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Tank C–106

Vadose Zone Characterization Project at the Hanford Tank Farms

Tank Summary Data Report for Tank C–106

August 1997

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U.S. Department of Energy

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

Prepared by
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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 1995c) and baseline monitoring plan (DOE 1995d). 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.

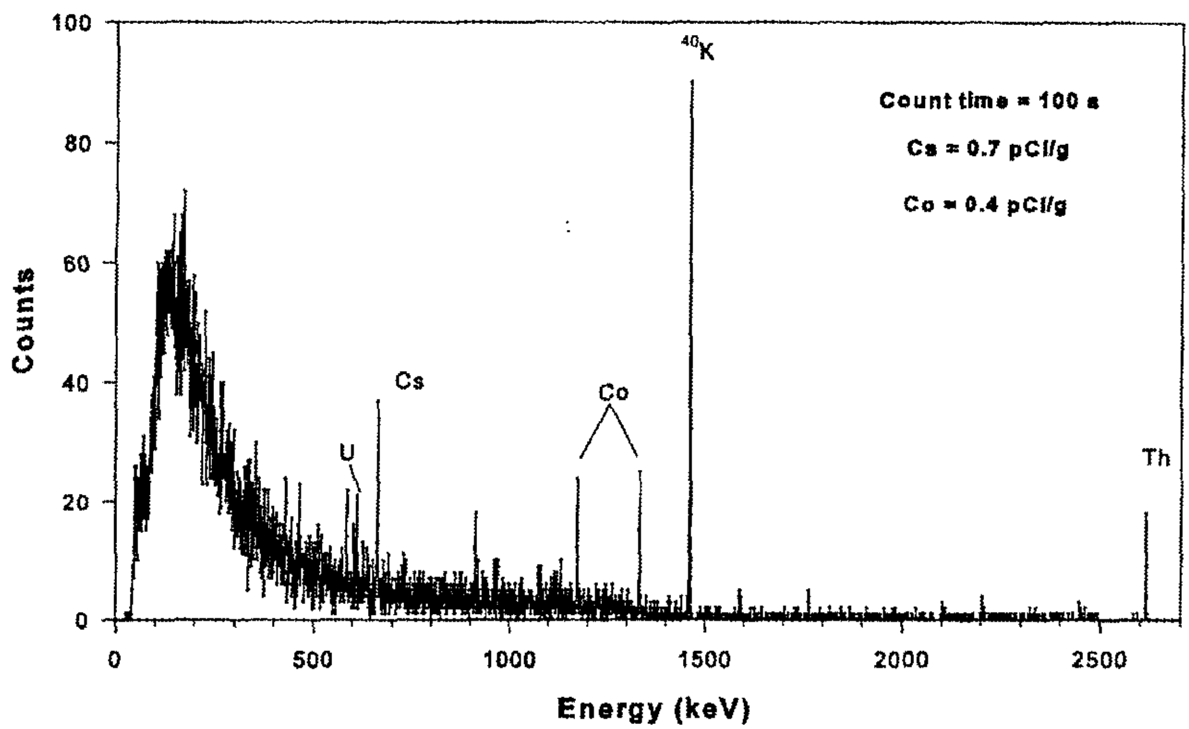

Figure 1. Gamma-Ray Spectrum

Data are acquired in boreholes in boreholes near the tanks according to methods described in the logging procedures (DOE 1995b). 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 1996b).

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 1996b). 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 1996a) 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 1996b) describes the application of the correction function in the data processing.

2.2 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-106," 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, allow 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.

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. 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,

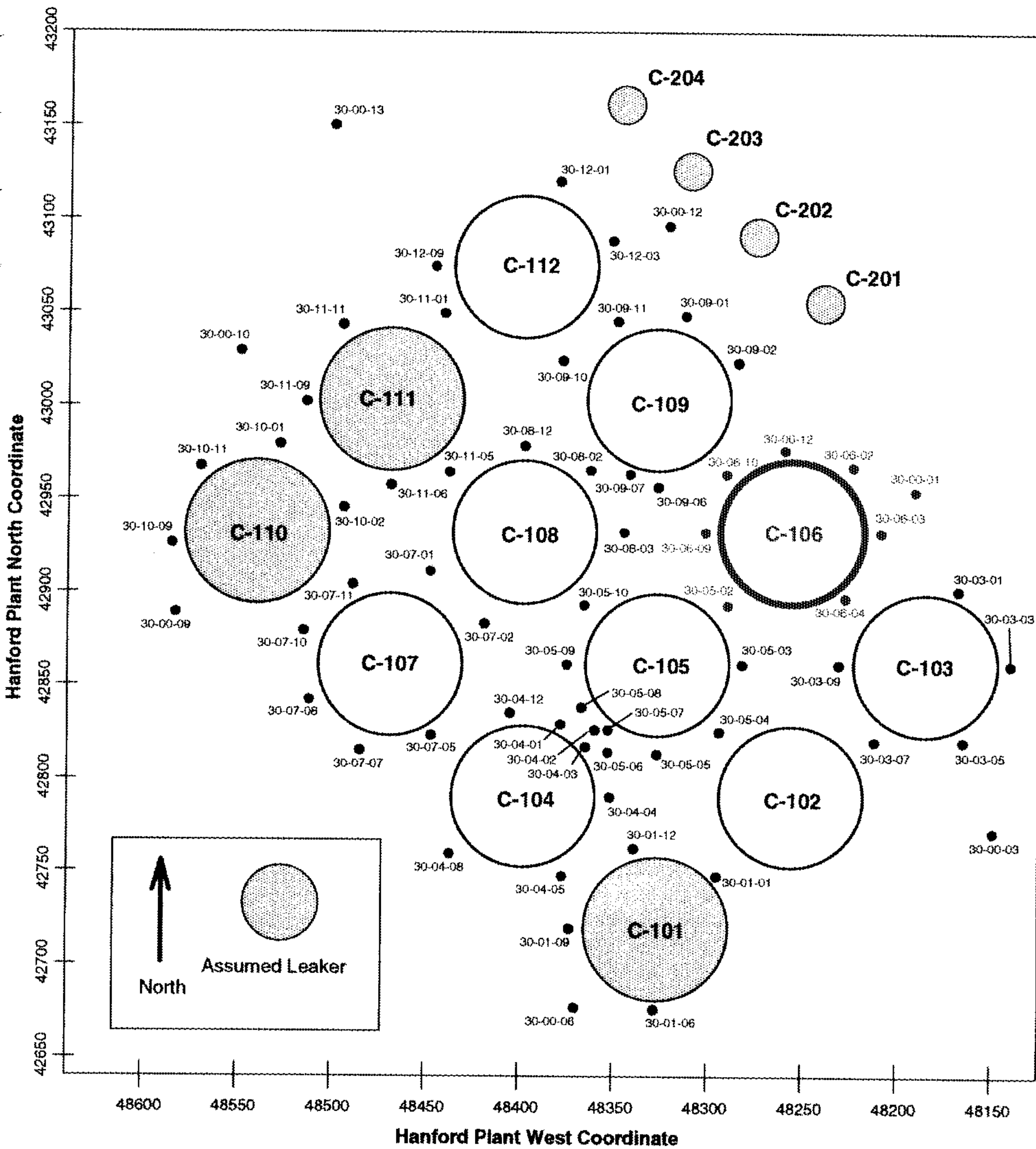

Figure 2. Plan View of Tanks and Boreholes in the C Tank Farm

-105, -108, -109, -111, -112, -201, -202, -203, and -204 are not equipped with primary leak-detection sources (Hanlon 1997).

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 1997). 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 1997). Detailed descriptions of the waste streams are presented in Anderson (1990) and Agnew (1995 and 1997). On the basis of information presented in Agnew (1997), 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-106

Tank C-106 was constructed during 1943 and 1944 and was placed into service in June 1947 (Welty 1988). Beginning in July 1947, metal waste from tank C-105 was cascaded into tank C-106, and the tank was filled to capacity by November 1947 (Anderson 1990). Water from a hose was believed to be the cause of a level increase in the tank during the first quarter of 1951. The metal waste in tank C-106 was sluiced for uranium recovery during the first quarter of 1953, and the tank functioned as a metal waste supernatant blend tank until the second quarter of 1954. Between 1954 and 1976, tank C-106 also received numerous waste types including U Plant waste, PUREX high-level waste, cladding waste, sludge supernatant, B Plant low-level waste, decontamination waste, strontium sludge, uranium recovery waste, coating waste, and waste water (Anderson 1990; Agnew 1996).

A program to recover strontium and cesium from aging waste stored in the A and AX Tank Farms was implemented in the late 1960s (Ecology 1992). The recovery process required washing the accumulated slurries with water to remove desirable soluble constituents from the waste. After settling, the supernate was decanted and pumped to tank C-106 and then pumped to tank C-105 for shipment to B Plant. Once the supernate arrived at B Plant, the wash solution was processed to recover cesium. This decanting process proved ineffective, and strontium solids were held in solution and transferred with the wash solution back to tank C-106 and in lesser amounts to tank C-105, where they accumulated (Ecology 1992).

In 1971, wastes within tank C-106 reached temperatures of 212 °F (Ecology 1992). A report by Atlantic Richfield Hanford Company attributed the rise in temperature to unacceptable quantities of strontium being transferred with the wash solution during the waste recovery process (Walker 1977). Transfers to tanks C-105 and C-106 were halted because these tanks were not designed or equipped for storing high-heat-generating (self-boiling) waste. Since 1971, tanks C-105 and C-106 have been actively ventilated with an exhauster system and water has been added periodically to keep the wastes wet and promote cooling (Ecology 1992).

Tank C-106 was removed from service and declared inactive in 1979. The tank was partially isolated in August 1983, and a level adjustment was made in April 1984. Various level changes during the 1980s can be explained by the water additions required to keep the tank temperature at a manageable level (Brevick et al. 1994b).

In 1992, an investigation by the Washington State Department of Ecology reported deficiencies in the preventive and contingency planning (Ecology 1992). It was concluded that gross liquid losses remained unaccounted for and that the integrity of tank C-106 remained suspect. The investigators also determined that leak-detection monitoring data from the current DOE/Westinghouse Hanford Company (WHC) systems were often poor or inadequate (Ecology 1992).

Representatives from Ecology met with officials from DOE-Richland Operations and WHC on July 22, 1992 to discuss leak detection and contingency planning for tanks C-105 and C-106 (Brodeur 1993). WHC agreed to perform spectral gamma-ray logging of the 14 boreholes surrounding tanks C-105 and C-106 with the Radionuclide Logging System (RLS), the intrinsic germanium logging system that was the predecessor to the SGLS. The logging operation was completed in April 1993; evidence of a large active leak was not identified from either tank in the assessment of the RLS data (Brodeur 1993).

Formerly, the surface level of the waste in tank C-106 was monitored with a Food Instrument Corporation (FIC) gauge. The liquid waste volume was determined by the FIC gauge and the solid waste volume was determined by a sludge level measurement device (Brevick et al. 1994b).

In February 1996, an ENRAF gauge was installed in tank C-106; this gauge is currently the primary instrument used for surface-level measurements and leak detection (Hanlon 1997).

Tank C-106 is categorized as "sound/deactivated" (Welty 1988). The tank is currently listed as containing noncomplexed waste (Hanlon 1997). The tank was placed on the High Heat-Load Watch List in January 1991 (Brevick et al. 1994b) and has been classified as partially isolated because water is added for cooling. The tank presently contains 197,000 gal of sludge (including 16,000 gal of drainable, interstitial liquid) and 32,000 gal of supernate (Hanlon 1997).

4.0 Boreholes in the Vicinity of Tank C-106

Eight vadose zone monitoring boreholes surround tank C-106. These boreholes are 30-06-02, 30-00-01, 30-06-03, 30-06-04, 30-05-02, 30-06-09, 30-06-10, and 30-06-12. All the boreholes are associated with tank C-106, except boreholes 30-05-02 and 30-00-01. Borehole 30-05-02 is associated with tank C-105. Borehole 30-00-01 is not associated with any tank in the C Tank Farm but is within proximity of tank C-106. Figure 2 shows the location of each borehole in red.

All the boreholes, except 30-00-01, are lined with 6-in.-inside-diameter steel casing. Borehole 30-00-01 is lined with 8-in.-inside-diameter steel casing. A section of 12-in.-inside-diameter steel casing surrounds the upper portion of the 8-in. 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 seven 6-in. boreholes and the single 8-in. borehole are assumed to be 0.280 in. and 0.313 in., respectively, on the basis of the published thickness for schedule-40, carbon-steel casing. The algorithm used for the calculation of radionuclide concentrations in borehole 30-00-01 did not include an attenuation correction factor for the region of the borehole containing the 12-in. casing. As a result, calculated radionuclide concentration values are reduced by approximately 35 to 40 percent along the dual-cased interval of the borehole.

The following sections present the analysis and interpretation of the SGLS data that were collected from the boreholes surrounding tank C-106. These boreholes 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.

As discussed in Section 3.2, WHC performed spectral gamma logging of 14 boreholes surrounding tanks C-105 and C-106 in 1993 using the RLS. The RLS used a lower efficiency detector and shorter data acquisition time than the SGLS; therefore, the 1993 RLS data exhibit a higher degree of uncertainty than the 1997 SGLS data. In addition, the 1997 SGLS data in some cases do not show very low concentrations of contamination where the 1993 RLS data do. This occurs because the 1997 SGLS concentration data are suppressed if the concentration is less than the MDL. This suppression did not occur with the 1993 RLS data and as a result, some of the 1993 data reported could be false detections. Also, the RLS was unable to log the bottom 6 ft of a borehole because the logging tool housing extended 6 ft below the position of the detector within the logging tool. However, the 1993 RLS data are quantitative spectral gamma-ray log data and are of high quality that allow comparison to the 1997 SGLS data. Individual plots comparing the measured concentrations of man-made radionuclides from 1993 and 1997 for each borehole are included in Appendix A.

The following sections present results of the spectral gamma-ray log data collected from these boreholes. Appendix A contains the plots of the log data. The most recent historical gross gamma data are presented on the combination plots in Appendix A. These data, historical gross gamma logs from 1975 to 1996, the RLS logging data, and results from other investigations were used in the preparation of this report.

4.1 Borehole 30-06-02

Borehole 30-06-02 is located approximately 6 ft from the northeast side of tank C-106. It was given the Hanford Site designation 299-E27-72. This borehole was drilled in November 1972 to a depth of 125 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 122.5 ft.

The man-made radionuclide ^{137}Cs was detected in this borehole. The presence of ^{137}Cs was measured continuously from the ground surface to a depth of 14.5 ft, delineating near-surface and shallow subsurface contamination. Numerous zones of continuous ^{137}Cs contamination were detected from 23.5 to 56 ft, 115 to 117 ft, and 121.5 to 122.5 ft. The maximum ^{137}Cs concentration was 9.3 pCi/g within the near-surface contamination and 5.8 pCi/g within the shallow subsurface contamination. The highest ^{137}Cs concentration was 11.9 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.

The KUT concentrations were derived from the SGLS logs. The drilling log for this borehole reports the base of the backfill material to be at approximately 39 ft. However, no significant concentration changes are shown on the KUT plots at this depth. The ^{232}Th concentration values increase at about 48.5 ft. The ^{40}K concentration values become slightly elevated and increasingly variable from 48 to 71.5 ft, increase below about 75 ft, and remain elevated to the bottom of the logged interval. The drilling log reports coarse sand from 42 to 60 ft, sand and gravel from 60 to 75 ft, and coarse sand below 75 ft. The drilling log generally supports the interpretation that the variation in the ^{40}K concentration values between 48 and 71.5 ft may represent the basal region of the gravel-dominated facies of the Hanford formation, and the increase in the ^{40}K concentrations at 75 ft probably represents the contact with the sand-dominated facies of the Hanford formation.

The SGLS total gamma-ray plot reflects the presence of the man-made radionuclides in the upper region of the vadose zone and the naturally occurring radionuclides elsewhere. The increase in the SGLS total count rate below a depth of about 48 ft corresponds to the increases shown on the ^{40}K and ^{232}Th concentration plots. The count rate steadily increases from 75 to 95 ft, generally corresponding with increases in ^{40}K concentrations within this depth range.

A data 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 very good repeatability of the data in the upper 15 ft of the vadose zone where the ^{137}Cs concentrations range from 2 to 10 pCi/g. In the deeper regions of the vadose zone, good repeatability of the data is evident only in areas where the ^{137}Cs concentrations exceed about 0.5 pCi/g.

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 plot does not illustrate the near-surface peak that is shown on the SGLS plot because no data were collected between 1 and 5 ft. However, the zone of ^{137}Cs contamination between 5 and 14 ft on the SGLS plot is evident on the gross gamma plot as a zone of slightly anomalous gamma-ray activity.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The shallow subsurface zone of ^{137}Cs contamination detected between 6.5 and 14 ft may represent surface contamination that has migrated along the surface of the tank dome into this region of the vadose zone. The zone of ^{137}Cs contamination detected between 39 and 40 ft may have resulted from the accumulation of tank-dome runoff that migrated along the outside of the tank to the base of the tank farm excavation. The relatively smaller amounts of ^{137}Cs contamination detected directly below these zones were probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing. The ^{137}Cs contamination near the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole or accumulated around the outside of the borehole casing.

4.2 Borehole 30-00-01

Borehole 30-00-01 is located approximately 27 ft from the east-northeast side of tank C-106. It was given the Hanford Site designation 299-E27-56. This borehole was drilled in December 1944 to a depth of 145 ft. The borehole was started with a 45-ft length of permanent 12-in. surface casing and was completed to a nominal depth of 145 ft using 8-in. casing. The 8-in. casing was perforated from 43 to 143 ft, and according to the drilling log, the bottom of the 8-in. casing was sealed with half a sack of cement. The drilling log does not indicate if the annulus between the 8-in. and 12-in. casing was grouted. The thicknesses of the 8-in. and 12-in. casings are presumed to be 0.313 in. and 0.500 in., respectively. The top of the 8-in. 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 67.5 ft.

The current total depth of the borehole was measured at 68.1 ft below the top of the casing using a weighted tape, although this borehole was drilled to a total depth of 145 ft in 1944. The total depths of historical gross-gamma log runs have become progressively shallower over time, decreasing from 102 ft in 1975 to 67 ft in 1993. This indicates that the casing perforations have allowed loose sand to infiltrate into and slowly fill the borehole or sand and silt has entered the hole from the surface.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The presence of ^{137}Cs was measured continuously from the ground surface to 20.5 ft, intermittently from 21.5 to 44.5 ft, and continuously from 45.5 ft to the bottom of the logged interval (67.5 ft), delineating two distinct zones of ^{137}Cs contamination. The highest ^{137}Cs concentration was 24.2 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 source-to-detector geometry used in the calibration.

The presence of ^{60}Co was detected at low concentrations between 58.5 ft and the bottom of the logged interval, delineating a contaminant plume that coexists with the ^{137}Cs contamination in the lower region of the borehole. The maximum ^{60}Co concentration within the plume was 0.21 pCi/g.

The ^{137}Cs concentrations measured between 5 and 50.5 ft are reduced by the attenuation of the 661-keV gamma-ray energies along the double-cased interval of this borehole. The radioassays may be reduced as much as 50 percent, as indicated by the region of relatively lower ^{40}K concentration values. As a result, the profile of the ^{137}Cs concentration values detected by the SGLS are not representative of the actual contaminant concentrations. In addition, potentially low ^{60}Co concentrations within the backfill material may not have been detected by the SGLS because the ^{60}Co radioassays may have been reduced below the detection limit along the double-cased interval.

