SMALL DIAMETER GEOPHYSICAL LOGGING AT THE 241-C-152 DIVERSION BOX

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Abstract: The report gives the gamma, neutron moisture and gyroscope results for 6 angled probe holes in 241-C Tank farm near diversion box 241-C-152.

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Small Diameter Slant-Hole Logging at the 241-C-152 Diversion Box

by

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to

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1.0 INTRODUCTION

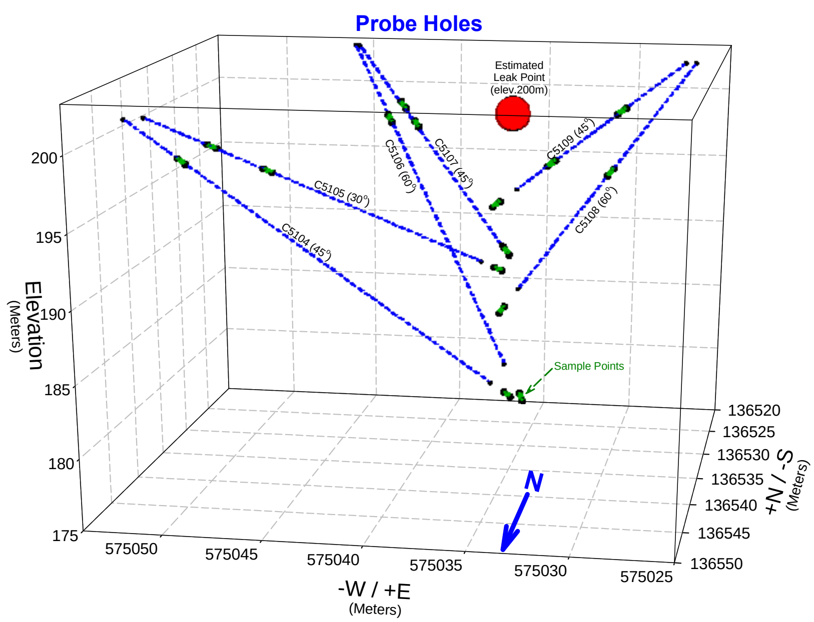
Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter logging in support of slant-hole probing and sampling activities at the C-152 Diversion Box (C Tank Farm) to investigate the extent of subsurface contamination. Logging surveys were conducted with two detectors: NaI (scintillation) gross gamma and neutron moisture. This report presents the results of these surveys for the 6 slant holes installed at the investigation site. A 3-D view of the probe-hole locations (copied from the gyro survey report) shows the slant hole drive angle, probe direction, and sample locations (see Figure 1).

The NaI gross gamma and neutron moisture logging sondes were calibrated in their respective borehole calibration models and the calibrations were (1) either performed at, or (2) extrapolated to, the probe hole conditions present at the investigation site (see section 2.0).

Log surveys were recorded at various times during the drilling, to track the predicted sub-surface soil conditions, so that the target sample locations (depths) would be collected for laboratory analysis. All log intervals and repeats are presented on the same plot, they confirm the precision (repeatability) of the logging system.

The survey results for each probe hole are presented graphically as depth versus detector response (in Appendix A). The plots are in numeric order of the probe holes (C5104 – C5109). The appendix also includes a table that summarizes for each probe hole: survey dates, detector type, and survey depth range.

Figure 1. C-152 Slant Hole Locations, Drive Angle, and Direction



2.0 GEOPHYSICAL LOGGING SYSTEM

The small-diameter logging unit deployed to the investigation site, is a portable unit (i.e. mounted on a wagon). The system is powered by the on-site generator (120v AC). The system contains a laptop computer that monitors encoder depth positions, controls the winch motor, and records detector responses.

The NaI gamma and neutron moisture detectors contain their own signal processing/counting hardware and each respond directly to the laptop computer communication commands, this configuration enhances detector stability, simplifies system setup, and improves calibration by minimizing the travel distance of detector signals before conversion to digital mode.

2.1 GROSS GAMMA CALIBRATION AND SURVEYS

The gross gamma scintillation detector is a sodium-iodide (NaI) crystal. The NaI crystal (1-in. long) is hydroscopic and is enclosed in a hermetically sealed can (1-in. diameter) to maintain its integrity. Other components of the gamma detector are the high-voltage supply, photo-multiplier tube, pre-amp, and multi-channel analyzer. The settings of the detector components are fixed (i.e. set up during assembly, prior to calibration) and are not adjustable by the field-logging engineer. The detector gain and lower threshold are set to record gamma ray activity of energies between 100 and 3000 keV. By comparison, the highest gamma ray encountered during logging is from a naturally occurring radionuclide (thorium-232) and it occurs at 2614 keV. Coleman lantern mantles containing thorium-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 NaI detector is calibrated in Gross gamma borehole calibration models located at the U.S.-DOE Hanford site near Richland, Washington. Calibration was performed in the two most appropriate (lowest concentration) gross gamma calibration zones (SBA and SBU). The detector was covered with a 4-ft long section of the probe/drill tubing (0.37-inch thick). The calibration data are summarized in Table 1. The calibration units are pCi/g of equivalent Radium-226 (eRa-226). See Figure 2 for the calibration certificate.

