3.3 Additional Vadose Zone Related Investigations

In fiscal year 1999, several vadose zone related activities were accomplished that have potential applicability across the Hanford Site. The 175 lysimeters of the Hanford Site were inventoried and described in fiscal year 1999. Also, 4 years of field data from the Hanford Site prototype surface barrier were analyzed and interpreted. Those data have important applicability to contaminated sites that may be left in place and monitored during natural attenuation. Finally, tritium and helium-3/helium-4 were obtained from vadose zone sediment to extrapolate concentrations in the soil to concentrations in groundwater. This section discusses these activities.

3.3.1 Hanford Site Lysimeters

D. G. Horton, R. R. Kirkham

In fiscal year 1998, the participants of a data quality objective process for vadose zone monitoring identified moisture content and moisture movement as elements of concern for vadose zone monitoring of past-practice liquid waste disposal facilities. Consequently, the Hanford Groundwater Monitoring Project undertook an inventory of existing lysimeters and their conditions in fiscal year 1999. That inventory is summarized in Table 3.3-1.

Lysimeters measure the amount of water percolating through soil. Approximately 175 lysimeters exist at the Hanford Site. Most of these are inactive and need repair before they can be used. Active lysimeters are at the Field Lysimeter Test Facility and the Solid Waste Landfill. Some water storage data are collected from the lysimeters at the Fitzner/Eberhardt Arid Lands Ecology Reserve via data loggers and radio link to backup tapes, but currently, the data are not used.

Drainage from the lysimeter at the Solid Waste Landfill is sampled at least monthly and the leachate analyzed for several constituents of concern. The U.S. Department of Energy (DOE) reports results quarterly to the Washington State Department of Ecology. At the Field Lysimeter Test Facility, the weighing lysimeters are monitored hourly and the drainage lysimeters are monitored monthly for water storage.

Lysimeters measure moisture content and movement in the vadose zone. There are 175 lysimeters on the Hanford Site; most are inactive and need repair.

Most of the lysimeters at the Hanford Site were designed for specific studies. As such, their application to vadose zone monitoring in the 200 Areas is limited. The limitation stems from the soil filling the lysimeters and the surface conditions of the lysimeters being different from the soil and surface conditions of most past-practice liquid disposal facilities. The lysimeters at the Field Lysimeter Test Facility and at the S-11 facility are the easiest to modify for potential vadose zone monitoring use.

3.3.2 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 *Comprehensive Environmental Response, Compensation, and Liability Act* (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. This section summarizes that work; a more complete discussion is found in DOE/RL-99-11.

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. Most of these natural construction materials are available in large quantities on the Hanford Site and some are known to have existed in place for thousands of years (e.g., basalt). The current barrier consists of a 2-meter-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 <0.5 millimeter per year. Figure 3.3-1 shows the construction details of the barrier.

A prototype surface barrier was constructed in 1994 to isolate a waste site from infiltrating moisture. Data collected since then indicate the barrier successfully prevents surface water and precipitation from reaching the waste site.

Each layer serves a distinct purpose. The fine soil layer acts as a medium to store moisture until the processes of evaporation and transpiration recycle any 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 percolation 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, fine soil 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 (*Artemsia tridentata*) plants to every one rabbitbrush (*Chrysothamnus nauseosus*) plant.

3.3.2.1 Results of Field Tests

Designing a maintenance-free barrier requires an understanding of how natural processes affect barrier performance. A series of tests was designed to provide a better understanding of these processes.

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 or 3 times the long-term annual average for the water year (November 1 through October 31). 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 event (70 millimeters of water).

Survival rates of the transplanted shrubs have been remarkably high; 97% for sagebrush and 57% for rabbitbrush (PNNL-11367). Heavy invasions of tumbleweed (*Salsola kali*) occurred in 1995 but were virtually absent in 1996. 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 non-irrigated surfaces (PNNL-11367).

Figure 3.3-2 compares temporal changes in mean soil water storage on the irrigated and non-irrigated 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 from the entire soil profile so that the soil water content of both irrigated and non-irrigated 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 (i.e., lower limit of plant-available water), for both the irrigated and non-irrigated 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 3.3-2 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 non-irrigated (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) 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 barriers 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 millimeters) precipitation. 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 3.3-3 compares cumulative drainage from the gravel and riprap slopes through October 31, 1998. On the non-irrigated treatments, the total amount of drainage from the clean fill 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. Advective drying similar to that described by Stormont et al. (1994) and Rose and Guo (1995) may be partly responsible for the lower drainage on the riprap side slopes and may also have an effect on water storage in the fine-soil cover. Additional testing and numerical modeling will be used to test this hypothesis.

