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Tank C–109

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Hanford Tank Farms Vadose Zone

Tank Summary Data Report for Tank C–109

December 1997

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CONTRACT NO.: DE-AC13-96GJ87335
TASK ORDER NO.: MAC-98-09
CONTROL NO.: 3100-T98-0418

December 29, 1997

Project Manager
Department of Energy S7-54
Richland Operations Office
825 Jadwin Ave.
Richland, WA 99352
ATTN: David Shafer

Subject: Contract No. DE-AC13-96GJ87335—Submittal of Tank Summary Data Report for Tank C-109 (GJ-HAN-91)

Dear Mr. Shafer:

Enclosed is one (1) copy of the subject Tank Summary Data Report (TSDR). This report is being submitted for your information/records and should be considered final. By cover of this letter a copy is being provided to DOE-GJO for their records.

Should technical questions or comments arise, please do not hesitate to contact John Brodeur or myself at (509) 946-3635.

Sincerely,

James F. Bertsch
Project Manager

JFB/jmm
Enclosure
cc/enc: V. A. Cromwell, DOE-GJO

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639 CULLUM AVENUE
RICHLAND, WASHINGTON 99352
(PHONE) 509/946-0882 (FAX) 509/946-0920

bcc:	D. Quamme
	Contract File (C. Spor)
bcc/enc:	D. Barnes, LMHC
	C. Brevick, LMHC
	J. Brodeur
	M. Dexter, LMHC (2)
	C. Koizumi
	C. Lewis, NHC
	S. McKinney, WDOE
	D. Myers, LMHC
	R. Smith, PNNL
	Central Files (L. Perry)
	Hanford File
	Jacobs Engineering Group
	JFB LB

GJ–HAN–91
Tank C-109

Vadose Zone Characterization Project at the Hanford Tank Farms

Tank Summary Data Report for Tank C-109

December 1997

Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Office
Grand Junction, Colorado

Prepared by
MACTEC-ERS
Grand Junction Office
Grand Junction, Colorado

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Contents

Contents (continued)

Figures

Vadose Zone Characterization Project at the Hanford Tank Farms

Tank Summary Data Report for Tank C-109

Prepared by:

E. Larsen ______ Date 12/24/97

Approved by:

J.F. Bertsch, Hanford Project Manager ______ Date 12/29/97

J.R. Brodeur, Hanford Project Technical Lead ______ Date 12-29-97

Executive Summary

The U.S. Department of Energy (DOE) Richland Operations Office tasked the DOE Grand Junction Office (GJO) with performing a baseline characterization of the gamma-ray-emitting radionuclides that are distributed in the vadose zone sediments surrounding the single-shell tanks (SSTs) at the Hanford Site. Information regarding vadose zone contamination was acquired by logging the monitoring boreholes positioned around the SSTs using a spectral gamma logging system (SGLS). The SGLS employs a high-purity germanium detector. This report documents the spectral gamma-ray logging results obtained from the monitoring boreholes that surround tank C-109.

Tank C-109 is categorized as sound with interim stabilization and intrusion prevention completed. The tank is currently listed as containing noncomplexed waste that consists of 62,000 gallons (gal) of sludge, 4,000 gal of supernate, and no interstitial liquid (Hanlon 1997).

Cesium-137 (^{137}Cs) and cobalt-60 (^{60}Co) were the major gamma-emitting contaminants detected in the vadose zone sediments surrounding this tank. Isolated occurrences of uranium-235 (^{235}U) were detected at the ground surface in two boreholes. A thin zone of europium-154 (^{154}Eu) was detected at the approximate depth of a cascade line in one borehole.

On the basis of shape factor analysis results, the ^{137}Cs contamination is, in most cases, interpreted to be uniformly distributed in the backfill material around the boreholes associated with tank C-109. This contamination most likely resulted from surface spills and/or airborne contamination releases related to routine tank farm operations. It appears that the contamination has migrated into the backfill material as deep as 15 feet (ft). However, the shape factors also identified several isolated areas of ^{137}Cs contamination that were localized to the borehole casings.

A distinct zone of subsurface ^{137}Cs and ^{154}Eu contamination was detected in a borehole located near the C-108-to-C-109 cascade line. However, shape factor analysis of the data indicates the radionuclides detected by the SGLS probably consist of residual waste contained within the cascade piping and that little or no leakage has occurred.

Zones of elevated ^{137}Cs contamination detected below the base of the tank farm excavation around six boreholes surrounding tank C-109 may have originated from a subsurface leak or possibly a surface spill. The shape factor analysis data indicate that most of the contamination is uniformly distributed in the formation as thin layers that have been penetrated by the boreholes.

Numerous zones of ^{60}Co contamination detected below the base of the tank farm excavation between 45 and 115 ft probably represent the remnants of contaminant plumes. The shape factor analysis results indicate that the ^{60}Co contamination is distributed in the formation around these boreholes and is not confined to the vicinity of the borehole casings. The plumes could be related to leaks from any of the tanks in the vicinity, including tank C-109; however, the dispersive nature of ^{60}Co suggests that tank C-109 is probably not the leak source.

1.0 Introduction

1.1 Background

The U.S. Department of Energy (DOE) Richland Operations Office tasked the DOE Grand Junction Office (GJO) with characterizing and establishing a baseline of man-made radionuclide concentrations in the vadose zone surrounding the single-shell tanks (SSTs) at the Hanford Site. These tasks are being accomplished using spectral gamma-ray borehole geophysical logging measurements made in the boreholes surrounding the tanks. The primary objective of this project is to provide data on the tanks for use by DOE organizations. These data may also be used to develop an SST Closure Plan in compliance with the Resource Conservation and Recovery Act and to prepare an Environmental Impact Statement for the Tank Waste Remediation Systems program.

1.2 Scope of Project

The scope of this project is to locate and identify the gamma-ray-emitting radionuclides and determine their concentrations in the vadose zone sediment by logging the monitoring boreholes around the SSTs with a Spectral Gamma Logging System (SGLS). Additional details regarding the scope and general approach to this characterization program are included in the project management plan (DOE 1995b) and baseline monitoring plan (DOE 1995c). This project may help to identify possible sources of any subsurface contamination encountered during the logging and to determine the implications of the contamination for Tank Farm operations. The acquired data will establish a contamination baseline that can be used for future data comparisons, for tank-leak verifications, and to help develop contaminant flow-and-transport models.

1.3 Purpose of Tank Summary Data Report

A Tank Summary Data Report (TSDR) will be prepared for each SST to document the results of the spectral gamma-ray logging in the boreholes around the tank. Each TSDR provides a brief review and a summary of existing information about a specific tank and an assessment of the implications of the spectral gamma-ray log information, including recommendations on future data needs or immediate corrective action, where appropriate. Appendix A of each TSDR presents logs of radionuclide concentrations versus depth for all boreholes around that specific tank. A comprehensive Tank Farm Report will be prepared for each tank farm after completion of characterization logging of all boreholes in the subject farm.

2.0 Spectral Gamma-Ray Log Measurements

2.1 Data Acquisition and Processing

The concentrations of individual gamma-ray-emitting radionuclides in the sediments surrounding a borehole can be calculated from the activities in the gamma-ray energy spectra measured in the borehole using calibrated instrumentation. Spectral gamma-ray logging is the process of collecting gamma-ray spectra at sequential depths in a borehole. Figure 1 shows a gamma-ray spectrum with peaks at energies, from 0 to 2,700 kilo-electron-volts (keV), that are characteristic of specific radionuclides. The spectrum includes peaks from naturally occurring radionuclides ^{40}K, ^{238}U, and ^{232}Th (KUT) and from man-made contaminants (e.g., ^{137}Cs and ^{60}Co). Gamma-ray source concentrations are cited in terms of picocuries per gram (pCi/g), even though this unit technically describes decay rate per unit mass of sample rather than concentration. The use of decay rate per unit mass is widespread in environmental work, where health and safety issues relate to the radioactivity, not the chemical concentration.

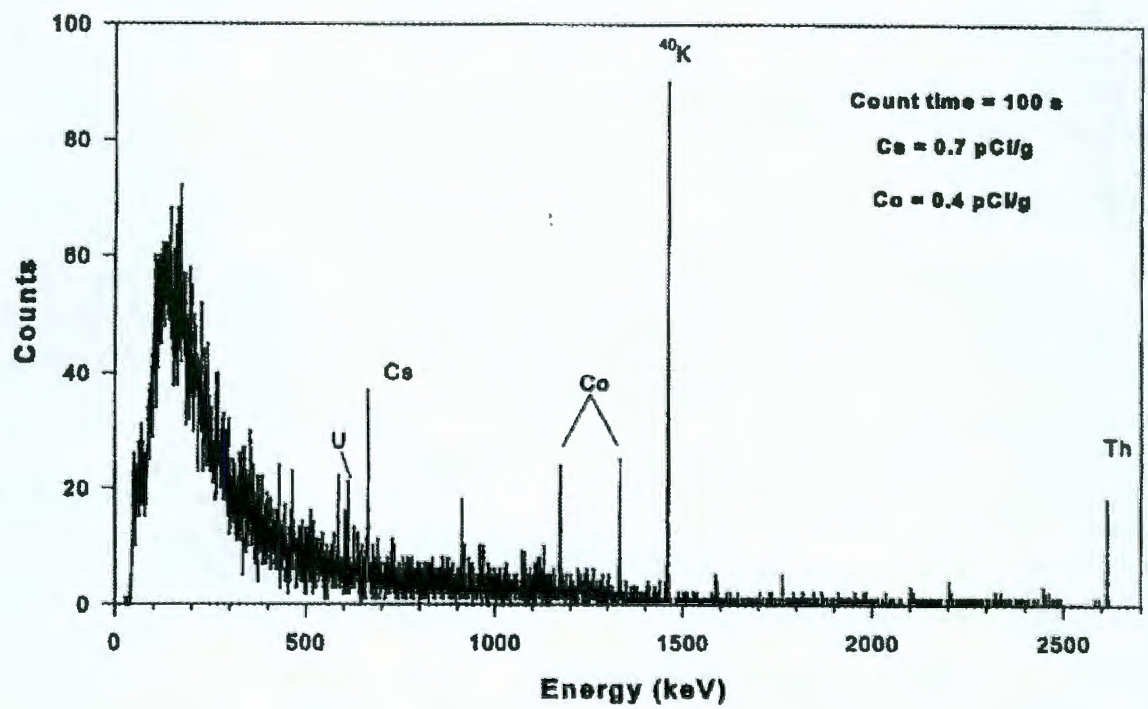

Figure 1. Gamma-Ray Spectrum

Data are acquired in boreholes near the tanks according to methods described in the logging procedures (DOE 1997b). Typical counting times at each measurement position are about 100 seconds (s), with a spectrum being collected every 0.5 foot (ft) along the length of the borehole.

Long data acquisition times can reduce the uncertainties in the calculated concentrations presented on the logs. However, economic and time constraints limit the amount of time available for data collection. The statistical uncertainty for gamma rays emitted from low-activity radionuclides such as ^{238}U and ^{232}Th can be high for this counting time, and the logs for these radionuclides will show high levels of statistical uncertainty, as evidenced on the logs by scatter in the plotted data and wide confidence intervals.

The minimum detection level (MDL) of a radionuclide represents the lowest concentration at which the positive identification of a gamma-ray peak for that radionuclide is statistically defensible. The spectrum analysis program calculates the MDL for a particular peak on the basis of a statistical analysis of the spectral background level in the vicinity of the peak. The same equations that translate peak intensities into decay rates per unit-sample mass also translate the MDLs from counts per second (cps) to picocuries per gram. A description of the MDL calculation is included in the data analysis manual (DOE 1997a).

The gamma-ray spectra measured in a borehole are processed using a variety of software programs to obtain the concentrations of individual gamma-ray-emitting radionuclides. All the algorithms used in the concentration calculations and their application is discussed in the data analysis manual (DOE 1997a). These calculated data, which are usually presented as vertical profiles, are used to make an interpretation of vadose zone contamination associated with each borehole. When data from all the boreholes associated with a specific tank have been processed and interpreted, a correlation interpretation is made of the vadose zone contamination surrounding each tank.

The initial SGLS calibration report (DOE 1995a) contains the results obtained from operating the logging tools in calibration models. The calibration report presents the mathematical functions used to convert the measured peak area count rates to radioelement concentration in picocuries per gram. The SGLS is routinely recalibrated (DOE 1997c) to ensure the accuracy of the calculated radionuclide concentrations. The calculated radionuclide concentrations derived with these conversion factors may be as much as 14 percent higher than the actual in situ concentrations because the concentrations of the calibration models are expressed in terms of gamma-ray activity per unit-sample mass of *dry* bulk material. However, the measurements made in the calibration models were in a water-saturated environment. The conversion factors in the calibration report (DOE 1995a) are strictly applicable only when the logged formation has the same water content as the calibration-model test zones. The vadose zone contains pore-space water in various percentages of saturation from near 0 percent to near 100 percent, and the boreholes are logged dry. Corrections for pore-space water cannot presently be applied to the vadose zone measurements because the in situ water content is not being measured.

The calibration data from which conversion factors were derived were recorded with a logging tool in a borehole drilled through a uniform homogeneous isotropic gamma-ray-source material. If the gamma-ray sources in the borehole being logged are not uniformly distributed in the sediments, the conversion factor produces apparent concentrations. The concentrations calculated for the top and bottom of a borehole are also apparent concentrations, because the source-to-detector geometries at these locations differ from the source-to-detector geometries during calibration.

When gamma-ray spectra are measured in cased boreholes, a casing correction must be applied to the peak count rates to compensate for gamma-ray attenuation by the casing. This correction function is described in the calibration report (DOE 1995a), and the data analysis manual (DOE 1997a) describes the application of the correction function in the data processing.

2.2 Shape Factor Analysis

Insights into the distribution of the radionuclides identified by the SGLS can be provided by using an analytical method known as shape factor analysis (Wilson 1997). Shape factor analysis takes advantage of 1) the SGLSs ability to record the specific energies of detected gamma rays, and 2) the Compton downscattering caused by the interaction of gamma rays with matter between the gamma-ray source and the detector.

Compton scattering results in higher energy photons being converted to lower energy photons; hence, Compton scattering within and outside of the detector accounts for the low-energy continuum in a pulse height spectrum. Many factors exterior to the detector influence the low-energy portion of the spectrum of gamma rays incident on the detector and, thereby, affect the low-energy continuum in the pulse height spectrum. Wilson (1997) has shown that variations in gamma-ray source distribution relative to a borehole produce measurable changes in the shapes of the pulse-height spectra recorded by logging the boreholes. The spectral shape changes are quantified by ratios of counts from various portions of the pulse-height spectrum, and these ratios are used to assess the distribution of the source.

Shape factor analysis can also be used to identify the presence of bremsstrahlung radiation from the beta-emitting radionuclide ^{90}Sr. Beta particles, emitted from the radioactive decay of ^{90}Sr, interact with the electromagnetic fields within the substances they traverse. The deflection and resulting deceleration of the beta particles produce x-rays, known as bremsstrahlung radiation, which are detected in the lower energy portion of the gamma-ray spectrum. In instances of high total gamma-ray activity, a preponderance of lower energy gamma radiation may be caused by the presence of beta emitters, such as ^{90}Sr.

Additional information on shape factor analysis theory is provided in Wilson (1997).

2.2.1 Specific Shape Factors

As stated previously, the ratios of gamma-ray counts from various portions of a spectrum are indicators of gamma-ray source distribution. Three ratios are used in shape factor analysis. These ratios, known as shape factors, are designated CsSF1, CoSF1, and SF2.

- CsSF1 is the ratio of the total number of counts in the continuum window (60 to 650 keV) to the counts in the ^{137}Cs peak. This shape factor is useful for evaluating the distribution of the radionuclide ^{137}Cs.

- CoSF1 is the ratio of the total number of counts in the continuum window (60 to 650 keV) to the sum of the counts in the two ^{60}Co peaks (1173 and 1332 keV). This shape factor is useful for evaluating the distribution of the radionuclide ^{60}Co.

- SF2 is the ratio of the total number of counts in the lower energy portion of the continuum window (60 to 350 keV) to the counts in the higher energy portion of the continuum window (350 to 650 keV). This parameter is somewhat sensitive to the radionuclide distribution, but is most applicable to the identification of the beta emitter ^{90}Sr and in distinguishing remote ^{137}Cs or ^{60}Co from ^{90}Sr.

At low concentrations, high uncertainties in the ^{137}Cs and ^{60}Co peak count rates and in the net continuum count rates cause large errors in the calculated values of CsSF1 and CoSF1, respectively. A minimum count rate of 1 cps must be present for the calculated CsSF1 to be meaningful, and a minimum count rate of 2 cps must be present for CoSF1 (Wilson 1997).

The values of CsSF1, CoSF1, and SF2 also become less reliable as the radionuclide concentrations and count rates become very high and the dead time increases. Inaccuracies in the measurement of the spectral regions occur when system dead time increases to above about 20 percent. However, the distortion of SF1 and SF2 is fairly predictable for dead times up to 40 percent. For measurements made at dead times below 20 percent, distortion of the spectrum is negligible (Wilson 1997).

2.2.2 Interpretation of Shape Factors

Values of CsSF1, CoSF1, and SF2 that can be expected for radionuclides in various distributions were established from investigations by Wilson (1997). These distributions are: 1) contamination confined to the borehole region, such as when contaminants occur on the borehole casing, 2) contamination uniformly distributed throughout the formation in a radial direction from the borehole, and 3) contamination in the formation but at discrete locations remote from the detector. The expected CsSF1, CoSF1, and SF2 values for various distributions of ^{137}Cs are summarized below.

^{137}Cs or ^{60}Co Source Distribution	Spectral Shape Factor	
	CsSF1 or CoSF1	SF2
Inside of 6-inch (in.) casing	4.5 - 5.5	2.8
Outside of 6-in. casing	6.8 - 7.4	2.8
Uniformly distributed in formation	13 - 15	3.5
Discrete source 10 centimeter (cm) radial distance	~ 19	~ 3.8
Discrete source 30 cm radial distance	~ 37	~ 4.2
Discrete source more than 50 cm radially distant	80 - 100	4.4 - 5.0

When CsSF1, CoSF1, and SF2 values exceed those listed, the presence of ^{90}Sr is suggested. However, photons from intense gamma-ray sources remote from the borehole can also produce spectra with high CsSF1 and CoSF1 values, indicating that elevated values of these two shape factors alone are not sufficient for a ^{90}Sr identification. The presence of ^{90}Sr can usually be inferred with confidence when SF2 significantly exceeds the extreme value (about 4.5) for a distant source. The interpretation may be aided by an SF2-SF1 cross plot. If ^{90}Sr is absent, then as the distance between the borehole and the inner edge of a (cylindrically symmetric) ^{137}Cs source increases, the points on the SF2-SF1 cross plot define a "trend line." ^{90}Sr is indicated if the SF2 values are so high that the points on the cross plot lie well above the trend line. However, a ^{90}Sr concentration of about 1,000 pCi/g is necessary to produce a noticeable increase in count rates (Wilson 1997).

2.2.3 Uncertainties of Shape Factor Analysis

The counts resulting from ^{137}Cs and ^{60}Co in the continuum windows are corrected for background by subtracting the counts contributed by the naturally occurring radionuclides ^{40}K, ^{238}U, and ^{232}Th from the continuum windows. Counting statistics for the gamma rays associated with ^{238}U and ^{232}Th are poor for the 100-s counting time typically used by the SGLS in borehole logging. Although this error is insignificant in areas of contaminant concentration that exceed about 10 pCi/g, a considerable error might be introduced in intervals of the borehole where the contaminant concentration is much lower. To minimize the effects of statistical counting uncertainties in the calculated background corrections, the corrections are calculated at each depth point, then filtered with a Gaussian smoothing function. The correction at a particular depth point is the average over a 5-ft interval that extends 2.5 ft above and 2.5 ft below the point. The other source of experimental uncertainty is systematic uncertainty in the stripping factors. Errors in these constants have been minimized with an heuristic approach, but, in general, the stripping constant errors are the ultimate limitation on the accuracy of the background corrections.

The use of shape factor analysis is currently limited to evaluating the distributions of ^{137}Cs and ^{60}Co and to identifying the presence of ^{90}Sr. At this stage of the method's development, other gamma-ray-emitting radionuclides (i.e., ^{125}Sb, ^{154}Eu, and ^{152}Eu) interfere with shape factor analysis. The contribution that these radionuclides make to the continuum must be considered when determining the net continuum from ^{137}Cs and ^{60}Co. Low activity radionuclides, such as ^{238}U, make scarcely any contribution to the continuum and might be ignored if the concentration is low. High activity radionuclides that emit multiple gamma rays can substantially increase the observed continuum. The number of other radionuclides present in a borehole is a quality indicator. Non-zero values of this indicator define intervals of a borehole in which special background stripping procedures must be followed and may even render certain intervals unsuitable for the application of shape factor analysis.

2.3 Log Data and Plots

The results of the processing and analysis of the log data presented in Appendix A, "Spectral Gamma-Ray Logs for Boreholes in the Vicinity of Tank C-109," are grouped into a set of data for each borehole. Each set includes a Log Data Report and log plots showing radionuclide concentration versus depth.

Log plots are presented that show the spatial distribution of the detected man-made radionuclides. Plots of the natural gamma-ray-emitting radionuclides, at the same vertical scale as the man-made contamination plots, allows for interpretation of geologic information and the correlation of these data with the man-made contamination. Rerun sections in selected boreholes are used to check the logging system for data acquisition repeatability.

The log plots show the concentrations of the individual radionuclides or the total gamma count rate in counts per second in each borehole. Where appropriate, log plots show the statistical uncertainties in the calculated concentrations at the 95-percent confidence level (±2 standard deviations).

A combination plot for each borehole shows the individual natural and man-made radionuclide concentrations, the total gamma log, and the Tank Farms gross gamma log. The total gamma log is a plot of the total number of gamma rays detected during each spectrum measurement. The combination plot provides information on the relative contributions of individual radionuclides to the total gamma-ray count. The total gamma log also provides a means for comparing the spectral data with the historical Tank Farms gross gamma log data.

Separate plots showing the results of shape factor analysis of some of the SGLS data are included with each set of borehole plots. The values of CsSF1, CoSF1 (as applicable), SF2, the radionuclide abundance expressed as counts per second, and applicable quality indicators are shown on graphs on these plots. The general expected values for the CsSF1, CoSF1 (as applicable), and SF2 parameters for radionuclides distributed uniformly in the formation or on the outside of the casing are shown on the plots as vertical lines.

The Tank Farms gross gamma log data were collected with a nonspectral logging system previously used by DOE contractors for leak-detection monitoring at the Hanford Tank Farms. This system does not identify specific radionuclides, but its logs provide an important historical record for the individual boreholes and offer a basis for temporal comparison. The gross gamma logs shown on the plots in Appendix A are the latest data available.

Rerun sections in selected boreholes are used to check the logging system for data acquisition repeatability and are provided as separate plots. Radionuclide concentrations shown on these plots are calculated independently from the separate gamma-ray spectra provided by the original and repeated logging runs.

The Log Data Report provides borehole construction information, casing information, logging system identification, and data acquisition parameters used for each log run. A log run is a set of spatially sequential spectra that are recorded in the borehole with the same data acquisition parameters. A single borehole may have several log runs, often occurring on different days because of the length of time required to log the deeper boreholes. The Log Data Report also contains analysis information, including analysis notes and log plot notes.

3.0 Review of Tank History

3.1 C Tank Farm

3.1.1 Construction History

The C Tank Farm is located in the east portion of the 200 East Area, north of 7th Avenue and west of Canton Avenue. This farm was constructed during 1943 and 1944 to store high-level radioactive waste generated by chemical processing of irradiated uranium fuel from C Plant. The tank farm consists of four Type I and twelve Type II single-shell storage tanks. Vadose zone boreholes are located around the tanks for purposes of leak detection. Figure 2 shows the relative positions of the storage tanks and the vadose zone monitoring boreholes around them.

All 16 tanks in the C Tank Farm were constructed to the first-generation tank design and were designed for non-boiling waste with a temperature of less than 220 °F. The twelve Type II tanks are 75 ft in diameter and have capacities of 530,000 gallon (gal) each. The four Type I tanks are 20 ft in diameter and have capacities of 55,000 gal each. Other than diameter, the Types I and II tanks are of the same basic design (Brevick et al. 1994a and 1994b).

The Type II tanks are domed and steel-lined, with a maximum operating depth (cascade overflow level) of approximately 17 ft above the center of the dished tank base; the tank base is 1 ft lower at its center than at its edges. The storage portion of each tank is lined with a 0.25-in.-thick carbon-steel liner. The steel liners on the tank sides extend to 19 ft above the dished bottoms of the tank bases. The interiors of the concrete dome tops are not steel lined, but were treated with a magnesium zincfluosilicate wash. The tanks are entirely below the ground surface and are covered with approximately 7.25 ft of backfill material (Brevick et al. 1994a and 1994b).

The twelve type II tanks are connected in four three-tank cascade series. These cascade series consist of tanks C-101, -102, and -103, C-104, -105, and -106, C-107, -108, and -109, and C-110, -111, and -112. The tanks in the cascade series are arranged with each successive tank sited at an elevation 1 ft lower than the previous tank, creating a gradient allowing fluids to flow from one tank to another as they were filled. The four Type I tanks are connected with tie lines. The tie lines allow the tanks to overflow to other tanks in the series and equalize tank volumes (Brevick et al. 1994a and 1994b).

For primary internal leak detection, tanks C-103, -106, and -107 are each equipped with an ENRAF level detector and tank C-110 is equipped with a manual tape. Tanks C-101, -102, -104, -105, -108, -109, -111, -112, -201, -202, -203, and -204 are not equipped with primary leak-detection sources (Hanlon 1997).

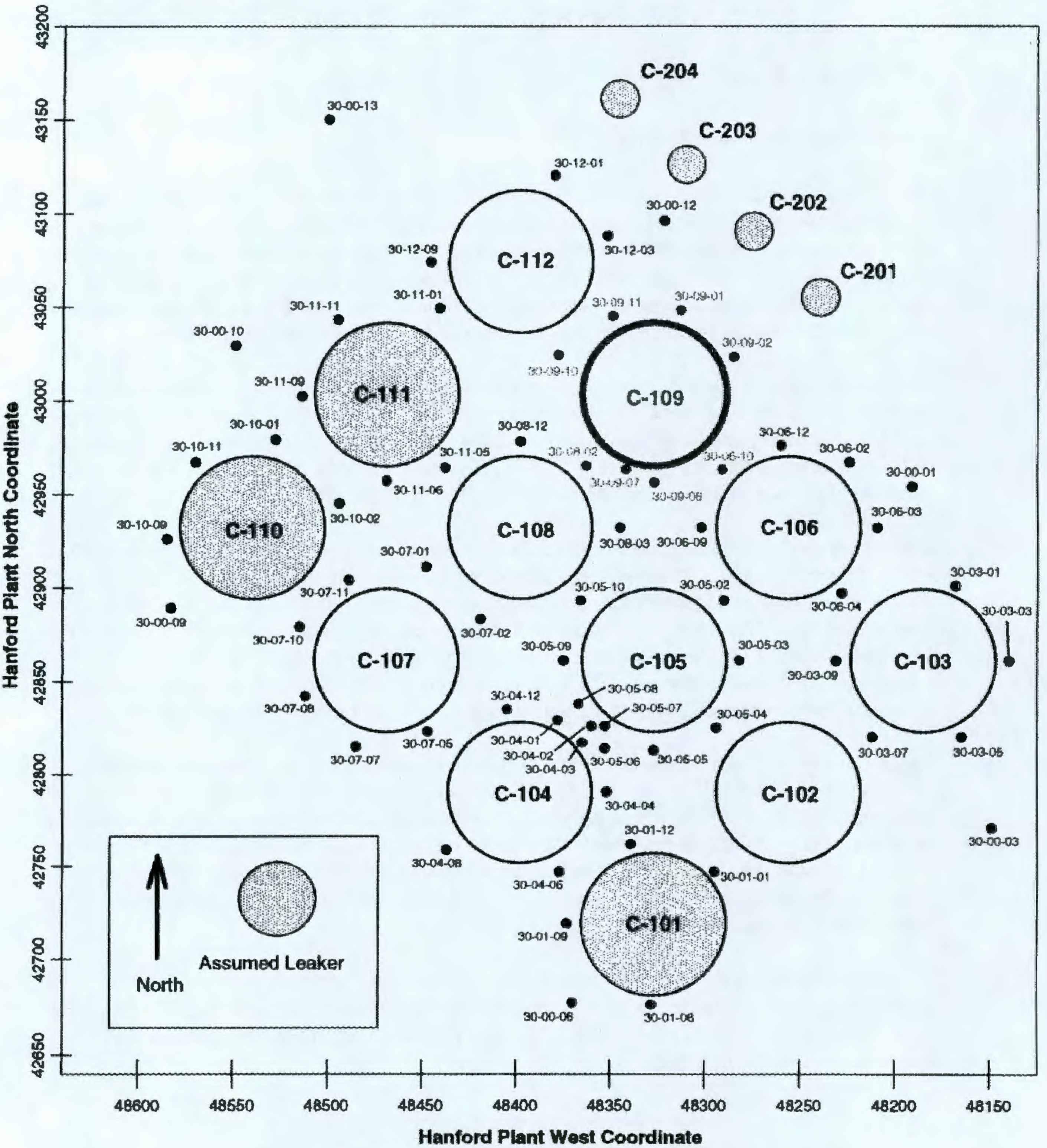

Figure 2. Plan View of Tanks and Boreholes in the C Tank Farm

3.1.2 Geologic and Hydrologic Setting

Excavation for the construction of the C Tank Farm occurred in glaciofluvial sediments of the Hanford formation. These sediments consist primarily of cobbles, pebbles, and coarse to medium sands with some silts. The excavated sediments were used as backfill around the completed tanks (Price and Fecht 1976).

Beneath the backfill material are the undisturbed sediments of the Hanford formation. The Hanford formation sediments consist of pebble to boulder gravel, fine- to coarse-grained sand, and silt. Three distinct facies were recognized by Lindsey (1992): gravel-dominated, sand-dominated, and silt-dominated (ordered from top to bottom of the formation). Baker et al. (1991) named these facies the coarse-grained deposits (generally referred to as the Pasco Gravels), the plane-laminated sand facies, and the rhythmite facies (commonly referred to as the Touchet Beds), respectively. The Hanford formation sediments extend to a depth of about 225 ft in the vicinity of the C Tank Farm (Lindsey 1993).

The distribution and similarities in lithologic succession of the facies types described above indicate the Hanford formation can be divided into three stratigraphic sequences across the 200 East Area. These sequences are designated: 1) upper gravel, 2) sandy, and 3) lower gravel. The sequences are composed mostly of the gravel-dominated and sand-dominated facies. The silt-dominated facies are relatively rare except in the southern part of the 200 East Area. Because of the variability of Hanford deposits, contacts between the sequences can be difficult to identify (DOE 1993).

In the vicinity of the C Tank Farm, the upper gravel sequence is dominated by deposits typical of the gravel-dominated facies of the Hanford formation. Lesser occurrences of the sand-dominated facies are encountered locally (DOE 1993). The upper gravel sequence consists of well-stratified gravels with lenticular sand and silt interbeds and extends to a depth of approximately 61 to 73 ft (23 to 35 ft below the base of the tank farm excavation). Strata within this interval generally dip to the east-southeast and thin to the south (Lindsey 1993). However, strata near the transition from the gravel-dominated to the sand-dominated facies locally dip to the north and east (Price and Fecht 1976).

The sandy sequence generally consists of deposits typical of the sand-dominated facies of the Hanford formation (DOE 1993). The sandy sequence is characterized by well-stratified coarse- to medium-grained sand with minor pebble and lenticular silt interbeds less than 1 ft thick. Localized silty intervals greater than 1 ft thick may be present and could potentially host perched water horizons that would probably not be laterally extensive because of pinchouts and clastic dikes. The sandy sequence extends to a depth of approximately 198 ft (Lindsey 1993).

The lower gravel sequence of the Hanford formation is dominated by deposits typical of the gravel-dominated facies. Local intercalated intervals of the sand-dominated facies are also found (DOE 1993). This unit is composed of interbedded sands and gravels with few silt interbeds. Perched water is considered unlikely in this unit. The lower gravel sequence is about 27 ft thick and extends to a depth of approximately 225 ft (Lindsey 1993).

The Ringold Formation directly underlies the Hanford formation in the vicinity of the C Tank Farm. The Ringold Formation is approximately 70 ft thick and extends to a depth of 295 ft. A thin, discontinuous silt-rich layer that dips to the south and pinches out to the north and west is present in the southern portion of the tank farm. Perched water may occur at the top of this unit. A variably cemented pebble to cobble gravel with a sand matrix occurs stratigraphically below the silt-rich layer. This gravel may contain mud interbeds that could cause perched water to form if the mud is cemented or well enough developed (Lindsey 1993).

In the vicinity of the C Tank Farm, the uppermost aquifer occurs within the Ringold Lower Mud Unit at a depth of approximately 245 ft (Lindsey 1993; PNNL 1997). This uppermost aquifer is generally referred to as the unconfined aquifer, but includes locally confined to semi-confined areas (DOE 1993).

The Ringold Formation is underlain by the Columbia River Basalt Group, which includes approximately 50 basalt flows. Sandwiched between the various basalt flows are sedimentary interbeds, collectively called the Ellensberg Formation. The Ellensberg Formation consists of mud, sand, and gravel deposited between volcanic eruptions. These sediments and porous flow tops and bottoms form confined aquifers that extend across the Pasco Basin (PNNL 1997).

At the Hanford Site, recharge of the unconfined aquifer by precipitation is highly variable depending on climate, vegetation, and soil texture. Recharge from precipitation is highest in coarse-textured soils with little or no vegetation (PNNL 1997). Fayer and Walters (1995) estimate that recharge to the unconfined aquifer in the area of the C Tank Farm is approximately 2 to 4 in. per year.

For more detailed information about the geology and hydrogeology below the C Tank Farm, the reader is referred to the following documents: Price and Fecht (1976), Caggiano and Goodwin (1991), Lindsey (1993), Lindsey (1995), and PNNL (1997).

3.1.3 Tank Contents

The C Tank Farm received a variety of waste types beginning in 1945. Initially, tanks C-101, -102, -103, -104, -105, and -106 received metal waste, and tanks C-107, -108, -109, -110, -111, and -112 received byproduct cake solution and waste solution from the first decontamination waste cycle (referred to collectively as first-cycle waste). Tanks C-201, -202, -203, and -204 were used to settle waste to allow the supernatant liquid to be sent to a crib (Brevick et al. 1994b). Over their operating life, the C Tank Farm tanks also received B-Plant decontamination waste, U Plant waste, cladding wastes, PUREX Plant fission product waste, waste water, and other waste types (Agnew 1997a). A large amount of strontium from the PUREX Plant fission product waste remains in tank C-106 and has caused a high heat load in the tank (Brevick et al. 1994b).

The tanks in the C Tank Farm currently contain an estimated 1,976,000 gal of mixed wastes (Hanlon 1997) consisting primarily of various cladding wastes, tributyl phosphate and uranium recovery wastes, and sludge produced by in-tank scavenging (Agnew 1997a). Detailed descriptions of the waste streams are presented in Anderson (1990) and Agnew (1995 and 1997a). On the basis of information presented in Agnew (1997a), some of the principal radionuclides in the tank wastes include ^{90}Sr, ^{137}Cs, ^{144}Ce, ^{151}Sm, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{63}Ni, ^{137m}Ba, ^{155}Eu, and ^{154}Eu.

The wastes currently contained in the C Tank Farm tanks are in the form of sludge, supernatant liquid, and interstitial liquid. Sludge is composed of a solid precipitate (hydrous metal oxides) that results from the neutralization of acid waste. The wastes were neutralized before being transferred to the tanks. Sludge forms the "solids" component of the tank waste. Liquids are present as supernatant and interstitial liquids. Supernatant liquid floats on the surface of the solid waste and interstitial liquid fills the interstitial voids within the solid waste. Interstitial liquid may be drainable if it is not held in the interstitial voids by capillary forces.

3.1.4 Tank Farm Status

All the tanks in the C Tank Farm were removed from service during the late 1970s and early 1980s (Brevick et al. 1994a). Nine tanks in the C Tank Farm are categorized as sound (C-102, -103, -104, -105, -106, -107, -108, -109, and -112), and seven are categorized as assumed leakers (C-101, -110, -111, -201, -202, -203, and -204) (Hanlon 1997). The tanks in the C Tank Farm that have been designated as "assumed leakers" are identified on Figure 2.

All the tanks in the C Tank Farm, except tanks C-103 and C-106, have been interim stabilized, and all the tanks, except tanks C-103, -105, and -106, have intrusion prevention completed. Tanks C-103, -105, and -106 have been partial interim isolated (Hanlon 1997).

Currently, tanks C-102 and C-103 are on the Organics Watch List and tank C-106 is on the High-Heat Load Watch List (Hanlon 1997). SSTs are added to a watch list because the waste in the tanks may be in a potentially unsafe condition and the handling of the waste material requires corrective action or special monitoring to reduce or eliminate the hazard. Resolution of the safety issues has been codified under Public Law 101-510 (generally known as the Wyden Amendment).

3.2 Tank C-109

Tank C-109 was constructed during 1943 and 1944 and was placed into service in April 1948 (Welty 1988), when it began receiving first-cycle waste from the cascade from tank C-108 (Anderson 1990). The entire C-107-to-C-109 cascade series was full by September 1948. The first-cycle waste remained in tank C-109 until the third quarter of 1952, when it was pumped to tank B-106 (B Tank Farm). The tank was then used for temporary supernatant storage for the C Tank Farm. Tank C-109 was pumped again in the first quarter of 1953 and received U Plant waste until the second quarter of 1957 (Anderson 1990). The tank was also used as a primary settling tank for the ferrocyanide scavenging program and received in-tank ferrocyanide waste from the first quarter of 1956 until the third quarter of 1957 (Anderson 1990; Agnew 1995). The supernatant waste from this tank was transferred to various ditches, trenches, and cribs, and the tank was ferrocyanide scavenged in the fourth quarter of 1957 (Anderson 1990). Tank C-109 received numerous waste types between 1958 and 1975, including evaporator bottoms waste, coating waste, fission product waste, waste water, strontium semiworks waste, and ion-exchange waste (Anderson 1990; Agnew 1996).

The waste sent to tank C-109 in the mid- to late-1950s resulted from the later part of the bismuth phosphate plutonium extraction process. During that time, the fuel rods were "burned" longer to cause a higher percentage of transmutation of uranium to plutonium in the reactors. The longer fuel burning times also created higher concentrations of activation products that were carried into the process feed material. ^{60}Co in particular was an activation product of concern because it is a high activity nuclide that emits high-energy gamma rays and it has a long half-life. ^{60}Co was generated from the activation of stable ^{59}Co that was present either as an impurity or as an intentional additive in the steel used as components of the fuel rods.

The high gamma flux from ^{60}Co became a problem during processing operations in the mid-1950s, until the specifications were changed to limit the amount of ^{59}Co present in the fuel rods. As a result, the waste stored in tank C-109 contained a relatively higher concentration of ^{60}Co. In addition, tank C-109 was used for in-tank ferrocyanide scavenging, which solidified the ^{137}Cs and ^{90}Sr and further increased the concentration of ^{60}Co in the supernatant liquid. Therefore, if the tank leaked, it is more than likely to have leaked a substantial amount of ^{60}Co that should be found in the vadose zone sediment. This information was obtained from personal communication with Dr. Steve Agnew (Agnew 1997b), who has studied the processing operations and historical records in order to discern tank chemistry and contents.