Table 1. Gross Gamma Calibration Data

Calibration Model	Concentration eRa-226 (pCi/g)	Gross Gamma Response[1] (cps)	Dead-Time Corrected Gross Gamma Count-Rate[2] (cps)
SBA	61.2	476.0	477.8
SBU	186	1396.6	1412.7

1-Count rates are mean of 10 sample measurements at 100-sec each.

2-NaI Detector system dead time is 8.15 microsecond

Figure 2. Gross Gamma Calibration Certificate

Certificate of Calibration
SDGR-4N4-NaI1
July 7, 2005

Data were taken at the Hanford KUT models on July 7, 2005. SDGR-4N4-NaI1 is the designated Scintillator tool. Two models were used for the gross gamma calibration (SBU and SBA). Ten spectra were recorded for each model in order to perform statistical analysis. The observed deviations were seen to be near the theoretically predicted variation, for this analysis, refer to the compressed files: Gross.xls.

This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

The instrument was covered with 0.37 inch wall-thickness probe-tubing.

The coefficient analysis is determined by the algorithm described in WHC-SD-EN-TI-293, Rev. 0. 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 Eq. ^{226}Ra 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 = .131 Eq.^{226}Ra pCi/g / (c/s)
b ≡ 0

Digital files condensed as Cal_SD-GR-02_2005-v0.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting

The undersigned certifies that the data archived in the file “Cal_SD-GR-02_2005-v0.zip” were collected and evaluated in accordance with WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models* and that the above stated calibration coefficients are correct and applicable for the tool SDGR-4N4-NaI1 effective July 7, 2005.

Signature: Russel Randall PhD　　　　Date: July 8, 2005

Company: Three Rivers Scientific

The NaI gamma surveys were acquired at 3 ft/minute. A spectrum of 256 channels was collected each 0.5 feet from the bottom of the probe-hole to the surface. The spectra were recorded in Ortec PHA “-.chn” format with one spectra per file. Detector count rates were dead-time corrected and the gamma survey data was processed as gross gamma response to determine the concentration of equivalent Radium-226 (eRa-226) in pCi/g.

The dead time correction is a nonparalyzeable relationship (Knoll, 1979) and 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 8.25μs (Randall & Price, 2006).

Also, the NaI gross gamma detector was calibrated for eCs-137 (pCi/g) in addition to the primary calibration for eRa-226 (Randall & Price, 2005). The calibration for eCs-137 was to report elevated gamma count-rate zones in units commonly encountered in Hanford soils. Calibration for eCs-137 was performed in Hanford well 299-W10-72 (a standard identified by Stoller Corporations’ logging group). The Cs-137 in the well is stable, except for the 30 year half life decay of the radio-isotope. Also, distribution of Cs-137 ranges from less than 1 pCi/g to 40,000 pCi/g along the depth of the well. The concentrations of Cs-137were established by two HPGe detectors (the 70% tool and the High Rate tool). The conversion factor from detector count rate (cps) to eCs-137 is 0.373 (pCi/g per cps) for casing thickness of 0.40-in.

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 neutron source is an integral component of a neutron-moisture detector and calibration factors are tied-to each neutron source. The neutron source is identified by the tool serial number (H38068291).

The integrity of the sealed neutron source was always maintained when it was used in calibration activities and in probe hole logging activities. Source integrity was achieved by inserting the PNG owned neutron detector module into the housing containing the sealed neutron source, manufactured by Campbell Pacific Nuclear.

Calibration was performed in six borehole calibration models (Meisner & Randall, 1995). Three models have 6-in. hole-size and three models have 8-in hole-size. The moisture content of each model in a set of three borehole models is different (5, 12, or 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* (cps)	8-inch Models* (cps)
5% vf	96.2	75.7
12% vf	142.7	106.5
20% vf	179.0	129.7

*Count rates are mean of 10 sample measurements at 60-sec each.

The probe holes size for this project was 2.51-inch. Therefore, the moisture calibration was extrapolated to the correct hole-size. The moisture calibration certificate for 2.51-in hole-size is shown in Figure 4.

The probe hole survey was collected at 1.5 ft/minute. Processing of the moisture survey data requires that the borehole survey data be normalized to the thickness of the steel casing present in the calibration models (0.325-in). Given that the probe hole casing thickness is 0.37-in, a correction factor of 1.055 is required to increase (normalize) the observed detector count rate to the conditions of the calibration model (Meisner, et al. 1996).

Figure 3. Moisture Calibration Certificate, Hole Size: 6-in. and 8-in.

Certificate of Calibration for Instrument SD-Moist291-2

June 6, 2005

On June 6, 2005 data were taken in the Moisture models for the SD-Moist291-2 neutron-neutron moisture tool. The neutron source from DOE moisture tool # H38068291 was used with the passive neutron detector probe from PNG. This calibration is required for the Direct Push logging, and it is funded by subcontract 013661.

Six models were used for moisture calibration, three for 6-in. casing and three for 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 (refer to the file Stats-moist.xls for this analysis).

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*, Rev. 0. The regression function used is a power law form and defined by:

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

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 deadtime corrected observed total count rate, (c/s).

