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Pacific Northwest
National Laboratory
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U.S. Department of Energy

# Measurement of Helium-3/ Helium-4 Ratios in Soil Gas at the 618-11 Burial Ground

K. B. Olsen
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October 2001


Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

# Summary

Pacific Northwest National Laboratory, in support of Bechtel Hanford, Inc., sampled and analyzed soil gas for helium-3 and helium-4 concentrations from the vicinity of the 618-11 burial ground. Helium-3, the first daughter product from tritium decay, was used to investigate the source and extent of tritium contamination in the area. Helium-3 is a non-reactive tracer for tritium in groundwater or the vadose zone.

Seventy soil gas sampling points were installed around the perimeter of the 618-11 burial ground, approximately 122 meters (400 feet) downgradient of well 699-13-3A, and in four transects downgradient of the burial ground to a maximum distance of 945.5 meters (3,100 feet). Soil gas samples were collected, analyzed for helium isotopes, and helium-3/helium-4 ratios were calculated from these 70 points. Helium-3/helium-4 ratios determined from the sampling points showed significant enrichments, compared to ambient air helium-3/helium-4 ratios. The highest helium-3/helium-4 ratios (normalized to the abundances in ambient air) were located along the north perimeter of the burial ground. Helium-3/helium-4 ratios ranged from 1.0 to 62 around the burial ground. The helium-3/helium-4 ratios from the 4 transect downgradient of the burial ground ranged from 0.988 to 1.68.

The helium-3/helium-4 ratios from around the burial ground suggest there is a vadose zone source of tritium along the north side of the burial ground. This vadose zone source is likely the source of tritium in the groundwater. The helium-3/helium-4 ratios also suggest the groundwater plume is traveling east-northeast from the burial ground and the highest groundwater tritium value may be to the north of well 699-13-3A. Finally, there appears to be no immediately upgradient sources of tritium impacting the burial ground since all the upgradient helium-3/helium-4 ratios approach or equal the air background level of 1.0. Based on the helium-3/helium-4 results from the soil gas survey, six downgradient groundwater grab and well locations were identified to verify the tritium groundwater plume locations, tritium groundwater concentrations as a function of depth in aquifer, and tritium groundwater concentrations. The measurement of helium isotopes in soil gas provided a rapid and cost-effective technique to define the shape and extent of tritium contamination from the 618-11 burial ground.

# Acknowledgments

We would like to acknowledge the help of $CH_2M$ HILL Hanford, Inc. staff for their assistance installing the soil gas sampling points. We would like to also acknowledge Dr. Robert Poreda of the University of Rochester for rapid analysis of the soil gas samples and assistance in data interpretation. Special thanks go to James (Mike) Faurote, William McMahon, Jane Borghese, and Roger Ovink.

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# Introduction

This study measured helium-3/helium-4 ratios relative to ambient air in soil gas samples to detect and delineate groundwater tritium plumes originating from the 618-11 burial ground. This approach is a modification of a successful technique developed in the late 1960s used for age-dating deep ocean water as part of the GEOSECS ocean monitoring program and applied to shallow aquifers in the late 1980s by Poreda et al. (1988) and Schlosser et al. (1988). An earlier study was conducted in 1999 on the Hanford Site to demonstrate proof of concept of using helium-3 as a tool to locate vadose zone sources of tritium and tracking groundwater tritium plumes (Olsen et. al. 1999). All these studies were based on the presence of tritium, which decays to a stable, inert isotope, helium-3, i.e.:

$$^{3}H \rightarrow {}^{3}He + \beta^{-} \quad t_{½} = 12.32 \text{ yr}$$

When soil moisture reacts with tritium waste, the result is tritiated moisture that is released into the vadose zone. The soil moisture mixes with meteoritic moisture and migrates downward to mix with groundwater. Concurrent with tritium's release to the vadose zone its daughter isotope, helium-3, begins to build up in the vadose zone and groundwater at the rate of tritium decay. The helium-3 then diffuses away from its vadose or groundwater source and migrates toward the surface. Throughout this process helium-3, acts as a nonreactive tracer for tritium. Because of helium-3 nonreactive behavior it is a good surrogate tracer for tritium in the vadose zone and groundwater.

This helium soil-gas survey was part of a study designed to help define the tritium plume originating from the 618-11 burial ground. This study began in January 2000 after elevated tritium was detected in well 699-13-3A, immediately east of the burial ground.

# Historical Background

The 618-11 burial ground consists of 3 trenches, 2 to 5 large-diameter caissons, and 50 vertical pipe storage units. The site covers an area of 3.5 hectares (8.6 acres) and is located adjacent to Energy Northwest Plant 2. The trenches are 274 meters (900 feet) long by 15 meters (50 feet) wide; vertical pipe units are five 208 liter (55 gallon) drums welded together end-to-end and are approximately 4.6 meters (15 feet) long by 56 centimeters (22 inches.) in diameter. The caissons are metal pipe 2.4 meters (8 feet) in diameter, 3 meters (10 feet) long, buried vertically 4.6 meters (15 feet) below grade, connected to the surface by offset pipe 91 centimeters (36 inches) in diameter pipe with a dome-type cap. All vertical pipe units and caissons were capped with concrete and covered with dirt (Demiter and Greenhalgh 1997).

The burial ground received low to high-activity dry waste, fission products, plutonium, and other transuranic constituents in a variety of waste forms from research operations associated with the 300 Area (DOE 2000). The burial ground operated from 1962 through 1967 (DOE 2000). The operation of this burial ground coincided with the development of the lithium aluminate tritium target project on the

Hanford Site. Circumstantial evidence suggests that tritium targets, as irradiated lithium aluminate, may have been disposed to the burial ground during its operational lifetime.

Driven by the strategic need for tritium production by our weapons program, it was recognized that co-production of plutonium and tritium during operations of the reactor would be technically, economically and strategically attractive. Thus, General Electric Company initiated a coproduct program for N Reactor early in 1963. Several fuel-target models were tested in the reactor and testing culminated in October 1965 with the selection of the Mark II design used for full reactor demonstrations. After irradiation tritium must efficiently be removed from the targets. Development of a tritium extraction process for ceramic targets was jointly assigned to Battelle, Pacific Northwest Laboratory and Savannah River Laboratories. Initial research in the development of a process for recovering tritium from irradiated lithium aluminate was done with samples weighing less than one gram. Production-size pellets (70 grams [2.5 ounces]) became available on February 7, 1966 (Johnson et al. 1976). These pellets were used in a series of experiments designed to determine the characteristics of the tritium extraction. Results of this study estimated that each target contained approximately 51 curies of tritium and that 35% of the tritium was recovered in a non-condensable form at -196°C with the remainder recovered in a condensable form as $T_2O$ or HTO. Furthermore, residual tritium remaining with the lithium aluminate target after processing ranged from <0.4 to 5% (Yunker 1976). Based on the aforementioned information, tritium remaining in each target could range from 0.204 curies to 2.55 curies. The condensable form is believed to be what mainly remains within the lithium aluminate target material after processing. This form is also an environmental labile form, which when released to the environment reacts with soil moisture in the vadose zone and can be carried downward with meteoritic water to groundwater.

# Methods

Seventy points to sample soil gas were installed during the course of this study. Forty-three sampling points were installed in August 2000 around the 618-11 burial ground and within 122 meters (400 feet) to the east (downgradient) of the burial ground. Twenty-seven sampling points were installed in April to May 2001 in four transects to the east of the burial ground. Sampling points ranging from 305 meters (1,000 feet) to the north, 518.5 meters (1,700 feet) to the south, and 945.5 meters (3,100 feet) to the east of groundwater monitoring well 699-13-3A. The logic for locating the soil gas points in the four transects are presented in the discussion section of this report.

## Sample Point Installation

Sampling points for soil gas were installed using a truck mounted Geoprobe™ Model 5400 system equipped with a probe 3.2 centimeters (1.25 inches) in diameter with a detachable steel tip. Target depth of installation of the screen interval was 6.1 meters (20 feet) below ground surface (bgs), but actually ranged from 4.4 to 6.3 meters (14.5 to 20.5 feet) bgs. When the tip achieved its desired depth, a 20.3 centimeter (8 inch) long, fine-mesh, stainless steel sampling point connected to the surface with a

polyethylene tube 1/4 inch outside diameter by 3/32 inch inside diameter that was strung down the center of the push rod. The rod assembly was withdrawn 15.2 centimters (6 inches) to release the steel tip and allow the sampling point to extend into the void space just below the push rod. Approximately 250 milliliters of 20 to 40 mesh washed silica sand was added around the sampling point through the center of the push rod. The push rod was slowly withdrawn and bentonite pellets were added through the center of the push rod. The bentonite was hydrated with 240 milliliters water several feet above the screened interval. Bentonite pellets were added to the surface of the hole. To complete those sampling points, a cement cap was poured around the sampling tube at the ground surface. Each sampling location was allowed to equilibrate for at least 24 hours and up to several weeks before soil gas samples were collected.

## Sample Collection

All samples were collected with the aid of a Thomas Model 107CA14 flexible diaphragm pump. Power to the pumps was supplied with a portable generator.

Pressurized samples were collected for helium analysis from each sampling location. The sampling vessels were 50-milliliter stainless steel cylinders with one end sealed with a pipe plug and the other end with a high vacuum needle valve with a 1/4-inch Swagelok™ fitting. Each vessel was evacuated to less than 5 torr before sampling. The sampling configurations used to collect helium-3 samples can be seen in Figure 1. After a short equilibration period (minutes), a Kurz Instruments™ mass flow meter was placed in the flow stream between the polyethylene raiser tube and the bottom of the rotometer. The initial flow was adjusted to 1 liter (0.035 cubic foot) per minute. The soil gas sampling point was allowed to purge at 1 liter (0.035 cubic foot) per minute for a minimum of 15 minutes. At the end of the purging period a hose was connected to the pressure side of the pump, and the sampling cylinder was pressurized to the maximum pressure of the pump, allowed to vent to atmospheric pressure twice without removing the sampling tube from the sample cylinder, then allowed to pressurize to the maximum pressure of the pump. Random duplicates were collected at 1 for every 20 samples, and an air background sample was included for each sampling day. When there were discontinuities in sampling (e.g., a day or weeks) a previously sampled soil gas location was resampled.

