RPP-38406, Rev. 0

Small Diameter Geophysical Logging for UPR-200-E-81

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U.S. Department of Energy Contract DE-AC27-99RL14047

EDT/ECN:	~~NA~~ DRF	UC:	NA
Cost Center:	NA	Charge Code:	NA
B&R Code:	NA	Total Pages:	30

Key Words: C Tank Farm, UPR-200-E-81, Direct Push, Small Diameter Probe Holes

Abstract: This report is a summary of direct push activities relating to driving small diameter probe hole, geophysical logging.

Release Approval Date 07/30/08

JUL 30 2008
DATE:
STA: 15
HANFORD RELEASE
ID: 65

Release Stamp

Approved For Public Release

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TERMS

Bgs	Below ground surface
DOE	U.S. Department of Energy
Energy*Solutions*	Energy*Solutions* Federal Services, Inc., Northwest Operations
PNG	Pacific Northwest Geophysics
VF	Volume Fraction

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SMALL DIAMETER GEOPHYSICAL LOGGING FOR UPR-200-E-81

1.0 INTRODUCTION

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter (slim-hole) logging at the unplanned release (UPR-200-E-81) near the 241-CR-151 Diversion Box. This logging was intended to aid in defining the extent of subsurface contamination resulting from apparent pipe failure, which caused the unplanned release. Logging surveys were conducted in five probeholes with a sodium-iodide (NaI) scintillation gross gamma detector and a neutron-neutron moisture probe. The surveys identified zones of interest for sample collection and laboratory analysis. A gyroscope survey was acquired in two deep probeholes: C6393 and C6399. This report includes the survey results for each of the probeholes, as well as the results of the gyroscope surveys (see Appendix A).

The NaI gross gamma detector was calibrated for the probehole conditions present at the investigation site. The calibration unit of equivalent radium-226 (Ra-226) (eRa-226 pCi/g) is used for background levels of the natural radionuclides. The calibration unit of equivalent cesium-137 (Cs-137) (eCs-137 pCi/g) is used for zones of elevated gamma activity (see Section 2.1).

The objective of the gamma survey logs was to identify depth intervals with elevated gamma activity (i.e., eCs-137 at concentrations greater than 10 pCi/g). Rapid scan gamma surveys (1.23 m/min [4 ft/min]) have a minimum detection threshold of 8 pCi/g for Cs-137.

Elevated gamma activity was detected in three of the project's probeholes: C6391, C6393, and C6395. The highest gamma activity was encountered in probehole C6393 with the maximum eCs-137 concentration of 45,000 pCi/g occurring at 1 m (3 ft) below ground surface (bgs). This contamination zone extended from 1 m to 13.4 m (3.3 ft to 44 ft) bgs.

Neutron-neutron moisture logs were also collected in the five probeholes. The moisture content in the five probeholes ranged from about 5 to over 20 percent volume fraction (% vf) moisture. This was determined using the neutron moisture detector that measures the distribution of hydrogen (moisture) in subsurface soils. Calibration of this detector is discussed in Section 2.2.

The gyroscope surveys were acquired to assess the degree of deviation from vertical for the deep probeholes. Discussions of the gyro equipment, data processing, and survey results are presented in Section 3.0.

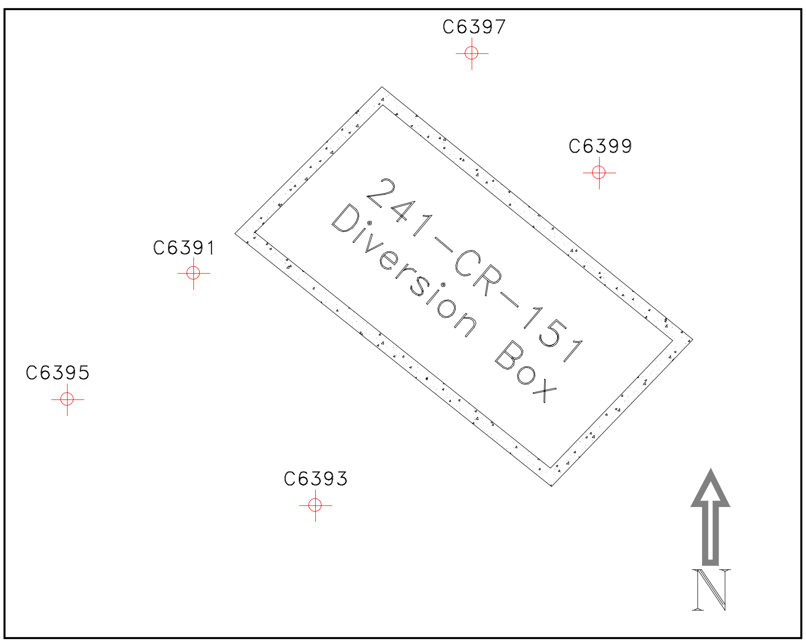
All calibrations, logging data acquisition, analysis and data management processes for this project were conducted in compliance with *Procedures: Calibration, Logging, Quality Assurance and Data Management* (PNG 2007) approved by Energy*Solutions* Federal Services, Inc., Northwest Operations (Energy*Solutions*).

2.0 GAMMA AND MOISTURE SURVEYS

The gamma and moisture logging surveys were recorded from the bottom of the probehole (maximum survey depth) to the ground surface. Zero depth reference is at the ground surface. A repeat measurement was acquired daily in at least one probehole to verify instrument repeatability. The main log and repeat intervals are presented on the same plot. The computed results of the main and repeat intervals were reviewed, and for all of the repeat intervals collected, the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probehole are presented as a depth-versus-concentration plot in Appendix A. The plots are in numeric order of the probeholes (C6391 – C6399). Appendix A also contains a table summarizing data for each probehole: detectors used, probehole depth, depth of maximum gamma activity, and maximum concentration of eCs-137 in pCi/g. Figure 1 shows a map view of the probehole locations.

Figure 1. Push Hole Locations at UPR-200-E-81 (241-CR-151 Diversion Box).



2.1 GROSS GAMMA CALIBRATION AND SURVEYS

The gross gamma scintillation detector uses a NaI crystal. The NaI crystal (2.54 cm [1 in.] long) is hydroscopic and is enclosed in a hermetically sealed can (2.54 cm [1-in.] diameter) to maintain its integrity. Other components of the gamma detector are the high-voltage supply, photomultiplier tube, and the pre-amp and multi-channel analyzer. The settings of the detector components are fixed (i.e., set up during assembly, prior to calibration) and cannot be adjusted by the field logging engineer. The detector gain and lower threshold are set to record gamma ray activity with energies between 100 and 3000 keV. By comparison, the highest gamma ray from naturally occurring radionuclides is from thorium-232 (Th-232), and it occurs at 2614 keV. Coleman[1] lantern mantles containing Th-232 are used as a field verifier at the beginning and ending of each day's logging activities to check detector resolution (integrity) and energy calibration (amplifier gain).

The gross gamma calibration models located at the U.S. Department of Energy (DOE) Hanford Site near Richland, Washington, were used to perform the NaI detector calibrations. Calibration was performed in the (low-concentration) gross gamma calibration zone, identified as SBL. The calibration method incorporated the attenuation effect of the steel casing of the probeholes. A section of the steel drill tubing (1 m [3 ft] long and 0.97 cm [0.38 in.] thick) was installed over the detector during calibration measurements to acquire spectra that properly represent logging conditions and the varying gamma ray energy. The calibration data are summarized in Table 1. The calibration units are pCi/g of equivalent Ra-226 (eRa-226) (Steele and George 1986).

The NaI gross gamma detector was also calibrated for eCs-137 (pCi/g). The ratio between the calibration coefficients of eRa-226 and eCs-137 was identified previously (Randall and Price 2006) and was used to assign the eCs-137 conversion factor of 0.316 (pCi/g per cps) for casing thickness of 0.97 cm (0.38 in.). Figure 2 shows the calibration certificate.

Table 1. Gross Gamma Calibration Data.

Calibration Model	Concentration eRa-226 (pCi/g)	Gross Gamma Response[a] (cps)	Dead Time Corrected Gross Gamma Count-Rate[b] (cps)
SBA	61.2	416.5	417.9

[a]Count rates are mean of 10 sample measurements at 100 sec each, 0.38-in. casing, 4/19/2008.
[b]NaI detector system dead time is 8.92 microsecond.

The NaI gamma surveys were logged at 1.2 m/min (4 ft/min). A spectrum of 256 channels was collected each 0.15 m (0.5 ft) from the bottom of the probehole to the surface. The spectra were recorded in Ortec[2] PHA format with one spectrum per file (filename extension of "-.chn"). Detector count rates were dead time corrected and the gamma survey data was processed as gross gamma response to determine the concentration of eRa-226 in pCi/g.