6" casing	8" casing
a = .0002069	a = .00008067
α = 2.210	α = 2.550

The undersigned certifies that the data archived in data file "SD-Moist291_2005.zip" were collected and evaluated in accordance with WHC-SD-EN-TI-306 and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 1, 2005
Three Rivers Scientific

Figure 4. Moisture Calibration Certificate, Hole Size 2.51-in.

Moisture Calibration Extrapolation to 2.51 Inch Borehole
Instrument SD-Moist291-2
June 6, 2005

Moisture calibration was performed in the Hanford physical models. These standards have 6-in. and 8-in. inside diameter (ID) casings. The Tank Farm Direct Push borehole is cased with a 2.51-in. outside diameter (OD) 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, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*, Rev. 0. The regression function used is a power law form and defined by:

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

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 deadtime corrected observed total count rate, (c/s). A linear extrapolation was applied to determine the 2.51 inch borehole diameter.

2.51" borehole
a = .000343
α = 1.951

The undersigned certifies that the analysis files are archived in the file "SD-Moist291_2005.zip" which was evaluated in accordance with DTS procedures and that the above stated calibration coefficients are correct and applicable for tool SD-Moist291-2, effective June 6, 2005.

Signature: Date:

Russel Randall, PhD July 12, 2005
Three Rivers Scientific

3.0 CONCLUSION

Scintillation Gross Gamma and Neutron Moisture survey logs were collected in 6 slanted probe holes installed in the investigation site at the C-152 Diversion Box. All probe holes were pushed to their target depth. The survey results are presented in Appendix A and a 3D view of the probe-hole locations showing the drive angle and direction is shown in Figure 1.

The probe holes are paired as a consequence of their initial starting location, i.e. (C5104, C5105), (C5106, C5107), and (C5108, C5109). These paired holes may be examined together by overlaying the plots. The gamma activities in all probe holes indicate low activity, (count rate levels are at or near the natural background activity), except for C5109 which encountered one zone with elevated count rate. However, the moisture surveys show significant variations with depth. The paired probe holes have similar distribution profiles. Except for the pair (C5108, C5109) which show the most difference between the depth range (elevation): 194 to 199 meters.

The moisture content is higher near the surface and significantly dryer 6-meters below ground surface in all probe holes. The dry zones are where the probe holes extend below the protective barrier that was placed over the C-152 Diversion Box.

The moisture content changed between logging runs on three probe holes (C5106 at 198.7 meters), (C5108 at 196.67 meters), and (C5109 at 197 meters). In each of these three occasions, the moisture change is between log runs where a soil sample was collected. During sampling, the drive tubing was retrieved to extract the sample. The moisture change probably occurred when then the drive-tubing was re-inserted, which permitted materials in the subsurface to be moved around. The consistency of moisture content between log runs and soil sampling events may support discussions in support of the probe hole driving technique.

The survey results show that the soil samples were collected at subsurface locations where moisture transition content was transitioning from high to low.

4.0 REFERENCES

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APPENDIX A: GAMMA SURVEY RESULTS

Gamma and Moisture Survey Plots follow for the 6 slant probe holes installed around the C-152 Diversion Box. The plots have two depth scales (y axis). (1) The vertical depth (elevation in meters) is presented on the left side of the plot. All plots have the same elevation depth range. (2) The measured distance along the slant hole (in feet) is presented on the right side of the plot.

Table 3 presents inclination and elevation information for each probe hole. Zero depth reference is at ground surface. Soil sample locations are shown on the plots as a wide green line connecting two black dots, one at the top and one at the bottom of the sample depths. Each probe hole was sampled at its maximum depth.

The neutron moisture survey results are presented in %-volume-fraction units, the plot scale is 0-25 %vf (green line). The plot scale for the gross gamma results are shifted to improve interpretation of the survey data and minimize overlap of the plotted curves, in zones with low moisture content (same for all plots). The gross gamma survey data were dead-time corrected and the results are converted to two calibration units

(1) Eq Ra-226 for natural radionuclides (concentrations less than 5 pCi/g), plot scale 1-26 pCi/g (blue line) and

(2) Eq Cs-137 for contamination zones (concentrations greater than 4 pCi/g), plot scale 0-100 pCi/g (red line). The scale is linear and only probe hole C5109 encountered gamma emitting contamination (greater than 5 pCi/g of eRa-226). No spectral gamma measurements were acquired.

Table 3. Slant Hole Inclination, Elevation at Ground Level, and True Vertical Depth

Hole	Inclination Angle (degrees) (90=vertical) (0=horizontal)	Sine (angle) Factor: TVD / Slant Hole	Elevation at Ground-Level (m)	Sample Max. Depth (Slant Hole ft)	Sample Vertical Depth (ft)	Sample Elevation Max Depth (m)
C5104	44	0.6947	201.76	110.5	76.76	178.36
C5105	31.5	0.5225	201.76	85	44.41	188.22
C5106	58	0.848	203.08	92	78.02	179.30
C5107	45.4	0.712	203.08	61	43.43	189.84
C5108	60.5	0.8704	203.15	68	59.18	185.11
C5109	45.4	0.712	203.19	47	33.47	192.99