Jensen (1976) reports that a liquid-level decrease of 0.9 in. occurred in tank C-109 in January 1976; however, there was no additional evidence suggesting that the tank was not sound. The liquid-level decrease was considered to have been caused primarily by buildup of solids on the FIC plummet, and, to a minor extent, by evaporative loss.

Prince (1982) reports that the radiation levels exceeded the increase criteria in December 1981 at a depth of approximately 78 ft in borehole 30-09-06. Consequently, borehole 30-09-07 was drilled in March 1982 to help determine the source of the activity in borehole 30-09-06. Welty (1988) reports that the radiation increase was attributed to the lateral migration of existing contamination from the vicinity of tank C-108. However, the contamination was never attributed to a tank source.

Tank C-109 was declared inactive in 1978 and pumping was completed in 1979. Intrusion prevention was completed in December 1982; interim stabilization and a level adjustment were completed in November 1983 (Brevick et al. 1994b).

The surface level of the waste in tank C-109 is monitored with a manual tape. The liquid waste volume is determined by the manual tape surface level gauge. The solid waste volume is determined by a sludge-level measurement device and photographic evaluation. There are no criteria for a surface-level decrease. From 1991 to 1994, the surface level of the tank waste has remained steady, with readings ranging between 18 and 18.5 in. (Brevick et al. 1994a). The tank is not equipped with liquid observation instrumentation (Hanlon 1997); therefore, the monitoring boreholes surrounding tank C-109 are the primary means of leak detection (Welty 1988).

Tank C-109 is categorized as sound with interim stabilization and intrusion prevention completed. The tank is currently listed as containing noncomplexed waste that consists of 62,000 gal of sludge, 4,000 gal of supernate, and no interstitial liquid (Hanlon 1997).

4.0 Boreholes in the Vicinity of Tank C-109

Eight vadose zone monitoring boreholes surround tank C-109. These boreholes are 30-09-01, 30-09-02, 30-06-10, 30-09-06, 30-09-07, 30-08-02, 30-09-10, and 30-09-11. All the boreholes are associated with tank C-109, except 30-06-10 and 30-08-02, which are associated with tanks C-106 and C-108, respectively. The locations of these boreholes are shown in red on Figure 2.

All the boreholes are lined with 6-in.-inside-diameter steel casing. The algorithms used for the calculation of the radionuclide concentrations from the SGLS data incorporate a correction for the attenuation of the gamma-ray intensity by the borehole casing walls. The surface exposures of most the borehole casings are flush with small-diameter concrete pads, making accurate measurements of the borehole casing wall thicknesses difficult. Therefore, the casing wall thicknesses for the 6-in. boreholes are assumed to be 0.280 in., on the basis of the published thickness for schedule-40, carbon-steel pipe, which was the typical casing used for 6-in.-diameter boreholes in the 1970s.

The boreholes surrounding tank C-109 are completed above the water table and contain no water. The SGLS data were collected in the move/stop/acquire logging mode with a 100-s acquisition time at 0.5-ft depth intervals.

In 1993, Westinghouse Hanford Company (WHC) performed spectral gamma logging of 14 boreholes surrounding tanks C-105 and C-106 using the Radionuclide Logging System (RLS). This system is the intrinsic germanium logging system that was the predecessor to the SGLS. Borehole 30-06-10 was one of the 14 boreholes included in the RLS logging operation; it is also one of the boreholes located near tank C-109 that was logged by the SGLS. The 1993 RLS data are quantitative spectral gamma-ray log data and are of sufficient high quality to allow comparison to the 1997 SGLS data. Individual plots that compare the measured concentrations of man-made radionuclides for borehole 30-06-10 from 1993 and 1997 are included in Appendix A. A more detailed discussion about the characteristics of the RLS detector is included in the TSDRs for tanks C-105 (DOE 1997d) and C-106 (DOE 1997e).

Shape factor analysis was applied to spectral gamma data obtained from all the boreholes surrounding tank C-109. The shape factor results for each borehole are illustrated on individual plots included in Appendix A.

The following sections present results of the spectral gamma-ray log data collected from the boreholes surrounding C-109. Appendix A contains the plots of the SGLS log data, a plot of the RLS log data from borehole 30-06-10, and plots showing shape factor results. The most recent historical gross gamma data are included on the combination plots in Appendix A. The SGLS and RLS data, shape factor analysis results, historical gross gamma logs from 1975 to 1996, and results from other investigations were used in the preparation of this report.

4.1 Borehole 30-09-01

Borehole 30-09-01 is located approximately 5 ft from the northeast side of tank C-109 and was given the Hanford Site designation 299-E27-96. This borehole was drilled in July 1974 to a depth of 100 ft using 6-in. casing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, is flush with the ground surface. The total logging depth achieved by the SGLS was 99.0 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The ^{137}Cs contamination was detected continuously from the ground surface to 37.5 ft. A near-surface zone of low ^{137}Cs contamination (3 to 5 pCi/g) extends to a depth of 2.5 ft. The levels of ^{137}Cs contamination gradually decrease to about 1 pCi/g or less below this zone. A continuous zone of increasing ^{137}Cs contamination (0.3 to 2 pCi/g) was detected from 95.5 ft to the bottom of the logged interval (99 ft).

A zone of ^{60}Co contamination was detected continuously from 89 to 93.5 ft and 96.5 to 97.5 ft with low concentrations ranging from 0.1 to 0.2 pCi/g. The ^{60}Co distribution delineates a weak contaminant plume located at considerable depth below the near-surface ^{137}Cs contamination.

The ^{40}K concentration values increase gradually from 40 to 44.5 ft, increase sharply from 46.5 to 50 ft, and remain elevated to a depth of 75 ft. The ^{40}K concentrations gradually increase below 75 ft and become variable between 75 and 93.5 ft. Although a drilling log was not available to support or contradict the KUT data, the increase in the ^{40}K concentrations at 40 ft may represent a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The increase in the ^{40}K concentration values at 75 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation. The variable ^{40}K concentrations between 75 and 93.5 ft may represent occasional gravel interbeds within the sand-dominated facies.

The SGLS total gamma-ray plot reflects the distribution of ^{137}Cs contamination around the upper portion of the borehole, the ^{137}Cs and ^{60}Co contamination around the lower portion of the borehole, and the naturally occurring radionuclides elsewhere. The count rate increases sharply at about 45.5 ft, corresponding to the increases in the ^{40}K and ^{238}U concentration values at this depth. The peak in the count rate between 91 and 92 ft appears to correspond with the ^{60}Co contamination and the increased ^{232}Th concentrations that occur along this depth interval.

The historical gross gamma log data from 1975 to 1994 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The near-surface contaminated zone and the contamination detected at the bottom of the logged interval were absent on the gross gamma plot because no data were collected from the uppermost and lowermost portions of the borehole. The earliest recorded historical gross gamma log data (January 1975) indicate that both the near-surface and deep ^{137}Cs contamination were present at that time.

Summaries of the historical gross gamma log data from 1974 to 1986 presented in Welty (1988) identify the peak gamma-ray activity levels below a depth of 20 ft. A weak activity peak was identified at a depth of 87 ft on the earliest recorded reading (August 1974), which correlates to the zone of ^{60}Co contamination shown on the SGLS plot. The activity peak decreased in intensity to below reportable levels by early 1975.

Plots of the spectrum shape factors, as described in Wilson (1997), are included in Appendix A. The ^{137}Cs shape factor results suggest that most of the ^{137}Cs contamination detected from 1 to 15 ft and 20 to 25 ft is distributed within the backfill material; however, a few small areas of ^{137}Cs contamination within these regions appear to be localized to the borehole casing. The shape factors also indicate uniformly distributed ^{137}Cs contamination between 28 and 36 ft. The CsSF1 values in this region are close to the order of magnitude expected for a uniform distribution. The CsSF1 values for spectra from near the bottom of the borehole are probably affected by the non-standard source geometry. The CsSF1 values may be inconclusive, but the occurrence of weak ^{137}Cs readings at the bottoms of many tank farm boreholes is evidence that the contaminant is probably on the inside of the casing.

Shape factor analysis was not used to determine the distribution of the ^{60}Co contamination because the ^{60}Co count rates detected were below the lower limits required to produce CoSF1 results.

The near-surface and shallow subsurface ^{137}Cs contamination may have resulted from a surface spill that migrated down into the backfill surrounding the borehole. The zone of ^{137}Cs contamination detected between 28 and 36 ft could have originated from a subsurface leak, but it may be the result of the downward migration of near-surface contamination. The shape factor analysis results suggest that most of this contamination is uniformly distributed around the borehole; however, some of the ^{137}Cs contamination probably adhered to the borehole casing and was carried down during drilling.

The zone of ^{60}Co contamination near the bottom of the logged interval probably represents the remnant of a plume that may have originated from a leak from any of the tanks in the vicinity, including tank C-109. The contamination correlates with the weak zone of ^{60}Co contamination detected at the same depth around borehole 30-09-02, and the contamination may be related to the extensive ^{60}Co plume detected around borehole 30-06-10. The contamination detected around boreholes 30-09-02 and 30-06-10 will be discussed in Sections 4.2 and 4.3, respectively.

The zone of increasing ^{137}Cs contamination at the bottom of the logged interval may be contamination that adhered to the inside of the borehole casing during drilling or the accumulation of particulate contamination that later fell down the inside of the borehole.

4.2 Borehole 30-09-02

Borehole 30-09-02 is located approximately 5 ft from the northeast side of tank C-109. It was given the Hanford Site designation 299-E27-97. This borehole was drilled in June 1974 to a depth of 100 ft using 6-in. casing. A drilling log was not available for this borehole; information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, is approximately flush with the ground surface. The total logging depth achieved by the SGLS was 100.0 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. A shallow subsurface zone of low ^{137}Cs contamination extends from 5 to 13 ft with concentrations generally ranging from 1 to 2 pCi/g. A minor zone of low ^{137}Cs concentrations (0.2 to 1 pCi/g) occurs from 48.5 to 49.5 ft. Isolated minor occurrences of ^{137}Cs contamination were detected at 54, 55.5, and 56.5 ft and at the bottom of the logged interval. The highest concentration of ^{137}Cs (7.3 pCi/g) was detected at the ground surface. However, as described in Section 2.1, this is not an accurate concentration value because the source-to-detector geometry at the top of the borehole casing differs from source-to-detector geometry used in the calibration.

A continuous zone of ^{60}Co contamination was detected from 48.5 to 58.5 ft. The highest concentration of ^{60}Co within this zone was about 6.4 pCi/g at a depth of 54 ft. A single ^{60}Co occurrence was detected at 91 ft. Low concentrations of ^{60}Co (less than 0.2 pCi/g) were detected continuously from 94.5 to 96.5 ft.

The ^{40}K concentration values gradually increase from 40.5 to 43 ft, increase again from 49 to 50 ft, and remain elevated from 50 to about 70 ft. The ^{40}K concentrations increase slightly and become variable below 70 ft. Although a drilling log was not available to support or contradict the KUT data, the increase in the ^{40}K concentrations at 40.5 ft may represent a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The slight increase in the ^{40}K concentration values below 70 ft may represent a gradational contact between the gravel- and sand-dominated facies of the Hanford formation.

It was not possible to identify any of the 609-keV peaks used to derive the ^{238}U concentrations between 53.5 and 56.5 ft. This occurred because high gamma-ray activity associated with the nearby ^{60}Co peaks (1173 and 1333 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured ^{238}U concentration.

The SGLS total gamma-ray plot reflects the distribution of the ^{137}Cs contamination around the upper portion of the borehole, the ^{60}Co contamination around the middle portion of the borehole, and the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The count rate increases sharply at about 48 ft, corresponding to the increases in the ^{40}K, ^{238}U, and possibly ^{137}Cs concentration values at this depth. The large peak in the count rate at 53.5 ft corresponds closely with the maximum ^{60}Co concentrations at this depth.

The interval between 40 and 60 ft was relogged as an additional quality check and to demonstrate the repeatability of the radionuclide concentration measurements made by the SGLS. A comparison of the measured ^{137}Cs and ^{60}Co concentrations and the naturally occurring radionuclides using the data sets provided by the original and repeated logging runs is included in Appendix A. The measurements repeat within two standard deviations (95-percent confidence level), indicating excellent repeatability of the measured gamma-ray spectral peak intensities used to calculate the radionuclide assays.

The historical gross gamma log data from 1975 to 1994 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The gross gamma activity clearly reflects the ^{60}Co contamination shown on the SGLS plot between 48 and 56 ft. This activity was evident at significantly higher count rates and at a shallower depth on the earliest recorded historical gross gamma log (January 1975), indicating that the ^{60}Co contamination was present in this region of the vadose zone at that time.

A group of representative historical gross gamma-ray logs acquired between 1975 and 1994 are presented in Appendix A. The log-plot sequence identifies anomalous activity within the zone of ^{60}Co contamination detected around the middle portion of the borehole by the SGLS. The plot also shows a progressive decrease in the count-rate intensity over the reporting period. The rate at which the gross gamma counts diminished is generally consistent with the decay rate of ^{60}Co. The log-plot sequence illustrates the downward migration of the ^{60}Co contamination between 1982 and 1988. The plot also shows that no further downward migration of the ^{60}Co contamination has occurred since 1988.

Summaries of the historical gross gamma log data from 1974 to 1986 are presented in Welty (1988). An activity peak was present at a depth of 49 ft on the earliest recorded log. The peak progressively decreased in intensity over the reporting period and slowly migrated downward to a depth of 53 ft between 1982 and 1986. The rate at which the gross gamma counts diminished between 1974 and 1975 suggests that other short-lived radionuclides, such as ^{106}Ru or ^{125}Sb, may have augmented the ^{60}Co contamination detected by the SGLS at this depth.

Plots of the spectrum shape factors are included in Appendix A. The CsSF1 values indicate that the ^{137}Cs contamination detected between 2 and 8 ft is generally distributed uniformly in the formation, but becomes progressively more localized to the borehole casing between 8 and 13 ft. Although somewhat inconclusive, the CsSF1 values indicate that the small amount of ^{137}Cs contamination detected at about 49 ft may be distributed remotely in the formation. The ^{60}Co shape factor results indicate that the ^{60}Co contamination detected at about 54 ft is distributed uniformly in the formation. The higher CoSF1 values above and below this depth region typically indicate the presence of a thin contaminated layer occurring within the formation.

The near-surface zone of ^{137}Cs contamination probably resulted from a surface spill that has migrated down into the backfill surrounding the borehole. The shape factor analysis results suggest that the upper portion of this contamination is distributed uniformly in the formation, but the lower portion becomes progressively more localized to the borehole casing with depth.

The isolated zone of ^{137}Cs contamination detected at about 49 ft may have originated from a surface spill or subsurface leak that migrated along the outside of the tank to the base of the tank footing, where it then preferentially migrated both downward and laterally through the native sediments below the tank farm excavation. The shape factor analysis results suggest that this contamination may occur as a confined source remote from the borehole.

The scattered ^{137}Cs contamination detected directly below this zone was probably carried down during the drilling of this borehole. The ^{137}Cs contamination detected at the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole.

The zone of ^{60}Co contamination detected from 48.5 to 58.5 ft probably represents the remnant of a plume that resulted from a remote subsurface source, such as a pipeline, cascade-line, or tank leak. The contamination may be related to the extensive ^{60}Co plume detected in borehole 30-08-02. The shape factor analysis results indicate that the ^{60}Co contamination occurs as a thin contaminated layer within the formation between 53 and 54 ft.

The weak zone of ^{60}Co contamination near the bottom of the logged interval probably represents the remnant of a plume that may have originated from a leak from any of the tanks in the vicinity, including tank C-109. The contamination correlates with the weak zone of ^{60}Co detected at the same depth in borehole 30-09-01 and may be related to the extensive ^{60}Co plume detected in borehole 30-06-10.

4.3 Borehole 30-06-10

Borehole 30-06-10 is located approximately 12 ft from the southeast side of tank C-109. It was given the Hanford Site designation 299-E27-71. This borehole was drilled in November 1972 to a depth of 130 ft using 6-in. casing. The drilling report does not indicate if the borehole casing was perforated or grouted. The top of the casing, which is the zero depth reference for the SGLS, is approximately flush with the ground surface. The total logging depth achieved by the SGLS was 129.0 ft.

The man-made radionuclides ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{235}U were detected in this borehole. ^{137}Cs contamination was measured continuously from the ground surface to a depth of 11 ft, delineating a shallow subsurface zone of low to moderate ^{137}Cs contamination. The maximum ^{137}Cs concentration within this zone was 7.7 pCi/g at a depth of 2.5 ft. Continuous zones of ^{137}Cs contamination were also detected at low concentrations (less than 0.5 pCi/g) from 12 to 17 ft, 45 to 57 ft, 65.5 to 67.5 ft, and 128.5 to 129 ft. Several isolated ^{137}Cs occurrences were detected between 19.5 and 37 ft. The highest ^{137}Cs concentration was 184 pCi/g at the ground surface. However, as described in Section 2.1, this is not an accurate concentration value because the source-to-detector geometry at the top of the borehole casing differs from the source-to-detector geometry used during calibration.

^{60}Co contamination was detected almost continuously from 86 to 116.5 ft, delineating a significant contaminant plume located at considerable depth below the ^{137}Cs contamination. The maximum ^{60}Co concentration was 1.3 pCi/g at a depth of 106.5 ft.

^{154}Eu and ^{235}U contamination was detected at the ground surface at concentrations of 0.21 and 6.21 pCi/g, respectively. However, these are probably not accurate concentration values for reasons discussed in Section 2.1.

A slight increase in the ^{40}K concentration values at 42 ft probably represents a change in lithology from backfill material to the undisturbed Hanford formation. The drilling log reports a change from sand and gravel to coarse sand and silt at about this depth. Elevated, slightly variable ^{40}K concentration values were detected from 42.5 to 77 ft. The ^{40}K concentrations increase at 77 ft, remain elevated to a depth of 122 ft, and decrease towards the bottom of the logged interval. The drilling log reports sand and gravel from 45 to 75 ft, sand and silt from 75 to 90 ft, and sand below 90 ft. Information reported in the drilling log supports the interpretation that the ^{40}K concentrations between 42.5 and 77 ft represent the basal region of the gravel-dominated facies of the Hanford formation, and that the increased ^{40}K concentrations at 77 ft represent the contact with the sand-dominated facies of the Hanford formation.

A sharp decrease in the ^{238}U concentrations was detected at 36 ft, which corresponds to the beginning and end of individual log runs. This concentration decrease is most likely the result of radon venting up the borehole between log runs. The variability in the ^{238}U background is not related to changes in the efficiency of the detector, but more likely to the weather conditions during a particular run. The 609-keV spectral peak used to calculate the ^{238}U concentration is actually emitted by ^{214}Bi, and the calculated ^{238}U concentration is only accurate if the ^{214}Bi and ^{238}U are in secular equilibrium. Because radon gas is an intermediate member of the ^{238}U decay chain, the equilibrium condition will be disturbed by changes in the barometric pressure. The variations in the calculated ^{238}U background do not affect the determination of man-made gamma-ray-emitting nuclides from the SGLS data set. Decreased ^{232}Th concentration values were detected from 119.5 ft to the bottom of the logged interval.

The SGLS total gamma-ray plot reflects the near-surface zone of ^{137}Cs contamination, the extensive zone of ^{60}Co contamination, and the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The increase in the total count rate at about 41 ft corresponds with increases in the ^{40}K and ^{232}Th concentration values at this depth. The decrease in the count-rate activity between 120 and 128.5 ft corresponds closely with the decrease in ^{232}Th concentrations in this region.

A plot included in Appendix A compares spectral gamma data collected with the RLS in 1993 with spectral gamma data collected with the SGLS in 1997. The plot shows good repeatability of the data in the upper 10 ft of the vadose zone where the ^{137}Cs concentrations range from 1 to 7 pCi/g. The data repeat less closely below 10 ft. The RLS and SGLS data indicate there is a large plume of ^{60}Co contamination extending from 85 to 117 ft. Between 1993 and 1997, the concentrations of ^{60}Co have decreased within the upper and middle regions of the plume, illustrating the radioactive decay of the ^{60}Co contamination in these areas. Since 1993, the data also indicate that downward migration of the ^{60}Co has occurred in the lower region of the plume, or additional ^{60}Co contamination has migrated into the region below 110 ft. The comparison shows that the ^{60}Co contamination has not been stable between 1993 and 1997.

The historical gross gamma log data from 1975 to 1996 were reviewed. The most recent historical gross gamma data are presented on the combination plot, which clearly shows the near-surface ^{137}Cs contamination. The earliest recorded historical gross gamma log (January 1975) illustrates the near-surface ^{137}Cs contamination. Some of the early historical logs show slightly anomalous activity between 87 and 110 ft that is probably related to the ^{60}Co contamination shown on the SGLS plot. However, the poor spatial resolution of the historical gross gamma logs makes it difficult to determine if the ^{60}Co concentrations have increased or decreased over time.

Plots of the spectrum shape factors are included in Appendix A. The SF2 shape factor results suggest the presence of a localized source of ^{90}Sr at a depth 0.5 ft. The anomalously high SF2 value (greater that 13) at this depth may indicate the presence of bremsstrahlung radiation originating from a ^{90}Sr source that is close to the borehole and localized to that depth. However, these conclusions are tentative because the SF2 could be affected by the nearby ground-air boundary.

The CsSF1 values indicate that there is a remote source of ^{137}Cs contamination located within 1.5 ft of the borehole at a depth of 4.5 ft. This source occurs below, and is separate from, the ^{137}Cs peak shown on the SGLS plot at about 2.5 ft. The relatively lower CsSF1 values that occur above and below the elevated CsSF1 values at 4.5 ft are associated with the remote source of ^{137}Cs. However, the CsSF1 values could be affected by the fairly rapid change in ^{137}Cs concentration with depth. Also, at the 4.5-ft depth, the CsSF1 value exceeds the asymptotic limit, but the SF2 value is in the normal range. This could be caused by the change in ^{137}Cs concentration with depth instead of radial variations in the ^{137}Cs concentration.

Shape factor analysis was not used to determine the distribution of the ^{60}Co contamination because the count rates were below the lower limits required to produce CoSF1 results.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. However, the shape factor analysis results indicate that some of the ^{137}Cs occurs as a discrete source remote from the detector. The ^{137}Cs contamination directly below 10 ft was probably carried down during the drilling of this borehole.

The distinct zone of ^{137}Cs contamination detected from 45 to 57 ft may have originated from a surface spill or subsurface leak that migrated along the outside of the tank to the base of the tank footing, where it then preferentially migrated both downward and laterally through the native sediments below the tank farm excavation. The ^{137}Cs contamination detected directly below this zone was either carried down during drilling or later migrated down the outside of the borehole casing. The ^{137}Cs contamination detected at the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole. The ^{137}Cs concentrations in these regions of the borehole were too low to permit meaningful shape factor calculations.

The extensive zone of ^{60}Co contamination detected from 86 to 116.5 ft may have originated from a remote subsurface source, such as the C-104-to-C-105 cascade line leak described in Welty (1988). This region of ^{60}Co contamination was also detected with the RLS. Consequently, Brodeur (1993) postulates that because ^{60}Co contamination migrates easily, and a high ^{137}Cs concentration was not found above or in conjunction with the ^{60}Co anomaly, the ^{60}Co contamination probably migrated horizontally some distance from the source to cause the detected radionuclide segregation. A comparison of the RLS and SGLS data shows the ^{60}Co contamination has migrated downward approximately 5 ft since 1993, suggesting that the plume is still moving through the vadose zone.

4.4 Borehole 30-09-06

Borehole 30-09-06 is located approximately 6 ft from the south side of tank C-109 and was given the Hanford Site designation 299-E27-98. This borehole was drilled in September 1974 to a depth of 100 ft using 6-in. casing. The drilling log was not available for this borehole; information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, rises approximately 1 ft above the ground surface. The total logging depth achieved by the SGLS was 98.0 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The ^{137}Cs contamination was detected nearly continuously from the ground surface to 32 ft, continuously from 35.5 to 37 ft, and nearly continuously from 41 to 73.5 ft. Except for the near-surface ^{137}Cs contamination, the ^{137}Cs concentrations ranged from 0.2 to 2 pCi/g, although most concentrations were less than 1 pCi/g. A single occurrence of weak ^{137}Cs contamination was detected at the bottom of the logged interval (98 ft). The highest concentration of ^{137}Cs (39 pCi/g) was detected at the ground surface. However, as described in Section 2.1, this is not an accurate concentration value because the source-to-detector geometry at the top of the borehole casing differs from source-to-detector geometry used during calibration.

A continuous zone of low ^{60}Co contamination was detected from 78 to 86.5 ft. The highest concentration of ^{60}Co within this zone was about 2.8 pCi/g at a depth of 82.5 ft. The ^{60}Co distribution delineates a small contaminant plume located at considerable depth below the near-surface ^{137}Cs contamination.

Relatively high ^{40}K concentration values occur between 1 and 4.5 ft. The KUT concentrations decrease at about 5 ft. The ^{40}K concentration values increase at 38 ft, become variable from 40 to 48.5 ft, then gradually decrease between 48.5 and 71 ft. The ^{40}K concentrations increase between 71 and 73 ft and remain elevated to the bottom of the logged interval. Although a drilling log was not available to support or contradict the KUT data, the relatively high ^{40}K concentration values between 1 and 4.5 ft may represent relatively finer grained backfill material or a concrete encasement around the borehole. The decreased KUT concentrations below 4.5 ft may indicate a zone of relatively coarser grained backfill material or possibly the presence of grout around the outside of the borehole. The increase in the ^{40}K concentrations at 38 ft probably represents a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The variable ^{40}K concentrations between 40 and 48.5 ft may represent sand or silt interbeds within the gravel-dominated facies. The increase in the ^{40}K concentration values at 71 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation.

The SGLS total gamma-ray plot reflects the ^{137}Cs contamination around the upper 16 ft of the borehole, the ^{60}Co contamination around the lower portion of the borehole, and the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The increases in the total count rate at 37 and 71 ft correspond closely with increases in the ^{40}K concentration values at these depths.

The historical gross gamma log data from 1975 to 1994 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The data show the slightly anomalous activity between 78 and 86 ft is probably related to the ^{60}Co contamination shown on the SGLS plot. The anomalous activity was detected between December 1979 and June 1981, indicating that the ^{60}Co contamination moved into this region of the vadose zone during that time interval.

A group of representative historical gross gamma-ray logs acquired between 1979 and 1987 are presented in Appendix A. The log-plot sequence identifies the ^{60}Co contamination detected by the SGLS and illustrates the changes in the count-rate intensity during the reporting period. A zone of anomalous activity was detected in June 1981 and increased in intensity through 1982, indicating that ^{60}Co and possibly other man-made radionuclides were actively moving through this region of the vadose zone. The sharp decrease in the count rate between 1985 and 1986 may indicate the movement of contamination away from this borehole. A review of more recent historical gross gamma logs indicates that the count rate diminished at a progressively slower rate between 1986 and 1994. The log-plot sequence also illustrates the downward migration of the ^{60}Co contamination between 1981 and 1986. A review of more recent historical gross gamma logs shows that no further downward migration of the ^{60}Co occurred between 1986 and 1994 and that the plume is now stable.

Summaries of the historical gross gamma log data from 1974 to 1986 are presented in Welty (1988). An activity peak was detected at a depth of 75 ft in July 1980. The peak intensity remained elevated (greater than 200 cps) from December 1981 until June 1985, then diminished to approximately 100 cps by June 1986. During this time, the activity peak slowly migrated downward to a depth of 83 ft. The downward movement and the changes in the peak intensity of the activity peak suggest that a plume of ^{60}Co contamination passed through this region during the reporting period.

Plots of the spectrum shape factors are included in Appendix A. The CsSF1 values indicate that the ^{137}Cs contamination detected between 1 and 15 ft is uniformly distributed in the formation. However, the KUT concentration values indicate there may be grout around this borehole that make the CsSF1 values inconclusive. The ^{137}Cs shape factors suggest that the small zone of slightly elevated ^{137}Cs contamination detected between 41.5 and 43.5 ft is localized to the borehole casing.

The ^{60}Co shape factor results suggest that much of the ^{60}Co contamination detected between 78 and 86.5 ft is basically within the formation but is somewhat concentrated on the casing. This is not surprising since ^{60}Co is known to react with and plate out on steel casing. Because the ^{60}Co is not found in the upper portion of the borehole and because it is found at depth in multiple boreholes, it is apparent that ^{60}Co is distributed in the formation.

The zone of ^{137}Cs contamination detected between 1 and 15 ft probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. Although inconclusive, the shape factor analysis results indicate that this contamination may be uniformly distributed in the backfill material around the borehole. Most of the ^{137}Cs contamination detected between 15 and 40 ft was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing.

Shape factor analysis results indicate that the ^{137}Cs contamination detected from 41.5 to 43.5 ft is probably localized to the borehole casing indicating drag-down. This suggests that the ^{137}Cs contamination detected below this zone was probably carried downward as the borehole was drilled.

The minor amount of ^{137}Cs contamination at the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole.

The zone of ^{60}Co contamination detected between 78 and 86.5 ft probably represents the remnant of a plume that resulted from a remote subsurface source. The contamination may be related to the extensive ^{60}Co plume detected around borehole 30-08-02. The shape factor analysis results indicate that the ^{60}Co contamination is generally uniformly distributed in the formation, although some concentration has occurred on the borehole casing.

4.5 Borehole 30-09-07

Borehole 30-09-07 is located approximately 1 ft from the southwest side of tank C-109. It was given the Hanford Site designation 299-E27-135. This borehole was drilled in March 1982 to a depth of 125 ft using 6-in. casing. A drilling log was not available for this borehole. Information presented in Chamness and Merz (1993) indicates that the borehole was grouted but not perforated; however, the depth of grouted interval was not specified. The top of the casing, which is the zero depth reference for the SGLS, rises approximately 2.5 ft above the ground surface. The total logging depth achieved by the SGLS was 124.5 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The ^{137}Cs contamination was detected continuously from the ground surface to 9.5 ft and nearly continuously from 16.5 to 35.5 ft. A near-surface zone containing low to moderate concentrations of ^{137}Cs (2 to 13 pCi/g) extends to a depth of 6 ft. The ^{137}Cs concentrations decrease to less than 1 pCi/g below this zone, except for an isolated interval of continuous ^{137}Cs contamination detected from 11.5 to 12.5 ft. The highest concentration of ^{137}Cs (139 pCi/g) was detected at the ground surface. However, as described in Section 2.1, this is not an accurate concentration value because the source-to-detector geometry at the top of the borehole casing differs from source-to-detector geometry used during calibration.

A continuous zone of ^{60}Co contamination was detected from 79 to 83.5 ft. The highest concentration of ^{60}Co within this zone was about 1.7 pCi/g at a depth of 80 ft. A few low concentrations of ^{60}Co (0.1 to 0.2 pCi/g) were detected between 85 and 92.5 ft. The ^{60}Co distribution delineates a small contaminant plume located at considerable depth below the near-surface ^{137}Cs contamination.

The steady decrease in the ^{40}K concentration values from 26.5 to 40 ft is uncharacteristic of ^{40}K concentration profiles in other nearby boreholes. Information presented in Chamness and Merz (1993) indicates that the borehole was grouted but does not specify the grouted interval. Grout is sometimes added to stabilize sloughing portions of a borehole. After the grout hardens, the borehole is advanced through the grout plug. It is clear that the low ^{40}K concentrations between 26.5 and 40 ft is caused by the presence of residual grout along this interval of the borehole. Judging from the location of the borehole relative to the tank, it is also possible that this borehole intercepted the concrete wall of the tank. Because a copy of the drilling log for this borehole was not available, this cannot be confirmed or denied. However, there are several instances of a tank being contacted during drilling.

The ^{40}K concentration values increase significantly from 40 to 41.5 ft and remain elevated to a depth of 73.5 ft. The ^{40}K concentration values increase again at 74 ft and remain elevated to a depth of about 118 ft. Although the presence of grout or the proximity of the borehole to the tank wall make interpretation of the KUT data difficult between 26.5 and 40 ft, the increase in the background ^{40}K concentrations at 40 ft may represent a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The increase in the ^{40}K concentration values at 74 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation.

It was not possible to identify most of the 609-keV peaks used to derive the ^{238}U concentrations between the ground surface and 3.5 ft. This occurred because high gamma-ray activity associated with the nearby ^{137}Cs peak (661 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured ^{238}U concentration.

The SGLS total gamma-ray plot reflects the distribution of ^{137}Cs contamination around the upper portion of the borehole, the ^{60}Co contamination around the lower portion of the borehole, and the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The count rate increases sharply at about 40 ft, corresponding to the increase in the ^{40}K concentration values at this depth. The count rate gradually decreases from 115 ft to the bottom of the logged interval, corresponding with decreases in the ^{40}K and ^{238}U concentrations along this depth interval.

The historical gross gamma log data from 1982 to 1994 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The plot shows a zone of anomalous gamma-ray activity, corresponding to the the near-surface ^{137}Cs contamination illustrated on the SGLS plot. A review of the historical data indicates that this contamination probably originated sometime between May 1982 and June 1984, and the contamination does not appear to have migrated during the reporting period. A slightly anomalous count rate occurs at a depth of 81 ft that may represent the ^{60}Co contamination detected by the SGLS at this depth. This activity was evident at significantly higher count rates and at a slightly shallower depth on the earliest recorded historical gross gamma log (April 1982), indicating that some type of man-made contamination was present in this region of the vadose zone at that time.

Summaries of the historical gross gamma log data from 1982 to 1986 are presented in Welty (1988). An activity peak was identified at a depth of 76 ft in early 1982. The peak decreased in intensity and slowly migrated downward to a depth of 81 ft by 1986. The rate at which the gross gamma counts diminished between 1982 and 1986 suggests that other short-lived radionuclides, such as ^{106}Ru or ^{125}Sb, may have augmented the ^{60}Co contamination detected by the SGLS at this depth, but have since decayed away. It was not possible to calculate reliable decay rates from the gross gamma log data because of the high counting uncertainty of the data.

Plots of the spectrum shape factors are included in Appendix A. Because the borehole casing rises approximately 0.5 ft above a 2-ft-high berm, the shape factor data collected from the upper 2.5 ft of the logged interval were not considered in determining the distribution of contamination around this portion of the borehole casing. Below this interval, the ^{137}Cs shape factor results suggest that the ^{137}Cs contamination detected within the upper 3.5 ft of the backfill material (between 2.5 and 6 ft below the casing) is distributed uniformly in the formation. Although the CsSF1 values within this zone are in excess of 20, the associated SF2 values are very close to those expected for a uniform distribution. However, the shape factors may be inconclusive because the ^{137}Cs concentrations decrease rapidly along this depth interval.

Valid ^{60}Co shape factor results could only be calculated for a small region at about 80 ft. These data indicate that the ^{60}Co contamination is in the formation rather than on the casing but is not uniformly distributed.

The near-surface zone of ^{137}Cs contamination probably resulted from a surface spill that has migrated down into the backfill surrounding the borehole. On the basis of historical gross gamma log data, it appears that the spill occurred sometime between May 1982 and June 1984. The shape factor analysis results suggest that this contamination is distributed uniformly in the formation around the borehole.

The isolated zone of ^{137}Cs contamination detected between 11.5 and 12.5 ft may represent surface contamination that has migrated along the surface of the tank dome into this region of the vadose zone. Most of the ^{137}Cs contamination detected below 15 ft was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing.

The zone of ^{60}Co contamination detected between 79 and 92.5 ft probably represents the remnant of a plume that resulted from a remote subsurface source, such as a tank leak. The contamination may be related to the extensive ^{60}Co plume detected around borehole 30-08-02.

4.6 Borehole 30-08-02

Borehole 30-08-02 is located approximately 11 ft from the southwest side of tank C-109 and was given the Hanford Site designation 299-E27-94. This borehole was drilled in September 1974 to a depth of 100 ft using 6-in. casing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, is assumed to be flush with the ground surface. The total logging depth achieved by the SGLS was 99.0 ft.

The man-made radionuclides ^{137}Cs, ^{60}Co, and ^{154}Eu were detected in this borehole. The ^{137}Cs contamination was detected continuously from the ground surface to 24.5 ft, which includes two highly contaminated zones. A near-surface zone of high ^{137}Cs contamination (30 to 600 pCi/g) extends to a depth of 3 ft. Low levels of ^{137}Cs contamination occur between 3.5 and 18.5 ft at concentrations generally less than 1 pCi/g. A discrete subsurface zone of very high ^{137}Cs contamination (150 to 1,100 pCi/g) was detected from 20 to 22 ft. Isolated zones of weak ^{137}Cs contamination (less than 0.5 pCi/g) were detected from 27 to 27.5 ft and 47 to 49 ft.

A zone of moderate to high ^{60}Co contamination was detected from 46.5 to 79.5 ft. The highest concentrations of ^{60}Co (about 7 to 10 pCi/g) were detected within the middle portion of this zone between 58 and 62.5 ft. The ^{60}Co contamination delineates an extensive contaminant plume located at considerable depth below the shallow subsurface ^{137}Cs contamination.

An isolated occurrence of ^{154}Eu was detected at a depth of 2.5 ft. A thin, nearly continuous zone of ^{154}Eu contamination, with concentrations ranging from 1 to 24 pCi/g, was detected from 19.5 to 22.5 ft.

The ^{40}K concentration values increase at 37.5 ft and generally remain elevated to a depth of 72.5 ft. The ^{40}K concentrations become increasingly variable with depth between 55 and 74.5 ft. The ^{40}K concentration values increase again at 74.5 ft and remain elevated to the bottom of the logged interval. Although a drilling log was not available to support or contradict the KUT data, the increase in the ^{40}K concentrations at 37.5 ft probably represents a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The variable ^{40}K concentrations between 55 and 74.5 ft may represent sand or silt interbeds within the gravel-dominated facies. The increase in the ^{40}K concentration values at 74.5 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation.

It was not possible to identify any of the 609-keV peaks used to derive the ^{238}U concentrations from 18 to 23.5 ft. In addition, it was not possible to identify any of the 1460- and 2614-keV peaks used to derive the ^{40}K and ^{232}Th concentrations between 20 and 22 ft. The KUT data were absent between 20 and 22 ft because this interval was logged by the SGLS in real time since the dead time exceeded 50 percent. Outside this region, the 609-keV peaks were not identified because high gamma-ray activity associated with the nearby ^{137}Cs peak (661 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured ^{238}U concentration. Furthermore, it was not possible to identify most of the 609-keV peaks in the lower region of the borehole between 57.5 and 65 ft. In this case, the high gamma-ray activity associated with the nearby ^{60}Co peaks (1173 and 1333 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured ^{238}U concentration.

The SGLS total gamma-ray plot reflects the distribution of the ^{137}Cs, ^{60}Co, and ^{154}Eu contamination around this borehole and some variations of the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The sharp peaks in the count rate at 2 and 23 ft correspond closely with the zones of highly concentrated ^{137}Cs contamination and the isolated zone of ^{154}Eu contamination shown on the man-made plot. The zone of elevated total count rates between 45 and 80 ft corresponds closely with the ^{60}Co contamination detected by the SGLS. The relative increase in the total count rate at about 37 ft corresponds with the increase in the ^{40}K concentrations at this depth. The slight increase in the count rate near the bottom of the logged interval corresponds to the increases in the ^{40}K and ^{232}Th concentrations at this depth.

