SMALL DIAMETER GEOPHYSICAL LOGGING IN THE 241-BX TANK FARM

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Abstract: The report gives the gamma logging results for 11 small diamater probe holes in 241-BX Tank Farm.

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Small Diameter Geophysical Logging In the 241-BX Tank Farm

by

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to

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April 2007

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1.0 INTRODUCTION

Pacific Northwest Geophysics (PNG) and Three Rivers Scientific provided small diameter (slim hole) logging in support of field activities at the 241-BX Tank Farm to investigate the extent of subsurface contamination. Logging surveys were conducted with three detectors: NaI (scintillation) gross gamma, and two Geiger Mueller tubes (GM). Spectral gamma measurements were acquired in selected probe holes to identify the dominant gamma emitting radionuclide. The surveys assisted in identifying zones of interest for sample collection and laboratory analysis. This report includes the results of these surveys for the 11 probe holes installed at the investigation site (see Appendix A). Additionally, Dry-well 21-02-04 was also logged to permit correlation of the PNG logging detectors with other DOE gamma surveys. The gamma activity exceeded 1,000,000 pCi/g of equivalent Cs-137 in four probe holes (i.e. C5119, C5121, C5127, and C5129). Spectral measurements in four other probe holes (i.e. C5123, C5125, C5131, and C5133) indicated that the subsurface gamma activity was likely the results of U-238. The gamma-ray spectra in these four probe holes either had a photo peak at 1001 keV or had an increase in gamma flux at about 1001 keV.

The objective of the gamma survey logs was to identify depth interval(s) with elevated gamma activity (i.e. equivalent Cs-137 concentrations greater than 10 pCi/g). Rapid scan gamma surveys (4 ft/minute) satisfy the contaminant detection threshold and the results are reported as gross gamma logs in pCi/g of equivalent Cs-137.

Low sensitivity gross gamma surveys, using the Green GM (5 holes) and the Red GM (2 holes) detector, were acquired in the probe holes containing the highest contaminant concentrations. The high gamma activity in these probe holes saturated the high sensitivity (NaI) scintillation detector.

Spectral gamma ray surveys were acquired through selected intervals in each probe hole where gamma activity exceeded background activity. The objective of the spectral survey was to identify the dominant gamma-emitting radionuclide. The spectra are plotted with the survey results in Appendix A.

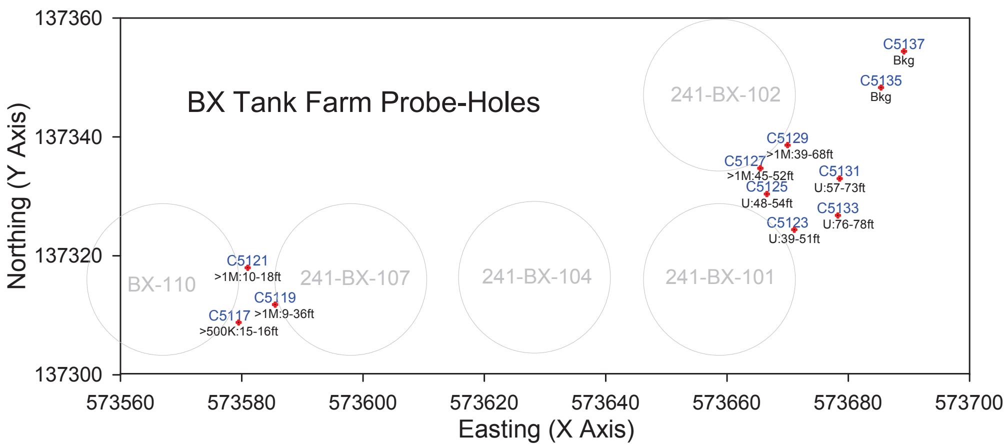
Each logging detectors (NaI gross gamma, and GM gross gamma) were calibrated for the probe hole conditions present at the investigation site (reference section 3.0).

2.0 SURVEY RESULTS

Log surveys were recorded from the bottom of the probe hole (maximum survey depth) to the ground surface. Zero depth reference is at ground surface. A daily repeat measurement was acquired in at least one probe hole to verify instrument repeatability. The main log and repeat intervals are both presented on the plot. The computed results of the main and repeat intervals were reviewed and the results agree within the uncertainty of the measurement counting statistics.

The survey results for each probe hole are presented as a depth versus concentration plot in Appendix A. The plots are in numeric order of the probe holes (C5117 – C5137). The appendix also contains a summary table of each probe hole, the detectors used, probe hole depth, depth of maximum gamma activity and maximum concentration (Eq Cs-137 in pCi/g). Figure 1 shows a graphic view of the probe-hole locations and level of contamination with depth interval.

Figure 1. Summary BX Push Hole Locations and Dominant Radionuclide



3.0 GEOPHYSICAL LOGGING SYSTEM

The small-diameter logging system deployed to the investigation site is portable (i.e. mounted on a wagon) and is powered by the on-site generator (120V AC). The logging system includes a laptop computer to monitor encoder depth positions (logging cable), control the winch motor, and record detector responses. The NaI and GM detectors contain their own signal processing/counting hardware and each respond directly to communication commands from the laptop computer. The down-hole digital-processing of detected signal pulses enhances stability, simplify system setup, and improves calibration.

3.1 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 with energies between 100 and 3000 keV. By comparison, the highest gamma ray from naturally occurring radionuclides is from 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) (Steele & George, 1986). 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:

$$\mathbf{Ra = a*GR + b}$$

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:

$$\mathbf{a = .131\ Eq.^{226}Ra\ pCi/g\ /\ (c/s)}$$
$$\mathbf{b \equiv 0}$$

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 logged at 4 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 non-paralyze-able 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).

The NaI gross gamma detector was also calibrated for eCs-137 (pCi/g). The calibration for eCs-137 was to identify high concentration zones that must be avoided for sample collection (i.e. RWP limiting condition of 100,000 DPM). 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.

The NaI gamma detector upper limit for identifying samples that will not exceed the RWP with the HPT survey instruments is estimated as follows:

Given:

a. The background activity 50 CPM = 500 DPM with the HPT survey meter (in a zone with no contamination at the surface).
b. The RWP limit is 100,000 DPM = 10,000 CPM with the HPT survey meter (200 times above background of 50 CPM).
c. The background activity is 25 cps with the 1x1-inch NaI Gamma detector in the 0.37-inch thick steel probe-hole casing.

Therefore: The suggested limit on the NaI gamma detector for avoiding samples that exceed 100,000 DPM is 25 * 200 = 5000 cps (dead time corrected) or 4800 cps (observed) count rate (conservative upper limit). Using the eCs-137 conversion factor (0.373 pCi/g per cps) this translates to about 1900 pCi/g of Cs-137.

3.2 GEIGER MUELLER (GM) CALIBRATION AND SURVEYS

The sensitivity of the Green GM detector is substantially lower than the NaI detector and is designed to measure high gamma ray flux. The GM detector was calibrated for Cesium-137 in the Cesium Calibration Well (299-W10-72 located in the 216-T-7 Crib). The concentration of ^{137}Cs was assigned from high-resolution gamma measurements collected by Stoller at 1-foot increments along the well depth. The Stoller instruments were calibrated at the Hanford borehole calibration facility, which is traceable to NIST standards.

The calibration for Eq ^{137}Cs assumes that all of the gammas are due to the presence of ^{137}Cs. The GM detector data were depth shifted to match the HPGe log data. Very good agreement between the raw count rate and Cs-137 activity indicated a low dead time correction, of approximately 0.5%. The calibration coefficient of the Green GM for Eq ^{137}Cs is 1324 (pCi/g) per (c/s). The dead-time of the GM detectors (160 uSec) was computed from calibration measurements. (Randall & Price, 2006)

GM survey were measured each 0.5 feet between the selected depth intervals in five probe holes in move-stop-acquire logging mode, the results are presented on the plot for each of the corresponding probe holes.

4.0 CONCLUSION

Scintillation Gross, Spectral Gamma, and GM survey logs were collected in 11 probe holes installed in the 241-BX Tank Farm and one dry well (BX-02-04). All probe holes were pushed to their target depth of 80 feet.