[1]Coleman is a registered trademark of The Coleman Company, Inc., Wichita, Kansas.
[2]Ortec is a registered trademark of EG&G Ortec, Gouda, Netherlands.

The dead time correction is a nonparalysable relationship (Knoll 1979) and is described by the following equation:

$$C_t = \frac{C_{obs}}{1 - \varepsilon \cdot C_{obs}}$$

where C_t is the true or dead time-corrected count rate in c/s, C_{obs} is the observed count rate in c/s, and ε is the dead time factor of 8.92 µs. The dead time factor was determined when the detector was calibrated for eCs-137 in the Hanford vadose well 299-W10-72.

The calibration for eCs-137 was performed in Hanford vadose well 299-W10-72 (Cs-137 calibration standard). The Cs-137 in the well is stable, except for the 30-year half-life decay of the radioisotope. Also, distribution of Cs-137 ranges from less than 1 pCi/g to 40,000 pCi/g along the well path (depth). The concentrations of Cs-137 were established by two high-purity germanium detectors (70% and high rate tools, operated by Stoller Corporation). Casing in the well is 0.731 cm (0.288 in.) thick. In order to duplicate the 0.97 cm (0.38-in.) casing of the small diameter probeholes, a section of steel tubing 0.24 cm (0.095 in.) thick was installed over the detector for calibration.

2.2 NEUTRON MOISTURE CALIBRATION AND SURVEYS

The neutron moisture sonde combines the PNG-owned thermal-neutron detector and a DOE-owned sealed neutron source (50 mCi AmBe). The DOE-owned neutron source was used because it was already on the Hanford Site and was managed by the DOE Radiation Management Program. The neutron source is an integral component of a neutron moisture detector that was manufactured by Campbell Pacific Nuclear, and is identified by the tool serial number H370608792.

The integrity of the sealed neutron source is always maintained when used in calibration and probehole logging activities. Source integrity is maintained by inserting the PNG-owned neutron detector module into the housing containing the sealed neutron source.

Calibration was performed in six borehole calibration models (Meisner and Randall 1995). Three of these models had a 15.24 cm (6-in.) hole size and three models had a 20.32 cm (8-in.) hole size. The moisture content was different for each borehole model within each set of three models (5, 12, and 20 percent by volume). The detector count rate in each of the six borehole calibration models is summarized in Table 2. The calibration certificate is shown in Figure 3.

Table 2. Moisture Calibration Data.

Moisture Content Percent – volume fraction	6 inch Models[a] (cps)	8 inch Models[a] (cps)
5% vf	105.20	82.78
12% vf	156.13	116.69
20% vf	196.27	141.46

[a]Count rates are mean of 10 sample measurements at 100 sec each, 11/7/2007.

The probehole size for this project was 6.35 cm (2.5 in.) outside diameter. Therefore, the moisture calibration was extrapolated to the correct hole size. Figure 4 shows the moisture calibration certificate for the 6.35 cm (2.5-in.) hole size.

The probehole moisture survey was collected at 0.61 m/min (2 ft/min) or slower. Processing of the survey data requires that the detector raw survey data be normalized to the thickness of the steel casing present in the calibration models (0.825 cm [0.325 in.]) Given that the probehole casing thickness is 0.97 cm (0.38 in.), a correction factor of 1.055 is required to increase (normalize) the observed neutron detector count rate to the conditions of the calibration model (Meisner et al. 1996).

3.0 GYROSCOPE BOREHOLE DEVIATION SURVEY

The gyroscope probe is designed to assay deviations in the path of both dipping and vertical boreholes. The gyroscope probe is 40 mm (1.575 in.) in diameter, 1.65 m (5.42 ft) long, and weighs 5.9 kg (13 lb). No centralizers are used in small diameter probeholes. Zero depth reference for the surveys is at ground level.

The gyroscope survey was recorded both as the sonde was lowered into the probehole (in-run) and as it was retrieved (out-run). Data from the sonde's sensors are recorded at the rate of two samples per second and the depth position of the sonde is recorded in feet. The logging probe speed is 9.1 m/min (30 ft/min) or less. At least four times each hour, during the survey, the hoist is momentarily halted to record the gyroscope drift rate at these stationary locations.

The gyroscope probe contains two high-precision components: an inclinometer and a gyroscope. The inclinometer records the probe tilt (dip) at the precision of 0.01 degree. The probe's orientation is determined by a very precise rate-gyro with a precision of 0.0001 degrees.

The path of the borehole is derived by post-processing of the raw survey data, which is performed as follows.

- Identify the gyroscope drift rate and remove the component from the survey data.
- Use X-Y data from the inclinometer to compute probe dip (vertical is -90 degrees).
- Compute path of borehole: Northing, Easting, elevation (vertical depth), and dip (tangent to borehole at each survey depth position).

The survey result is the probehole path, which is presented graphically with these components.

- 3-D trajectory plot of XYZ (Northing and Easting versus elevation).
- X and Y deviation plots (2D plots of Northing versus depth and Easting versus depth).
- Dip plot of tangential angle versus depth.
- Gyro Survey Information in text format:
  - Coordinates at survey Top,
  - Coordinates at survey Base,
  - Maximum deviation (dip) angle and depth location,
  - Measured depth and vertical depth at survey Base.

Figure 2. Gross Gamma Calibration Certificate (eRa-226 and eCs-137).

Certificate of Calibration

SD.GR.NaI.1

May 6, 2008

Data were taken at the Hanford KUT models on April 19, 2008, with the designated scintillator tool, SD.GR.NaI.1. The SBA model was used for the gross gamma calibration and at least ten spectra were recorded in the model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation; refer to the file "-Calibrations\NaI\2008\NaI-stats.xls" for this analysis.

The instrument was covered with 0.97 cm (0.38-in.) wall-thickness probe tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* (Randall and Stromswold 1995). The gross gamma calibration for equivalent ^{226}Ra in pCi/g is a regression function and is generally defined by:

$$Ra = a*GR + b$$

Where Ra is the eRa-226 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficients of a & b are the fit coefficients. A more physical relationship constrains the intercept (b) to a zero value. This computation yields improved response extrapolated to low concentrations of K, U, and Th (clean zones). The coefficients were determined to be:

$$a = .139 \text{ eRa-226 (pCi/g) / (c/s)}$$
$$b \equiv 0$$

The calibration for eCs-137 for the SD.GR.NaI.1 instrument is described in RPP-RPT-27605, *Gamma Surveys of Single Shell Tank Laterals for A and SX Tank Farm* (Randall and Price 2006). The gross gamma calibration for equivalent ^{137}Cs in pCi/g is a regression function and is generally defined by:

$$Cs = \alpha*GR$$

Where Cs is the eCs-137 in pCi/g, and GR is the observed gross gamma count rate (c/s), dead time corrected. The coefficient α is the fit coefficient.

There is a ratio of eRa-226 calibration coefficient to the eCs-137 calibration coefficient for each instrument. The resulting coefficient, a*Cs, was found to be .316 (Randall and Price 2006) for a ratio between the two coefficients of 2.27. Thus a factor of 2.27 times the eRa-226 calibration will yield the eCs-137 calibration coefficient. Thus: α=0.316 eCs-137 (pCi/g)/(c/s)

The digital files contain:

- Calibration raw data
- MathCad[a] data analysis files
- Spreadsheet data formatting

The undersigned certifies that the analysis files are archived in "SD-GR-NaI-1_2008.zip" and this file was evaluated in accordance with Randall and Price 2006 and that the above-stated calibration coefficients are correct and applicable for the SD.GR.NaI.1 tool, effective April 19, 2008.

Signature:

/s/ Russel Randall, PhD   May 6, 2008
Three Rivers Scientific

[a]MathCAD is a registered trademark of Mathsoft Corporation, Cambridge, Massachusetts.

Figure 3. Moisture Calibration Certificate, 15.24 cm (6-in.) and 20.32 cm (8-in.) Hole.

Certificate of Calibration for
SD-Moist792 Instrument
November 7, 2007

Data were taken in the moisture models June 7, 2007, for the SD-Moist792 neutron-neutron moisture tool. The neutron source from DOE moisture tool #H370608792 was used with the passive neutron detector probe from PNG. This calibration is required for the small diameter logging, and funded by Energy*Solutions*, Master Ordering Agreement 017194.

Six models were used for moisture calibration, three for 15.24 cm (6-in.) casing and three for 20.32 cm (8-in.) casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation; for this analysis refer to the Stats-moist.xls file.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration* (Meisner et al. 1996). The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the dead time corrected observed total count rate, (c/s).

