the DOE's Grand Junction Office specifically for borehole nuclear logging. Continuing calibration is performed at regular intervals using the Hanford calibration models. Results of the most recent continuing calibrations are reported in the sixth and seventh recalibration reports (GJO-99-100-TAR, GJO-HAN-26; GJO-2000-142-TAR, GJO-HAN-30). The calibration of the high rate logging system is described in GJO-99-118-TAR, GJO-HAN-29.

Spectral gamma log data analysis is performed in accordance with procedures documented in MAC-VZCP-1.7.9 (Rev. 1). Verification measurements are made before and after each logging run. The verification spectra are evaluated to ensure consistent system performance and to provide energy and resolution calibration for spectral analysis. Data files containing specific activity, uncertainty, and minimum detectable activity as a function of depth are generated for each radionuclide. A file is also generated for total gamma activity as a function of depth. These files are imported into a commercially available graphics package and log plots are created.

If significant concentrations of cesium-137 or cobalt-60 are encountered, shape factor analysis may be performed. The concept of shape factor analysis is that the relationship between background radiation and the full energy peak in a gamma energy spectrum is influenced by the spatial distribution of the gamma ray source with respect to the detector. Various ratios, or shape factors are computed and plotted to help identify the likely distribution of the source of the gamma activity. For example, the contamination may be localized on the inside or outside of the casing. In addition, large gamma signals associated with a strictly localized source, such as a nearby pipeline, may be detected. These situations are not representative of vadose zone contamination, and must be recognized if an accurate baseline is to be produced.

High rate log data analysis is performed using the same general approach and software as that used for spectral gamma analysis. However, only the cesium-137 peak is used for energy calibration. A correction for 6-inch-diameter, 0.28-inch-thick casing is built into the calibration of the high rate detector, and there is no provision for a water correction. If the shields are used, the calculated concentration is increased by a factor based on relative attenuation. Adjustments for other casing configurations are also made on the basis of attenuation relative to a 0.28-inch-thick casing. The method of shape factor analysis cannot be applied to the high rate spectra.



## Activities During 1999

**Baseline Logging, Tank Summary Data Reports, and Tank Farm Reports.** In early 1999, spectral gamma baseline logging for boreholes associated with single-shell tanks was completed. During 1999, the remaining 16 tank summary data reports and 2 tank farm reports were completed. In addition, the high rate logging system was developed and deployed. The tank summary data reports included tanks B-102 (GJ-HAN-113), B-104 through B-112 (GJ-HAN-125 through GJ-HAN-133), and T-101 through T-106 (GJ-HAN-115 through GJ-HAN-120). The report for tank farm A (GJO-98-64-TAR, GJO-HAN-23) was issued early in 1999, and the report for tank farm T was completed and issued in September 1999 (GJO-99-101-TAR, GJO-HAN-27). Work was also in progress on the B tank farm report, which is scheduled to be issued in March 2000 as GJO-99-113-TAR, GJO-HAN-28. The B tank farm report is the last of the 12 tank farm reports to be issued. During 2000, the Tank Farms Vadose Zone Characterization Project is scheduled to complete shape factor analysis for those tank farms where it was not initially applied, process and analyze repeat logging and high rate logging data, and to prepare addenda to the tank farm reports that summarize the additional data and present revised visualizations. The revised three-dimensional visualizations also will be used to estimate the total volume of contaminated material and total activity in curies represented by the contaminant plumes shown in the visualizations. The estimates will be prepared to present contaminated volume and total activity as a function of contaminant threshold level.

**Vadose Zone Characterization of Tank Farm A.** The tank summary data reports for tank farm A in the 200-East Area were completed in 1998. The A tank farm report (GJO-98-64-TAR, GJO-HAN-23) was issued in March 1999. Figure 6.2.4 shows a three-dimensional visualization of subsurface contamination in the A tank farm.

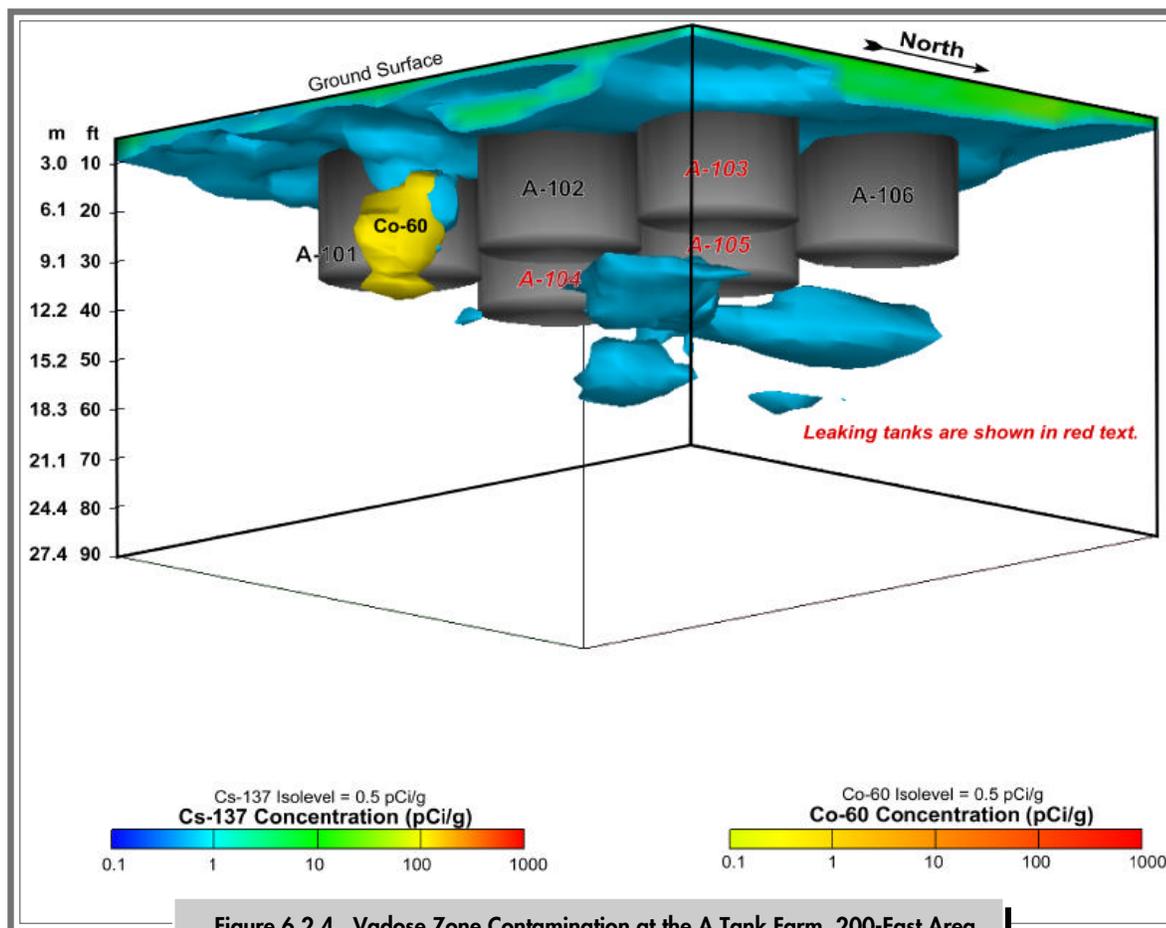
Cesium-137 and cobalt-60 were the major gamma-emitting contaminants detected in the A tank farm vadose zone. Cesium-137 contamination was detected at the ground surface throughout the tank farm. This contamination, which migrated or was carried downward through the backfill sediments to depths between 3 and 6.1 meters (10 and 20 feet), is related to spills and leaks associated with tank farm operations. The highest surface cesium-137 concentrations of more than 100 pCi/g were measured in an area north of tanks A-105 and A-106. Below depths of about 6.1 meters (20 feet), concentrations generally decreased to less than 0.1 pCi/g, which is the minimum detection limit of the logging systems.

The highest cesium-137 concentrations (greater than 1,000 pCi/g) measured in tank farm A occurred along the southeast side of tank A-101 and are associated with a leak from the 241-A-01B sluice pit located above the dome of tank A-101.

The most continuous cobalt-60 contamination occurred along the southeastern quarter of tank A-101; this plume of contamination is more than 7.6 meters (25 feet) thick and is associated with leakage from the 241-A-01B sluice pit. Cesium-137 and europium-154 were also detected within this plume.

Cesium-137 was detected in boreholes surrounding tanks A-103 and A-105, both of which are assumed to be leaking. The contamination detected in the boreholes around these two tanks is relatively minimal, suggesting the leakage from these tanks may have migrated more vertically than laterally and that the contamination did not reach the monitoring boreholes. Gross gamma anomalies were detected in the lateral boreholes under both tanks.

Tank A-104 is also assumed to have leaked, and elevated gamma-ray activity was detected in the leak detection lateral boreholes beneath this tank. Minimal cesium-137 contamination was detected in the boreholes surrounding this tank, also suggesting the leakage did not reach the lateral extent necessary to be detected in the tank monitoring boreholes.

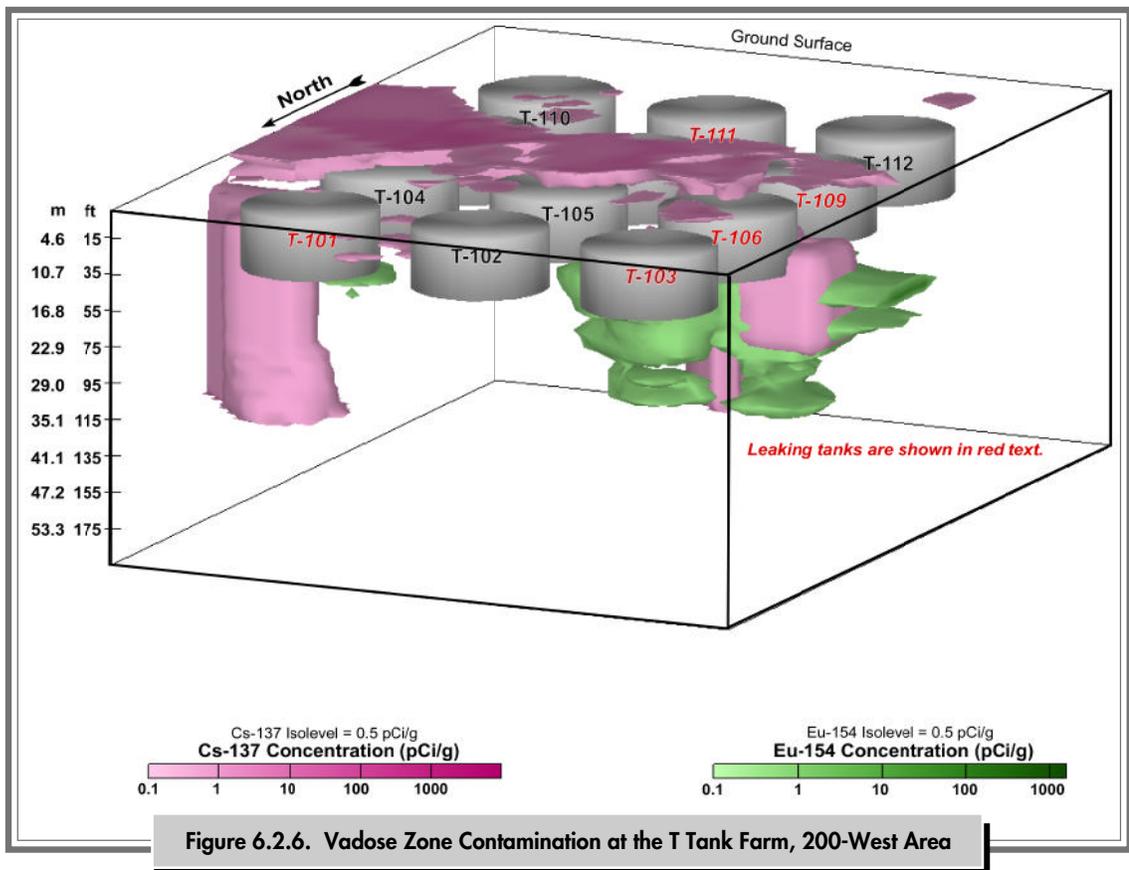
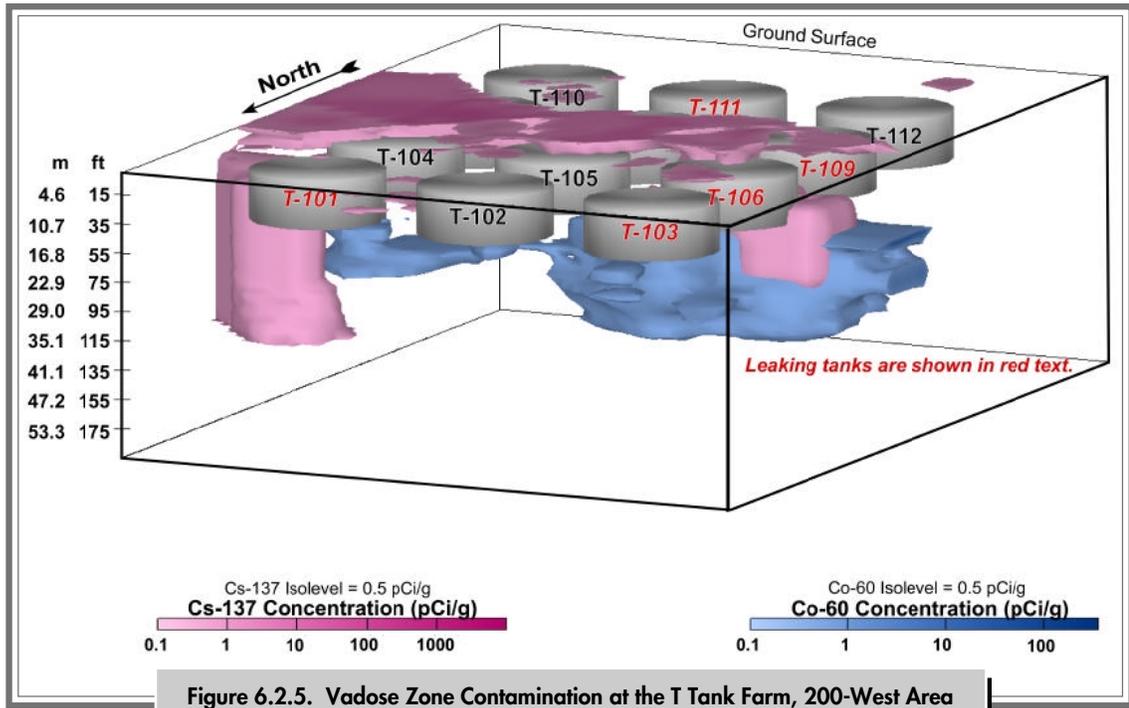