Table 4. Probe Hole Survey Summary

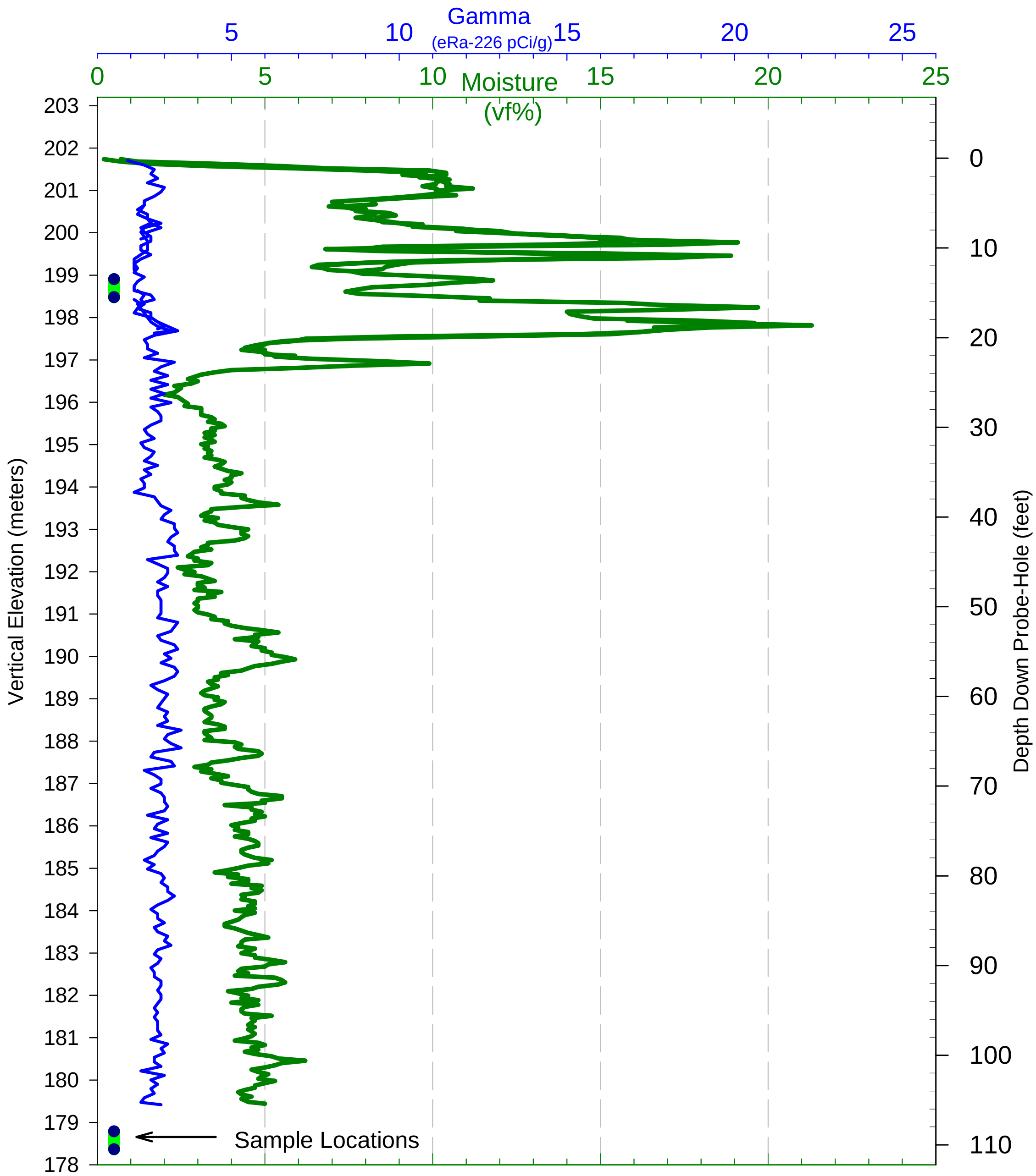
Probe Hole	Log Date	Gross Gamma	Moisture	Survey Bottom Depth	Survey Top Depth
C5104	5/2/2006		Moist	12.6	0.0
C5104	5/2/2006	Gamma		12.5	0.0
C5104	5/3/2006	Gamma		105.5	7.0
C5104	5/4/2006		Moist	105.4	0.0
C5105	5/23/2006	Gamma		12.0	0.0
C5105	5/26/2006	Gamma		25.3	8.0
C5105	5/30/2006	Gamma		79.0	19.0
C5105	6/1/2006		Moist	79.3	0.0
C5106	4/10/2006	Gamma		17.5	0.0
C5106	4/10/2006		Moist	17.8	0.0
C5106	4/12/2006		Moist	84.0	13.0
C5106	4/13/2006	Gamma		84.0	12.0
C5107	4/19/2006	Gamma		6.9	0.0
C5107	4/19/2006	Gamma		15.7	5.0
C5107	4/20/2006	Gamma		21.5	14.0
C5107	4/25/2006	Gamma		55.4	16.5
C5107	4/25/2006		Moist	55.5	0.0
C5108	3/21/2006		Moist	30.0	2.0
C5108	3/22/2006	Gamma		26.5	0.0
C5108	3/22/2006		Moist	26.4	0.5
C5108	3/27/2006	Gamma		63.5	16.0
C5108	3/28/2006		Moist	63.4	19.5
C5109	3/30/2006	Gamma		13.1	0.0
C5109	4/3/2006	Gamma		30.0	5.0
C5109	4/3/2006		Moist	30.0	0.0
C5109	4/5/2006	Gamma		41.7	25.0
C5109	4/5/2006		Moist	41.8	33.3

Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5104 (45-degrees)

Log Date: May 2006
Depth Ref: Ground Level

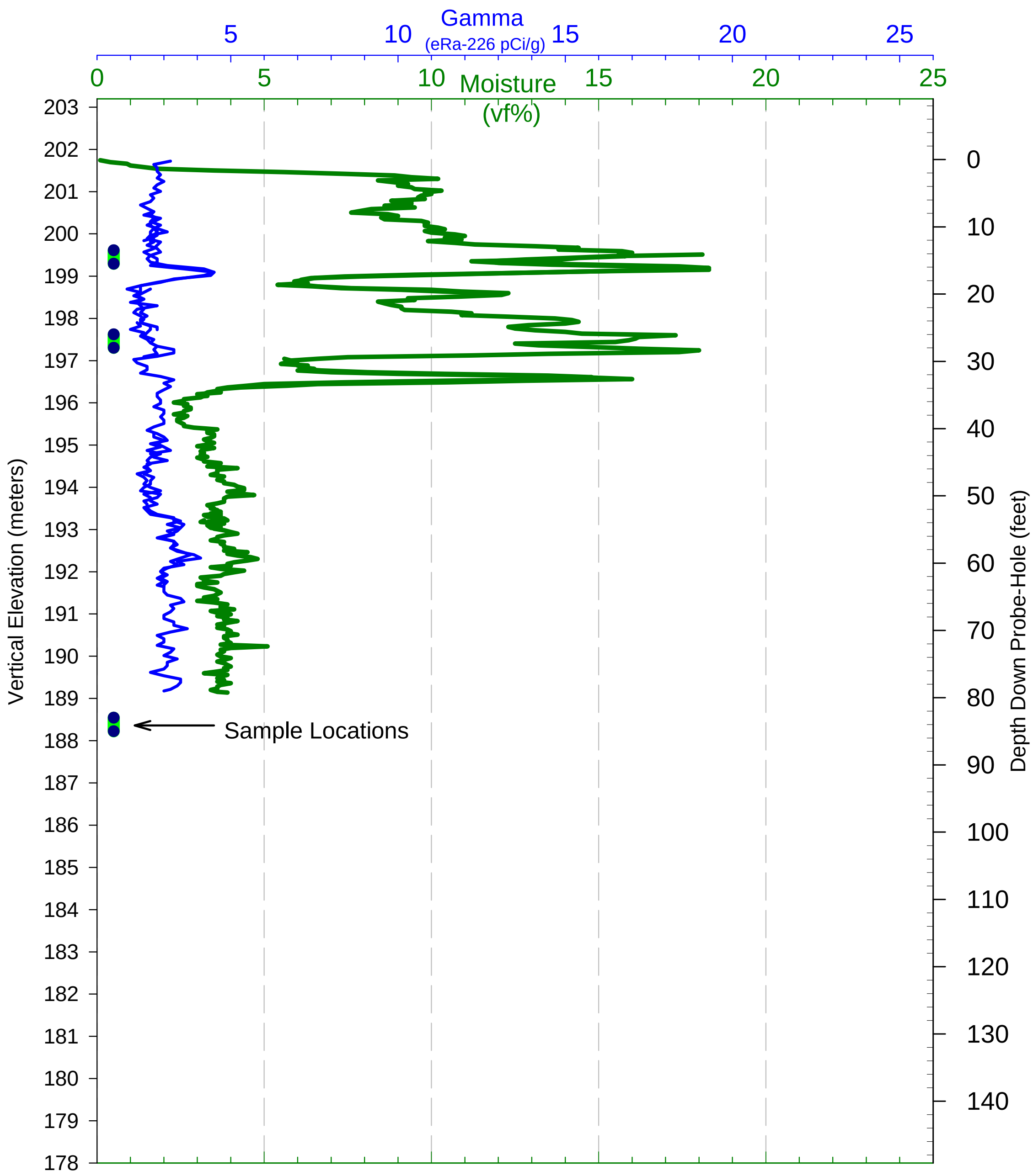


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5105 (30-degrees)