Relatively lower ^{40}K concentration values were detected from 5 to 50.5 ft, corresponding with the double-cased interval of the borehole. The presence of the 12-in. outer casing along this interval has attenuated the 1460-keV gamma ray, resulting in ^{40}K concentration values that are approximately 50 percent of the ^{40}K concentration values above and below the double-cased interval. Similarly, the 609-keV and 2614-keV gamma rays are attenuated by the double-cased interval, resulting in reduced ^{238}U and ^{232}Th concentration values. Furthermore, many of the 609-keV and some of the 2614-keV gamma-ray energies in this region were not detected by the SGLS because the ^{238}U and ^{232}Th radioassays were reduced below the detection limit by casing attenuation.

It was not possible to identify many of the 609-keV peaks used to derive the ^{238}U concentrations near the ground surface and below the double-cased interval. 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 presence of the man-made radionuclides in the near-surface portion of the borehole and the attenuation of the naturally occurring radionuclides along the double-cased portion of the borehole. The increase in the SGLS total count rate below a depth of 50 ft corresponds with significant increases shown on the ^{137}Cs and ^{40}K concentration plots, indicating the bottom of the double-cased interval.

The historical gross gamma log data from 1975 to 1993 were reviewed. The most recent historical gross gamma data are presented on the combination plot. The plot does not illustrate the near-surface peak that is shown on the SGLS plots because no data were collected at the 1-ft and 2-ft intervals. However, this peak is clearly evident on many of the historical gross-gamma logs that were reviewed. The gross-gamma log plot illustrates attenuation of the gamma-ray flux along the double-cased portion of the borehole.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that migrated down into the backfill surrounding the borehole.

The subsurface zone of coexisting ^{137}Cs and ^{60}Co contamination may represent a contaminant plume that originated from a nearby subsurface source (i.e., a tank leak) that migrated laterally and downward through the vadose zone. The vertical extent of the contamination cannot be determined because of the limited depth logged by the SGLS.

4.3 Borehole 30-06-03

Borehole 30-06-03 is located approximately 5 ft from the east side of tank C-106. It was given the Hanford Site designation 299-E27-84. This borehole was drilled in June 1974 to a depth of 100 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 98.5 ft.

The man-made radionuclide ^{137}Cs was detected in this borehole. ^{137}Cs contamination was measured continuously from the ground surface to a depth of 72.5 ft. A zone of high ^{137}Cs contamination (as much as 100 pCi/g) was detected between the ground surface and a depth of 2 ft. A thick zone of low to moderate ^{137}Cs contamination was detected from 5 to 76.5 ft. This zone contains discrete layers of elevated ^{137}Cs contamination that range in concentration from 2 to 10 pCi/g. An isolated occurrence of ^{137}Cs was also detected at 98.5 ft. The maximum ^{137}Cs concentration was 94.7 pCi/g within the near-surface zone of contamination.

The ^{40}K concentration values are slightly elevated between 46 and 80 ft. The ^{40}K concentration values increase below 80 ft and remain elevated to the bottom of the logged interval. The drilling log for this borehole was not sufficiently detailed to support or contradict the interpretation of the changes shown on the KUT plots. However, the increase in the ^{40}K concentration values at about 80 ft probably represents the contact between the gravel- and sand-dominated facies of the Hanford formation.

Between the ground surface and 3 ft, it was not possible to identify most of the 609-keV peaks used to derive the ^{238}U concentrations. 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 presence of the man-made radionuclides in the upper and middle regions of the borehole and the changes in the naturally occurring radionuclides in the lower region of the borehole. The numerous peaks that occur in the SGLS total count rate between the ground surface and 60 ft correspond closely to the peaks shown on the ^{137}Cs concentration plot. The total count rate steadily increases from 75 ft to the bottom of the logged interval, generally corresponding with increases in KUT concentrations within this depth range.

A data 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 poor repeatability of the ^{137}Cs data between the ground surface and 4 ft. This may be the result of migration of the ^{137}Cs due to infiltration of water. Generally excellent repeatability of the ^{137}Cs data occurs between 4 and 70 ft.

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 plot does not illustrate the near-surface peak that is shown on the SGLS plot because no data were collected between 1 and 5 ft. However, this peak is clearly evident on the earliest recorded historical gross gamma log (January 1975). The zone of increased ^{137}Cs contamination at 5 ft shown on the SGLS plot is evident on the gross gamma plot as a zone of slightly anomalous gamma-ray activity.

Summaries of the historical gross-gamma log data from 1974 to 1987 are presented in Welty (1988). A slightly anomalous zone of contamination was identified at a depth of about 25 ft between 1975 and 1979. The activity within this zone decreased to below background levels by early 1980.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The zone of increased ^{137}Cs contamination at 27 ft may be the result of a subsurface leak from a nearby pipeline. The relatively smaller amounts of ^{137}Cs contamination detected directly below these zones were probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing. The ^{137}Cs contamination at the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole.

Based on an assessment of RLS data, Brodeur (1993) concluded that some of the ^{137}Cs contamination detected around this borehole may not have originated from surface deposition. The elevated ^{137}Cs contamination detected at 27 ft may indicate the presence of a subsurface source and correlates with a region of slightly anomalous gamma-ray activity detected as early as January 1975. Below this interval, the layers of increased concentration at depth and the persistence of the contamination with depth is not consistent with a typical surface contamination source (Brodeur 1993). The recent SGLS data support these interpretations.

4.4 Borehole 30-06-04

Borehole 30-06-04 is located approximately 3 ft from the southeast side of tank C-106. It was given the Hanford Site designation 299-E27-73. 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 129.5 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The presence of ^{137}Cs was measured continuously from the ground surface to a depth of 57 ft, delineating a broad zone of moderate to high ^{137}Cs concentrations in the upper portion of the borehole and zones of relatively higher ^{137}Cs concentrations at depths of about 26, 40, and 52 ft. Numerous occurrences of ^{137}Cs were detected at low concentrations (less than 0.5 pCi/g) from 58.5 to 66 ft and 119 to 129.5 ft. Isolated occurrences of ^{137}Cs were detected between 71 and 111 ft. The highest ^{137}Cs concentration (153 pCi/g) was measured 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.

The presence of ^{60}Co was detected continuously from 85 to 90.5 ft and at 93 ft. The ^{60}Co contamination was detected at very low concentrations and delineates a minor contaminant plume located at considerable depth below the majority of the ^{137}Cs contamination.

The drilling log for this borehole reports the base of the backfill material at a depth of approximately 39 ft. However, no significant concentration changes are shown on the KUT plots at this depth. The ^{40}K concentration values increase gradually from 43 to 49 ft, then remain elevated and become increasingly variable to a depth of 75 ft. The ^{40}K concentration values increase again at about 79 ft and generally remain elevated to the bottom of the logged interval. The variation in the ^{40}K concentration values between 49 and 75 ft may represent the basal region of the gravel-dominated facies of the Hanford formation. The increase in the ^{40}K concentrations at 79 ft probably represents the contact with the sand-dominated facies of the Hanford formation.

Between the ground surface and 27 ft, it was not possible to identify many of the 609-keV peaks used to derive the ^{238}U concentrations. 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 presence of the man-made radionuclides in the upper region of the borehole. The numerous peaks in the SGLS total count rate between the ground surface and 53 ft correspond closely to the peaks shown on the ^{137}Cs concentration plot.

A data 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 very good repeatability of the ^{137}Cs data between the ground surface and 53 ft. In the deeper regions of the vadose zone, good repeatability of the data is evident only in areas where the ^{137}Cs concentrations exceed about 0.5 pCi/g. The RLS and SGLS data show a plume of ^{60}Co contamination between about 85 and 95 ft. Between 1993 and 1997, the concentrations of ^{60}Co have decreased along some regions of the plume, illustrating the radioactive decay of the ^{60}Co. The data also indicate that no downward migration of the ^{60}Co has occurred since 1993.

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. Gross gamma activity is absent on the plot between 1 and 5 ft because no data were collected from this interval. The gross gamma activity on the plot reflects a portion of the near-surface ^{137}Cs contamination and the ^{137}Cs peak at a depth of 27 ft. The earliest recorded historical gross gamma log (January 1975) shows the near-surface ^{137}Cs zone, the peak at 27 ft, and a very small anomaly at 52 ft. Subsequent historical logs show that the anomaly persisted until the early 1980s. The anomaly can be attributed to the ^{137}Cs peak shown on the SGLS plot and trace amounts of ^{60}Co reported by Brodeur (1993). The ^{137}Cs has now decayed to levels that are not detectable with the gross gamma system, and the ^{60}Co has decayed to levels that are below the MDL of the SGLS.

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 23 ft in early 1974. This peak, which moved to a depth of 27 ft over time, corresponds with the ^{137}Cs peak identified on the SGLS plot. A very small anomaly was identified at a depth of 39 ft in 1984. The anomaly corresponds to the small ^{137}Cs peak shown on the SGLS plot at the same depth. The anomalous activity decreased to levels below the detection limit of the gross gamma system by 1985.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The shallow subsurface ^{137}Cs contamination may represent surface contamination that has migrated along the surface of the tank dome into this region of the vadose zone.

On the basis of RLS data interpreted by Brodeur (1993) and recent SGLS data, the magnitude of the ^{137}Cs peaks detected below 25 ft suggests a subsurface source. The significant ^{137}Cs contamination detected from 25.5 to 27.5 ft may be the result of a leak from a pipeline or tank. The small zone of ^{137}Cs contamination from 39 to 40.5 ft may have resulted from the accumulation of tank-dome runoff that migrated along the outside of the tank to the base of the tank farm excavation. The thin zone of ^{137}Cs contamination detected at about 52 ft may indicate the accumulation of this contamination within finer-grained material.

The relatively smaller amounts of ^{137}Cs contamination detected below about 56 ft were probably carried down during drilling of this borehole or later migrated down the outside of the borehole casing. The ^{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 continuous zone of ^{60}Co contamination between 85 and 90.5 ft probably represents the remnant of a plume that migrated a considerable distance from the contaminant source.

4.5 Borehole 30-05-02

Borehole 30-05-02 is located approximately 11 ft from the southwest side of tank C-106 and was given the Hanford Site designation 299-E27-70. 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 127.5 ft.

The man-made radionuclides ^{137}Cs, ^{60}Co, and ^{154}Eu were detected in this borehole. ^{137}Cs contamination was measured continuously from the ground surface to a depth of 81 ft. Alternating zones of intermittent and continuous ^{137}Cs contamination were detected from 82 to 127.5 ft. A zone of high ^{137}Cs contamination (ranging from 200 to 775 pCi/g) was detected from 0.5 to 2 ft. A thick zone of moderate ^{137}Cs contamination was measured from about 5 to 30 ft. Discrete layers of elevated ^{137}Cs contamination ranging in concentration from 2 to 10 pCi/g are located near the bottom of this zone. A very large zone of generally low ^{137}Cs contamination (less than 1 pCi/g) was detected from about 30 ft to the bottom of the logged interval. The highest ^{137}Cs concentration (1,169 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 the source-to-detector geometry used in the calibration.

^{60}Co contamination was detected continuously from 75 to 80.5 ft. Isolated ^{60}Co concentrations were detected at 65 and 83 ft. The ^{60}Co contamination was detected at very low concentrations and delineates a minor contaminant plume located at considerable depth below the majority of the ^{137}Cs contamination. The maximum ^{60}Co concentration was 0.33 pCi/g at a depth of 75 ft.

A single ^{154}Eu occurrence was detected at the ground surface with a concentration of 1.5 pCi/g. This is probably not an accurate concentration value for reasons discussed previously. The detected gamma rays probably originated from an above-ground source, such as nearby contaminated equipment.

The increase in the ^{40}K concentration values at 38 ft probably represents a change in lithology from backfill material to the undisturbed Hanford formation. The drilling log reports a change from silt, sand, and gravel to coarse sand and silt at this depth. Variable ^{40}K concentration values were detected from 48 to 73 ft. The ^{40}K concentration values increase at 73 ft, increase again at 86 ft, and remain elevated to the bottom of the logged interval. The drilling log reports very coarse sand from 41 to 55 ft, coarse sand and gravel from 55 to 70 ft, and generally medium to coarse sand and silt below 70 ft. The lithologic information reported in the drilling log generally supports the interpretation that the variation in the ^{40}K concentration values between 48 and 73 ft may represent the basal region of the gravel-dominated facies and that the increase at 73 ft probably represents the contact with the sand-dominated facies of the Hanford formation.

It was not possible to identify many of the 609-keV peaks used to derive the ^{238}U concentrations between the ground surface and 22.5 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 small ^{238}U anomaly at 38 ft may have been caused by a build-up of radon gas within a low permeability strata at the base of the tanks.

The SGLS total gamma-ray plot reflects the presence of the man-made radionuclides and the naturally occurring radionuclides. The peak in the total count rate at 39 ft corresponds closely with peaks in the ^{40}K and ^{238}U concentrations at this depth. The count rate steadily increases at the bottom of the logged interval, corresponding with a consistent increase in the ^{137}Cs concentrations at this depth.

A data 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 very good repeatability of the ^{137}Cs data along the zone of continuous ^{137}Cs contamination. However, the data repeated less closely along the alternating zones of intermittent and continuous ^{137}Cs that occurred below 90 ft. The RLS and SGLS data show a plume of ^{60}Co contamination between about 75 and 85 ft. Between 1993 and 1997, the concentrations of ^{60}Co have decreased within the plume, illustrating the radioactive decay of the ^{60}Co. The data also indicate that no downward migration of the ^{60}Co has occurred since 1993.

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 near-surface peak shown on the SGLS plot is absent on the gross-gamma plot because no data were collected between 1 and 5 ft. The gross gamma activity on the plot reflects the shallow subsurface ^{137}Cs contamination. The earliest recorded historical gross-gamma log (January 1975) shows the near-surface and shallow subsurface ^{137}Cs contamination. A small anomaly was identified at about 75 ft; subsequent historical logs show that the anomaly persisted until the late 1970s. The anomaly can be attributed to ^{60}Co, which has now decayed to the current concentration levels of less than 0.5 pCi/g.

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 22 ft in early 1973. The location and amplitude of the peak remained largely unchanged over the recording period. This peak appears to correspond with the lower portion of the shallow subsurface ^{137}Cs contamination identified on the SGLS plot. A small anomaly was identified at a depth of 72 ft in 1976; however, historical gross-gamma log data indicate this anomaly was present as early as 1975. This anomalous activity, which moved to a depth of 76 ft by 1981, corresponds with the zone of ^{60}Co contamination shown on the SGLS plot. The anomalous activity decreased to levels below the detection limit by 1982.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The shallow subsurface ^{137}Cs contamination may represent surface contamination that has migrated along the surface of the tank dome into this region of the vadose zone.

Slightly elevated ^{137}Cs contamination was detected below 41 ft, directly below the tank farm excavation. The drilling log reports an increase in the silt content of the Hanford formation at this depth. Based on the assessment of RLS data, Brodeur (1993) suggests this contamination may have resulted from the accumulation of tank-dome runoff that migrated along the outside of the tank to the base of the tank footing. The recent SGLS data support this interpretation.

The continuous zone of ^{60}Co contamination between 75 and 80.5 ft probably represents the remnant of a plume that migrated a considerable distance from a subsurface contaminant source. The ^{60}Co contamination zone correlates with an increase on the ^{40}K plot, a silt and sand layer identified in the drilling log, and the interpreted contact between the gravel- and sand-dominated facies of the Hanford formation.

Much of the ^{137}Cs contamination detected below about 30 ft was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing. The zone of increasing ^{137}Cs contamination at the bottom of the logged interval is probably from particulate matter that has either fallen down the inside of the borehole or accumulated around the outside of the borehole casing.

4.6 Borehole 30-06-09

Borehole 30-06-09 is located approximately 5 ft from the west side of tank C-106. It was given the Hanford Site designation 299-E27-85. This borehole was drilled in July 1974 to a depth of 100 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 98.5 ft.

The man-made radionuclides ^{137}Cs, ^{60}Co, and ^{235}U were detected in this borehole. ^{137}Cs contamination was measured almost continuously from the ground surface to a depth of 52.5 ft, delineating a shallow subsurface zone of moderate ^{137}Cs concentrations (5 to 20 pCi/g) and a deeper subsurface zone of low ^{137}Cs concentrations (1 to 3 pCi/g) near the base of the tank farm excavation. Measurable ^{137}Cs contamination was also detected intermittently from 54 to 72.5 ft, at 91.5 ft, and continuously from 97 ft to the bottom of the logged interval (98.5 ft). The highest ^{137}Cs concentration (439 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.

The presence of ^{60}Co was detected at very low concentrations from 22 to 22.5 ft and at 74.5 ft. The maximum ^{60}Co concentration was 0.2 pCi/g at a depth of 75 ft.

A single occurrence of ^{235}U (processed uranium) was detected at the ground surface with a concentration of 19.9 pCi/g. 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.

The increase in the ^{40}K concentration values between 37.5 and 39.5 ft may represent a change in lithology from backfill material to the undisturbed Hanford formation. However, the lithology reported on the drilling log at this depth interval is not detailed enough to support or contradict the interpretation of the concentration increase shown on the ^{40}K plot. Variable ^{40}K concentration values were detected from 41 to 71 ft. The ^{40}K concentrations increase gradually from 72 to 80 ft then remain elevated to the bottom of the logged interval. The drilling log reports slightly silty sand from 50 to 60 ft, gravelly sand from 60 to 75 ft, and sand and silty sand below 75 ft. This lithologic information reported in the drilling log generally supports the interpretation that the variation in the ^{40}K concentration values between 41 and 71 ft may represent the basal region of the gravel-dominated facies of the Hanford formation and that the increase in the ^{40}K concentrations at about 72 ft probably represents the contact with the 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 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 presence of the man-made radionuclides where they occur and the naturally occurring radionuclides elsewhere. The count rate steadily increases from 76 ft to the bottom of the logged interval, corresponding with the gradual increase in the ^{40}K concentrations along this depth interval.

A data plot is included in Appendix A that compares spectral gamma data collected with the RLS in 1993 with spectral gamma data collected with the SGLS in 1997. The plot shows excellent repeatability of the data in the upper 15 ft of the vadose zone where the ^{137}Cs concentrations range from 5 to 20 pCi/g. Below 15 ft, good repeatability of the data is evident only in areas where the ^{137}Cs concentrations exceed about 1 pCi/g.

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 uppermost portion of the near-surface contaminant zone is absent on the gross gamma plot because no data were collected at the 1-ft and 2-ft intervals. The earliest recorded historical gross-gamma log (January 1975) shows the near-surface and shallow subsurface ^{137}Cs contamination. Some of the early historical logs show a slight increase in activity from depths of about 39 to 43 ft, corresponding to the weak zone of ^{137}Cs contamination identified on the SGLS plot.

Summaries of the historical gross-gamma log data from 1973 to 1987 included in Welty (1988) do not identify any zones of anomalous gamma-ray activity.

The ^{137}Cs concentration data shown on the SGLS plot indicate significant shallow subsurface contamination, probably resulting from surface spills that have migrated down into the backfill surrounding the borehole.

A zone of slightly elevated ^{137}Cs and minor ^{60}Co contamination was detected from 26 to 27.5 ft. Elevated ^{137}Cs contamination was detected at the same depth interval in other nearby boreholes and may be the related to a leak from a nearby pipeline or tank.

The elevated ^{137}Cs contamination detected between 41 and 46 ft may have resulted from tank-dome runoff that migrated along the outside of the tank to the base of the tank footing, then accumulated within finer-grained sediments of the Hanford formation below the tank farm excavation.

The isolated ^{60}Co concentration detected at 75 ft may be related to ^{60}Co contamination detected in other boreholes at the same interval.