Cesium-137 was detected continuing to the bottoms of several of the 38.1-meter (125-foot) boreholes. Because the boreholes were not deep enough to intercept the bottoms of contamination intervals, the vertical extent of cesium-137 into the deeper regions of the vadose zone could not be determined.

Correlation of man-made contaminant distribution with naturally occurring potassium-40, uranium-238, and thorium-232 concentration data suggests that much of the contamination occurs within the Hanford formation upper gravel sequence, which may have encouraged vertical contaminant migration.

**Vadose Zone Characterization of Tank Farm T.** Two tanks in tank farm T (located in the

200-West Area), T-107 and T-110, were characterized in 1995, and the tank summary data reports were issued in August 1995 as GJ-HAN-2 and GJ-HAN-1, respectively. However, most of the boreholes associated with the T tank farm were logged in 1998. Tank summary data reports for T-108, T-109, T-111, and T-112 were issued in 1998 as GJ-HAN-121, GJ-HAN-122, GJ-HAN-123, and GJ-HAN-124, respectively. Tank summary data reports for T-101 to T-106 were issued in 1999 as GJ-HAN-115 through GJ-HAN-120. The report from tank farm T was issued as GJO-99-101-TAR, GJO-HAN-27 in September 1999. Figures 6.2.5 and 6.2.6 show three-dimensional visualizations of subsurface contamination in the T tank farm.





Cesium-137, cobalt-60, europium-154, and, to a lesser degree, europium-152 were the major gamma-emitting contaminants detected in the vadose zone at tank farm T. Limited and relatively isolated occurrences of niobium-94, antimony-125, tin-126, uranium-235, and uranium-238 were also detected around several boreholes.

Most of the monitoring boreholes in the T tank farm were modified in the late 1970s, apparently in an effort to control infiltration of surface runoff through the monitoring boreholes. The 15-centimeter (6-inch) casing was perforated near the bottom and top of the borehole and a 10-centimeter (4-inch) casing was installed and grouted into place. The presence of the double casing and grout reduces the gamma flux inside the borehole by at least 40% and effectively precludes the application of shape factor analysis. Spectra count times were increased from 100 to 200 seconds to compensate for the lower gamma flux, and the casing correction allows for the additional thickness of steel, but it is impossible to determine a reliable correction factor to account for the presence of variable amounts of annular grout. Therefore, most log data results from tank farm T are labeled as apparent concentration.

Near-surface and shallow subsurface cesium-137 contamination was detected primarily in the central and eastern portions of tank farm T. This contamination most likely resulted from surface spills or leaks from piping systems related to routine tank farm operations. The highest cesium-137 concentrations were detected within the near-surface backfill material in the east-central portion of the tank farm between tanks T-104 and T-107. The thickest distributions (8.2 meters or 27 feet) of cesium-137 contamination were also detected in this region, suggesting a larger spill or several spills or leaks may have occurred in this area.

A vertically continuous, elongated cesium-137 plume was detected around one borehole near the southeast side of tank T-101, which is assumed to

have leaked. The plume extends to a depth of more than 30 meters (100 feet) and appears to be the result of a large volume leak that probably resulted from overfilling the tank. The overfilling may have resulted in leakage through penetrations installed along the southeast quadrant of the tank for spare inlet lines. A large cobalt-60 and europium-154 plume identified near the south side of tank T-101 may also have originated from the same leak source. The visualization shows that the cobalt-60 component of the plume trends in a southwesterly direction, passing under the southern portion of tank T-101 and portions of tanks T-104 and T-105.

A cesium-137 and cobalt-60 plume was identified in one borehole near the south side of tank T-102. Although tank T-102 is classified as sound, the data indicate that the plume probably originated from a leak from the spare inlet ports in a manner similar to leaks originating from adjacent tanks within the cascade series. The cesium-137 component of the plume appears to have spread laterally from the suspected leak source to the south and west along the base of the tank farm excavation.

A distinct plume of cobalt-60, europium-154, and europium-152 contamination was intercepted by boreholes located near the southeast and south sides of tank T-103. The contamination is believed to have originated from a leak at the spare fill line on the southeast side of the tank. Some of the contamination within the plume has migrated laterally to the south and has apparently intermingled with contamination resulting from a large leak from tank T-106.

The extensive plume of cesium-137, cobalt-60, europium-154, and europium-152 contamination identified around and below the base of the tank T-106 originated from the large leak that occurred in 1973. The leak source is located on the southeast side of the tank, and the resulting plume extends laterally as much as 30 meters (100 feet). Man-made radionuclide contamination was detected at the bottom of several of the deepest boreholes monitoring tank



farm T, indicating that contamination associated with this leak has penetrated to a depth of at least 37 meters (120 feet).

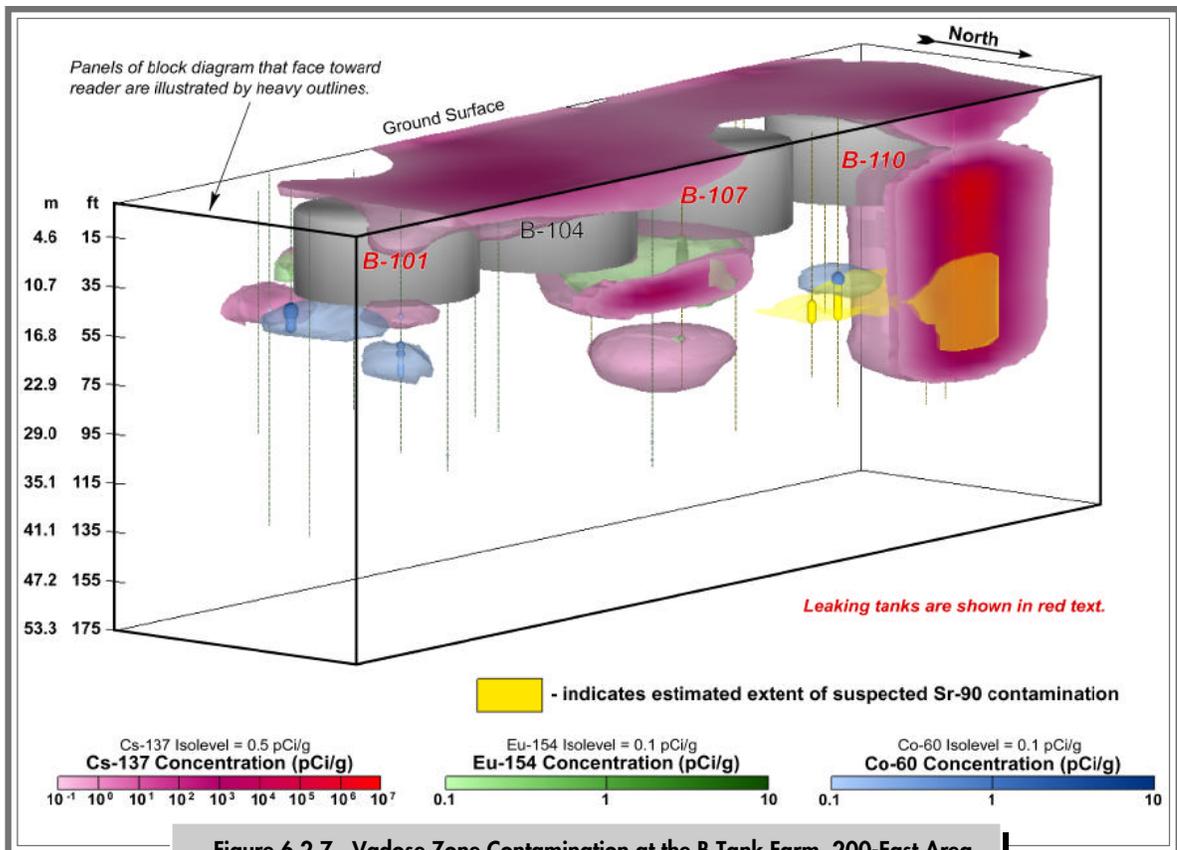
**Vadose Zone Characterization of Tank Farm B.** The B tank farm is located in the 200-East Area. Tank summary data reports for tanks B-101 and B-103 were issued in July 1998 as GJ-HAN-112 and GJ-HAN-114, respectively. The tank summary data reports for B-102 and B-104 through B-112 were issued in 1999 as GJ-HAN-113 and GJ-HAN-125 through GJ-HAN-133. The report from tank farm B is scheduled to be issued in March 2000 as GJO-99-113-TAR, GJO-HAN-28. Figure 6.2.7 shows a three-dimensional visualization of subsurface contamination in a portion of tank farm B.

Cesium-137 was the major gamma-emitting contaminant detected in the B tank farm vadose zone. Cobalt-60, europium-154, and, to a lesser degree,

europium-152 were also detected in the vadose zone sediments and were often associated with occurrences of cesium-137. In addition, the presence of the beta-emitting radionuclide strontium-90 is suspected around several boreholes.

Near-surface cesium-137 contamination was detected primarily in the southern portion of the B tank farm. This contamination most likely resulted from surface spills that migrated into the shallow backfill material. The maximum near-surface cesium-137 contamination was detected in the southeast portion of the tank farm between tanks B-101 and B-104.

Shallow subsurface cesium-137 contamination was generally detected throughout the area of the B tank farm. This contamination may also be the result of surface spills or possibly leaks from piping systems that migrated into the backfill material. In



**Figure 6.2.7. Vadose Zone Contamination at the B Tank Farm, 200-East Area**



a few cases, some of the shallow cesium-137 contamination may have remobilized and migrated deeper into the backfill material. The thickest distributions of cesium-137 are 3 to 6 meters (10 to 20 feet) thick and were detected in the southeast, northeast, and southwest portions of the tank farm, suggesting a larger spill or several spills or leaks may have occurred in these areas.

A small plume of cesium-137 and europium-154 was identified around one borehole near the south side of tank B-101, a tank that is assumed to have leaked. Regions of cesium-137 and cobalt-60 contamination were also detected deeper in the vadose zone around boreholes located near the northeast and south sides of the tank. This contamination is believed to have originated from a leak in the wall of tank B-101 near the maximum operating level of the tank.

An interval of deep, low intensity cobalt-60 contamination was identified around one borehole near the west side of tank B-102. The contamination appears to have migrated from a distant leak source such as tank B-105 to the west, or tank B-103 to the north, both of which are designated as leaking tanks.

Regions of highly concentrated cesium-137 contamination were detected around individual boreholes located near both the north and south sides of tank B-105. Available data suggest the contamination detected in these boreholes probably originated from tank B-105, but from separate leak events.

A large plume of cesium-137, cobalt-60, and europium-154 contamination detected around one borehole located near the northeast side of tank B-107 is probably directly attributable to a leak from tank B-107. A deeper plume of cesium-137 contamination detected around this borehole probably also originated from a leak from tank B-107 and migrated to this region through the Hanford formation sediment.