## Sample Analysis

After collection, soil gas samples were sent to the University of Rochester for helium isotopes (helium-3 and helium-4) analysis. Upon receipt of the samples, a 0.5 milliliters aliquot of soil gas was processed through a high vacuum line constructed of stainless steel and Corning-1724 glass to minimize helium diffusion. After removal of water vapor and carbon dioxide at -90°C and -195°C respectively, the amount of non-condensable gas (helium, neon, argon, oxygen, nitrogen, and methane) was measured using a calibrated volume and a capacitance manometer. Gas ratios (argon, nitrogen, methane) were analyzed on a Dycor Quadrupole mass spectrometer fitted with a variable leak valve. The results are combined with the capacitance manometer measurement to obtain gas concentrations (±2%). Prior to helium isotope analyses, nitrogen and oxygen were removed by reaction with zirconium/aluminum alloy (SAES ST707), argon and neon were adsorbed on activated charcoal at 77°K and at 40°K, respectively. SAES-ST-101 Getters (one in the inlet line and 2 in the mass spectrometer) reduced the $HD^+$ background to ~1,000 ions/sec.

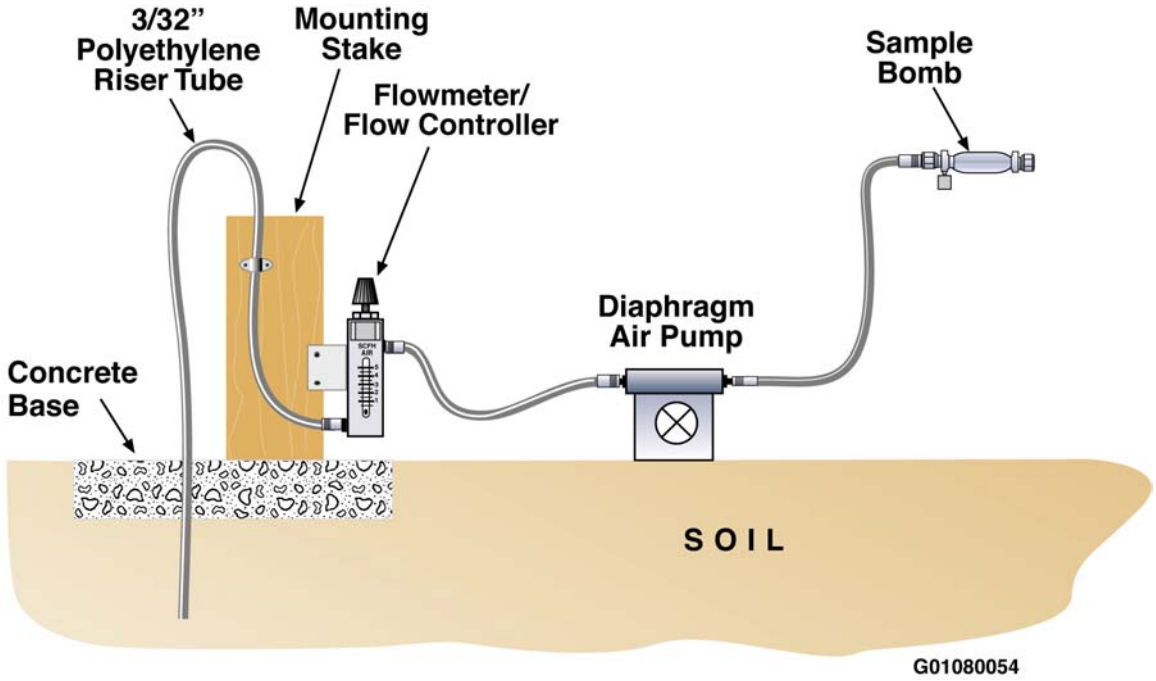


**Figure 1**. Schematic Diagram of the Soil Gas Sampling System Used for Collection of Helium Soil Gas Sample

Helium isotope ratios and concentrations were analyzed on a VG 5400 Rare Gas Mass Spectrometer fitted with a Faraday cup (resolution of 200) and a Johnston electron multiplier (resolution of 600) for sequential analyses of the helium-4 (F-cup) and helium-3 (multiplier) beams. On the axial collector (resolution of 600), $3He^+$ was completely separated from $HD^+$ with a baseline separation of <2% of the $HD^+$ peak. The contribution of $HD^+$ to the helium-3 peak was <0.1 ion/sec at 1,000 ions/sec of $HD^+$. For 2.0 ml of helium with an air ratio sensitivity of $2 \times 10^{-4}$ Amps/torr, the helium-3 signal averaged 2,500 ions/sec with a background signal of ~15 cps, due to either scattered helium-4 ions or the formation of helium-4 ions at lower voltage potentials within the source of the mass spectrometer. All helium-3/helium-4 ratios were reported relative to the atmospheric ratio ($R_A$), using air helium as the absolute standard. Errors in the helium-3/helium-4 ratios result from the precision of the sample measurement (±0.2%) and variation in the ratio measurement in air (±0.2%) and give a total error of ±0.3% at 2σ for the reported helium isotope value. Helium concentrations were derived from comparison of the total sample to a standard of known size. The value, as measured by peak height comparison, was accurate to ±1% (2σ).

# Results and Discussion

Sampling points for soil gas were installed and sampled in two time periods (DOE 2001). Installation of the first set of sampling points occurred in August and September 2000 around the 618-11 burial ground and within 122 meters (400 feet) of the burial ground in a downgradient direction from groundwater monitoring well 699-13-3A. The second set of sampling points were installed in April to May 2001 and focused on locations downgradient and cross-gradient of the groundwater flow direction beneath 618-11 burial ground. The second set of sampling points were arranged in four transects ranging 305 meters (1,000 feet) to the north, 518.5 meters (1,700 feet) to the south, and 945.5 meters (3,100 feet) to the east of groundwater monitoring well 699-13-3A located on the east side of the 618-11 burial ground. Complete information regarding the installation parameters of the soil gas sampling points can be found in Appendix A. Complete analytical results from all samples collected under this project are tabulated in Appendix B.

## Burial Ground Results

Figure 2 displays the results from soil gas samples collected from the perimeter and in the parking lot serving Energy Northwest (ENW) Plant 2 in the immediate vicinity of the burial ground downgradient of well 699-13-3A. Helium-3/helium-4 ratios ranged from 1.00 to 62.5 in this region. The highest helium-3/helium-4 ratios were located on the north side of the burial ground where two distinct maxima were observed. One maximum (62.5) was located near the middle of the north side fence line. The second maximum (10.93) was located at the northeast corner of the burial ground. The highest helium-3/helium-4 ratio along the north side of the burial ground was believed to be either from a tritium source in the vadose zone or tritium contaminated groundwater. In order to determine the likely source of helium-3 (vadose zone source or groundwater), a groundwater grab sample was collected at the location of the highest helium-3/helium-4 ratio. This sample was collected using cable tool drilling techniques. The groundwater grab sample from that location contained 6,510 pCi/l of tritium. After the sample was collected, the hole was abandoned. This result strongly suggested that the highest helium-3 concentrations midway along the north side of the burial ground was from a vadose source of tritium located within the burial ground rather than from tritium-contaminated groundwater. Thus, the likely source of the tritium is a series of caissons located along the north side of the burial ground.

The second helium-3/helium-4 maximum along the north side of the burial ground is located at the northeast corner. The source of the elevated helium-3/helium-4 ratios could also be from a vadose zone source of tritium or a tritium groundwater plume. However, it is believed that the source of the elevated helium-3/helium-4 ratios is from the tritium groundwater plume that affects well 699-13-3A. The tritium concentration in groundwater samples from that well measured from 1.86 to 8.38 million pCi/L (Figure 3). The direction of groundwater flow is believed to be in a generally easterly direction. It appears that the highest groundwater tritium concentration is slightly to the north of well 699-13-3A, corresponding to the highest helium-3/helium-4 ratios along the northeast corner of the burial ground, though this has not been confirmed by groundwater sampling. If you compare the helium-3/helium-4 ratio at the