The rapid-scan gamma surveys of the probe holes can be summarized as follows:

- 2 probe holes (C5135, C5137) contained only background activity from the natural radionuclides.
- 4 probe holes (C5123, C5125, C5131, and C5133) contain low level count rate increase at depths greater than 40feet. Spectral measurements in the zone of highest gamma activity identified elevated gamma flux at 1001 keV (which indicates that U-238 may be present).
- 5 probe holes (C5117, C5119, C5121, C5127, and C5129) encountered high gamma activity at concentrations greater than 100,000 pCi/g (equivalent-Cs-137).
- 1 Dry Well (BX-02-04) was logged with the NaI and both GM detectors (Green & Red).

5.0 REFERENCES

Knoll, G. (1979), "Radiation Detection and Measurement", Copyright 1979 by John Wiley & Sons, Inc. ISBN "0-471-49545-X"

Randall, Russel R. PhD and Stromswold, David C. PhD, 1995, "Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools Using Hanford Formation Models", WHC-SD-EN-TI-293 Rev 0, Westinghouse Hanford Co., Richland, WA.

Randall, Russel R. PhD and Price, Randall K., 2006, "Gamma Surveys of Single Shell Tank Laterals for A and SX Tank Farm", CH2M Hill Hanford Group, RPP-RPT-27605 Rev.0, Richland, WA.

Steele, W. Douglas and George, David C., 1986, "Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium", Bendix Field Engineering Corp., Grand Junction, CO.

APPENDIX A: GAMMA SURVEY RESULTS

Gross Gamma Survey Plots follow for the 11 probe holes installed in the 241-BX Tank Farm and Dry-well BX-02-04. 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 (**wide blue line**) Hanford sediments have concentrations less than 5 pCi/g of eq. Ra-226. The plot scale for Eq Ra-226 is 0-25 pCi/g (blue scale).

(2) Eq Cs-137 for contamination zones (narrow red line) shown for concentrations greater than 4 pCi/g eq. Cs-137.

The plot scale for Eq Cs-137 is displayed as one of two scales (red scale).

(1) Linear: 0-100 pCi/g (low level) or

(2) Logarithmic scale (10^0 to 10^8, i.e. eight orders of magnitude)

The **Green GM** is displayed as a **green dotted line** as Eq Cs-137 (pCi/g) and use the Logarithmic scale (10^0 to 10^8).

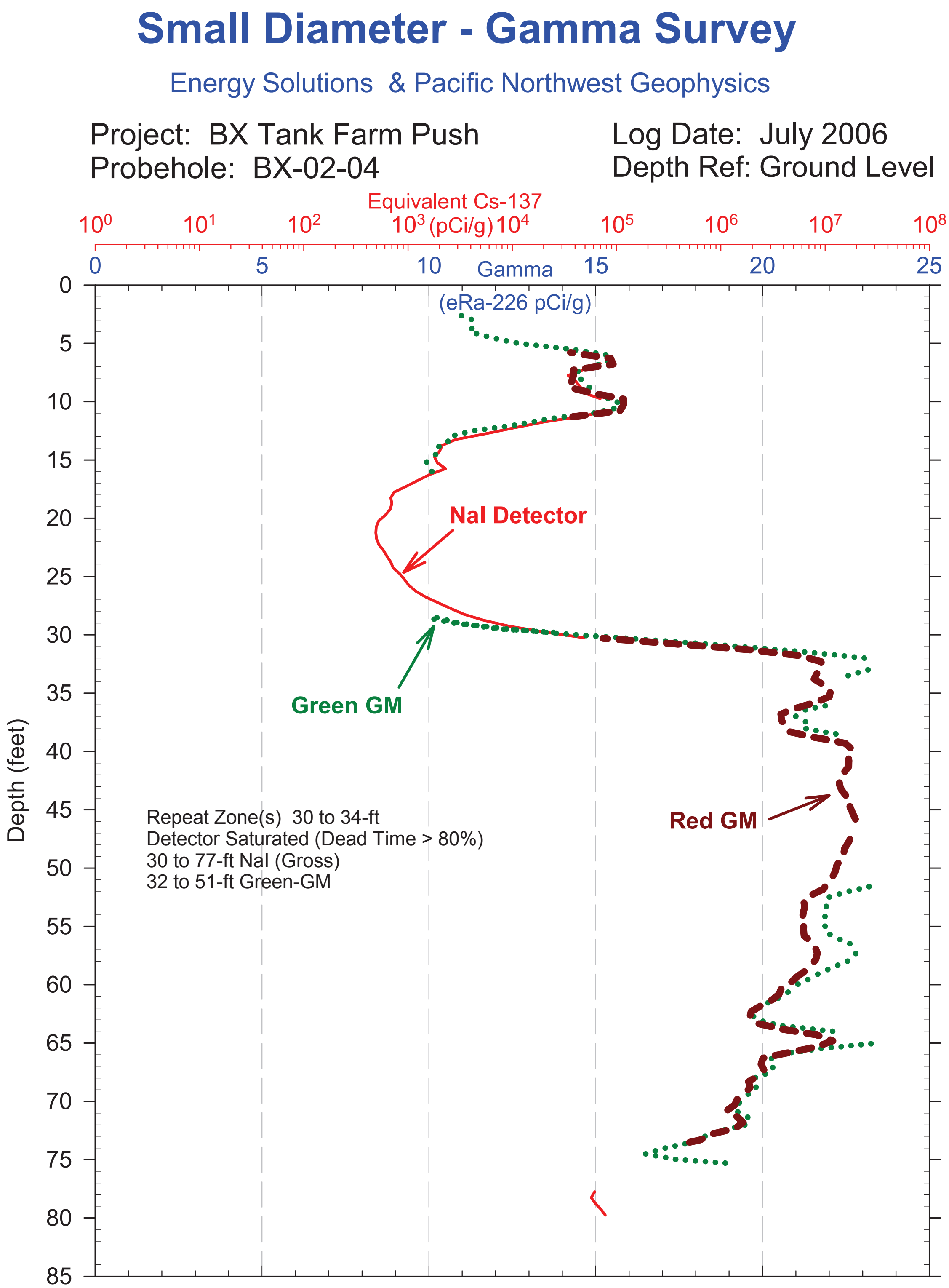
The **Red GM** is displayed as a **dark red dashed line** as Eq Cs-137 (pCi/g) with the Logarithmic scale (10^0 to 10^8).