A discrete zone of cesium-137 and europium-154 contamination was detected around one

borehole located near a cluster of inlet pipes connected to the southwest side of tank B-110. Available data suggest this contamination may consist of residual waste contained within the inlet piping.

An extensive region of highly concentrated cesium-137 contamination was detected around one borehole located near the north side of tank B-110. This contamination likely originated from a leak from the B-110 to B-111 cascade line or from tank B-110 itself. The location and magnitude of the cesium-137 contamination within this region of the vadose zone indicate that this borehole is very close to the leak source. The plume appears to be comprised primarily of cesium-137, but probably also contains strontium-90 and lesser amounts of cobalt-60 and europium-154. Suspected strontium-90 contamination has been identified at the same depth intervals around boreholes located ~12 meters (40 feet) southeast and 24 meters (80 feet) northeast of the leak source, suggesting the presence of a relatively extensive contaminant plume.

**Shape Factor Analysis.** Experience with logging in the tank farm drywells has shown that contamination localized to the borehole can be a significant factor in overall log response. This may occur either as a result of contaminant dragdown during drilling, internal or external contamination of the casing, or possible contaminant migration along the borehole. Because this contamination is not representative of subsurface plumes, it must be identified and removed from the data set to present a representative visualization of subsurface contamination. The technique of shape factor analysis was developed in response to Expert Panel recommendations after the report for tank farm SX was issued. This approach takes into account the shape of the overall spectra and the ratio between peak counts and the low energy background counts to provide insights as to the probable distribution of the contamination with respect to the borehole axis. Shape factor analysis is described in GJO-96-13-TAR, GJO-HAN-7 and GJO-97-25-TAR, GJO-HAN-15.



Shape factor analysis was applied to boreholes in the A, B, BX, C, S, and TY tank farms, and the results have been incorporated in the tank summary data reports for those tank farms. Intervals of contamination attributable to borehole effects or remote contamination were identified and eliminated from the interpreted data set used to prepare the visualizations. Shape factor analysis is generally not applicable to boreholes in tank farm T because almost all boreholes are double-cased. However, the tank summary data reports and tank farm reports for tank farms AX, BY, SX, TX, and U were prepared without benefit of shape factor analysis. During 1998 and 1999, shape factor analysis was performed on baseline log data from boreholes in these farms and the results will be used to help revise the interpreted data set to be used in preparation of the three-dimensional visualizations. These results will be discussed in tank farm report addenda to be prepared in 2000.

**Repeat Logging.** As a quality assurance measure, selected intervals in boreholes in all 12 tank farms were relogged by the spectral gamma logging system in 1999. Intervals selected for repeat logging were selected to resolve ambiguities or possible depth errors with the original baseline data, or to investigate intervals of potential contaminant migration. Repeat logging operations were completed in 1999. The data will be processed and analyzed in 2000 and discussed in the respective tank farm report addenda.

**High Rate Logging.** In 1999, a high rate logging system was developed and deployed to investigate borehole intervals where radiation levels exceeded the range of the spectral gamma logging system. High rate log data will be processed and analyzed in 2000 and discussed in the respective tank farm report addenda.

Evaluation of historical gross gamma data from intervals of high gamma flux suggests that count rates may be anomalously low in some intervals. This may be due in part to detector paralysis, a phenomenon in which the detector system fails to respond properly at high gamma flux. Although the spectral gamma

logging system is nonparalyzable, and can be corrected for dead time effects, it becomes ineffective in zones of very high gamma flux, and individual peaks cannot be identified because of detector “saturation.” In previous work, cesium-137 values in the range of 8,000 to 10,000 pCi/g were assumed in intervals of detector saturation. The high rate logging system was specifically designed to operate in zones of high gamma flux, and tungsten shields are provided to further extend the measurement range. Preliminary evaluation of high rate logging data indicate cesium-137 concentrations as high as 50,000,000 to 100,000,000 pCi/g. Inclusion of the high rate data in the interpreted data set used to create the three-dimensional visualizations is expected to have a relatively minor impact on the spatial distribution of the contaminant plumes, but it will have a substantial impact on the estimated total curie activity within the plume volume.

Both the spectral gamma logging system and the high rate logging system are essentially nonparalyzable. In nonparalyzable systems, the deposition of photon energy in the detector is followed by a dead period of fixed duration. During this time, the system is unresponsive to any additional photons that may enter the detector. Any photons that interact with the detector during this time are simply ignored. As the gamma-ray flux increases, more and more photons may be uncounted, but the length of the dead period is not affected. Thus, as the gamma flux increases, the count rate rises, but it is nonlinear in relation to flux. Linearity can be imposed by applying a dead time correction, which is a function of the proportion of the accumulated dead periods relative to the total count time. The percent dead time is reported by the logging system.

The high rate logging system was specifically designed to operate in regions of high gamma flux intense enough to “saturate” the spectral gamma logging system. Saturation refers to the circumstance in which the spectral peaks are tiny or even absent. This situation is an extreme manifestation of “pileup” (Knoll 1989). Pileup events yield output pulses with



variable amplitudes because the amplitude of each output pulse depends on the total energy of multiple photons that impact the detector within a very short time period, so that they cannot be counted individually. These pulses add counts to the background continuum, and the individual photons are “lost,” in the sense that they do not contribute to a peak. Consequently, the peak intensities are no longer proportional to the source concentrations. The high rate logging system achieves a higher radiation measurement capability in part by utilizing a smaller and less efficient detector, such that a smaller fraction of incident photons interact with the detector. In addition, it is provided with two tungsten shields, which can be used individually or in combination to extend the range of the system. With both shields in place, the maximum detection capability is extended by approximately two orders of magnitude. In previous work, concentration values in the range of 8,000 to 10,000 pCi/g were assumed for saturated intervals. Preliminary evaluation of high rate log data indicates maximum cesium-137 concentrations on the order of 50,000,000 to 100,000,000 pCi/g (50 to 100  $\mu$ Ci/g). Inclusion of the high rate data in the interpreted data set used to create the three-dimensional visualizations is expected to have a relatively minor impact on the spatial distribution

of the contaminant plumes, but it will have a substantial impact on the estimated total curie activity within the plume volume.

**Future Work.** With the completion of the tank farm addenda, the baseline characterization project will be completed. The data and reports generated by this project provide a “snapshot” showing the nature and extent of contamination resulting from gamma-emitting radionuclides (primarily cesium-137, cobalt-60, uranium-235/238, and europium-154/152) within the vadose zone in the immediate vicinity of the single-shell tanks. Individual reports contain conclusions regarding the nature of subsurface contamination and provide specific recommendations regarding additional investigative and monitoring activities. This information, in conjunction with evaluation of historical gross gamma data from 1974 to 1994, can be used to assess the stability of contaminant plumes resulting from gamma-emitting radionuclides; evaluate contaminant transport mechanisms and verify contaminant transport models; suggest probable migration pathways for nongamma-emitting contaminants of concern, such as strontium-90 or technetium-99; and provide a basis for planning future investigation and monitoring activities.

## 6.2.2 Vadose Zone Characterization and Monitoring at Liquid Waste Disposal Facilities

*D. G. Horton*

Vadose zone characterization and monitoring activities were conducted at past-practice liquid waste disposal facilities in the 100 and 200 Areas of the Hanford Site in 1999. Considerable vadose zone contamination is associated with those past-practice activities in those areas. Current decontamination and remediation activities focus on sites in the 100 Area because they are located near the Columbia River. Most of the current vadose zone monitoring occurs in the 200 Areas because that is where most effluent was discharged to the soil column.

Vadose zone characterization activities that occurred in the 100 Areas in 1999 included soil sampling and analysis to support remediation of the 116-C-1 process effluent trench, in the 100-B,C Area, and the 1301-N and 1325-N cribs and trenches in the 100-N Area. Also accomplished were sampling and analysis to select a waste site for initial deployment of technology for in situ reduction of hexavalent chromium and laboratory studies to measure the distribution coefficient and leachability of chromium in sediment to support future remedial action goals and plans.



The 200 Areas are the locations of the most significant vadose zone contamination at the Hanford Site. Vadose zone activities that occurred in the 200 Areas in 1999 included spectral gamma-ray logging at specific retention facilities in the 200-East Area, which are some of the most significant remaining potential sources of groundwater contamination. Also, remediation and monitoring of carbon tetrachloride in the 200-West Area continued during 1999. An additional 832 kilograms (1,660 pounds) of carbon tetrachloride were removed from the 200-West Area vadose zone in fiscal year 1999.

### 6.2.2.1 Soil Remediation at 116-C-1 Trench, 100-B,C Area

The 116-C-1 process effluent trench was remediated in 1997, and a test pit was dug to groundwater in early 1998 by Bechtel Hanford, Inc. to evaluate the remediation effort. Analysis of data from the pit became available in 1999 (CVP-98-00006, Rev. 0).

The 116-C-1 trench is located in the northeast corner of the 100-B,C Area of the Hanford Site. The trench was used to dispose of 700 million liters (185 million gallons) of contaminated cooling water from the 100-B,C Area retention basins after ruptured fuel elements were detected in the reactors. The 116-C-1 trench continued to receive contaminated cooling water until reactor operations ceased in 1968. An additional 40 billion liters (10.5 billion gallons) of high-temperature reactor cooling water was discharged to the trench during a 150-day infiltration test in 1967. (Infiltration tests are used to measure the capacity of the soil column to transmit water.) That water contained 700 parts per billion chromium as the major contaminant. The water from the infiltration test likely redistributed contaminants beneath the site.

The vadose zone beneath the 116-C-1 site consists of predominantly sand and gravel with various amounts of silt and cobble-size material. The groundwater is ~12.8 meters (42 feet) below the surface.

The test pit was 38 by 38 meters (125 by 125 feet) square and was centered at an area of elevated radioactivity near the trench inlet pipe. Material was removed from the pit in 1.5-meter (5-foot) depth increments using a backhoe. Soil samples were taken from each quadrant of the test pit and composited for each of the eight lifts.

Analyses of the soil samples showed that most remaining contamination in the vadose zone was within ~5 meters (16 feet) of the base of the remedial action excavation. The more mobile contaminants, such as strontium-90, however, were slightly deeper in the soil column. The most mobile contaminants, such as hexavalent chromium, were flushed through the vadose zone to groundwater by the infiltration test done on the trench after disposal of contaminated cooling water.

As part of the remedial action, the RESRAD computer code (ANL 1997) was used to model the impact of residual contaminants of concern in the vadose zone, groundwater, and Columbia River. A rural residential exposure scenario was used because, at the time the work was done, the future land use of the 100-B,C Area was not yet defined (CVP-98-00006, Rev. 0). The model predicted a maximum dose rate from direct exposure to the soil of 8.2 mrem/yr in 1999, decreasing to 0.066 mrem/yr in 1,000 years. The total excess cancer risk from direct exposure was calculated to be  $7.7 \times 10^{-5}$  in 1999, and decreasing to  $1.8 \times 10^{-7}$  in 1,000 years.

All concentrations of the nonradionuclide contaminants of concern (total chromium, hexavalent chromium, lead, and mercury) were below remedial action goals, or cleanup levels, for direct exposure to the soil. The excess cancer risk from hexavalent chromium in the overburden and the excavated zone was well below the individual and cumulative risk limits.

The estimated radionuclide dose via the groundwater and/or the Columbia River was well below the 4-mrem/yr dose rate limit. Also, the remaining concentrations of total chromium, hexavalent



chromium, lead, and mercury in the soil were either less than 100 times the maximum contamination level, less than background concentration, or modeled with RESRAD to be less than remedial action goals.

Remediation of the 116-C-1 trench met cleanup standards and the site was reclassified as closed in accordance with the Tri-Party Agreement (Ecology et al. 1998). A more complete description of the project and the results can be found in CVP-98-00006, Rev. 0.

### **6.2.2.2 Soil Sampling and Analysis at 1301-N and 1325-N Trenches, 100-N Area**

Bechtel Hanford, Inc. collected and analyzed four subsurface soil samples from test pits excavated in each of the 1301-N and 1325-N trenches in 1998. Both trenches are located in the 100-N Area. They also collected and analyzed four samples of surface soil from each of the 1301-N trench and the 1325-N crib. The purpose of the sampling was to facilitate the disposal of contaminated soil excavated from the site.

The 1301-N and 1325-N cribs and trenches received radioactive liquid waste containing activation and fission products as well as small quantities of corrosive liquids and laboratory chemicals generated by various N Reactor operations. Overflow from the cribs was discharged to the trenches. As the liquid waste percolated through the vadose zone soil beneath the trenches, radioactive and hazardous materials were sorbed onto the soil. Different contaminants would have migrated to different depths based on adsorption characteristics of individual constituents.

Four samples of soil were obtained from the surface of the 1301-N trench and four from the surface of the 1325-N crib. The data from analysis of the samples showed that, within a factor of 10, concentrations of radionuclides were fairly constant within the 1325-N crib and along the length of the 1301-N trench.