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 millimeters (~2% of the 70 millimeters applied). 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 provide 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 has been designed to stress the prototype so that barrier performance can be determined within a reasonable time frame.

3.3.2.2 Conclusions

The study of surface barriers at the Hanford Site has evolved into an integrated demonstration of key features of barriers designed to minimize water intrusion, erosion, and biointrusion. The results of field tests, experiments, and lysimeter studies provide baseline information on which barrier designs can be based. Test results show that a well-designed capillary barrier limits drainage to near-zero amounts in the Hanford Site's arid climate. A subsurface asphalt layer provides additional redundancy. Data collected under extreme conditions (excess precipitation) provide confidence that the barrier has the ability to meet its performance objectives for the 1,000-year design life. Data from the prototype surface barrier confirm earlier observations with lysimeters and field plots and show that virtually all available water can be removed from the soil surfaces by evapotranspiration, under the tested elevated precipitation conditions. Side slopes, in contrast, drain because they are barren. The side-slope drainage is less than predicted because of advective heating and wind action but is non-zero. Thus, this drainage must be accommodated in the final design. Asphalt sublayers can be successful in extending areas of surface protection and can divert drainage water away from underlying waste but the durability of the asphalt must be evaluated.

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

K. B. Olsen, G. W. Patton, E. P. Dresel, J. C. Evans

The Hanford Groundwater Monitoring Project sampled and analyzed soil gas and soil moisture in fiscal year 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.

In fiscal year 1999, investigators measured tritium and helium-3 in soil vapor at two vadose zone sites. Results indicate helium-3 may be useful to trace vadose zone or groundwater sources of tritium.

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 of helium, helium-3. 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 volatilized 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 is expected to act as a conservative (non-reactive) 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 and thus 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.

3.3.3.1 Experimental Methods

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. The KE Area was chosen to study because there is a known tritium plume but there is some uncertainty as to its distribution. It was hoped that the helium-3/helium-4 method would help better define the existing groundwater contamination.

Eight sampling points, in two clusters, were installed between 1.5 and 9.7 meters below ground surface adjacent to well 699-41-1A, south of the Old Hanford Townsite (Figure 3.3-4). Sixteen sampling points between 2.1 and 3.1 meters below ground surface were installed to the north and east of the KE Reactor (Figure 3.3-5). Soil gas and soil moisture samples were collected in mid-July and in early September from the Old Hanford Townsite and in early September from the KE Reactor.

Soil moisture samples were collected from all eight sampling locations at the Old Hanford Townsite and the eight locations at the KE Reactor. Soil moisture samples were collected using a flexible diaphragm sampling pump. The samples were passed through a single 18-centimeter-long, silica gel column to adsorb soil moisture. Samples were collected at a flow rate of 1 liter per minute for a period of ~24 hours.

Soil gas samples, for helium-3 measurements, were collected at all sampling points using a sampling apparatus constructed from a 30-milliliter stainless steel cylinder. One end of the cylinder was fitted with a high-vacuum needle valve and the other end sealed with a pipe plug. Each cylinder was evacuated to less than 5 torr before sampling.

Two different sampling configurations were used to sample soil gas. During the July sampling at the Old Hanford Townsite, a silica gel trap, identical to that described above for soil moisture samples, was placed in the soil gas stream to remove all soil moisture. The soil gas sampling point was allowed to purge at 1 liter per minute for a minimum of 60 minutes. At the end of the purge period, a hose was connected to the pump and the cylinder was pressurized to the maximum pressure of the pump.

During a subsequent sampling event at the Old Hanford Townsite in September, cluster SG-1 was resampled for helium-3. Silica gel was not used because tritium was not observed in the soil moisture samples previously collected. Instead, a rotometer and pump were hooked in series to the riser tube that extended from the soil gas sampling point to the sampling cylinder. Flow was adjusted to 1 liter per minute, and the sampling point was purged for a minimum of 60 minutes. At the end of the purge, the cylinder was connected to the pump and allowed to pressurize to the pump's maximum pressure.