The historical gross gamma log data from 1980 to 1989 were reviewed. The most recent historical gross gamma data (June 1989) are presented on the combination plot. The gross gamma activity reflects the near-surface and shallow subsurface ^{137}Cs contamination shown on the SGLS plot. However, the gross gamma data do not reflect the distribution of the distinct subsurface ^{60}Co plume detected by the SGLS. A zone of elevated gross gamma activity occurs between 74 and 80 ft that does not correspond with any radionuclides illustrated on the SGLS plots. It is possible that the anomalous activity may represent other short-lived radionuclides, such as ^{106}Ru or ^{125}Sb, that have decayed to below detectable levels since 1989.

Summaries of the historical gross gamma log data from 1974 to 1987 presented in Welty (1988) identify the peak gamma-ray activity levels below a depth of 20 ft. Significant activity peaks were identified at depths of 21 and 48 ft on the earliest recorded logs.

The activity peak at 21 ft was identified in October 1974 and correlates to the depth of the ^{137}Cs and ^{154}Eu contamination shown on the SGLS plot. The activity peak shifted in depth as much as 5 ft, which is probably attributable to the depth-control problems related to the gross gamma system. In general, the anomalous activity at 21 ft gradually decreased in intensity from 1974 to 1980, possibly indicating the radioactive decay of the ^{154}Eu. The activity peak was no longer reported after 1980 because the location of the peak intensity moved to a depth of 19 ft, which is above the depth threshold that data are reported in Welty (1988).

An activity peak at 48 ft was identified in November 1974. The activity peak increased in intensity until July 1975, then progressively decreased in intensity and slowly migrated downward to a depth of 75 ft by 1986.

A group of representative historical gross gamma-ray logs acquired between 1980 and 1989 are presented in Appendix A. The log-plot sequence illustrates the near-surface ^{137}Cs contamination detected on the SGLS plot and shows that this contamination probably originated sometime between January 1982 and June 1984. The log-plot sequence shows that the near-surface ^{137}Cs contamination did not migrate or decrease in intensity during the reporting period.

The subsurface ^{137}Cs and ^{154}Eu contamination shown on the SGLS plot from 20 to 22 ft is also evident on the log-plot sequence. This contamination appears to have migrated downward as much as 4 ft through the vadose zone since 1980; however, the apparent movement may be attributable to the depth-control problems associated with the gross gamma system discussed previously.

On the 1980 plot, the earliest data set available for the log plot sequence, a large count-rate anomaly was evident within the region of ^{60}Co contamination shown on the SGLS plot. Similar to the data reported in Welty (1988), the activity peak decreased in intensity and slowly migrated downward to a depth of 76 ft by 1986. No further migration occurred from 1986 to 1989, but the intensity of the activity peak continued to decrease to about one-ninth of the count rate measured in 1980. On the basis of decay-rate calculations from the gross gamma log data, the decrease in the gross gamma activity between 1984 and 1988 indicates that ^{60}Co and a shorter-lived radionuclide may have been present within the contaminant plume during that time.

Plots of the spectrum shape factors, as described in Wilson (1997), are included in Appendix A. The ^{137}Cs shape factor analysis results indicate that the ^{137}Cs contamination detected between 1 and 4 ft occurs as a thin zone within the formation. The CsSF1 values indicate that the ^{137}Cs contamination detected between 13 and 17 ft is distributed uniformly in the formation but becomes increasingly remote to the borehole below 17 ft. The CsSF1 and SF2 values between 17 and 23 ft are indicative of a line source remote from the borehole. The ^{60}Co shape factor results indicate that the ^{60}Co contamination detected between 50 and 80 ft is distributed uniformly in the formation. The CoSF1 values along this interval are close to the range expected for a uniform contaminant distribution.

The near-surface zone of ^{137}Cs contamination may have resulted from a large surface spill that migrated down into the backfill surrounding the borehole. On the basis of historical gross gamma log data, it appears that the spill occurred sometime between January 1982 and June 1984.

The distinct zone of ^{137}Cs and ^{154}Eu contamination detected around borehole 30-08-02 between 19 and 23.5 ft may be the result of a leak from the C-108-to-C-109 cascade line. However, the discrete nature of the contaminated zone suggests that this borehole is located very close to this cascade line and may indicate direct detection of the line itself. As discussed in Section 3.2, the cascade line became plugged in 1952. Consequently, the ^{137}Cs and ^{154}Eu contamination detected may consist of residual waste contained within the cascade piping. The shape factor analysis data indicate that this contamination is remote to the borehole, supporting the theory that the contamination may be isolated to the region along the inside of the pipeline.

The zone of slightly increased ^{137}Cs between 13 and 17 ft suggests that contamination from the C-108-to-C-109 cascade line may have migrated upward into this region of the vadose zone, possibly during the time period that the cascade line was plugged. The shape factor analysis results indicate that most of this contamination is uniformly distributed in the formation around the borehole.

The zone of ^{137}Cs contamination detected from 47 to 49 ft may have originated from a surface spill or subsurface leak that migrated along the outside of the tank to the base of the tank footing, where it then preferentially migrated both downward and laterally within one of the basal gravel units below the tank farm excavation.

The significant zone of ^{60}Co contamination that underlies the base of the tank farm excavation may have originated from a remote subsurface source, such as the C-104-to-C-105 cascade line leak described in Welty (1988). The shape factor analysis indicates that the contamination is distributed uniformly within the formation and is not confined to the vicinity of the casing. It is postulated that the anomalous gross gamma activity originally identified by Welty (1988) in 1974 at 48 ft probably indicates the early presence of the ^{60}Co contamination identified on the SGLS plot. Historical gross gamma logs indicate that the contaminant plume migrated to a depth of 60 ft by 1980. The gross gamma log-plot sequence indicates that other short-lived radionuclides, such as ^{106}Ru or ^{125}Sb, may have initially coexisted with the ^{60}Co contamination and slowly migrated to deeper portions of the vadose zone between 1980 and 1986, but have since decayed to levels below the detection limit of the SGLS.

4.7 Borehole 30-09-10

Borehole 30-09-10 is located approximately 14 ft from the northwest side of tank C-109. It was given the Hanford Site designation 299-E27-99. This borehole was drilled in July 1974 to a depth of 100 ft using 6-in. casing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) does not indicate that the borehole was grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, is approximately flush with the ground surface. The total logging depth achieved by the SGLS was 98.0 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The ^{137}Cs contamination was measured continuously from the ground surface to 67 ft and from 74 ft to the bottom of logged interval. A near-surface zone of moderate to high ^{137}Cs contamination (125 to 250 pCi/g) occurs from 1 to 3.5 ft. The ^{137}Cs concentrations gradually decrease from 70 pCi/g to less than 2 pCi/g between 6 and 16 ft. Two broad zones of elevated ^{137}Cs contamination were detected from 27 to 38 ft (2 to 12 pCi/g) and from 49 to 62 ft (2 to 5 pCi/g). A significant zone of increasing ^{137}Cs contamination (1 to 7 pCi/g) was detected from 94.5 ft to the bottom of the logged interval (98 ft).

A broad zone of intermittent ^{60}Co contamination was detected at low concentrations between 53 ft and the bottom of the logged interval. The highest concentrations of ^{60}Co (greater than 0.2 pCi/g) were detected within the middle portion of this zone.

The ^{40}K concentration values increase at 39.5 ft, become variable from 41 to 55 ft, and remain elevated to a depth of 69.5 ft. The ^{40}K concentration gradually increase below 69.5 ft and become variable from 80 ft to the bottom of the logged interval. Although a drilling log was not available to support or contradict the KUT data, the increase in the ^{40}K concentrations at 39.5 ft probably represents a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The variable ^{40}K concentrations between 41 and 55 ft may represent sand or silt interbeds within the gravel-dominated facies. The increase in the ^{40}K concentration values at 69.5 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation. The variable ^{40}K concentrations between 80 ft and the bottom of the logged interval may represent coarse sand or gravel interbeds within the sand-dominated facies.

The SGLS total gamma-ray plot reflects the presence of the ^{137}Cs contamination where it occurs at concentrations above 1 pCi/g or combined with areas of ^{60}Co contamination. The count rate does not reflect the changes in the naturally occurring radionuclides because of the widespread presence of ^{137}Cs around this borehole.

The historical gross gamma log data from 1975 to 1996 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The gross gamma activity reflects the near-surface and shallow subsurface ^{137}Cs contamination shown on the SGLS plot to a depth of 34 ft. The earliest recorded historical gross gamma log (January 1975) reflects this region of ^{137}Cs contamination, indicating that it was present in the vadose zone at that time. The earliest recorded log also shows slightly anomalous count rates at depths of 76 and 84 ft that may represent portions of the ^{60}Co contamination detected by the SGLS within this region.

Summaries of the historical gross gamma log data from 1973 to 1987 are presented in Welty (1988). An activity peak was identified at a depth of 29 ft in January 1975 that correlates to the zone of elevated ^{137}Cs contamination shown on the SGLS plot. The activity peak shifted in depth as much as 5 ft during the reporting period; however, this may be attributable to the depth-control problems associated with the gross gamma system. The activity peak slowly decreased in intensity to below reportable levels by 1986.

Plots of the spectrum shape factors are included in Appendix A. The CsSF1 values indicate that the ^{137}Cs contamination is generally distributed uniformly in the formation between 1 and 4 ft, but becomes progressively more localized to the borehole casing between 5 and 16 ft. The SF2 values are generally consistent with the trend of the CsSF1 values along this interval. The CsSF1 values indicate isolated areas at 18, 20, and 23.5 ft where the ^{137}Cs contamination is probably fixed to the borehole casing. Because the concentrations of ^{137}Cs change rapidly with depth from 5 to 20 ft, the shape factor analysis for this interval should be considered tentative. Although somewhat inconclusive, the shape factors indicate that the ^{137}Cs contamination is mainly localized to the borehole casing between 27.5 and 38 ft. The CsSF1 values suggest that the zone of elevated ^{137}Cs contamination between 48 and 63 ft is generally distributed uniformly in the formation. However, the shape factors indicate that the ^{137}Cs contamination is fixed to the borehole casing at a depth of 53 ft. The shape factor results indicate that the ^{137}Cs contamination detected at the bottom of the borehole is distributed on both the inside and outside of the borehole casing. However, further research is required to verify the shape factor indications in this situation.

Shape factor analysis was not used to determine the distribution of the ^{60}Co contamination because the count rates were below the lower limits required to produce CoSF1 results.

The zone of ^{137}Cs contamination detected between 1 and 3.5 ft may have resulted from a large surface spill that migrated down into the backfill surrounding the borehole. Most of the ^{137}Cs contamination detected below this zone was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing. This interpretation is supported by the shape factor analysis results. The results indicate that the uppermost portion of this contamination is mainly distributed uniformly in the formation, but the lower portion becomes progressively more localized to the borehole casing with depth.

The zone of ^{137}Cs contamination from 48 to 63 ft may have originated from a surface spill or subsurface leak that migrated along the outside of the tank to the base of the tank footing, where it then preferentially migrated downward and laterally through the native sediments below the tank farm excavation. The shape factor analysis results indicate that the majority of the contamination within this region is uniformly distributed in the formation. The ^{137}Cs contamination detected below 63 ft was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing.

The shape factor analysis suggests that the zone of increasing ^{137}Cs contamination at the bottom of the logged interval may be the result of contamination that adhered to the bottom of the borehole casing during drilling, or may be caused by the accumulation of particulate contamination that later fell down the inside of the borehole.

The zone of intermittent ^{60}Co contamination detected between 53 ft and the bottom of the logged interval probably represents the remnant of a plume that resulted from a remote subsurface source, such as a tank or cascade-line leak. The contamination may represent the distal edge of the extensive ^{60}Co plume detected in borehole 30-08-02.

4.8 Borehole 30-09-11

Borehole 30-09-11 is located approximately 6 ft from the northwest side of tank C-109. It was given the Hanford Site designation 299-E27-100. This borehole was drilled in July 1974 to a depth of 100 ft using 6-in. casing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) does not indicate that the borehole was grouted or perforated. The top of the casing, which is the zero depth reference for the SGLS, is approximately flush with the ground surface. The total logging depth achieved by the SGLS was 98.5 ft.

The man-made radionuclide ^{137}Cs was detected in this borehole. A shallow subsurface zone of continuous ^{137}Cs contamination was detected at low concentrations from the ground surface to a depth of 15.5 ft. The measured concentrations of ^{137}Cs ranged from 1 to 4 pCi/g between 1 and 13 ft. Continuous zones of low ^{137}Cs contamination were detected from 44.5 to 47.5 ft and from 93.5 ft to the bottom of the logged interval (98.5 ft). Isolated occurrences of low ^{137}Cs contamination were detected between 16.5 and 41 ft and at 66.5 ft. The highest concentration of ^{137}Cs (19 pCi/g) was detected at the ground surface; however, this is not an accurate concentration measurement because the source-to-detector geometry at the top of the borehole differs from the source-to-detector geometry used during calibration.

The ^{40}K concentration values increase at 41 ft, remain elevated to a depth of 78 ft, and gradually increase from 78 ft to the bottom of the logged interval. Although a drilling log was not available to support or contradict the KUT data, the increase in the ^{40}K concentrations at 41 ft probably represents a change in lithology from backfill material to the undisturbed gravel-dominated facies of the Hanford formation. The increase in the ^{40}K concentration values at 78 ft may represent the contact between the gravel- and sand-dominated facies of the Hanford formation.

The SGLS total gamma-ray plot reflects the distribution of the ^{137}Cs contamination around the upper and lower portions of this borehole and the variations in the naturally occurring radionuclides along the intervals where man-made radionuclides are absent or present in trace amounts. The total count rate increase at 40.5 ft corresponds with increases in the ^{40}K and ^{238}U concentration values at this depth. The gradual count rate increase below 78 ft corresponds to the gradual increase in the ^{40}K concentrations in this region. The total count rate peaks at 86.5 ft, corresponding with peaks in the ^{238}U and ^{232}Th concentrations at this depth.

The historical gross gamma log data from 1975 to 1994 were reviewed. The most recent historical gross gamma data are presented on the combination plot. No zones of anomalous gamma-ray activity were identified on any of the historical logs.

Summaries of the historical gross gamma log data from 1974 to 1987, included in Welty (1988), do not identify any zones of anomalous gamma-ray activity.

Plots of the spectrum shape factors are included in Appendix A. The shape factor results indicate that the ^{137}Cs contamination detected from 3 to 6 ft is probably localized to the borehole casing. The CsSF1 values indicate that the ^{137}Cs contamination detected from 7.5 to 13 ft is distributed in the backfill material. Because the ^{137}Cs concentrations change rapidly with depth from 11 to 13 ft, the shape factor analysis for this interval should be considered inconclusive. Although somewhat inconclusive, the shape factors indicate a thin layer of uniformly distributed ^{137}Cs contamination at 46.5 ft. The CsSF1 values indicate that the ^{137}Cs contamination detected at the bottom of the borehole may be distributed on the inside and the outside of the borehole casing. However, further research is required to verify the shape factor indications in this situation.

The near-surface zone of ^{137}Cs contamination (0 to 2 ft) probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The zone of slightly increased

^{137}Cs contamination between 7 and 13 ft may represent surface contamination that has remobilized and migrated along the surface of the tank dome into this region of the vadose zone. The shape factor analysis results indicate that most of the contamination detected within these zones is distributed uniformly in the formation. The shape factors also identify an isolated area of ^{137}Cs contamination that is localized to the borehole casing, suggesting that the near-surface contamination adhered to the borehole casing and was carried downward as the borehole was advanced or later migrated down along the outside of the borehole casing.

The zone of ^{137}Cs contamination from 45 to 47 ft may have originated from a subsurface leak or a surface spill that migrated along the outside of the tank to the base of the tank footing, where it then preferentially migrated both downward and laterally through the native sediments below the tank farm excavation. The shape factor analysis results indicate that this contamination is uniformly distributed in the formation as a thin contaminant layer.

The shape factor analysis suggests that the zone of increasing ^{137}Cs contamination at the bottom of the logged interval may be the result of contamination that adhered to the bottom of the borehole casing during drilling, or it may be caused by the accumulation of particulate contamination that later fell down the inside of the borehole.

5.0 Discussion of Results

Figure 3 presents a correlation plot of the man-made radionuclide concentration profiles for the eight boreholes surrounding tank C-109 The man-made radionuclides ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{235}U were detected by the SGLS.

The SGLS detected moderate to high concentrations of ^{137}Cs at the ground surface in all the boreholes. Isolated occurrences of ^{235}U were detected at the ground surface in boreholes 30-06-10 and 30-09-06. A single occurrence of ^{154}Eu was also detected at the ground surface in borehole 30-06-10. The source of this contamination is probably direct gamma radiation from nearby contaminated equipment or contamination that is localized to the ground surface. As described in Section 2.1, the concentration values calculated at the ground surface are not considered accurate because the source-to-detector geometry at the top of the borehole casing differs from the source-to-detector geometry used in the calibration. As a result, the ^{137}Cs, ^{235}U, and ^{154}Eu concentration values detected at the ground surface using the SGLS are probably higher than the actual concentration levels of these radionuclides.

The SGLS detected near-surface and shallow subsurface ^{137}Cs contamination around all the boreholes. This contamination could have resulted from surface spills, airborne contamination releases, or a combination of these. The contamination may have migrated, in some undetermined manner, down around the outside of the boreholes. It is also possible that the contamination has been driven downward into the backfill material by precipitation infiltration. This interpretation is supported by the shape factor analysis results, which indicate that most of the shallow ^{137}Cs contamination detected around the majority of the boreholes occurs as layers of

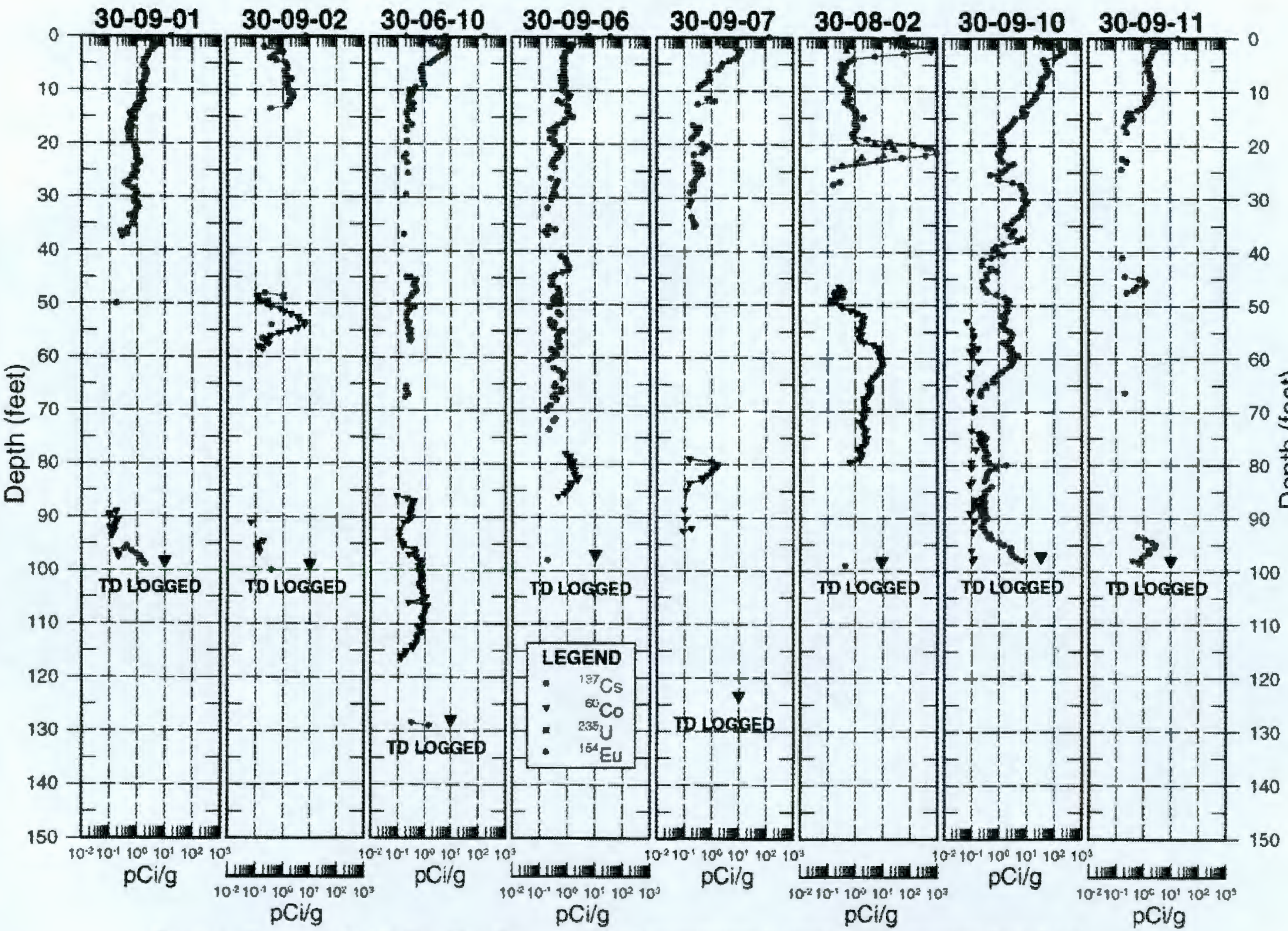

Figure 3. Correlation Plot of ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{235}U Concentrations in Boreholes Surrounding Tank C-109

uniformly distributed contamination that have migrated as deep as 15 ft. However, the shape factors also identified several isolated areas of ^{137}Cs contamination that may be localized to the borehole casings. If the contamination detected around the upper portions of the boreholes was carried down during drilling or later migrated downward along the borehole casings or the outside of the tank wall, then the total contamination in the vadose zone is minor. If the contamination has migrated downward into the backfill material, then the volume of contaminated material is large and is a significant portion of the overall contamination in the vadose zone around this tank.

The near-surface zone of high ^{137}Cs contamination detected around borehole 30-08-02 probably resulted from a surface spill. Historical gross gamma log data indicate that the spill occurred sometime between January 1982 and June 1984. It appears that the majority of the ^{137}Cs contamination was deposited in the upper 5 ft of the backfill material surrounding the borehole. Similar contaminated zones, albeit at lower concentrations, were detected in boreholes 30-09-07 and 30-09-10. The data indicate that although the surface spill was concentrated in the area near borehole 30-08-02, it probably spread over an area of about 100 ft in length between tanks C-108 and C-109. The shape factor analysis results support this interpretation by indicating that the near-surface ^{137}Cs contamination is uniformly distributed in the formation.

The shape factor analysis results indicate the presence of isolated zones of uniformly distributed ^{137}Cs contamination between 7 and 17 ft in boreholes 30-08-02 and 30-09-11. This contamination may represent surface contamination that has been remobilized by infiltrating meteoric water and migrated laterally along the surface of the tank dome into these regions of the backfill material.

The distinct zone of ^{137}Cs and ^{154}Eu contamination detected around borehole 30-08-02 between 19 and 23.5 ft may be the result of a leak from the C-108-to-C-109 cascade line. However, the discrete nature of the contaminated zone suggests that this borehole is located very close to this cascade line and may indicate direct detection of the line itself. As discussed in Section 3.2, the cascade line became plugged in 1952. Consequently, the ^{137}Cs and ^{154}Eu contamination detected may consist of residual waste contained within the cascade piping. The shape factor analysis data indicate that this contamination occurs as a thin source that is remote to the borehole, supporting the theory that it may be isolated to the region along the inside of the pipeline.

The zones of elevated ^{137}Cs contamination detected below the base of the tank farm excavation around boreholes 30-09-02, 30-06-10, 30-09-06, 30-08-02, 30-09-10, and 30-09-11 may have originated from a surface spill or a subsurface leak. It is possible that the ^{137}Cs contamination traveled from the leak source down along the outside of tank C-109, spread horizontally along the base of the tank, and then preferentially migrated both downward and laterally through the native sediments below the tank farm excavation into regions near these boreholes. The shape factor analysis data indicate that most of the contamination is uniformly distributed in the formation as layers around or proximal to the borehole casings.

The zones of ^{60}Co contamination that underlie the base of the tank farm excavation around all the boreholes, except 30-09-11, could have originated from a leak from any of the tanks in the vicinity, including tank C-109. Where applicable, the shape factor analysis results indicate that the ^{60}Co contamination is distributed in the formation around these boreholes and is not confined to the vicinity of the borehole casings, suggesting that the ^{60}Co contamination has migrated a considerable distance both downward and laterally through the vadose zone and may be related to the same contaminant source. In boreholes 30-09-02, 30-09-07, and 30-08-02, the rate of decrease of the gamma-ray intensity indicated by the historical gross gamma logs suggests that other short-lived radionuclides, such as ^{106}Ru or ^{125}Sb, may have initially coexisted with the ^{60}Co contamination but have since decayed to levels below the detection limit of the SGLS.

The comparison of the 1993 RLS and 1997 SGLS data collected from borehole 30-06-10 shows good repeatability of the ^{137}Cs distribution in the upper region of the borehole. The shapes of the RLS and SGLS ^{137}Cs profiles between the ground surface and 10 ft were very similar, suggesting that the ^{137}Cs contamination in this region is not actively mobile and has remained fixed in the vadose zone since 1993. The RLS and SGLS data also indicate that a large plume of ^{60}Co contamination extends from 85 to 117 ft. Between 1993 and 1997, the concentrations of ^{60}Co have decreased within the upper and middle regions of the plume, illustrating the radioactive decay of the ^{60}Co contamination in these areas. The data also indicate that since 1993, downward migration of the ^{60}Co has occurred in the lower region of the plume or additional ^{60}Co has migrated into the region below 110 ft. This comparison shows that the ^{60}Co contamination has not been stable between 1993 and 1997.

6.0 Conclusions

The characterization of the gamma-ray-emitting contamination in the vadose zone surrounding tank C-109 was completed using the SGLS. The data obtained using the SGLS and the geologic and historical information available from other sources do not identify any large active leaks from tank C-109. However, the data do indicate the following.

- Shallow ^{137}Cs contamination resulting from surface spills is distributed in the backfill material around the tank.

- Zones of elevated ^{137}Cs contamination are distributed in the formation below the base of the tank farm excavation.

- Extensive ^{60}Co contamination exists at considerable depth below the majority of the ^{137}Cs contamination; the source of this contamination is unknown.

- Areas of ^{60}Co contamination are continuing to migrate through the vadose zone.

7.0 Recommendations

Tank C-109 is currently listed as containing approximately of 62,000 gal of sludge, 4,000 gal of supernate, and no interstitial liquid (Hanlon 1997). Continued monitoring of the boreholes surrounding this tank is recommended to identify changes in the distribution of the contaminant plumes identified within the vadose zone. Because the lithology appears to play an important role in the radionuclide distribution beneath this tank, especially for ^{60}Co, further lithologic characterization is recommended by logging a few of the boreholes using a long counting time or a very high efficiency system. This system can properly define the individual natural radionuclide concentrations and, thus, better characterize site-specific geology.

The intervals where anomalous historical gross gamma-ray activity occurred around boreholes 30-09-02, 30-09-07, and 30-08-02 should be relogged using a long counting time. This work might identify the remnants of other short-lived man-made radionuclides that may occur.

8.0 References

Agnew, S.F., 1995. *Hanford Defined Wastes: Chemical and Radionuclide Compositions,* LA-UR-94-2657, Rev. 2, Los Alamos National Laboratory, Los Alamos, New Mexico.

__________, 1996. *Waste Status and Transaction Record Summary for the Northeast Quadrant of the Hanford 200 Area,* WHC-SD-WM-TI-614, Rev. 1, prepared by Los Alamos National Laboratory for the U.S. Department of Energy, Richland, Washington.

__________, 1997a. *Hanford Tank Chemical and Radionuclide Inventories: HDW Model Rev. 4,* LA-UR-96-3860, Los Alamos National Laboratory, Los Alamos, New Mexico.

__________, 1997b. Personal communication with J.R. Brodeur.

Anderson, J.D., 1990. *A History of the 200 Area Tank Farms,* WHC-MR-0132, Westinghouse Hanford Company, Richland, Washington.

Baker, U.R., B.N. Bjornstad, A.J. Busacca, K.R. Fecht, E.P. Kiver, U.L. Moody, J.G. Rigby, O.F. Stradling, and A.M. Tallman, 1991. "Quaternary Geology of the Columbia Plateau," in *Quaternary Non-Glacial Geology: Coterminous U.S., Boulder, Colorado, GSA, The Geology of North America,* Vol. K-2, edited by R.B. Moerrison.

Brevick, C.H., L.A. Gaddis, and E.D. Johnson, 1994a. *Historical Tank Content Estimate for the Southwest Quadrant of the Hanford 200 West Area,* WHC-SD-WM-ER-352, Westinghouse Hanford Company, Richland, Washington.

__________, 1994b. *Supporting Document for the Historical Tank Content Estimate for C Tank Farm,* WHC-SD-WM-ER-313, Westinghouse Hanford Company, Richland, Washington.

Brodeur, J.R., 1993. *Assessment of Unsaturated Zone Radionuclide Contamination Around Single-Shell Tanks 241-C-105 and 241-C-106*, WHC-SD-EN-TI-185, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J.A., and S.M. Goodwin, 1991. *Interim Status Groundwater Monitoring Plan for the Single-Shell Tanks*, WHC-SD-EN-AP-012, Westinghouse Hanford Company, Richland, Washington.

Chamness, M.A., and J.K. Merz, 1993. *Hanford Wells*, PNL-8800, prepared by Pacific Northwest Laboratory for the U.S. Department of Energy, Richland, Washington.

Fayer, M.J., and T.B. Walters, 1995. *Estimated Recharge Rates at the Hanford Site*, PNL-10285, Pacific Northwest Laboratory, Richland, Washington.

Hanlon, B.M., 1997. *Waste Tank Summary Report for Month Ending February 28, 1997*, HNF-EP-0182-107, Lockheed Martin Hanford Corporation, Richland, Washington.

Jensen, H.F., 1976. Occurrence Report, Subject: "Liquid Level Decrease in Tank 109-C," 76-14, Atlantic Richfield Hanford Company, Richland, Washington.

Lindsey, K.A., 1992. *Geologic Setting of the 200 East Area; An Update*, WHC-SD-EN-TI-012, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

__________, 1993. Memorandum to G.D. Bazinet with attached letter report *Geohydrologic Setting, Flow, and Transport Parameters for the Single Shell Tank Farms*, written by K.A. Lindsey and A. Law, 81231-93-060, Westinghouse Hanford Company, Richland, Washington.

__________, 1995. *Miocene to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*, BHI-00184, Bechtel Hanford, Inc., Richland, Washington.

Pacific Northwest National Laboratory (PNNL), 1997. *Hanford Site Groundwater Monitoring for Fiscal Year 1996*, PNNL-11470, Pacific Northwest Laboratory, Richland, Washington.

Price, W.H., and K.R. Fecht, 1976. *Geology of the 241-C Tank Farm*, ARH-LD-132, Atlantic Richfield Hanford Company, Richland, Washington.

Prince, J.K., 1982. Occurrence Report, Subject: "Radiation Peak in Drywell No. 30-09-06 Exceeding the Increase Criterion," 82-01, Rockwell Hanford Operations, Richland, Washington.

U.S. Department of Energy (DOE), 1993. *200 East Groundwater Aggregate Area Management Study Report*, DOE/RL-92-19, Richland, Washington.

U.S. Department of Energy (DOE), 1995a. *Vadose Zone Characterization Project at the Hanford Tank Farms, Calibration of Two Spectral Gamma-Ray Logging Systems for Baseline Characterization Measurements in the Hanford Tank Farms*, GJPO-HAN-1, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1995b. *Vadose Zone Characterization Project at the Hanford Tank Farms, Project Management Plan*, P-GJPO-1780, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1995c. *Vadose Zone Characterization Project at the Hanford Tank Farms, Spectral Gamma-Ray Logging Characterization and Baseline Monitoring Plan for the Hanford Single-Shell Tanks*, P-GJPO-1786, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

__________, 1997a. *Hanford Tank Farms Vadose Zone, Data Analysis Manual*, MAC–VZCP 1.7.9, prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

__________, 1997b. *Hanford Tank Farms Vadose Zone, High-Resolution Passive Spectral Gamma-Ray Logging Procedures*, MAC–VZCP 1.7.10-2, Rev. 2, prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

__________, 1997c. *Hanford Tank Farms Vadose Zone, Third Biannual Recalibration of Two Spectral Gamma-Ray Logging Systems Used for Baseline Characterization Measurements in the Hanford Tank Farms*, GJO-HAN-13, prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

__________, 1997d. *Vadose Zone Characterization Project at the Hanford Tank Farms, Tank Summary Data Report for Tank C-105*, GJ-HAN-83, prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

__________, 1997e. *Vadose Zone Characterization Project at the Hanford Tank Farms, Tank Summary Data Report for Tank C-106*, GJ-HAN-84, prepared by MACTEC-ERS for the Grand Junction Office, Grand Junction, Colorado.

Welty, R.K., 1988. *Waste Storage Tank Status and Leak Detection Criteria*, SD-WM-TI-356, Westinghouse Hanford Company, Richland, Washington.

Wilson, R.D., 1997. *Spectrum Shape-Analysis Techniques Applied to the Hanford Tank Farms Spectral Gamma Logs*, GJO-HAN-7, prepared by MACTEC-ERS for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Appendix A
Spectral Gamma-Ray Logs for Boreholes in the Vicinity of Tank C-109

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Log Event A

Borehole 30-09-01

Borehole Information

Farm : C	Tank : C-109	Site Number : 299-E27-96
N-Coord : 43,048	W-Coord : 48,313	TOC Elevation : 644.85
Water Level, ft : None	Date Drilled : 7/31/74	

Casing Record

Type : Steel-welded	Thickness : 0.280	ID, in. : 6
Top Depth, ft. : 0	Bottom Depth, ft. : 100	

Borehole Notes:
This borehole was drilled in July 1974 and completed to a depth of 100 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero reference for the SGLS, is approximately flush with the ground surface.