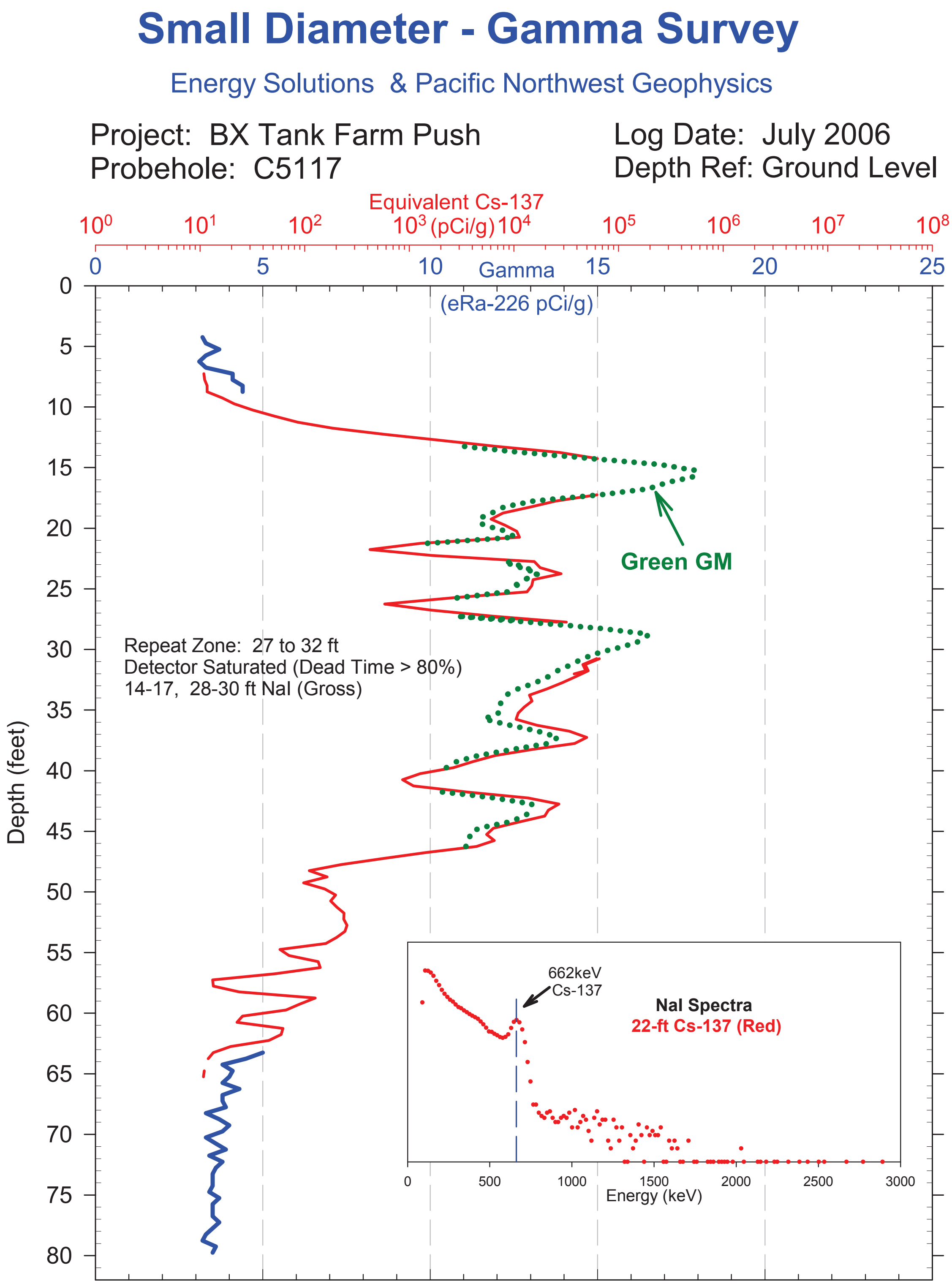
NaI spectra measurements from three probe holes (C5117, C5119, and C5127) identified Cs-137 as the dominant radionuclide. Two spectra are shown for C5127, one at the bottom of the hole shows that Cs-137 is NEAR the hole (notice that the 662 keV peak is nearly as intense as the low energy gammas at 100 keV). The second spectra at 36-ft shows that the Cs-137 is DISTANT from the detector (notice there is no clear gamma peak at 662 keV).

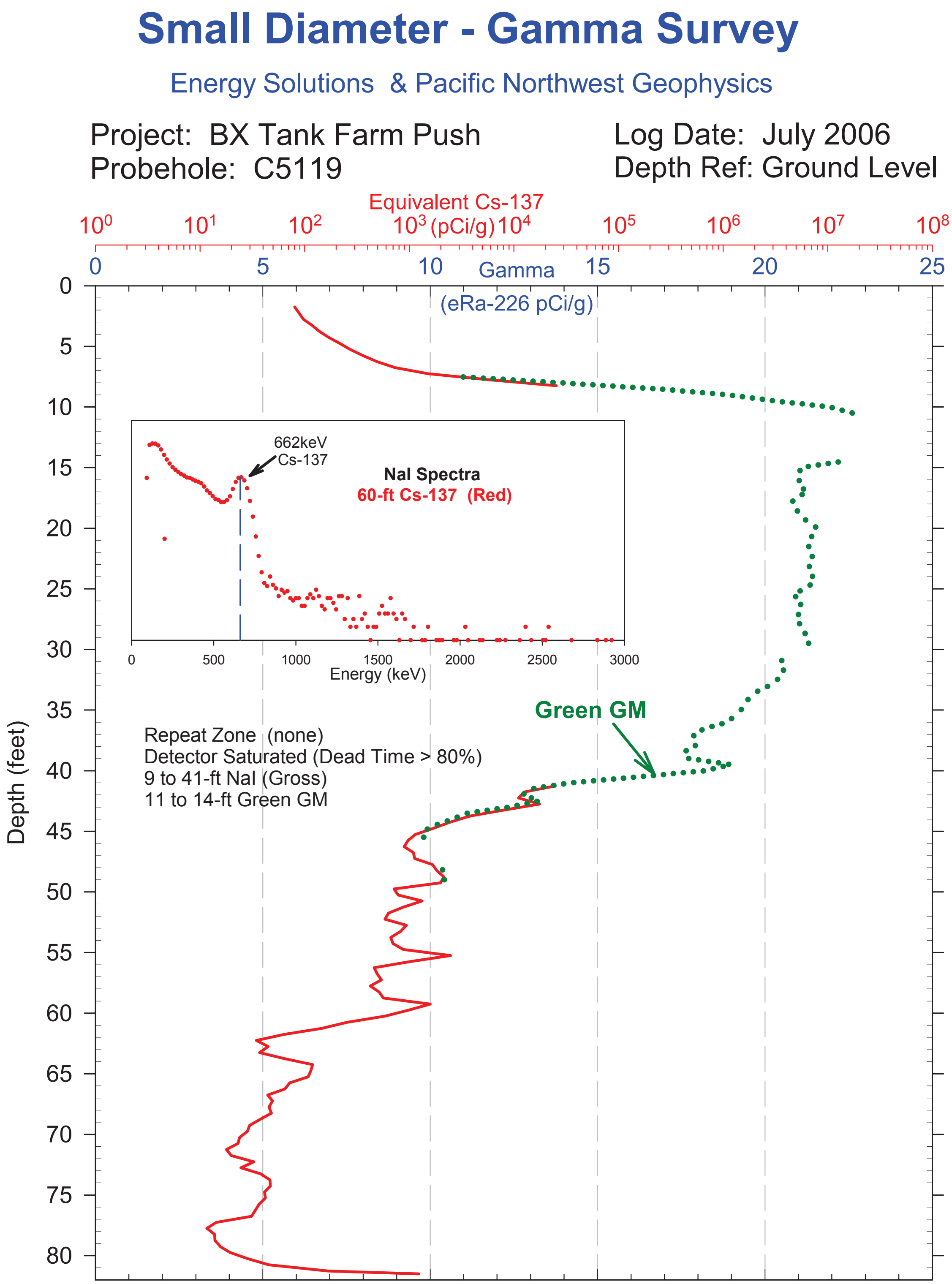
NaI spectral measurements indicated that U-238 is likely present in four probe holes (C5123, C5125, C5131, and C5133). The gamma-ray spectra in these probe holes either had a photo peak at 1001 keV or had an increase in gamma flux at about 1001 keV. Spectra are shown on with the survey plot. No calibration factor is available for equivalent U-238, Such calibration factor is beyond the scope of the logging activities for this project. Therefore, the Eq Cs-137 scaling factor is used to high-light the depth intervals containing radioactive contaminants.