Soil moisture samples were sent to Quanterra Environmental Services laboratory in Richland, Washington for analysis. In brief, the sample was heated to desorb the soil moisture from the silica gel. The tritium content of the desorbed water was determined by liquid scintillation counting. Detection limit in the liquid, using a 10-milliliter sample aliquot, is estimated at 240 pCi/L.

Soil gas samples were sent to the University of Rochester for helium analysis. Helium isotope ratios and concentrations were analyzed on a VG 5400 Rare Gas Mass Spectrometer fitted with a Faraday cup (resolution of 200 counts) and a Johnston electron

multiplier (resolution of 600 counts) for sequential analyses of the helium-4 (Faraday cup) and helium-3 (multiplier) beams. All helium-3/helium-4 ratios are reported relative to the atmospheric ratio (R_A), using air helium as the absolute standard.

3.3.3.2 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 at the Old Hanford Townsite. This is in spite of the fact that tritium in groundwater from well 699-41-1A, adjacent to the soil moisture sampling points, occurs at a concentration of 117,000 pCi/L at a depth to groundwater of 21 meters. 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). Concentrations of tritium in natural precipitation normally range from 50 to 100 pCi/L, well below the detection limit of the analytical method used to measure tritium. 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 below ground surface to 2.157 at 9.7 meters below ground surface (Figure 3.3-6).

Helium-3/-4 ratios show a significant variability with time. Figure 3.3-6 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 are greater than at the beginning of the event. The variability with time is 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 meter samples from the SG-1 cluster nearer well 699-41-1A. Comparing the two results shows a 62% increase in enrichment of helium-3 in the September sample.

The temporal variations might be attributable to atmospheric pumping in the vadose zone because of fluctuations in atmospheric pressure. That is, higher atmospheric pressure may dilute the helium-3 in the vadose zone with low helium-3/-4 atmospheric air. This dilution might occur through the soil-atmosphere interface at the surface or through a well if the vadose zone is exposed to perforations or open screen above the water table. At the time of soil gas sampling, there was ~0.3 meters of screened interval open to the atmosphere in well 699-41-1A directly adjacent to one of the sampling clusters SG-1. Thus, atmospheric pumping may have affected the helium-3/-4 ratios.

Helium-3/-4 ratios in the soil gas samples collected near the KE Reactor ranged from 0.972 to 1.131 (see Figure 3.3-5). The greatest helium-3 enrichment (sample point SG-16) 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 SG-16, helium-3 must be coming from a source greater than 3 meters 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 <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.

3.3.3.3 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 pumping. Nevertheless, helium-3 can be a useful tracer for either vadose zone or groundwater sources of tritium.

Because atmosphere pumping can affect the results of helium-3 analysis, the entire suite of samples for such analysis should be collected in as short a time span as possible. This is particularly important if samples are to be collected deep in the vadose zone near a groundwater well screened across the water table.

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.

Table 3.3-1. Lysimeters at the Hanford Site

Lysimeter Type and Number	Purpose	Current Status	Potential for Future Use
	Field Lysimeter Test Facility		
Drainage, 14 Weighing, 4 Clear tube, 6	Test water balance in layered soils common to engineered barriers	Active, requires minor maintenance	High potential for future infiltration studies
	Buried Waste Test Facility		
Drainage, 6 Weighing, 2	Test water balance in coarse-grained sediments	Inactive, requires maintenance, 5 of 6 drainage lysimeters leak	Potential for infiltration studies in coarse sand and no vegetation environment. Potential test environment for sensors
	Commercial Waste Lysimeters		
Drainage, 10	Test commercial low-level waste solidification	Inactive	Scheduled to be decommissioned in fiscal year 2000
	Solid Waste Landfill		
Drainage, 1	Monitoring	Active	Continued monitoring
	Fitzner/Eberhardt Arid Lands Ecology Reserve		
Weighing, 2	Examine water balance in sagebrush and bunchgrass community after a fire	Intermittent data collection	Potential for studies of site conditions but not 200 Areas conditions
	Small Tube Lysimeters		
Drainage and Weighing, 105 total	Examine statistical repetition of lysimeter data	Inactive, requires minor maintenance	Too small for most purposes. Potential for small scale tests
	S 11 Lysimeters		
Storage, 24	Water balance effects of barriers on plant intrusion and infiltration	Inactive, requires minor maintenance	Possible use for chemical tracer studies
	200 East Area Lysimeters		
Drainage, 1	Infiltration studies	Inactive, requires maintenance, limited access in radiological zone	Limited potential for future use because of high expense to operate