Equipment Information

Logging System : 1B	Detector Type : HPGe	Detector Efficiency : 35.0 %
Calibration Date : 2/97	Calibration Reference : GJO-HAN-14	Logging Procedure : P-GJPO-1783

Log Run Information

Log Run Number : 1	Log Run Date : 3/27/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 99.0	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 31.0	MSA Interval, ft. : 0.5	Log Speed, ft/min.: n/a	

Log Run Number : 2	Log Run Date : 3/28/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 0.0	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 32.0	MSA Interval, ft. : 0.5	Log Speed, ft/min.: n/a	

Analysis Information

Analyst : E. Larsen

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/30/97

Analysis Notes :

This borehole was logged by the SGLS in two log runs. The pre-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency, but the post-survey field verification spectra for logging run two failed to meet the acceptance criteria. The energy calibration and peak-shape calibration from the pre-survey field verification spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging runs.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The Cs-137 contamination was detected continuously from the ground surface to 37.5 ft and from 95.5 ft to the bottom of the logged interval (99 ft). A single occurrence of Cs-137 was detected at 50 ft. Co-60 contamination was detected continuously from 89 to 93.5 ft and 96.5 to 97.5 ft.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentrations increase gradually from 40 to 44.4 ft, increase sharply from 46.5 to 50 ft, and remain elevated to a depth of 75 ft. The K-40 concentrations gradually increase below 75 ft and are variable between 75 and 93.5 ft. Sharp increases in the U-238 and Th-232 values occur at 47.5 and 90.5 ft, respectively. Additional information and interpretations of log data are included in the main body of the Tank Summary Data Report for tank C-109.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

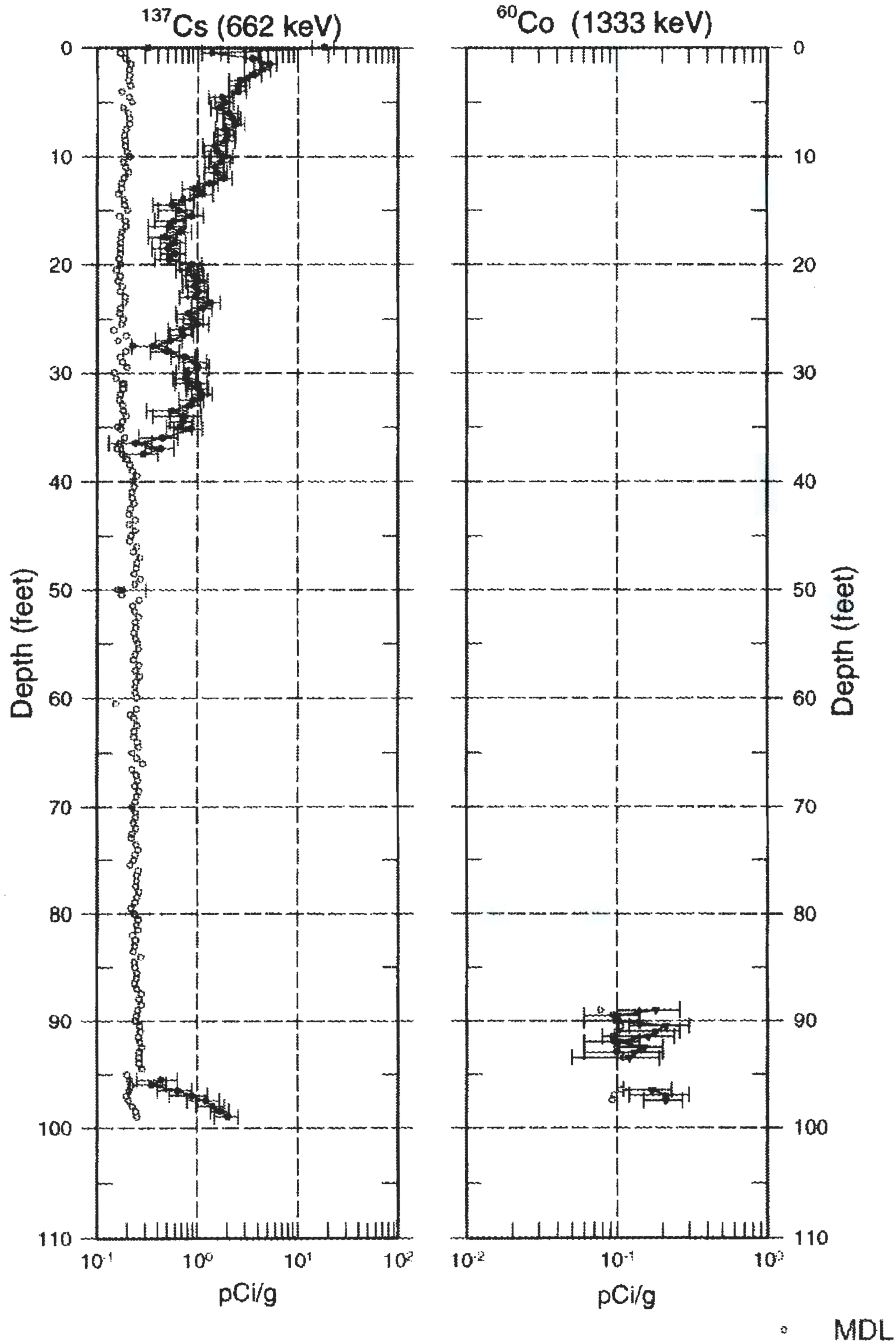
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

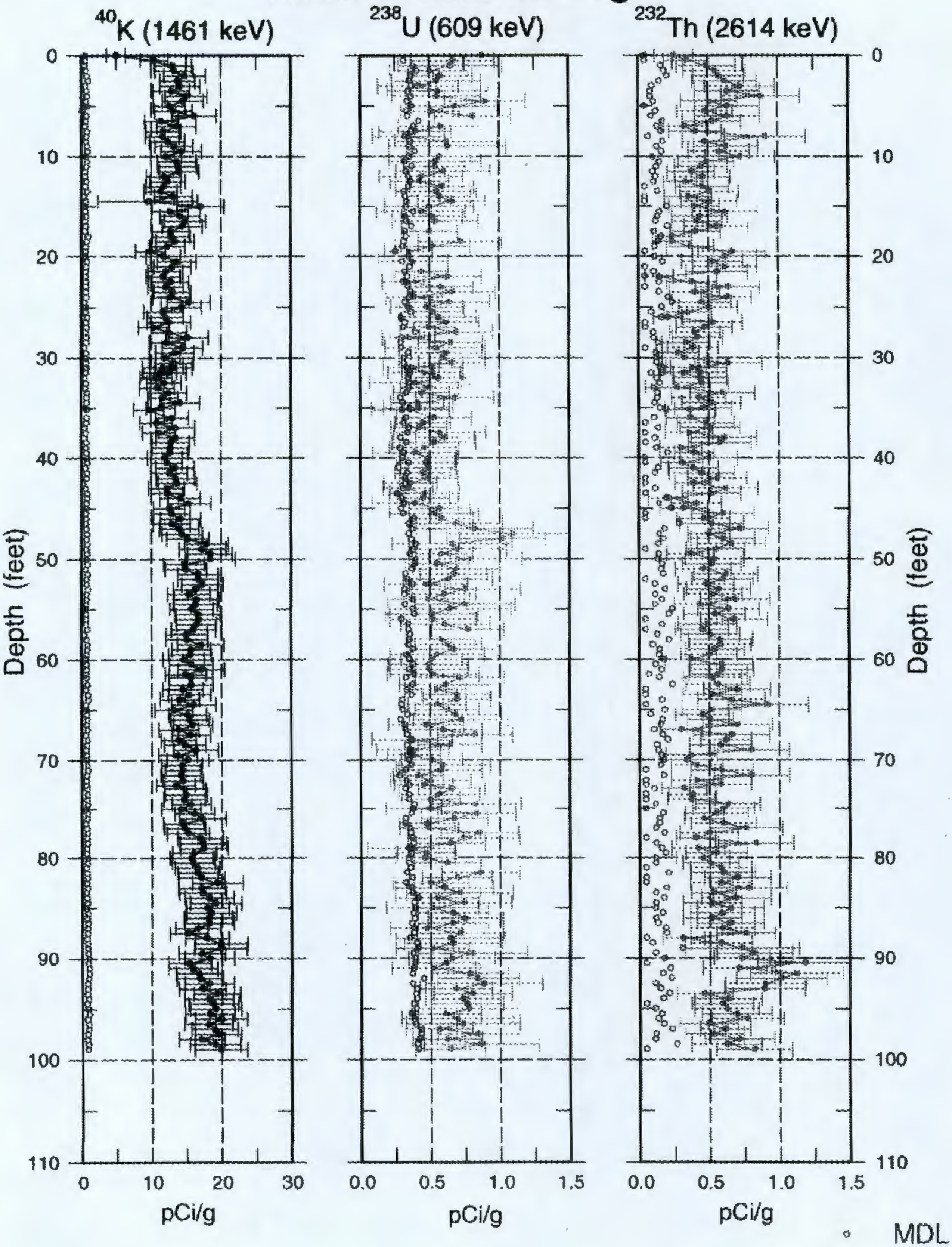
Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-09-01

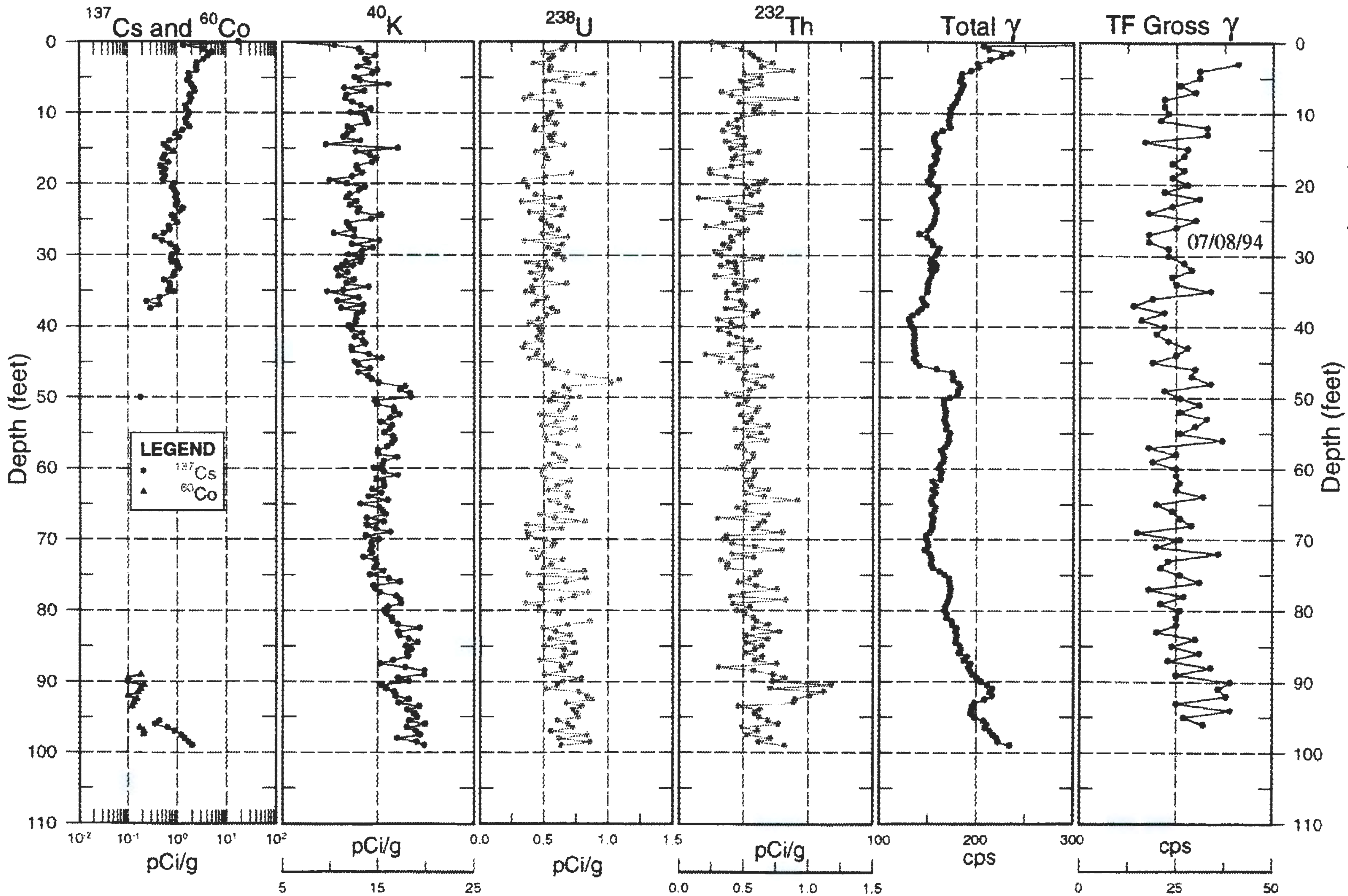
Man-Made Radionuclide Concentrations



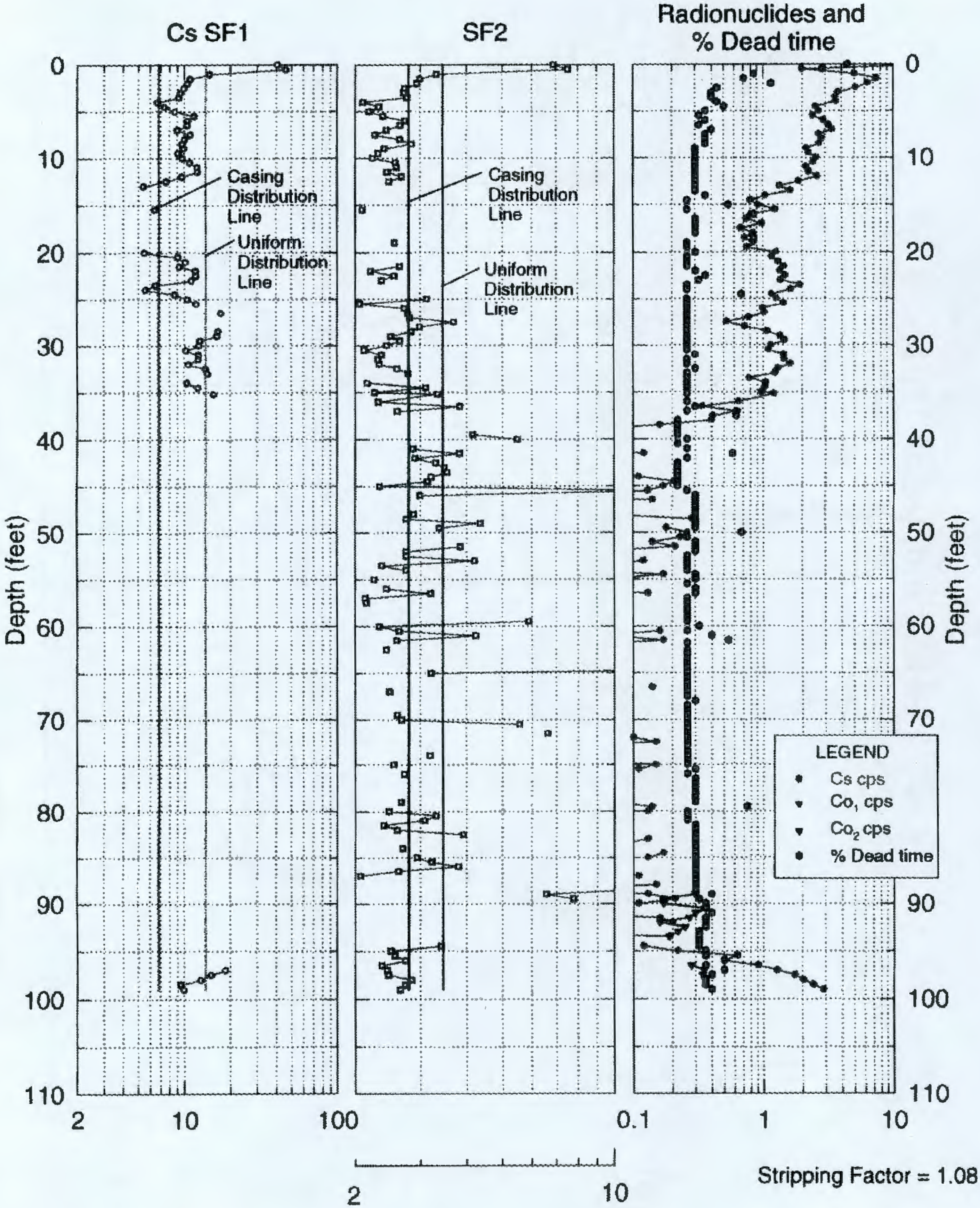
30-09-01
Natural Gamma Logs



30-09-01 Combination Plot



30-09-01 ^{137}Cs Shape Factor Analysis Plot



Stripping Factor = 1.08

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Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole 30-09-02

Borehole Information

Farm :	C	Tank :	C-109	Site Number :	299-E27-97
N-Coord :	43,023	W-Coord :	48,285	TOC Elevation :	645.17
Water Level, ft :	None	Date Drilled :	6/30/74		

Casing Record

Type :	Steel-welded	Thickness, in. :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	100		

Borehole Notes:

This borehole was drilled in June 1974 and completed to a depth of 100 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero reference for the SGLS, is approximately flush with the ground surface.

Equipment Information

Logging System :	1B	Detector Type :	HPGe	Detector Efficiency :	35.0 %
Calibration Date :	2/97	Calibration Reference :	GJO-HAN-14	Logging Procedure :	P-GJPO-1783

Log Run Information

Log Run Number :	1	Log Run Date :	3/28/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	100.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	49.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	3/31/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	50.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	20.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	3	Log Run Date :	3/31/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	21.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	12.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

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Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole # 30-09-02

Log Run Number :	4	**Log Run Date :**	4/1/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	13.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	0.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	5	**Log Run Date :**	4/1/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	60.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	40.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Analysis Information

Analyst :	E. Larsen		
Data Processing Reference :	MAC-VZCP 1.7.9	Analysis Date :	9/30/97

Analysis Notes :

This borehole was logged by the SGLS in five log runs. Four log runs were required to log the length of the borehole. A fifth log run was performed as an additional quality assurance check on a segment of one of the primary log runs.

The pre-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency, but the post-survey field verification spectra for logging runs one, four, and five failed to meet the acceptance criteria. The energy calibration and peak-shape calibration from the pre-survey field verification spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging runs.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The Cs-137 contamination was detected continuously from the ground surface to 13 ft and 48.5 to 49.5 ft. Isolated occurrences of Cs-137 were detected at 54, 55.5, and 56.5 ft and at the bottom of the logged interval (100 ft). The Co-60 contamination was detected continuously from 48.5 to 58.5 ft and 94.5 to 96.5 ft. A single occurrence of Co-60 was detected at 91 ft.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 and Co-60 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentrations values increase from 40.5 to 43 ft and increase again from about 49 to 50 ft. The K-40 concentrations remain elevated from 50 ft to a depth of about 70 ft. The K-40 concentration values increase slightly and become variable below 70 ft.

A sharp increase in the U-238 values occurs at about 50 ft. Most of the U-238 concentration data are absent between 53.5 and 56.5 ft.

Borehole 30-09-02

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Report for tank C-109.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

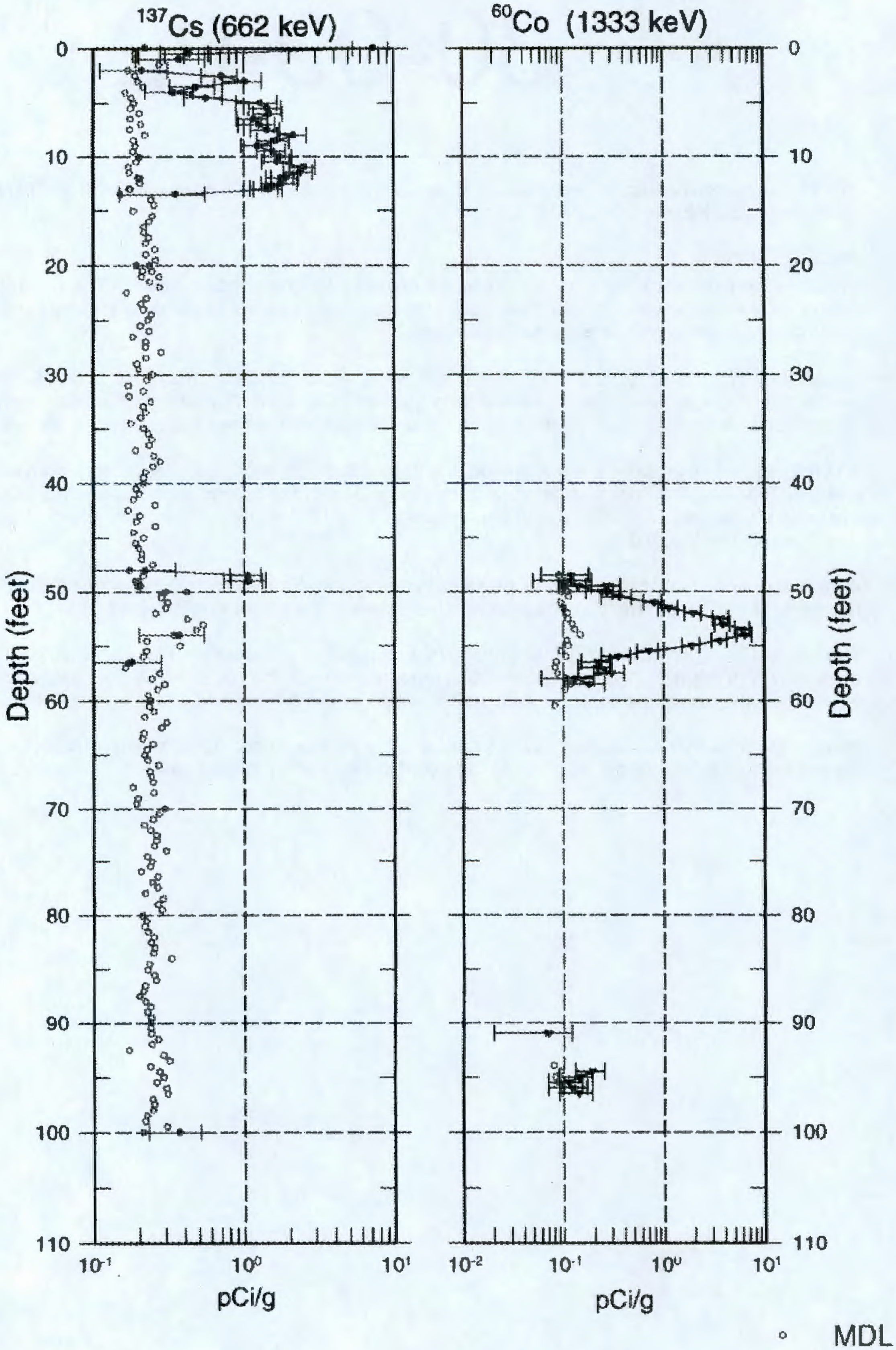
A time-sequence plot of the historical gross gamma log data from 1975 to 1994 is included. The headings of the plots identify the date on which the data in the plots were gathered.

The interval between 40 and 60 ft was relogged as a quality assurance measure to establish the repeatability of the radionuclide concentration measurements. The radionuclide concentrations shown were calculated using the separate data sets provided by the original and rerun logging runs.

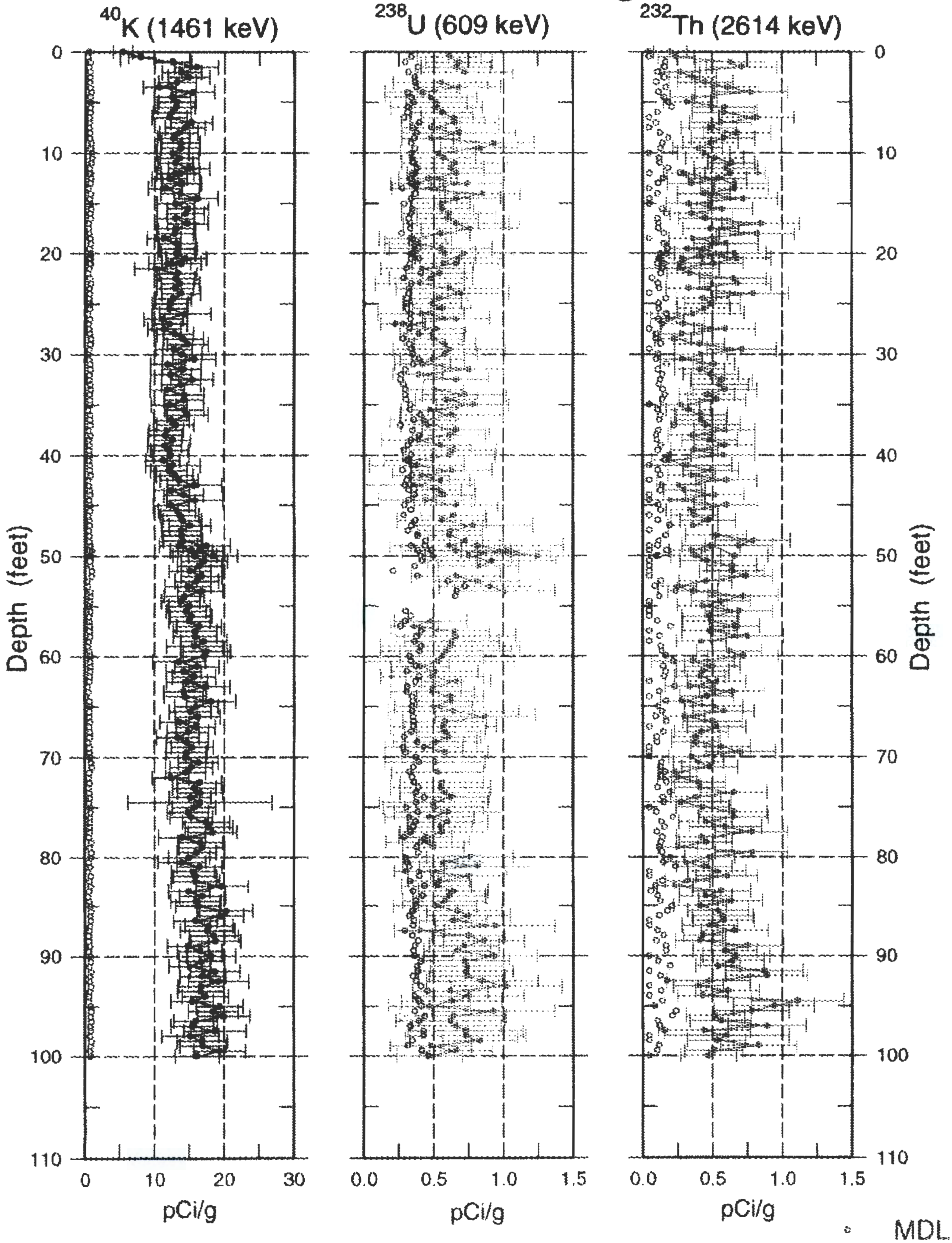
Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-09-02

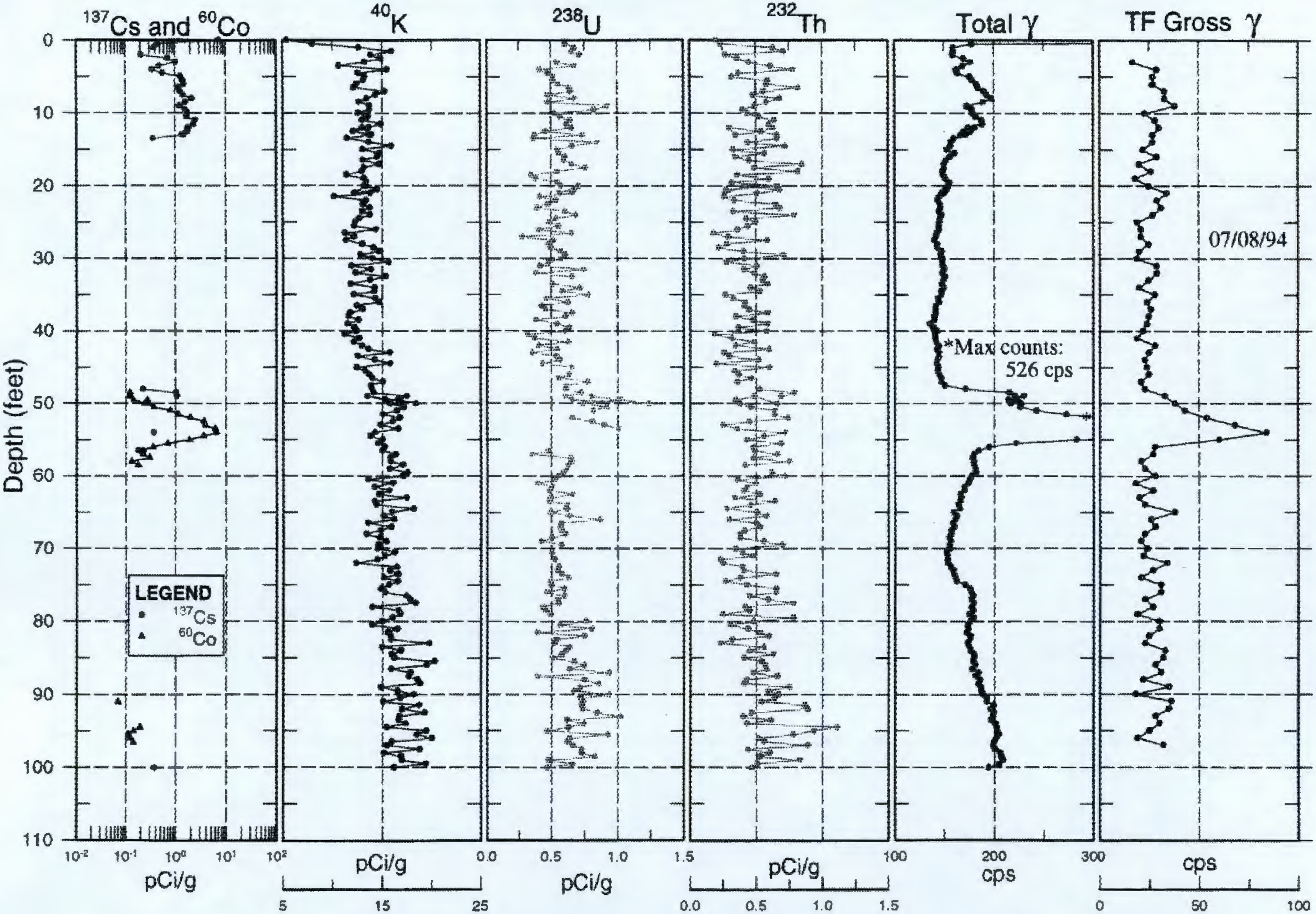
Man-Made Radionuclide Concentrations



30-09-02
Natural Gamma Logs

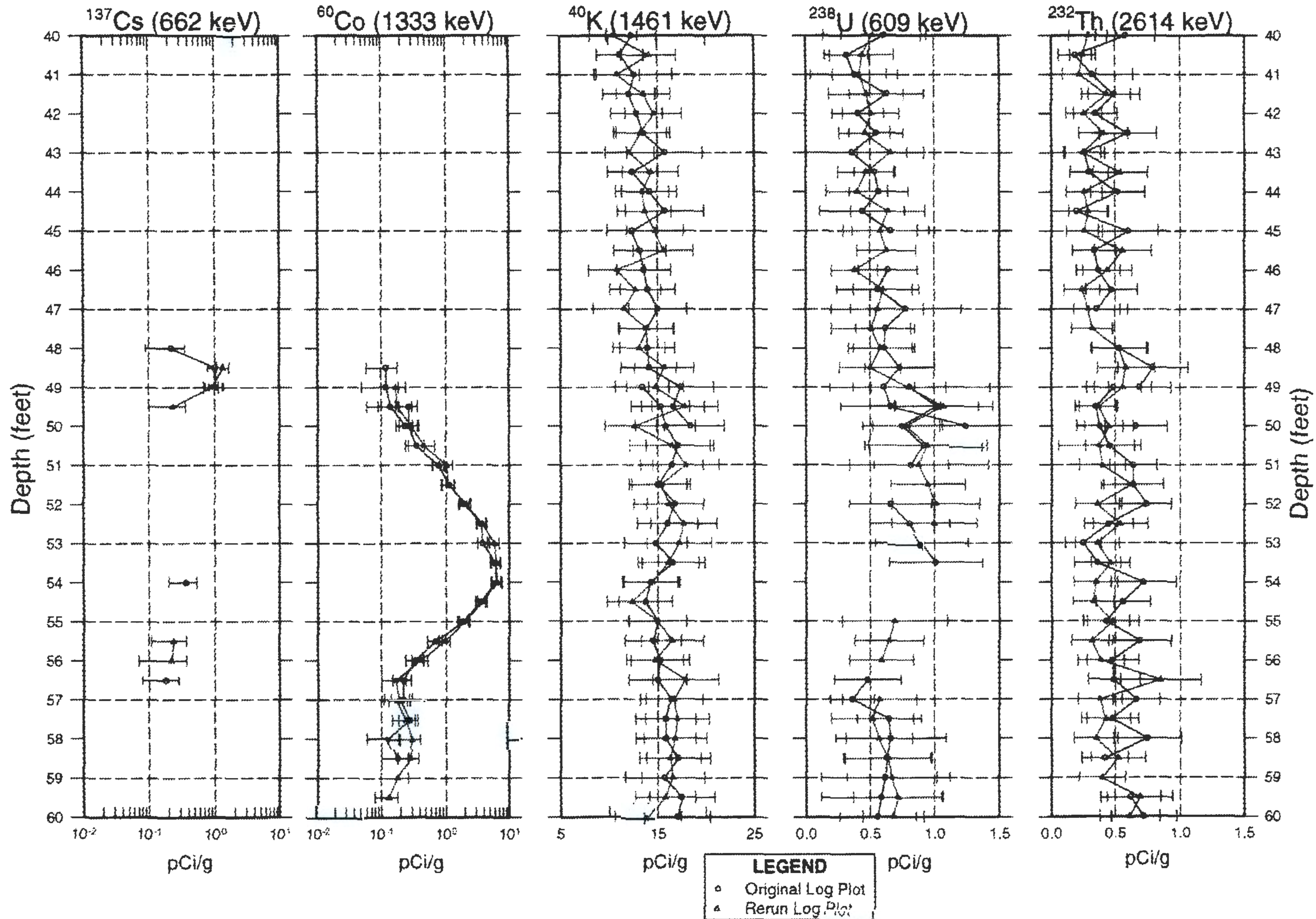


30-09-02 Combination Plot

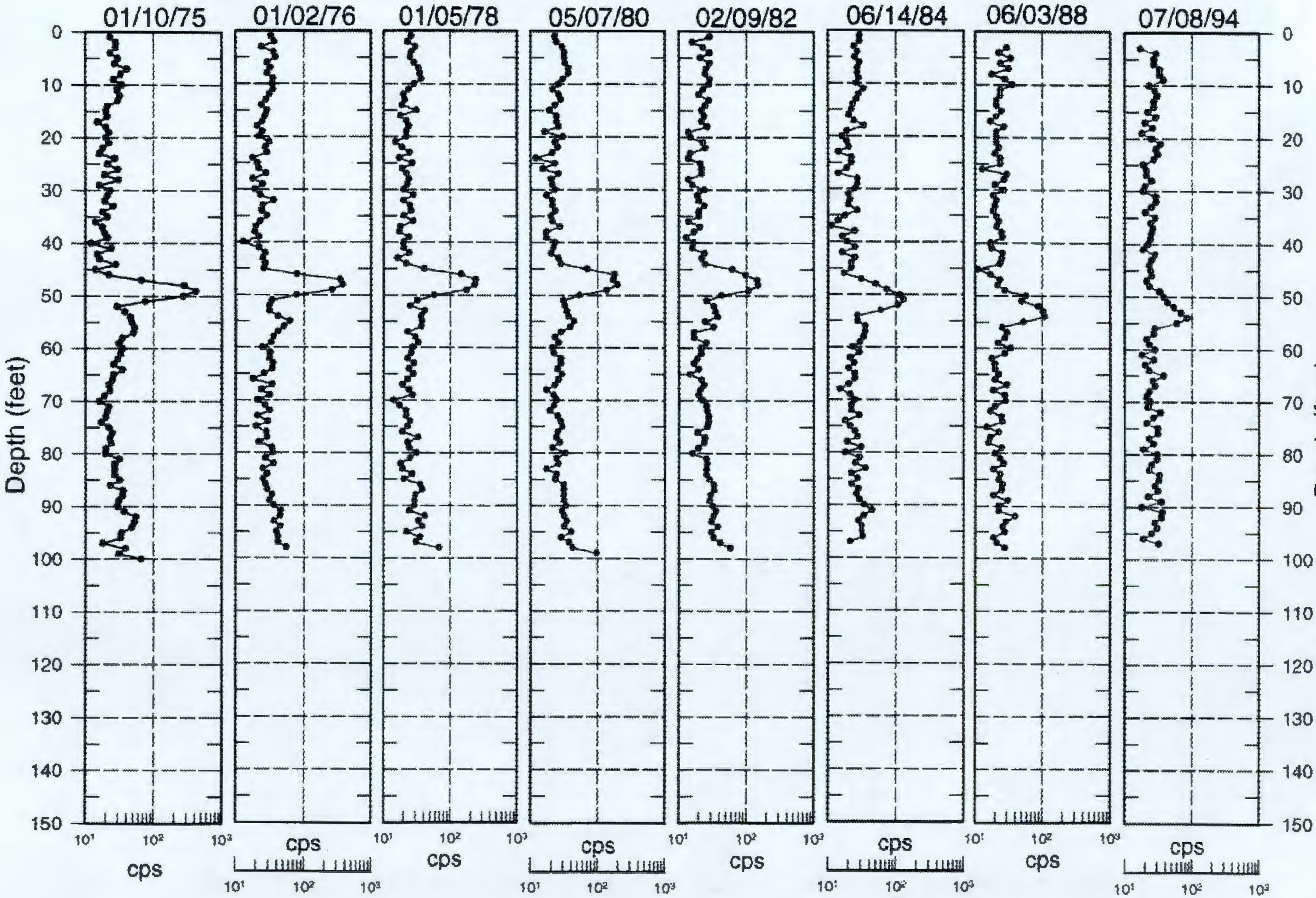


30-09-02

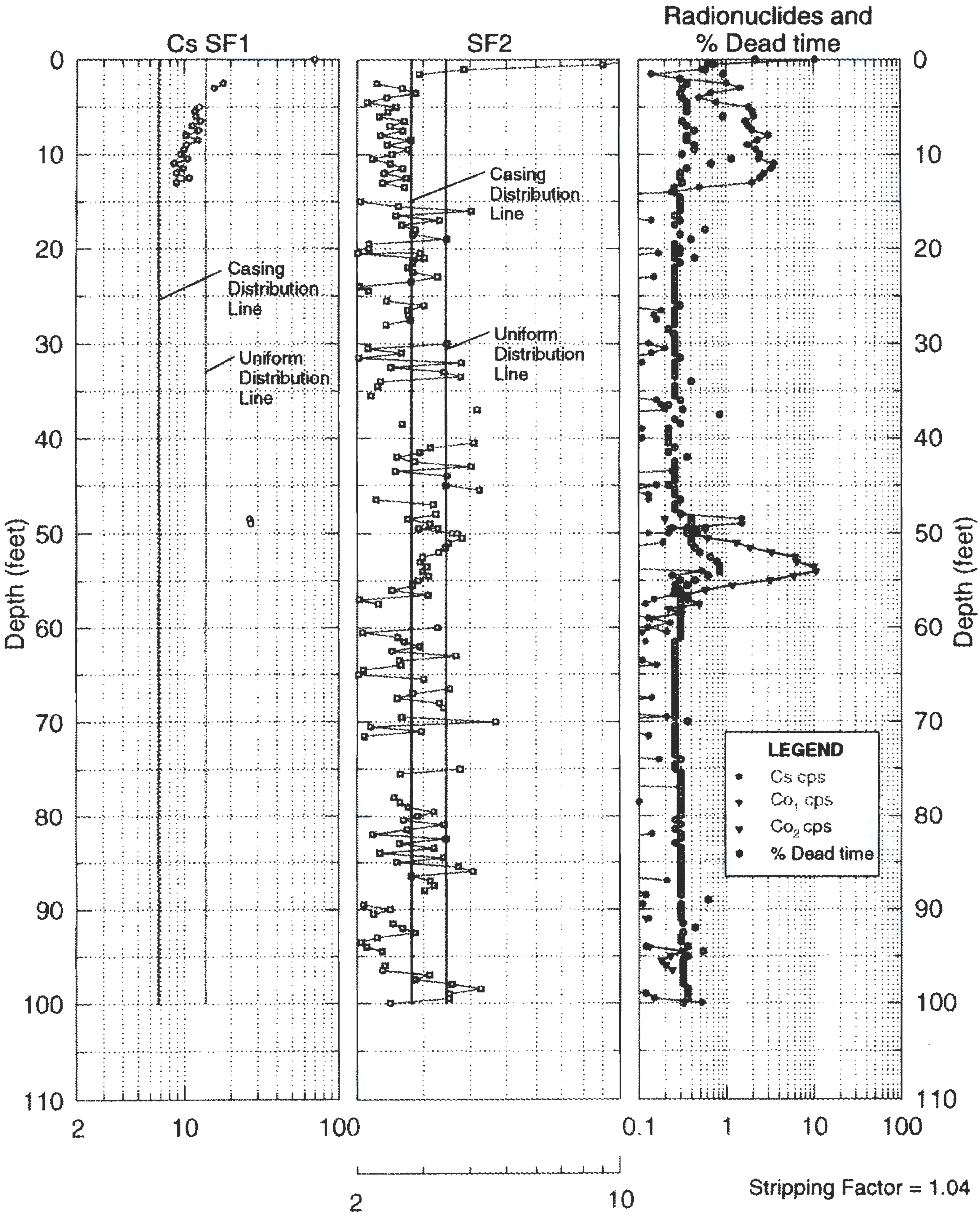
Rerun Section of the Man-Made and Natural Gamma Logs



Historical Gross Gamma Logs for Borehole 30-09-02



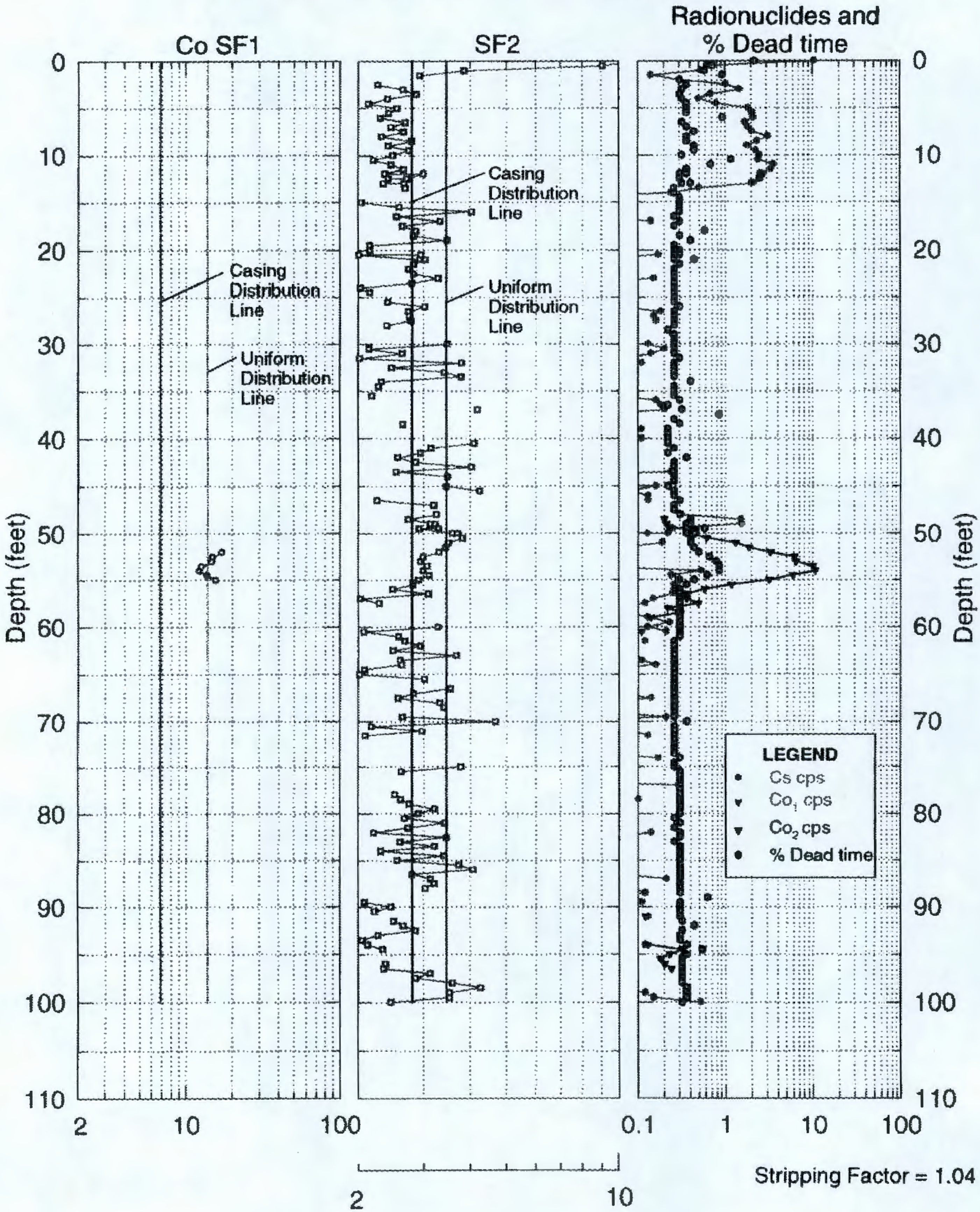
30-09-02
^{137}Cs Shape Factor Analysis Plot



Stripping Factor = 1.04

30-09-02

^{60}Co Shape Factor Analysis Plot



Log Event A

Borehole 30-06-10

Borehole Information

Farm :	C	Tank :	C-106	Site Number :	299-E27-71
N-Coord :	42,963	W-Coord :	48,291	TOC Elevation :	645.31
Water Level, ft :	None	Date Drilled :	11/30/72		

Casing Record

Type :	Steel-welded	Thickness, in. :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	130		

Borehole Notes:
This borehole was drilled in November 1972 to a depth of 130 ft using 6-in. casing. The drilling report does not indicate if the borehole casing was perforated or grouted. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. The top of the casing, which is the zero reference for the SGLS, is approximately flush with the ground surface.