Table 2. Probe Hole Survey Summary

Probe Hole	Gross Gamma	Spectral Gamma	Green GM	Red GM	Hole Depth	Depth Max Activity	Max eCs-137 (pCi/g)	Comment
BX-02-04	X		**Green**	**Red**	80	31-72 ft	>1,000,000	Red GM max dead-time 12%
C5117	X	**Spectra**	**Green**		80	15-16 ft	> 500,000	**Spectra** 19-26ft
C5119	X	**Spectra**	**Green**		81.5	9-36 ft	>1,000,000	**Green GM** Dead-time > 80% 10-14ft **Spectra** 50-52, 58-60ft
C5121	X				80.5	10-18 ft	>1,000,000	**Green GM** Dead-time > 80% 11-14ft
C5123	X	**Spectra**			80.5	39-51 ft	**U-238 (1001 keV)**	**Spectra** 37-54ft
C5125	X	**Spectra**			80.4	48-54 ft	**U-238 (1001 keV)**	**Spectra** 47-56ft
C5127	X	**Spectra**	**Green**		80	45-52 ft	>1,000,000	**Green GM** Dead-time > 80% 46-50 ft **Spectra** 27-36, 59-66, 78-80ft
C5129	X		**Green**	**Red**	80.5	39-68 ft	>1,000,000	Red GM max dead-time 21%
C5131	X	**Spectra**			80.5	57-64, 71-73 ft	**U-238 (1001 keV)**	**Spectra** 58-60, 63-64, 71-73ft
C5133	X	**Spectra**			80.5	76-78 ft	**U-238 (1001 keV)**	**Spectra** 74-79ft
C5135	X				80.5			Background
C5137	X				80.5			Background


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: BX-02-04
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137
(pCi/g)
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8
Gamma
(eRa-226 pCi/g)
0 5 10 15 20 25
Depth (feet)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
NaI Detector
Green GM
Red GM
Repeat Zone(s) 30 to 34-ft
Detector Saturated (Dead Time > 80%)
30 to 77-ft NaI (Gross)
32 to 51-ft Green-GM


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5117
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137
10^0 10^1 10^2 10^3 (pCi/g) 10^4 10^5 10^6 10^7 10^8
0 5 10 Gamma 15 20 25
(eRa-226 pCi/g)
Depth (feet)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Green GM
Repeat Zone: 27 to 32 ft
Detector Saturated (Dead Time > 80%)
14-17, 28-30 ft NaI (Gross)
662keV
Cs-137
NaI Spectra
22-ft Cs-137 (Red)
0 500 1000 1500 2000 2500 3000
Energy (keV)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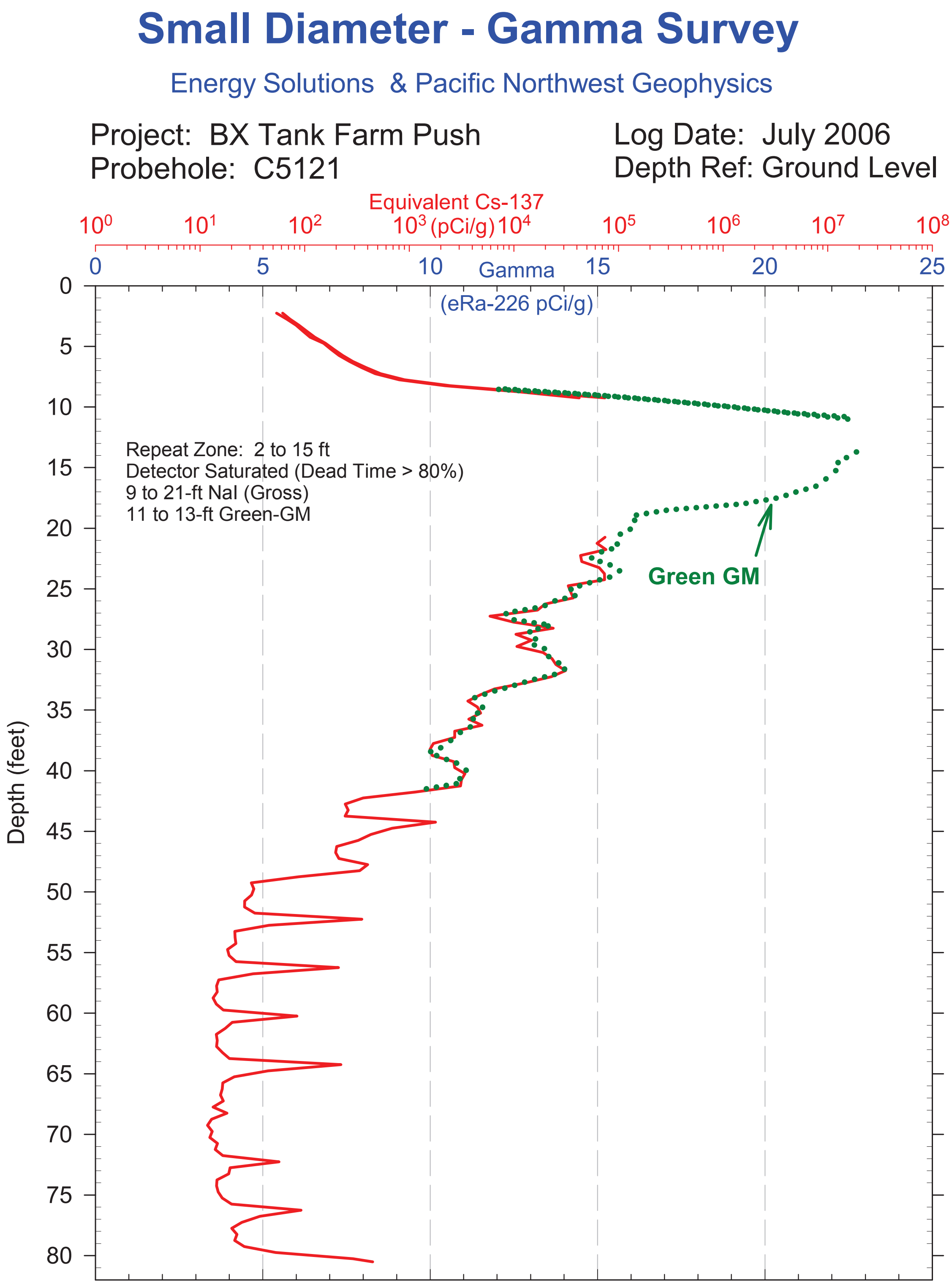
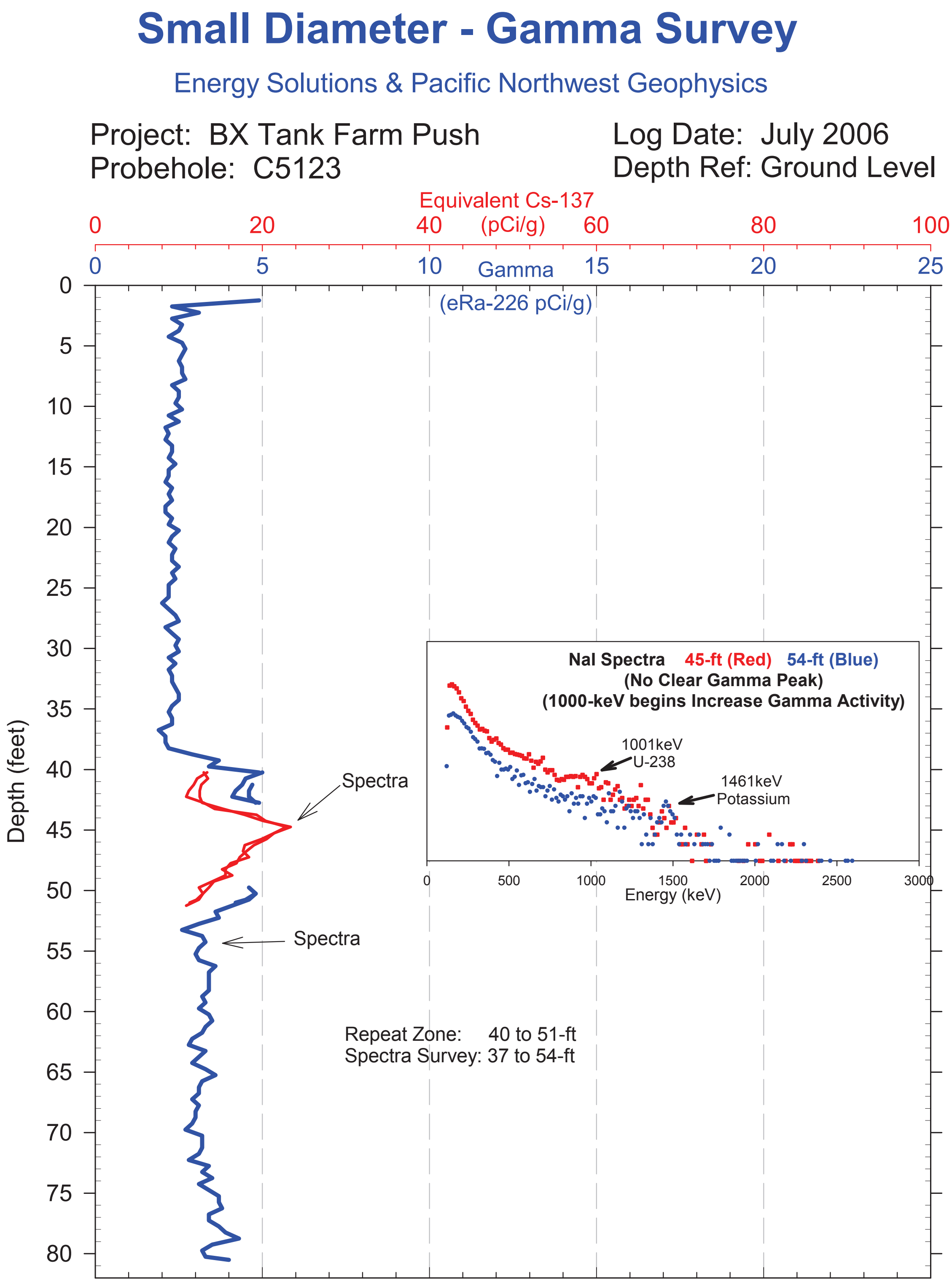
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5119
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137
(pCi/g)
Gamma
(eRa-226 pCi/g)
Depth (feet)
662keV
Cs-137
NaI Spectra
60-ft Cs-137 (Red)
Energy (keV)
Green GM
Repeat Zone (none)
Detector Saturated (Dead Time > 80%)
9 to 41-ft NaI (Gross)
11 to 14-ft Green GM