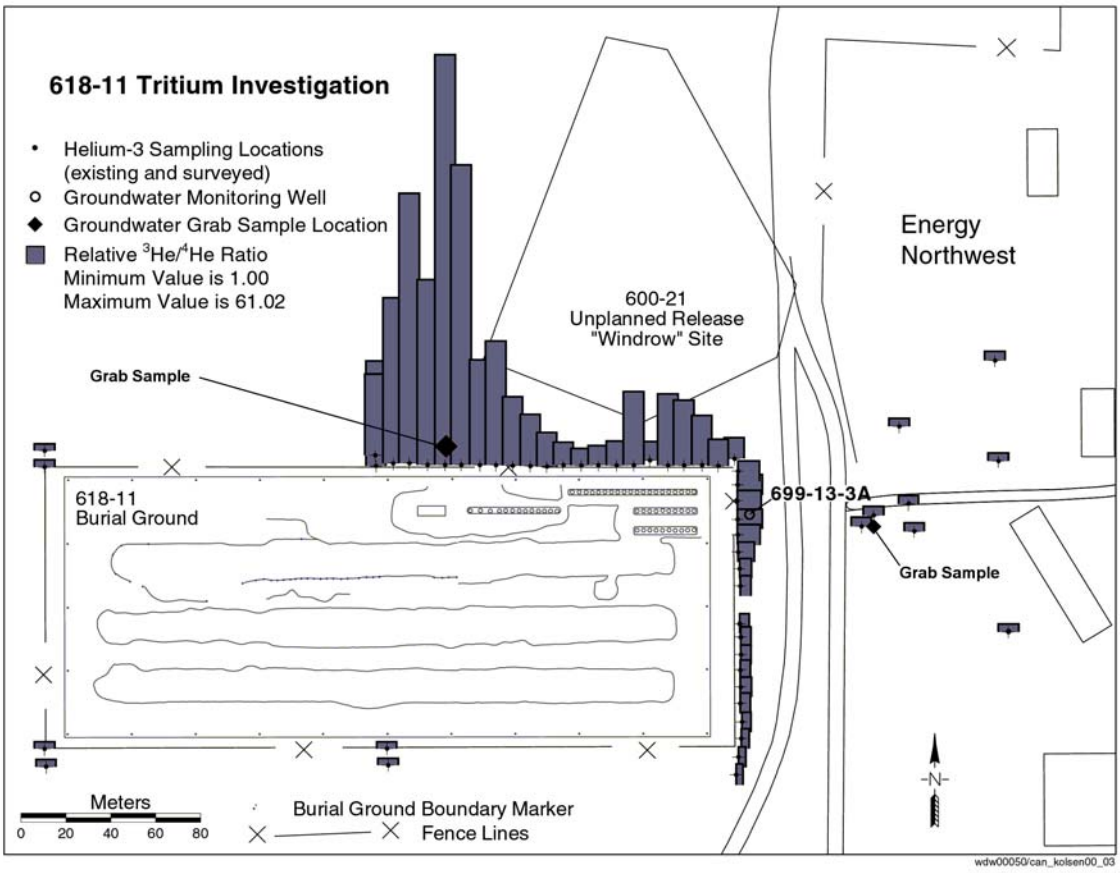


**Figure 2**. Helium-3/Helium-4 Ratio Results from Soil Gas Samples from Around 618-11 Burial Ground and Immediately Downgradient of Well 699-13-3A

soil gas point nearest the well (3.73) to the highest helium-3/helium-4 ratio at the northeast corner of the burial ground (10.93) one would estimate a tritium concentrations in groundwater below that point at between 23 to 24 million pCi/L.

The helium-3/helium-4 ratios on the east side of the burial ground are highest at the northeast corner, adjacent to well 699-13-3A, and decrease to 1.0 at the south side of the burial ground (Figure 4). This maximum helium-3/helium-4 ratio (3.73) is believed to be from the tritium groundwater plume affecting well 699-13-3A and follows the discussion presented above for the north side of the burial ground. There appears to be a second smaller maximum (1.63) located 45.7 meters (150 feet) north of the southeast corner of the burial ground. The second maximum may be a vadose zone source of tritium or a ground-water tritium source. The remaining points along the south and west sides of the burial ground are approach the ambient air helium-3/helium-4 background ratio of 1.0.

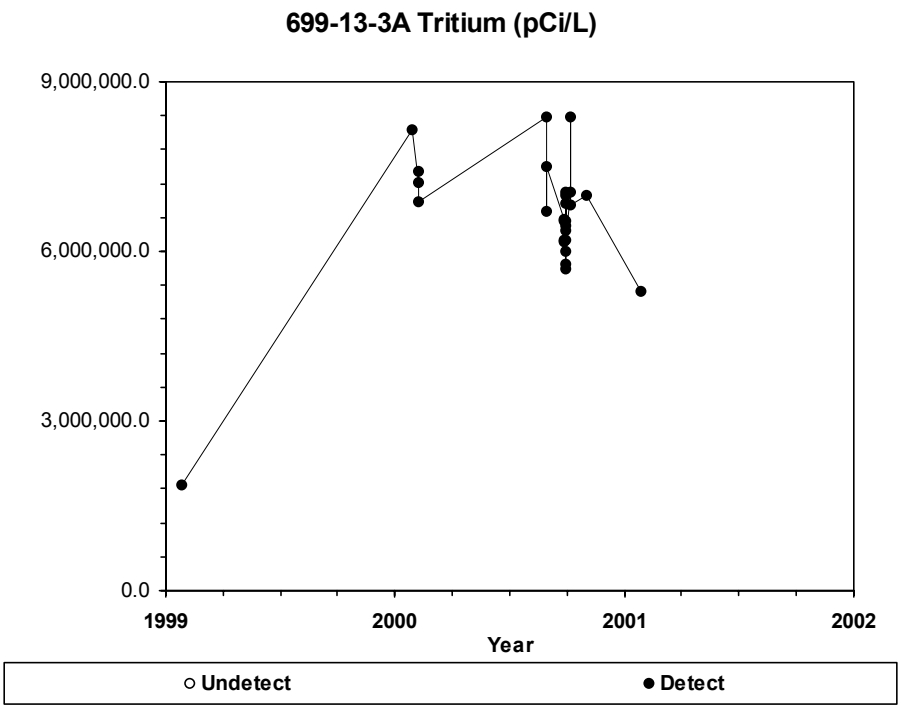


**Figure 3**. Tritium Concentrations from Well 699-13-3A

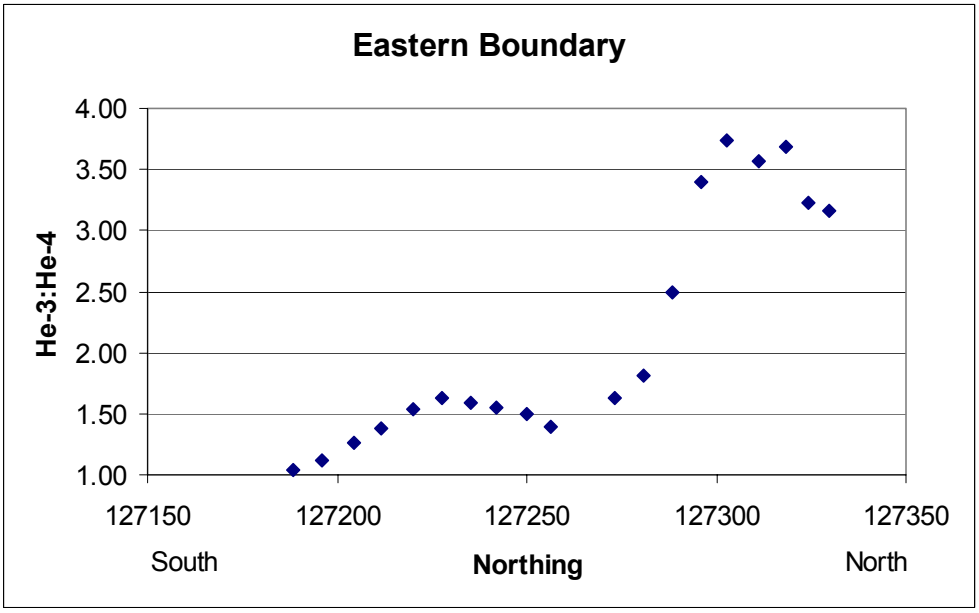


**Figure 4**. Helium-3/Helium-4 Ratio Results from Soil Gas Samples from the East Side of the 618-11 Burial Ground

## Downgradient Results

Helium-3/helium-4 ratios were determined in soil gas sampling points installed within 122 meters (400 feet) east of the 618-11 burial ground in an unpaved portion of a parking lot serving ENW Plant 2 in August and September 2000 and the four transects downgradient from the burial ground in April to May 2001. Soil gas sampling points in the four transects ranged from 305 meters (1,000 feet) to the north, 518.5 meters (1,700 feet) to the south, and 945.5 meters (3,100 feet) to the east of groundwater monitoring well 699-13-3A.

The helium-3/helium-4 ratios in the first round of sampling from soil gas locations within 122 meters (400 feet) of the burial ground ranged from 1.12 to 1.38. Based on these results, a groundwater grab sample was collected near the cluster of soil gas sampling points approximately 45.7 meters (150 feet) east of well 699-13-3A (see Figure 2). The tritium concentration in the groundwater from this grab sample location was measured at 1.5 million pCi/L.

Based on the helium-3/helium-4 results from the perimeter of burial ground and within a radius of 122 meters (400 feet) of well 699-13-3A in the downgradient direction and the two groundwater grab samples, a tritium groundwater plume appears to be heading east–northeast from the burial ground. Based on this assumption, 27 additional soil gas sampling points were installed in four transects further downgradient of well 699-13-3A (Figure 5). To assure there were no additional tritiums sources in the area of the 618-11 burial ground and, with some certainty, that helium-3/helium-4 ratios returned to background levels (1.00) Transect 1 and 3 spanned 793 meters (2,600 feet) and 732 meters (2,400 feet), respectively. Transect 2 consisted of two soil gas samples point. Transect 2 was limited because of industrial facilities and construction activities in the immediate area. Transect 4 was located 945.5 meters (3,100 feet) from well 699-13-3A and spanned 213.5 meters (700 feet) across the potential path of the tritium plume.

The helium-3/helium-4 ratios in Transect 1 ranged from 0.99 to 1.68. Background helium-3/helium-4 ratios were obtained at the ends of each transect and the maximum helium-3/helium-4 ratios were near the imaginary centerline of the tritium plume generated from earlier data. The graph of data from Transect 1 shows that the helium-3/helium-4 signal has an asymmetrical shape with high ratios extending farther south of the maximum point (Figure 6). This asymmetry appears to be an extension of the secondary maximum seen along the east boundary of the burial ground (see Figure 4).

The helium-3/helium-4 ratios in Transect 2, which included only two sampling points, ranged from 1.06 to 1.27. The highest ratio was closest to the imaginary centerline of the plume.

The helium-3/helium-4 ratios in Transect 3 ranged from 0.987 to 1.049. Clearly elevated helium-3/ helium-4 ratios were only seen in two sampling points. Background helium-3/helium-4 ratios were obtained at the ends of each transect and the maximum helium-3/helium-4 ratios were near the imaginary centerline of the tritium plume generated from the earlier data.