A hydraulic excavator was used to dig one test pit in each trench. Three discrete grab samples of soil were collected at selected depths in each pit. One composite soil sample was created at each trench by combining and homogenizing a portion of each grab sample. The samples from the 1301-N trench were collected from depths of 0 to 0.3 meter (0 to 1 foot), 0.3 to 0.6 meter (1 to 2 feet), and 0.6 to 1.5 meters (2 to 5 feet). Samples from the 1325-N trench were obtained from depths of 0.61 to 1 meter (2 to 3.2 feet), 1 to 1.4 meters (3.2 to 4.6 feet), and 1.4 to 1.8 meters (4.6 to 6 feet). A 0.61-meter (2-foot) layer of backfill was removed before collecting the shallowest sample.

Field instruments were used to map the soil in each excavation bucket to locate the highest alpha and beta-gamma concentrations. Samples were collected from the areas of highest concentration.

The analytical data show that the concentrations of most radionuclides drop off rapidly with depth by a factor of 10 to 100 within the first 0.6 meter (2 feet) of the surface at the 1301-N trench or from the base of the gravel backfill at the 1325-N trench. However, the concentrations of most isotopes below 0.6 meter (2 feet) remain substantial. A full description of this work can be found in BHI-01271, Rev. 0.

### **6.2.2.3 Bench Scale Distribution Coefficient and Leach Studies on Hexavalent Chromium in Contaminated Vadose Zone Sediment from 100-D Area**

*R. J. Serne and D. G. Horton*

Important decisions affecting the cost and extent of remedial actions in the 100 Areas are currently based on the predictions of the very conservative computer model RESRAD. To date, the RESRAD code has used only the distribution coefficient ( $K_d$ ), and not leachability, to evaluate impact to



groundwater. The  $K_d$  is a measure of the relative concentration of contaminant sorbed on the sediment to that dissolved in solution; the smaller the  $K_d$ , the more contaminant is in solution (groundwater). The modeling results indicate a potential impact to groundwater from contaminated vadose sediment at the 100-D Area, assuming a hexavalent chromium  $K_d$  value of zero (i.e., 100% in solution).

Use of the distribution coefficient by the model assumes that hexavalent chromium is adsorbed on mineral surfaces in the sediment. Alternatively, hexavalent chromium, in 100-D Area contaminated sediment, may be present as an insoluble precipitate. Leach tests are appropriate to evaluate this alternative. The rate of hexavalent chromium movement through the vadose zone to groundwater will depend on which alternative releases hexavalent chromium to pore water.

Experiments were done in 1999 to measure both the leach rate and  $K_d$  of hexavalent chromium using sediment samples from the 100-D Area. The RESRAD computer model can evaluate hexavalent chromium impact on groundwater using leachability parameters, which represent combined dissolution and desorption effects. Implementing the results of the 1999 experiments will provide a more accurate picture of actual potential impact to groundwater and support future remedial action cleanup goals and planning.

**Samples and Methods.** The 116-D-7 retention basin, in the 100-D Area, was selected as the field area to obtain samples for  $K_d$  and leach tests. Both contaminated and uncontaminated samples were obtained. The primary objectives of the tests were to estimate  $K_d$  and leach rates for hexavalent chromium specific to the Hanford formation sediment in the 100 Areas.

Batch adsorption tests used 50 grams (1.75 ounces) of oven dry Hanford formation sediment and 200 milliliters (0.05 gallon) of Hanford Site groundwater spiked with hexavalent chromium. Three different spike levels, 0.1, 1.0, and 10 milligrams per liter of

hexavalent chromium (as sodium dichromate) were used. Tests were run in triplicate for contact times of 4 and 14 days.

In addition, one leach test was performed using contaminated Hanford formation sediment from the 100-D Area. The test was done by allowing uncontaminated Hanford Site groundwater to flow through a measured amount of sediment at a constant rate for 43 days.

Hexavalent chromium was measured by colorimetry in solutions from the batch tests and by both colorimetry and inductive coupled plasma/mass spectrometry in column leach tests.

**Results and Conclusion.** The results of the  $K_d$  batch adsorption tests are shown in Tables 6.2.6 and 6.2.7. The conclusion from the tests is that there was no significant hexavalent chromium adsorption onto the Hanford formation sediment. Most  $K_d$ s measured were zero or near zero (standard deviation larger than  $K_d$ ). The very low  $K_d$  measured from the smallest hexavalent chromium concentrations may well be an artifact of 1) using batch tests with very low sorbing constituents and 2) using concentrations very near the analytical detection limit.

The results of the column leach test show that typical Hanford Site groundwater does not readily leach chromium bound to the Hanford formation sediment. After 43 days, less than 1% of the chromium present in the sediment was removed by leaching with ~12 pore volumes of uncontaminated groundwater. The 12 pore volumes represent the total amount of water that would flush through the vadose zone from 15 centimeters (59 inches) of rainfall and 0.76 meter (2.5 feet) of irrigation per year.

Measurements of the hexavalent chromium in the sediment before and after leaching showed no measurable loss of hexavalent chromium from the sediment. This corroborates the leachate solution analyses that found less than 1% of the hexavalent chromium was removed from the sediment.



**Table 6.2.6. Average 4-Day Sediment-Water Contact Time  $K_d^{(a)}$  and Standard Deviation for Hexavalent Chromium (Cr[VI]) and Total Chromium Adsorption in Batch Adsorption Tests on Contaminated Vadose Zone Sediments from the 100-D Area**

Cr(VI) Concentration (mg/L)	$K_d$ for Cr(VI) (mL/g)	Standard Deviation (mL/g)	$K_d$ for Total Cr (mL/g)	Standard Deviation (mL/g)
0.1	0.3	0.1	0.0	0.3
1.0	0.0	0.0	0.2	0.3
10.0	0.0	0.05	0.3	0.3

(a) A measure of the relative concentration of contaminant sorbed on the sediment to that dissolved in solution. The smaller the  $K_d$ , the more contaminant is in solution.

**Table 6.2.7. Average 14-Day Sediment-Water Contact Time  $K_d^{(a)}$  and Standard Deviation for Hexavalent Chromium (Cr[VI]) and Total Chromium Adsorption in Batch Adsorption Tests on Contaminated Vadose Zone Sediments from the 100-D Area**

Cr(VI) Concentration (mg/L)	$K_d$ for Cr(VI) (mL/g)	Standard Deviation (mL/g)	$K_d$ for Total Cr (mL/g)	Standard Deviation (mL/g)
0.1	0.2	0.1	0.0	0.1
1.0	0.0	0.0	0.1	0.1
10.0	0.0	0.0	-0.2	0.1

(a) A measure of the relative concentration of contaminant sorbed on the sediment to that dissolved in solution. The smaller the  $K_d$ , the more contaminant is in solution.

The findings of this study suggest that there is very little soluble chromium in the vadose zone sediment of the 100-D Area. This is contrary to the existence of high chromium concentrations in groundwater from some 100-D locations. The apparent incongruity may be an artifact of sampling (i.e., samples were collected outside areas of chromium contamination) or of an, as yet, unidentified geochemical process.

The leach test results from mixing contaminated sediment with uncontaminated groundwater

suggest that a hexavalent chromium-bearing precipitate, that is very insoluble in Hanford Site groundwater, may be present in the sediment. Alternatively, the chromium in the sediment may be trivalent chromium that slowly oxidizes when leached with water. If hexavalent chromium in solution is controlled by slow oxidation of trivalent chromium, then more kinetic testing is needed to extrapolate from the short-term laboratory leach data to the longer time spans of natural dissolution of chromium in Hanford formation sediment.



#### 6.2.2.4 Carbon Tetrachloride Monitoring and Remediation in 200-West Area

V. J. Rohay, D. G. Horton

Soil-vapor extraction is being used to remove carbon tetrachloride from the vadose zone in the 200-West Area. The EPA and the Washington State Department of Ecology authorized DOE to initiate this remediation in 1992 as a CERCLA expedited response action. The primary focus in the following discussion is on 1999 activities associated with the carbon tetrachloride removal.

**Monitoring at the Soil-Vapor Extraction System.** Soil-vapor extraction to remove carbon tetrachloride from the vadose zone operated from March 29 to June 30, 1999, at the 216-Z-9 well field (Figure 6.2.8). Initial on-line wells were selected close to the 216-Z-9 trench. As extraction continued, wells farther away from the crib were brought on-line. Each selection of on-line wells included wells open near the groundwater and wells open near a less-permeable zone above the groundwater table, where the highest carbon tetrachloride concentrations have consistently been detected. Initial carbon tetrachloride concentrations measured at the soil-vapor extraction inlet were ~90 ppmv (Figure 6.2.9). After 3 months of extraction, concentrations had decreased to ~30 ppmv. The daily mass-removal rate increased significantly twice during the 3 months of extraction as a result of adjustments in the mix of on-line wells and the flow rate (see Figure 6.2.9).

Soil-vapor extraction resumed June 30, 1999, at the 216-Z-1A/-12/-18 well field (see Figure 6.2.8). Extraction wells open near the less permeable zone were selected within the 216-Z-1A tile field to optimize mass removal of contaminant. Initial carbon tetrachloride concentrations measured at the soil-vapor extraction inlet were ~40 ppmv. After 3 months of extraction, concentrations had decreased to ~25 ppmv. The daily mass-removal rate increased significantly twice during the 3 months of extraction

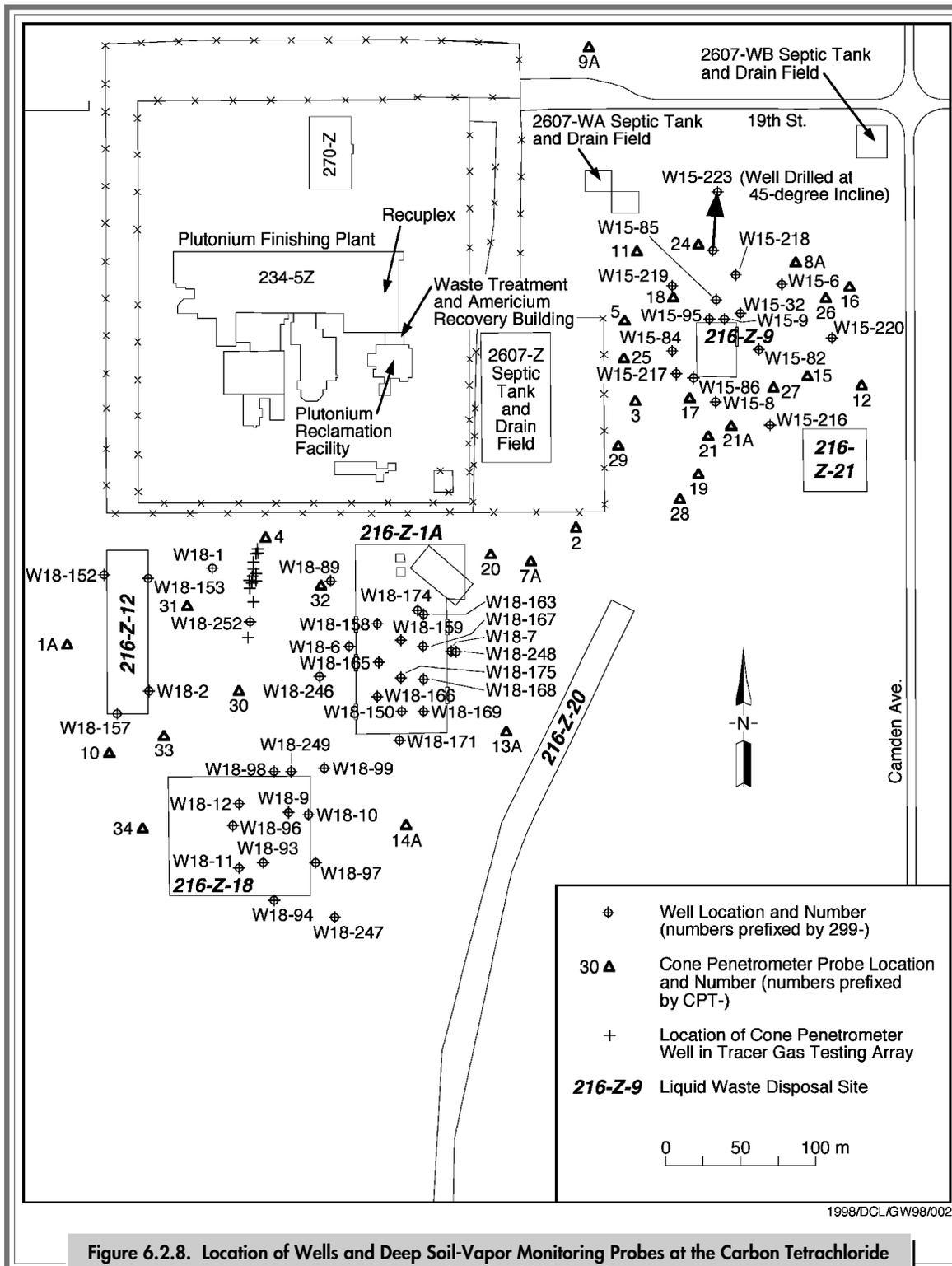
as a result of adjustments in the mix of on-line wells and the flow rate (see Figure 6.2.9).