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5121
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137
(pCi/g)
Gamma
(eRa-226 pCi/g)
Depth (feet)
Repeat Zone: 2 to 15 ft
Detector Saturated (Dead Time > 80%)
9 to 21-ft NaI (Gross)
11 to 13-ft Green-GM
Green GM

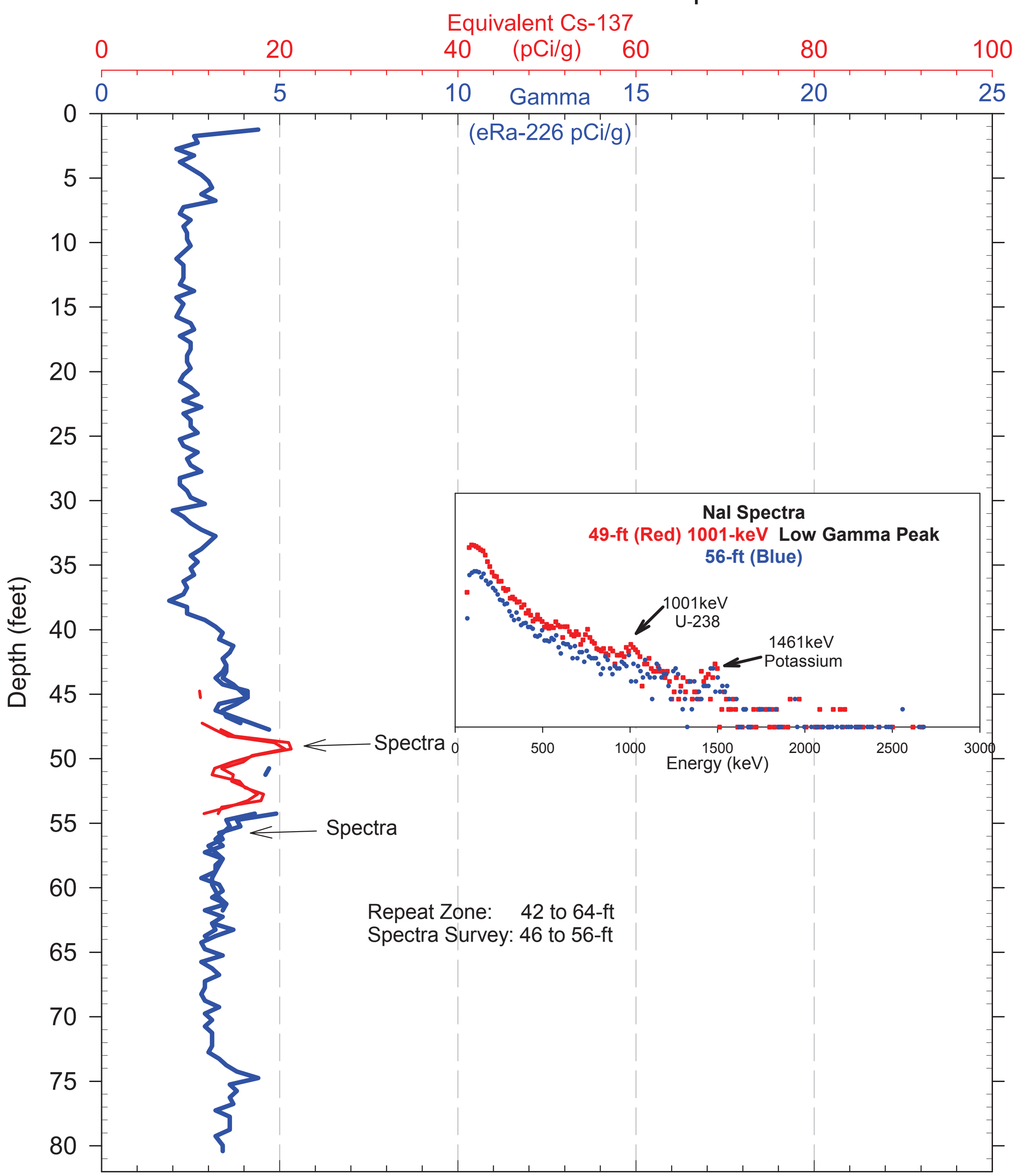

Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5123
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
Gamma (eRa-226 pCi/g)
Depth (feet)
Spectra
Spectra
NaI Spectra 45-ft (Red) 54-ft (Blue)
(No Clear Gamma Peak)
(1000-keV begins Increase Gamma Activity)
1001keV U-238
1461keV Potassium
Energy (keV)
Repeat Zone: 40 to 51-ft
Spectra Survey: 37 to 54-ft