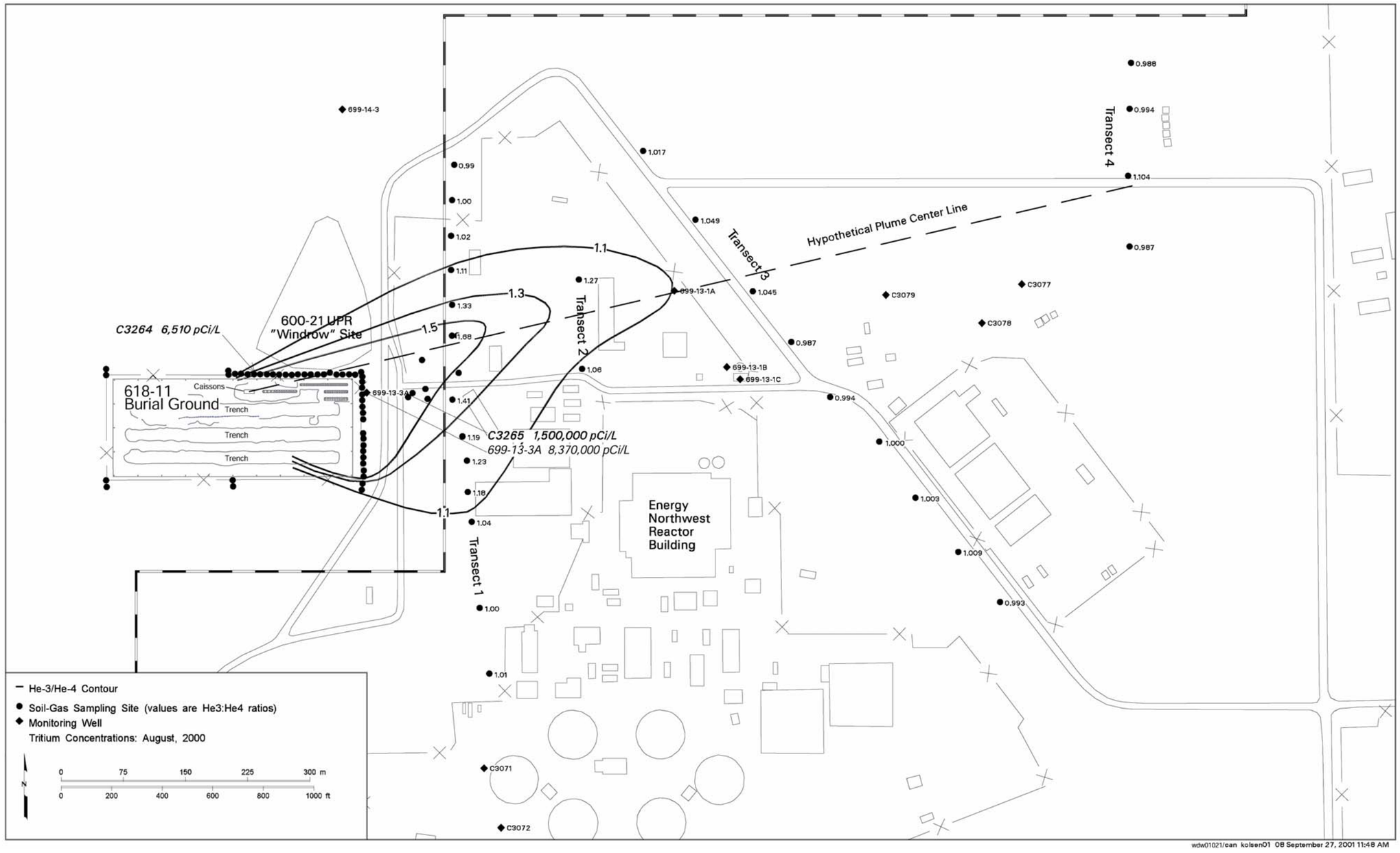


**Figure 5**. Results of Helium-3/Helium-4 Ratio Results from Soil Samples Downgradient of the 618-11 Burial Ground

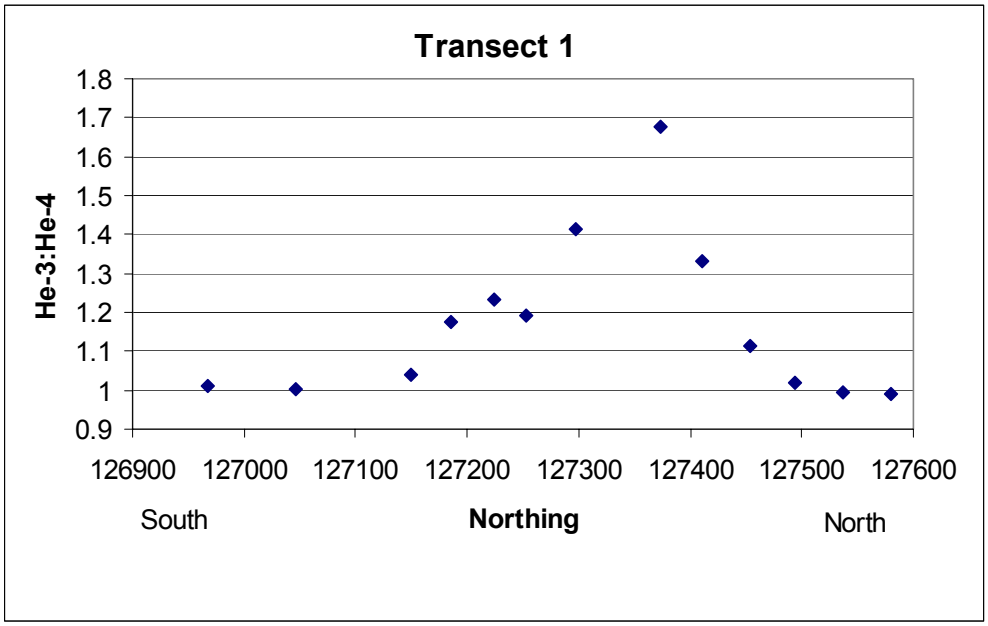


**Figure 6**. Helium-3/Helium-4 Ratio Results from Soil Gas Samples from Transect 1

The helium-3/helium-4 ratios in Transect 4 ranged from 0.987 to 1.104. Background helium-3/helium-4 ratios were obtained at the ends of each transect and elevated helium-3/helium-4 ratios were observed in only one sampling point. Transect 4 is topographically lower than the other transects so the sample points are closer to the water table. This may explain why the maximum helium-3/helium-4 ratio seen in Transect 4 is greater than the maximum seen closer to the source, in Transect 3.

# Conclusions

The helium soil gas measurement provided a rapid and cost-effective technique to define the probable shape and extent of tritium contamination from the 618-11 burial ground. Based on the helium-3/helium-4 ratio results from around the burial ground and the groundwater grab samples from the highest helium-3/helium-4 ratio on the north side, the main vadose zone source of the tritium is likely from within the burial ground near the mid point of the north side. The second helium-3/helium-4 ratio maximum located at the northeast corner of the burial ground is probably from the groundwater tritium plume affecting well 699-13-3A.

Based upon the helium-3/helium-4 ratio data immediately downgradient of burial ground 618-11 and the downgradient transects, a groundwater tritium plume appears to be traveling toward the east-northeast direction. The tritium groundwater plume has reached the furthest transect for the burial ground 950 meters (3,100 feet) downgradient of the burial ground. The width of the tritium plume is estimated to

be 305 meters (1,000 feet) at Transect 1, 204.3 meters (670 feet) at Transect 3, and 88.5 meters (290 feet) at Transect 4. The helium-3/helium-4 ratio results also suggest there are no other tritium sources either upgradient of the burial ground or cross gradient of the burial ground. Based on the helium-3/helium-4 results from the soil gas survey, 6 downgradient groundwater grab and well locations were identified to verify the tritium groundwater plume locations, tritium groundwater concentrations as a function of depth in aquifer, and tritium groundwater concentrations.