Between March 29 and September 30, 1999, 832 kilograms (1,800 pounds) of carbon tetrachloride were removed from the vadose zone in the 200-West Area. Of this total, 447 kilograms (985 pounds) were removed from the 216-Z-9 well field during 93 days of operation and 385 kilograms (850 pounds) were removed from the 216-Z-1A/-12/-18 well field during 92 days of operation.

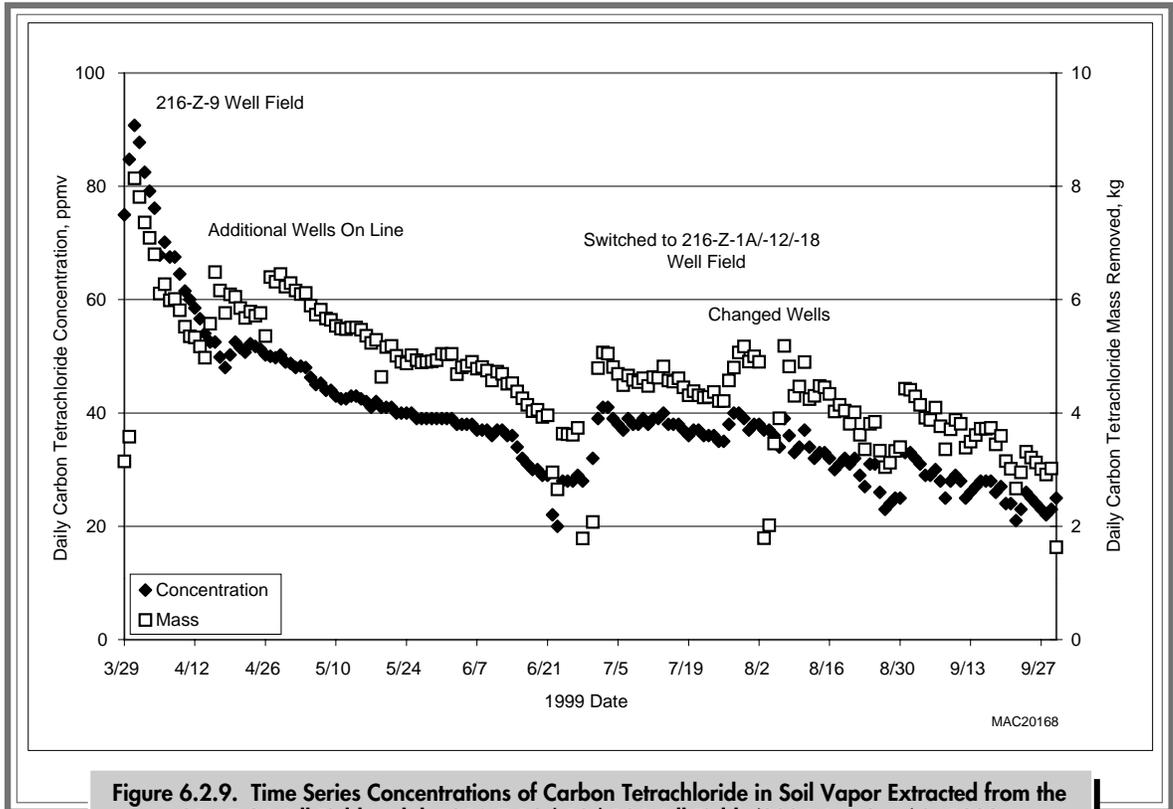
As of September 1999, ~76,500 kilograms (168,700 pounds) of carbon tetrachloride had been removed from the vadose zone since extraction operations started in 1992 (Table 6.2.8). Since initiation, the extraction systems are estimated to have removed 7% of the residual mass at the 216-Z-1A/-12/-18 well 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), dissolved in groundwater (2% of the original inventory), or biodegraded (1% of the original inventory) is still available in the vadose zone as residual mass (BHI-00720, Rev. 3; WHC-SD-EN-TI-101).

**Monitoring at Off-Line Wells and Probes.** During October 1998 through March 1999, soil-vapor concentrations of carbon tetrachloride 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 near the ground surface (between 2 and 10 meters [6.5 and 33 feet] below ground surface) was 8 ppmv. Near the groundwater, at depths ranging from 58 to 64 meters (190 to 210 feet) below ground surface, the maximum concentration was 29 ppmv.

Soil-vapor concentrations were also monitored near the less permeable zone located above the groundwater table to provide an indication of vapor concentrations that could be expected during restart of the soil-vapor extraction system. The maximum



1998/DCL/GW98/002



**Figure 6.2.9. Time Series Concentrations of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-9 Well Field and the 216-Z-1A/-12/-18 Well Fields (200-West Area) in 1999**

**Table 6.2.8. Carbon Tetrachloride Inventory in 200-West Area Primary Disposal Sites**

Well Field	Estimated Mass Discharged 1955 to 1973 <sup>(a)</sup> (kg)	Estimated Mass Lost to Atmosphere 1955 to 1990 <sup>(b)</sup> (kg)	Mass Removed From Vadose Zone Sediments Using Soil-Vapor Extraction 1991 to 1999 <sup>(c)</sup> (kg)
216-Z-1A	270,000	56,700	23,508 <sup>(d)</sup>
216-Z-9	130,000 to 480,000	27,300 to 100,800	52,954
216-Z-18	170,000	35,700	
Total	570,000 to 920,000	119,700 to 196,800	76,462

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

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

(c) Based on BHI-00720, Rev. 3.

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



concentration detected near this zone (between 25 and 41 meters [82 and 134 feet] below ground surface) was 561 ppmv. These results, after 6 to 9 months of nonoperation of the soil-vapor extraction system, were similar to those obtained during the 8-month rebound study conducted in fiscal year 1997 (BHI-01105) and during the 6 months of nonoperation during the winter of fiscal year 1998 (BHI-00720, Rev. 3).

During April through June 1999, soil-vapor monitoring was continued at the 216-Z-1A/-12/-18 well field, while the soil-vapor extraction system was operated at the 216-Z-9 site. Concentrations detected during these additional 3 months of rebound (a buildup of carbon tetrachloride vapor following cessation of extraction activities) were similar to those observed during the previous 6 months. Near the less permeable zone, maximum concentrations ranged from 0 to 492 ppmv. These results were obtained after 9 months of rebound and are similar to those obtained during the 8-month rebound study conducted in fiscal year 1997 (BHI-01105).

During July through September 1999, soil-vapor monitoring was resumed at the 216-Z-9 site while the soil-vapor extraction system was operated at the 216-Z-1A/-12/-18 site. The highest concentration detected near the ground surface was 4 ppmv and the highest concentration detected near the groundwater was 24 ppmv. The maximum concentration detected was 267 ppmv at the less permeable zone. These results were obtained after only 3 months of rebound.

Because carbon tetrachloride concentrations did not increase significantly at the near-surface probes monitored in 1999, temporarily suspending operation of the soil-vapor extraction system for 6 to 9 months appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil 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

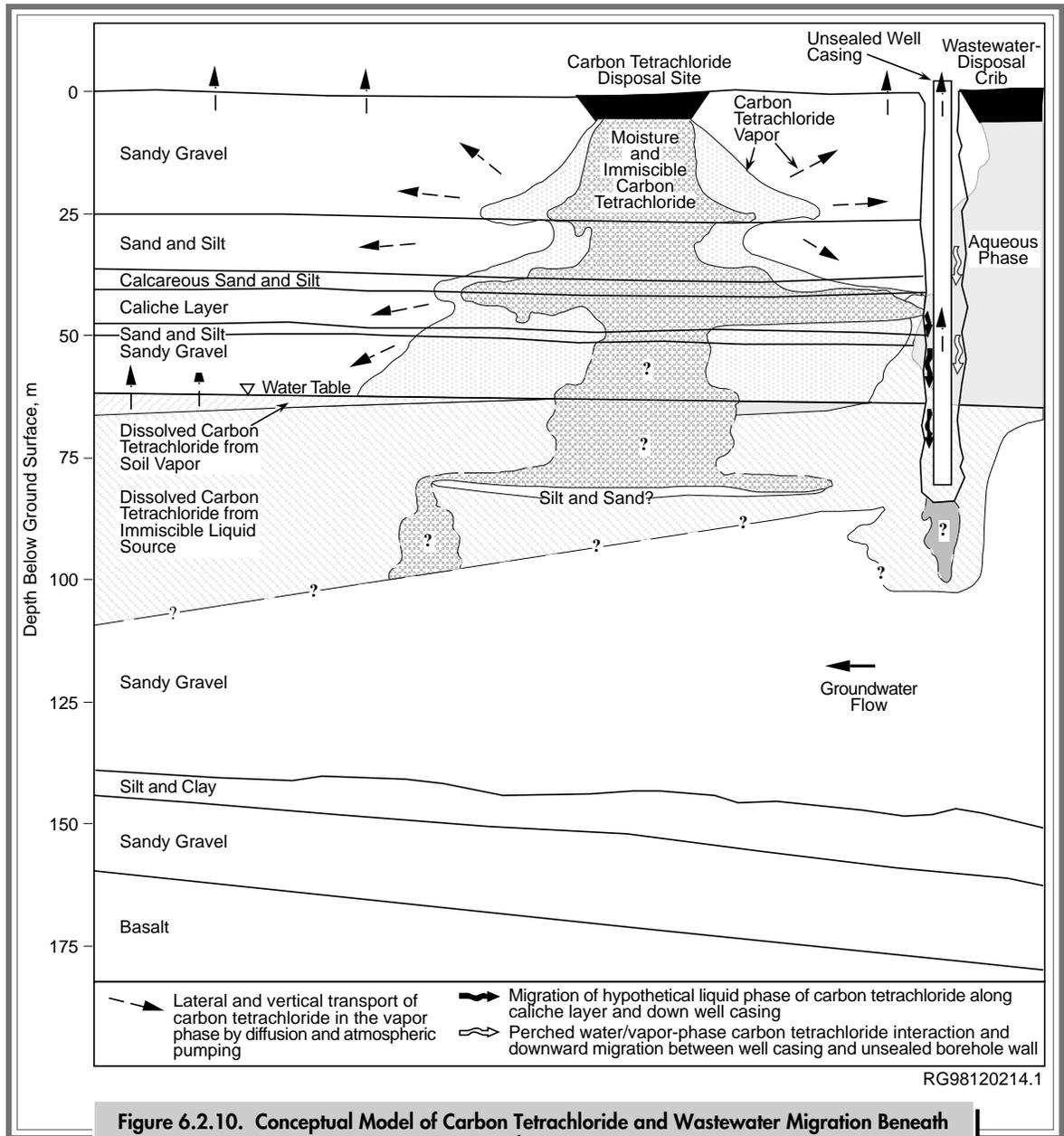
system appears to have had no immediate negative impact on groundwater quality.

**Carbon Tetrachloride Migration.** Three major pathways through the vadose zone to groundwater are possible:

- sinking and lateral spreading of a heavier-than-air vapor phase down to the top of the aquifer
- transport of an organic 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
- transport of carbon tetrachloride dissolved in the aqueous phase either through disposal of aqueous waste or by contact between infiltrating recharge and carbon tetrachloride soil vapor and/or 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 6.2.10. A numerical model was developed (BHI-00459) to simulate the primary transport processes shown in Figure 6.2.10, using local stratigraphy, documented discharge volumes to the well field, and soil properties. Results of initial simulations suggested that over two-thirds of the discharged carbon tetrachloride would be retained in the soil column and that a dense, nonaqueous-phase liquid would continue to drain slowly through the vadose zone and be transported into the underlying aquifer for years into the future. The initial modeling results indicated that the dense, nonaqueous-phase liquid dissolved in the groundwater and the depth of penetration was dependent on the groundwater flow rate.

Additional modeling is needed to assess the influence of porosity and groundwater velocity. Nevertheless, the modeling results support the conceptualization of the liquid-phase transport illustrated in Figure 6.2.10. The vapor-phase results were



**Figure 6.2.10. Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench, 200-West Area**

less definitive but suggested that vapor-phase transport is secondary to dense, nonaqueous-phase liquid as a groundwater contamination pathway in the vicinity of the disposal site.