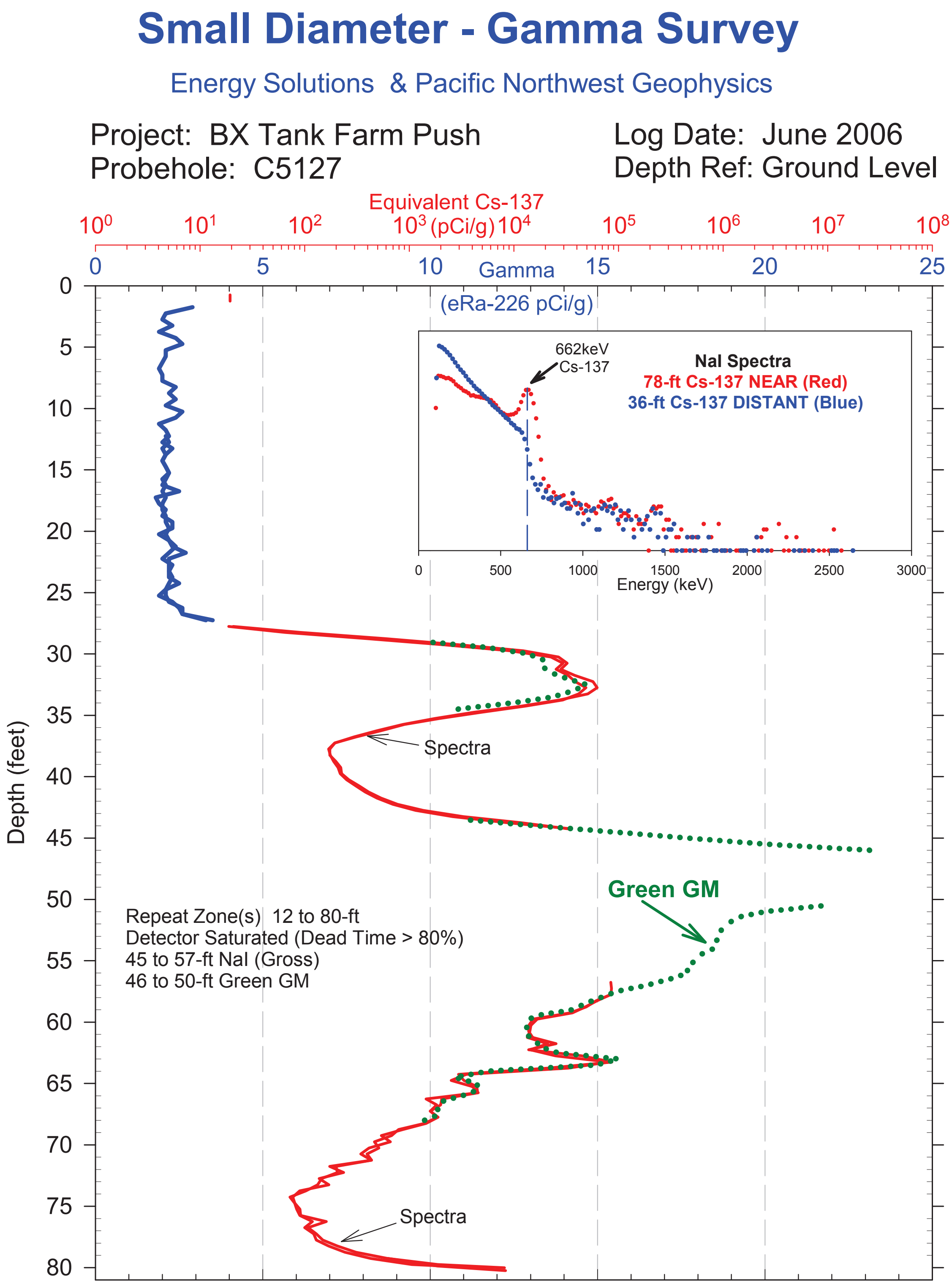
Small Diameter - Gamma Survey

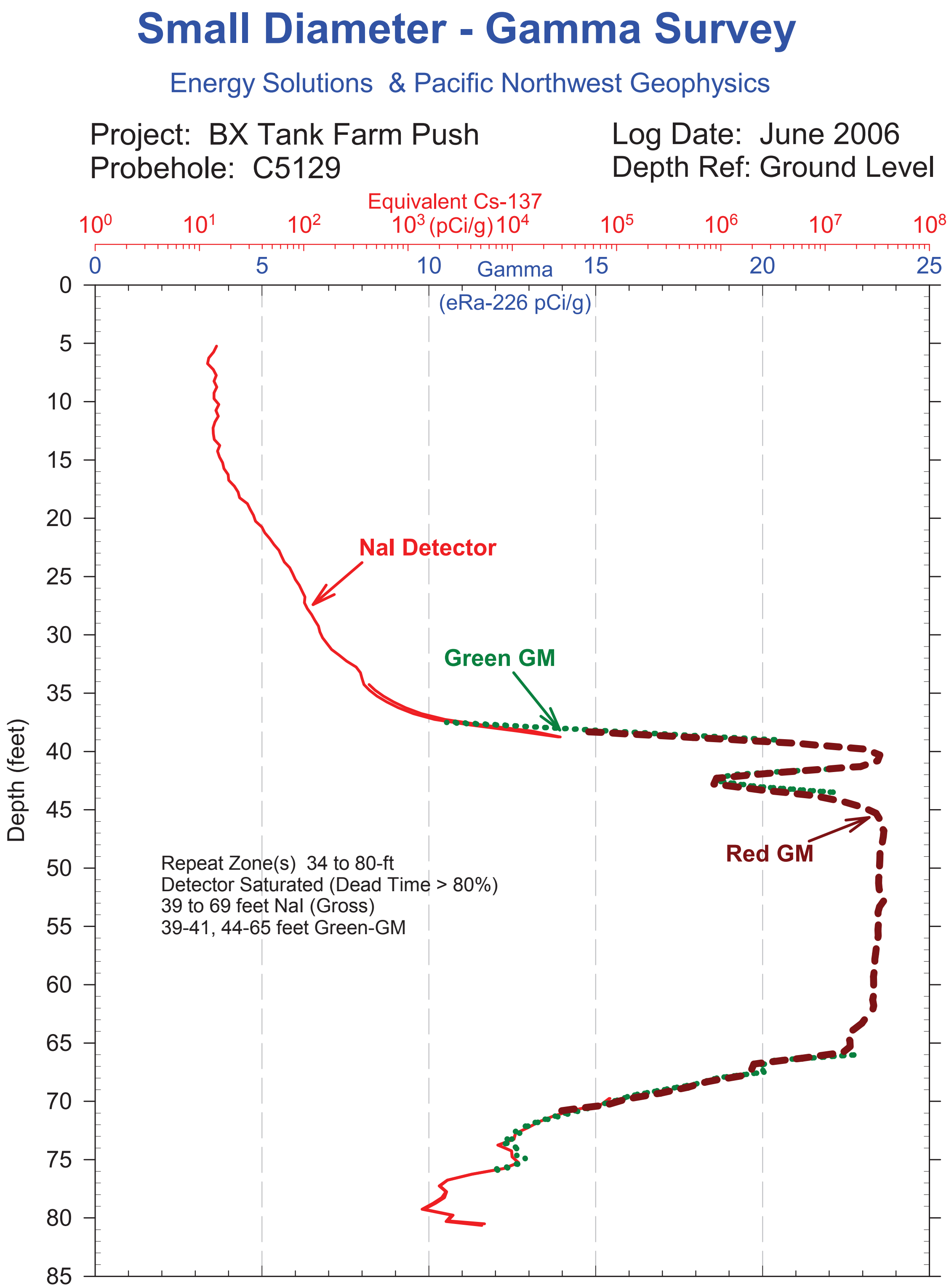
Energy Solutions & Pacific Northwest Geophysics