Except for the contamination that may have accumulated from the migration of tank dome runoff discussed above, most of the ^{137}Cs contamination detected below about 17 ft was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing. The ^{137}Cs contamination at the bottom of the logged interval is probably from particulate matter that has fallen down the inside of the borehole.

4.7 Borehole 30-06-10

Borehole 30-06-10 is located approximately 6 ft from the northwest side of tank C-106. 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 in the 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.

Isolated occurrences of ^{154}Eu and ^{235}U contamination were detected at the ground surface with 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 very slight concentration increase of ^{40}K 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 primarily sand and gravel from 45 to 75 ft, sand and silt from 75 to 90 ft, and sand below 90 ft. The lithologic information reported in the drilling log supports the interpretation that the ^{40}K concentrations between 42.5 and 77 ft may represent the basal region of the gravel-dominated facies of the Hanford formation and that the ^{40}K concentrations at 77 ft probably 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 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 logging system, 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 weather conditions in the vicinity of the borehole. Wind, or the absence of it, affects the rate of radon venting from the borehole. 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 data 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 repeated less closely below 10 ft. The RLS and SGLS data indicate a large plume of ^{60}Co contamination that 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 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 the ^{60}Co 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; the plot clearly shows the near-surface ^{137}Cs contamination on the SGLS plot. The earliest recorded historical gross-gamma log (January 1975) identifies 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.

The near-surface zone of ^{137}Cs contamination probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The ^{137}Cs contamination directly below this zone 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 resulted from tank-dome runoff that migrated along the outside of the tank to the base of the tank footing, where it then accumulated below the tank farm excavation within the finer-grained sediments of the Hanford formation. The ^{137}Cs contamination detected directly below this zone most likely 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 extensive zone of ^{60}Co contamination detected from 86 to 116.5 ft may have originated from a remote subsurface source, such as a leak from a pipeline or tank. This region of ^{60}Co contamination was also detected with the RLS. Consequently, Brodeur (1993) postulated 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 actively moving through the vadose zone.

4.8 Borehole 30-06-12

Borehole 30-06-12 is located approximately 3 ft from the north side of tank C-106. It was given the Hanford Site designation 299-E27-86. This borehole was drilled in August 1974 to a depth of 100 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 99.5 ft.

The man-made radionuclides ^{137}Cs and ^{60}Co were detected in this borehole. The presence of ^{137}Cs was measured continuously from the ground surface to a depth of 31.5 ft and from 48.5 to 65 ft, delineating a shallow subsurface zone of moderate ^{137}Cs contamination (5 to 15 pCi/g) and a deeper subsurface zone of low ^{137}Cs contamination (0.2 to 3 pCi/g). Small zones of continuous ^{137}Cs contamination were also detected from 34 to 35 ft, 43 to 45.5 ft, and 99 to 99.5 ft. Several isolated ^{137}Cs occurrences were detected between 66 and 80 ft. The highest ^{137}Cs concentration was 75 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 in the calibration.

Low ^{60}Co concentrations (0.1 to 0.4 pCi/g) were measured continuously from 19.5 to 22.5 ft and intermittently between 90 ft and the bottom of the logged interval. A few isolated ^{60}Co concentrations were detected at 25.5, 27.5, and 34 ft. The maximum ^{60}Co concentration was 0.4 pCi/g at a depth of 20 ft.

The ^{40}K concentration values increase at about 38 ft, become slightly variable from 41 to 80 ft, increase at 80 ft, and generally remain elevated to the bottom of the logged interval. The increase in the ^{40}K concentration values at 38 ft may represent a change in lithology from backfill material to the undisturbed Hanford formation. The variation in the ^{40}K concentration values between 41 and 80 ft may represent the basal region of the gravel-dominated facies of the Hanford formation. The increase in ^{40}K concentrations at 80 ft probably indicates the contact with the sand-dominated facies. The lithology reported on the drilling log was not detailed enough to support or contradict the interpretation of the changes in the concentration values shown on the ^{40}K plot.

A peak is shown on the ^{238}U plot at a depth of 48.5 ft. It was not possible to identify any of the 609-keV peaks used to derive the ^{238}U concentrations between the ground surface and 1.5 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 ^{137}Cs and ^{60}Co contamination where it occurs and the naturally occurring radionuclides elsewhere. The peaks in the total count rate at 48.5 ft correspond closely with the peak shown on the ^{238}U concentration plot at this depth.

The interval between 15 and 30 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 concentrations and the naturally occurring radionuclides using the data sets provided by the original and repeated logging runs is included with 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.

A data 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 very good repeatability of the data in the upper 30 ft of the vadose zone where the ^{137}Cs concentrations generally range from 1 to 10 pCi/g. Along the ^{137}Cs zone between 40 and 65 ft, good repeatability of the data is evident only in areas where the ^{137}Cs concentrations exceed about 0.5 pCi/g. The RLS and SGLS data show a small continuous zone of ^{60}Co contamination that occurs at about 20 ft. Between 1993 and 1997, the concentrations of ^{60}Co have decreased within this zone, illustrating the radioactive decay of the ^{60}Co. The data also indicate that no downward migration of the ^{60}Co has occurred since 1993. Minor amounts of ^{60}Co contamination were detected by the SGLS near the bottom of the borehole in 1997 that were not detected by the RLS in 1993. This is because the RLS logging tool configuration prevented the bottom portion of the borehole from being logged. It is possible that the ^{60}Co detected below 95 ft was not present in 1993, but the available data are not sufficient to make that determination.

An additional data plot included in Appendix A provides a more detailed comparison of the ^{137}Cs, ^{60}Co, and ^{40}K detected by the RLS and SGLS between 10 and 40 ft. The radionuclide concentrations were plotted on a linear scale to provide a more quantitative comparison of the data. The plot shows very good repeatability of the ^{137}Cs data, suggesting that the ^{137}Cs contamination has remained fixed in the vadose zone since 1993. The plot shows good repeatability of the ^{60}Co contamination detected between 19.5 and 22.5 ft and illustrates the radioactive decay of the ^{60}Co between 1993 and 1997. By averaging the relative decrease in these ^{60}Co concentrations since 1993, it was calculated that 35 percent of the ^{60}Co has decayed away during the past 4 years. The calculated decay rate is fundamentally consistent with the 5.27-year half-life of the ^{60}Co radioisotope. The plot shows poor repeatability of the ^{40}K data along several zones of the logged interval. The 1997 ^{40}K data exhibit much less variation and appear to be more consistent than the 1993 ^{40}K data.

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. Most of the near-surface peaks shown on the SGLS plot are absent on the gross-gamma plot because no data were collected between 1 and 5 ft. The earliest recorded historical gross-gamma log (January 1975) shows elevated count rates that represent the near-surface and shallow subsurface ^{137}Cs contamination, indicating that it was deposited before that time.

Summaries of the historical gross-gamma log data from 1973 to 1987 are presented in Welty (1988). A small anomaly was identified at a depth of 21 ft in 1984; however, historical gross-gamma log data indicate that this anomaly was present at 19 ft as early as 1975. The anomalous activity moved to a depth of 23 ft by 1987. The historical data may correspond with the zone of ^{60}Co contamination shown on the SGLS plot. The anomaly can be attributed to ^{60}Co, which has decayed away to less than 0.5 pCi/g.

The extensive zone of ^{137}Cs contamination detected from the ground surface to 8 ft probably resulted from surface spills that have migrated down into the backfill surrounding the borehole. The shallow subsurface ^{137}Cs contamination detected between 10 and 30 ft may represent surface contamination that has migrated along the surface of the tank dome into this region of the vadose zone.

The zone of ^{137}Cs contamination detected between 43 and 62 ft may have resulted from tank-dome runoff that migrated along the outside of the tank to the base of the tank footing, where it then accumulated below the tank farm excavation. The thin zone of elevated ^{137}Cs contamination detected between 59 and 62 ft may indicate the accumulation of this contamination within a zone of finer-grained material. The ^{137}Cs contamination detected directly below this zone was probably carried down during the drilling of this borehole or later migrated down the outside of the borehole casing.

The ^{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 continuous zone of ^{60}Co contamination detected between 19.5 and 22.5 ft may be the result of a leak from a nearby pipeline. The ^{60}Co contamination in this region does not appear to be related to the thick zone of ^{137}Cs contamination detected between 10 and 30 ft. The deeper zone of ^{60}Co contamination detected between 90 ft and the bottom of the logged interval can be correlated to the extensive ^{60}Co contaminant zone in borehole 30-06-10. The vertical extent of this contamination is unknown due to the limited depth of the borehole.

5.0 Discussion of Results

A plot of the man-made radionuclide concentration profiles for the eight boreholes surrounding tank C-106 is presented in Figure 3. The man-made radionuclides ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{235}U were detected by the SGLS.

The SGLS detected a significant amount of near-surface and shallow subsurface ^{137}Cs contamination in all the boreholes. This contamination could have resulted from surface spills, airborne contamination releases, or a combination of the two (Brodeur 1993). The contamination may have migrated, in some undetermined manner, down around the outside of the boreholes. However, it is more likely the contamination has been driven downward into the backfill material by precipitation infiltration to as deep as the base of the tank farm excavation. If the contamination in the upper portions of the boreholes has migrated downward along the borehole casings, then the total contamination in the near-surface vadose zone is minor. If this contamination has migrated downward into the backfill material, then the volume of contaminated material is great and is a significant portion of the overall contamination in the vadose zone around this tank.

The SGLS detected moderate to very high ^{137}Cs concentrations at the ground surface in all the boreholes. Isolated ^{154}Eu and ^{235}U occurrences were also detected at the ground surface in the boreholes along the west side of tank C-106. 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, ^{154}Eu, and ^{235}U concentration values detected using the SGLS are probably higher than the actual concentration levels of these radionuclides at the ground surface.

It is important to note that borehole 30-00-01 is double-cased between 5 and 50.5 ft, causing the attenuation of gamma-ray energies and thereby reducing the ^{137}Cs concentration values.

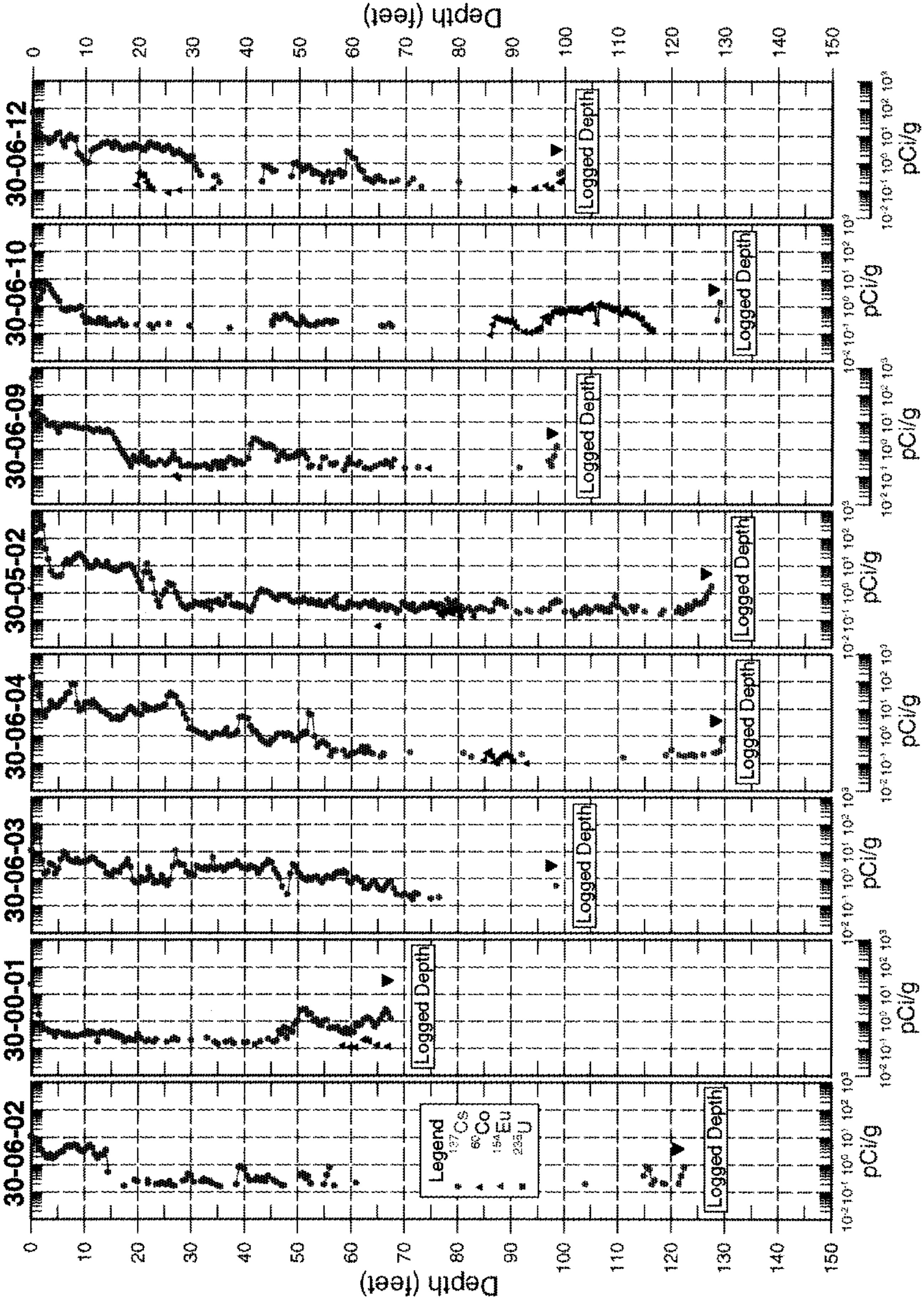

Figure 3. Repeatability Plot of ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{235}U Concentrations in Boreholes Surrounding Tank C-106

Consequently, along the double-cased interval of this borehole, the low ^{137}Cs concentrations within the backfill material may not have been detected by the SGLS, and the profile of the ^{137}Cs concentration values detected by the SGLS may not be representative of the actual contaminant distribution.

The zone of elevated ^{137}Cs concentrations detected between 5 and 10 ft in boreholes 30-06-02, 30-06-03, 30-06-04, and 30-05-02 may represent surface contamination that has migrated laterally along the surface of the tank dome into this depth region of the backfill material.

A zone of elevated ^{137}Cs contamination that occurs primarily between 40 and 50 ft can be correlated among all the boreholes associated with tank C-106. The top of this contamination zone occurs approximately 1 to 6 ft below the base of the tanks. Based on an assessment of RLS data presented in Brodeur (1993) and recent SGLS data, it is probable that increased runoff from the tank dome may have carried ^{137}Cs contamination along the outside of the tank to the base of the tank footing, where it accumulated below the tank farm excavation within the finer grained sediments of the Hanford formation.

The RLS data included in Brodeur (1993) and the recent SGLS data indicate that all the boreholes surrounding tank C-106 contain subsurface ^{137}Cs contamination that does not appear to be strictly the result of downward migration of surface contamination through the vadose zone sediment. Brodeur (1993) stipulates that some minor movement of radionuclides could have occurred along the boreholes, but this would be reflected in changes in the shapes of the contamination profile in the higher concentration zones. Such changes are not evident.

The SGLS detected a zone of relatively higher ^{137}Cs contamination at a depth of about 27 ft in boreholes 30-06-03, 30-06-04, 30-05-02, and 30-06-09. This region of ^{137}Cs contamination was also detected with the RLS. This contamination probably originated from a separate source because it is a relatively significant anomaly that is persistent at this depth and is found in several boreholes. The contamination may have originated from a tank leak from tanks C-106 or C-103 (to be published). It could also be the result of a large surface spill or a transfer-line leak (Brodeur 1993). However, it should be noted that most transfer lines are approximately 22 ft deep.

In borehole 30-00-01, a continuous ^{137}Cs contamination zone was detected from 50.5 ft (directly below the double-cased interval) to the bottom of the logged interval (67.5 ft). A zone of intermittent ^{60}Co contamination coexists with the ^{137}Cs contamination in the lower region of the borehole. The attenuation of the 661-keV gamma-ray energies by the double-cased interval above this zone and the limited depth of the open borehole make it difficult to ascertain the distribution of the ^{137}Cs contamination and to determine a probable contaminant source. However, the combination of ^{137}Cs and ^{60}Co contamination in this borehole may represent a contaminant plume that originated from a subsurface source, such as a leak from a nearby tank. The downward vertical extent of this potential plume cannot be determined because of the limited depth logged by the SGLS.

The ^{137}Cs contamination detected in borehole 30-06-04 at 52 ft may have resulted from a leak from tank C-103 or from extensive surface contamination that moved down along the outside of C-103 and was deposited below the base of the tanks. The SGLS data indicate that this contamination zone is more widely distributed and is found at a higher concentration around borehole 30-03-01.

The comparison of the 1993 RLS and 1997 SGLS data shows generally good repeatability of ^{137}Cs distributions in all of the boreholes. The shape of the RLS and SGLS ^{137}Cs profiles were very similar, suggesting that the ^{137}Cs contamination originating from both surface and subsurface sources is not actively mobile and has remained fixed in the vadose zone since 1993.

The SGLS detected subsurface ^{60}Co contamination in all the boreholes except 30-06-02 and 30-06-03. The RLS detected ^{60}Co contamination in most of the same boreholes at similar depth intervals. The comparison of the 1993 RLS and 1997 SGLS data illustrates the radioactive decay of ^{60}Co in several of these boreholes.

A review of the geology indicates a good repeatability between the lithology and ^{60}Co deposition around tank C-106. In most the boreholes, coarse-grained deposits containing high percentages of gravel are found overlying layers of sand and silt in which the ^{60}Co is found (Brodeur 1993).

The continuous ^{60}Co contamination detected from 75 to 80.5 ft in borehole 30-05-02 and from 85 to 90.5 ft in borehole 30-06-04 can be correlated with the extensive ^{60}Co zone detected by the SGLS in borehole 30-03-09. The ^{60}Co contamination in borehole 30-03-09 represents some of the highest ^{60}Co concentrations detected in the C Tank Farm; it also corresponds to a potential leak from tank C-103 (Brodeur 1993).

The data from borehole 30-06-10 suggest that a subsurface source was responsible for the extensive ^{60}Co contaminant plume detected from 86 to 116.5 ft. This contamination may have originated from tank C-106, but it is more likely that tank C-109 (to be published) was the source (Brodeur 1993). The comparison of RLS and SGLS data showed the downward migration of the ^{60}Co plume, suggesting that active movement of ^{60}Co contamination is occurring in the vadose zone around this borehole.

The continuous ^{60}Co contamination zone detected from 19.5 to 22.5 ft in borehole 30-06-12 may be the result of a leak from a transfer line or pipeline. The deeper, intermittent zones of ^{60}Co contamination detected between 90 ft and the bottom of the logged interval probably resulted from a subsurface source. The vertical extent of the contamination is not known; however, this ^{60}Co contamination zone can be correlated to the extensive ^{60}Co contamination zone detected in borehole 30-06-10, and the contamination probably originated from the same source.

6.0 Conclusions

The characterization of the gamma-ray-emitting contamination in the vadose zone surrounding tank C-106 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-106. However, the data indicate that surface spills and subsurface leaks may have previously occurred in the vicinity of the tank and may be related to activities associated with tank C-106 or other nearby tanks. A comparison of the 1997 SGLS data with the 1993 RLS data show that the ^{137}Cs is stable, but at least one instance was found where ^{60}Co has migrated.

7.0 Recommendations

Approximately 16,000 gal of drainable, interstitial liquid and 32,000 gal of supernatant liquid remain in tank C-106 (Hanlon 1997). It is recommended that monitoring of the boreholes surrounding tank C-106 be continued annually to detect potential future leakage from the tank and associated tank facilities and to monitor the potential movement of contaminant plumes. 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 surrounding tank C-106 with a very high-efficiency system. This type of logging system can properly define the individual natural radionuclide concentrations and thus better characterize site-specific geology.