Field measurements of carbon tetrachloride vapor concentrations are not completely consistent with the numerical modeling results. If a major

fraction of the carbon tetrachloride originally discharged to the 216-Z-9 trench is still present in the soil column as a nonaqueous phase, a relatively high soil-vapor concentration would be expected. For example, vapor-extraction concentrations more than 12,000 ppmv of carbon tetrachloride would indicate that the soil near the extraction well is saturated with nonaqueous-phase liquid. During



initial extraction operations at the 216-Z-9 well field, soil-vapor carbon tetrachloride concentrations extracted from wells open above the less permeable zone were more than 12,000 ppmv, suggesting the presence of a nonaqueous phase. Soil vapor extracted from wells open below the less permeable zone were an order of magnitude lower and do not suggest the presence of a nonaqueous-phase liquid. However, the depths and locations of the extraction wells below the less permeable zone 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.

During the soil-vapor monitoring of rebound concentrations conducted in 1997 through 1999, 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 less permeable zone; 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 deep, vadose zone, nonaqueous-phase, liquid source in the area of the 216-Z-9 trench 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

- nonuniform discharge, migration, and distribution of the nonaqueous-phase carbon tetrachloride
- nonoptimal locations for monitoring
- nonequilibrium partitioning of carbon tetrachloride within the vadose zone

- discharge of organic mixtures containing carbon tetrachloride rather than the pure phase
- vadose zone geologic heterogeneities and nonhorizontal geologic layers.

Vertical and areal distribution of dissolved carbon tetrachloride in groundwater is consistent with a dense, nonaqueous-phase, liquid transport mechanism. If the numerical model predictions are correct, for example, slowly dissolving carbon tetrachloride distributed with depth in the aquifer should continue to emanate from the point of origin over time, with the highest concentrations at the source, and should result in dissolved carbon tetrachloride distributed with depth in the aquifer (BHI-00459). If vapor-phase transport was a primary pathway, the top of the aquifer should have the highest concentrations and concentrations should decline rapidly with depth over a 1- to 2-meter (3.3- to 6.5-foot) interval.

The carbon tetrachloride plume map and vertical profiles (Section 2.8.1.2, PNNL-13116) suggest there is a continuing source of groundwater contamination 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. One 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. This would theoretically drive the contaminated water deep into the aquifer.

The continuing presence, 35 years after termination of disposal operations, of relatively high, dissolved, carbon tetrachloride concentrations in groundwater in the immediate vicinity of the 216-Z-9 trench 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 fiscal year 1997 through 1999 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-rich regions in the subsurface (e.g., lower-permeability zones such as the lower Hanford formation silt, 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.

### **6.2.2.5 Spectral Gamma-Ray and Neutron Moisture Monitoring of 200-East Area Inactive Liquid Waste Disposal Facilities**

*D. G. Horton*

The Hanford Groundwater Monitoring Project monitored 25 inactive liquid waste disposal facilities in the 200-East Area of the Hanford Site in 1999 (PNNL-12222; PNNL-13077). The monitored facilities consisted of 6 cribs and 19 specific retention facilities. Specific retention facilities were liquid waste disposal sites designed to use the moisture retention capability of the soil to retain contaminants. These facilities were chosen for monitoring because they are among the highest priority sites as determined by an evaluation of past-practice, liquid waste disposal facilities (PNNL-11958,

Rev. 2). Ideally, liquid disposed to specific retention facilities was to be limited to 6% to 10% of the soil volume between the facility and the groundwater so that the liquid would be retained in the soil and not reach the groundwater (WHC-MR-0227). No such limits were imposed at normal cribs and trenches. The relatively small volumes of liquid discharged to specific retention facilities was probably insufficient to flush contaminants through the vadose zone to groundwater. Thus, these sites represent potential sources for future contamination of groundwater at the Hanford Site. Monitoring of the past practice sites consisted of spectral gamma-ray and neutron moisture logging of 28 wells and boreholes.

The facilities monitored in 1999 can be placed into three groups based on geographic location and the type of effluent received. The three groups are

- Plutonium-Uranium Extraction facilities
- BC controlled area facilities
- BX trenches.

Table 6.2.9 lists the facilities that were monitored in each group. Descriptions of the facilities, their associated waste streams and operating histories can be found in DOE/RL-92-04, Rev. 0 and DOE/RL-92-05, Rev. 0.

High-resolution gamma spectroscopy instrumentation and a neutron moisture tool were used to log the boreholes. Details concerning the logging methods, data analysis, and data interpretation can be found in PNNL-13080 and PNNL-13077.

Four of the wells logged in 1999 were previously logged with the high-resolution spectral gamma logging instrument. Time-lapse comparison of spectral log data was done for those boreholes. Also, historical gross gamma logs were compared with the gross gamma logs collected by the spectral instrument in 1999. Interpretations of contaminant redistribution were based on changes among the data sets.

All depths referred to in the following discussion of results are relative to ground surface.



**Table 6.2.9. Liquid Disposal Facilities and Associated Boreholes and Wells in the 200-East Area Monitored with Spectral Gamma-Ray and Neutron Moisture Tools, Fiscal Year 1999**

Facility	Well or Borehole	Facility	Well or Borehole
<b>PUREX Facilities<sup>(a)</sup></b>			
216-A-2 crib	299-E24-53	216-A-7 crib	299-E25-54
216-A-4 crib	299-E24-54	216-A-18 trench	299-E25-10
<b>BC Controlled Area Facilities</b>			
216-B-14 crib	299-E13-1	216-B-26 trench	299-E13-12
216-B-15 crib	299-E13-2	216-B-27 trench	299-E13-57
216-B-16 crib	299-E13-2	216-B-30 trench	299-E13-52
	299-E13-21		
216-B-17 crib	299-E13-4	216-B-31 trench	299-E13-58
216-B-18 crib	299-E13-5	216-B-32 trench	299-E13-59
216-B-19 crib	299-E13-6	216-B-33 trench	299-E13-60
216-B-23 trench	299-E13-55	216-B-52 trench	299-E13-54
216-B-25 trench	299-E13-56	216-B-53A trench	299-E13-61
<b>BX Trenches</b>			
216-B-35 trench	299-E33-286	216-B-41 trench	299-E33-8
216-B-37 trench	299-E33-287	216-B-42 trench	299-E33-10
	299-E33-288		
216-B-38 trench	299-E33-289		
	299-E33-290		

(a) PUREX = Plutonium-Uranium Extraction.

#### **Plutonium-Uranium Extraction Facilities.**

The isotopes cesium-137, cobalt-60, europium-154, uranium-235, and uranium-238 were identified on the spectral gamma logs from boreholes monitoring the Plutonium-Uranium Extraction specific retention facilities. One gross gamma log obtained in 1976 was digitized for comparison with the 1999 log (borehole 299-E24-53 at the 216-A-2 crib). The presence of several man-made, gamma-emitting radionuclides made the comparison very difficult, but the two logs showed the same general character suggesting no vertical movement of radionuclides. Lateral movement could not be ruled out by the comparison. Qualitative, visual (not digitized) comparisons of the other 1999 gross gamma logs with historical gross

gamma logs, from the monitored Plutonium-Uranium Extraction facilities, suggested that no vertical movement of radionuclides had occurred since the previous logging events. Most differences between historical logs and the 1999 logs could be explained by decay of relatively short-lived radionuclides.

#### **BC Controlled Area Cribs and Trenches.**

The isotopes antimony-125, cesium-137, cobalt-60, and europium-154 were identified on the spectral gamma logs from boreholes monitoring the BC controlled area cribs and trenches. Three of the wells in this area had been previously logged in 1992 with a spectral gamma tool. In two of the three wells with



both 1992 and 1999 logs, zones were identified where the cesium-137 concentration had increased since 1992. The cesium-137 concentration increased by ~20% between 20 and 27 meters (66 and 88 feet) in well 299-E13-1, at the 216-B-14 crib, and by ~32% at ~25 meters (82 feet) in well 299-E13-5, at the 216-B-18 crib. The movement of cesium-137 in well 299-E13-5 is interpreted to be lateral because there was no change in cesium-137 concentration above and below the zone of increase. The increase in cesium-137 concentration in well 299-E13-1 could have resulted from vertical movement but more information is needed to make a definite interpretation.

Historical gross gamma logs from two wells, 299-E13-2 and 299-E13-4 were digitized to allow comparison with 1999 gross gamma logs. Differences between the 1976 and 1999 logs can be explained by natural decay of relatively short-lived radionuclides; the comparison, however, is qualitative. Similarly, most of the differences between the 1999 logs and other historical logs reflect the decay of relatively deeper, short-lived isotopes and the much slower decay of the shallower and longer-lived isotopes.

**BX Specific Retention Trenches.** The isotopes antimony-125, cesium-137, and cobalt-60 were identified on the spectral gamma logs from boreholes at the BX specific retention trenches. The antimony-125 and cobalt-60 were identified only at or near detection limits.

A 1984 gross gamma log from borehole 299-E33-289 was digitized and compared to the 1999 gross gamma results. The different instrument efficiencies allow only qualitative comparison but the depth profile of the contaminants match very well. It is believed that no vertical migration of contaminants has occurred in the borehole since 1984.

Borehole 299-E33-290 at the 216-B-38 trench was previously logged with a spectral gamma tool in 1992. Cesium-137 was the only man-made radioisotope noted in both the 1992 and 1999 logs. Comparison of the 1992 and 1999 gross gamma logs indicated that a change in the distribution of cesium-137 was

highly unlikely. Most of the qualitative differences between the 1999 logs and the historical logs from the BX trenches reflect the decay of short-lived isotopes, primarily ruthenium-106.

**Summary.** Only four of the boreholes logged in 1999 had previous spectral gamma logs for comparison. Two of those logs showed that changes in the subsurface distribution of man-made radioisotopes had occurred since 1992. Although the changes are not great, they do point to continued movement of contaminants in the vadose zone. The logs obtained in 1999 create a larger baseline for comparison with future logs.

None of the facilities monitored in 1999 have been used for at least 30 years and some for 40 years. Thus, the driving force for the changes is not known for certain but must be either natural recharge, residual moisture from past facility operations, or moisture from adjacent facilities. There are several facilities, including cribs and tank farms near the BX trenches, that may contribute moisture to the subsurface under the trenches. There are no nearby liquid waste disposal facilities near the cribs and trenches in the BC controlled area, so the driving force there must be residual moisture from past operations or natural recharge.

The radionuclides that were observed to have moved since 1992 are cesium-137 and cobalt-60. Given the amount of movement and the half-lives of the isotopes, it is expected that they will decay to insignificant amounts before reaching groundwater. Although not seen to have moved in 1999, the same is expected for all of the other detected isotopes except those of uranium.

Unfortunately, gamma-ray logging cannot detect many of the contaminants of interest such as technetium-99, nitrate, and iodine-129, all of which can be highly mobile in the vadose zone and, for the radionuclides, have long half-lives. The time series of gross gamma logs (ARH-ST-156) for many of the specific retention facilities show large decreases in gamma intensity between the late 1950s



and 1976. The maximum intensity is generally between a depth of 10 and 20 meters (66 feet). The rapid decay is probably due to ruthenium-106 (half-life 1.02 year), and the ruthenium-106 probably reached a maximum depth of 10 to 20 meters (33 to 66 feet) with the original slug of water disposed in the short time (generally ~1 month) the facilities operated. Depending on the chemical characteristics of the waste stream, the mobility of iodine-129 and

technetium-99, as gauged by experimentally determined  $K_d$ s, is either near that of or greater than that of ruthenium-106. Thus, the minimum depth that iodine-129, nitrate, and technetium-99 probably reached during facility operation is indicated by the depth of rapid ruthenium-106 decay. Subsequent movement of the long-lived and mobile nongamma emitting constituents cannot be measured with the available geophysical logging tools.

### 6.2.3 Hanford Site Surface Barrier Technology

G. W. Gee, A. L. Ward

A field-scale prototype surface barrier was constructed in 1994 over an existing waste site as part of a CERCLA treatability test. The barrier was designed to be used at waste sites in arid climates and to have a 1,000-year performance. The barrier was monitored for 4 years to ascertain its stability and long-term performance. The 4 years of data were compiled and analyzed in 1999. A summary of those data is presented here; a more complete discussion is found in DOE/RL-99-11, Rev. 0.

Natural construction materials (e.g., fine soil, sand, gravel, cobble, basalt riprap, asphalt) were selected because of the demand for the barrier to perform for at least 1,000 years without maintenance. The current barrier consists of a 2-meter (6.5-foot) thick, fine-soil layer overlying other layers of coarser materials that include sands, gravels, and basalt rock (riprap) and a low permeability asphalt layer. The barrier is designed to limit recharge to less than 0.5 millimeter (0.02 inch) per year. Figure 6.2.11 shows the construction details of the barrier.