6-in. casing	8-in. casing
a = .0001748	**a = .00006272**
α = 2.203	**α = 2.555**

The undersigned certifies that the data archived in data file “SD-Moist792_2007.zip” were collected and evaluated in accordance with Meisner et al. 1996 and that the above-stated calibration coefficients are correct and applicable for the SD-Moist792 tool, effective November 7, 2007.

Signature:

/s/ Russel Randall, PhD November 13, 2007
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, 6.35 cm (2.5-in.) Hole.

Moisture Calibration Extrapolation to 2.5-Inch Borehole
SD-Moist792 Instrument
November 7, 2007

Moisture calibration was performed in the Hanford physical models. These standards have 15.24 cm (6-in.) and 20.32 cm (8-in.) inside diameter casings. The Tank Farm Direct Push borehole is cased with a 6.35 cm (2.5 in.) outside diameter iron casing. The calibration for the moisture response is a function of borehole diameter.

The coefficient generation is determined by the algorithm described in WHC-SD-EN-TI-306. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the dead time-corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 6.38 cm (2.51 in.) borehole diameter.

2.51-in. borehole
a = .0003057
α = 1.938

The undersigned certifies that the analysis files are archived in the "SD-Moist792_2007.zip" file that was evaluated in accordance with Energy*Solutions* procedures and that the above-stated calibration coefficients are correct and apply to the SD-Moist792 tool, effective November 7, 2007.

Signature:

/s/ Russel Randall, PhD — November 13, 2007
Three Rivers Scientific

4.0 CONCLUSION

Scintillation Gross Gamma and Neutron Moisture survey logs were collected in five probeholes installed at the UPR-200-E-81 investigation site near the 241-CR-151 Diversion Box. Two probeholes (C6393 and C6399) were driven to the depth of 73.8 m (242 ft). These two probeholes were also logged with the gyroscope sonde to document their path. The remaining three probeholes were driven to approximately 47.2 m (155 ft) bgs.

The rapid-scan gamma surveys of the probeholes can be summarized as follows.

- Two of the five probeholes (C6397 and C6399) showed only background activity from the natural radionuclides. Gamma activity, above background levels, was encountered in three probeholes (C6391, C6393, and C6395) with the highest activity occurring at shallow depths. The maximum depth of the gamma-emitting contamination was encountered in probehole C6393 at 13.4 m (44 ft) bgs. C6393 also contained the highest gamma activity. The maximum depth of gamma-emitting contamination was less than 3.6 m (12 ft) in the other two probeholes (C6391 and C6395).
- The maximum gamma activity encountered was 45,000 pCi/g of eCs-137 at 0.9 m (3 ft) bgs in probehole C6393.

The neutron moisture surveys for all probeholes had unique profiles when each log was examined in detail. However, a generalized review of the profiles of all probeholes reveals the following similarities (discussed below and shown in Table 3).

- All five of the probeholes have a clearly recognizable moisture peak at approximately 41 m (135 ft) bgs. See Column B in Table 3. This feature is accompanied by baseline character changes above and below the feature. The baseline (average moisture content) below the feature has fewer deflections and maintains moisture at approximately 5% vf; whereas, the baseline above the feature has a higher number of excursions (increases and decreases) in moisture content. This change in response character of the moisture log above and below along with a sharp identifiable and correlatable peak indicates a change in formation materials (e.g., more homogenous sediments below the feature as opposed to higher moisture content in a number of zones above). These changes in log character may indicate a dispositional or facies type change in the Hanford sediments encountered in this area.
- At the top of each probehole, a high-moisture zone is present that extends from the surface down to depths of 7.62 to 13.72 m (25 to 45 ft). The moisture content in this upper zone varies and is characteristic of stratigraphy-controlled conditions. The maximum depth of this upper moisture zone is shown in column C of Table 3.
- An intermediate zone of high-moisture content that varies between 16.15 and 20.42 m (53 and 67 ft) is shown in column D of Table 3.
- Probehole C6399 has a thin zone with high moisture content near the bottom of the hole at 72.16 m (236.75 ft). There is no corresponding high-moisture zone at the bottom of the other deep probehole (C6393). A review of the log response indicated it is not likely that the large

peak is an artifact of moisture condensation inside the tubing. The high-moisture zone in probehole C6399 occurs 0.30 m (1 ft) above the bottom of the probehole (at 72.47 m [237.76 ft]). This type of log response is not characteristic of moisture accumulation in the bottom of tubing.

Table 3. Moisture Survey Summary.

Probehole	Column B Lower Moisture Zone (meters, feet)	Column C Upper Moisture Zone (meters, feet)	Column D Intermediate Moisture Zone (meters, feet)
C6391	40.9 m, 134 ft	7.9 m, 26 ft	17.4 m, 57 ft
C6393	41.2 m, 135 ft	13.7 m, 45 ft	18.0 m, 59 ft
C6395	40.9 m, 134 ft	7.6 m, 25 ft	16.2 m, 53 ft
C6397	41.5 m, 136 ft	8.5 m, 28 ft	19.8 m, 65 ft
C6399	41.5 m, 136 ft	10.7 m, 35 ft	20.4 m, 67 ft

The gyroscope deviation surveys for probeholes C6393 and C6399 are shown in Appendix A. The plot shows both the in-run and out-run survey results that are summarized in Tables 4 and 5. The Closure Distance column shows the distance from the probehole Northing and Easting positions to the vertical position. The deviation (dip) is measured from vertical (0 degrees). The Depth column shows the distance measured down the probehole and the Elevation column shows the vertical depth computed from the gyro survey.

Table 4. Gyroscope Survey Results for C6393.

Depth (meters, feet)	Northing (feet)	Easting (feet)	Closure Distance (meters, feet)	Elevation (feet)	Dip (degrees)
0.0 m, 0 ft	0.00	0.00	0.00 m, 0.00 ft	0.0	0.24
15.24 m, 50 ft	-0.55	0.18	0.17 m, 0.6 ft	-50.0	1.00
30.49 m, 100 ft	-1.64	0.84	0.56 m, 1.8 ft	-99.9	1.90
45.73 m, 150 ft	-3.76	2.06	1.31 m, 4.3 ft	-149.8	3.64
60.98 m, 200 ft	-5.92	3.89	2.16 m, 7.1 ft	-199.8	3.12
72.04 m, 236.3 ft	-6.961	5.55	2.71m, 8.9 ft	-236.1	2.95

Table 5. Gyroscope Survey Results for C6399.

Depth (meters, feet)	Northing (feet)	Easting (feet)	Closure Distance (meters, feet)	Elevation (feet)	Dip (degrees)
0.0 m, 0 ft	0.00	0.00	0.00 m, 0.00 ft	0.0	0.60
15.24 m, 50 ft	-0.69	0.11	0.18 m, 0.6 ft	-50.0	1.59
30.49 m, 100 ft	-1.97	0.91	0.55 m, 1.8 ft	-100.0	1.84
45.73 m, 150 ft	-2.41	1.89	0.93 m, 3.1 ft	-150.0	1.55
60.98 m, 200 ft	-3.00	2.77	1.25 m, 4.1 ft	-200.0	0.78
71.74 m, 235.3 ft	-3.24	3.10	1.37m, 4.5 ft	-235.3	0.40

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APPENDIX A
GAMMA AND MOISTURE SURVEY RESULTS

Survey plots follow for the five probeholes installed around the UPR-200-E-81 investigation site. Each probehole was surveyed with both the gross gamma and moisture sondes. The two deep probeholes, C6393 and C6399, were also surveyed with the gyroscope sonde. Also, the two deep probeholes, C6393 and C6399, are displayed twice: (1) at the standard depth scale of 47.2 m (155 ft) and (2) at the depth scale of 76.2 m (250 ft).

The gyro survey shows the borehole path in the following ways.

- 3-D trajectory plot of XYZ (Northing and Easting versus depth in meters). Also two projections are shown.
  - Blue dashed line from start location to ending location.
  - Gray solid line at surface as a rectangle that encompasses the starting location and projected ending location.
- X and Y deviation plots (2-D plots of Northing and Easting versus depth in meters).
- Dip plot of tangential angle (degrees) versus depth (meters).

The gross gamma survey data were dead time corrected and the results are converted to the two calibration units (i.e., eRa-226 and eCs-137). The results are plotted as either eRa-226 or eCs-137, depending on the gamma activity level.