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Appendix A
Spectral Gamma-Ray Logs for Boreholes in the Vicinity of Tank C-106

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Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-06-02

Borehole Information

Farm : C	Tank : C-106	Site Number : 299-E27-72
N-Coord : 42,967	W-Coord : 48,244	TOC Elevation : 645.33
Water Level, ft : None	Date Drilled : 11/30/72	

Casing Record

Type : Steel-welded	Thickness : 0.280	ID, in. : 6
Top Depth, ft. : 0	Bottom Depth, ft. : 125	

Borehole Notes:
This borehole was drilled in November 1972 to a depth of 125 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 : 1/22/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 0.0	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 22.0	MSA Interval, ft. : .5	Log Speed, ft/min.: n/a	

Log Run Number : 2	Log Run Date : 1/23/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 21.0	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 37.0	MSA Interval, ft. : .5	Log Speed, ft/min.: n/a	

Log Run Number : 3	Log Run Date : 1/24/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 122.5	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 46.0	MSA Interval, ft. : .5	Log Speed, ft/min.: n/a	

Log Run Number : 4	Log Run Date : 1/27/97	Logging Engineer: Alan Pearson	
Start Depth, ft.: 36.0	Counting Time, sec.: 100	L/R : L	Shield : N
Finish Depth, ft. : 47.0	MSA Interval, ft. : .5	Log Speed, ft/min.: n/a	

Log Event A

Borehole 30-06-02

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 four 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 radionuclide Cs-137 was detected in this borehole. The presence of Cs-137 was measured continuously from the ground surface to 14.5 ft, discontinuously from 17 to 61 ft and near the bottom of the logged interval.

Slightly elevated and increasingly variable K-40 concentration values were detected between 48 and 71.5 ft. The K-40 concentration values increase at about 75 ft and remain elevated to the bottom of the logged interval. The Th-232 concentration values increase at about 48.5 ft.

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

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.

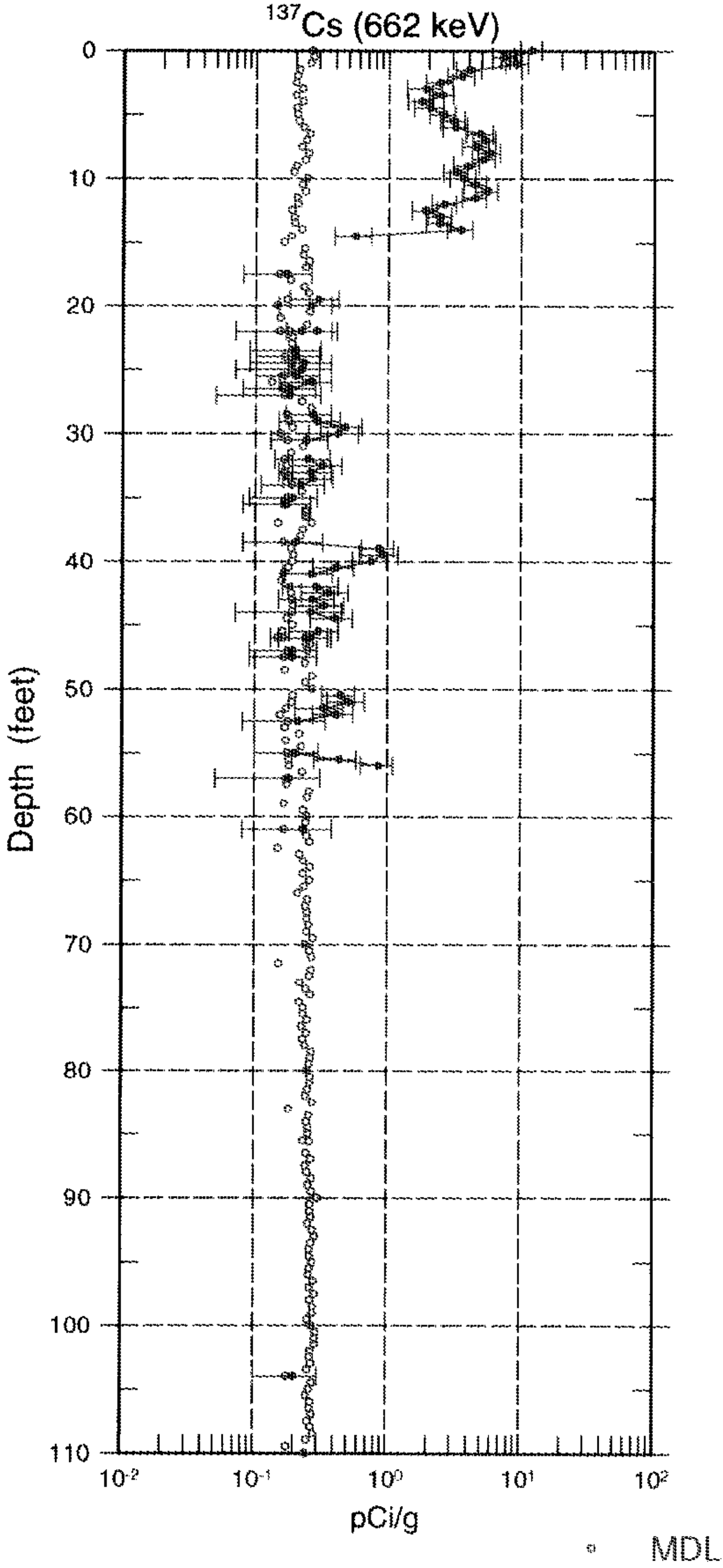
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

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.