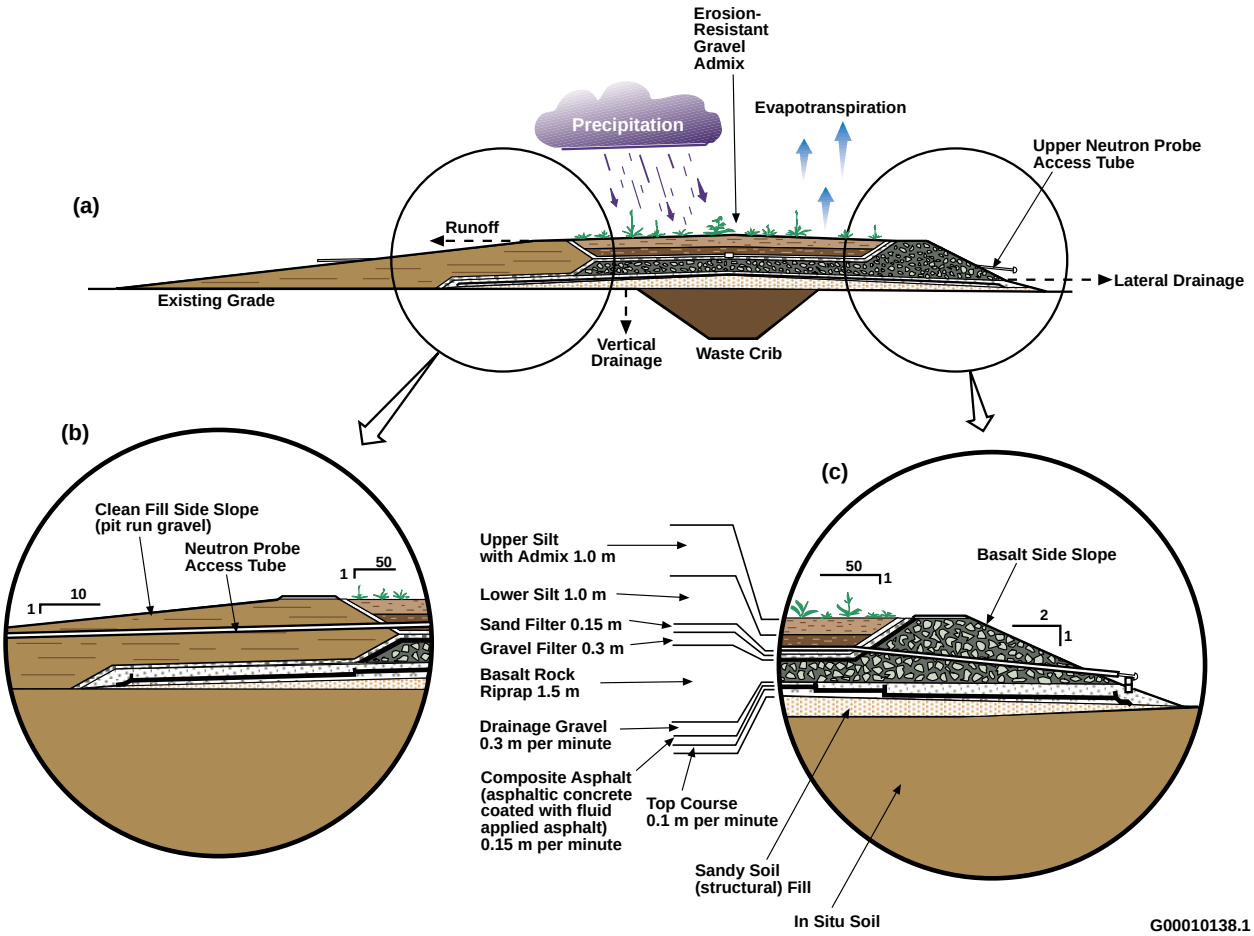

Figure 3.3-1. Cross Section of the Hanford Site Prototype Barrier Showing (a) Interactive Water Balance Processes, (b) Gravel Side Slope, and (c) Basalt Riprap Slope