Log Date: June 2006
Depth Ref: Ground Level

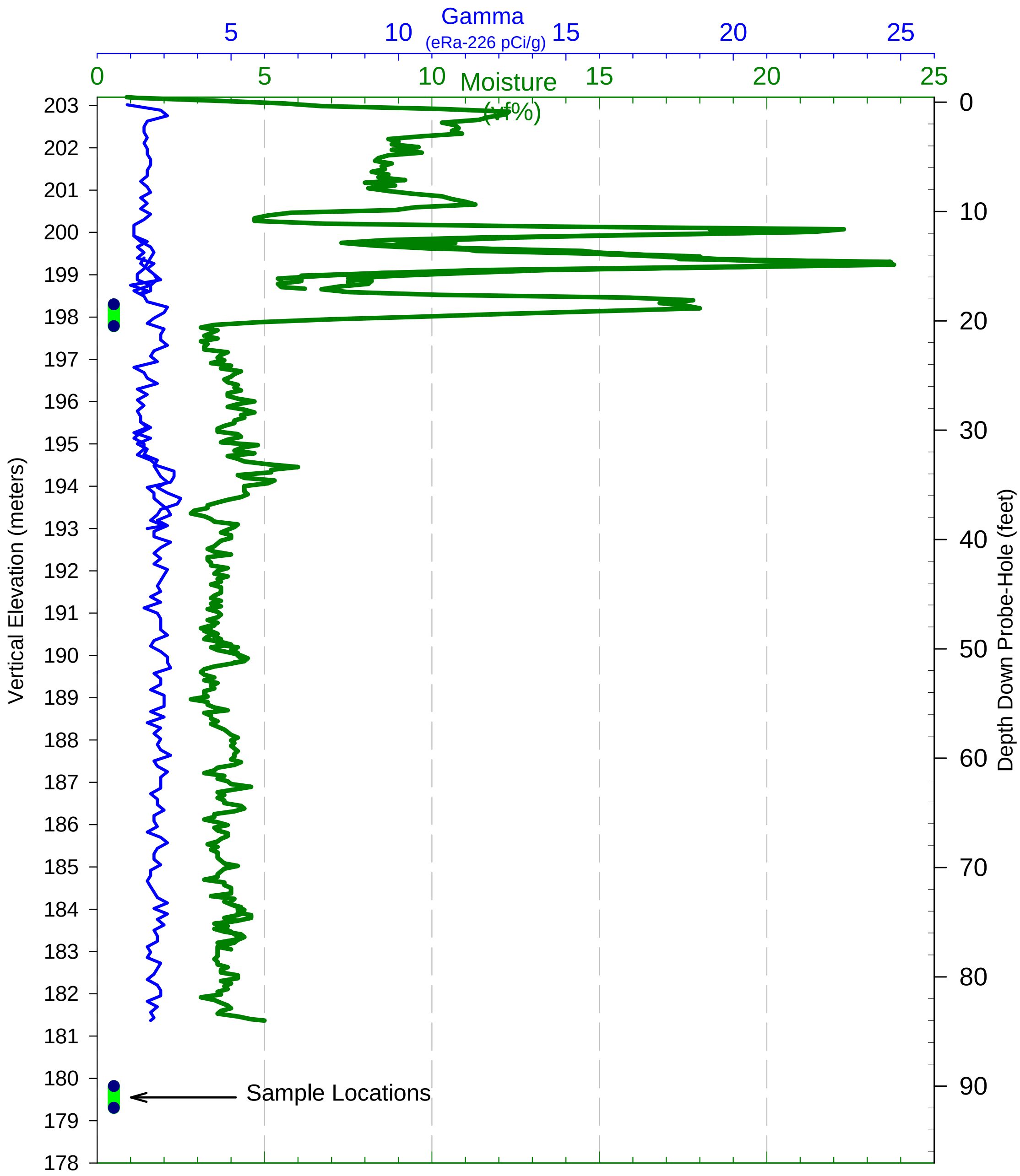


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5106 (60-degrees)