Each layer serves a distinct purpose. The fine soil layer (silt) acts as a medium to store moisture until the processes of evaporation and transpiration recycle excess water back to the atmosphere. The fine soil layer also provides the medium to establish plants that are necessary for transpiration to take place. The coarser materials placed directly below the fine soil layer create a capillary break that inhibits

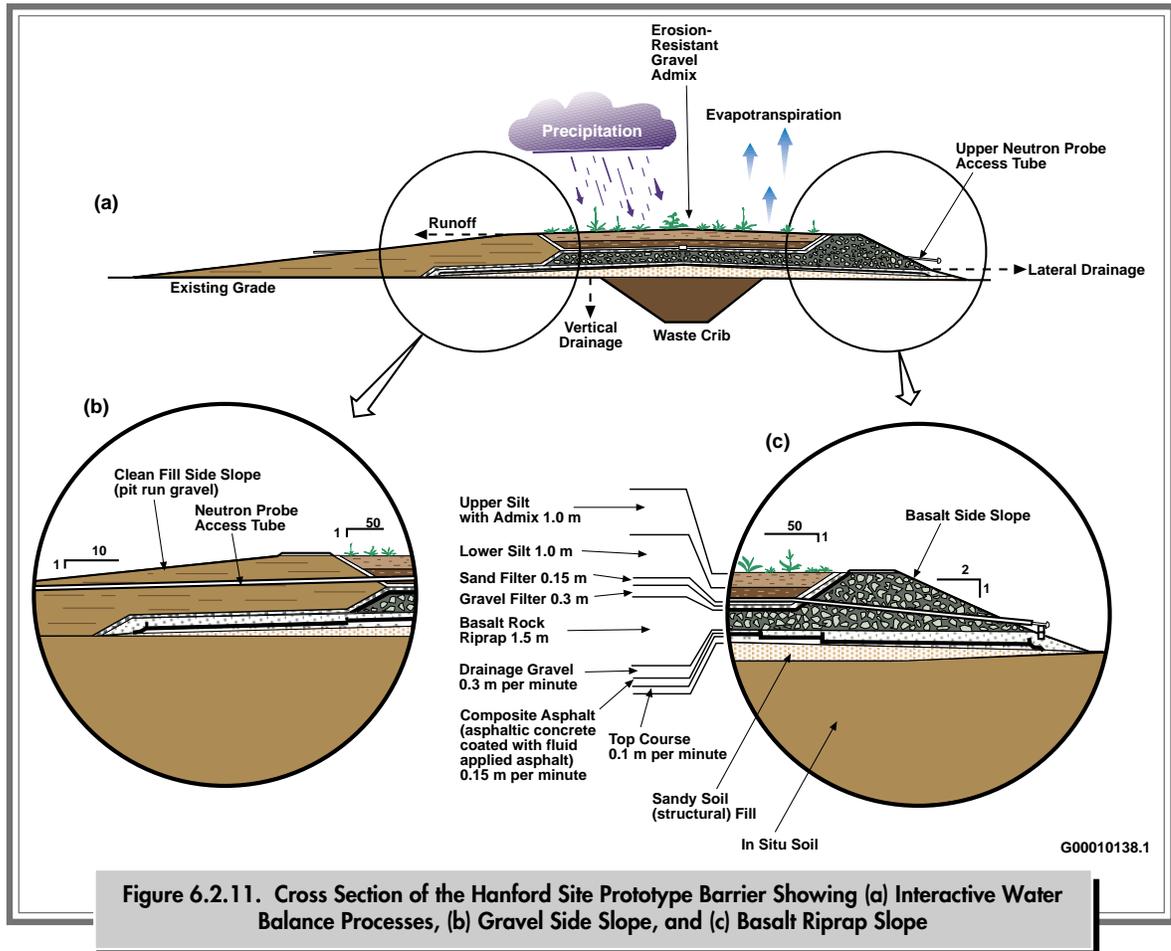
downward movement of water through the barrier. The placement of fine soil directly over coarser materials also encourages plants and animals to limit their biological activities to the upper portion of the barrier, thereby reducing biointrusion into the lower layers. The coarser materials also help to deter inadvertent human intruders from digging deeper into the barrier profile.

Low-permeability layers are placed below the capillary break to 1) divert any percolating water that crosses the capillary break away from the waste zone and 2) limit the upward movement of noxious gases from the waste zone. The coarse materials located above the low-permeability layers also serve as a drainage medium to channel any percolating water to the edges of the barrier.

In addition to testing the performance of a capillary barrier, the prototype is being used to test two different side-slope designs:

- a relatively flat apron (10:1, horizontal:vertical) of clean fill gravel
- a relatively steep (2:1) embankment of fractured basalt riprap (PNL-8391; Ward and Gee 1997).

A shrub and grass cover was established on the soil surfaces of the prototype in November 1994. Shrubs were planted at a density of two plants per square meter with four sagebrush (*Artemisia tridentata*) plants to every one rabbitbrush (*Chrysothamnus nauseosus*) plant.



**Figure 6.2.11. Cross Section of the Hanford Site Prototype Barrier Showing (a) Interactive Water Balance Processes, (b) Gravel Side Slope, and (c) Basalt Riprap Slope**

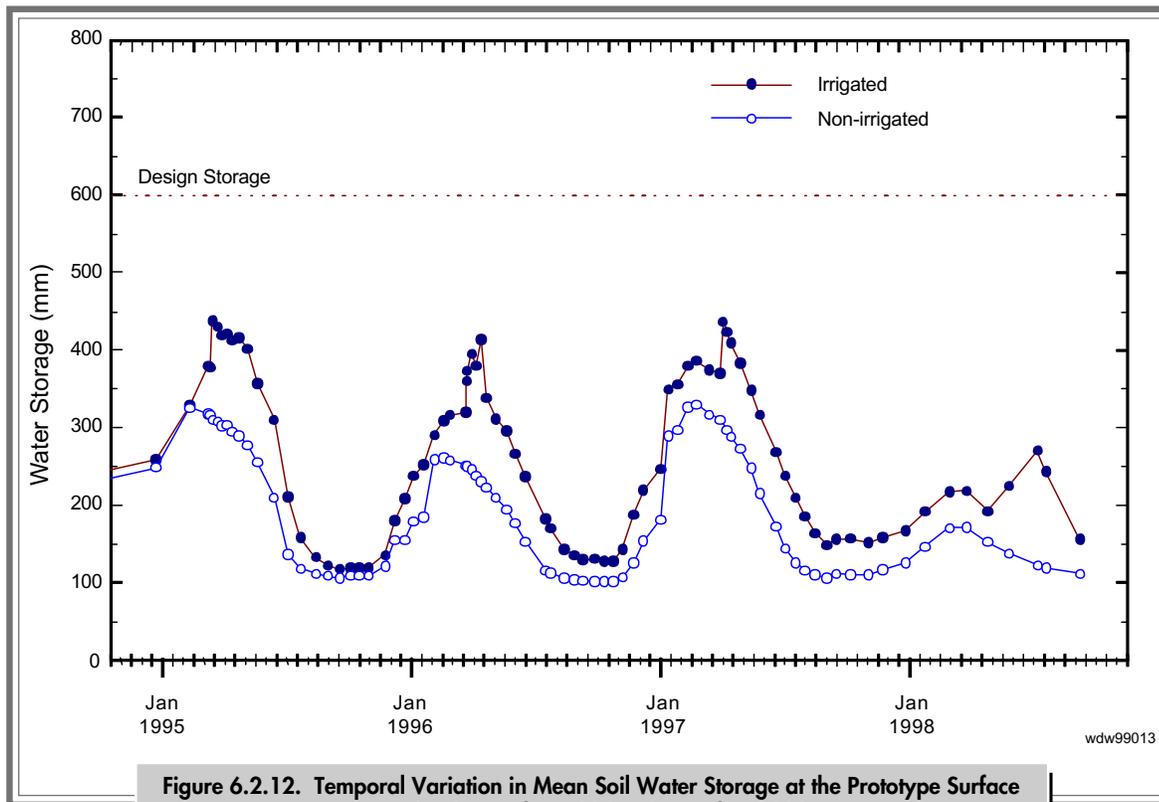
### 6.2.3.1 Results of Field Tests

From November 1994 through October 1997, soil plots on the northern half of the prototype barrier were irrigated such that the total water applied, including natural precipitation, was 480 millimeters per year (18.9 inches per year) or 3 times the long-term annual average. This treatment included application of sufficient irrigation water on 1 day, during the last week of March for 3 years (1995 through 1997), to mimic a 1,000-year storm (70 millimeters [2.75 inches] of water).

Survival rates of the transplanted shrubs have been remarkably high; 97% for sagebrush and 57% for rabbitbrush (PNNL-11367). Grass cover, consisting of 12 varieties of annuals and perennials, including cheatgrass, several bluegrasses, and bunch grasses,

dominated the surfaces, particularly those that were irrigated. Approximately 75% of the surface was covered by vegetation; a cover value typical of shrub-steppe plant communities. In all respects, the vegetated cover appeared to be healthy and normal. There was nearly twice as much grass cover on the irrigated surfaces than on the nonirrigated surfaces (PNNL-11367).

Figure 6.2.12 compares temporal changes in mean soil water storage on the irrigated and nonirrigated portions of the prototype barrier through September 1998. All irrigation and natural precipitation plus all available stored soil water were removed via evapotranspiration during the first year of surface barrier operation. By late summer of each year, water was removed via evapotranspiration



**Figure 6.2.12. Temporal Variation in Mean Soil Water Storage at the Prototype Surface Barrier, November 1994 to September 1998**

from the entire soil profile so that the soil water content of both irrigated and nonirrigated plots reached a relatively uniform lower limit of 5 to 8 volume percent throughout the soil profile. Correspondingly, water storage was reduced to levels of 100 to 150 millimeters (3.9 to 5.9 inches) (i.e., lower limit of plant-available water), for both the irrigated and nonirrigated soil surfaces. This is approximately one-fifth the amount of water required for drainage. Based on these observations and considering the irrigation treatment to represent the extreme in wet climate, the soil cover would not be expected to drain, even under the wettest Hanford Site climate conditions.

Figure 6.2.12 also shows that all of the water was removed from the soil profile following each simulated 1,000-year storm. Because no drainage occurred, the change in storage is attributed to water loss by evapotranspiration, thus demonstrating the continued positive benefits of having vegetation on

the barrier surface. Evapotranspiration for the irrigated plots was nearly double that for the nonirrigated (ambient) plots, suggesting that vegetation is capable of adjusting to water applications. It is apparent that the capacity of vegetation for water consumption has not been exceeded even at three times the long-term annual average precipitation rates. This further supports the hypothesis that the combination of vegetation and soil storage capacity is more than sufficient to remove all applied water under the imposed test conditions.

Drainage did not occur from the soil covered part of the prototype barrier until the third year and then only in a minute amount (less than 0.2 millimeter [0.008 inch] for one of the soil plots subjected to irrigation. The drainage was attributed to lateral flow from water diverted off an adjacent roadway. These observations agree with the results of extensive lysimeter testing of capillary barrier designs (PNL-7209; PNL-8911) and suggest that the water

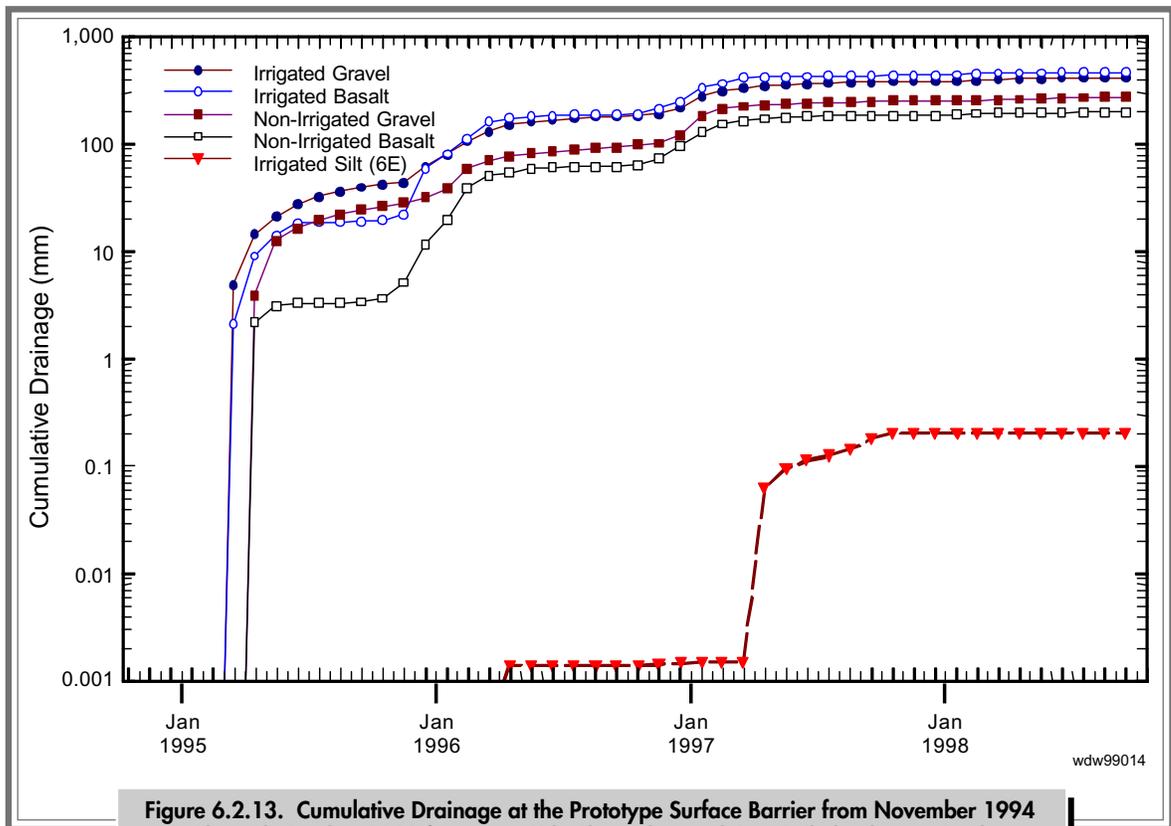


storage capacity of the soil is well in excess of three times the long-term annual average (480 millimeter [19 inches] precipitation. (Lysimeters measure moisture content and movement through the soil.) In contrast, both side-slope configurations drained, though the amount of drainage was significantly less than predicted, based on the lysimeter testing that has been done with coarse materials (PNL-8911).