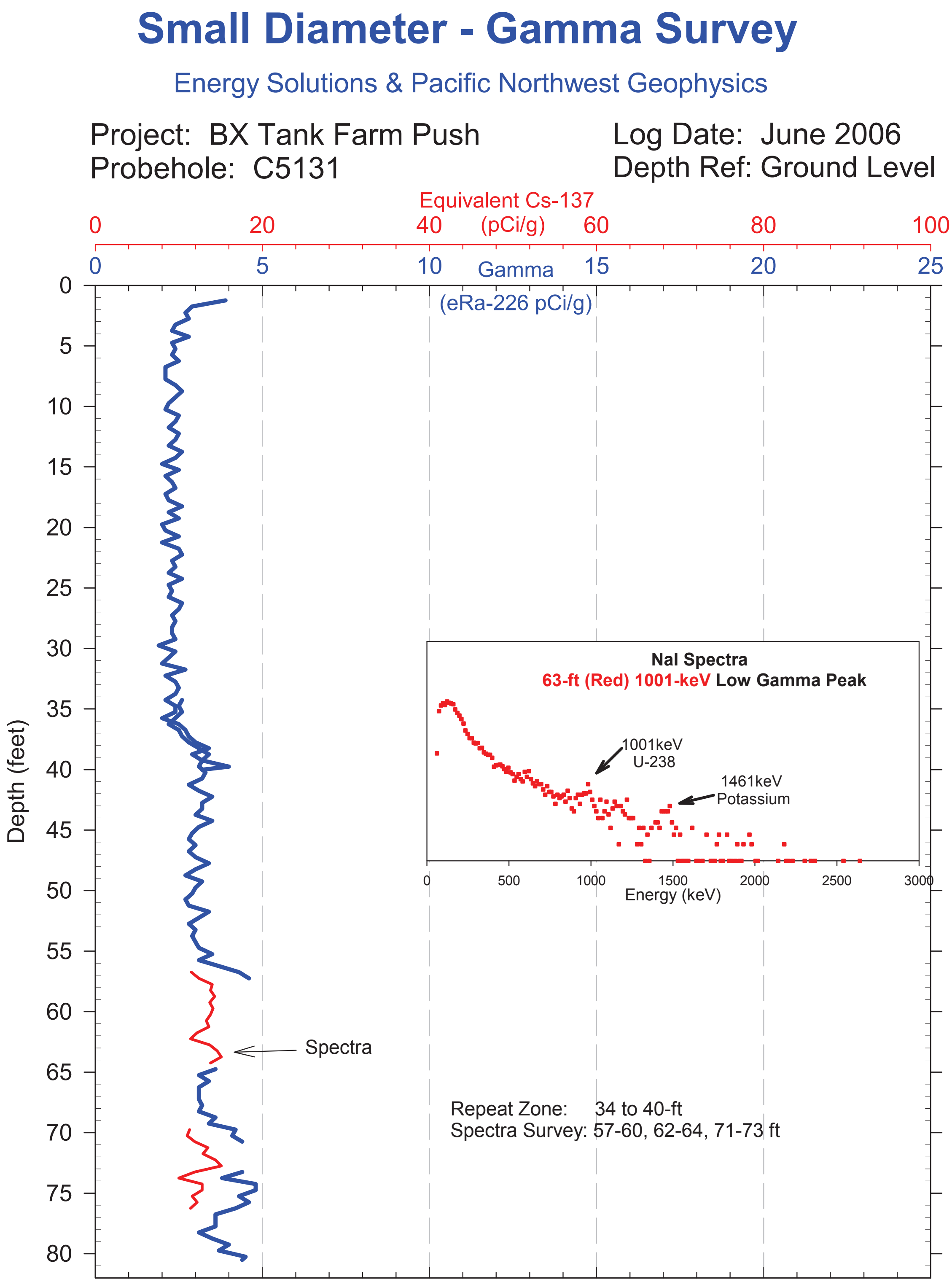
Project: BX Tank Farm Push
Probehole: C5125

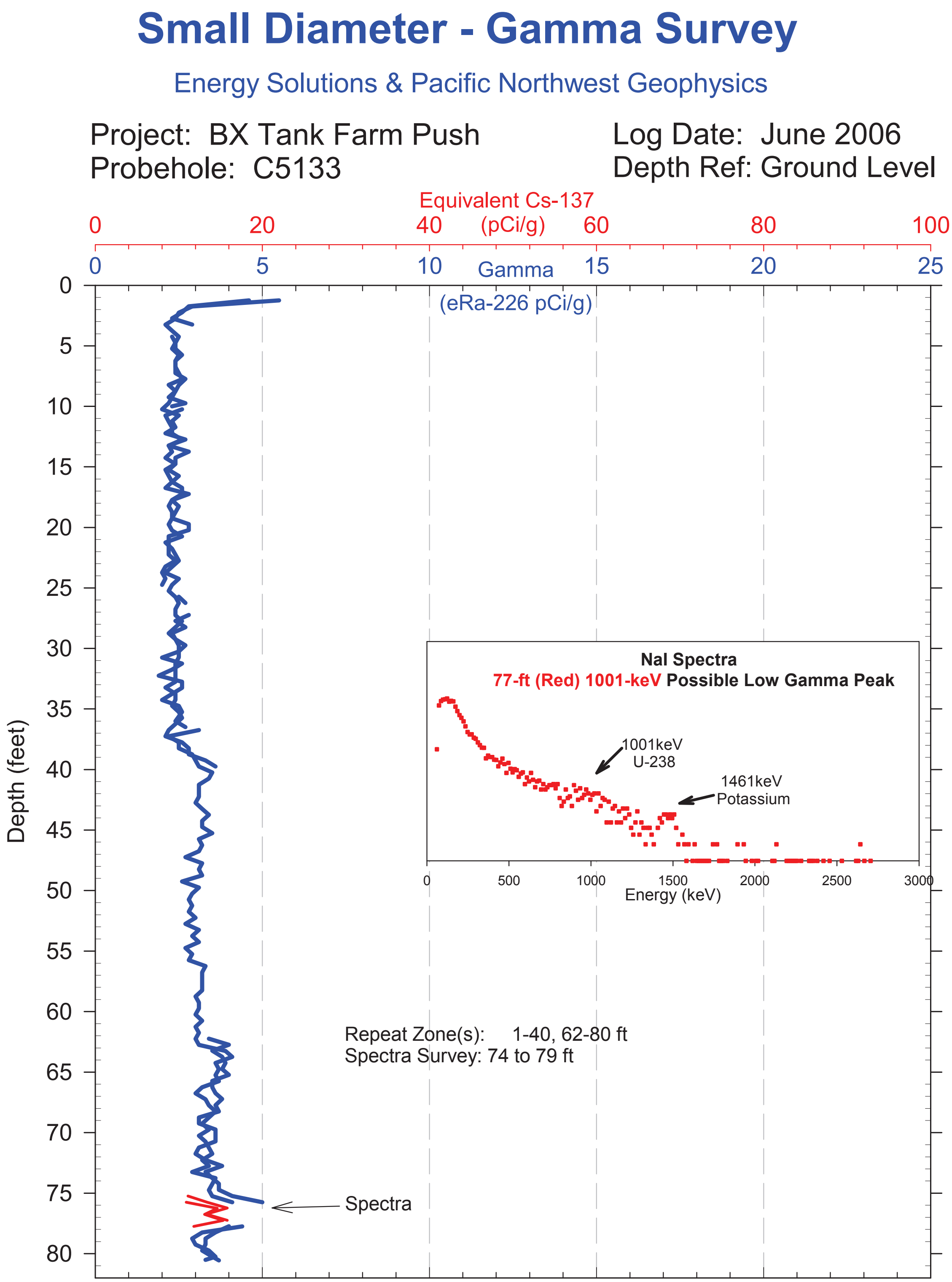
Log Date: June 2006
Depth Ref: Ground Level




Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5127
Log Date: June 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
Gamma (eRa-226 pCi/g)
Depth (feet)
662keV Cs-137
NaI Spectra
78-ft Cs-137 NEAR (Red)
36-ft Cs-137 DISTANT (Blue)
Energy (keV)
Spectra
Green GM
Repeat Zone(s) 12 to 80-ft
Detector Saturated (Dead Time > 80%)
45 to 57-ft NaI (Gross)
46 to 50-ft Green GM
Spectra


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5129
Log Date: June 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8
Gamma (eRa-226 pCi/g)
0 5 10 15 20 25
Depth (feet)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
NaI Detector
Green GM
Red GM
Repeat Zone(s) 34 to 80-ft
Detector Saturated (Dead Time > 80%)
39 to 69 feet NaI (Gross)
39-41, 44-65 feet Green-GM