Log Date: April 2006
Depth Ref: Ground Level

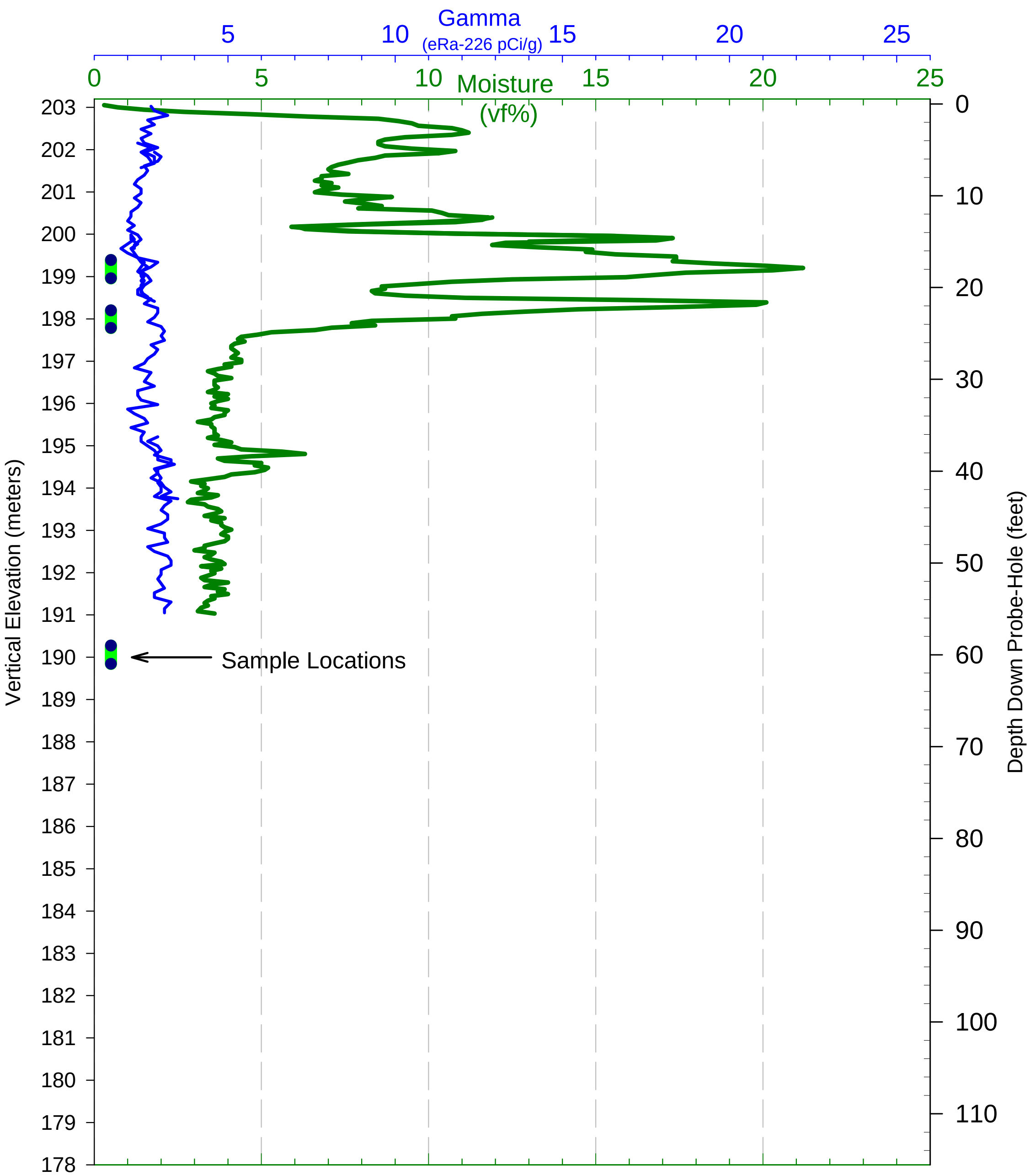


Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5107 (45-degrees)