Figure 6.2.13 compares cumulative drainage from the gravel and riprap slopes through October 1998. On the nonirrigated treatments, the total amount of drainage from the gravel side-slope was greater than that from the basalt riprap side slopes. A similar trend was observed on the irrigated slopes up until November 1995. Whereas irrigation of the soil surfaces started in February 1995, irrigation of the side slopes did not start until November 1995. A closer look at these results show a seasonal influence on drainage. Whereas drainage from the gravel side slope was

continuous, there was essentially no drainage from the riprap in the summer. In the winter, both side-slope configurations drained at similar rates.

The rapid establishment of vegetation on the soil surface was thought to be responsible for at least three positive benefits to surface barrier performance. First, the vegetation was dominant in the water removal process from the soil surfaces. Second, the surface was stabilized against water erosion and runoff. Runoff from the 1,000-year storm in 1995 was 1.8 millimeter (0.07 inch) [~2% of the 70 millimeters (2.75 inches)]. There was no runoff in 1996. The improvement was attributed to plant growth. Finally, there has been a positive benefit in controlling wind erosion. There has been no measurable loss of soil from the surface of the prototype barrier by wind erosion since the establishment of plants in November 1994.





Four years of testing provided important but limited information for long-term barrier performance estimates. Because only a finite amount of time exists to test a barrier that is intended to

function for a minimum of 1,000 years, the testing program was designed to stress the prototype so that barrier performance could be determined within a reasonable time frame.

## 6.2.4 Measurement of Tritium in Soil Moisture and Helium-3 in Soil Gas at the Old Hanford Townsite and KE Reactor

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The Hanford Groundwater Monitoring Project sampled and analyzed soil gas and soil moisture in 1999 to

- demonstrate the adaptability of soil gas sampling techniques to the measurement of tritium and helium-3 concentrations in Hanford Site soil
- determine tritium and helium-3 concentrations in soil gas at two locations on the Hanford Site
- attempt to extrapolate tritium and helium-3 concentrations in the soil to tritium concentrations in groundwater at the 100-K Area.

Tritium/helium-3 age dating of shallow aquifer groundwater was successfully applied in the late 1980s by Poreda et al. (1988). The technique is based on the presence of the radioactive isotope tritium and its decay to the stable, inert isotope, helium-3. (Helium-4 is the common, stable isotope of helium found in the atmosphere.) At the Hanford Site, tritium was released to the soil column as effluent from past operations. In some areas of the Hanford Site, the effluent migrated through the vadose zone to mix with groundwater. In other areas, the effluent was retained in the vadose zone. Subsequently, moisture laden with tritium evaporated from the flow path and the water table and began to diffuse upward through the vadose zone toward the surface.

At the same time, helium-3 began to build up in both the groundwater and the vadose zone at the rate of tritium decay (the half-life of tritium is 12.3 years) and diffuse upward to the surface. Throughout this

process, helium-3 was expected to act as a conservative (nonreactive) tracer moving through the vadose zone. Tritium, as tritiated water, would be a reactive tracer freely exchanging with hydroxyl groups on the surface of sediment, which would retard its movement through the vadose zone. Based on the above principles and conceptual model, soil gas and soil moisture samples were collected and analyzed to obtain a better understanding of their vadose zone properties and attempt to map vadose zone and groundwater tritium distribution.

Two areas of the Hanford Site were chosen to investigate: south of the Old Hanford Townsite and east of the KE Reactor. The Old Hanford Townsite was chosen because it is an area with a known tritium plume at groundwater depths similar to those in the 100 Areas and the site had easy access. Eight samples were collected during July and September 1999 at the Old Hanford Townsite. The KE Reactor was chosen as a study area because there is a known tritium plume; however, there is some uncertainty as to its distribution. Sixteen samples were collected in September 1999 at the KE Reactor. It was hoped that the helium-3/helium-4 isotope ratio would help better define the existing groundwater contamination. Details describing the sampling points and the experimental methods are given in PNNL-13116.

### 6.2.4.1 Results and Discussion

Analysis of the soil moisture samples found no detectable tritium (minimum detection limit less than 240 pCi/L) in the soil moisture from either the

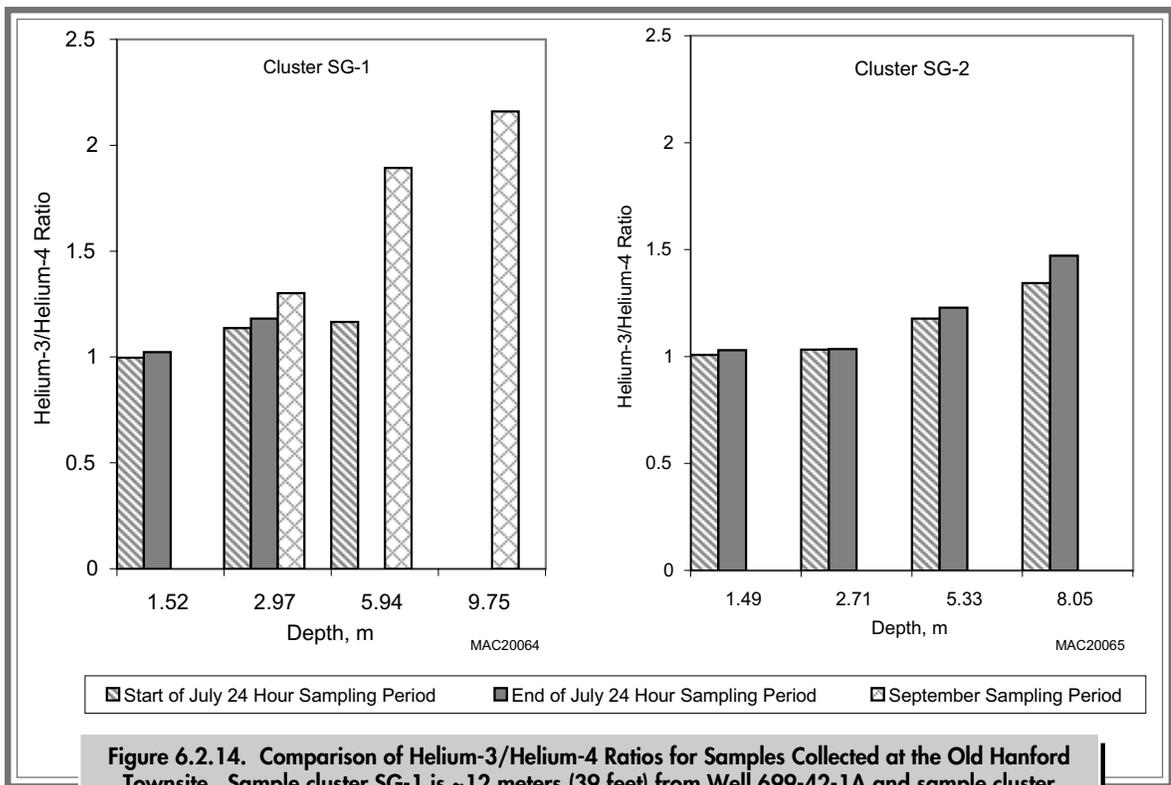


Old Hanford Townsite or KE Reactor sampling points. This suggests that tritiated moisture from groundwater is not migrating upward to the sampling points. This is in spite of the fact that tritium in groundwater from a well adjacent to the soil moisture sampling points, occurs at a concentration of 117,000 pCi/L at a depth to groundwater of 21 meters (69 feet). These data indicate that the soil moisture can be attributed to recharge of natural precipitation into the vadose zone at the Old Hanford Townsite, which agrees with work done by Fayer et al. (1997). The lack of tritium in soil moisture at the KE Reactor also suggests that there are no vadose zone sources of tritium in the immediate study area.

Results of the helium analyses of the soil gas samples from the Old Hanford Townsite showed significant enrichment of helium-3 concentrations compared to ambient air, and an inverse relationship between helium-3 concentration and distance from the source (groundwater). Helium-3/-4 ratios at the

Old Hanford Townsite location ranged from 1.012 at 1.5 meters (5 feet) below ground surface to 2.157 at 9.7 meters (32 feet) below ground surface (Figure 6.2.14). For comparison, the helium-3/-4 ratio of normal atmosphere is very close to 0.

Helium-3/-4 ratios show a significant variability with time. Figure 6.2.14 shows the helium-3/-4 ratios from samples taken at the beginning and at the end of the 24 hour July sampling event. In all but one sample, the ratios at the end of the event were greater than at the beginning of the event. The variability with time was even more pronounced by comparing the July and September sampling events. The greatest difference is shown by the helium-3/-4 ratios from the 5.9 meters (19 feet) samples from the SG-1 cluster. Comparing the two results shows a 62% increase in enrichment of helium-3 in the September sample.



**Figure 6.2.14. Comparison of Helium-3/Helium-4 Ratios for Samples Collected at the Old Hanford Townsite. Sample cluster SG-1 is ~12 meters (39 feet) from Well 699-42-1A and sample cluster SG-2 is ~48 meters (157 feet) from well 699-42-1A.**



The temporal variations might be attributable to dilution of the helium-3 in the vadose zone with low helium-3/4 atmospheric air during times of high atmospheric pressure. Thus, the helium-3/4 ratios from the soil samples probably reflect atmospheric conditions as well as soil vapor.

Helium-3/4 ratios in the soil gas samples collected near the KE Reactor ranged from 0.972 to 1.131 (Figure 6.2.15). The greatest helium-3 enrichment is in the southeastern part of the study area suggesting that there may be a tritium source around that location. Because there was no tritium found in the soil moisture in the immediate area of sample site SG-16 (see Figure 6.2.15), helium-3 must be coming from a source farther than 3 meters (10 feet) from SG-16. This source may be located in the vadose zone or groundwater. The source could possibly be the solid waste burial ground or one or more of several cribs east of the KE Reactor. Alternatively, the source could be from the groundwater plume in the area. However, a groundwater monitoring well, 199-K-111 located adjacent to several soil gas monitoring points at the southeastern end of the study area has no measurable tritium (minimum detection level below 240 pCi/L). This suggests that a tritium groundwater plume, if it exists, could be located farther to the south of the study area. Further investigation is necessary to define and identify the source of helium-3 around the southeastern corner of the study area. The helium-3 results from all the sampling points near the KE Reactor suggest no tritium plume is located within the study area.

**Conclusions.** Measurements of tritium in soil moisture do not appear to be useful for delineating tritium groundwater plumes or estimating concentrations of tritium in groundwater. The major source of moisture in the vadose zone at the two investigated sites appears to be natural precipitation and not upward migration of moisture from groundwater into the vadose zone. However, analysis of vadose zone moisture samples for tritium may be helpful in identifying vadose zone sources of tritium near the sampling sites.

Analyses of soil gas from samples collected at the Old Hanford Townsite area show that the gas is enriched in helium-3. This enrichment is due to decay of tritium in the groundwater beneath the site. The amount of enrichment appears to vary with time, most likely because of atmospheric influences. Nevertheless, helium-3 can be a useful tracer for either vadose zone or groundwater sources of tritium.

Helium-3 results from samples from the KE Reactor area do not suggest the presence of tritiated groundwater beneath the study area. Based on the relative enrichment factors for helium-3, there may be a groundwater or vadose zone source of tritium southeast of the study area. Potential sources include a groundwater tritium plume, the solid waste burial ground, the 116-KE-1 gas condensate crib east of the KE Reactor, or KE fuel storage basins.