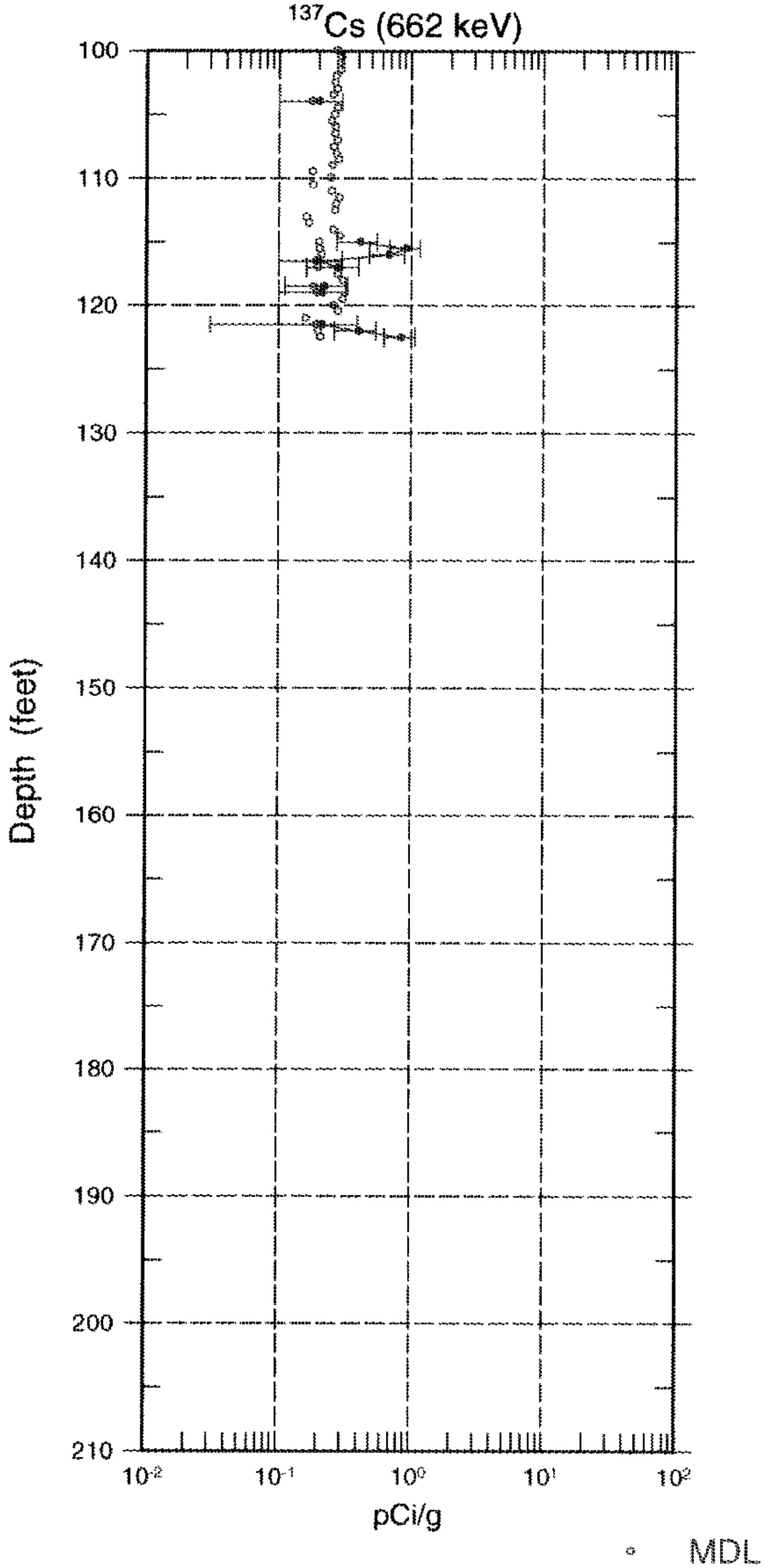
30-06-02

Man-Made Radionuclide Concentrations

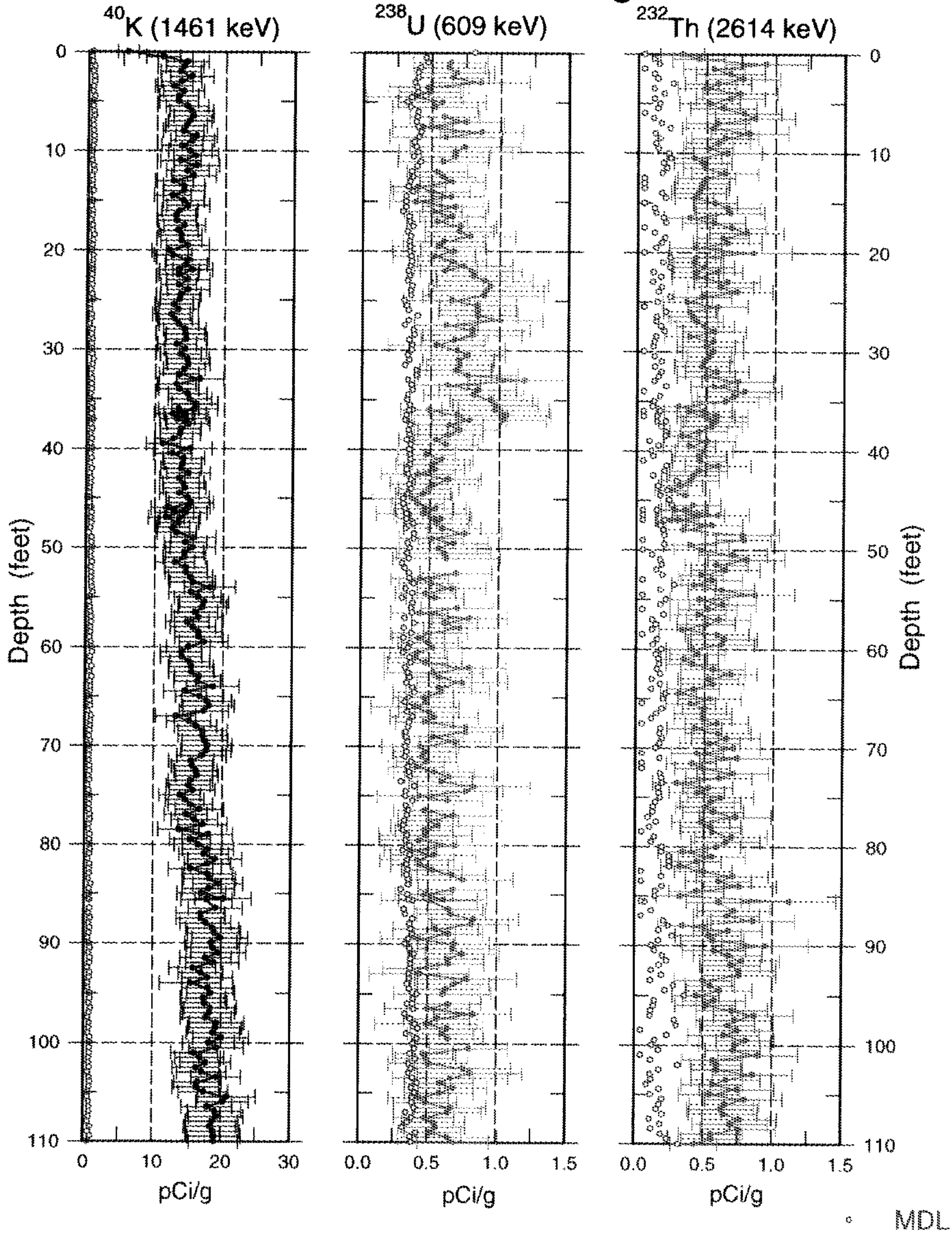


30-06-02

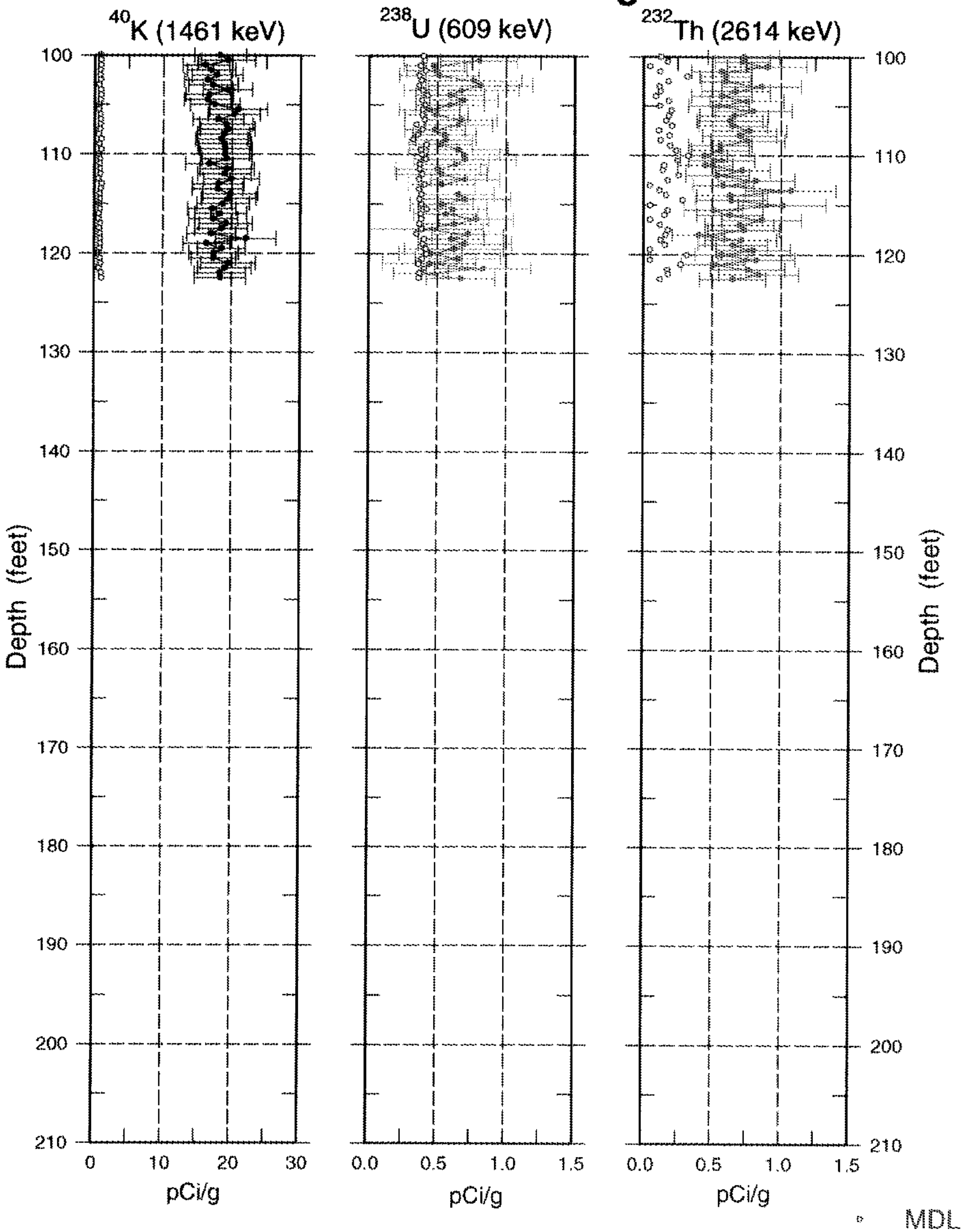
Man-Made Radionuclide Concentrations



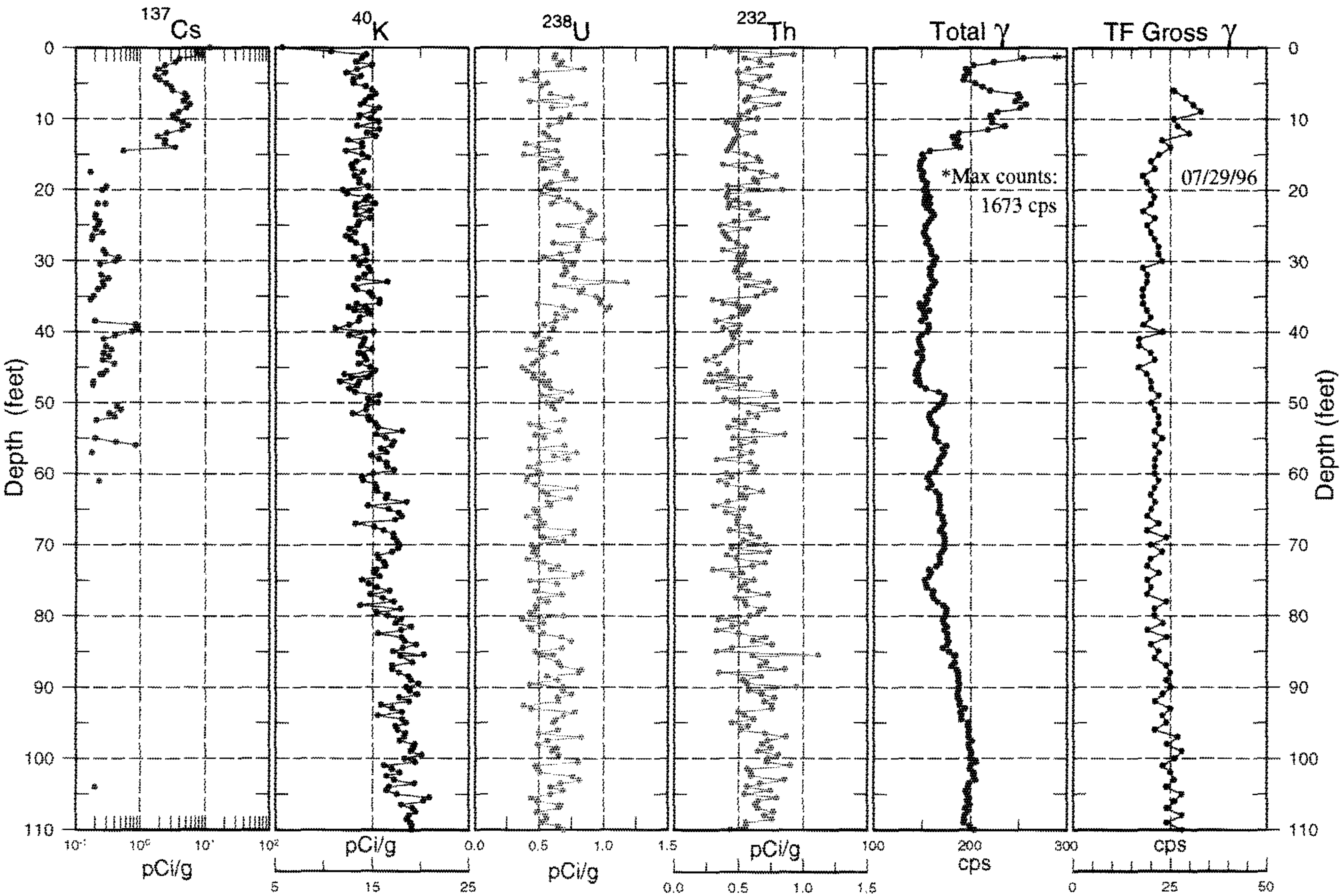
30-06-02
Natural Gamma Logs



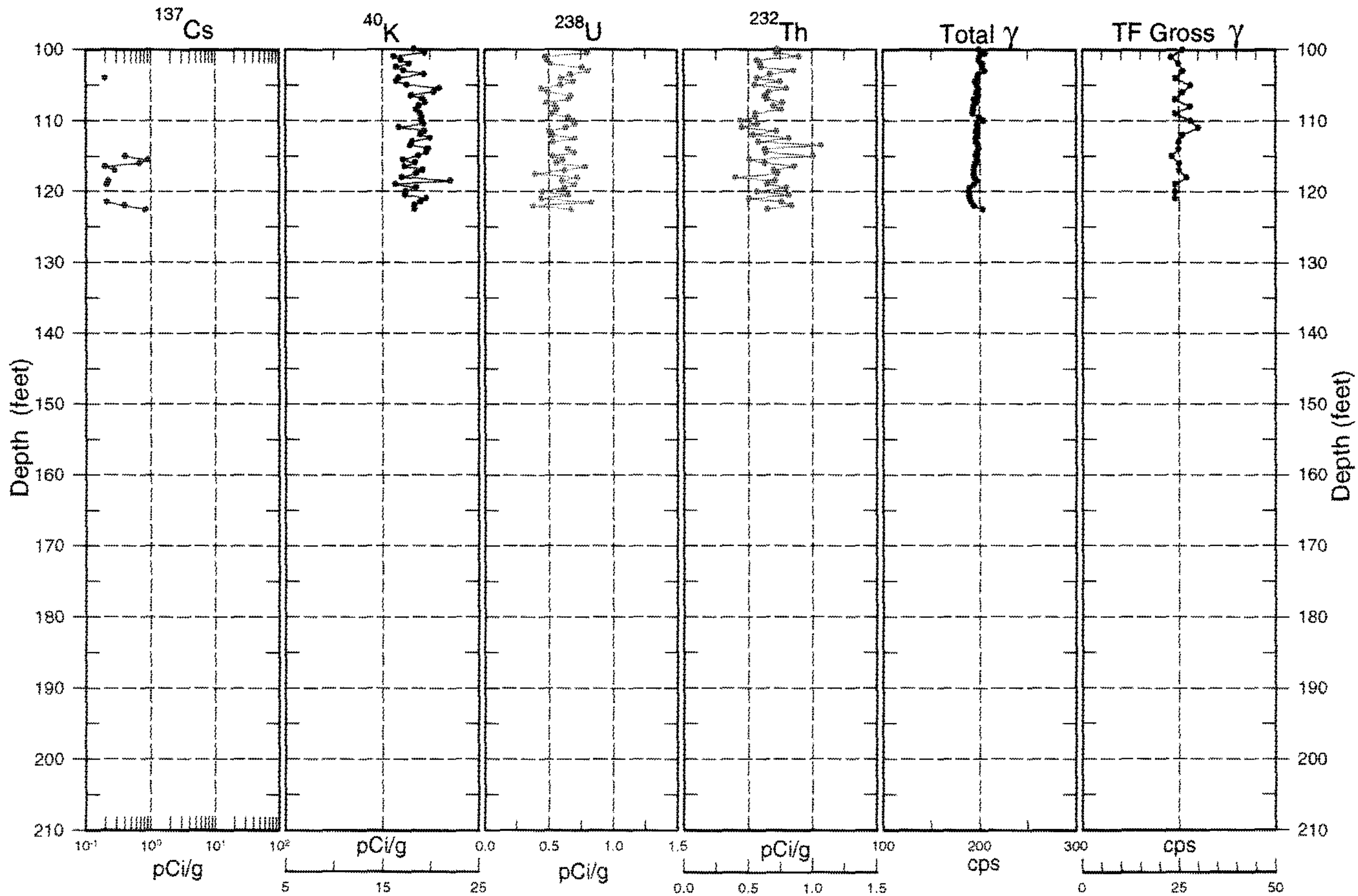
30-06-02
Natural Gamma Logs



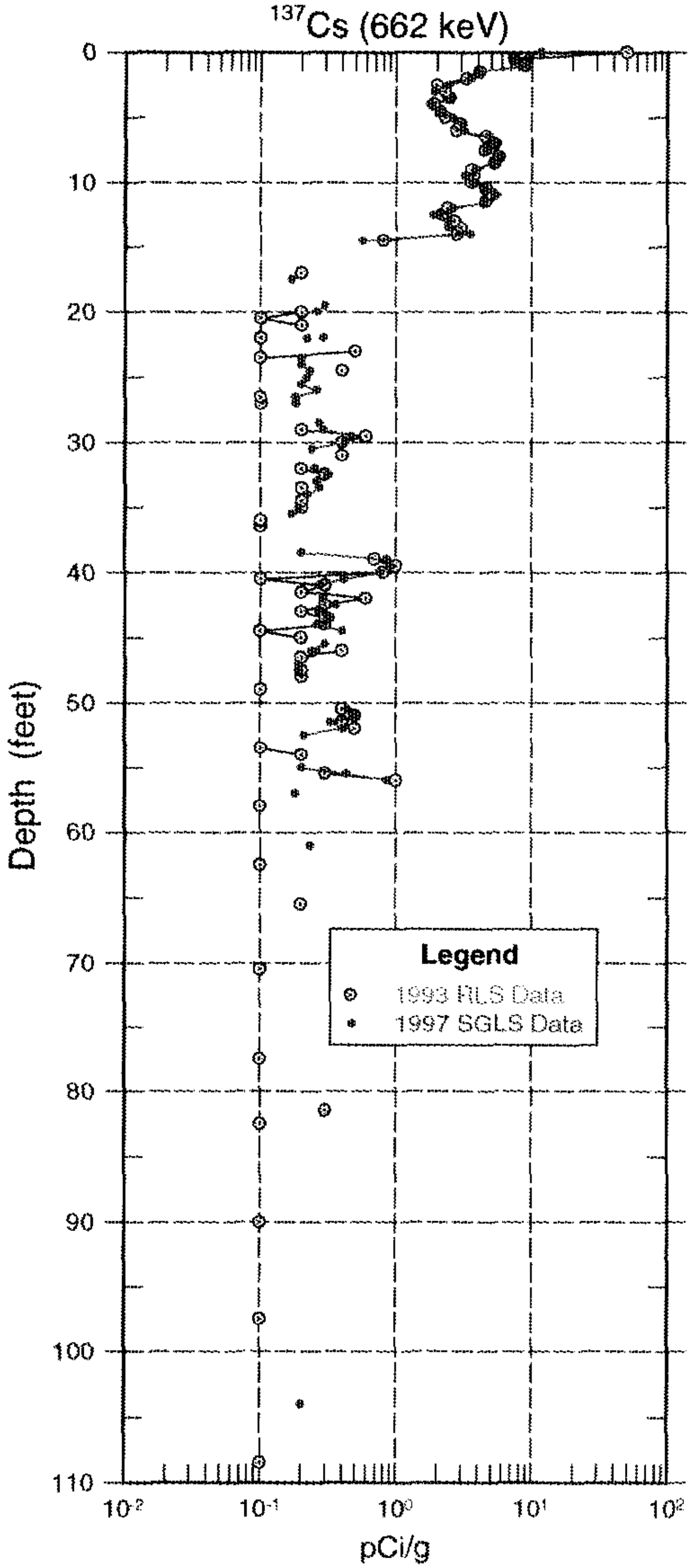
30-06-02 Combination Plot



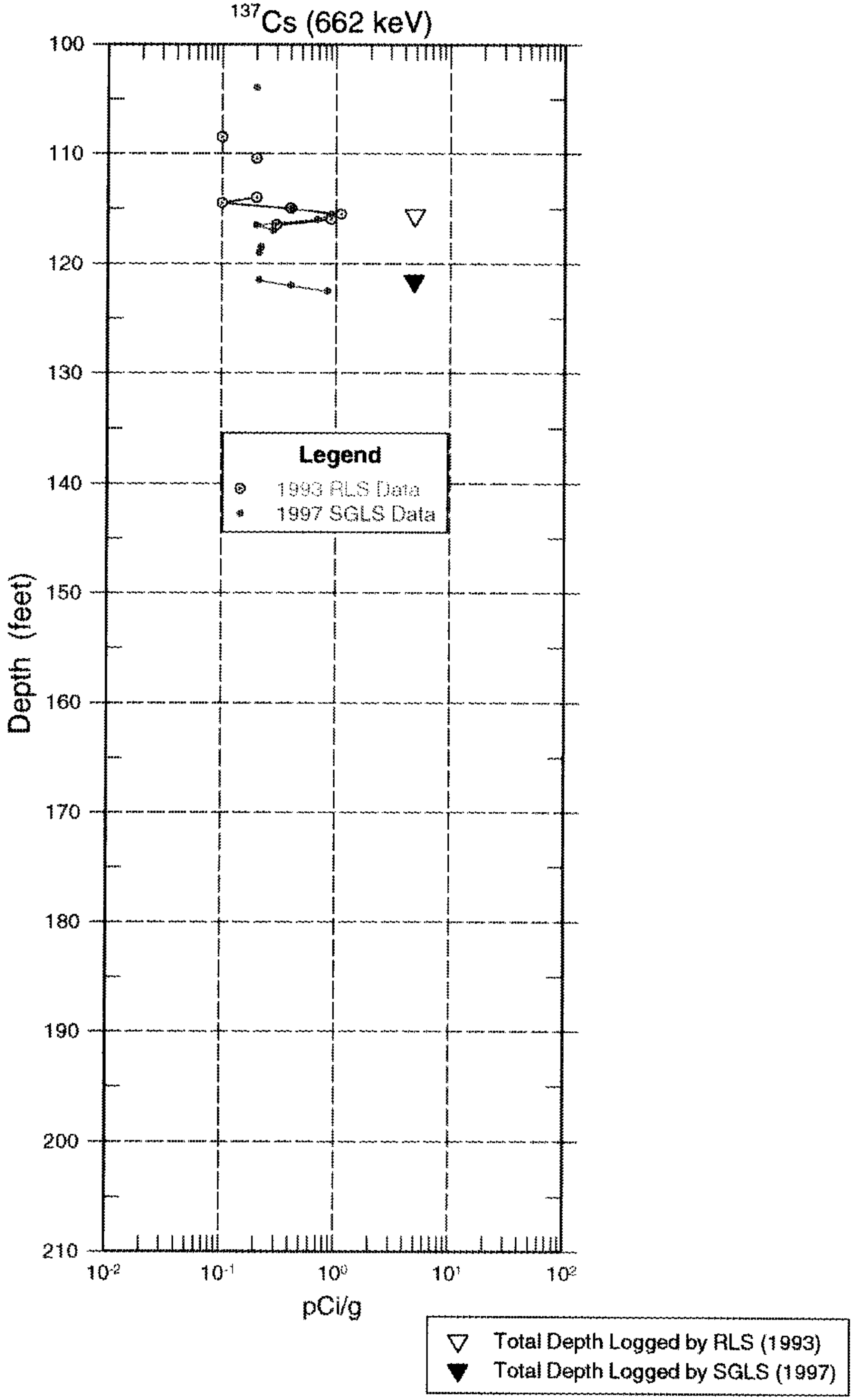
30-06-02 Combination Plot



30-06-02
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



30-06-02
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



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Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-00-01

Borehole Information

Farm :	C	Tank :	C-106	Site Number :	299-E27-56
N-Coord :	42,954	W-Coord :	48,191	TOC Elevation :	639.17
Water Level, ft :	None	Date Drilled :	12/27/44		

Casing Record

Type :	Steel-welded	Thickness, in. :	0.313	ID, in. :	8
Top Depth, ft. :	0	Bottom Depth, ft. :	145		
Type :	Steel-welded	Thickness, in. :	0.500	ID, in. :	12
Top Depth, ft. :	0	Bottom Depth, ft. :	45		

Cement Bottom, ft. : 145 Cement Top, ft. : 143

Borehole Notes:

This borehole was drilled in December 1944 to a depth of 145 ft. The borehole was started with a 45-ft length of permanent 12-in. surface casing and was completed to a nominal depth of 145 ft using 8-in. casing. According to the drilling log, the 8-in. casing was perforated from 43 to 143 ft and the bottom of the 8-in. casing was sealed with half a sack of cement. The drilling log does not indicate if the annulus between the 8-in. and 12-in. casings was grouted. The thickness of the 8-in. casing is presumed to be 0.313 in.; the thickness of the 12-in. casing is presumed to be 0.500 in. The top of the casing, which is the zero reference for the SGLS, is approximately flush with the ground surface.

The current total depth of the borehole was measured at 68.1 ft below the top of the casing using a weighted tape, although this borehole was drilled to a total depth of 145 ft in 1944. The total depths of historical gross-gamma log runs have become progressively shallower over time, indicating that the casing perforation have allowed loose sand to infiltrate into and slowly fill the borehole, or sand and silt has entered the borehole from the surface.

Equipment Information

Logging System :	2	Detector Type :	HPGe	Detector Efficiency :	35.0 %
Calibration Date :	10/96	Calibration Reference :	GJPO-HAN-13	Logging Procedure :	P-GJPO-1783

Log Run Information

Log Run Number :	1	Log Run Date :	4/14/97	Logging Engineer:	Bob Spatz		
Start Depth, ft.:	67.5	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	29.5	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Log Event A

Borehole 30-00-01

Log Run Number :	2	Log Run Date :	4/15/97	Logging Engineer:	Bob Spatz
Start Depth, ft.:	31.5	Counting Time, sec.:	100	L/R : L	Shield : N
Finish Depth, ft. :	0.0	MSA Interval, ft. :	.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 two 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 0.322-in.-thick steel casing were applied during analysis. The combined casing thickness along the double-cased interval of the borehole is known to be greater than 0.322 in. Consequently, the calculated concentrations within this region is underestimated.

The man-made radionuclides Cs-137 and Co-60 were detected in this borehole. The presence of Cs-137 was measured continuously from the ground surface to 20.5 ft, intermittently from 21.5 to 44.5 ft, and continuously from 45.5 ft to the bottom of the logged interval (67.5 ft). Co-60 contamination was detected intermittently from 58.5 ft to the bottom of the logged interval.

It was not possible to identify many of the 609-keV peaks used to derive the U-238 concentrations near the ground surface and below the double-cased interval of the borehole. This occurred because high gamma-ray activity associated with the nearby Cs-137 peak (661 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured U-238 concentration.

The 609-, 1460-, and 2614-keV gamma-ray energies have been attenuated along the double-cased interval of the borehole, resulting in reduced U-238, K-40, and Th-232 concentration values, respectively. As a result, many of the 609-keV and some of the 2614-keV gamma-ray peaks in this region were not detected by the SGLS because the U-238 and Th-232 activities were reduced below the detection limit by casing attenuation.

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

Log Plot Notes:

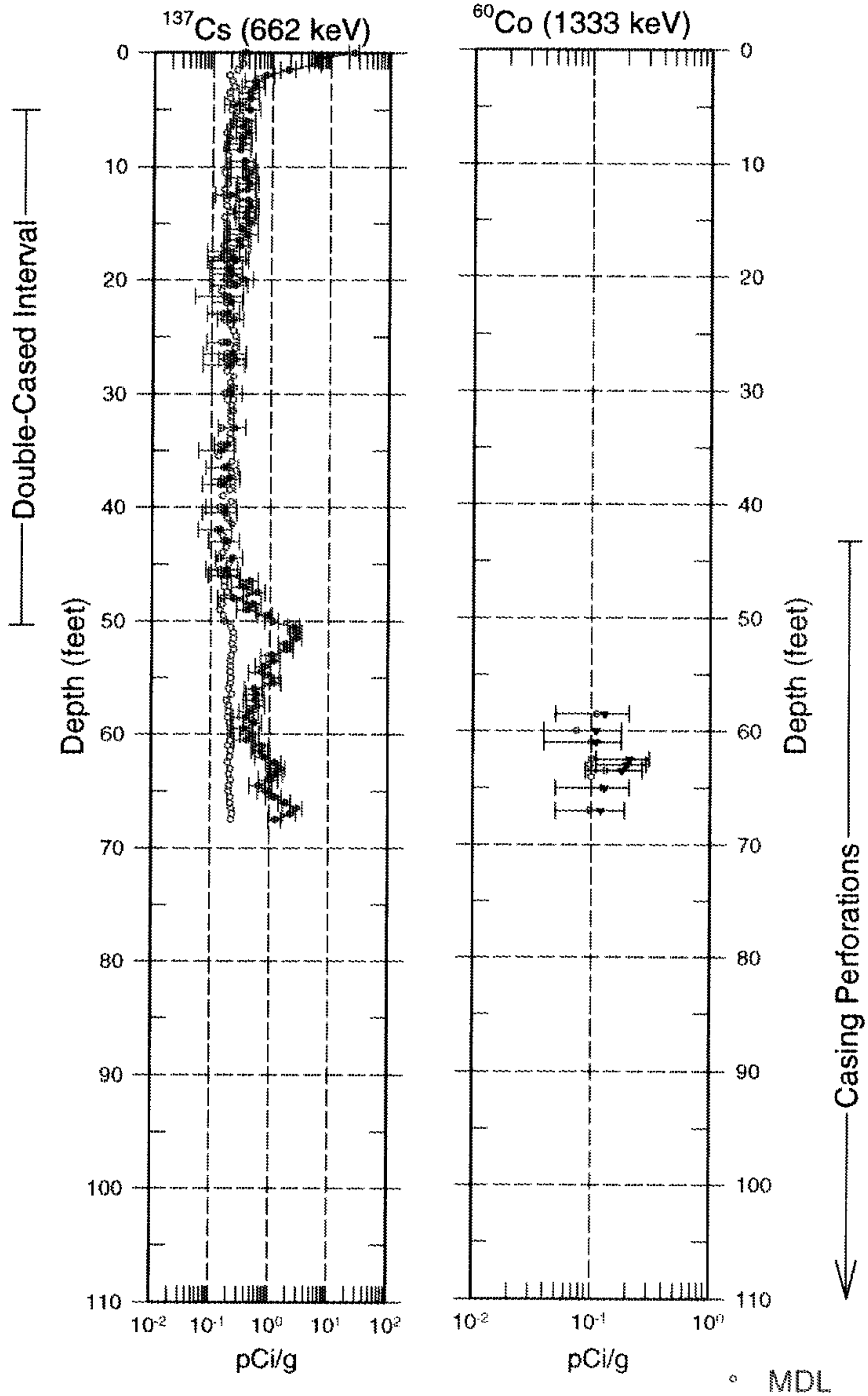
Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

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.