Equipment Information

Logging System :	1	Detector Type :	HPGe	Detector Efficiency :	35.0 %
Calibration Date :	10/96	Calibration Reference :	GJO-HAN-13	Logging Procedure :	P-GJPO-1783

Log Run Information

Log Run Number :	1	Log Run Date :	1/29/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	0.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	11.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	1/30/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	10.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	24.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	3	Log Run Date :	1/30/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	23.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	36.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Event A

Borehole 30-06-10

Log Run Number : 4	**Log Run Date :** 1/31/97	**Logging Engineer:** Alan Pearson			
Start Depth, ft.: 129.0	**Counting Time, sec.:** 100	**L/R :** L	**Shield :** N		
Finish Depth, ft. : 45.0	**MSA Interval, ft. :** 0.5	**Log Speed, ft/min.:** n/a			

Log Run Number : 5	**Log Run Date :** 2/3/97	**Logging Engineer:** Alan Pearson			
Start Depth, ft.: 46.0	**Counting Time, sec.:** 100	**L/R :** L	**Shield :** N		
Finish Depth, ft. : 35.0	**MSA Interval, ft. :** 0.5	**Log Speed, ft/min.:** n/a			

Analysis Information

Analyst : E. Larsen

Data Processing Reference : P-GJPO-1787 Analysis Date : 5/16/97

Analysis Notes :

This borehole was logged by the SGLS in five log runs. The pre- and post-survey field verification spectra met the acceptance criteria established for the peak shape and detector efficiency, confirming that the SGLS was operating within specifications. The energy calibration and peak-shape calibration from these spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging operation.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137, Co-60, Eu-154, and U-235 were detected in this borehole. The presence of Cs-137 was measured continuously from the ground surface to a depth of 11 ft, 12 to 17 ft, 45 to 57 ft, 65.5 to 67.5 ft, and at the bottom of the logged interval (128.5 to 129 ft). Isolated concentrations of Cs-137 were detected between 19.5 and 37 ft. The presence of Co-60 was measured continuously from 86 to 116.5 ft. The presence of Eu-154 and U-235 was detected at the ground surface.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentration values increase at 42 ft. Elevated, slightly variable K-40 concentration values were detected from 42.5 to 77 ft. The K-40 concentrations increase at 77 ft, remain elevated to a depth of 122 ft, then decrease toward the bottom of the logged interval. A sharp decrease in the U-238 concentration values occurs at a depth of 36 ft. Decreased Th-232 concentration values occur from 119.5 ft to the bottom of the logged interval.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-102, C-106, and C-109.

Log Event A

Borehole 30-06-10

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

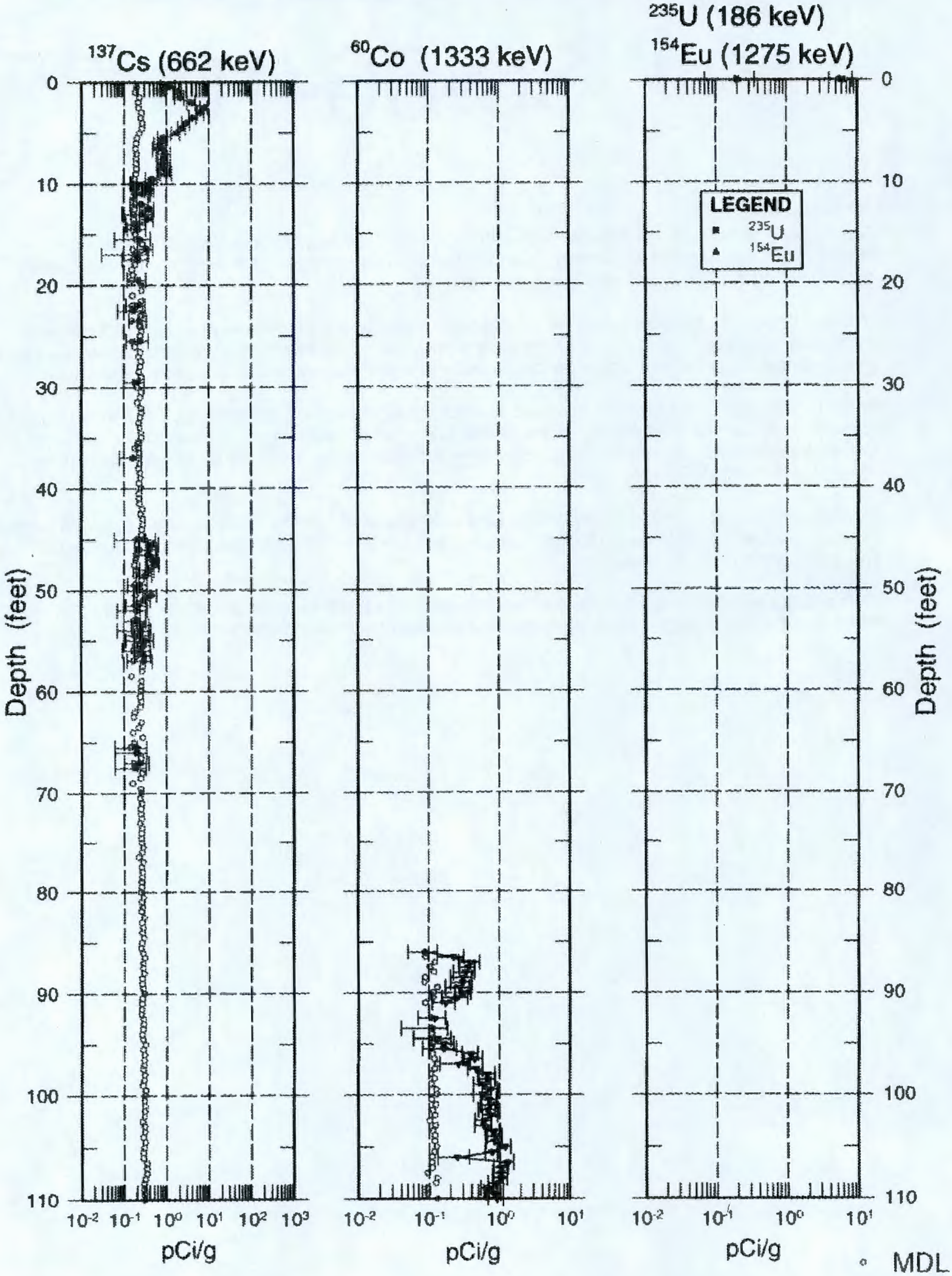
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

An additional log plot compares spectral gamma data collected with the Radionuclide Logging System (RLS) in 1993 with spectral gamma data collected with the SGLS in 1997. Uncertainty bars and MDLs are not included on these plots.

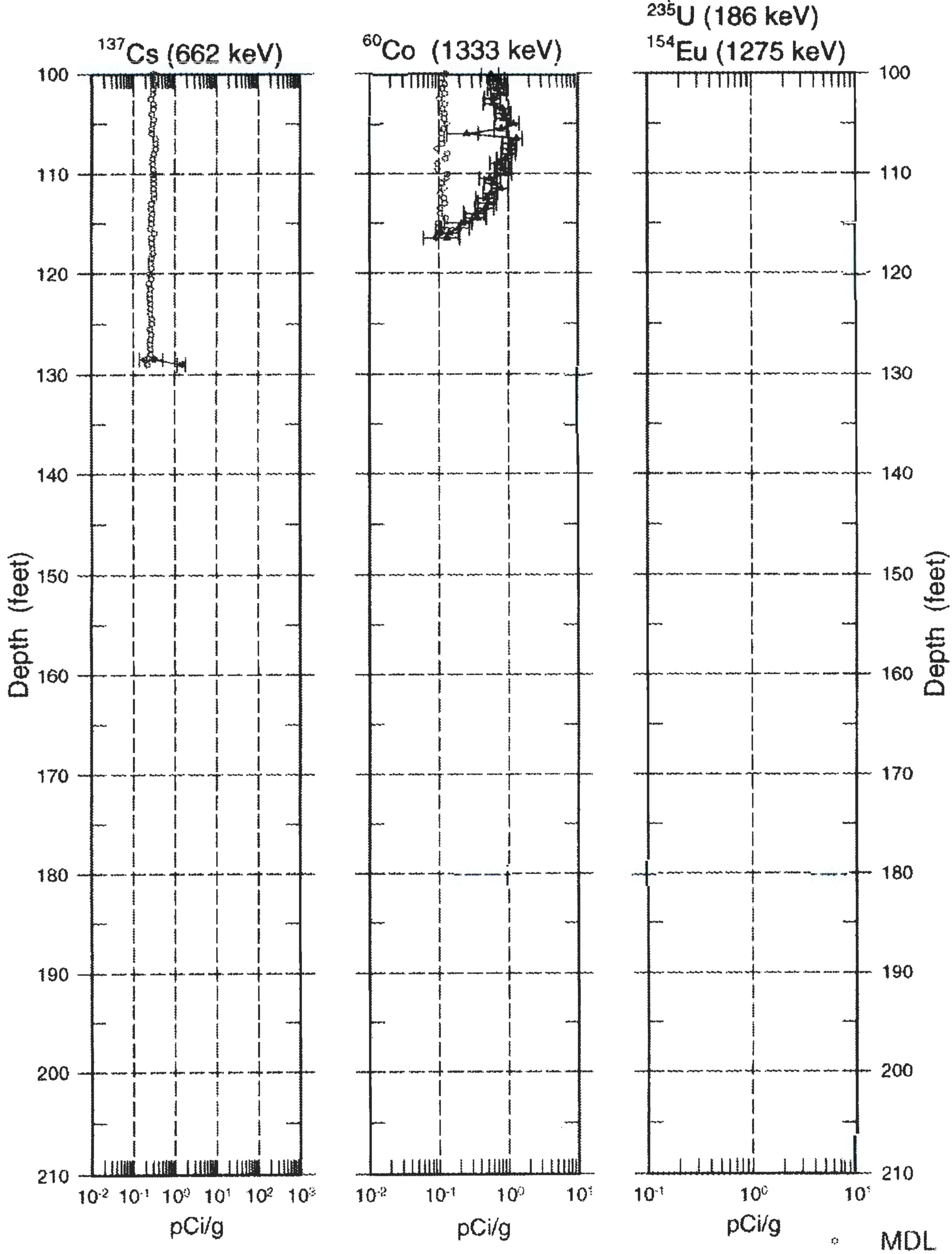
Plots of the spectrum shape factors are also included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-06-10
Man-Made Radionuclide Concentrations

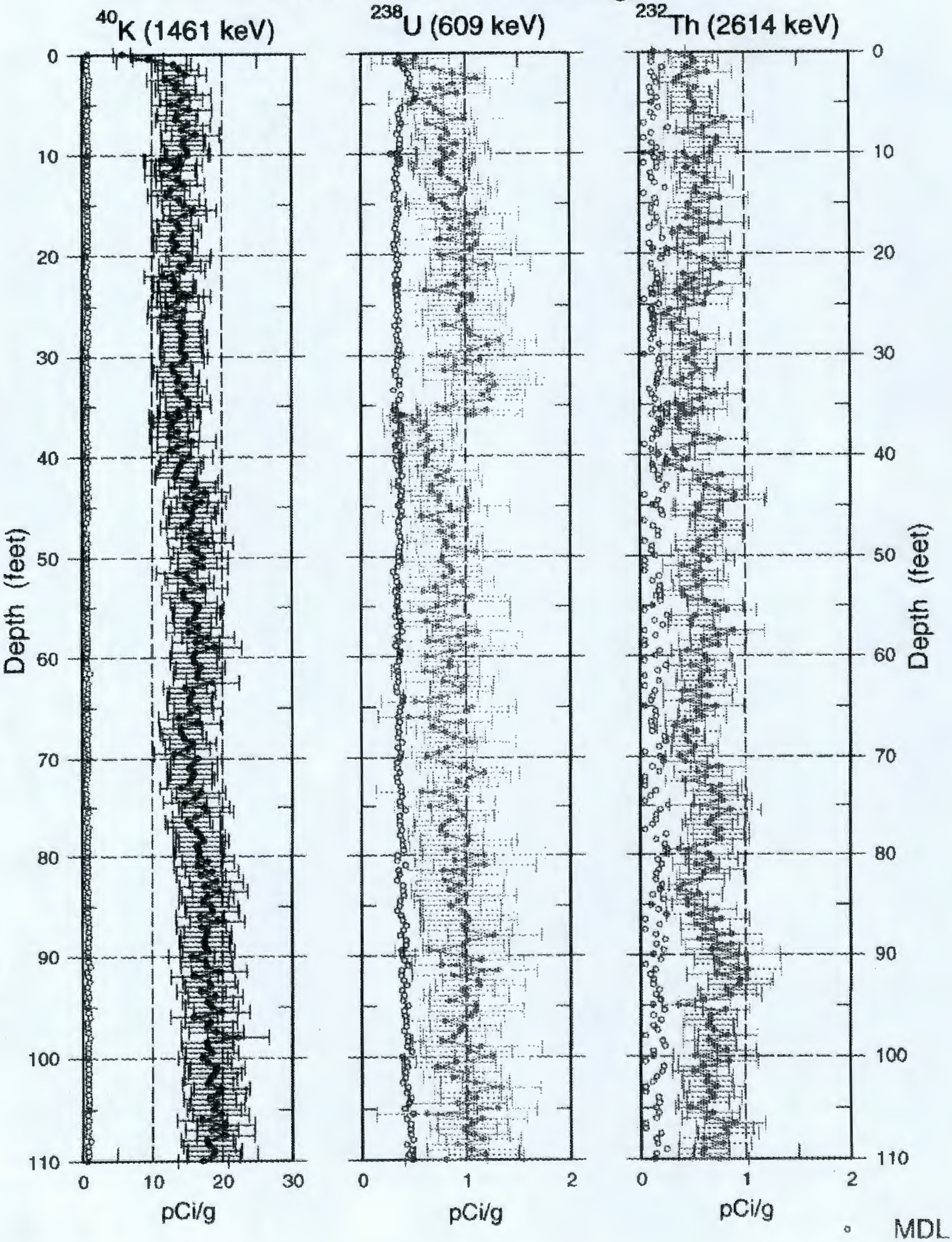


30-06-10

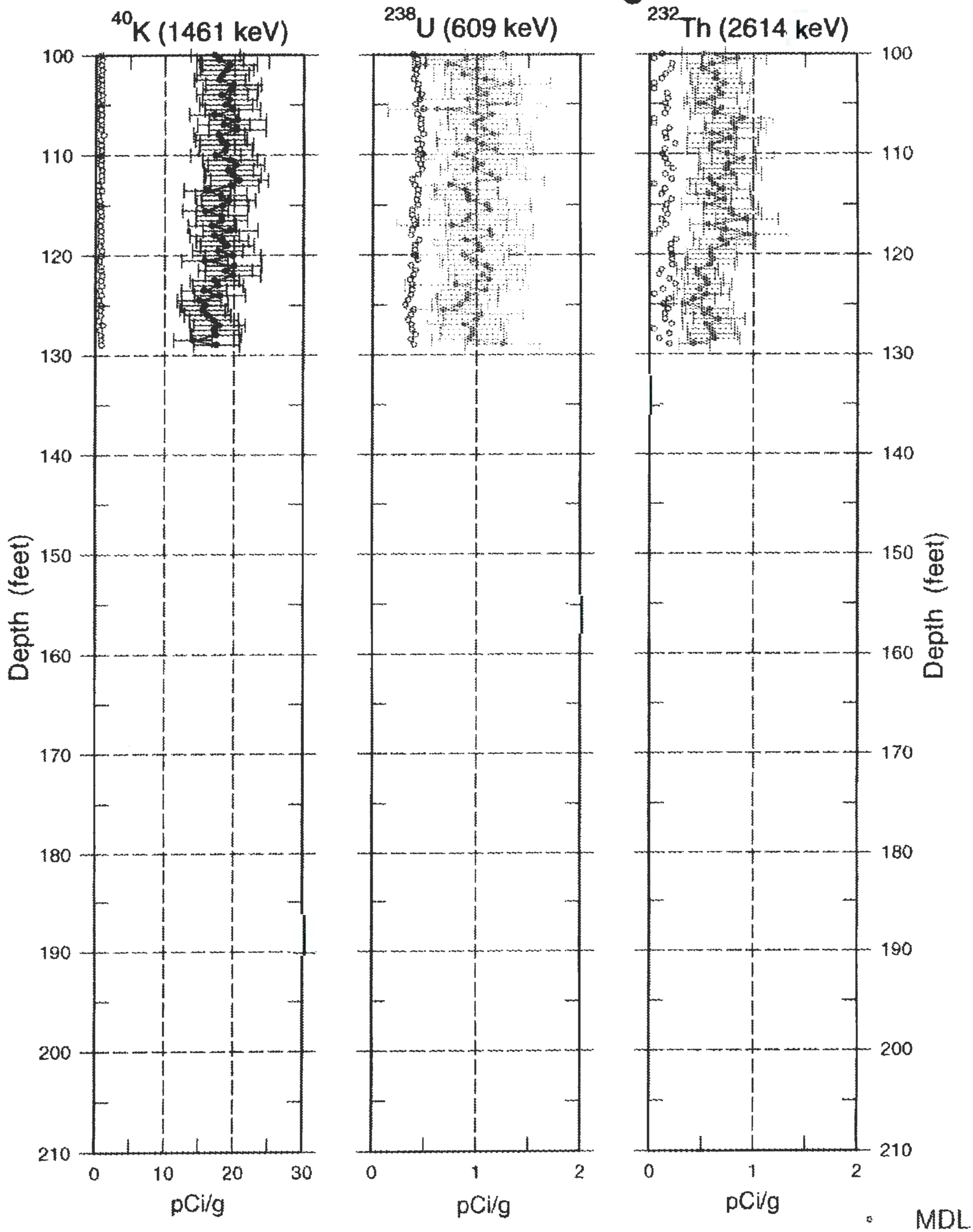
Man-Made Radionuclide Concentrations



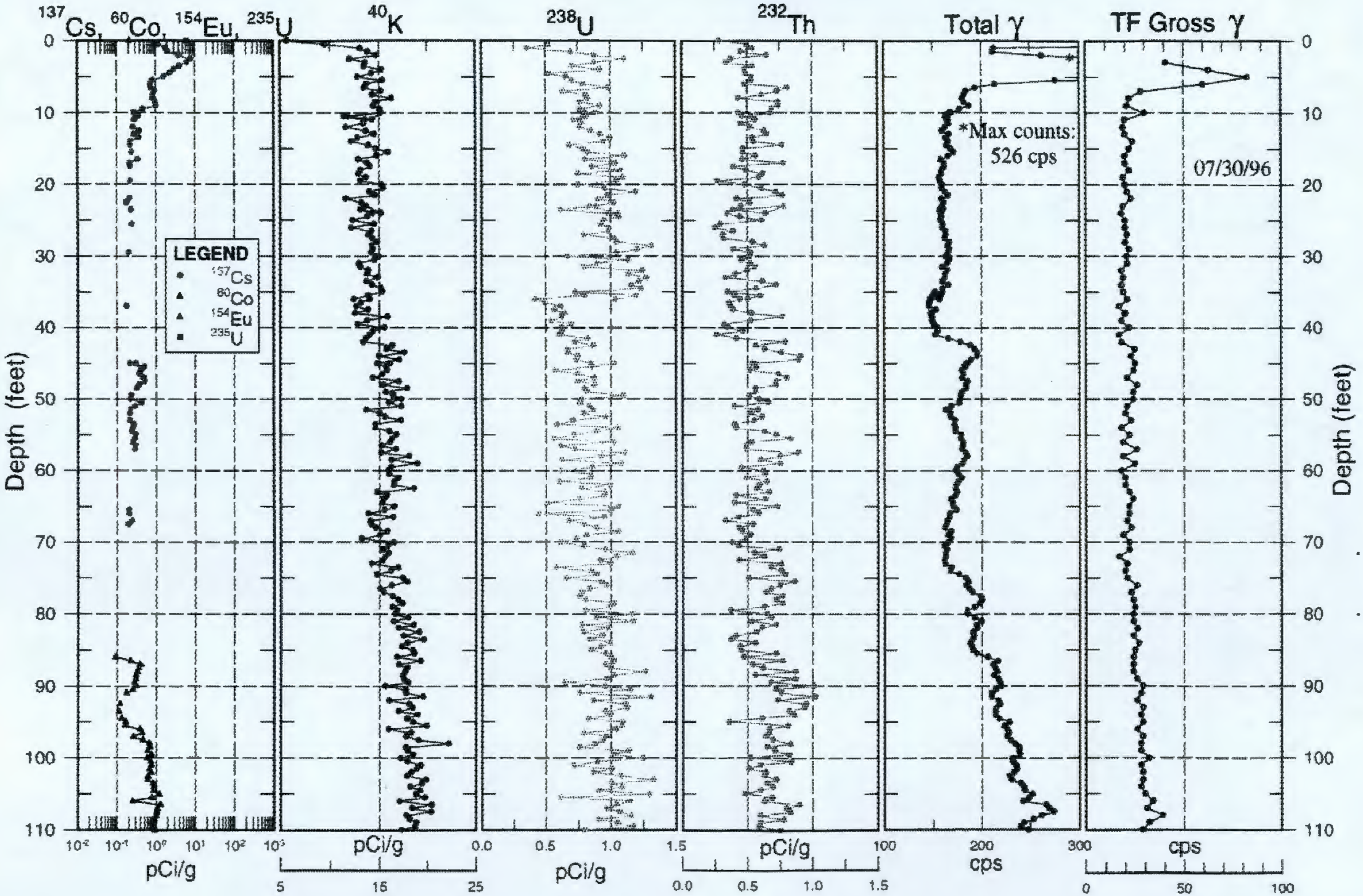
30-06-10
Natural Gamma Logs



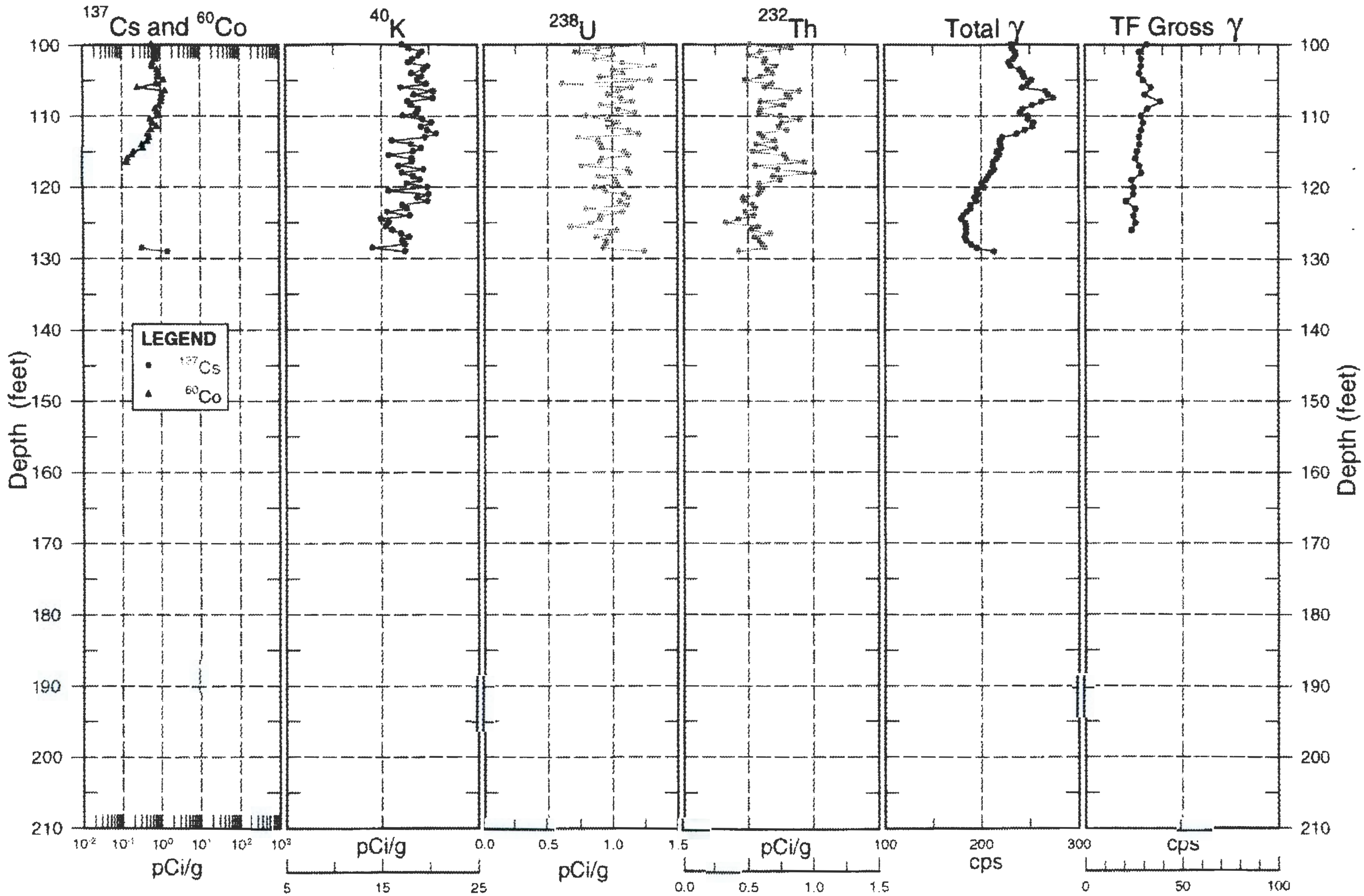
30-06-10
Natural Gamma Logs



30-06-10 Combination Plot



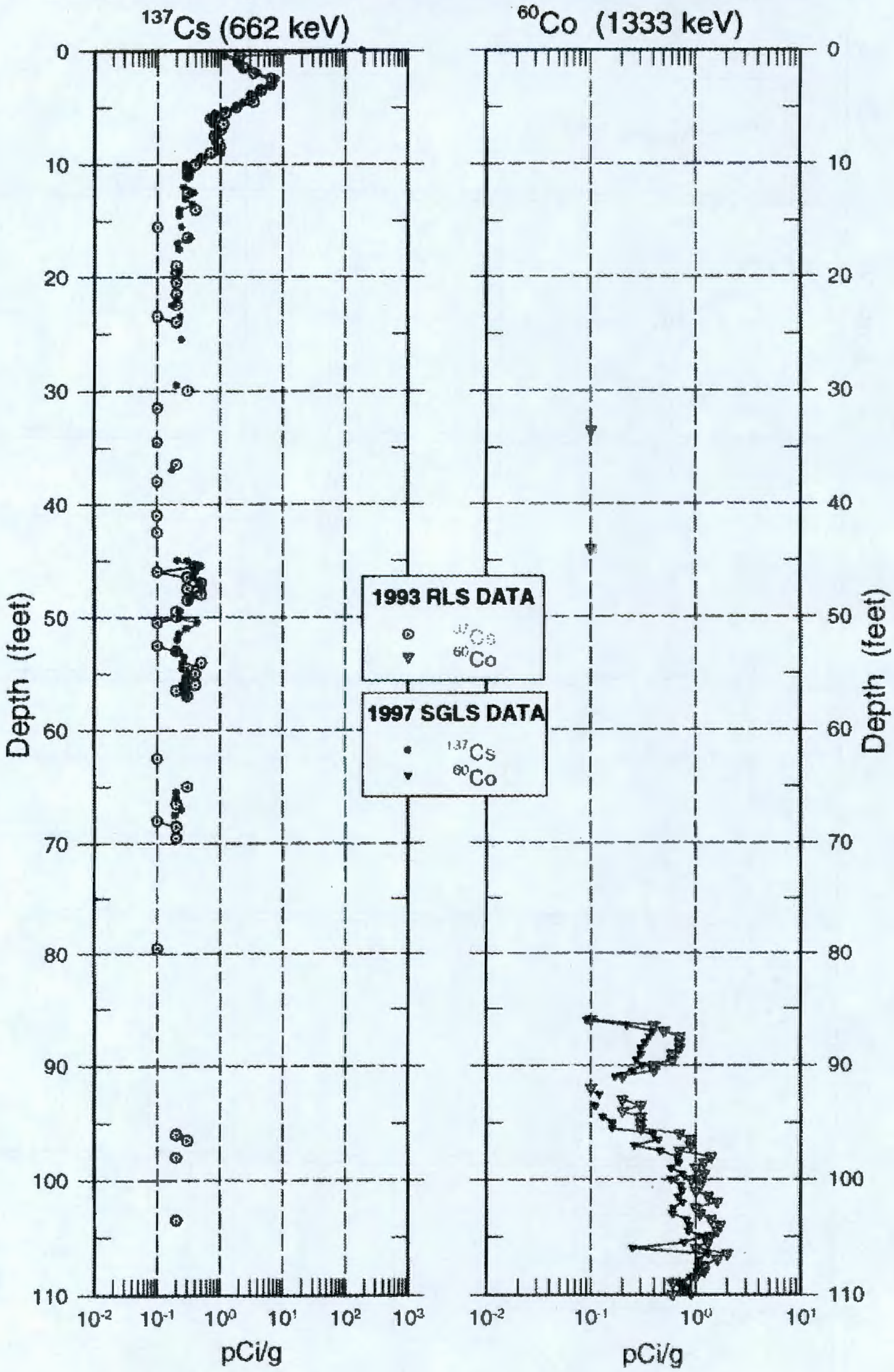
30-06-10 Combination Plot



30-06-10

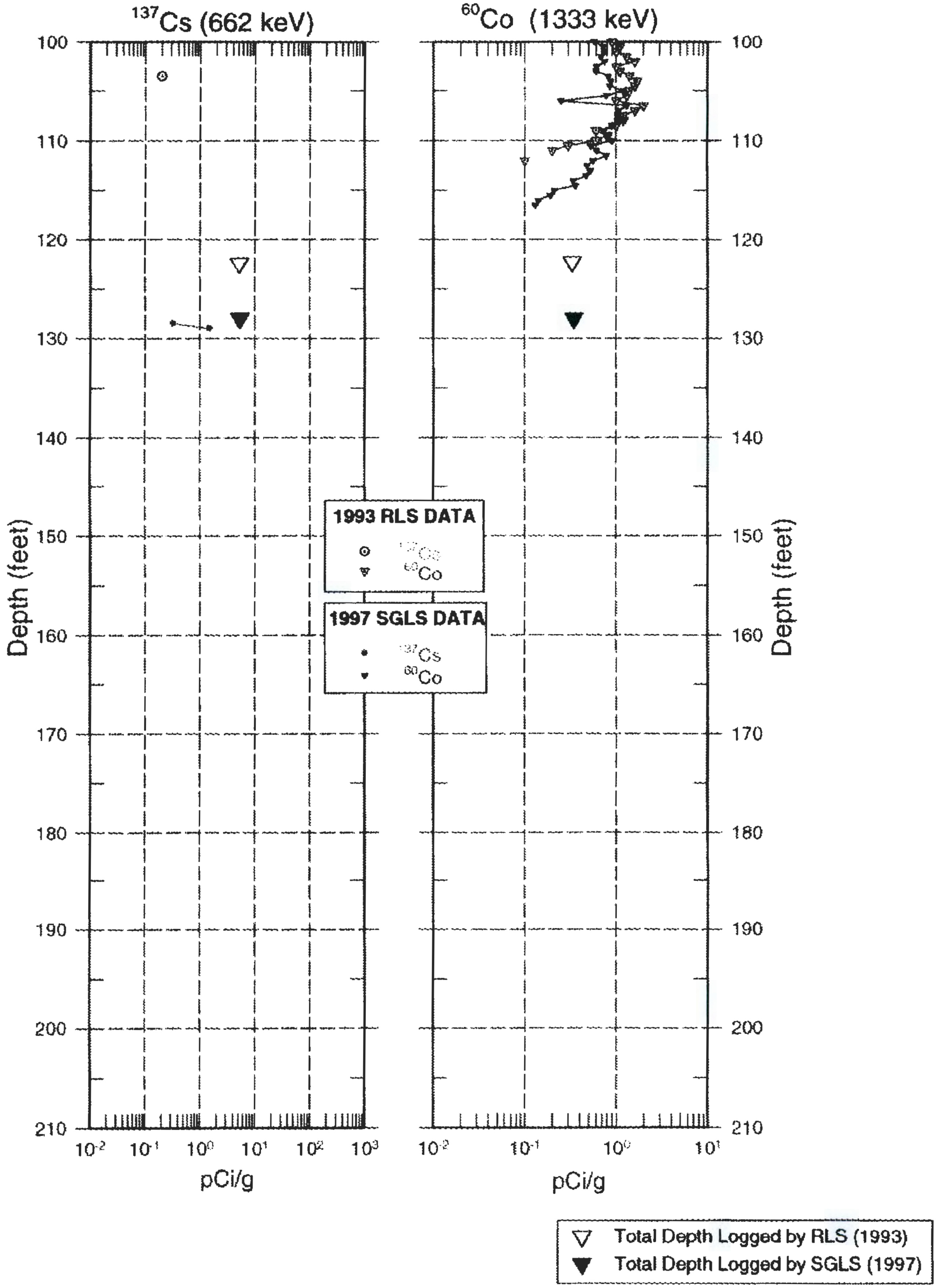
Man-Made Radionuclide Concentrations

1993/1997 Spectral Gamma Data Comparison



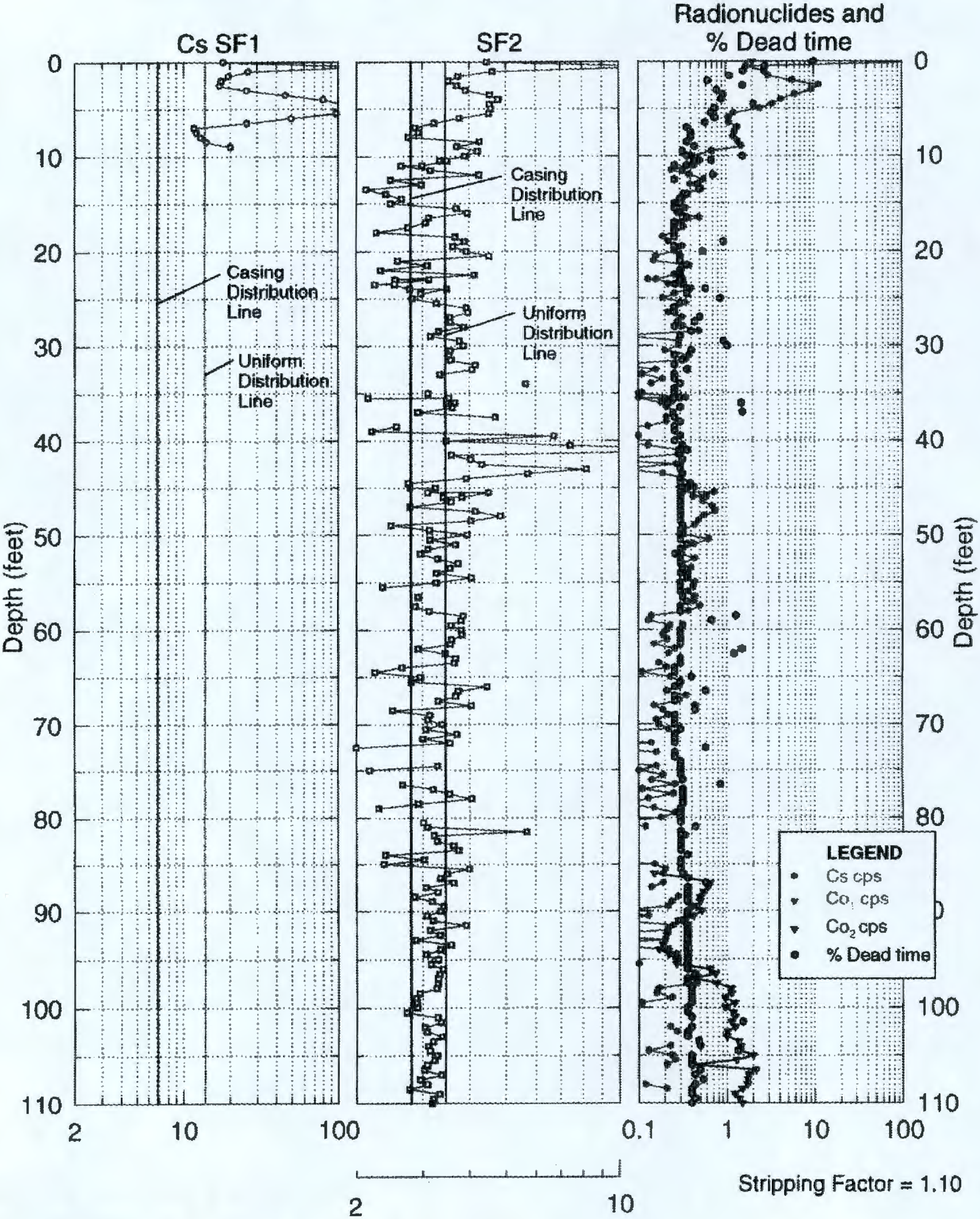
30-06-10

Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison

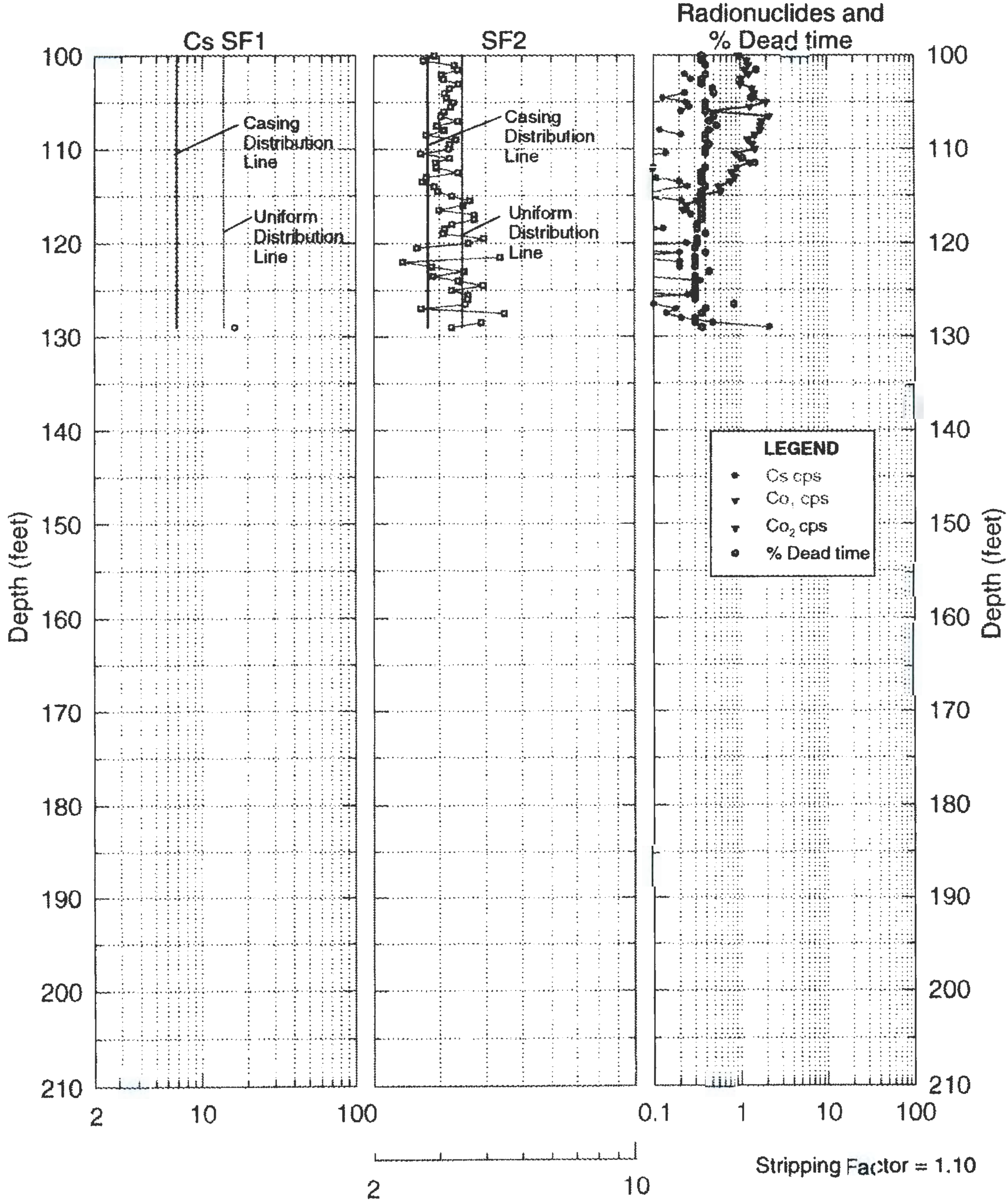


30-06-10

^{137}Cs Shape Factor Analysis Plot



30-06-10
^{137}Cs Shape Factor Analysis Plot



Stripping Factor = 1.10

mactec-ers
MACTEC ENVIRONMENTAL RESTORATION SERVICES, LLC

Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-09-06

Borehole Information

Farm :	C	**Tank :**	C-109	**Site Number :**	299-E27-98
N-Coord :	42,956	**W-Coord :**	48,327	**TOC Elevation :**	645.00
Water Level, ft :	None	**Date Drilled :**	9/30/74		

Casing Record

Type :	Steel-welded	Thickness :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	100		

Borehole Notes:
This borehole was drilled in September 1974 and completed to a depth of 100 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero reference for the SGLS, rises approximately 1 ft above the ground surface.