- The Equivalent Ra-226 is used for low gamma ray activity, which is characteristic of Hanford sediments (brown solid line). The plot scale for eRa-226 is 0-25 pCi/g. The concentration of the natural radionuclides in the Hanford sediments is less than 5 pCi/g of eRa-226, and the low gamma activity zones are displayed as eRa-226 when the concentrations are less than 5 pCi/g. The higher gamma activity zones are displayed with the eCs-137 plot scale.
- Equivalent Cs-137 (orange dot-dashed line) is used for displaying gamma activity zones that have concentrations greater than the natural radionuclides (if present). The gamma activity is displayed as eCs-137 when high gamma activity zones are present and when the computed concentrations are greater than 4 pCi/g of eCs-137. The plot scale for eCs-137 is logarithmic from 1 to 100,000 (i.e., 10^0 to 10^5 or five orders of magnitude).

The neutron-neutron moisture survey data are shown with a blue dashed line. The moisture plot scale is 0-25 (% vf).

The plot legend is shown in Figure A1. The probehole survey summary is shown in Table A1.

Figure A1. Plot Legend.

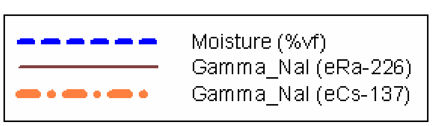


Table A1. Probehole Survey Summary.

Hole	Gross Gamma	Neutron Moisture	Hole Depth (meters, feet)	Depth Max Gamma Activity	Max eCs-137 (pCi/g)	Comment
C6391	**X**	**Moisture**	46.6 m, 153 ft	9 ft	500	
C6393	**X**	**Moisture**	72.2 m, 237 ft	3 ft	45,000	Deep Hole. Gyroscope Survey
C6395	**X**	**Moisture**	46.3 m, 152 ft	2 ft	45	
C6397	**X**	**Moisture**	46.6 m, 153 ft	Natural	Background	
C6399	**X**	**Moisture**	72.2 m, 237 ft	Natural	Background	Deep Hole. Gyroscope Survey

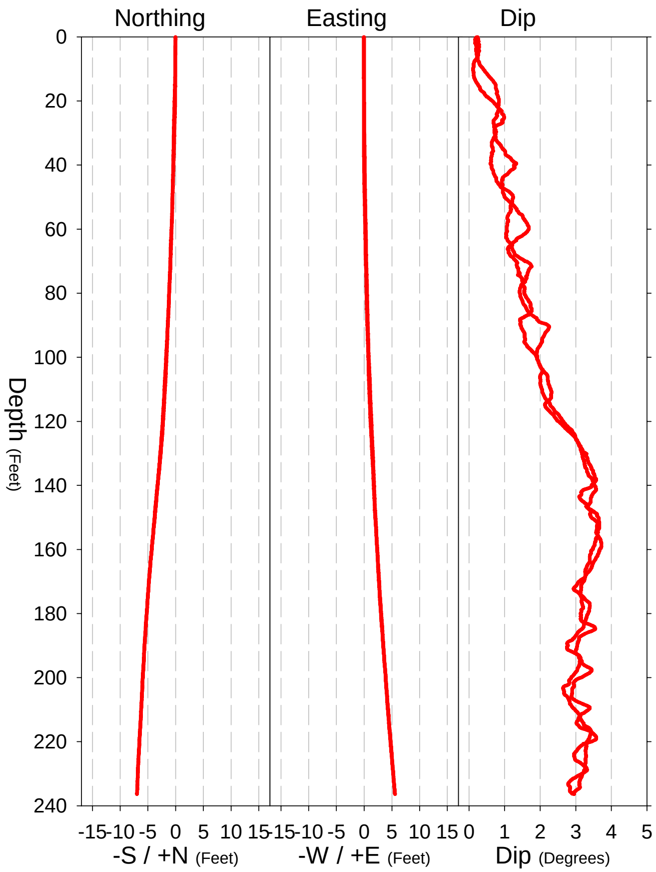
Gyroscope Hole Path Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

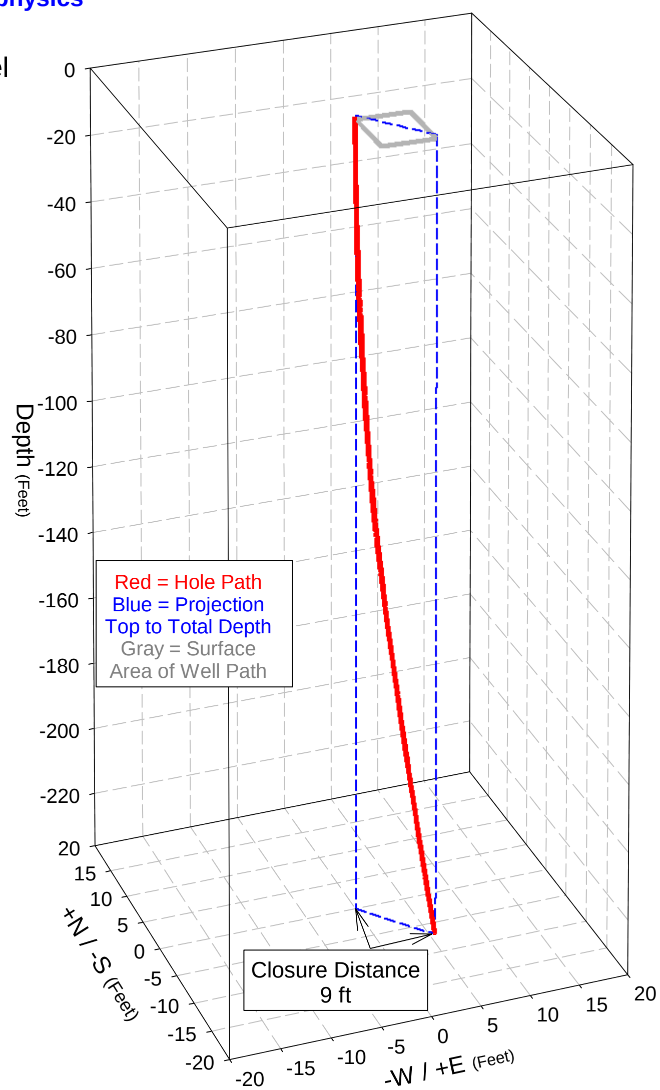
Project: UPR-200-E-81
Hole: C6393

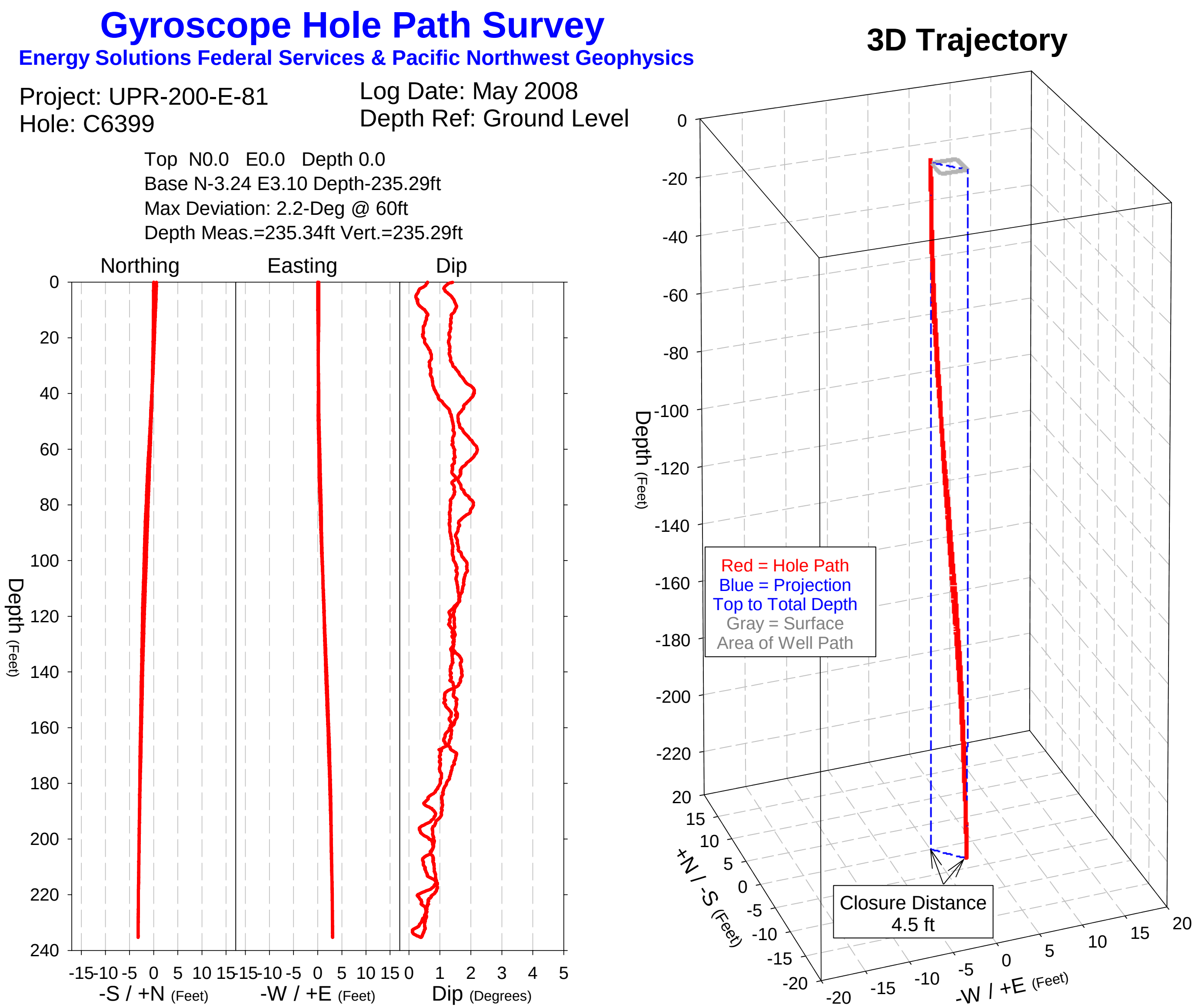
Log Date: May 2008
Depth Ref: Ground Level