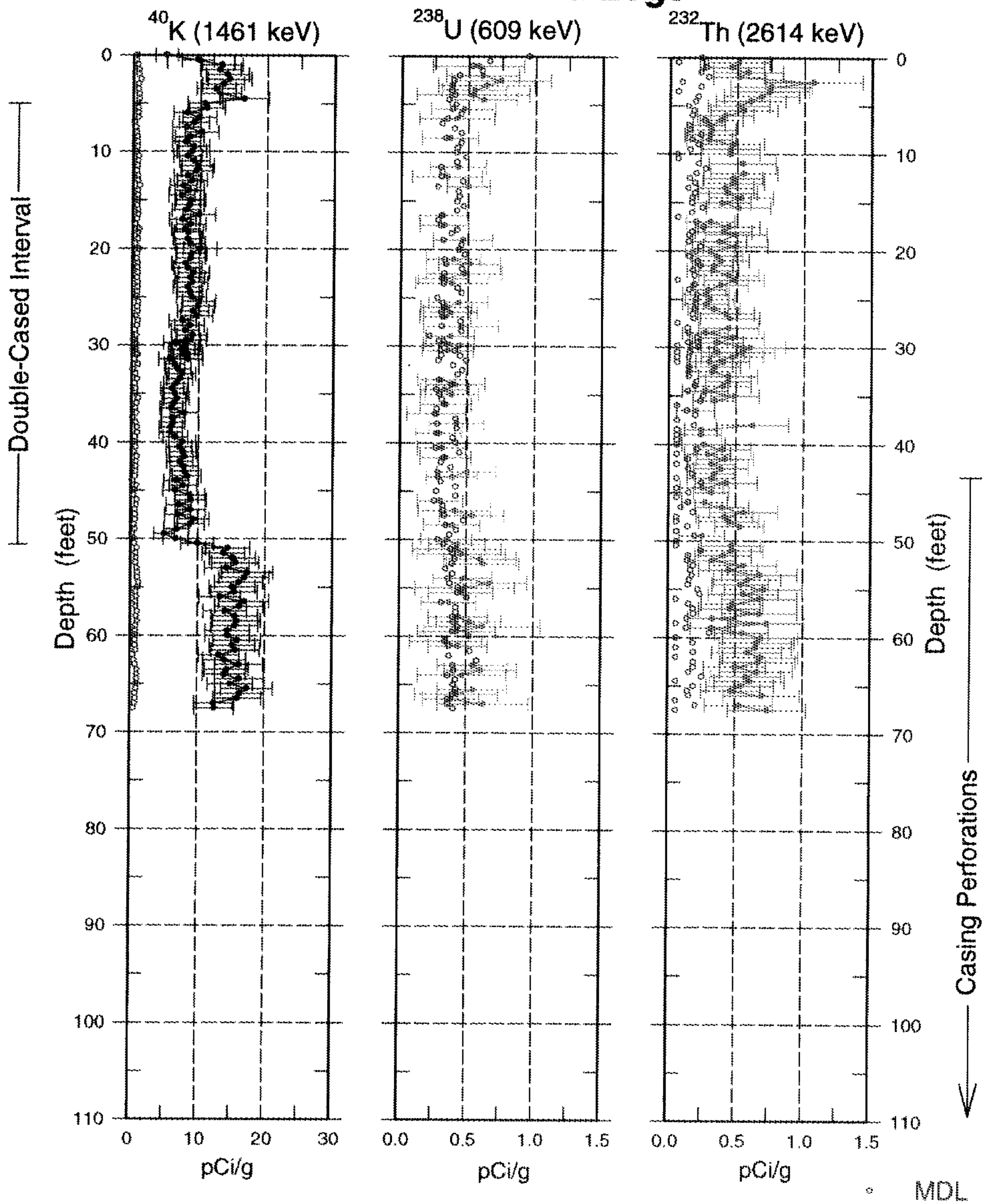
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with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

30-00-01

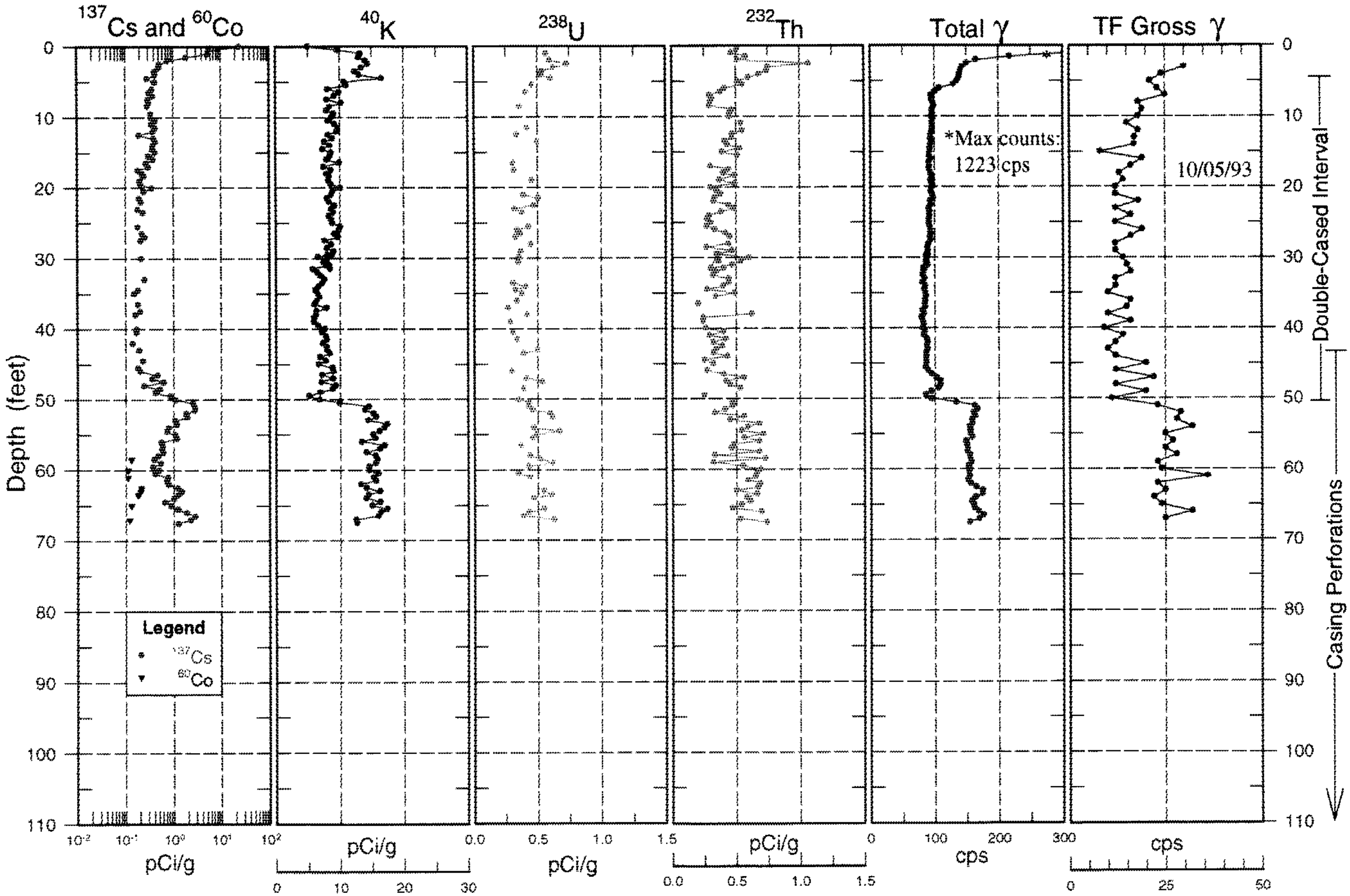
Man-Made Radionuclide Concentrations



30-00-01
Natural Gamma Logs



30-00-01 Combination Plot



Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-06-03

Borehole Information

Farm :	C	Tank :	C-106	Site Number :	299-E27-84
N-Coord :	42,932	W-Coord :	48,209	TOC Elevation :	644.80
Water Level, ft :	None	Date Drilled :	6/30/74		

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 June 1974 to a depth of 100 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 :	1/16/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	0.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	22.5	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	1/21/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	98.5	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	51.0	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Log Run Number :	3	Log Run Date :	1/22/97	Logging Engineer:	Alan Pearson		
Start Depth, ft.:	52.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	21.5	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Borehole **30-06-03**

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 three 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 radionuclide Cs-137 was detected in this borehole. The presence of Cs-137 was measured from the ground surface to a depth of 76.5 ft and at 98.5 ft (the bottom of the logged interval).

Slightly elevated K-40 concentration values were generally detected between 46 and 80 ft. The K-40 concentration values increase at about 80 ft and remain elevated to the bottom of the logged interval. The U-238 and Th-232 concentration values increase gradually from 75 ft to the bottom of the logged interval.

Between the ground surface and 3 ft, it was not possible to identify most of the 609-keV peaks used to derive the U-238 concentrations. This occurred because high gamma-ray activity associated with the nearby Cs-137 peak (661 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured U-238 concentration.

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

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.

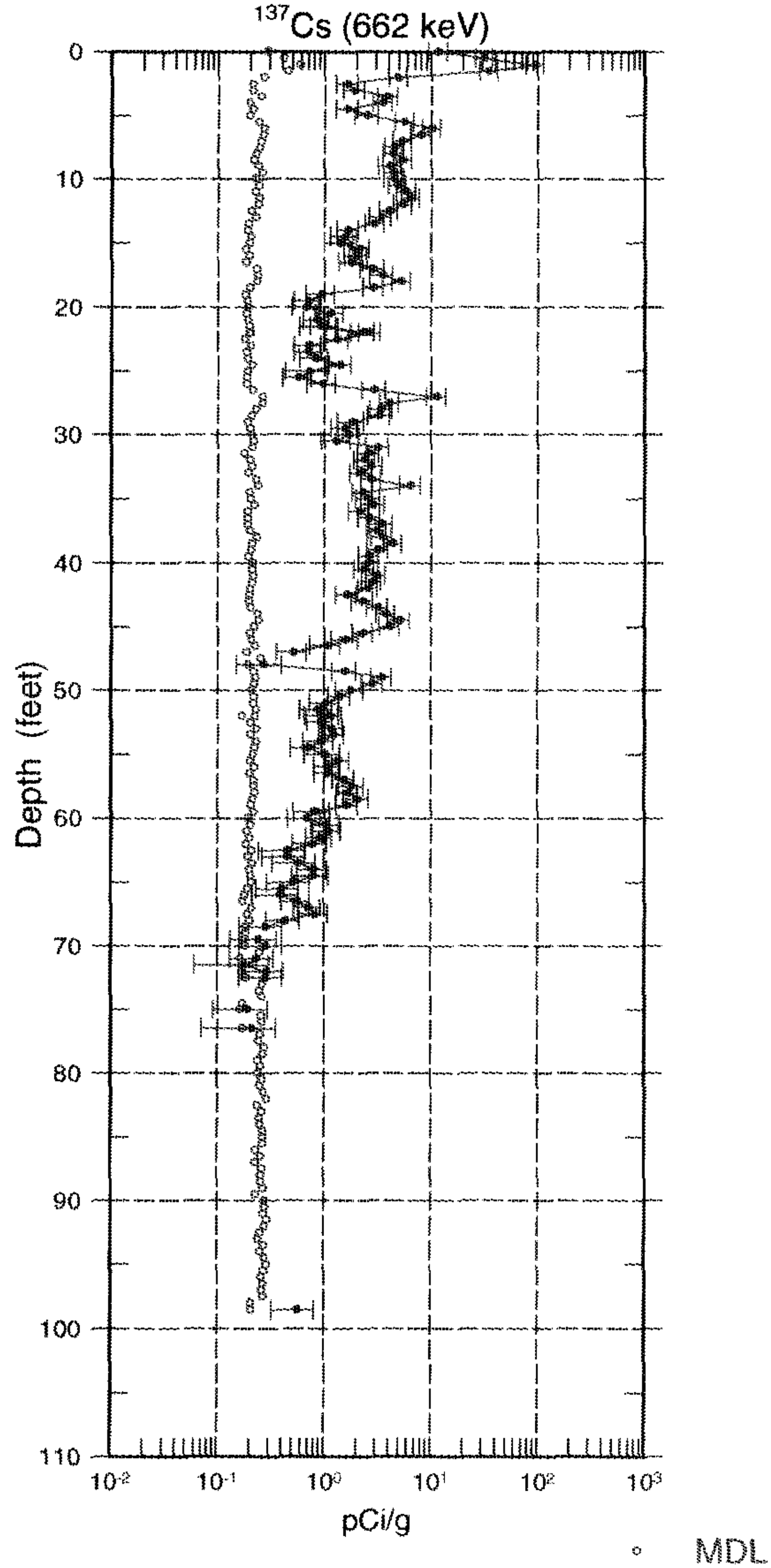
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

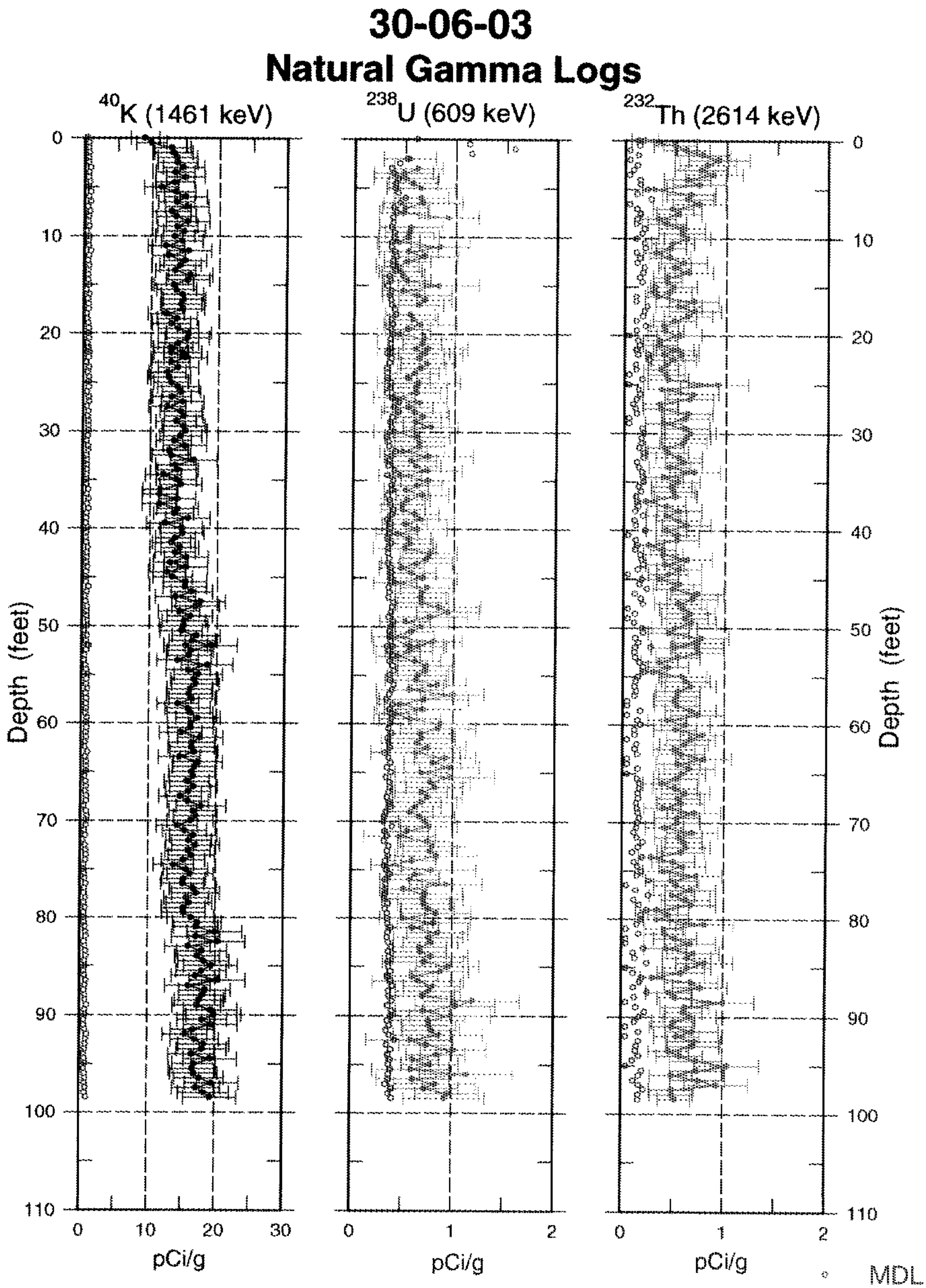
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with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