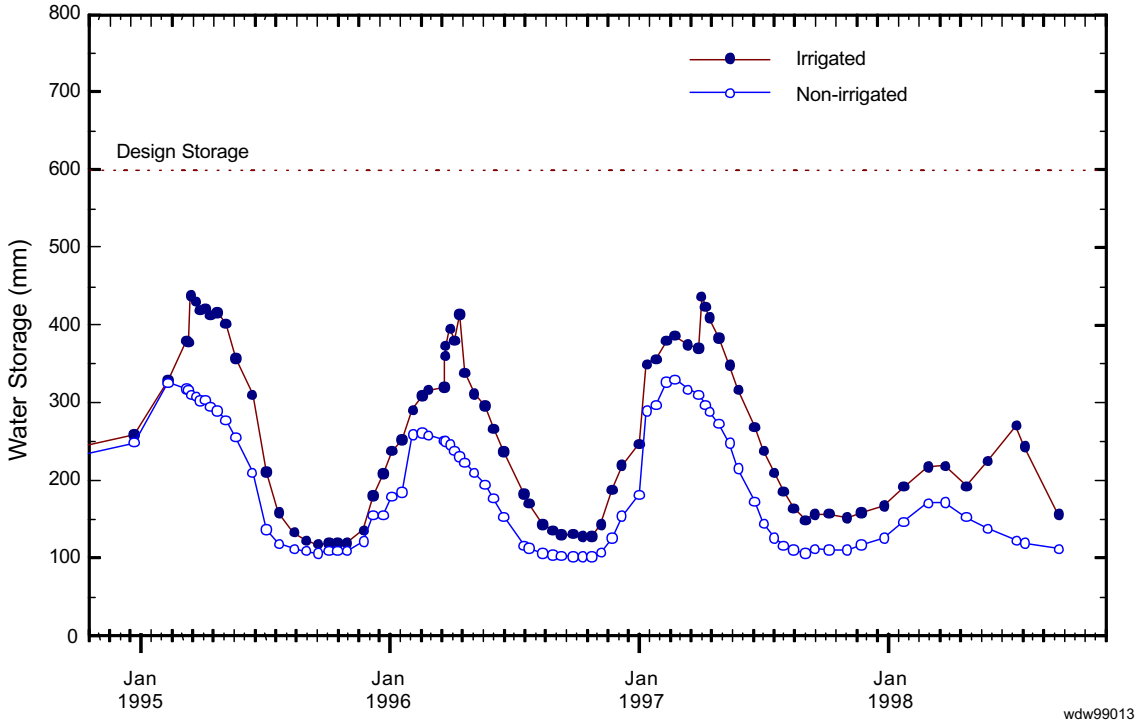

Figure 3.3-2. Temporal Variation in Mean Soil Water Storage at the Prototype Barrier, November 1994 to September 1998