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# Appendix A

# Installation Parameters of Soil Gas Sampling Points

**Table A.1.** Soil Gas Sampling Point Information at 618-11 Burial Ground

| Point Name | Alias | Screen Depth (ft BGS) | Date Installed | Date Surveyed | Northing (m) | Easting (m) | Elevation (m) | Comments |
|---|---|---|---|---|---|---|---|---|
| C 3141 | N6 | 19 -19.5 | 8/3/2000 | 08/15/00 | 127329.254 | 589093.027 | 135.833 | Depth test for the GW sampling point |
| C 3142 | W0 | 19.5-20 | 8/4/2000 | 08/15/00 | 127329.908 | 589130.726 | 135.958 | Depth test for the GW sampling point |
| C 3188 | 618-11-S1 | 19.5-20.0 | 8/4/2000 | 08/15/00 | 127318.316 | 589132.085 | 136.065 | The S was later changed to "E" |
| C 3189 | 618-11-S2 | 19.8-20.4 | 8/4/2000 | 08/15/00 | 127311.144 | 589131.958 | 136.176 | The S was later changed to "E" |
| C 3190 | 618-11-S3 | 19.5-20.0 | 8/4/2000 | 08/15/00 | 127302.869 | 589132.067 | 136.200 | The S was later changed to "E" |
| C 3191 | 618-11-S4 | 19.6-20.1 | 8/7/2000 | 08/15/00 | 127295.982 | 589132.132 | 136.218 | The S was later changed to "E" |
| C 3192 | 618-11-S5 | 19.9-20.4 | 8/7/2000 | 08/15/00 | 127288.201 | 589132.284 | 136.213 | The S was later changed to "E" |
| C 3193 | 618-11-S6 | 19.4-19.9 | 8/7/2000 | 08/15/00 | 127280.790 | 589132.992 | 136.352 | The S was later changed to "E" |
| C 3194 | 618-11-S7 | 19.6-20.1 | 8/7/2000 | 08/15/00 | 127273.039 | 589133.273 | 136.439 | The S was later changed to "E" |
| C 3195 | 618-11-S8 | 19.6-20.1 | 8/7/2000 | 10/02/00 | 127256.187 | 589133.114 | 136.091 | The S was later changed to "E" |
| C 3196 | 618-11-S9 | 19.7-20.2 | 8/7/2000 | 10/02/00 | 127250.204 | 589133.544 | 135.859 | Thread Failure move hole 2' east |
| C 3197 | 618-11-S10 | 19.6-20.1 | 8/8/2000 | 08/15/00 | 127242.059 | 589133.594 | 135.622 | |
| C 3198 | nw cor | 16.6-20.1 | 8/9/2000 | 08/15/00 | 127326.278 | 588823.182 | 136.389 | |
| C 3199 | nw cor-n | 19.5-20.0 | 8/9/2000 | 08/15/00 | 127333.559 | 588823.214 | 136.729 | 25 feet north of C3198 |
| C 3200 | sw cor | 19.9-20.4 | 8/9/2000 | 08/15/00 | 127199.910 | 588823.146 | 135.949 | |
| C 3201 | sw cor-s | 19.8-20.3 | 8/9/2000 | 08/15/00 | 127191.926 | 588823.859 | 135.775 | 25 feet south of C3200 |
| C 3202 | south half | 19.7-20.2 | 8/9/2000 | 08/15/00 | 127200.054 | 588975.791 | 135.424 | Midpoint of the south fenceline |
| C 3203 | south half-s | 19.4-19.9 | 8/9/2000 | 08/15/00 | 127192.580 | 588976.346 | 135.444 | 25 feet south of C3202 |
| C 3204 | north half | 19.5-20.0 | 8/9/2000 | 08/15/00 | 127326.771 | 588970.900 | 136.278 | |
| C 3205 | north half-n | 19.6-20.1 | 8/10/2000 | 08/15/00 | 127331.543 | 588970.571 | 136.463 | 25 feet north of C3204 |
| C 3206 | Parking lots | 19.3-19.8 | 8/10/2000 | 9/12-13/00 | 127299.695 | 589187.351 | 135.628 | GPR segment H |
| C 3207 | Parking lots | 19.7-20.2 | 8/10/2000 | 9/12-13/00 | 127304.658 | 589192.737 | 135.587 | GPR segment H |
| C 3208 | Parking lots | 19.8-20.3 | 8/10/2000 | 9/12-13/00 | 127297.561 | 589210.873 | 135.436 | GPR segment F |
| C 3209 | Parking lots | 19.5-20.0 | 8/10/2000 | 9/12-13/00 | 127344.418 | 589204.174 | 135.657 | GPR segment G |
| C 3210 | Parking lots | 19.5-20.0 | 8/11/2000 | 9/12-13/00 | 127373.853 | 589246.850 | 135.816 | GPR segment J |
| C 3211 | Parking lots | 18.5-19.0 | 8/11/2000 | 10/02/00 | 127252.613 | 589252.957 | 135.192 | Beside the connex boxes |
| C 3212 | Parking lots | 19.2-19.7 | 8/18/2000 | 10/02/00 | 127309.561 | 589208.335 | 135.599 | North End of GPR segment F |
| C 3213 | Parking lots | 19.15-19.75 | 8/18/2000 | 9/12-13/00 | 127328.921 | 589248.357 | 135.468 | South of GPR segment J |
| C 3214 | E11 | 19.1-19.6 | 8/18/2000 | 9/12-13/00 | 127235.127 | 589133.250 | 135.598 | |
| C 3215 | E12 | 19.45-20.05 | 8/18/2000 | 9/12-13/00 | 127227.522 | 589133.417 | 135.435 | |
| C 3216 | E13 | 18.9-19.5 | 8/18/2000 | 9/12-13/00 | 127220.207 | 589133.231 | 135.492 | |
| C 3217 | E14 | 19.6-30.2 | 8/19/2000 | 9/12-13/00 | 127211.747 | 589134.015 | 137.794 | |
| C 3218 | E15 | 19.6-20.2 | 8/19/2000 | 9/12-13/00 | 127204.400 | 589133.724 | 137.820 | |
| C 3219 | E16 | 19.55-20.15 | 8/19/2000 | 9/12-13/00 | 127196.073 | 589132.456 | 136.405 | |
| C 3220 | E17 | 18.9-19.5 | 8/19/2000 | 9/12-13/00 | 127188.487 | 589131.545 | 136.324 | |
| C 3221 | E0 | 19.4-20 | 8/19/2000 | 9/12-13/00 | 127324.416 | 589132.247 | 135.991 | |
| C 3222 | N21 | 19.4-20.0 | 8/23/2000 | 9/12-13/00 | 127327.821 | 588978.550 | 136.239 | |
| C 3223 | N20 | 18.46-19.04 | 8/23/2000 | 9/12-13/00 | 127327.952 | 588985.786 | 136.297 | |
| C 3224 | N19 | 19.4-20.0 | 8/23/2000 | 9/12-13/00 | 127327.275 | 588993.879 | 136.410 | |
| C 3225 | N18 | 19.7-20.3 | 8/23/2000 | 9/12-13/00 | 127327.281 | 589001.707 | 136.227 | |
| C 3226 | N17 | 19.6-20.2 | 8/23/2000 | 9/12-13/00 | 127327.261 | 589008.919 | 136.225 | |

**Table A.1**. (contd)

| Point Name | Alias | Screen Depth (ft BGS) | Date Installed | Date Surveyed | Northing (m) | Easting (m) | Elevation (m) | Comments |
|---|---|---|---|---|---|---|---|---|
| C 3227 | N16 | 19.3-19.9 | 8/23/2000 | 9/12-13/00 | 127327.163 | 589017.205 | 136.141 | |
| C 3228 | N15 | 19.6-20.2 | 8/23/2000 | 9/12-13/00 | 127327.074 | 589024.384 | 136.075 | |
| C 3229 | N14 | 19.6-20.2 | 9/6/2000 | 9/12-13/00 | 127326.841 | 589031.872 | 136.219 | |
| C 3230 | N13 | 19.6-20.2 | 9/6/2000 | 9/12-13/00 | 127326.681 | 589039.691 | 136.253 | |
| C 3231 | N12 | 19.5-20.1 | 9/6/2000 | 9/12-13/00 | 127326.489 | 589047.095 | 135.973 | |
| C 3232 | N11 | 19.5-20.1 | 9/6/2000 | 9/12-13/00 | 127327.149 | 589054.440 | 135.876 | |
| C 3233 | N10 | 19.9-20.5 | 9/6/2000 | 9/12-13/00 | 127326.951 | 589062.442 | 135.888 | |
| C 3234 | N9 | 19.9-20.5 | 9/6/2000 | 9/12-13/00 | 127327.119 | 589069.959 | 135.904 | |
| C 3235 | N8 | 19.5-20.1 | 9/7/2000 | 9/12-13/00 | 127326.984 | 589078.172 | 136.020 | |
| C 3236 | N7 | 19.7-20.3 | 9/7/2000 | 9/12-13/00 | 127327.095 | 589085.812 | 136.022 | |
| C 3237 | N5 | 19.3-19.9 | 9/7/2000 | 9/12-13/00 | 127326.927 | 589101.077 | 136.017 | |
| C 3238 | N4 | 19.4-20.0 | 9/7/2000 | 9/12-13/00 | 127327.039 | 589108.229 | 136.041 | |
| C 3239 | N3 | 19.5-20.1 | 9/7/2000 | 9/12-13/00 | 127327.140 | 589116.232 | 135.945 | |
| C 3240 | N2 | 19.4-20.0 | 9/7/2000 | 9/12-13/00 | 127326.776 | 589123.503 | 135.935 | |
| C 3249 | | 16.5-16.0 | 5/9/2001 | 5/11/2001 | 127647.125 | 590057.694 | 125.972 | |
| C 3250 | | 16.3-15.8 | 5/9/2001 | 5/11/2001 | 127702.452 | 590059.458 | 125.69 | |
| C 3483 | | 15.0-14.5 | 5/8/2001 | 5/11/2001 | 127053.27 | 589901.427 | 126.014 | |
| C 3484 | | 20.0-19.5 | 5/8/2001 | 5/11/2001 | 127113.639 | 589851.07 | 127.426 | |
| C 3485 | | 20.0-19.5 | 5/8/2001 | 5/11/2001 | 127178.944 | 589799.375 | 128.283 | |
| C 3486 | | 20.2-19.7 | 5/8/2001 | 5/11/2001 | 127246.56 | 589755.769 | 128.504 | |
| C 3487 | | 20.2-19.7 | 5/8/2001 | 5/11/2001 | 127299.865 | 589696.414 | 130.123 | |
| C 3488 | | 20.25-19.75 | 5/8/2001 | 5/11/2001 | 127366.219 | 589649.639 | 130.765 | |
| C 3489 | | 20.25-19.75 | 5/9/2001 | 5/11/2001 | 127427.258 | 589603.181 | 133.165 | |
| C 3490 | | 20.2-19.7 | 5/9/2001 | 5/11/2001 | 127513.475 | 589534.005 | 135.445 | |
| C 3491 | | 20.3-19.8 | 5/9/2001 | 5/11/2001 | 127596.346 | 589470.858 | 134.837 | |
| C 3492 | | 16.8-16.3 | 5/9/2001 | 5/11/2001 | 127481.186 | 590057.625 | 125.888 | |
| C3493 | | 19.8-19.3 | 5/9/2001 | 5/11/2001 | 127566.361 | 590055.868 | 126.102 | |
| C3469 | | 19.5'-19.0' | 4/18/2001 | 4/23/2001 | 127579.639 | 589243.052 | 134.04 | |
| C3470 | | 19.3'-18.8' | 4/18/2001 | 4/23/2001 | 127537.056 | 589240.416 | 133.631 | |
| C3471 | | 20.0'-19.5' | 4/18/2001 | 4/23/2001 | 127494.079 | 589239.278 | 133.6 | |
| C 3472 | | 20.5'-20.0' | 4/18/2001 | 4/23/2001 | 127452.979 | 589239.277 | 135.356 | |
| C 3473 | | 19.9'-19.4' | 4/18/2001 | 4/23/2001 | 127410.927 | 589240.525 | 135.567 | |
| C 3474 | | 20.2'-19.7' | 4/18/2001 | 4/23/2001 | 127373.743 | 589240.352 | 135.833 | |
| C 3475 | | 20.3'-19.8' | 4/18/2001 | 4/23/2001 | 126967.051 | 589285.362 | 136.487 | |
| C 3476 | | 20.3'-19.8' | 4/18/2001 | 4/23/2001 | 127185.846 | 589259.388 | 135.435 | |
| C 3477 | | 19.0'-18.5' | 4/19/2001 | 4/23/2001 | 127149.912 | 589264.098 | 135.28 | |
| C 3478 | | 20.2'-19.7' | 4/19/2001 | 4/23/2001 | 127441.391 | 589393.346 | 135.326 | |
| C 3479 | | 20.4'-19.9' | 4/19/2001 | 4/23/2001 | 127333.747 | 589397.257 | 135.357 | |
| C 3480 | | 20.5'-20.0' | 4/19/2001 | 4/23/2001 | 127296.713 | 589240.843 | 135.329 | |
| C 3481 | | 20.3'-19.8' | 4/19/2001 | 4/23/2001 | 127046.197 | 589273.755 | 135.797 | |
| C 3482 | | 20.5'-20.0' | 4/19/2001 | 4/23/2001 | 127223.636 | 589258.417 | 135.305 | |