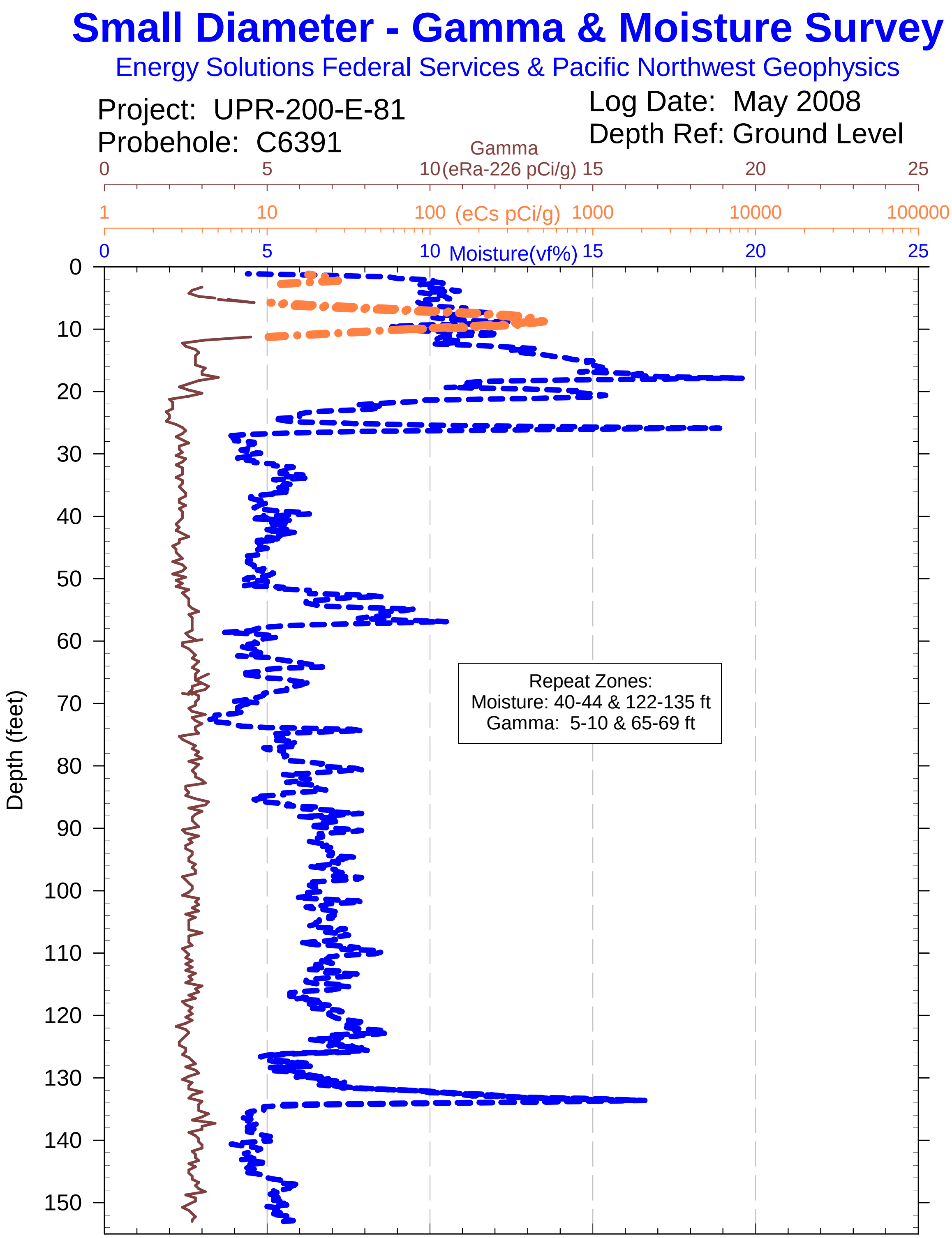
Top N0.0 E0.0 Depth 0.0
Base N-7 E5.5 Depth-236.1ft
Max Deviation: 3.6-Deg @ 159ft
Depth Meas.=236.35ft Vert.=236.13ft