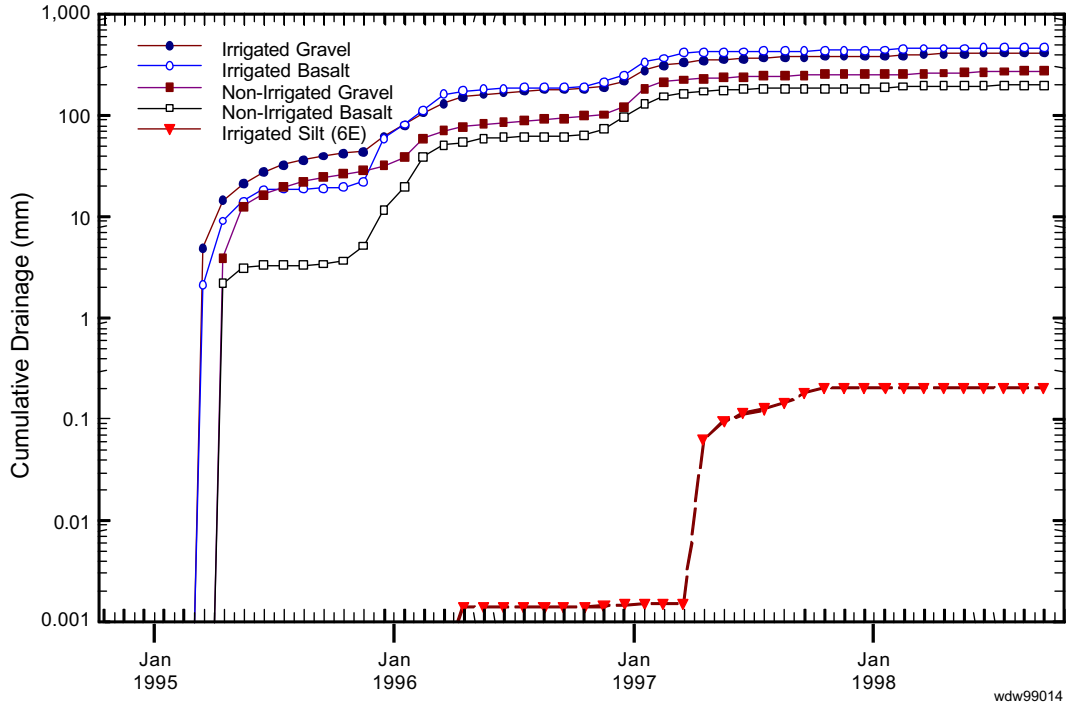

Figure 3.3-3. Cumulative Drainage from November 1994 through September 1998 from Four Side-Slope Plots and One Soil Plot that Drained