30-06-03

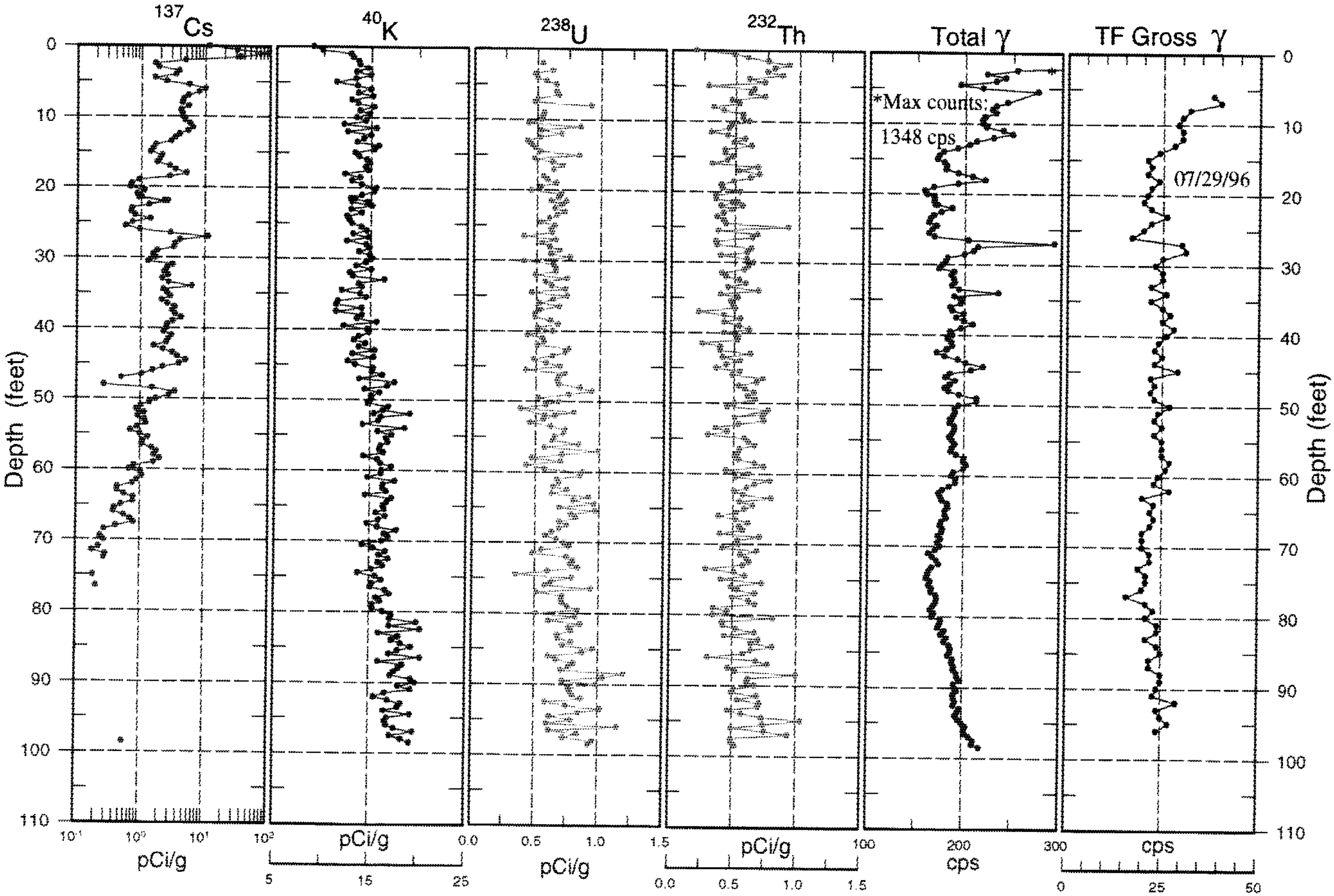
Man-Made Radionuclide Concentrations



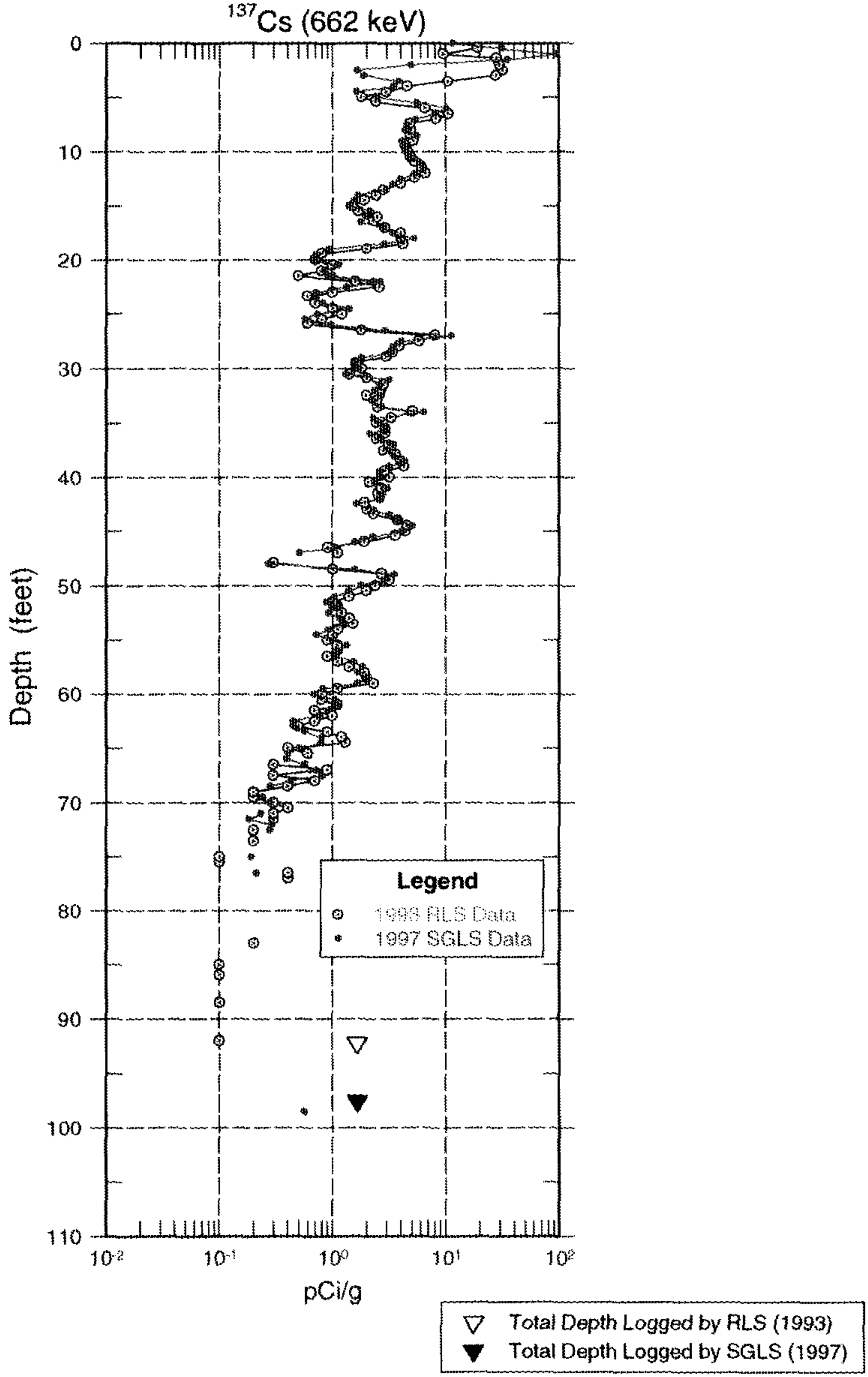


30-06-03
Natural Gamma Logs
40K (1461 keV)
238U (609 keV)
232Th (2614 keV)
Depth (feet)
0
10
20
30
40
50
60
70
80
90
100
110
0
10
20
30
pCi/g
0
1
2
pCi/g
0
1
2
pCi/g
MDL

30-06-03 Combination Plot



30-06-03
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



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Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-06-04

Borehole Information

Farm : C Tank : C-106 Site Number : 299-E27-73
N-Coord : 42,897 W-Coord : 48,288 TOC Elevation : 644.71
Water Level, ft : None Date Drilled : 11/30/72

Casing Record

Type : Steel-welded Thickness : 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 : 2/5/97 Logging Engineer: Alan Pearson
Start Depth, ft.: 129.5 Counting Time, sec.: 100 L/R : L Shield : N
Finish Depth, ft. : 66.0 MSA Interval, ft. : .5 Log Speed, ft/min.: n/a

Log Run Number : 2 Log Run Date : 2/6/97 Logging Engineer: Alan Pearson
Start Depth, ft.: 0.0 Counting Time, sec.: 100 L/R : L Shield : N
Finish Depth, ft. : 67.0 MSA Interval, ft. : .5 Log Speed, ft/min.: n/a

Borehole 30-06-04

Log Event 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 two 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 and Co-60 were detected in this borehole. Cs-137 contamination was detected from the ground surface to about 66 ft with the contamination level generally decreasing with depth. Isolated concentrations of Cs-137 were also detected between 71 and 111 ft. The presence of Co-60 was detected continuously from 85 to 90.5 ft and at 93 ft.

The K-40 concentration values increase gradually from 43 to 49 ft, remain elevated and become increasingly variable to a depth of 75 ft, increase again at 79 ft, and remain elevated to bottom of the logged interval.

It was not possible to identify many of the 609-keV peaks used to derive the U-238 concentrations between the ground surface and 27 ft because of an elevated Compton continuum from the Cs-137.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-102, C-103, and C-106.

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.

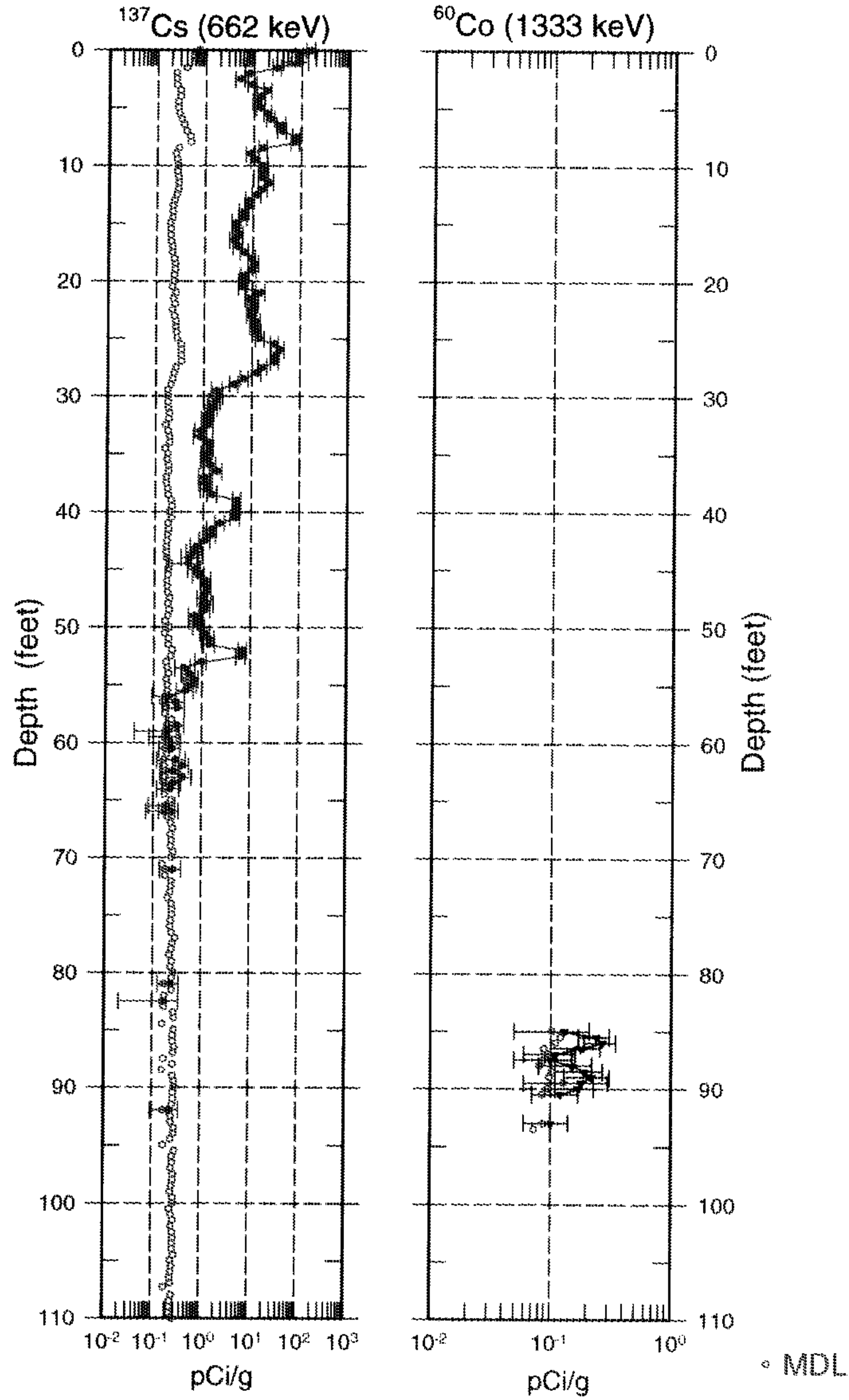
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

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 comparison plot is also provided showing the Cs-137 and Co-60 concentrations determined from the SGLS in 1997 and those determined from the Radionuclide Logging System (RLS) in 1993.

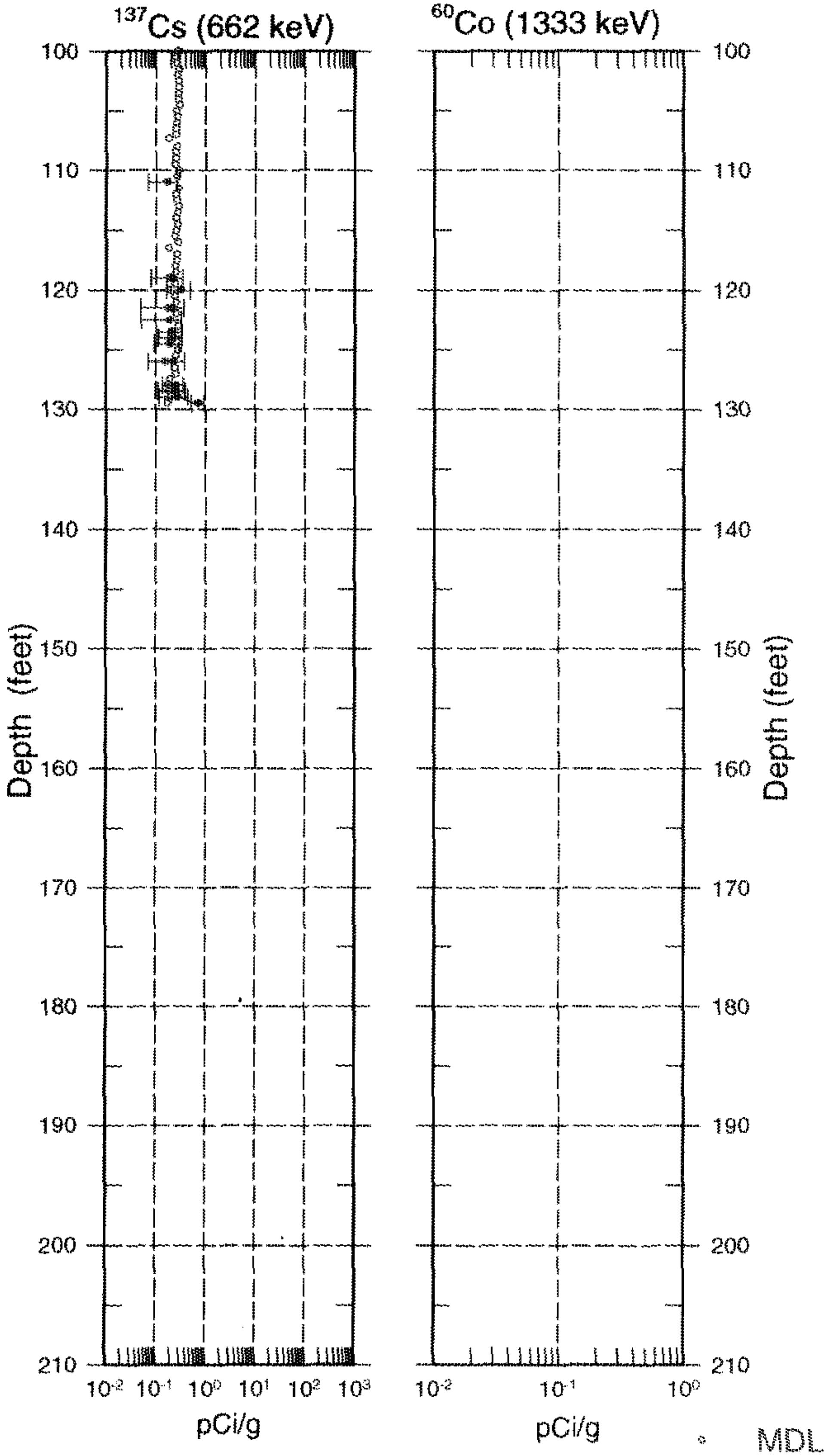
A plot of representative historical gross gamma-ray logs from 1975 to 1993 is included. The headings of the plots identify the date on which the data in the plots were gathered.