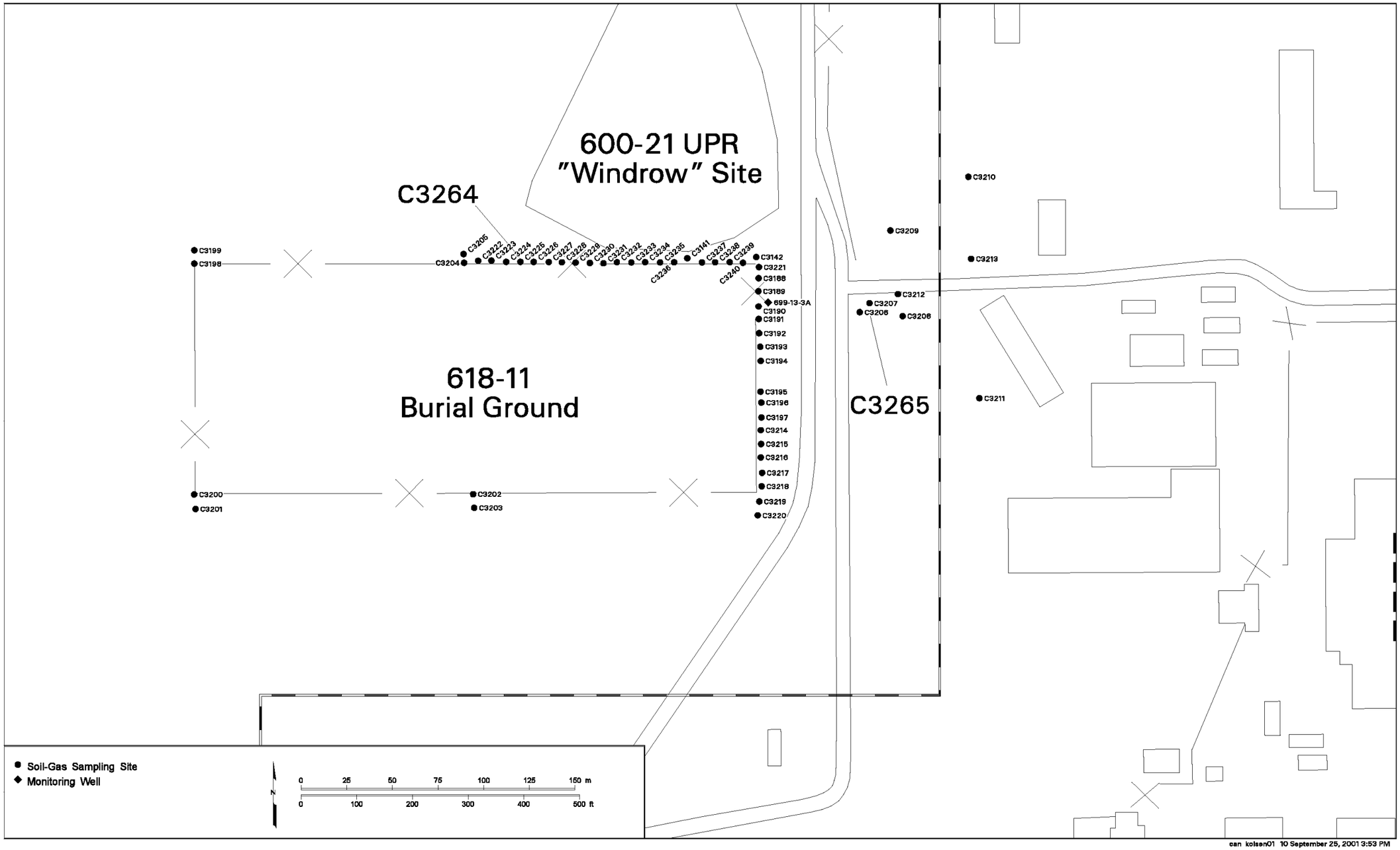


**Figure A.1**. Location of Soil Gas Sampling Points, Around and Immediately Downgradient of 618-11 Burial Ground

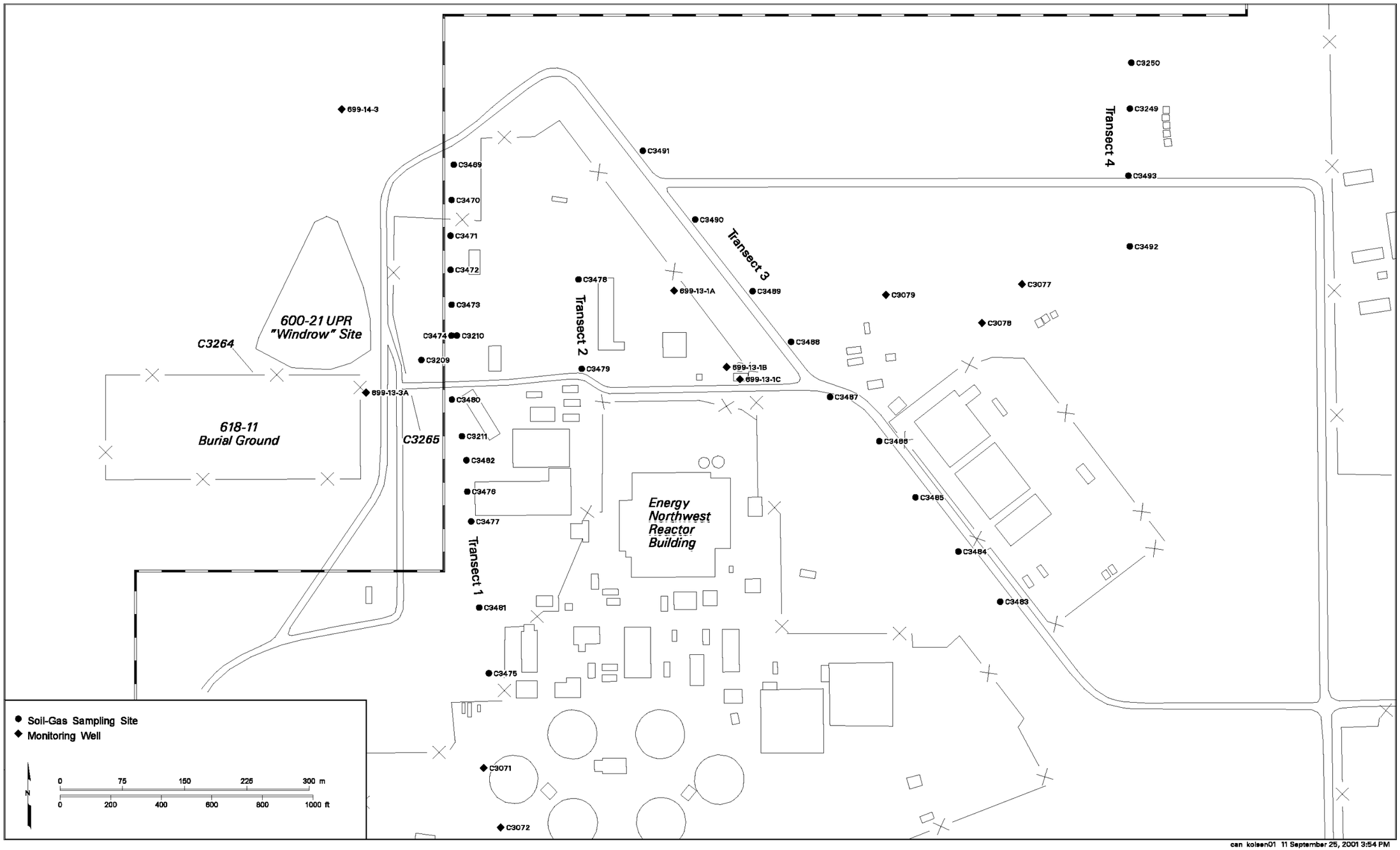


**Figure A.2**. Location of Soil Gas Sampling Points in Transect 1-4, Downgradient of 618-11 Burial Ground

# Appendix B

# Complete Gas Analytical Results for all Soil Gas Samples Collected

**Table B.1.** Analytical Results for Soil Gas Samples from 618-11 Burial Ground

| Location | Date | Cylinder Number | $^3He$ / $^4He$ ($R$ / $R_a$) | He/Ne Air | $^4He$ (ppm) | N2 (%) | O2 (%) | Ne (ppm) | Ar (ppm) | N2/Ar |
|---|---|---|---|---|---|---|---|---|---|---|
| C 3142 | 8/24/2000 | 1 | 3.217 | 1.048 | 5.61 | 78.65 | 20.36 | 18.59 | 9841 | 79.92 |
| C 3221 | 8/24/2000 | 2 | 3.233 | 1.124 | 5.41 | 76.68 | 22.36 | 16.70 | 9576 | 80.08 |
| C 3188 | 8/24/2000 | 3 | 3.691 | 1.064 | 5.59 | 81.27 | 17.72 | 18.23 | 10105 | 80.42 |
| C 3189 | 8/24/2000 | 4 | 3.567 | 1.127 | 5.52 | 81.14 | 17.87 | 17.00 | 9896 | 81.99 |
| C 3190 | 8/24/2000 | 5 | 3.734 | 1.052 | 5.53 | 78.13 | 20.89 | 18.26 | 9875 | 79.12 |
| C 3191 | 8/24/2000 | 6 | 3.393 | 1.015 | 5.51 | 81.63 | 17.35 | 18.84 | 10100 | 80.83 |
| C 3192 | 8/24/2000 | 7 | 2.519 | 1.155 | 5.50 | 83.21 | 15.75 | 16.53 | 10380 | 80.17 |
| C 3192 | 8/24/2000 | 8 | 2.466 | 1.033 | 5.68 | 78.23 | 20.81 | 19.08 | 9654 | 81.03 |
| C 3193 | 8/24/2000 | 9 | 1.811 | 1.069 | 5.50 | 80.88 | 18.13 | 17.87 | 9908 | 81.63 |
| C 3194 | 8/24/2000 | 10 | 1.625 | 1.111 | 5.58 | 81.83 | 17.17 | 17.44 | 9929 | 82.42 |
| C 3195 | 8/24/2000 | 11 | 1.389 | 1.070 | 5.56 | 79.35 | 19.67 | 18.05 | 9784 | 81.10 |
| C 3196 | 8/24/2000 | 12 | 1.495 | 1.013 | 5.67 | 80.72 | 18.28 | 19.43 | 9978 | 80.90 |
| C 3197 | 8/24/2000 | 13 | 1.551 | 1.088 | 5.34 | 76.55 | 22.51 | 17.03 | 9450 | 81.01 |
| C 3214 | 8/24/2000 | 14 | 1.589 | 1.165 | 5.40 | 81.11 | 17.92 | 16.08 | 9728 | 83.38 |
| C 3215 | 8/24/2000 | 15 | 1.631 | 1.045 | 5.63 | 76.25 | 22.85 | 18.72 | 9011 | 84.62 |
| C 3216 | 8/24/2000 | 17 | 1.536 | 0.994 | 5.56 | 77.64 | 21.40 | 19.41 | 9549 | 81.31 |
| C 3217 | 8/24/2000 | 18 | 1.382 | 1.094 | 5.58 | 81.70 | 17.29 | 17.72 | 10141 | 80.56 |
| C 3218 | 8/24/2000 | 19 | 1.260 | 1.009 | 5.47 | 81.53 | 17.48 | 18.81 | 9950 | 81.93 |
| C 3219 | 8/24/2000 | 21 | 1.116 | 1.028 | 5.41 | 80.54 | 18.46 | 18.27 | 9981 | 80.69 |
| C 3220 | 8/24/2000 | 22 | 1.042 | 1.040 | 5.68 | 79.67 | 19.32 | 18.94 | 10100 | 78.88 |
| C 3206 | 8/24/2000 | 24 | 1.386 | 1.036 | 5.66 | 78.47 | 20.43 | 18.97 | 11009 | 71.27 |
| C 3206 | 8/24/2000 | 25 | 1.375 | 1.035 | 5.54 | 78.77 | 20.26 | 18.57 | 9725 | 81.00 |