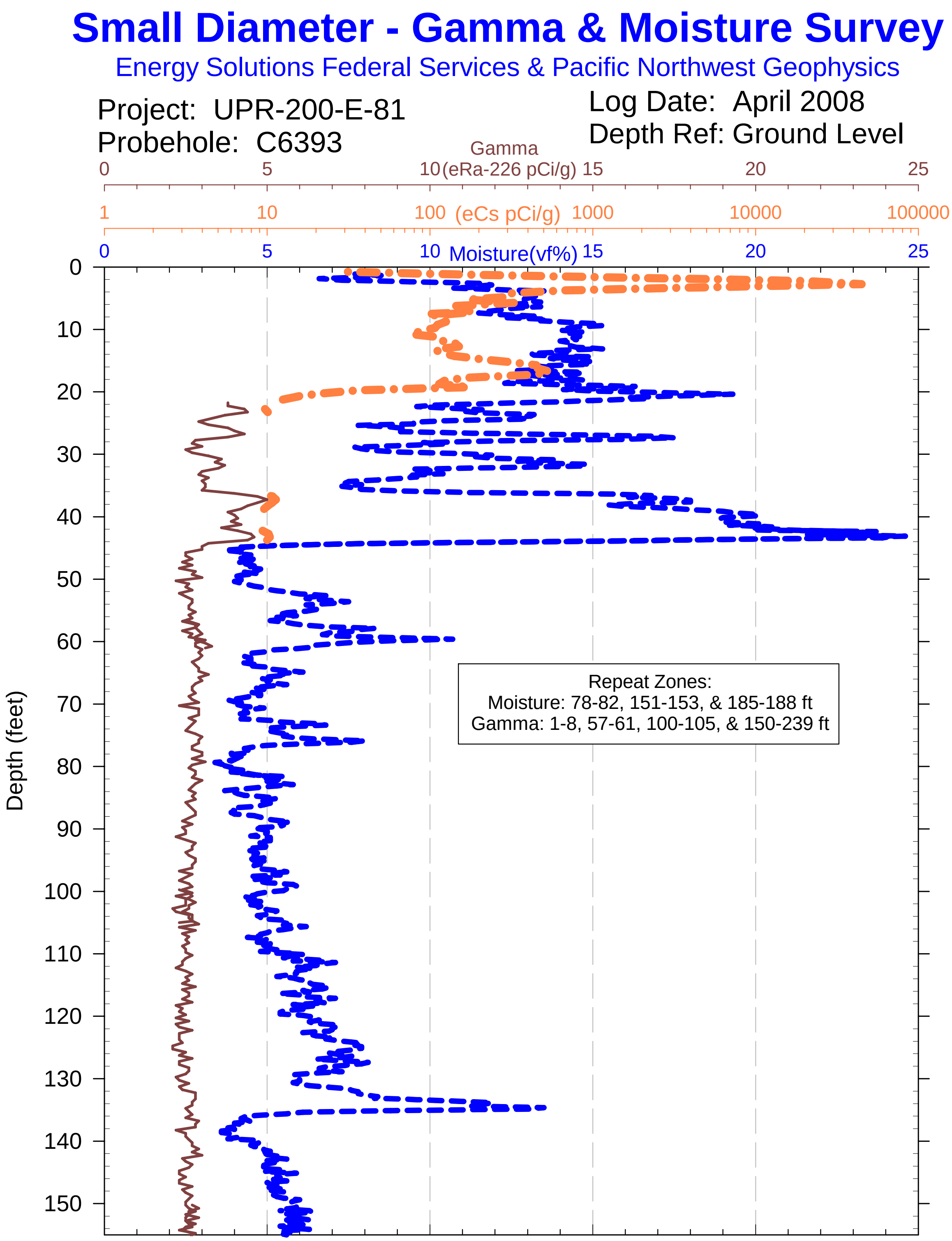


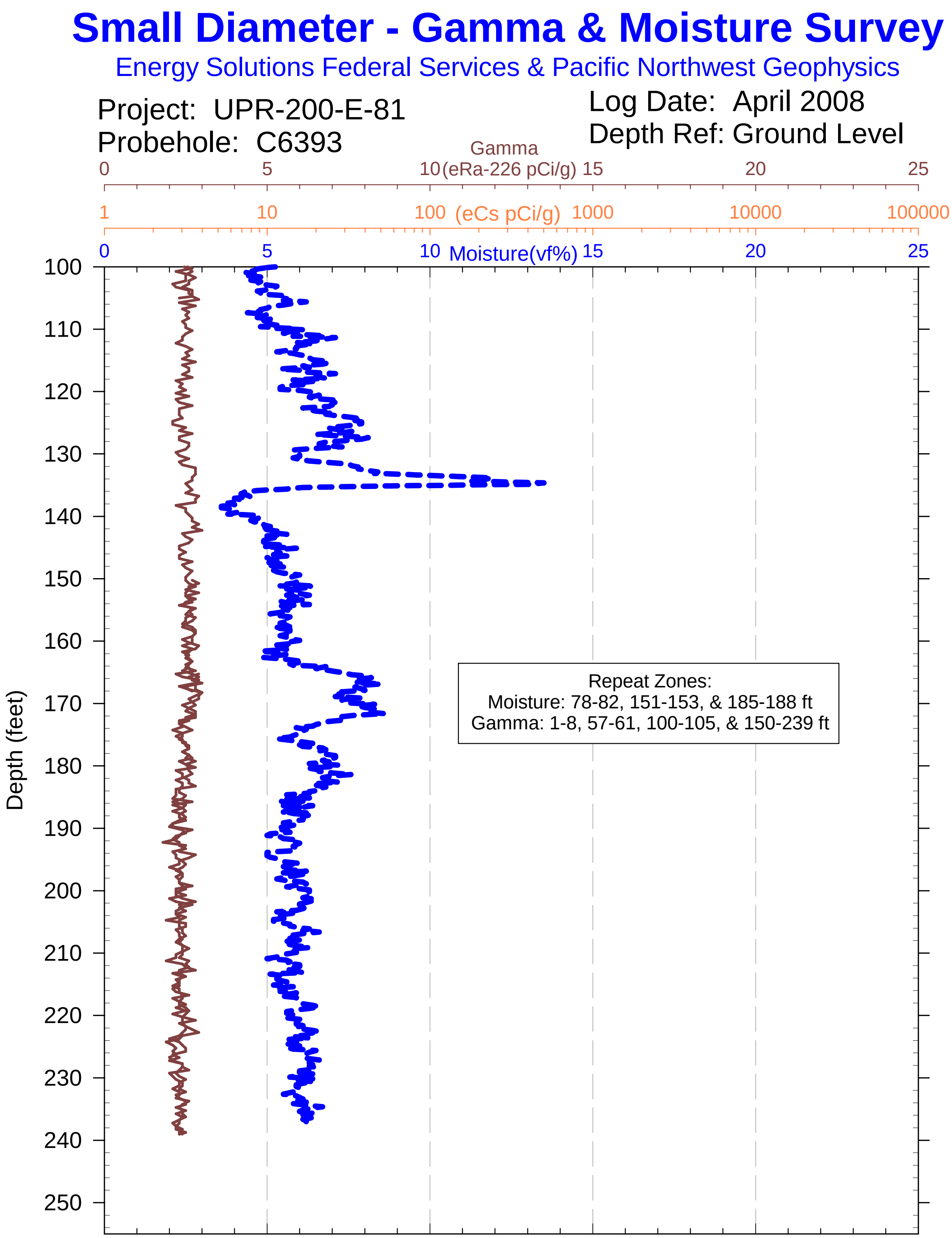
3D Trajectory



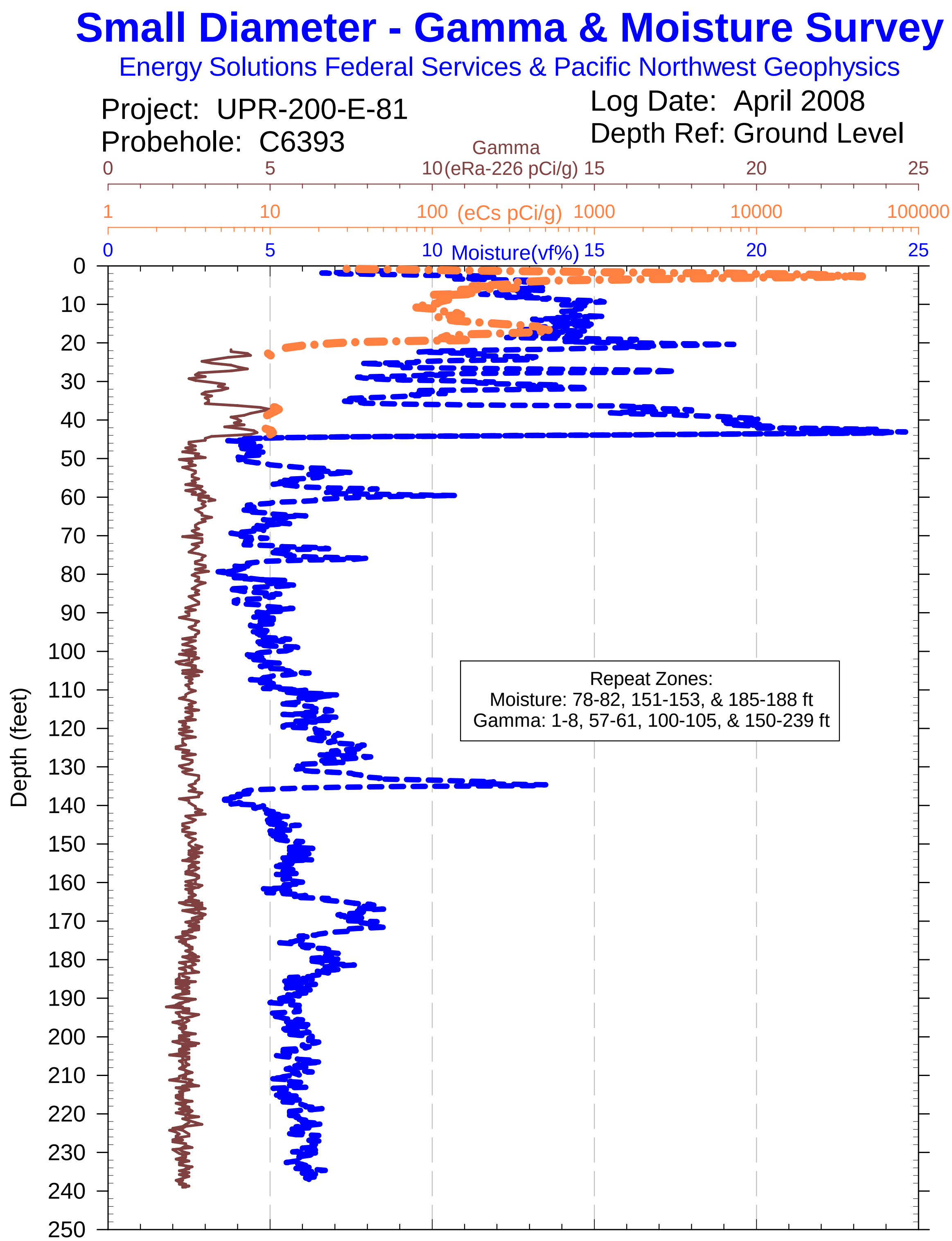

Gyroscope Hole Path Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Hole: C6399
Log Date: May 2008
Depth Ref: Ground Level
Top N0.0 E0.0 Depth 0.0
Base N-3.24 E3.10 Depth-235.29ft
Max Deviation: 2.2-Deg @ 60ft
Depth Meas.=235.34ft Vert.=235.29ft
Northing
Easting
Dip
Depth (Feet)
-S / +N (Feet)
-W / +E (Feet)
Dip (Degrees)
3D Trajectory
Depth (Feet)
Red = Hole Path
Blue = Projection
Top to Total Depth
Gray = Surface
Area of Well Path
+N / -S (Feet)
-W / +E (Feet)
Closure Distance
4.5 ft


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6391
Log Date: May 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
(eCs pCi/g)
Moisture(vf%)
Depth (feet)
Repeat Zones:
Moisture: 40-44 & 122-135 ft
Gamma: 5-10 & 65-69 ft