Equipment Information

Logging System :	1B	**Detector Type :**	HPGe	**Detector Efficiency :**	35.0 %
Calibration Date :	2/97	**Calibration Reference :**	GJO-HAN-14	**Logging Procedure :**	P-GJPO-1783

Log Run Information

Log Run Number :	1	**Log Run Date :**	4/1/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	98.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	49.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	2	**Log Run Date :**	4/8/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	50.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	0.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Analysis Information

Analyst : E. Larsen

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/30/97

Analysis Notes :

This borehole was logged by the SGLS in two log runs. The pre-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency, but the post-survey field verification spectra for logging run one failed to meet the acceptance criteria. The energy calibration and peak-shape calibration from the pre-survey field verification spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging runs.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The Cs-137 contamination was detected nearly continuously from the ground surface to 32 ft, continuously from 35.5 to 37 ft, and nearly continuously from 41 to 73.5 ft. An isolated occurrence of Cs-137 was detected at the bottom of the logged interval. The Co-60 contamination was detected continuously from 78 to 86.5 ft.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 and Co-60 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

Relatively high K-40 concentration values occur between 1 and 4.5 ft. The K-40 concentrations decrease sharply at 4.5 ft then increase gradually from 5.5 to 25 ft. The K-40 concentrations increase again at 38 ft, become variable from 40 to 48.5 ft, then gradually decrease between 48.5 and 71 ft. The K-40 concentrations increase between 71 and 73 ft and remain elevated to the bottom of the logged interval (98 ft).

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Report for tank C-109.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

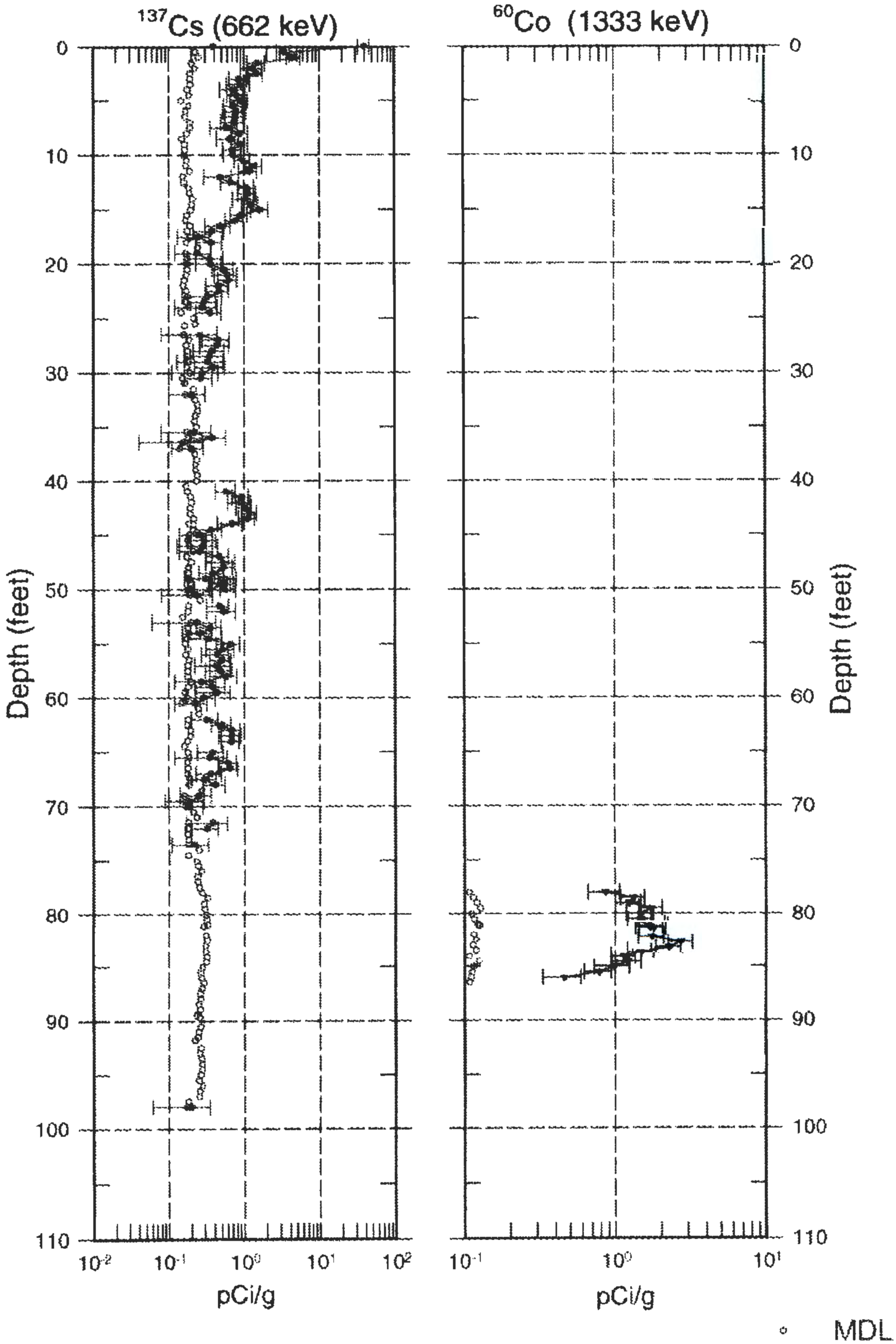
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

A time-sequence plot of the historical gross gamma log data from 1979 to 1987 is included. The headings of the plots identify the date on which the data in the plots were gathered.

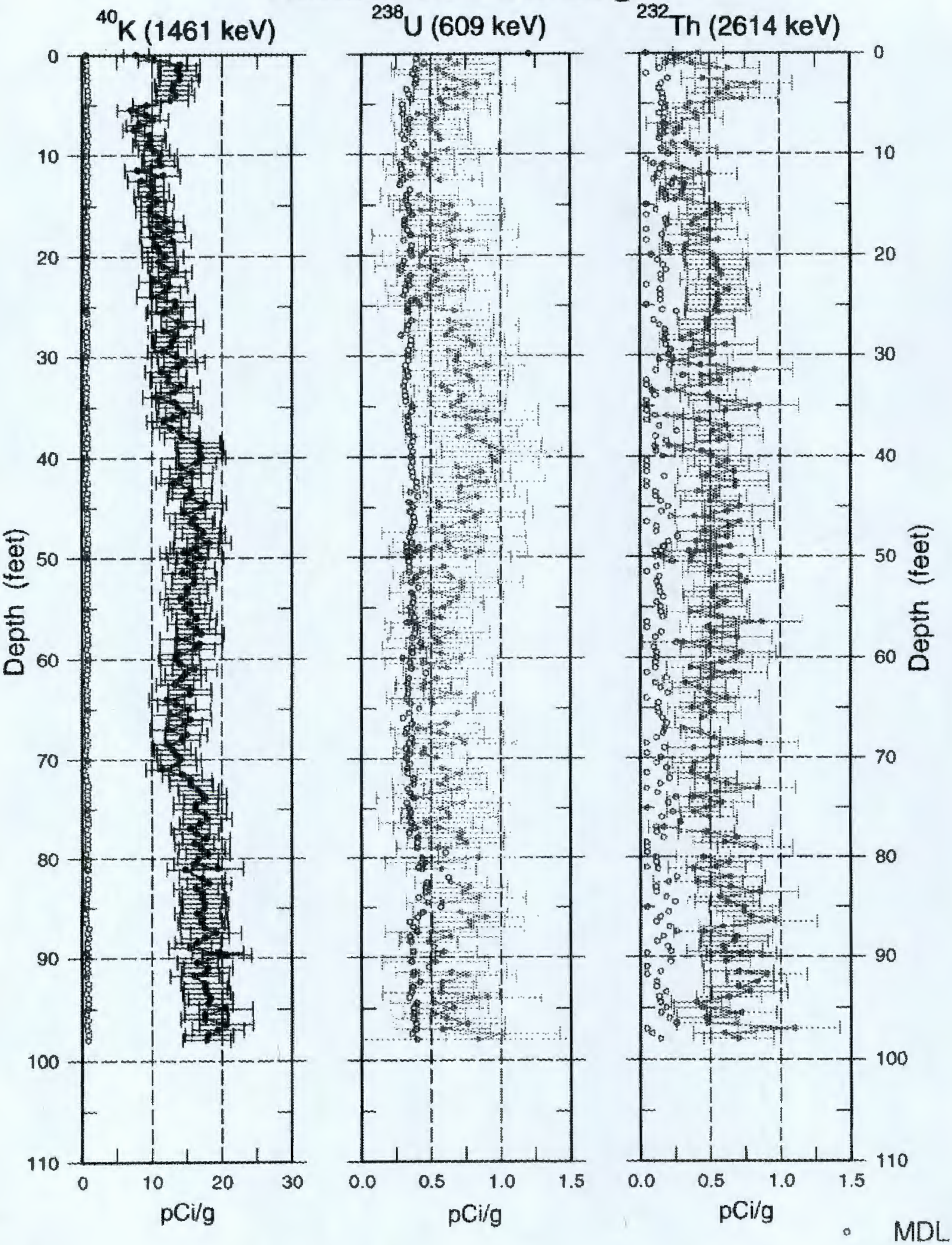
Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-09-06

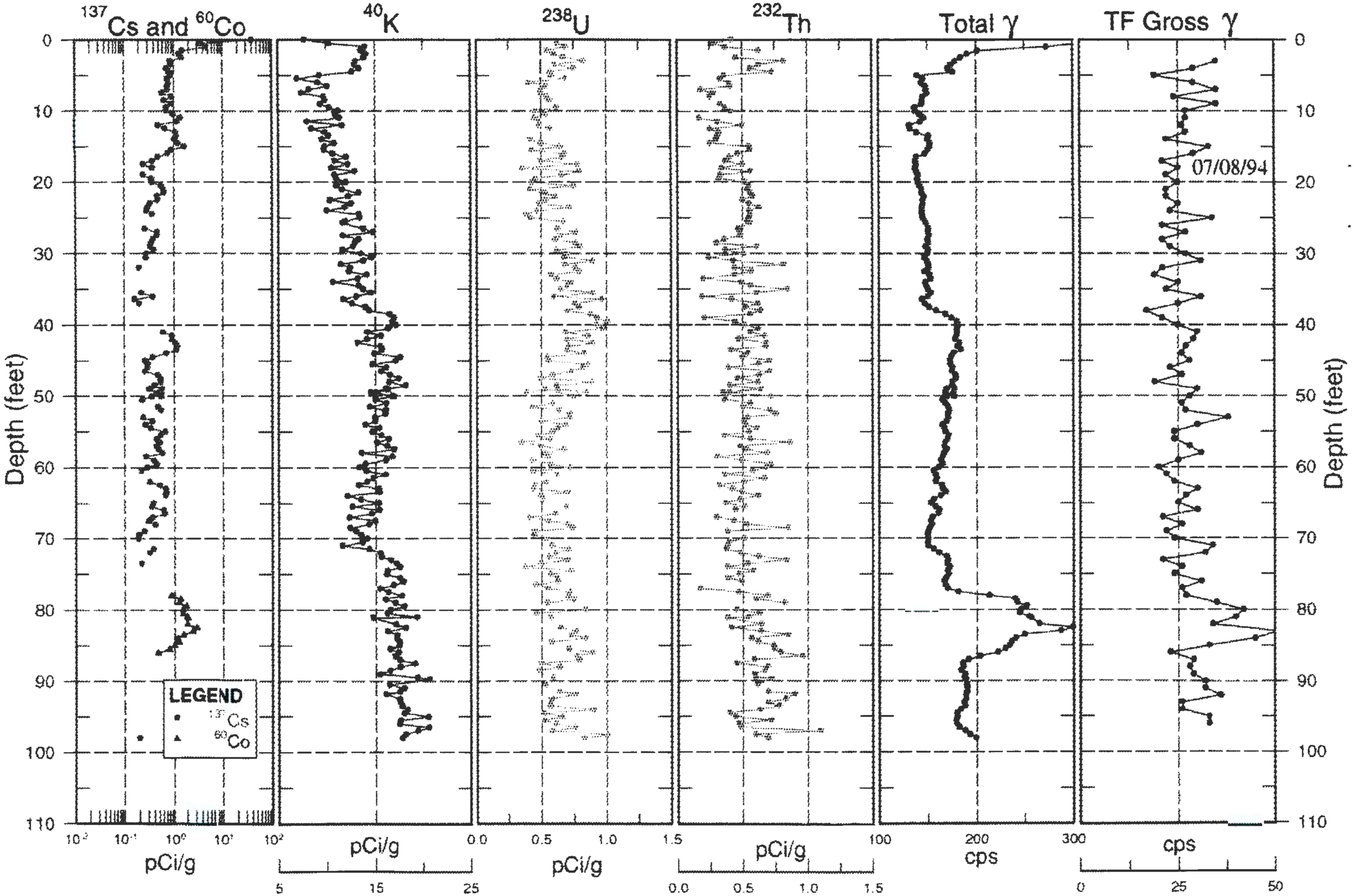
Man-Made Radionuclide Concentrations



30-09-06
Natural Gamma Logs

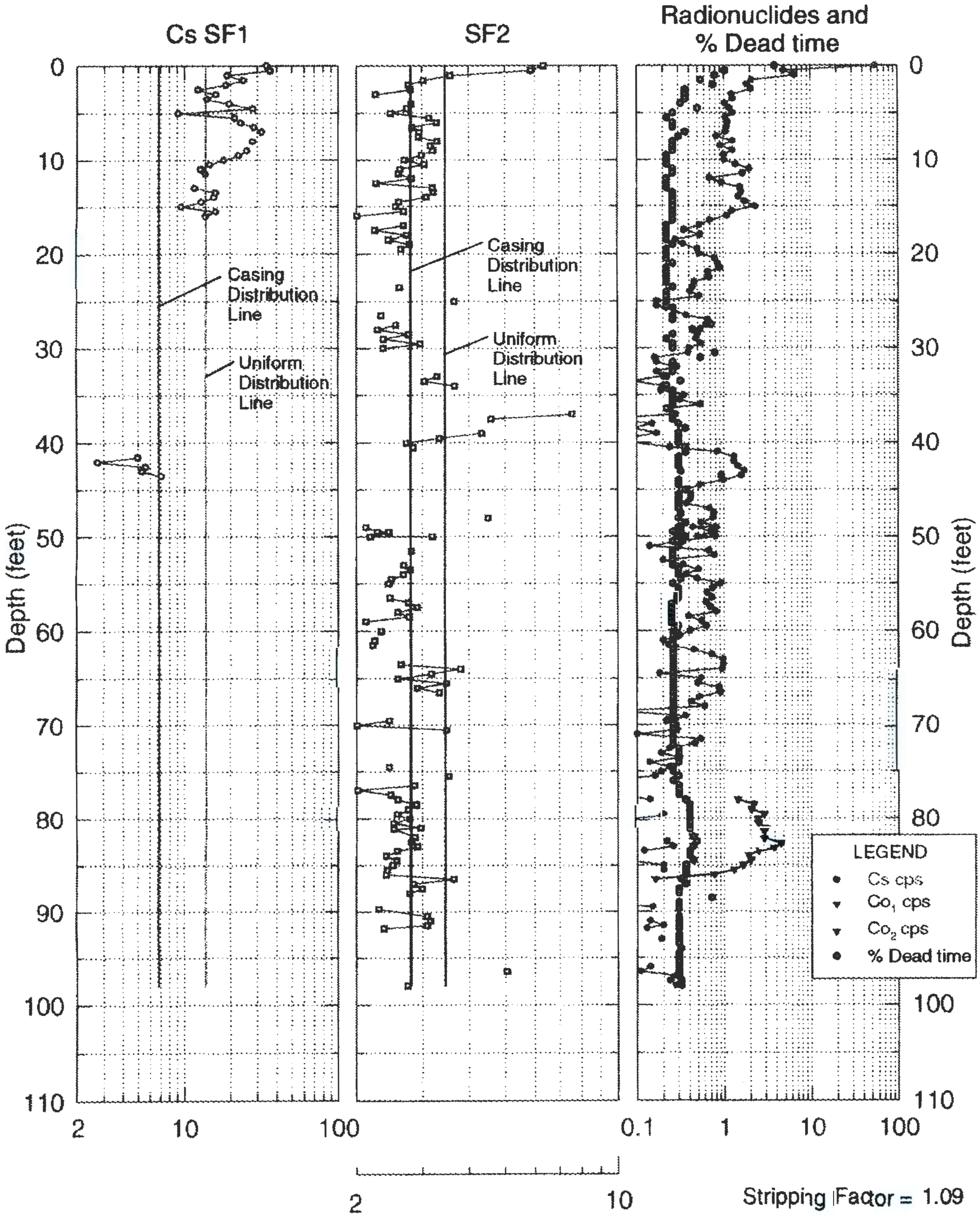


30-09-06 Combination Plot

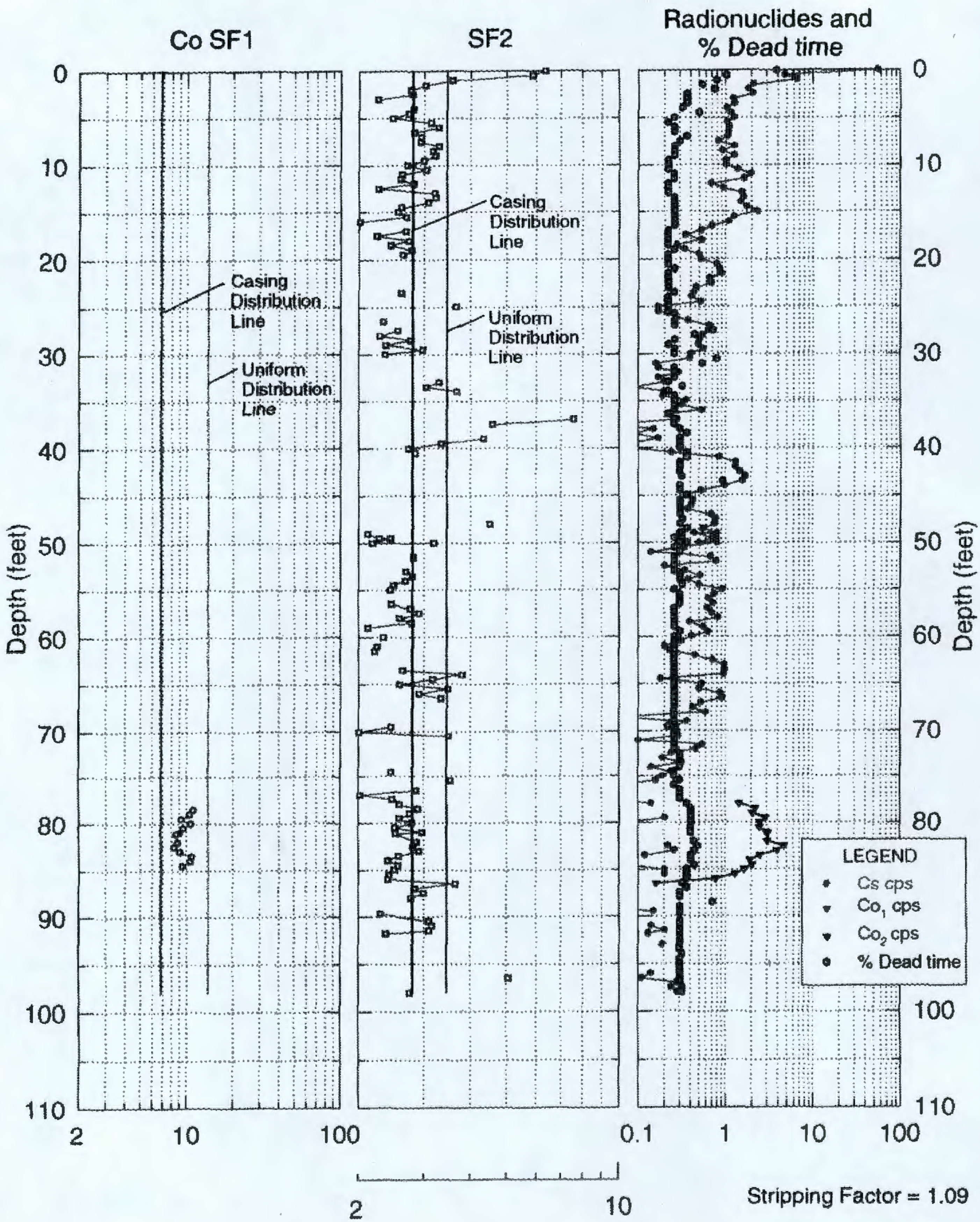


Historical Gross Gamma Logs for Borehole 30-09-06

30-09-06 ¹³⁷Cs Shape Factor Analysis Plot



30-09-06 ^{60}Co Shape Factor Analysis Plot



mactec-ers
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Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole 30-09-07

Borehole Information

Farm :	C	Tank :	C-109	Site Number :	299-E27-135
N-Coord :	42,963	W-Coord :	48,342	TOC Elevation :	649.00
Water Level, ft :	122.10	Date Drilled :	3/31/82		

Casing Record

Type :	Steel-welded	Thickness :	0.280	ID, in. :	6
Top Depth, ft. :	1	Bottom Depth, ft. :	125		

Borehole Notes:
This borehole was drilled in March 1982 and completed to a depth of 125 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was grouted but not perforated. The depth of the grouted interval was not specified. The top of the casing, which is the zero reference for the SGLS, is approximately 2.5 ft above the ground surface. Because elevation data was not available for this borehole, the elevation of top of the casing was estimated to be approximately 649 ft.

Equipment Information

Logging System :	1B	Detector Type :	HPGe	Detector Efficiency :	35.0 %
Calibration Date :	2/97	Calibration Reference :	GJO-HAN-14	Logging Procedure :	P-GJPO-1783

Log Run Information

Log Run Number :	1	Log Run Date :	3/20/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	0.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	14.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	3/21/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	124.5	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	42.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	3	Log Run Date :	3/24/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	43.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	13.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Event A

Borehole 30-09-07

Analysis Information

Analyst : E. Larsen

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/5/97

Analysis Notes :

This borehole was logged by the SGLS in three log runs. The pre-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency, but the post-survey field verification spectra for logging run two failed to meet the acceptance criteria. The energy and peak-shape calibration from the pre-survey field verification spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging runs.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The Cs-137 contamination was detected continuously from the ground surface to 9.5 ft and nearly continuously from 16.5 to 35.5 ft. An isolated zone of Cs-137 contamination was detected from 11.5 to 12.5 ft. The Co-60 contamination was detected continuously from 79 to 83.5 ft and intermittently between 85 and 92.5 ft.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 and Co-60 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentration values steadily decrease from 26.5 to 40 ft, increase significantly from 40 to 41.5 ft, and remain elevated to a depth of 73.5 ft. The K-40 concentrations increase again at about 74 ft, remain elevated to a depth of about 118 ft, then gradually decrease to the bottom of the logged interval.

Most of the U-238 concentration data are absent from the ground surface to 3.5 ft. The U-238 concentrations decrease from 120 ft to the bottom of the logged interval.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-108 and C-109.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

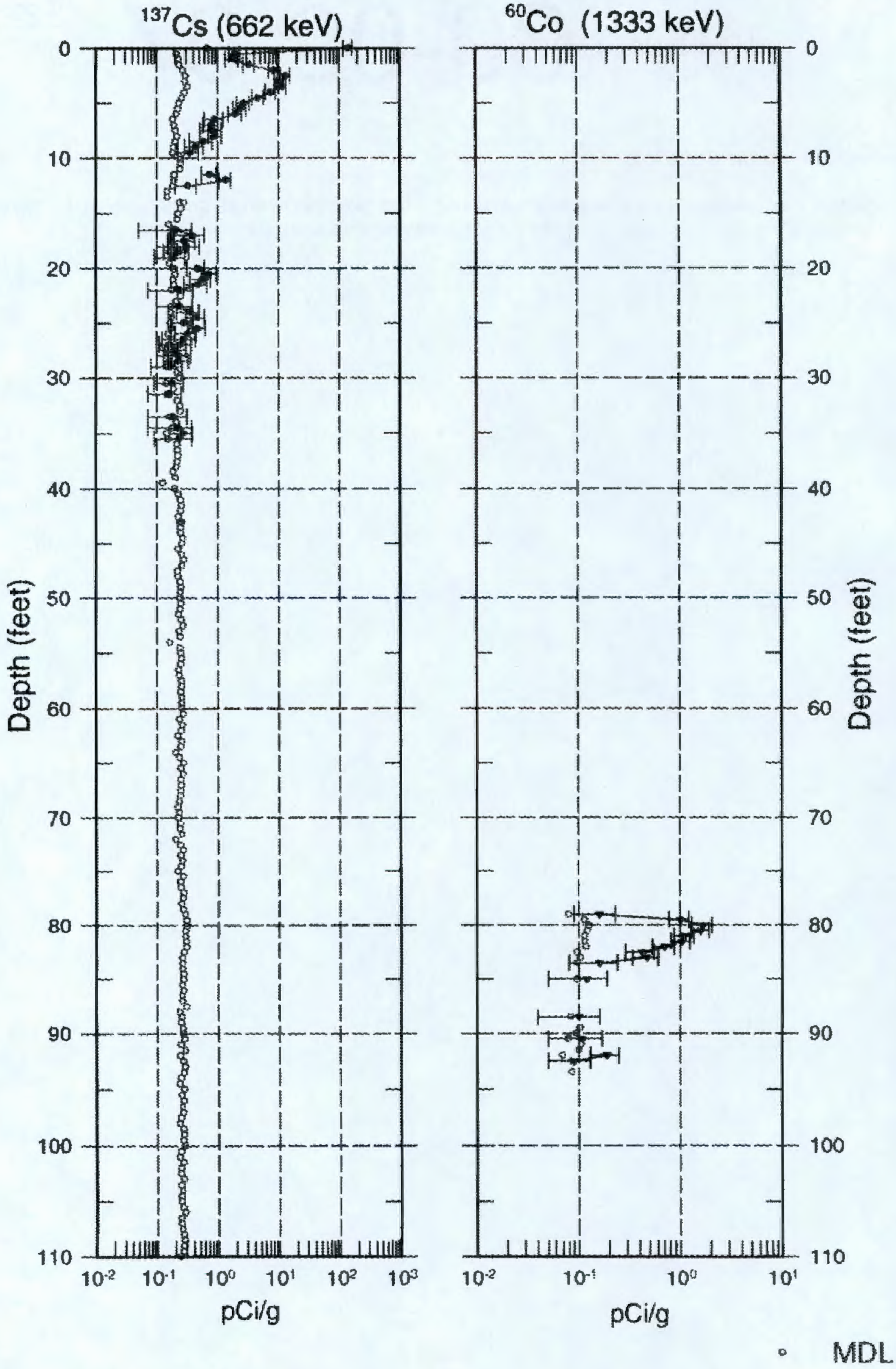
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