| C 3207 | 8/24/2000 | 26 | 1.343 | 1.060 | 5.59 | 80.44 | 18.56 | 18.30 | 10044 | 80.09 |
| C 3212 | 8/24/2000 | 27 | 1.280 | 1.032 | 5.58 | 79.20 | 19.80 | 18.78 | 9930 | 79.76 |
| C 3208 | 8/24/2000 | 28 | 1.271 | 1.167 | 5.27 | 79.41 | 19.43 | 15.67 | 11581 | 68.57 |
| C 3211 | 8/24/2000 | 29 | 1.124 | 1.067 | 5.54 | 81.02 | 18.00 | 18.03 | 9792 | 82.74 |
| C 3209 | 8/24/2000 | 30 | 1.230 | 1.161 | 5.26 | 81.30 | 17.71 | 15.73 | 9877 | 82.31 |
| C 3213 | 8/24/2000 | 31 | 1.190 | 1.088 | 5.35 | 80.64 | 18.38 | 17.07 | 9819 | 82.13 |
| C 3210 | 8/24/2000 | 32 | 1.341 | 1.102 | 5.32 | 77.75 | 21.30 | 16.76 | 9496 | 81.88 |
| C 3205 | 8/25/2000 | 33 | 12.120 | 1.101 | 5.35 | 79.49 | 19.51 | 16.86 | 9972 | 79.72 |
| C 3204 | 8/25/2000 | 34 | 15.642 | 1.014 | 5.59 | 79.90 | 19.10 | 19.15 | 9983 | 80.04 |
| C 3222 | 8/25/2000 | 35 | 24.576 | 0.939 | 5.05 | 82.19 | 16.77 | 18.68 | 10425 | 78.84 |
| C 3223 | 8/25/2000 | 36 | 39.229 | 0.936 | 5.74 | 80.22 | 18.79 | 21.28 | 9887 | 81.14 |
| C 3224 | 8/25/2000 | 37 | 49.430 | 1.070 | 5.47 | 80.95 | 17.98 | 17.74 | 10709 | 75.59 |
| C 3225 | 8/25/2000 | 38 | 58.115 | 0.956 | 5.89 | 80.04 | 18.97 | 21.41 | 9944 | 80.48 |
| C 3226 | 8/25/2000 | 39 | 44.792 | 1.063 | 5.59 | 82.08 | 16.92 | 18.27 | 10077 | 81.45 |
| C 3227 | 8/25/2000 | 40 | 28.459 | 0.995 | 5.33 | 81.40 | 17.58 | 18.61 | 10188 | 79.89 |
| C 3228 | 8/25/2000 | 41 | 18.010 | 1.037 | 5.49 | 81.64 | 17.28 | 18.40 | 10767 | 75.82 |
| C 3228 | 8/25/2000 | 42 | 17.820 | 0.984 | 5.81 | 81.10 | 17.90 | 20.51 | 9971 | 81.34 |
| C 3202 | 8/25/2000 | 44 | 1.073 | 1.032 | 5.67 | 80.36 | 18.63 | 19.08 | 10052 | 79.95 |
| C 3203 | 8/25/2000 | 45 | 1.051 | 1.090 | 5.46 | 79.28 | 19.71 | 17.40 | 10119 | 78.35 |
| C 3203 | 8/25/2000 | 46 | 0.998 | 1.053 | 5.94 | 80.76 | 18.23 | 19.58 | 10058 | 80.30 |
| C 3201 | 8/25/2000 | 47 | 1.046 | 1.031 | 5.31 | 81.40 | 17.59 | 17.89 | 10107 | 80.54 |
| C 3198 | 8/25/2000 | 48 | 1.011 | 1.080 | 5.59 | 80.84 | 18.17 | 17.95 | 9904 | 81.63 |
| C 3199 | 8/25/2000 | 49 | 1.008 | 1.104 | 5.95 | 82.68 | 16.25 | 18.70 | 10688 | 77.35 |
| C 3199 | 8/25/2000 | 50 | 0.999 | 1.060 | 5.66 | 83.21 | 15.74 | 18.56 | 10568 | 78.74 |
| C 3222 | 9/11/2000 | 51 | 17.923 | 1.038 | 5.68 | 80.20 | 18.82 | 18.98 | 9876 | 81.21 |
| C 3223 | 9/11/2000 | 52 | 41.075 | 1.05 | 5.57 | 81.08 | 17.94 | 18.44 | 9803 | 82.71 |
| C 3224 | 9/11/2000 | 53 | 5.495 | 1.037 | 5.51 | 80.33 | 18.69 | 18.44 | 9796 | 82.00 |
| C 3225 | 9/11/2000 | 54 | 62.477 | 1.087 | 5.52 | 79.91 | 19.12 | 17.64 | 9711 | 82.29 |
| C 3226 | 9/11/2000 | 55 | 44.465 | 1.04 | 5.54 | 82.90 | 16.10 | 18.47 | 10013 | 82.79 |