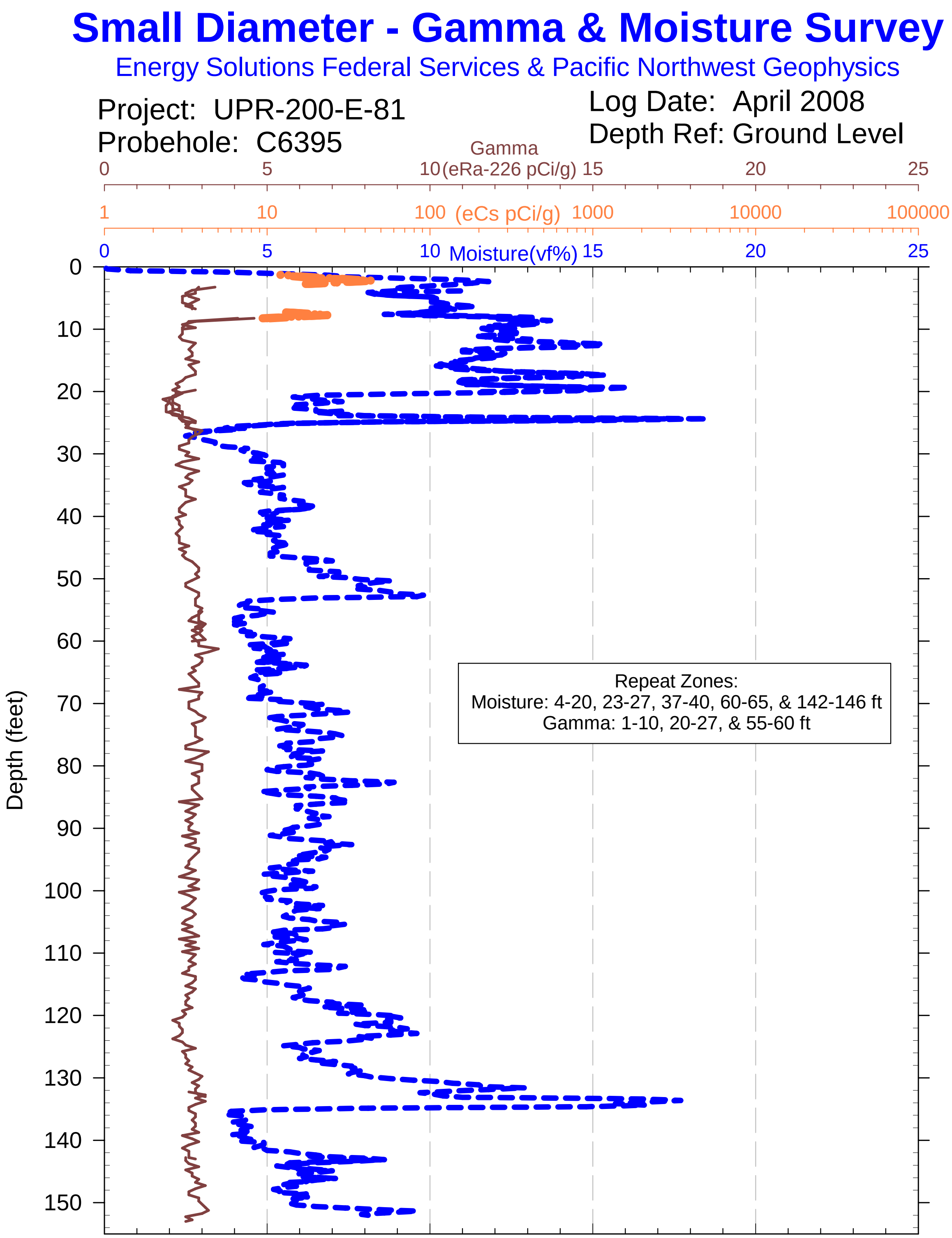

Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
0
5
10
15
20
25
1
10
100
(eCs pCi/g)
1000
10000
100000
Moisture(vf%)
Depth (feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft

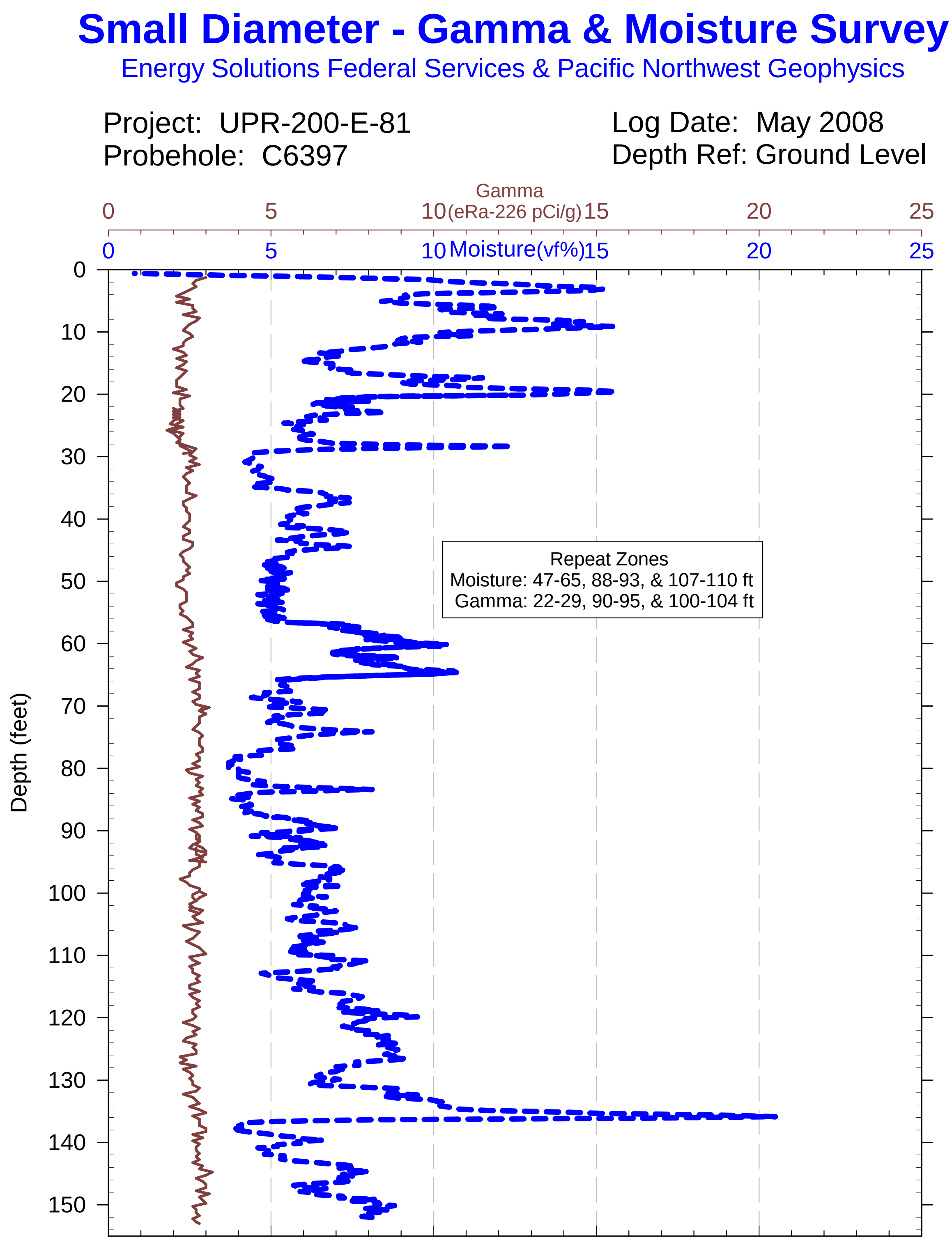


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
0
5
10
15
20
25
(eCs pCi/g)
1
10
100
1000
10000
100000
Moisture(vf%)
0
5
10
15
20
25
Depth (feet)
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft



Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6393
Log Date: April 2008
Depth Ref: Ground Level
Gamma (eRa-226 pCi/g)
0
5
10
15
20
25
1
10
100
(eCs pCi/g)
1000
10000
100000
Moisture(vf%)
Depth (feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
Repeat Zones:
Moisture: 78-82, 151-153, & 185-188 ft
Gamma: 1-8, 57-61, 100-105, & 150-239 ft


Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6395
Log Date: April 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
0
5
10
15
20
25
(eCs pCi/g)
1
10
100
1000
10000
100000
Moisture(vf%)
0
5
10
15
20
25
Depth (feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Repeat Zones:
Moisture: 4-20, 23-27, 37-40, 60-65, & 142-146 ft
Gamma: 1-10, 20-27, & 55-60 ft