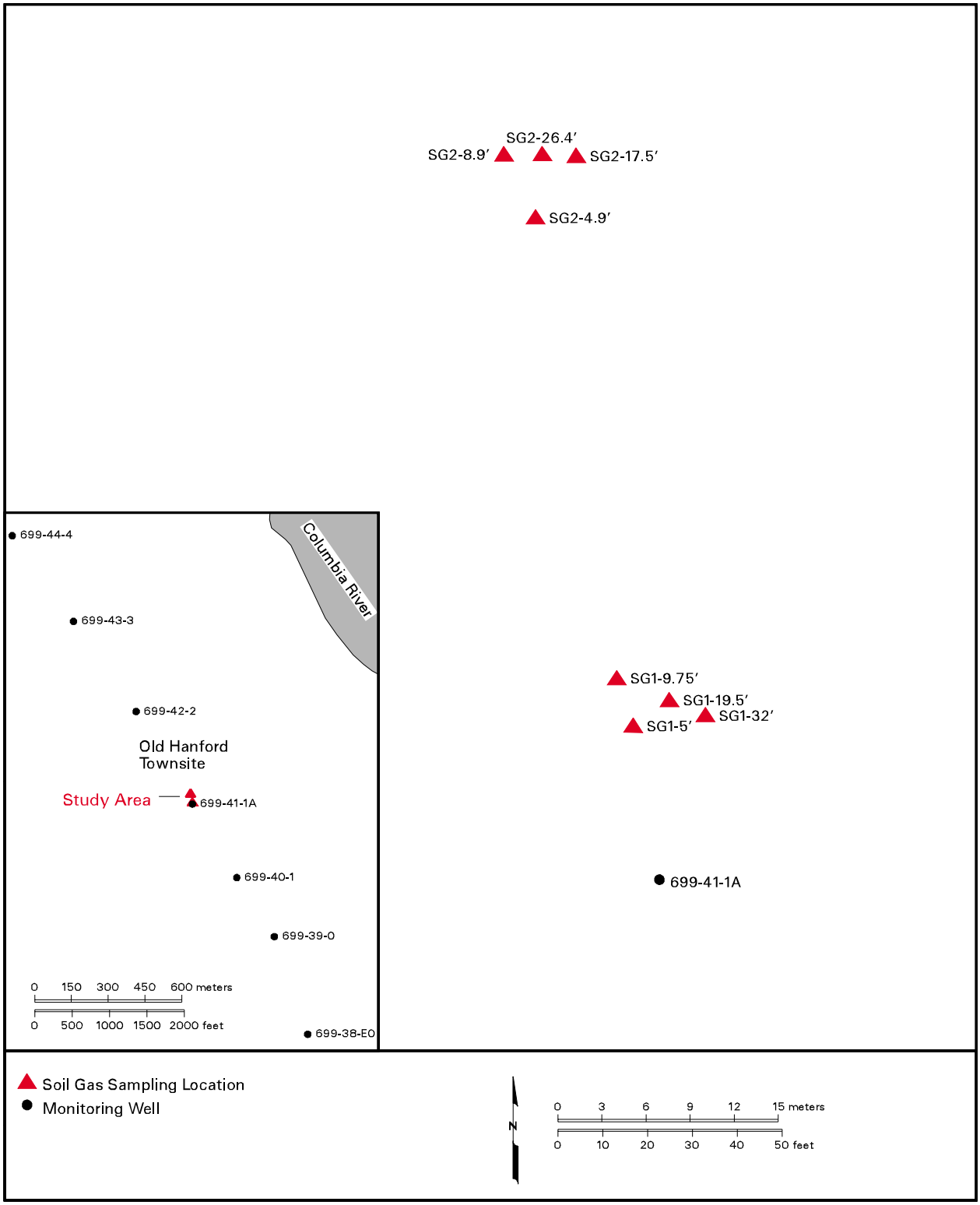

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Figure 3.3-4. Location of Soil Gas Sampling Points Adjacent to Well 699-41-1 Near the Old Hanford Townsite