Log Date: April 2006
Depth Ref: Ground Level

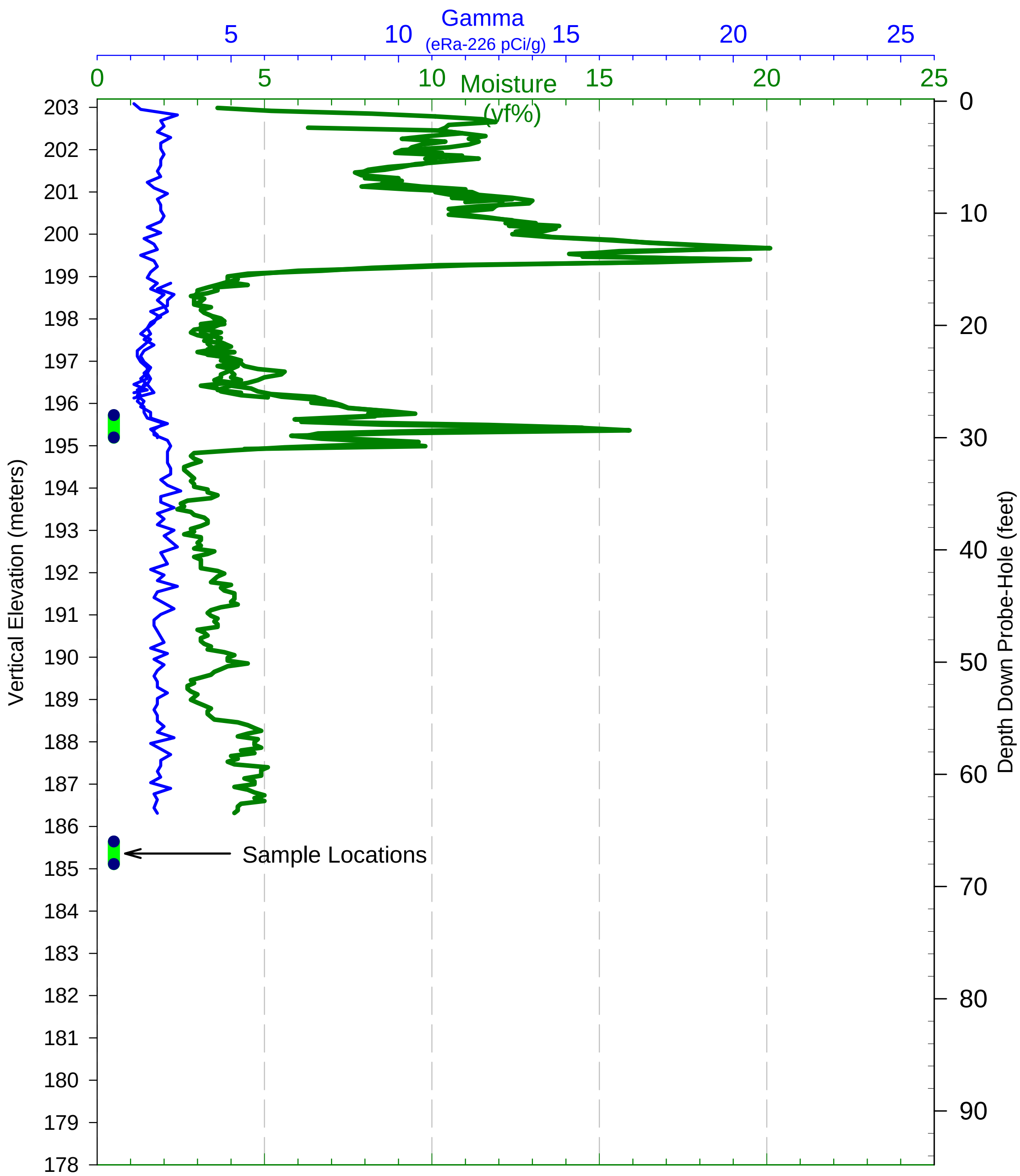


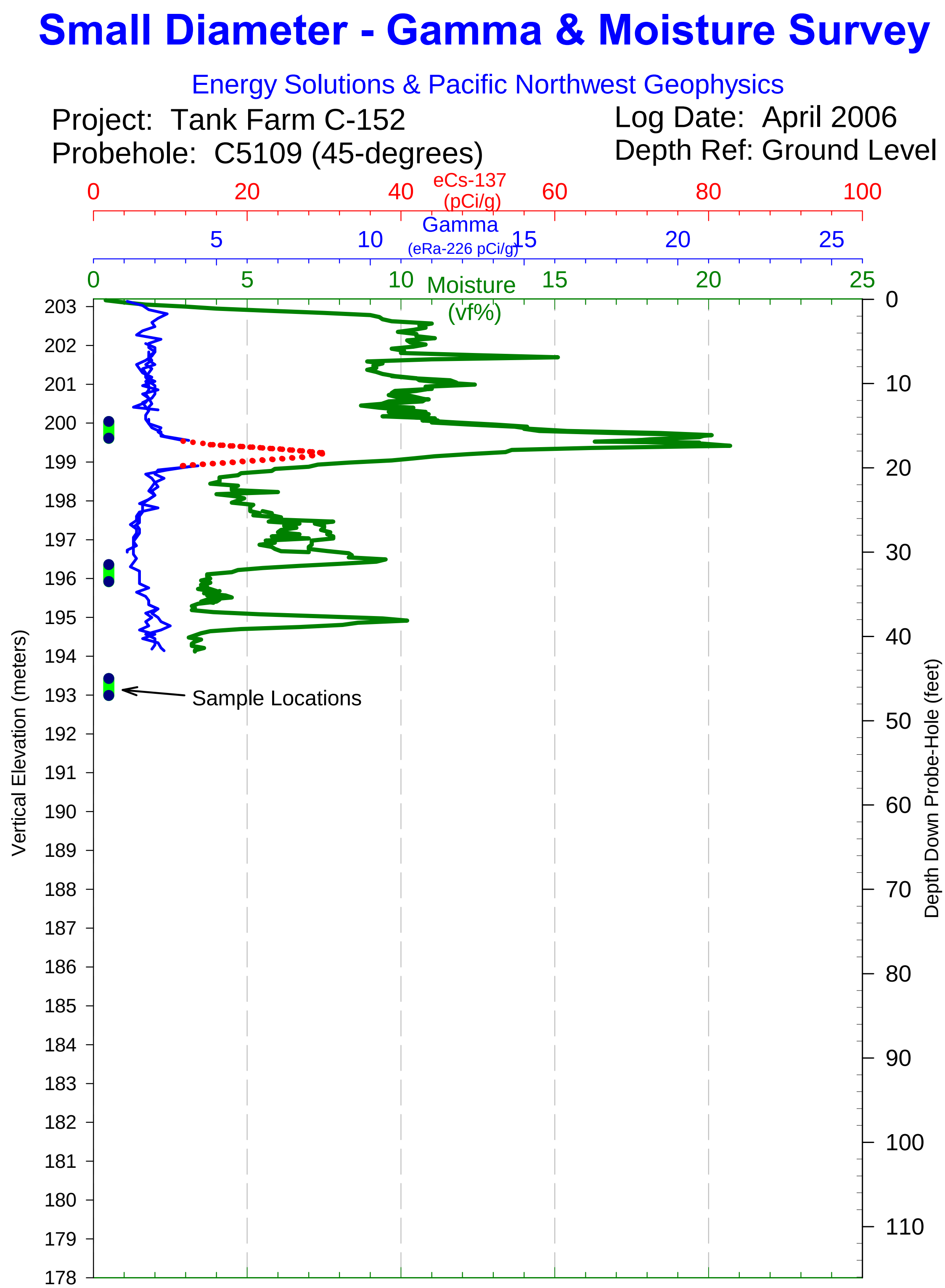
Small Diameter - Gamma & Moisture Survey

Energy Solutions & Pacific Northwest Geophysics

Project: Tank Farm C-152
Probehole: C5108 (60-degrees)

Log Date: March 2006
Depth Ref: Ground Level





Small Diameter - Gamma & Moisture Survey
Energy Solutions & Pacific Northwest Geophysics
Project: Tank Farm C-152
Probehole: C5109 (45-degrees)
Log Date: April 2006
Depth Ref: Ground Level
eCs-137 (pCi/g)
0 20 40 60 80 100
Gamma (eRa-226 pCi/g)
5 10 15 20 25
Moisture (vf%)
0 5 10 15 20 25
Vertical Elevation (meters)
203 202 201 200 199 198 197 196 195 194 193 192 191 190 189 188 187 186 185 184 183 182 181 180 179 178
Depth Down Probe-Hole (feet)
0 10 20 30 40 50 60 70 80 90 100 110
Sample Locations