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5131
Log Date: June 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
0 20 40 60 80 100
Gamma (eRa-226 pCi/g)
0 5 10 15 20 25
Depth (feet)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Spectra
NaI Spectra
63-ft (Red) 1001-keV Low Gamma Peak
1001keV U-238
1461keV Potassium
0 500 1000 1500 2000 2500 3000
Energy (keV)
Repeat Zone: 34 to 40-ft
Spectra Survey: 57-60, 62-64, 71-73 ft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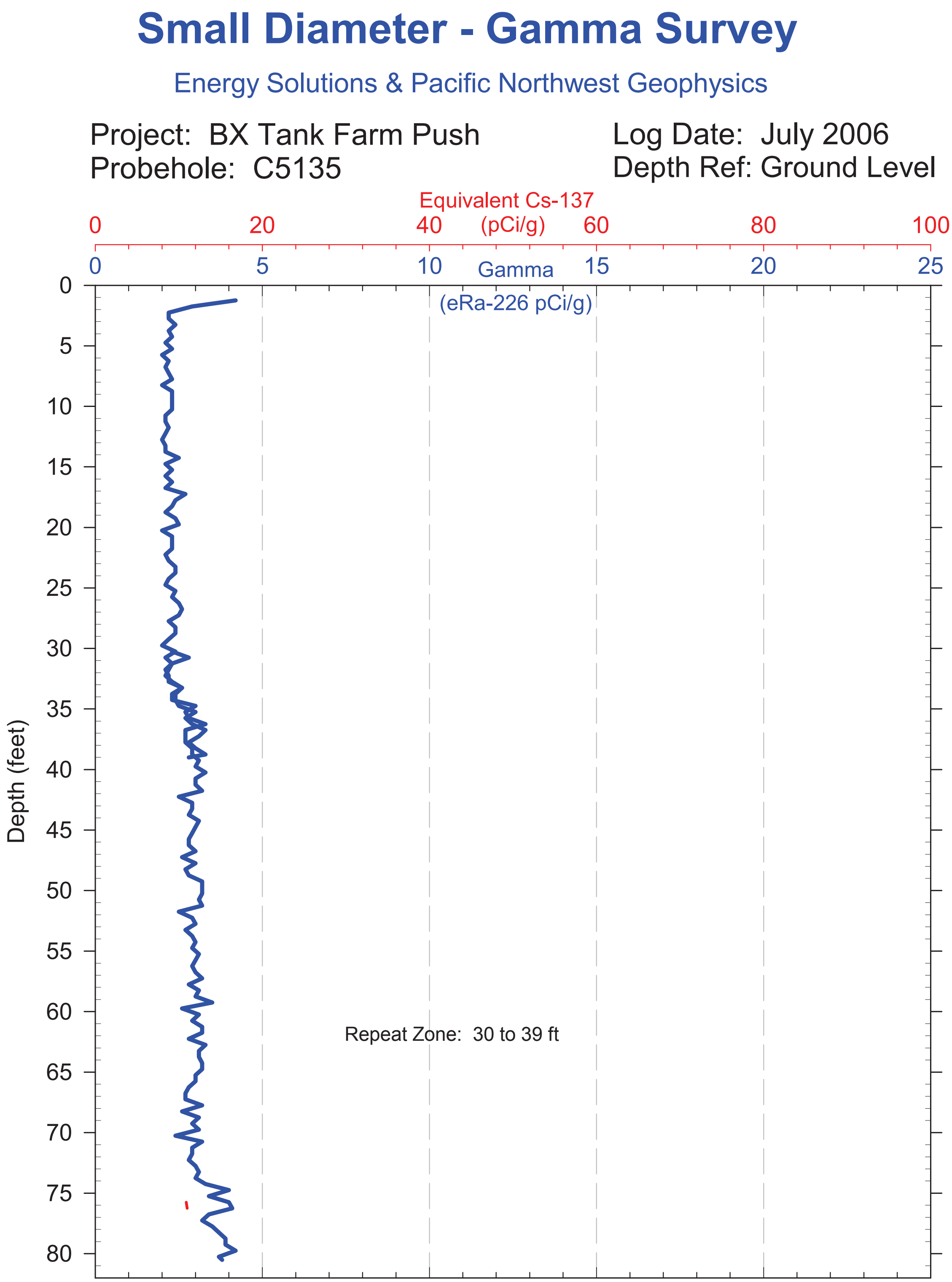
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5133
Log Date: June 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
Gamma (eRa-226 pCi/g)
Depth (feet)
NaI Spectra
77-ft (Red) 1001-keV Possible Low Gamma Peak
1001keV U-238
1461keV Potassium
Energy (keV)
Repeat Zone(s): 1-40, 62-80 ft
Spectra Survey: 74 to 79 ft
Spectra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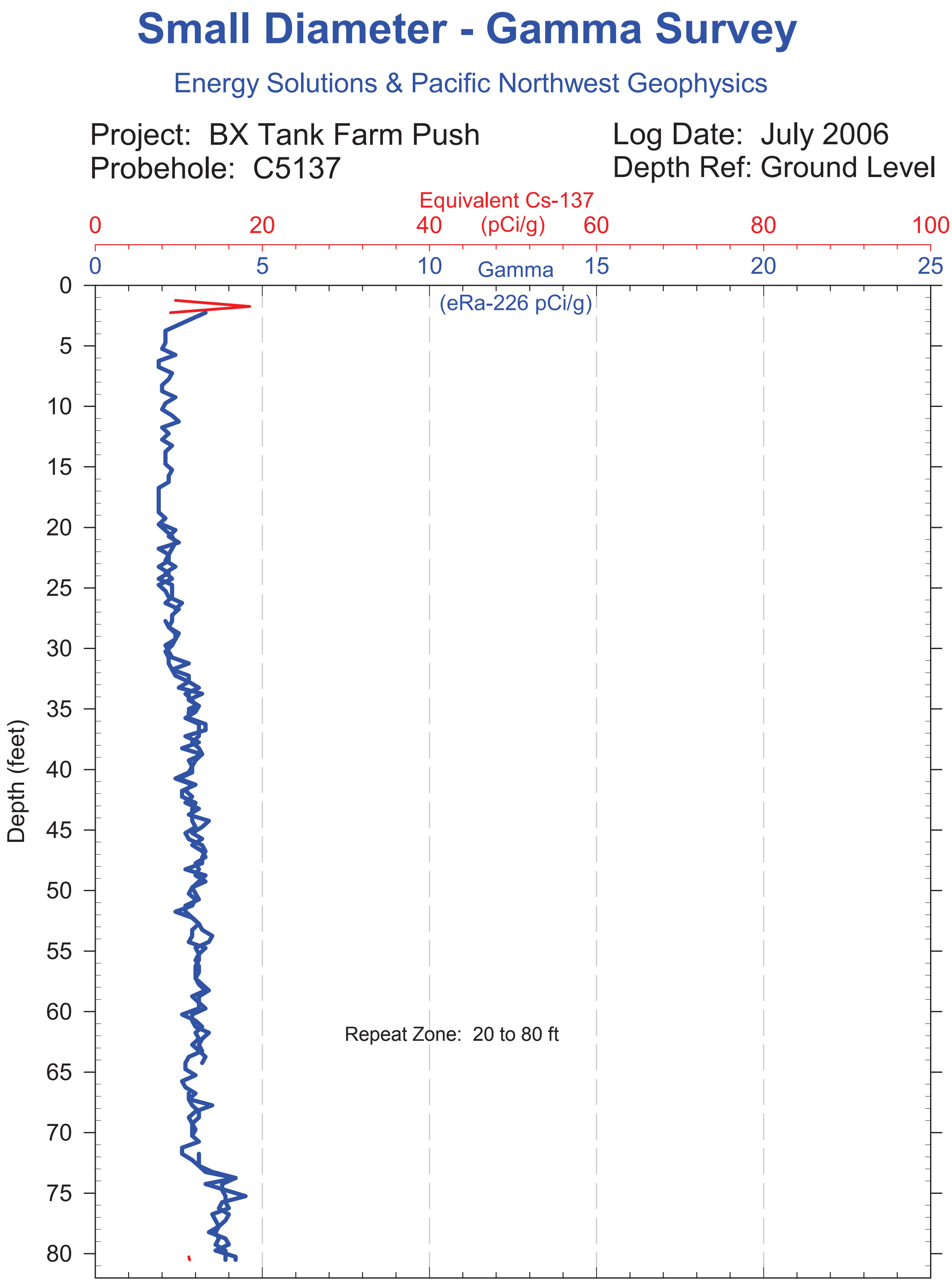
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5135
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137 (pCi/g)
0 20 40 60 80 100
0 5 10 15 20 25
Gamma (eRa-226 pCi/g)
Depth (feet)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Repeat Zone: 30 to 39 ft


Small Diameter - Gamma Survey
Energy Solutions & Pacific Northwest Geophysics
Project: BX Tank Farm Push
Probehole: C5137
Log Date: July 2006
Depth Ref: Ground Level
Equivalent Cs-137
(pCi/g)
0
20
40
60
80
100
Gamma
(eRa-226 pCi/g)
0
5
10
15
20
25
Depth (feet)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Repeat Zone: 20 to 80 ft