**Table B.1**. (contd)

| Location | Date | Cylinder Number | $^3He$ / $^4He$ ($R$ / $R_a$) | He/Ne Air | $^4He$ (ppm) | N2 (%) | O2 (%) | Ne (ppm) | Ar (ppm) | N2/Ar |
|---|---|---|---|---|---|---|---|---|---|---|
| C 3227 | 9/11/2000 | 56 | 2.809 | 1.07 | 5.53 | 80.55 | 18.48 | 17.92 | 9714 | 82.92 |
| C 3228 | 9/11/2000 | 57 | 19.549 | 1.061 | 5.62 | 81.68 | 17.31 | 18.40 | 10110 | 80.79 |
| C 3225 | 9/11/2000 | 58 | 62.454 | 1.027 | 5.72 | 81.24 | 17.78 | 19.33 | 9827 | 82.67 |
| C 3229 | 9/11/2000 | 59 | 10.294 | 1.046 | 5.75 | 83.87 | 15.12 | 19.09 | 10126 | 82.82 |
| C 3230 | 9/11/2000 | 60 | 7.673 | 1.032 | 5.77 | 79.52 | 19.49 | 19.41 | 9911 | 80.23 |
| C 3231 | 9/11/2000 | 61 | 5.088 | 1.07 | 5.53 | 80.71 | 18.32 | 17.89 | 9664 | 83.52 |
| C 3232 | 9/11/2000 | 62 | 3.421 | 1.07 | 5.52 | 80.38 | 18.64 | 17.95 | 9796 | 82.06 |
| C 3233 | 9/11/2000 | 63 | 2.567 | 1.06 | 5.46 | 82.11 | 16.90 | 17.83 | 9862 | 83.26 |
| C 3234 | 9/11/2000 | 64 | 2.903 | 1.053 | 5.57 | 81.36 | 17.63 | 18.37 | 10055 | 80.92 |
| C 3235 | 9/11/2000 | 65 | 3.604 | 1.03 | 5.53 | 80.82 | 18.20 | 18.56 | 9765 | 82.77 |
| C 3236 | 9/11/2000 | 66 | 10.295 | 1.07 | 5.48 | 80.33 | 18.70 | 17.82 | 9709 | 82.74 |
| C 3141 | 9/11/2000 | 67 | 2.764 | 1.036 | 5.72 | 80.88 | 18.14 | 19.18 | 9811 | 82.44 |
| C 3237 | 9/11/2000 | 68 | 10.698 | 1.062 | 5.43 | 83.10 | 15.83 | 17.75 | 10694 | 77.70 |
| C 3238 | 9/11/2000 | 69 | 9.664 | 1.025 | 5.63 | 81.85 | 17.17 | 19.07 | 9867 | 82.95 |
| C 3239 | 9/11/2000 | 70 | 7.355 | 1.026 | 5.73 | 80.79 | 18.21 | 19.37 | 9939 | 81.29 |
| C 3240 | 9/11/2000 | 71 | 3.919 | 1.004 | 5.79 | 82.58 | 16.42 | 20.01 | 9971 | 82.82 |
| C 3142 | 9/11/2000 | 72 | 3.137 | 1.054 | 5.90 | 82.91 | 16.02 | 19.44 | 10733 | 77.25 |
| C 3142 | 9/11/2000 | 73 | 3.155 | 1.029 | 5.76 | 80.97 | 18.05 | 19.43 | 9833 | 82.34 |
| C 3475 | 4/21/2001 | 1 | 1.010 | 1.117 | 5.66 | 81.27 | 17.75 | 17.59 | 9849 | 82.52 |
| C 3481 | 4/21/2001 | 2 | 1.003 | 1.087 | 5.54 | 82.61 | 16.45 | 17.69 | 9344 | 88.41 |
| C 3482 | 4/21/2001 | 3 | 1.232 | 1.123 | 5.49 | 80.32 | 18.73 | 16.99 | 9441 | 85.08 |
| C 3211 | 4/21/2001 | 4 | 1.192 | 1.010 | 5.41 | 81.92 | 17.05 | 18.60 | 10234 | 80.05 |
| C 3476 | 4/21/2001 | 5 | 1.177 | 1.051 | 5.63 | 79.90 | 19.09 | 18.58 | 10055 | 79.47 |
| C 3477 | 4/21/2001 | 6 | 1.040 | 1.052 | 5.58 | 81.92 | 17.13 | 18.43 | 9513 | 86.12 |
| C 3213 | 4/21/2001 | 8 | 1.403 | 1.126 | 5.54 | 80.18 | 18.88 | 17.07 | 9371 | 85.57 |
| C 3213 | 4/21/2001 | 9 | 1.373 | 1.067 | 5.62 | 79.11 | 19.98 | 18.29 | 9080 | 87.13 |
| C 3480 | 4/21/2001 | 10 | 1.413 | 1.053 | 5.68 | 80.49 | 18.54 | 18.74 | 9633 | 83.57 |
| C 3473 | 4/21/2001 | 11 | 1.330 | 1.044 | 5.67 | 80.22 | 18.82 | 18.84 | 9544 | 84.05 |
| C 3210 | 4/21/2001 | 12 | 1.680 | 1.072 | 5.63 | 80.27 | 18.74 | 18.25 | 9917 | 80.95 |
| C 3474 | 4/21/2001 | 13 | 1.677 | 1.068 | 5.54 | 79.48 | 19.60 | 18.01 | 9228 | 86.13 |
| C 3472 | 4/21/2001 | 14 | 1.113 | 1.043 | 5.51 | 80.27 | 18.77 | 18.35 | 9599 | 83.62 |
| C 3471 | 4/21/2001 | 15 | 1.018 | 1.050 | 5.66 | 79.12 | 19.92 | 18.72 | 9582 | 82.57 |
| C 3469 | 4/21/2001 | 17 | 0.992 | 1.023 | 5.55 | 78.27 | 20.77 | 18.85 | 9562 | 81.86 |
| C 3470 | 4/21/2001 | 18 | 0.996 | 1.067 | 5.54 | 80.85 | 18.16 | 18.04 | 9921 | 81.50 |
| C 3479 | 4/21/2001 | 19 | 1.066 | 1.095 | 5.58 | 78.67 | 20.40 | 17.70 | 9281 | 84.77 |
| C 3478 | 4/21/2001 | 21 | 1.273 | 1.058 | 5.68 | 80.41 | 18.55 | 18.63 | 10371 | 77.53 |
| C 3479 | 4/21/2001 | 22 | 1.058 | 1.107 | 5.59 | 84.62 | 14.39 | 17.54 | 9827 | 86.11 |
| C 3483 | 5/17/2001 | 33 | 0.993 | 1.102 | 5.63 | 81.34 | 17.65 | 17.73 | 10132 | 80.27 |
| C 3484 | 5/17/2001 | 34 | 1.009 | 1.097 | 5.72 | 80.18 | 18.87 | 18.10 | 9582 | 83.67 |
| C 3485 | 5/17/2001 | 35 | 1.016 | 1.067 | 5.85 | 80.09 | 18.95 | 19.04 | 9590 | 83.51 |
| C 3485 | 5/17/2001 | 36 | 0.991 | 1.059 | 5.80 | 80.39 | 18.62 | 19.03 | 9849 | 81.62 |
| C 3486 | 5/17/2001 | 37 | 1.000 | 1.088 | 5.69 | 82.24 | 16.79 | 18.17 | 9713 | 84.67 |
| C 3487 | 5/17/2001 | 38 | 0.994 | 1.044 | 5.95 | 81.42 | 17.61 | 19.80 | 9779 | 83.26 |
| C 3491 | 5/17/2001 | 40 | 1.017 | 1.120 | 5.50 | 77.85 | 21.20 | 17.05 | 9433 | 82.53 |
| C 3488 | 5/17/2001 | 41 | 0.987 | 1.137 | 5.64 | 78.61 | 20.44 | 17.21 | 9568 | 82.15 |
| C 3489 | 5/17/2001 | 42 | 1.045 | 1.100 | 5.74 | 80.24 | 18.76 | 18.10 | 10039 | 79.93 |
| C 3490 | 5/17/2001 | 43 | 1.049 | 1.086 | 5.89 | 83.19 | 15.79 | 18.81 | 10267 | 81.02 |
| C 3492 | 5/17/2001 | 44 | 0.987 | 1.118 | 5.84 | 79.62 | 19.41 | 18.13 | 9754 | 81.63 |
| C 3493 | 5/17/2001 | 45 | 1.104 | 1.043 | 5.72 | 82.72 | 16.28 | 19.04 | 9934 | 83.27 |
| C 3249 | 5/17/2001 | 46 | 0.994 | 1.061 | 5.62 | 76.85 | 22.20 | 18.40 | 9435 | 81.45 |
| C 3250 | 5/17/2001 | 47 | 0.988 | 1.082 | 5.85 | 80.22 | 18.83 | 18.78 | 9540 | 84.08 |

**Table B.1**. (contd)

| Location | Date | Cylinder Number | $^3He$ / $^4He$ ($R / R_a$) | He/Ne Air | $^4He$ (ppm) | N2 (%) | O2 (%) | Ne (ppm) | Ar (ppm) | N2/Ar |
|---|---|---|---|---|---|---|---|---|---|---|
| C 3210 | 5/17/2001 | 48 | 1.617 | 1.073 | 5.75 | 77.43 | 21.63 | 18.61 | 9432 | 82.10 |
| C 3190 | 5/17/2001 | 49 | 5.102 | 1.133 | 5.67 | 75.60 | 23.47 | 17.37 | 9325 | 81.07 |
| C 3190 | 5/17/2001 | 50 | 5.082 | 1.120 | 5.60 | 78.97 | 20.08 | 17.37 | 9520 | 82.95 |
| | | | | | | | | | | |
| Ambient Air | 8/24/2000 | 23 | 1.001 | 1.034 | 5.72 | 78.38 | 20.65 | 19.20 | 9668 | 81.07 |
| Ambient Air | 8/25/2000 | 43 | 1.022 | 1.093 | 5.36 | 79.87 | 19.10 | 17.04 | 10253 | 77.90 |
| Ambient Air | 9/11/2000 | 74 | 0.998 | 1.02 | 5.50 | 82.74 | 16.26 | 18.66 | 9965 | 83.03 |
| Ambient Air | 4/21/2001 | 7 | 0.988 | 1.085 | 5.47 | 79.84 | 19.22 | 17.51 | 9420 | 84.76 |
| Ambient Air | 5/17/2001 | 39 | 1.000 | 1.096 | 5.69 | 80.14 | 18.90 | 18.03 | 9604 | 83.45 |

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