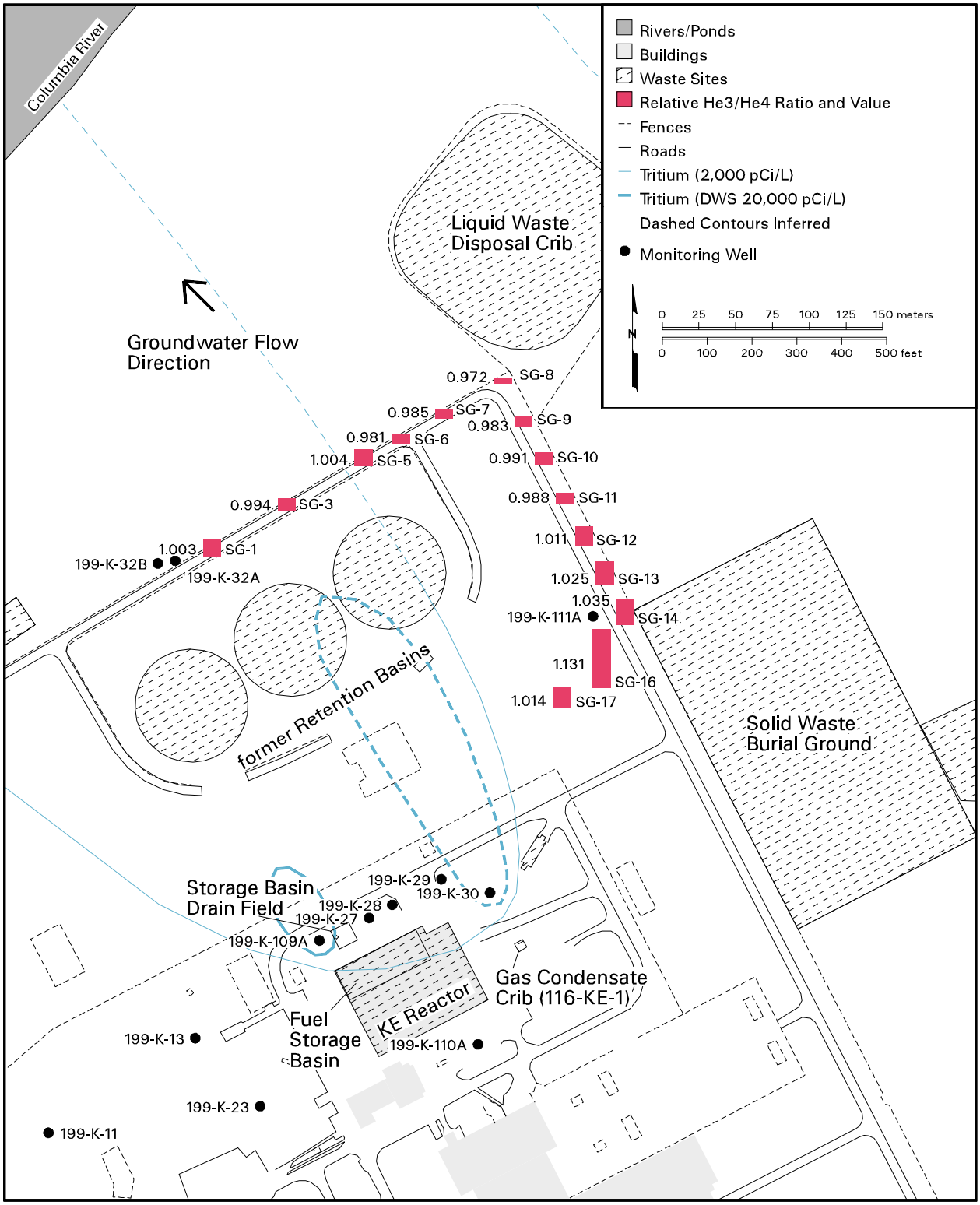

Figure 3.3-5. Helium-3/Helium-4 Ratios at the Study Site Near KE Reactor

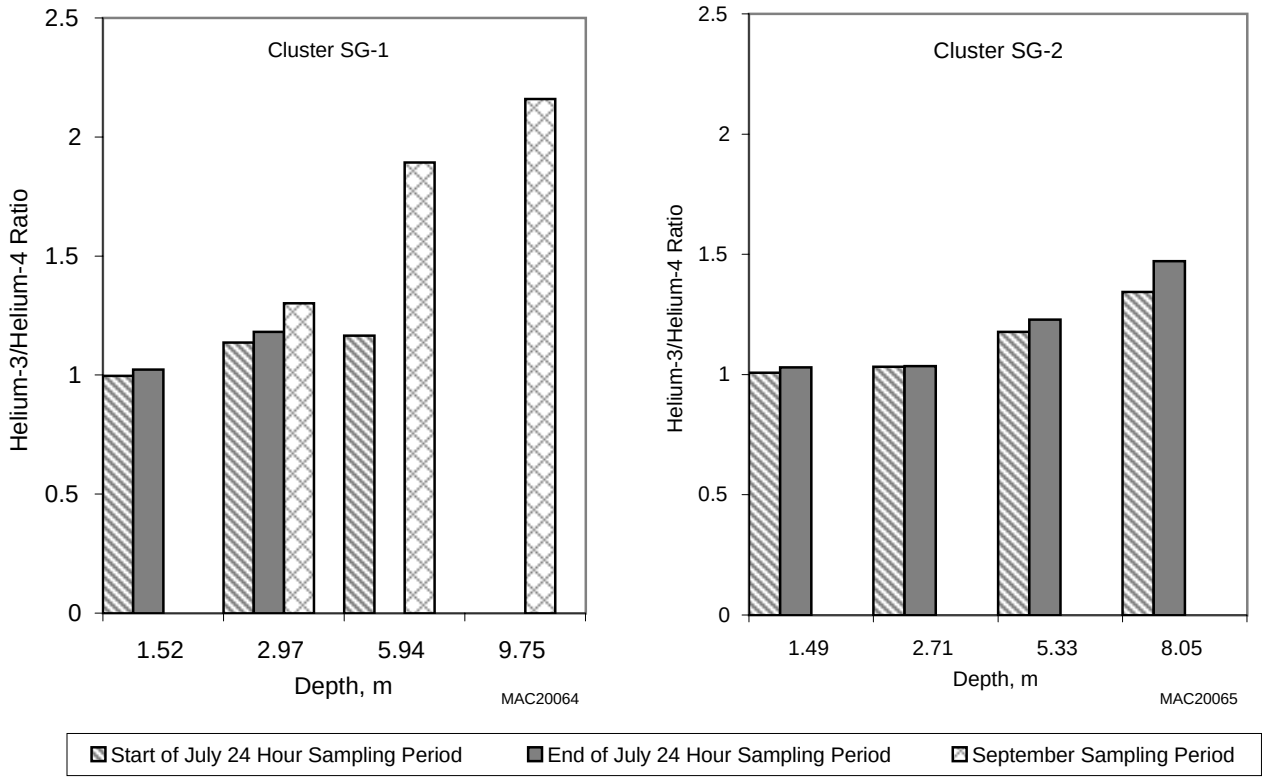

Figure 3.3-6. Comparison of Helium-3/Helium-4 Ratios for Samples Collected at the Old Hanford Townsite. Cluster SG-1 is ~12 meters from well 699-42-1A and cluster SG-2 is ~48 meters from well 699-42-1A