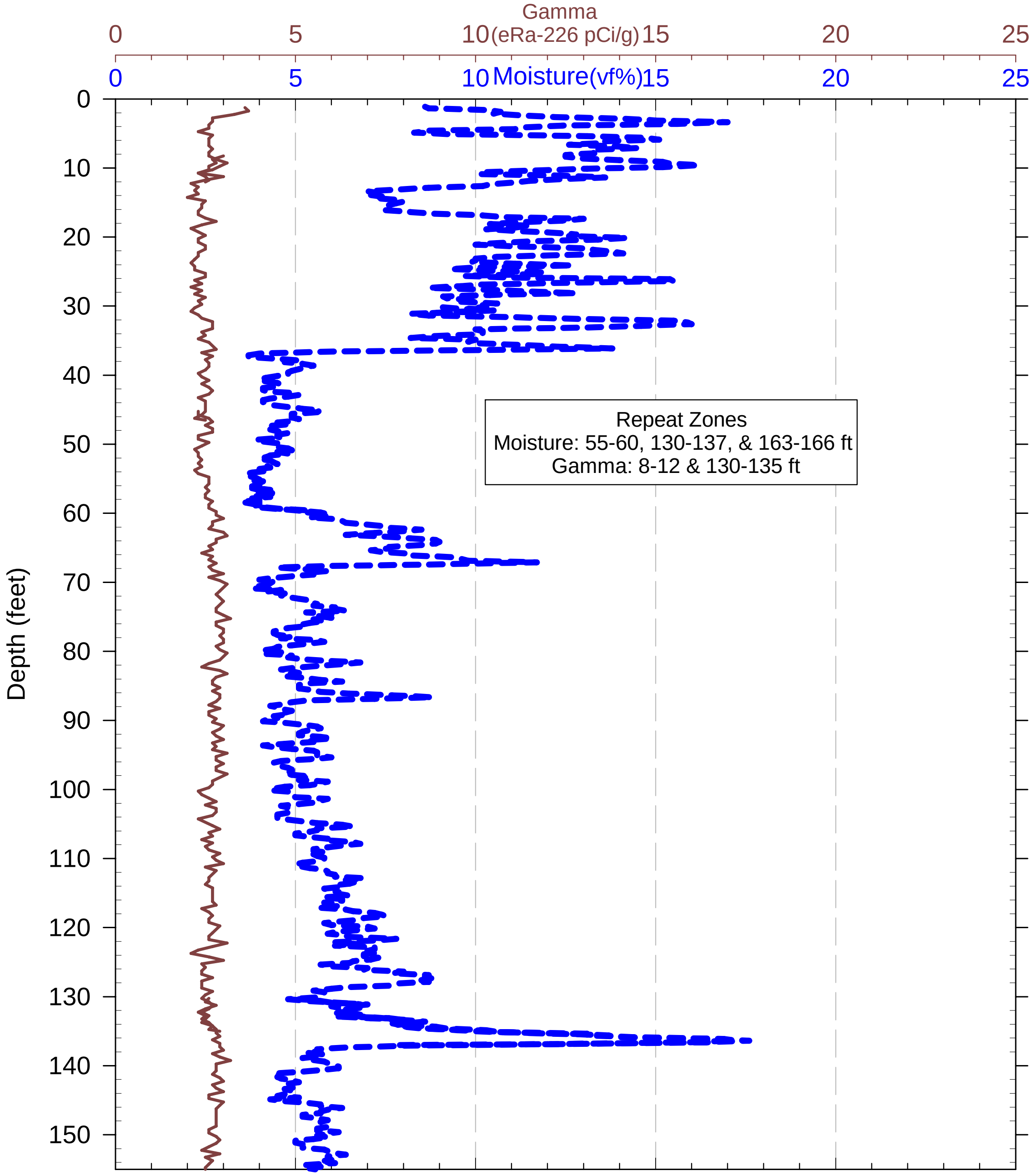

Small Diameter - Gamma & Moisture Survey
Energy Solutions Federal Services & Pacific Northwest Geophysics
Project: UPR-200-E-81
Probehole: C6397
Log Date: May 2008
Depth Ref: Ground Level
Gamma
(eRa-226 pCi/g)
0 5 10 15 20 25
Moisture(vf%)
0 5 10 15 20 25
Depth (feet)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Repeat Zones
Moisture: 47-65, 88-93, & 107-110 ft
Gamma: 22-29, 90-95, & 100-104 ft

Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6399

Log Date: May 2008
Depth Ref: Ground Level

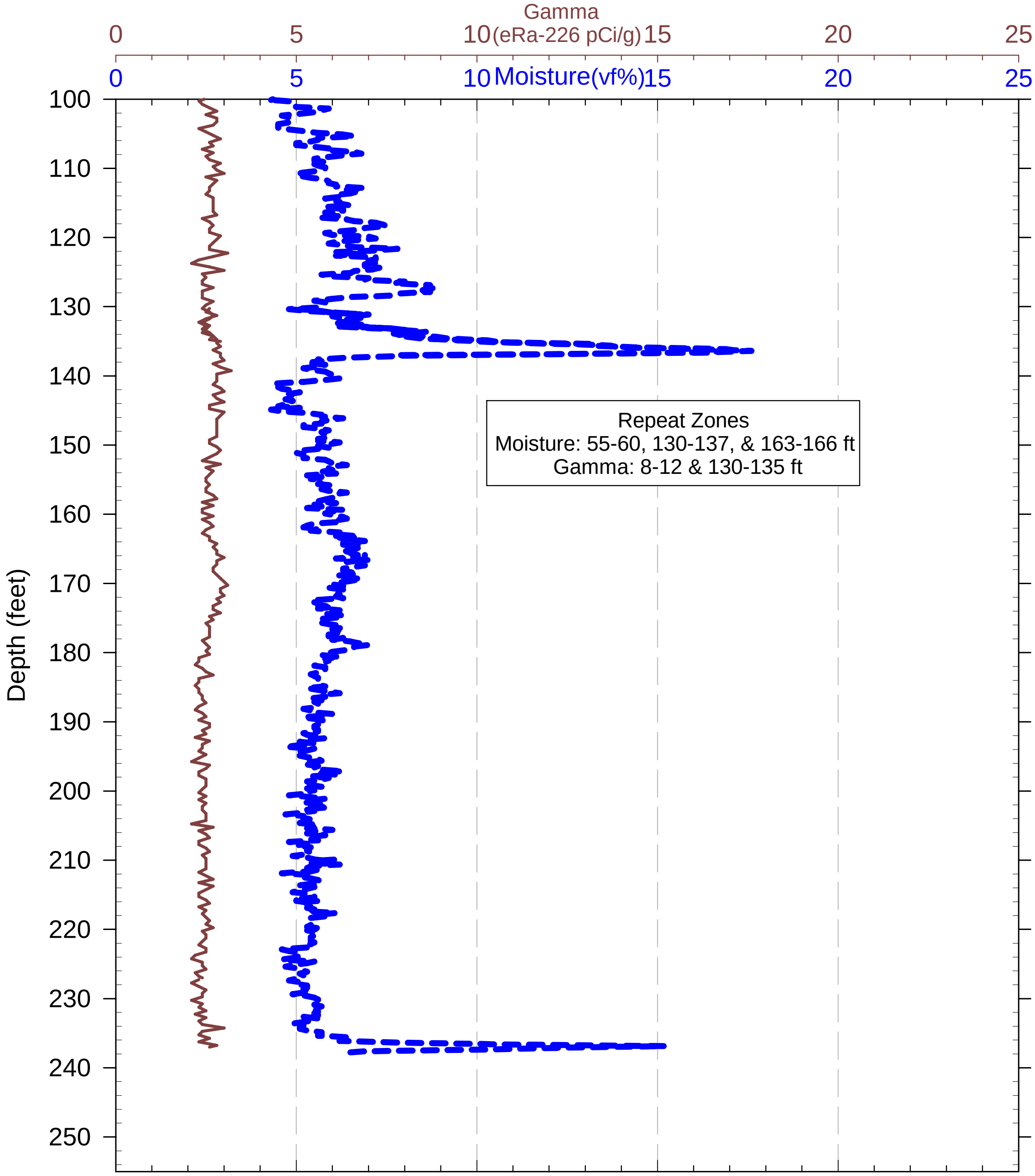


Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81 Log Date: May 2008

Probehole: C6399 Depth Ref: Ground Level



Small Diameter - Gamma & Moisture Survey

Energy Solutions Federal Services & Pacific Northwest Geophysics

Project: UPR-200-E-81
Probehole: C6399

Log Date: May 2008
Depth Ref: Ground Level