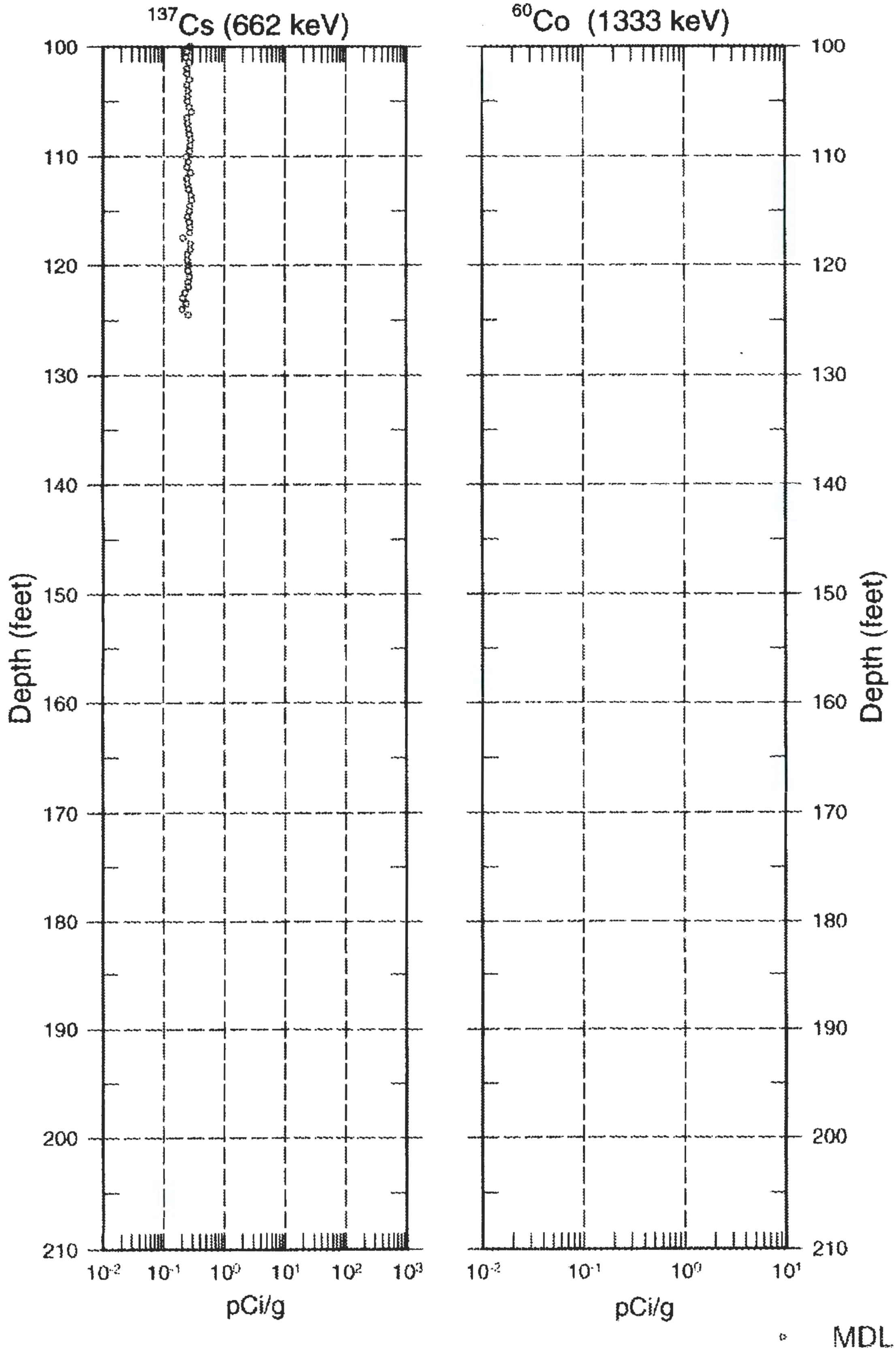
30-09-07

Man-Made Radionuclide Concentrations

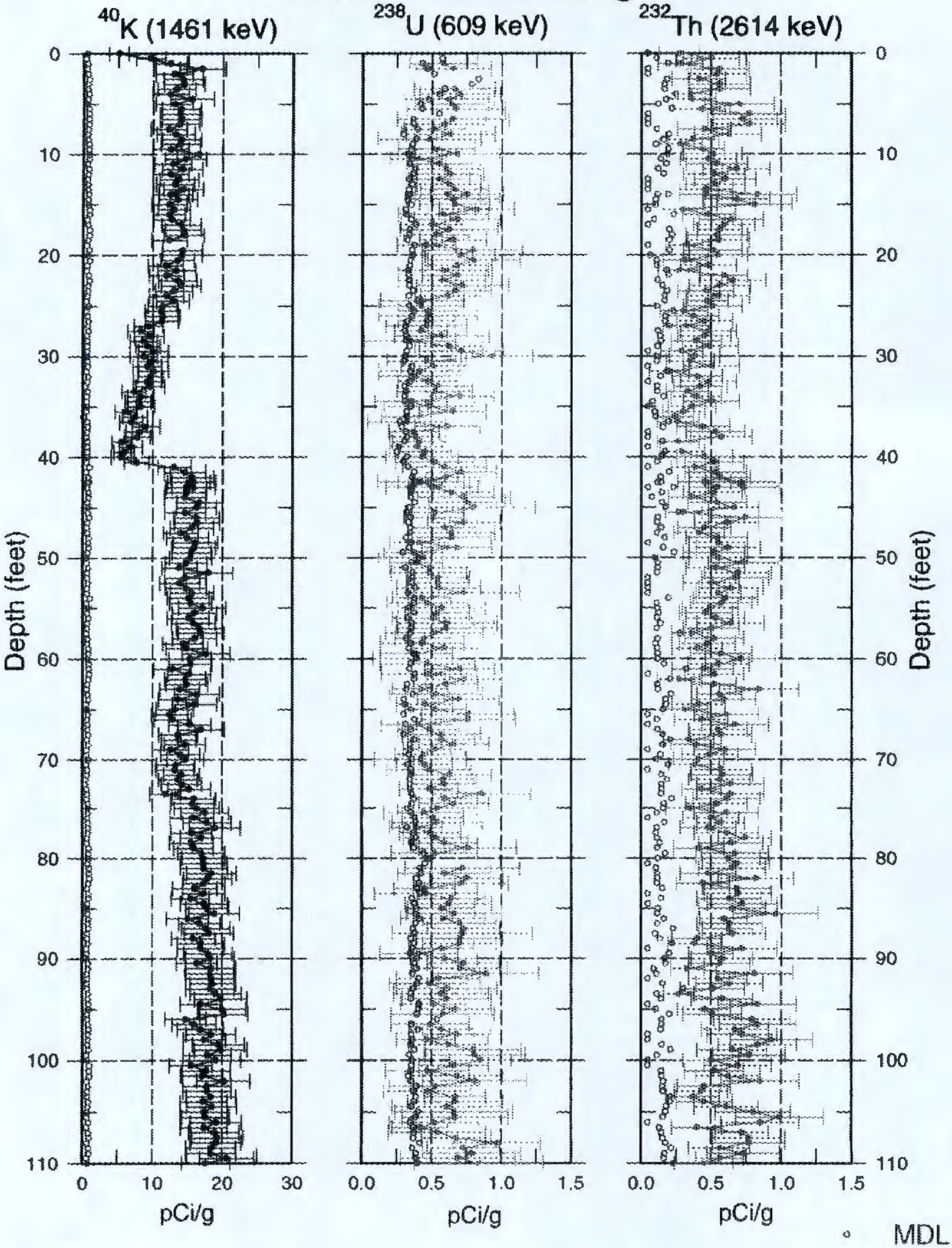


30-09-07

Man-Made Radionuclide Concentrations

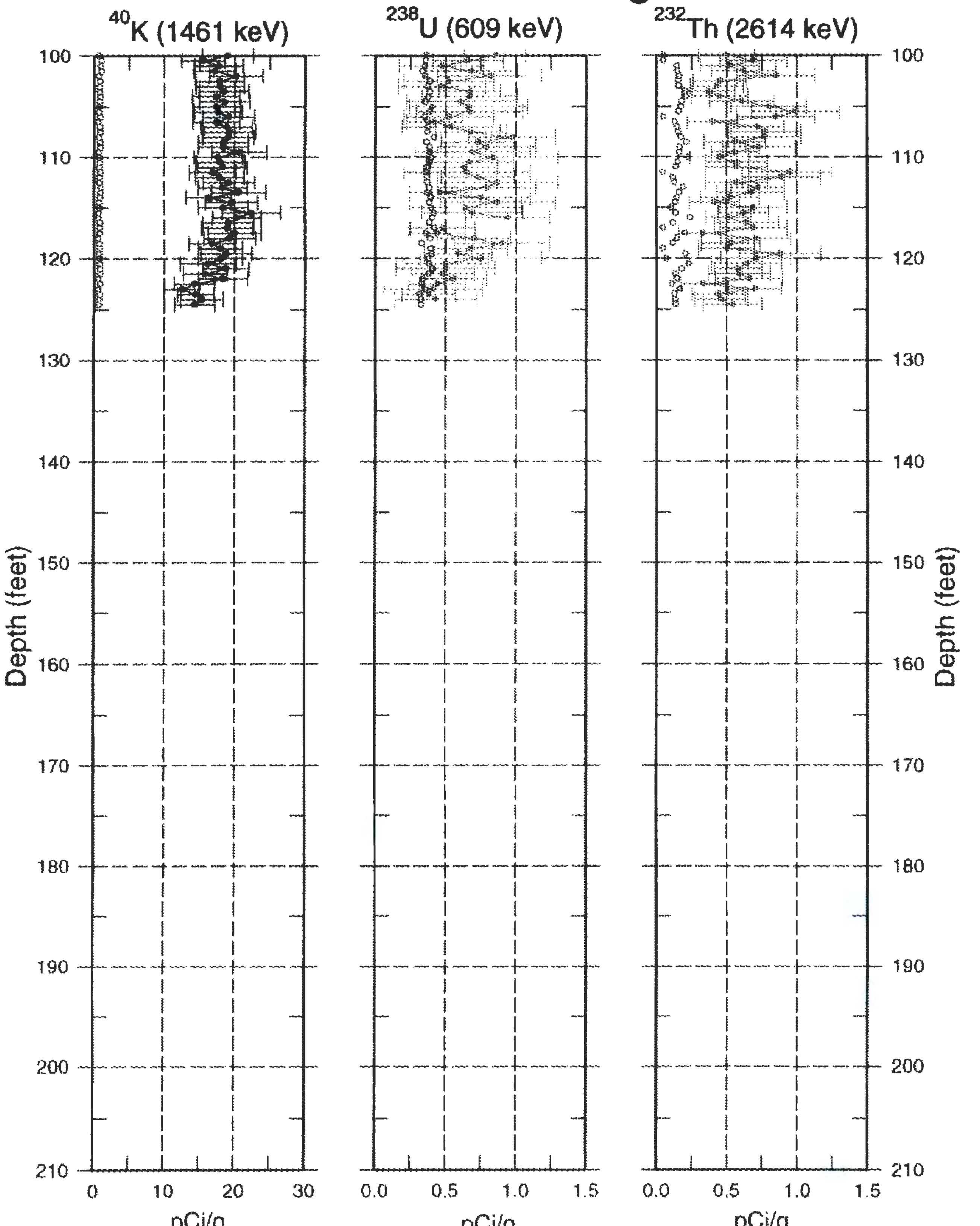


30-09-07
Natural Gamma Logs

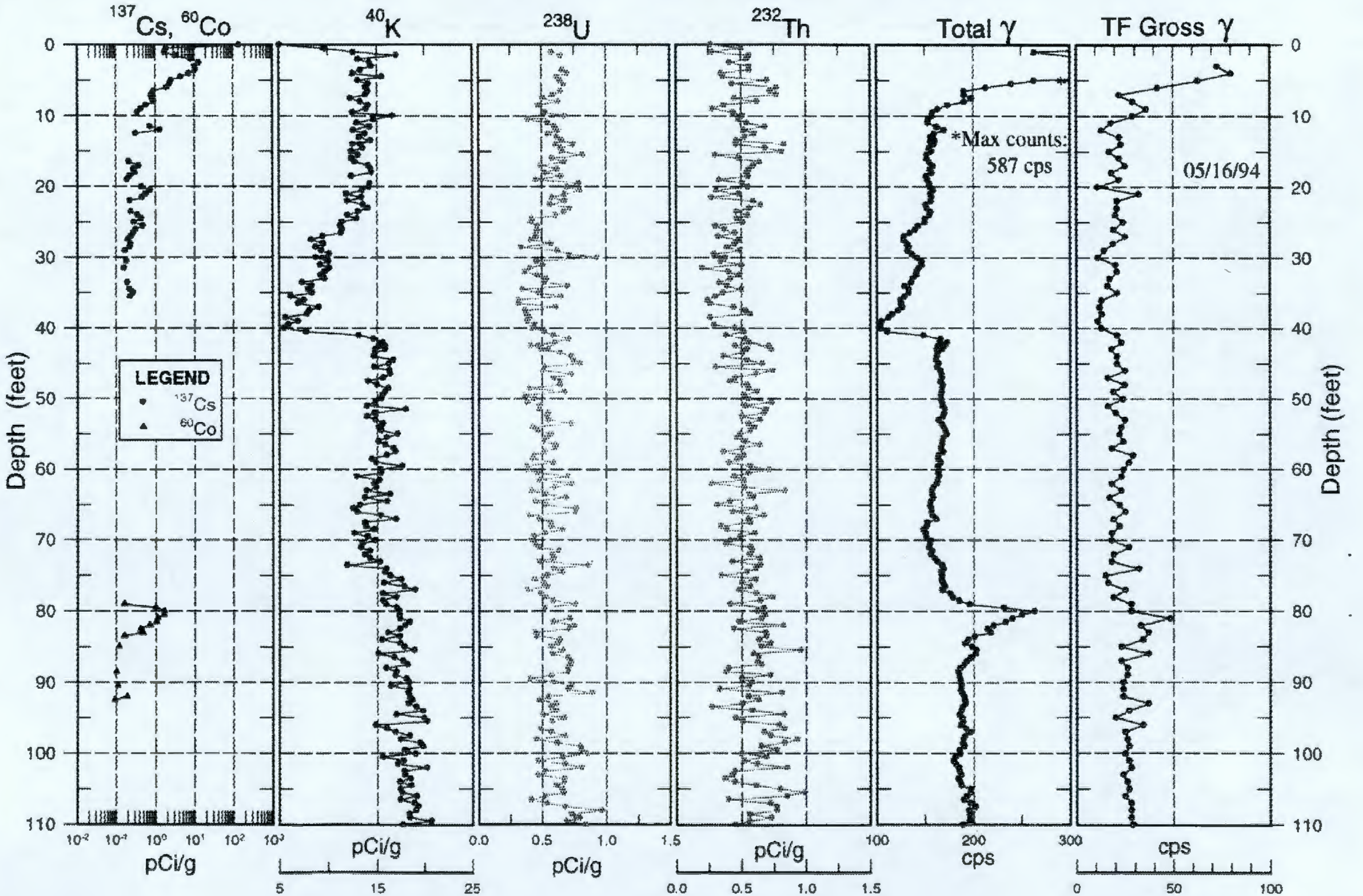


30-09-07

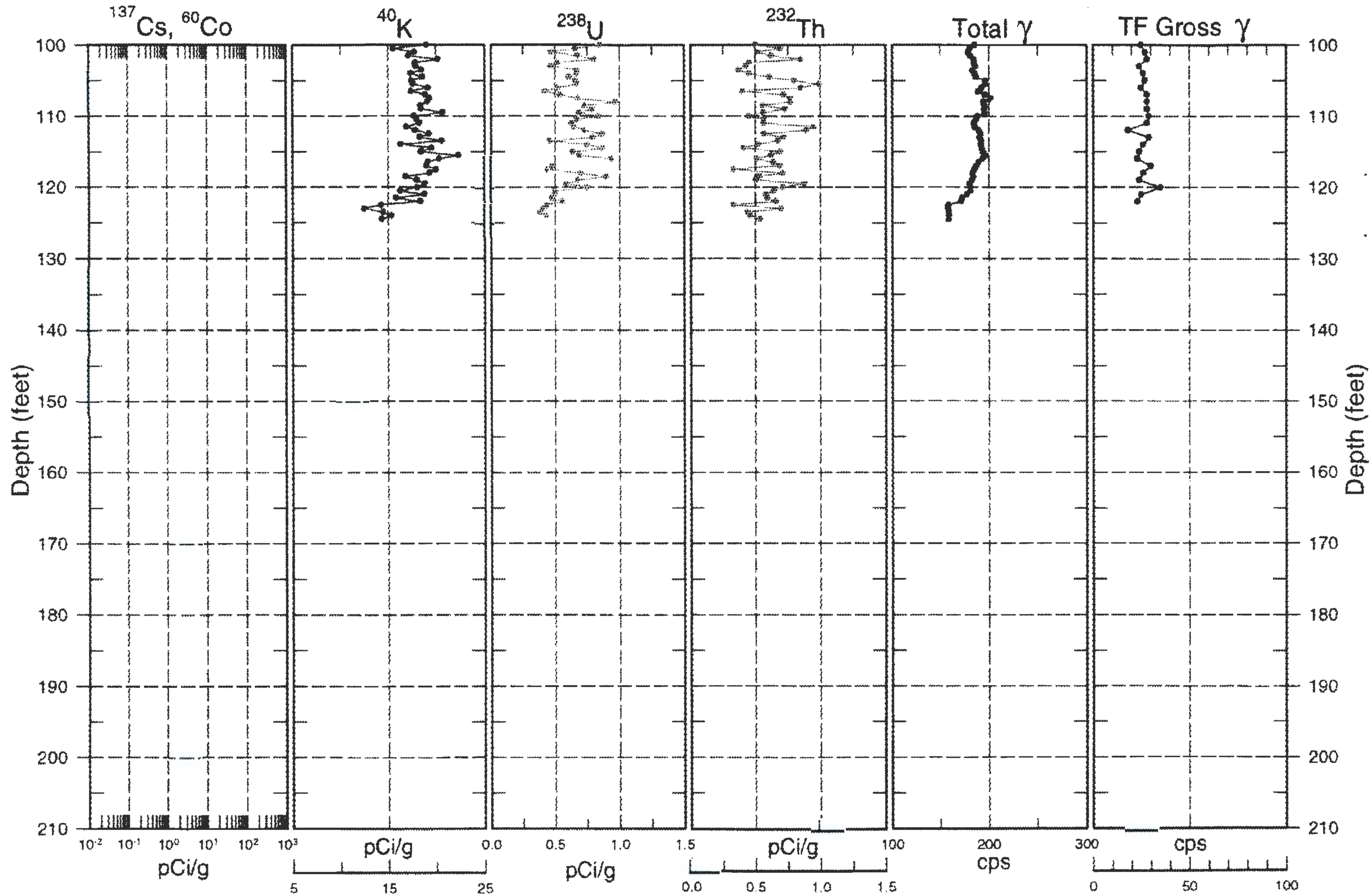
Natural Gamma Logs



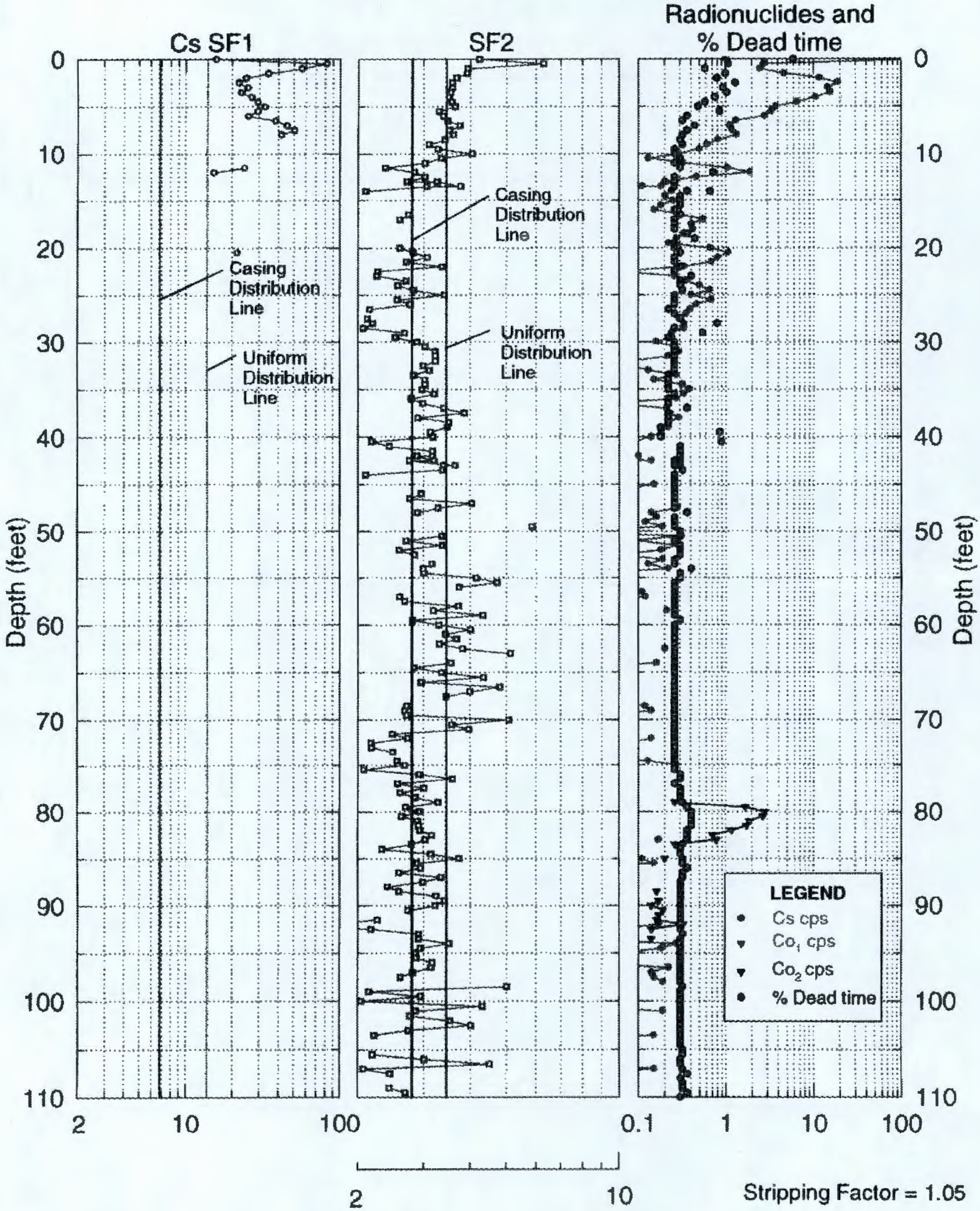
30-09-07 Combination Plot



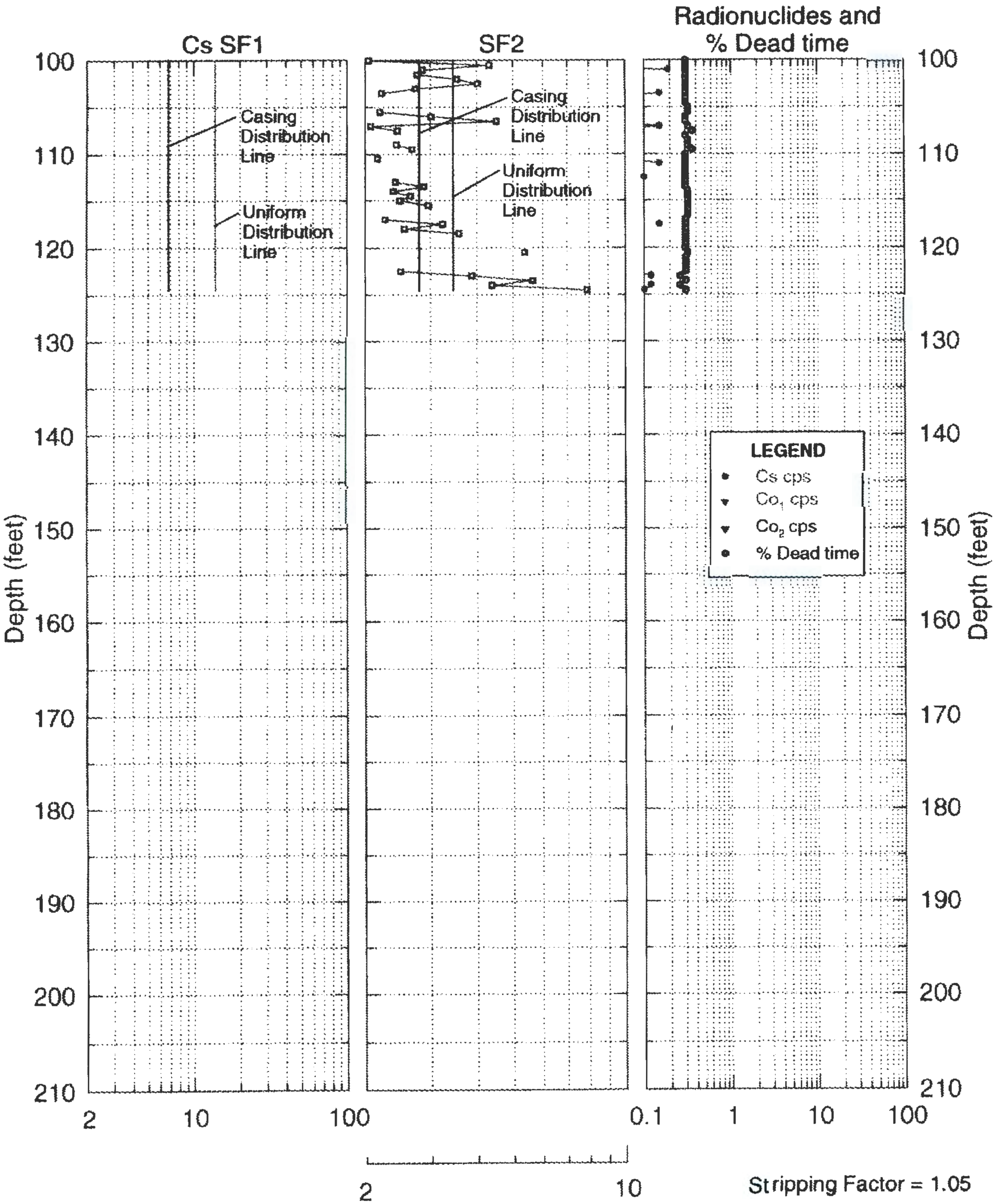
30-09-07 Combination Plot



30-09-07
^{137}Cs Shape Factor Analysis Plot

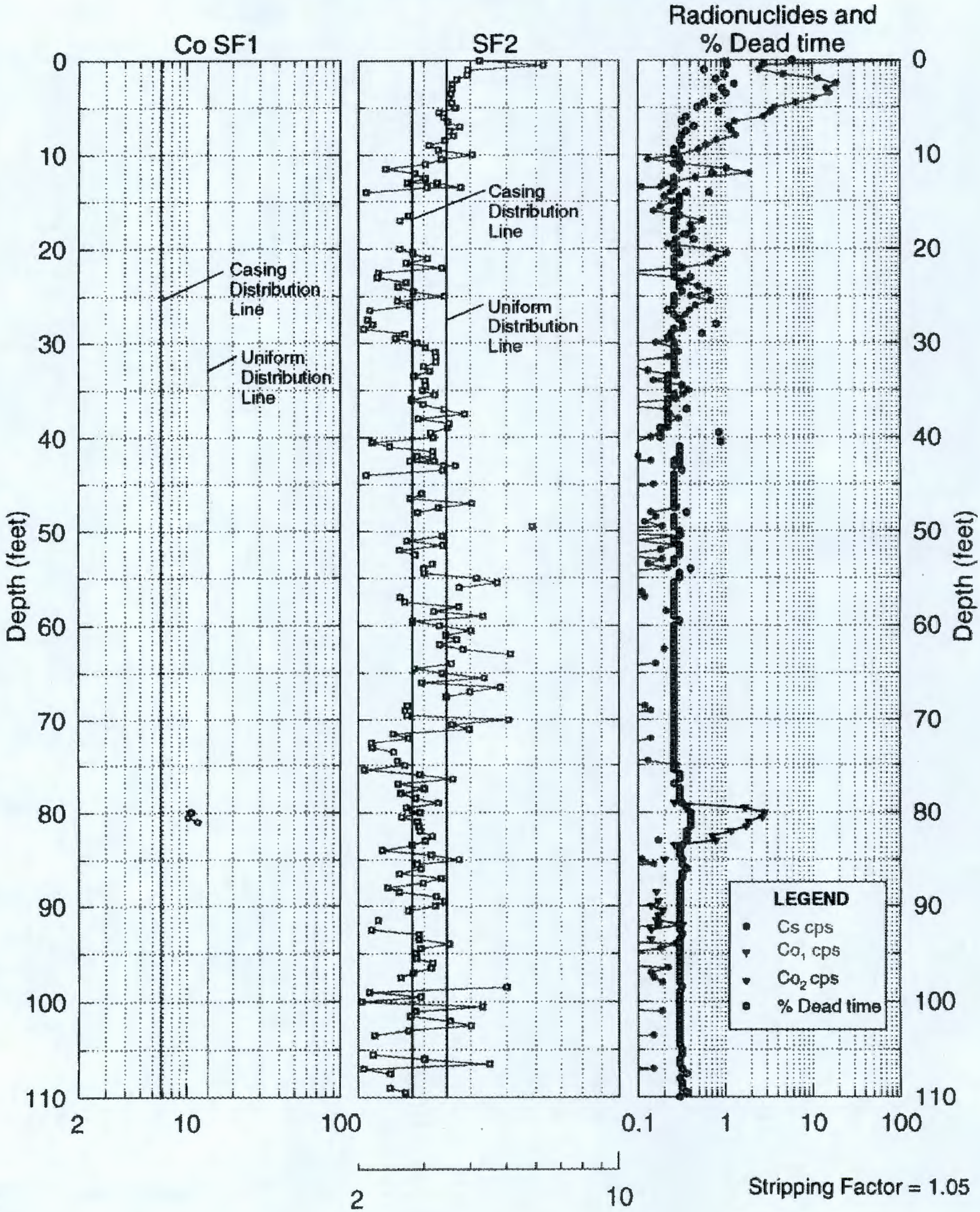


30-09-07
^{137}Cs Shape Factor Analysis Plot



Stripping Factor = 1.05

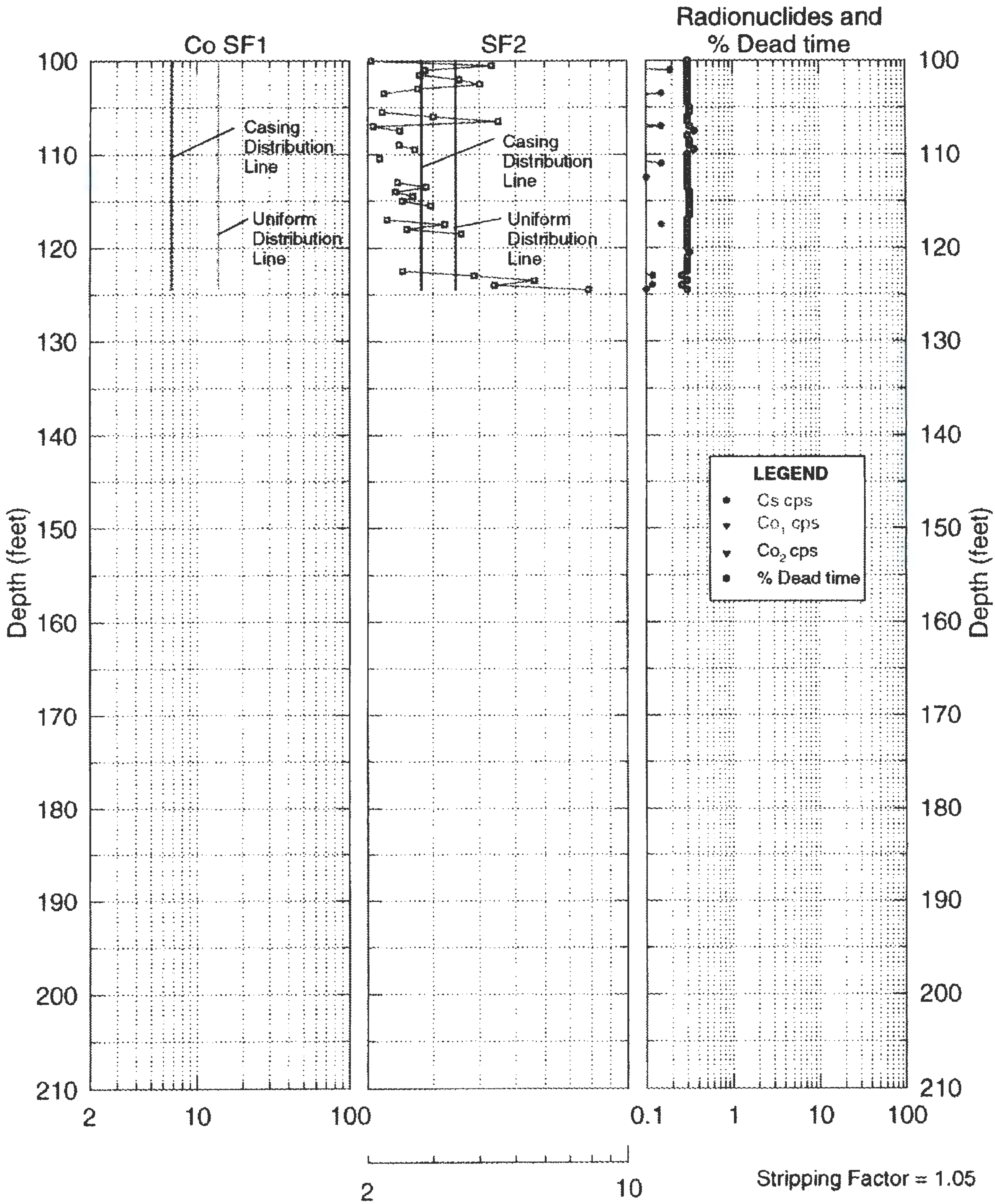
30-09-07
^{60}Co Shape Factor Analysis Plot



Stripping Factor = 1.05

30-09-07

^{60}Co Shape Factor Analysis Plot



Stripping Factor = 1.05

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Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-08-02

Borehole Information

Farm :	C	**Tank :**	C-108	**Site Number :**	299-E27-94
N-Coord :	42,965	**W-Coord :**	48,363	**TOC Elevation :**	647.00
Water Level, ft :	None	**Date Drilled :**	9/30/74		

Casing Record

Type :	Steel-welded	Thickness, in. :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	100		

Borehole Notes:

This borehole was drilled in September 1974 and completed to a depth of 100 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. No information was available that indicated the borehole casing was perforated or grouted; therefore, it is assumed that the borehole was not perforated or grouted. The top of the casing, which is the zero reference for the SGLS, is flush with the ground surface.

Equipment Information

Logging System :	1B	**Detector Type :**	HPGe	**Detector Efficiency :**	35.0 %
Calibration Date :	2/97	**Calibration Reference :**	GJO-HAN-14	**Logging Procedure :**	P-GJPO-1783

Log Run Information

Log Run Number :	1	**Log Run Date :**	3/18/97	**Logging Engineer:**	Gary Lekvold		
Start Depth, ft.:	0.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	21.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	2	**Log Run Date :**	3/19/97	**Logging Engineer:**	Gary Lekvold		
Start Depth, ft.:	20.0	**Counting Time, sec.:**	100	**L/R :**	R	**Shield :**	N
Finish Depth, ft. :	24.5	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	3	**Log Run Date :**	3/19/97	**Logging Engineer:**	Gary Lekvold		
Start Depth, ft.:	22.5	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	93.5	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Borehole 30-08-02

Log Event A

Log Run Number :	4	**Log Run Date :**	3/20/97	**Logging Engineer:**	Alan Pearson
Start Depth, ft.:	99.0	**Counting Time, sec.:**	100	**L/R :** L	**Shield :** N
Finish Depth, ft. :	92.5	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a

Analysis Information

Analyst : E. Larsen

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/5/97

Analysis Notes :

This borehole was logged by the SGLS in four log runs. Excessive dead time (greater than 50 percent) was encountered during log run one at a depth of 21 ft. As a result, log run two was logged in real time from 20 to 24.5 ft. Log runs three and four were logged in live time from 22.5 to 99 ft, after the dead time dropped below 50 percent.

The pre- and post-survey field verification spectra met the acceptance criteria established for the peak shape and detector efficiency, confirming that the SGLS was operating within specifications. The energy calibration and peak-shape calibration from these spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging operation.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137, Co-60, and Eu-154 were detected around this borehole. Cs-137 contamination was detected continuously from the ground surface to 24.5 ft. Cs-137 contamination was also detected from 27 to 27.5 ft, 47 to 49 ft, and at the bottom of the logged interval (99 ft). The Co-60 contamination was detected continuously from 46.5 to 79.5 ft. The Eu-154 contamination was detected at 2.5 ft and nearly continuously from 19.5 to 22.5 ft.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 and Co-60 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentration values increase at 37.5 ft and generally remain elevated to a depth of 72.5 ft. The K-40 concentrations become increasingly variable between 55 and 74.5 ft. The K-40 concentrations increase again at 74.5 ft and remain elevated to the bottom of the logged interval. The Th-232 concentrations gradually increase near 85 ft to the bottom of the logged interval.

Most of the K-40 and Th-232 concentration data are absent between 20 and 22 ft. The U-238 concentration data are absent between 18 and 23.5 ft and mostly absent between 57.5 and 65 ft.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-108 and C-109.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

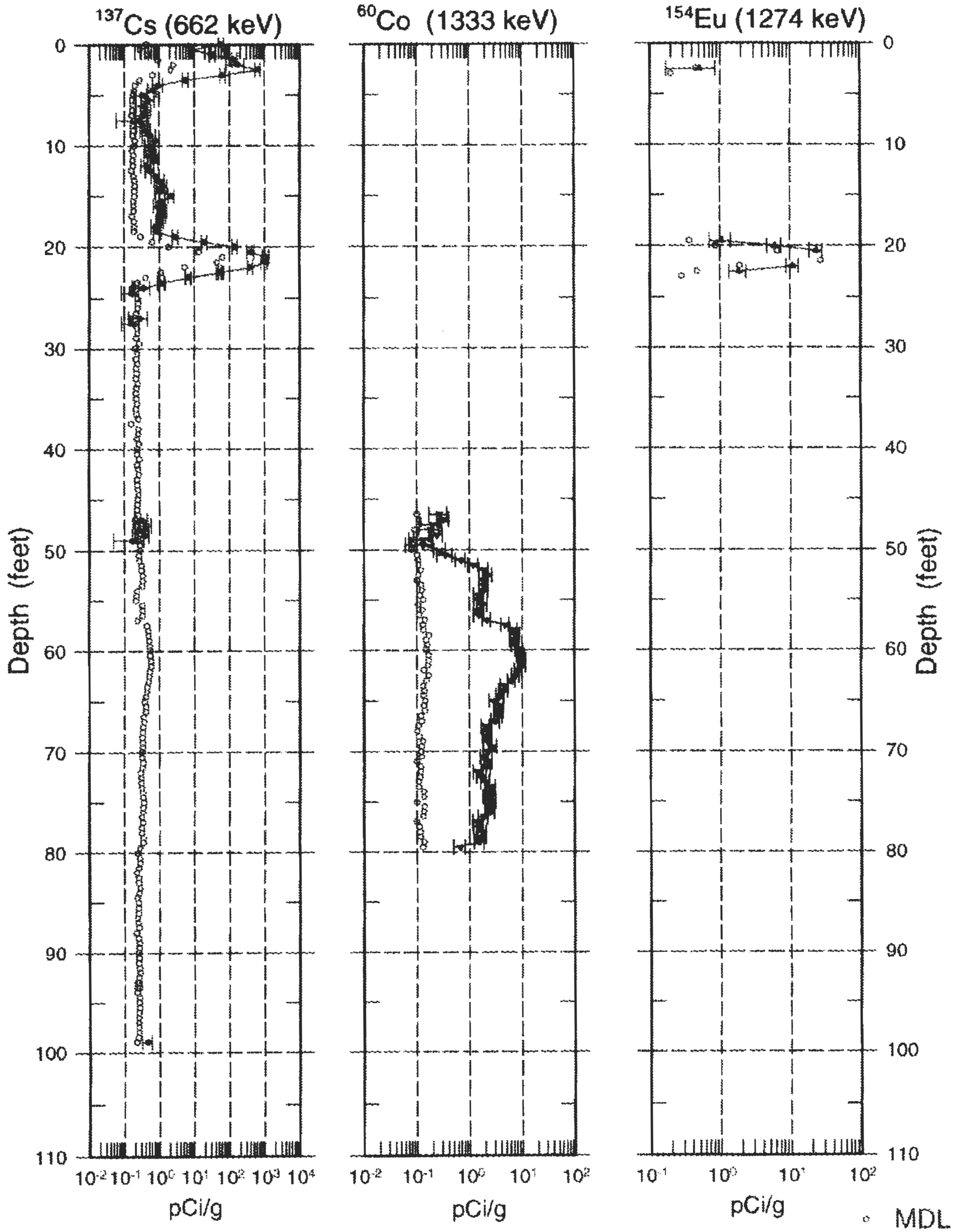
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

A plot of representative historical gross gamma-ray logs from 1980 to 1989 is included. The headings of the plots identify the date on which the data in the plots were gathered.

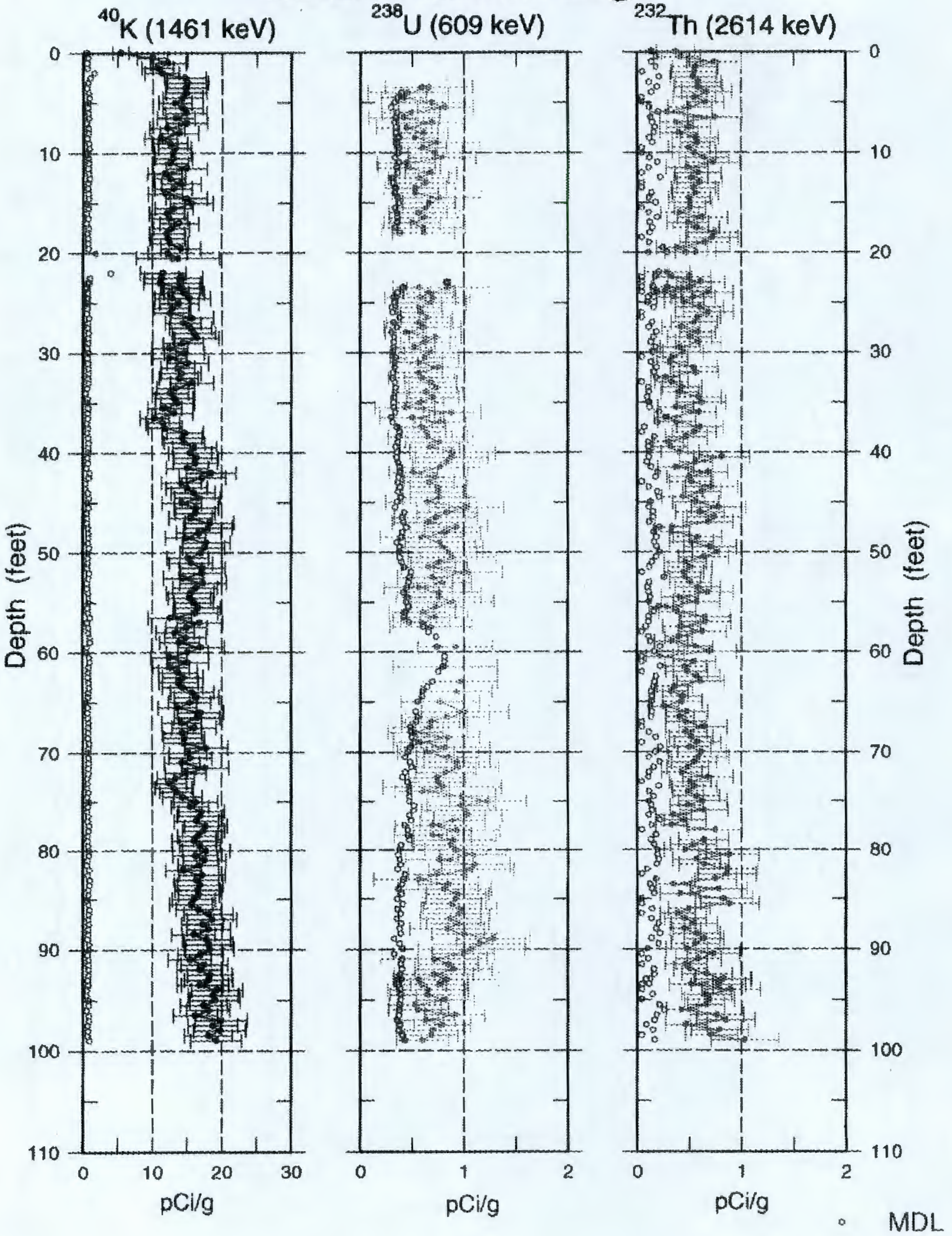
Plots of the spectrum shape factors are also included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-08-02

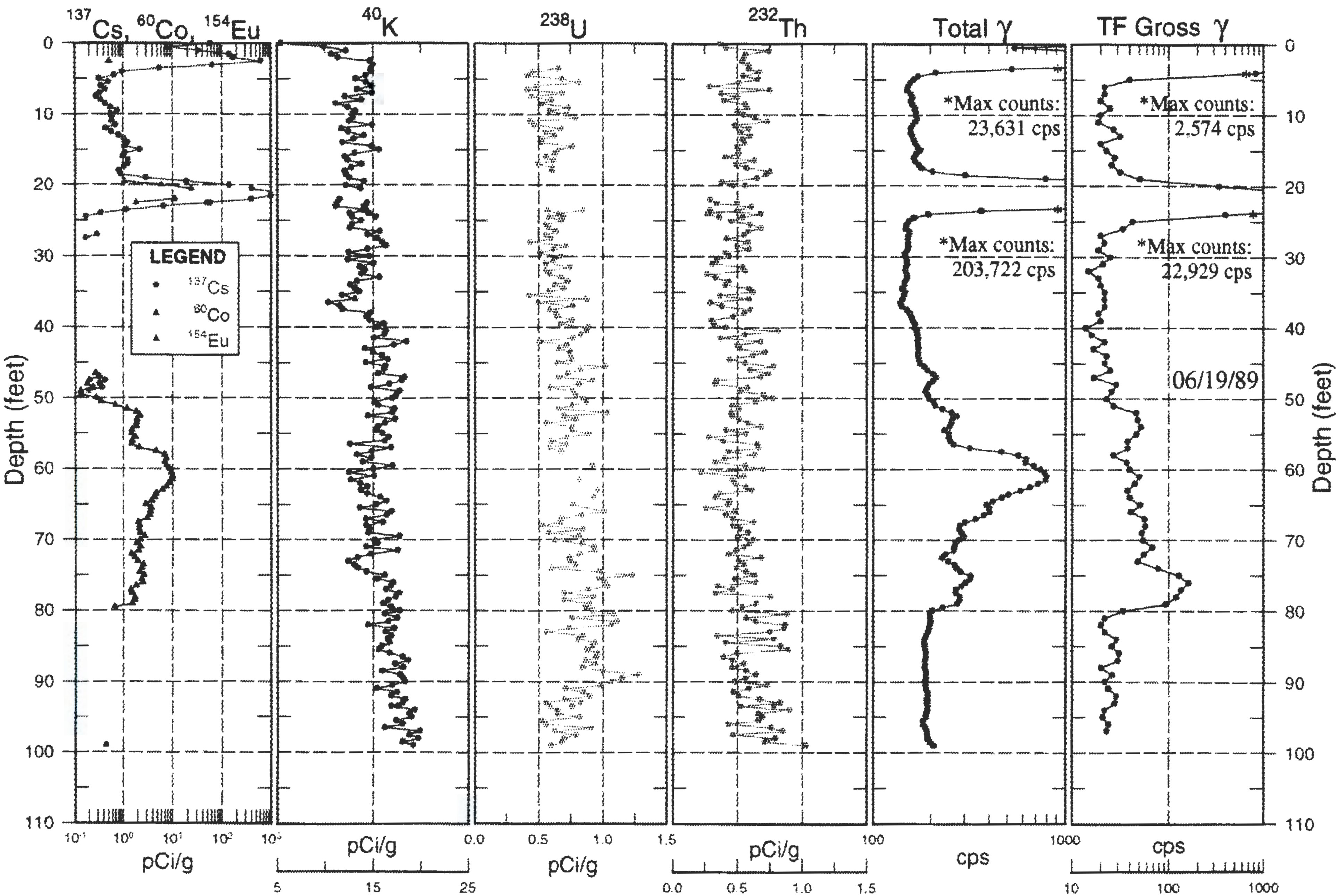
Man-Made Radionuclide Concentrations



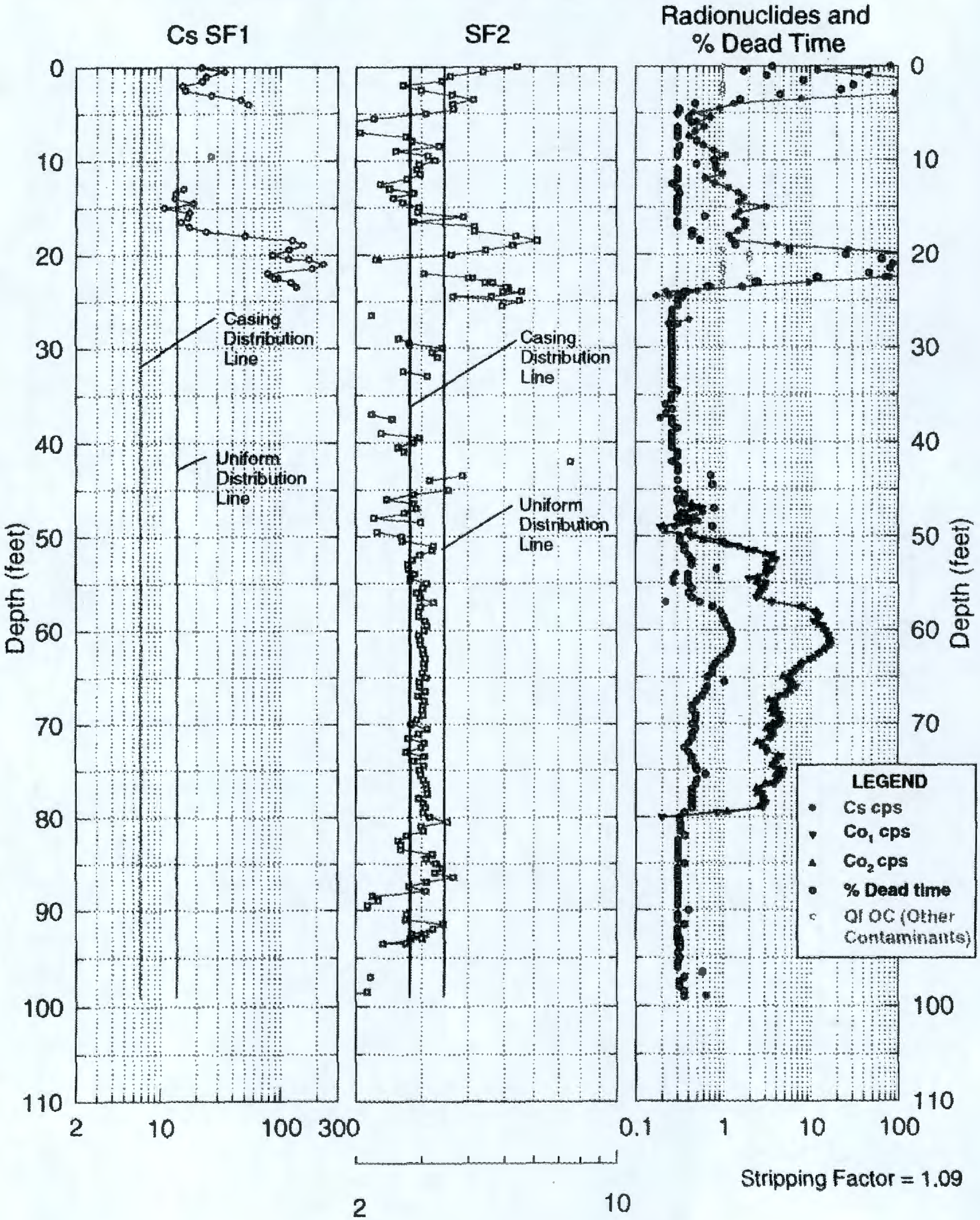
30-08-02
Natural Gamma Logs



30-08-02 Combination Plot

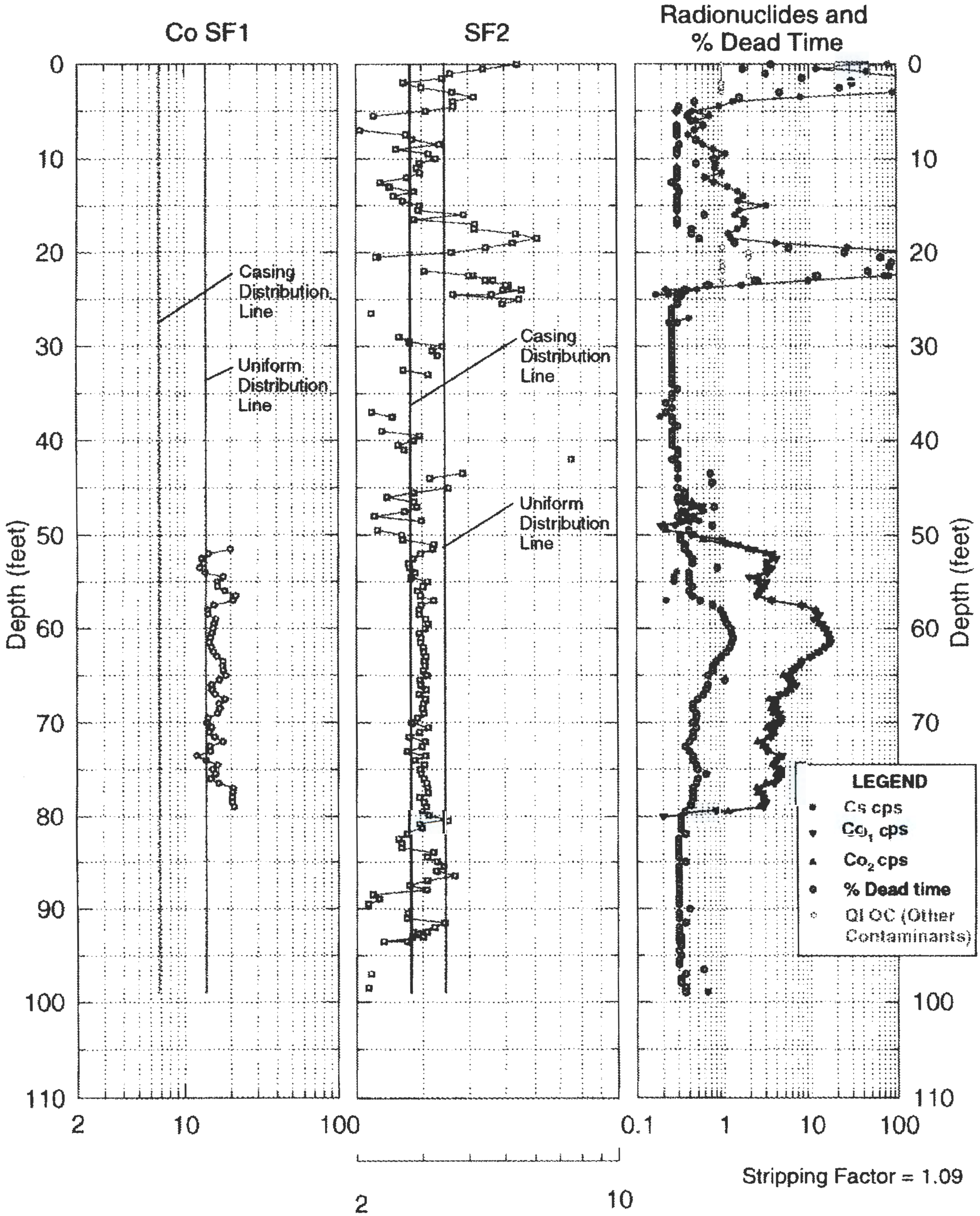


30-08-02
Shape Factor Analysis Logs



Stripping Factor = 1.09

30-08-02
Shape Factor Analysis Logs



Stripping Factor = 1.09

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Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole 30-09-10

Borehole Information

Farm :	C	**Tank :**	C-109	**Site Number :**	299-E27-99
N-Coord :	43,024	**W-Coord :**	48,378	**TOC Elevation :**	645.43
Water Level, ft :	None	**Date Drilled :**	7/31/74		

Casing Record

Type :	Steel-welded	Thickness :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	100		

Borehole Notes:

This borehole was drilled in July 1974 and completed to a depth of 100 ft with 6-in. casing. The casing thickness is presumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. steel tubing. A drilling log was not available for this borehole; however, information presented in Chamness and Merz (1993) indicates that the borehole was not grouted or perforated. The top of the casing, which is the zero reference for the SGLS, is approximately flush with the ground surface.

Equipment Information

Logging System :	1B	**Detector Type :**	HPGe	**Detector Efficiency :**	35.0 %
Calibration Date :	2/97	**Calibration Reference :**	GJO-HAN-14	**Logging Procedure :**	P-GJPO-1783

Log Run Information

Log Run Number :	1	**Log Run Date :**	3/24/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	0.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	18.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	2	**Log Run Date :**	3/25/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	98.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	17.0	**MSA Interval, ft. :**	0.5	**Log Speed, ft/min.:**	n/a		

Log Event A

Borehole 30-09-10

Analysis Information

Analyst : E. Larsen

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/30/97

Analysis Notes :

This borehole was logged by the SGLS in two log runs. The pre-survey and post-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency. The energy calibration and peak-shape calibration from these spectra were used to establish the peak resolution and channel-to-energy parameters used in processing the spectra acquired during the logging operation.

Casing correction factors for a 0.280-in.-thick steel casing were applied during analysis.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The Cs-137 contamination was detected continuously from the ground surface to 67 ft and from 74 ft to the bottom of the logged interval (98 ft). The Co-60 contamination was detected intermittently from 53 ft to the bottom of the logged interval.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The K-40 concentration values increase at 39.5 ft, become variable from 41 to 55 ft, and remain elevated to a depth of 69.5 ft. The K-40 concentrations gradually increase below 69.5 ft and become variable from 80 ft to the bottom of the logged interval.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-109 and C-112.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

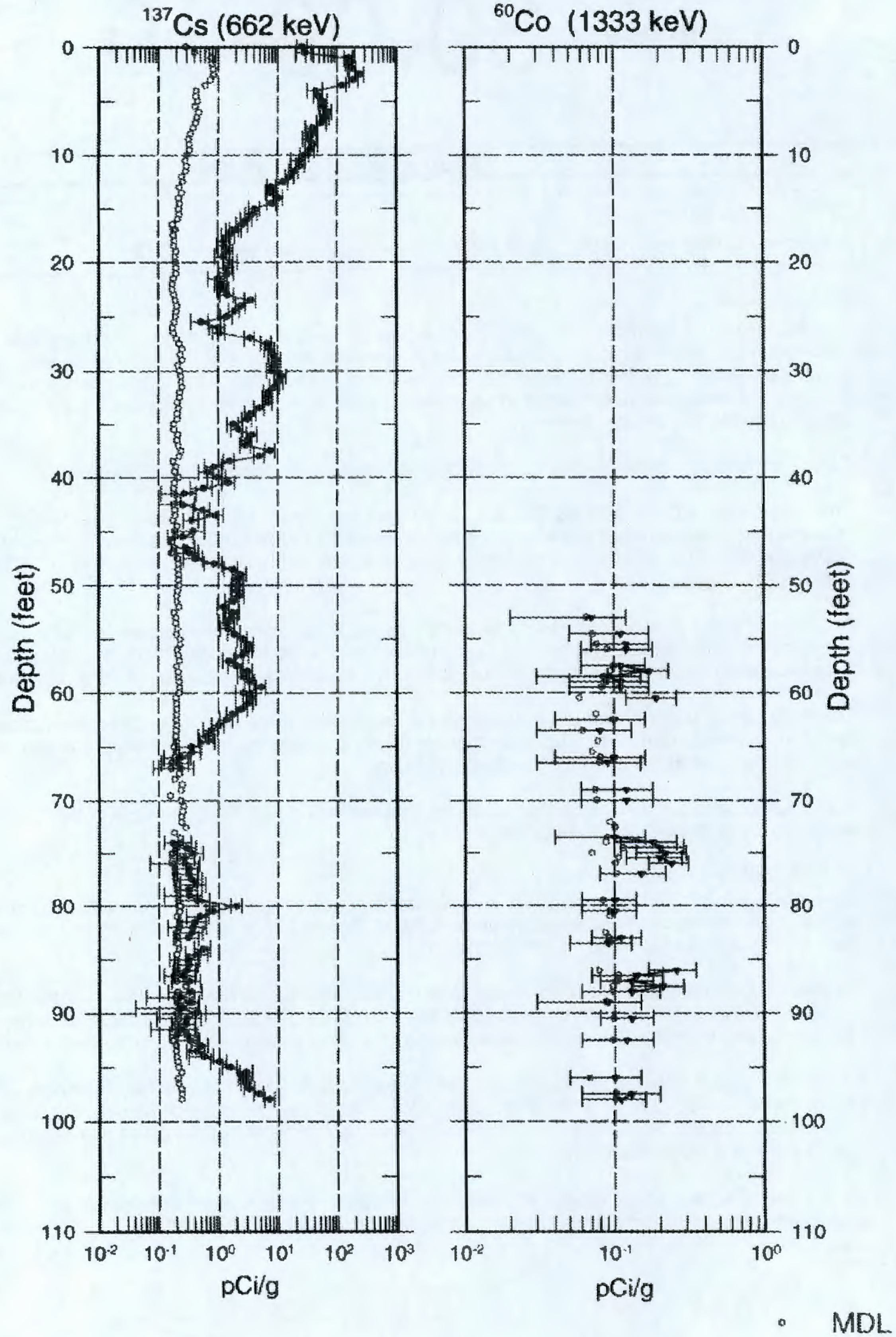
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

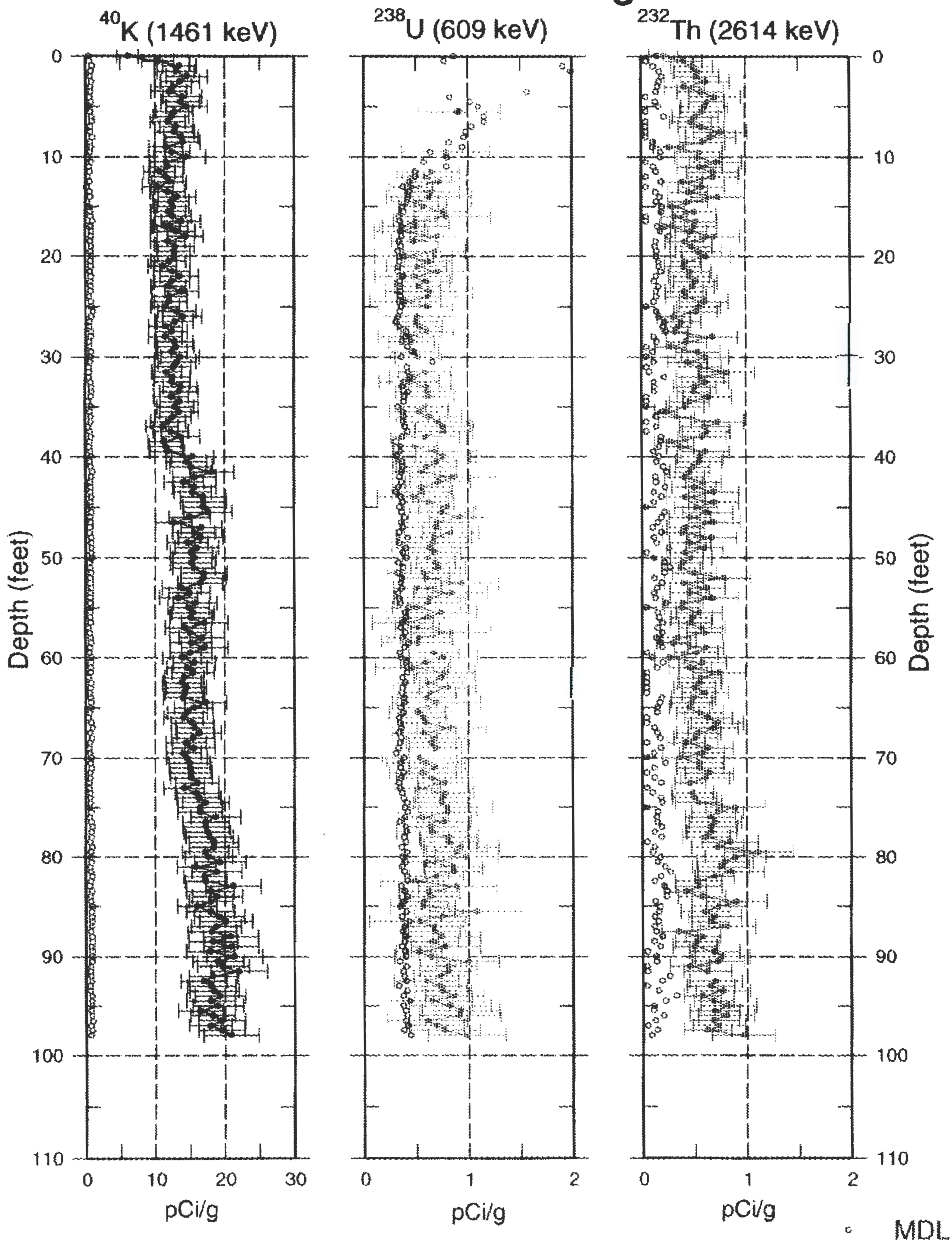
Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-09-10

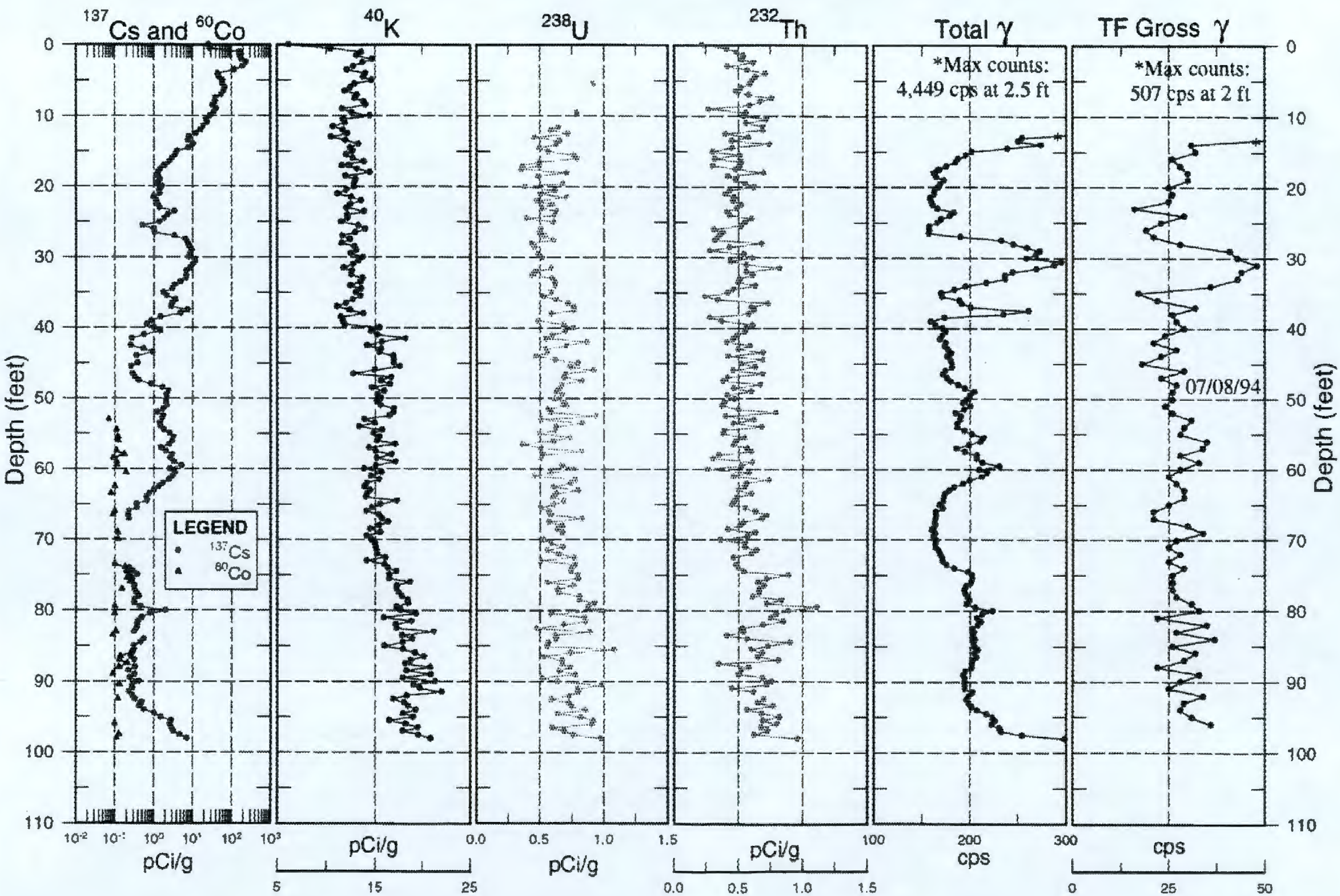
Man-Made Radionuclide Concentrations



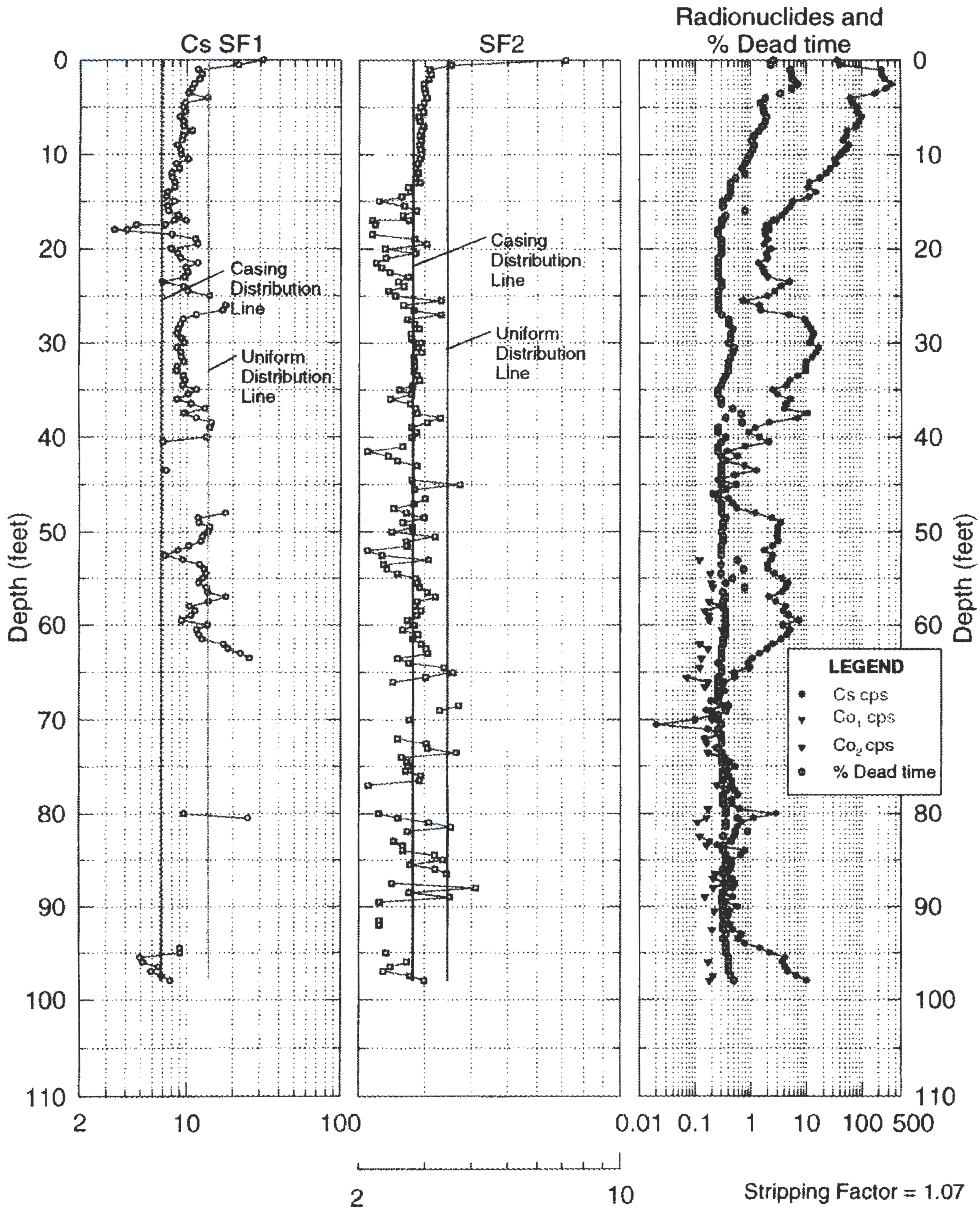
30-09-10
Natural Gamma Logs



30-09-10 Combination Plot



30-09-10
^{137}Cs Shape Factor Analysis Plot



Stripping Factor = 1.07

Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-09-11

Borehole Information

Farm :	C	Tank :	C-109	Site Number :	299-E27-100
N-Coord :	43,045	W-Coord :	48,349	TOC Elevation :	644.99
Water Level, ft :	None	Date Drilled :	7/31/74		

Casing Record

Type :	Steel-welded	Thickness :	0.280	ID, in. :	6
Top Depth, ft. :	0	Bottom Depth, ft. :	100		

Borehole Notes:
This borehole was drilled in July 1974. A driller's log was not available for this borehole. According to Chamness and Merz (1993), the borehole was completed to a depth of 100 ft with 6-in. diameter casing. There was no mention of perforations or grouting; therefore, it is assumed that the casing is not perforated or grouted. The casing thickness is assumed to be 0.280 in., on the basis of the published thickness for schedule-40, 6-in. casing. The top of the casing is the zero reference for the log. The casing lip is approximately even with the ground surface.

Equipment Information

Logging System :	1B	Detector Type :	HPGe	Detector Efficiency :	35.0 %
Calibration Date :	2/97	Calibration Reference :	GJO-HAN-14	Logging Procedure :	P-GJPO-1783

Log Run Information

Log Run Number :	1	Log Run Date :	3/25/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	0.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	10.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	3/26/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	98.5	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	14.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Log Run Number :	3	Log Run Date :	3/27/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	15.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	9.0	MSA Interval, ft. :	0.5	Log Speed, ft/min.:	n/a		

Analysis Information

Analyst : H.D. Mac Lean

Data Processing Reference : MAC-VZCP 1.7.9 Analysis Date : 9/23/97

Analysis Notes :

The SGLS log of this borehole was completed in three logging runs using a centralizer. The pre-survey field verification spectra for all logging runs met the acceptance criteria established for peak shape and system efficiency, but the post-survey field verification spectra for logging run two failed to meet the acceptance criteria. The energy and peak-shape calibration from the pre-survey field verification spectra were used to establish the channel-to-energy parameters used in processing the spectra acquired during the logging runs. There was negligible gain drift during the logging runs and it was not necessary to adjust the established channel to energy parameters to maintain proper peak identification.

Casing correction factors for a 0.280-in.-thick casing were applied during the analysis.

Cs-137 was the only man-made radionuclide detected in this borehole log. Cs-137 contamination was detected continuously from the ground surface to a depth of 15.5 ft, intermittently from 16.5 to 41 ft, continuously from 44.5 to 47.5 ft, at 66.5 ft, and continuously from 93.5 to 98.5 ft. The measured concentration in the upper 12 ft of the logged interval ranged from 2 to 4 pCi/g. The measured Cs-137 concentrations below a depth of about 12 ft ranged from 0.2 pCi/g (just above the MDL) to about 3 pCi/g. Peaks in the measured concentrations occur at depths of 1, 9, 45.5, and 95 ft. The measured Cs-137 concentration at the ground surface was about 19 pCi/g.

An analysis of the shape factors associated with applicable segments of the spectra was performed. The shape factors provide insights into the distribution of the Cs-137 contamination and into the nature of zones of elevated total count gamma-ray activity not attributable to gamma-emitting radionuclides.

The logs of the naturally occurring radionuclides show that the K-40 concentrations increase from a background of about 14 pCi/g from the ground surface to 41 ft, increase to about 16 pCi/g from 41 to 78 ft, and increase again to a background of 17 to 20 pCi/g below 78 ft. The K-40 concentration is variable between 41 and 78 ft, with 5-ft to 7-ft-thick intervals showing slightly higher or slightly lower concentrations.

Increased U-238 concentrations occur from 40.5 to 44.5 ft. The U-238 and Th-232 concentrations peak at 86.5 ft.

Details concerning the interpretation of data for this borehole are presented in the Tank Summary Data Reports for tanks C-109 and C-111.

Log Plot Notes:

Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

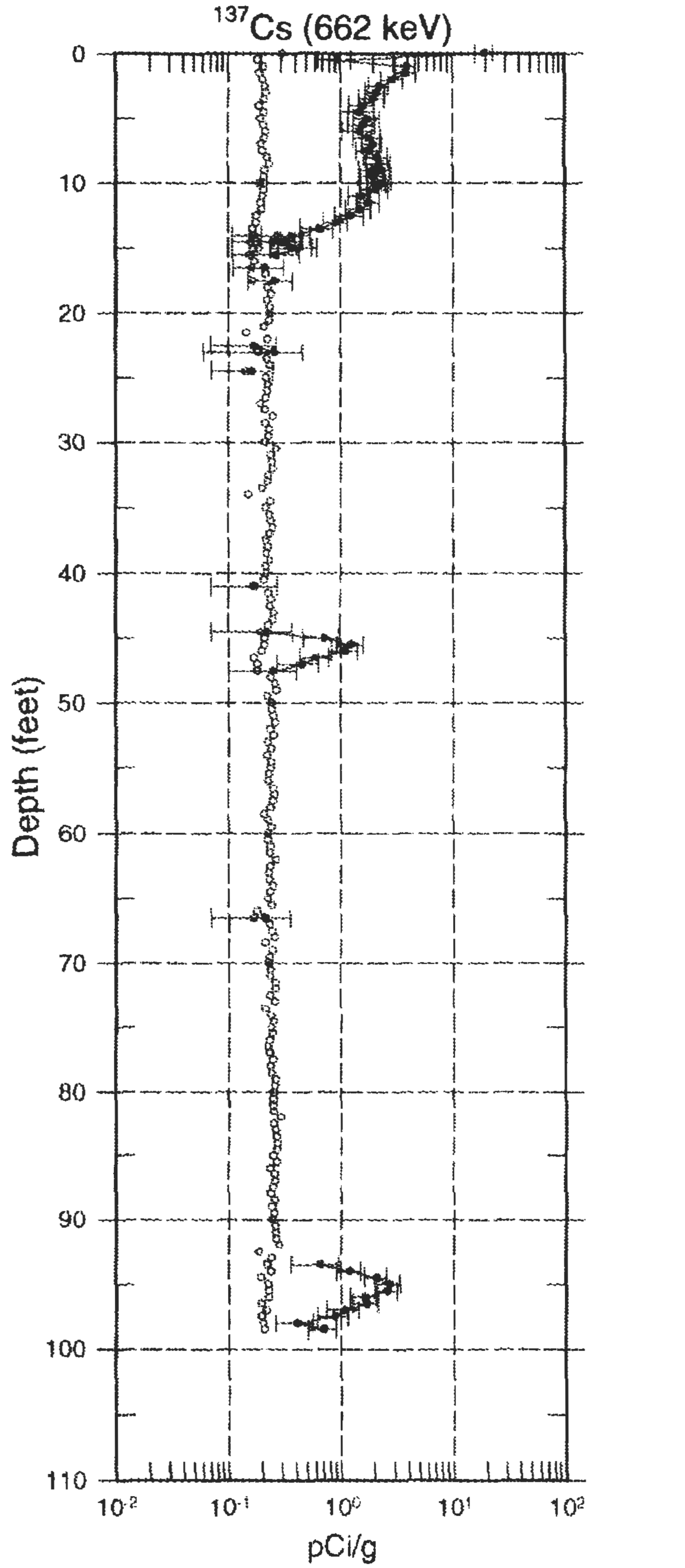
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with the SGLS data.

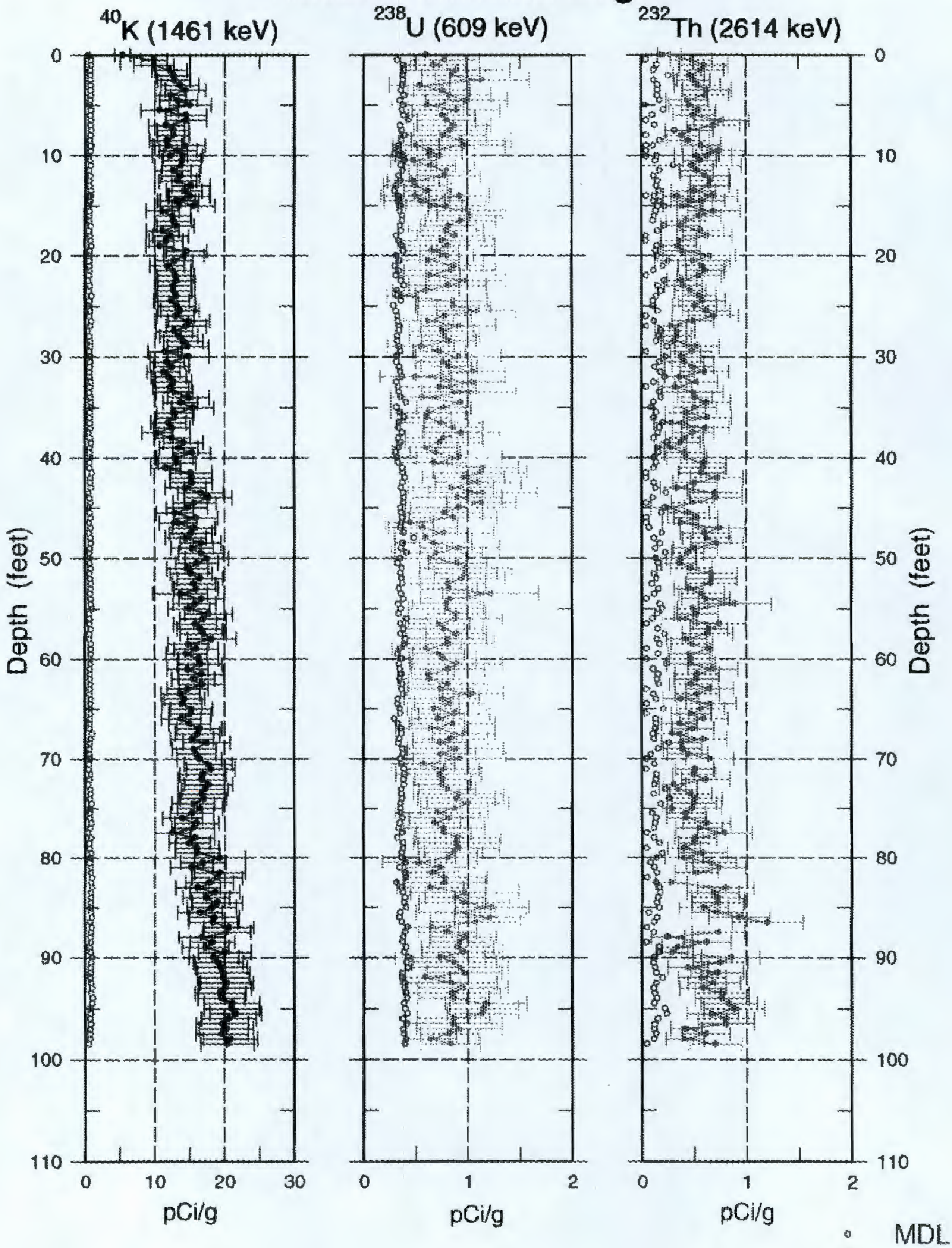
Plots of the spectrum shape factors are included. The plots are used as an interpretive tool to help determine the radial distribution of man-made contaminants around the borehole.

30-09-11

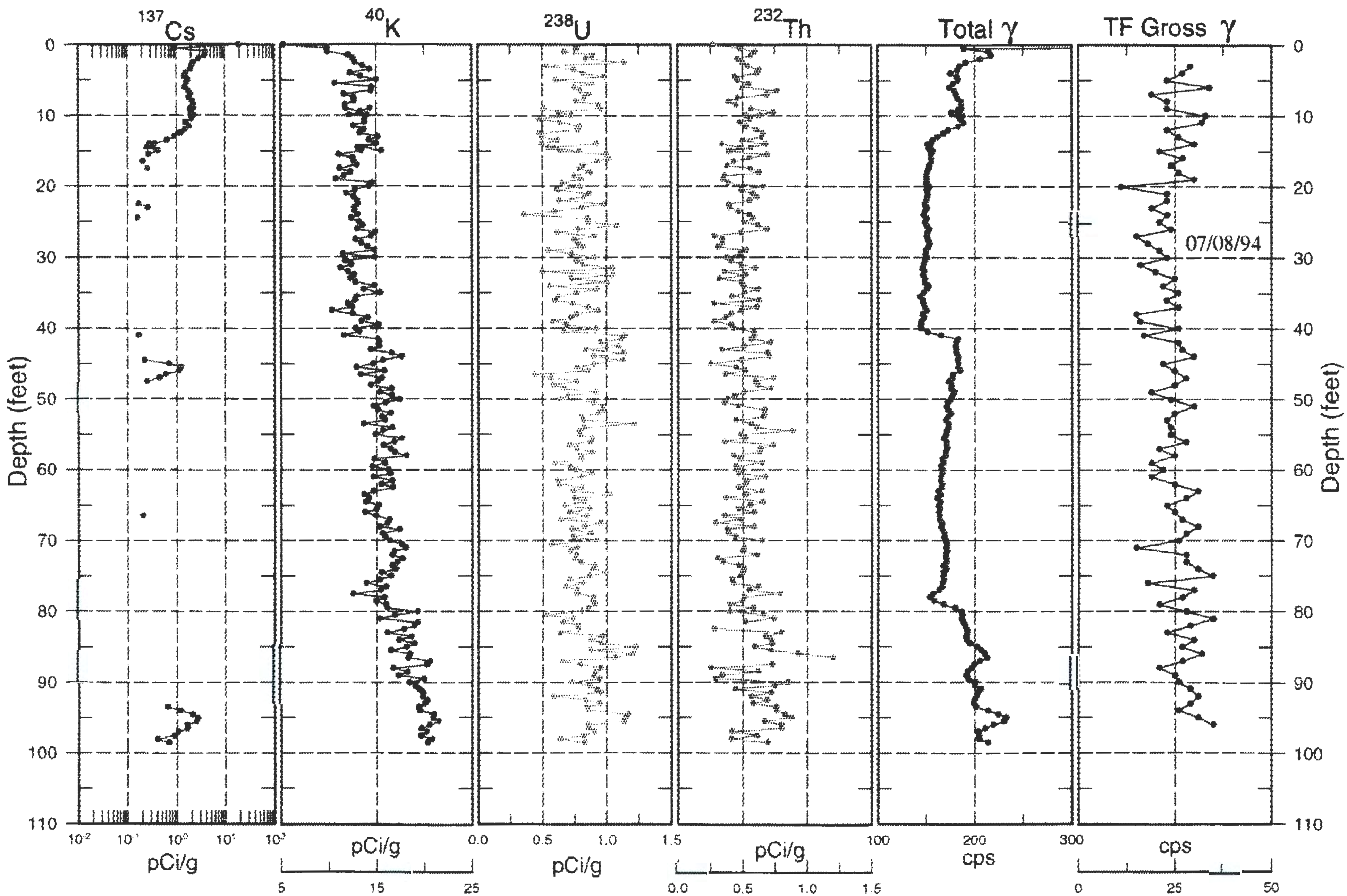
Man-Made Radionuclide Concentrations



30-09-11
Natural Gamma Logs



30-09-11 Combination Plot



30-09-11 ^{137}Cs Shape Factor Analysis Plot