30-06-04
Man-Made Radionuclide Concentrations

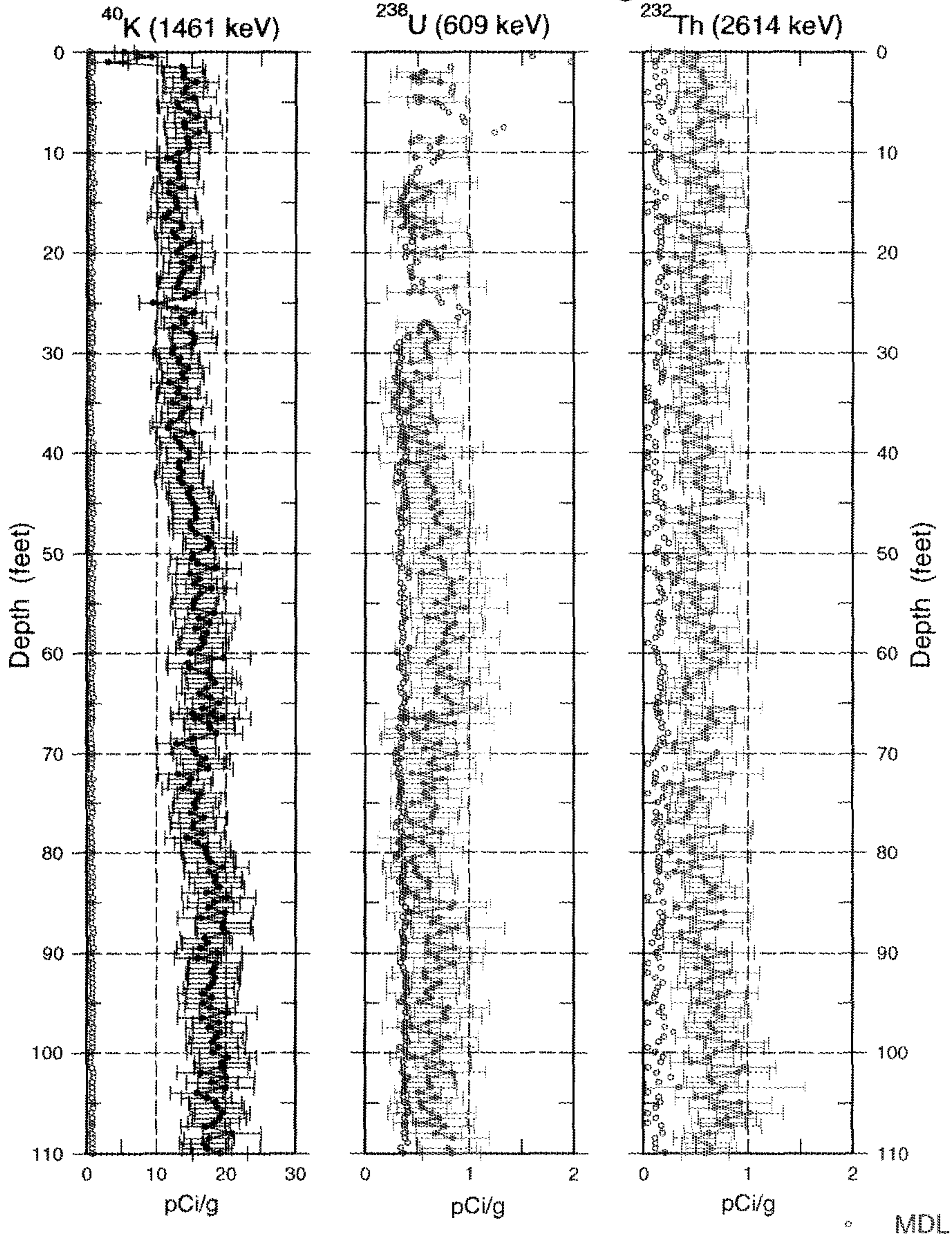


30-06-04

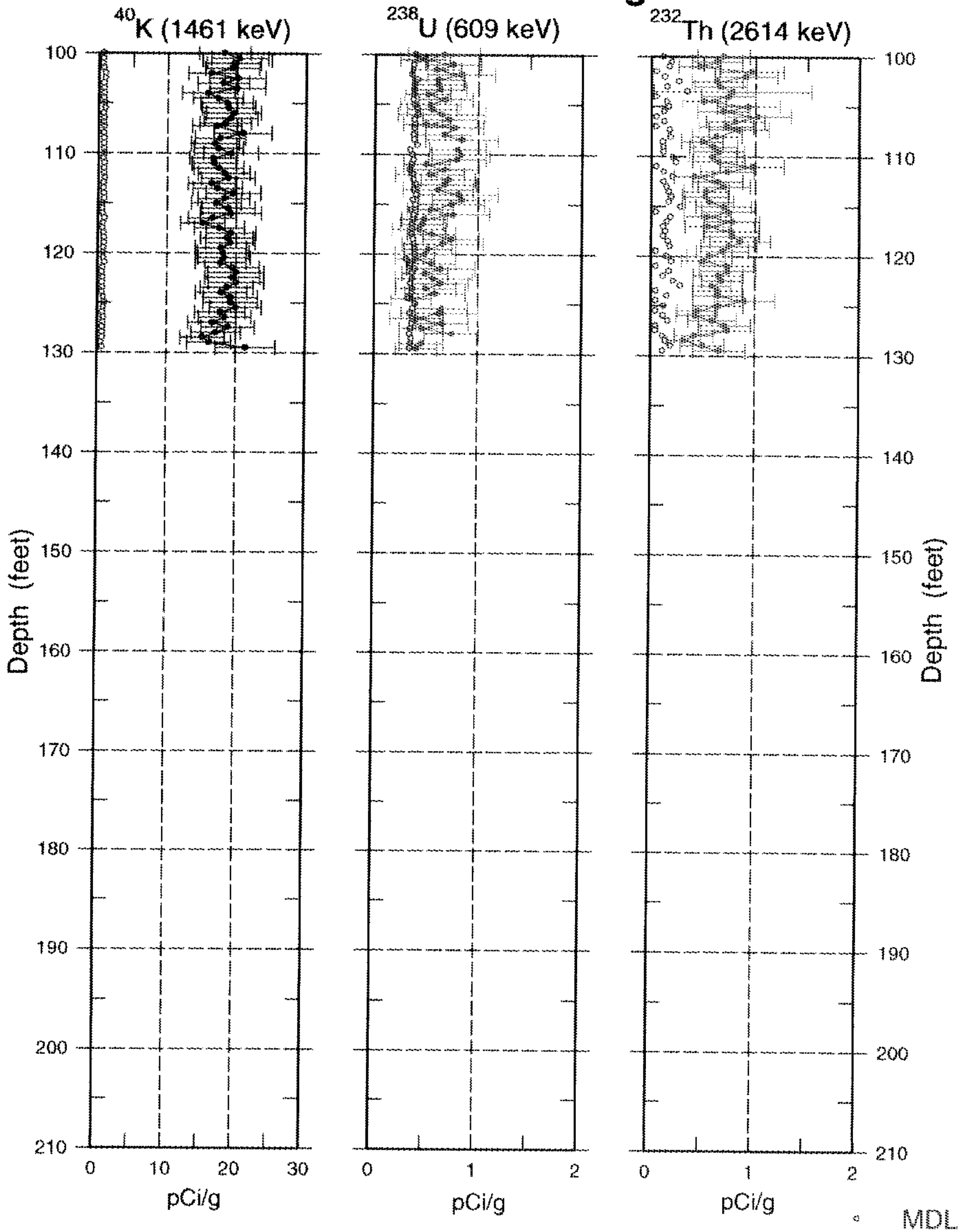
Man-Made Radionuclide Concentrations



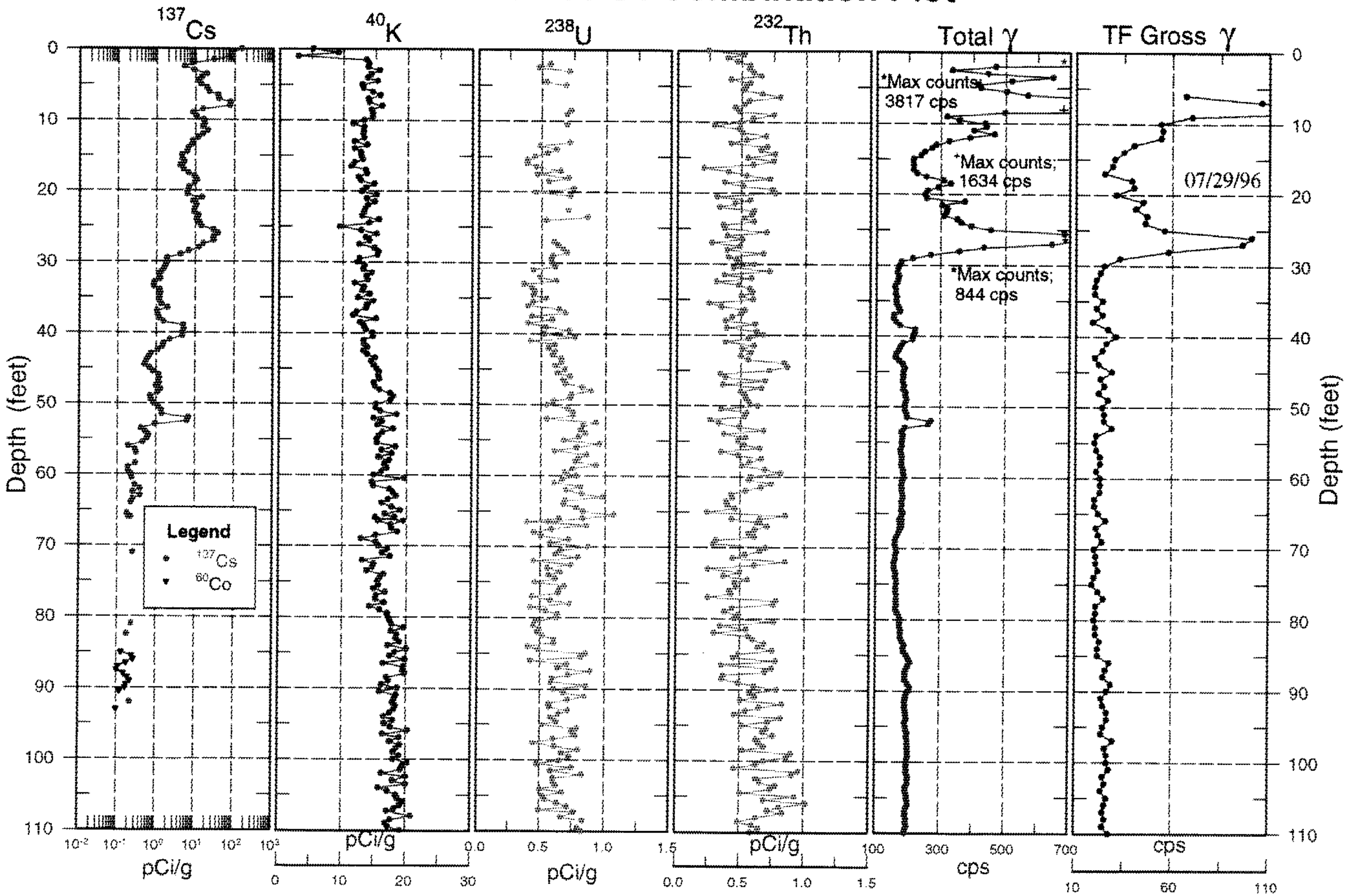
30-06-04
Natural Gamma Logs



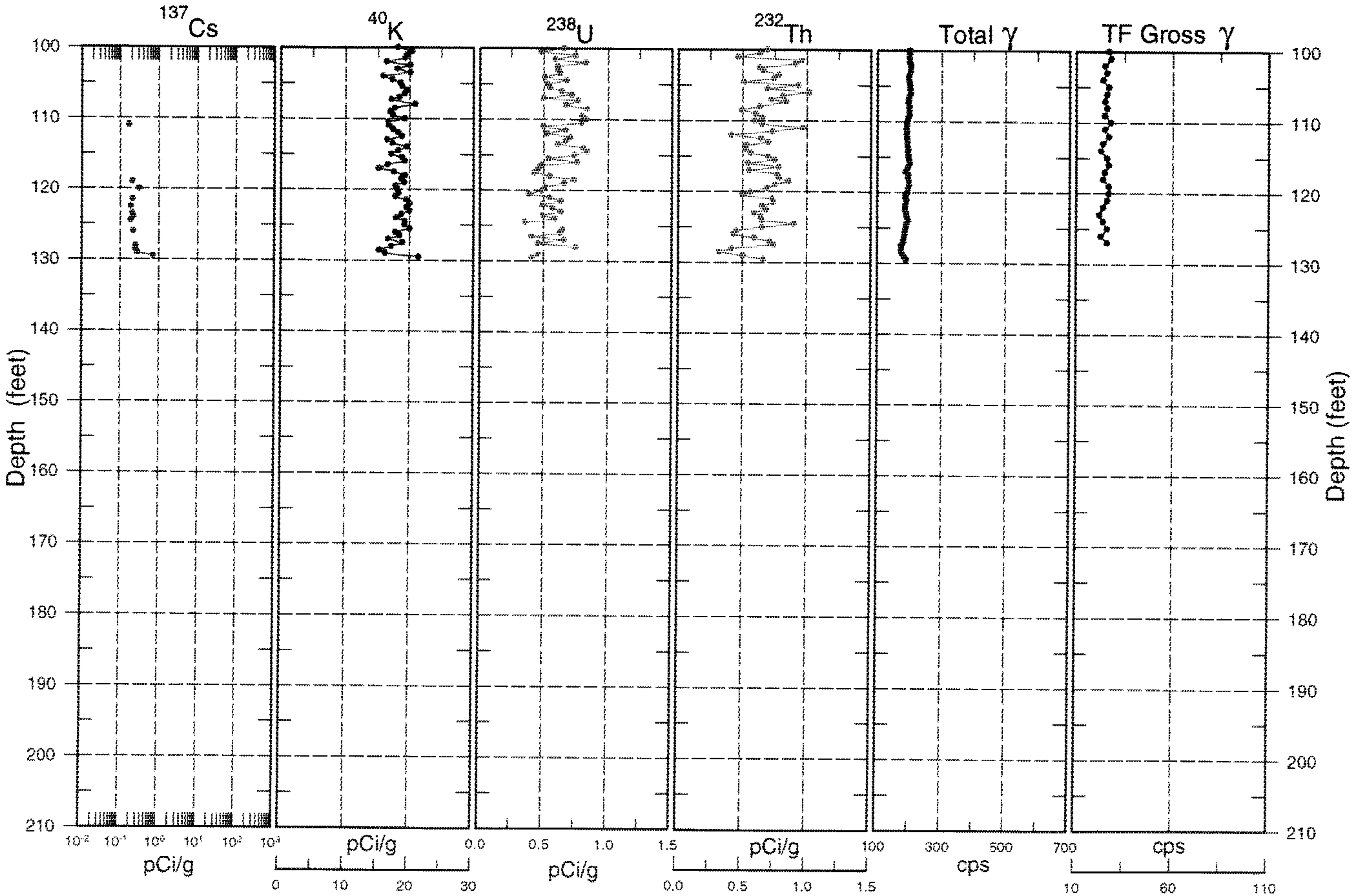
30-06-04
Natural Gamma Logs



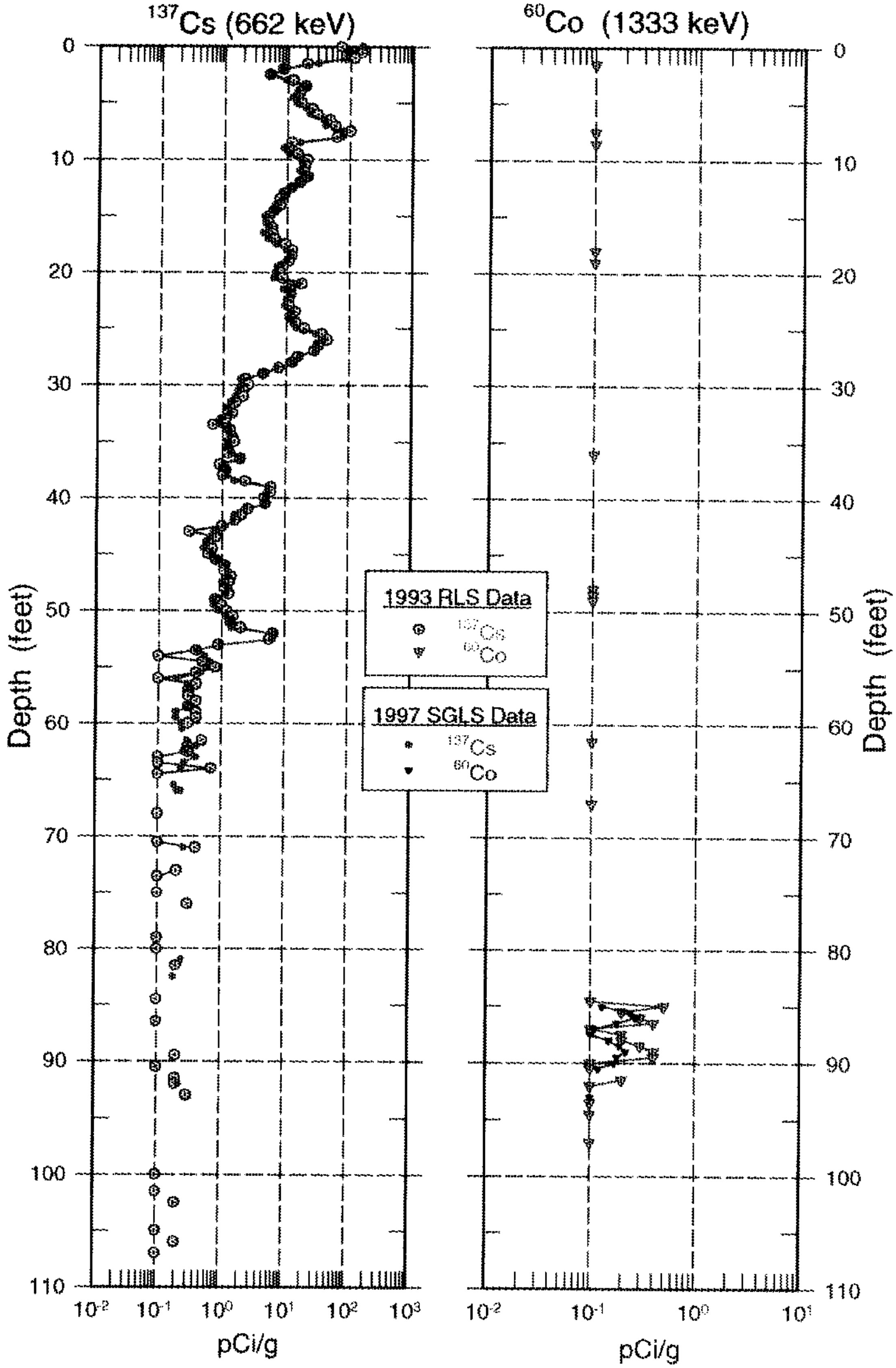
30-06-04 Combination Plot



30-06-04 Combination Plot



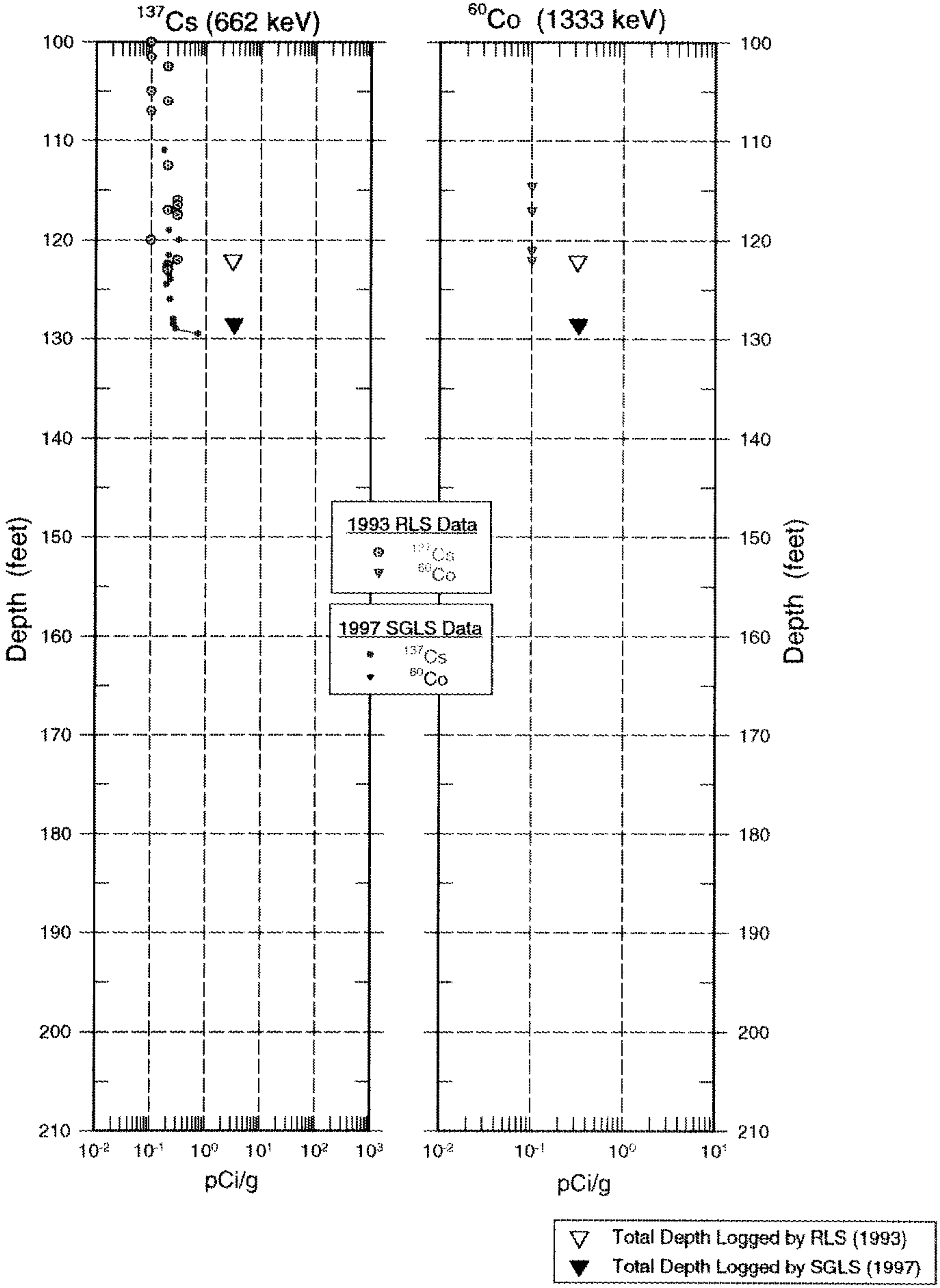
30-06-04
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



30-06-04

Man-Made Radionuclide Concentrations

1993/1997 Spectral Gamma Data Comparison



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Spectral Gamma-Ray Borehole Log Data Report

Log Event A

Borehole 30-05-02

Borehole Information

Farm :	C	Tank :	C-105	Site Number :	299-E27-70
N-Coord :	42,893	W-Coord :	48,290	TOC Elevation :	645.70
Water Level, ft :	None	Date Drilled :	11/30/72		

Casing Record

Type :	Steel-welded	Thickness :	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 :	2	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 :	2/5/97	Logging Engineer:	Bob Spatz		
Start Depth, ft.:	127.5	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	64.0	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Log Run Number :	2	Log Run Date :	2/6/97	Logging Engineer:	Bob Spatz		
Start Depth, ft.:	65.0	Counting Time, sec.:	100	L/R :	L	Shield :	N
Finish Depth, ft. :	0.0	MSA Interval, ft. :	.5	Log Speed, ft/min.:	n/a		

Log Event A

Borehole 30-05-02

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 two 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, and Eu-154 were detected in this borehole. Continuous Cs-137 contamination was measured from the ground surface to a depth of 81 ft. Alternating zones of intermittent and continuous Cs-137 contamination were detected from 82 ft to the bottom of the logged interval (127.5 ft). Continuous Co-60 contamination was detected from 75 to 80.5 ft. Isolated occurrences of Co-60 were also detected at 65 and 83 ft. A single occurrence of Eu-154 was detected at the ground surface.

The K-40 concentration values increase at about 38 ft and become variable from 48 to 73 ft. The K-40 concentration values increase again at 73 and 86 ft, then remain elevated to the bottom of the logged interval. A definitive peak is shown on the U-238 plot at a depth of 39 ft.

Additional information and interpretations of log data are included in the main body of the Tank Summary Data Reports for tanks C-102, C-105, and C-106.

Log Plot Notes:

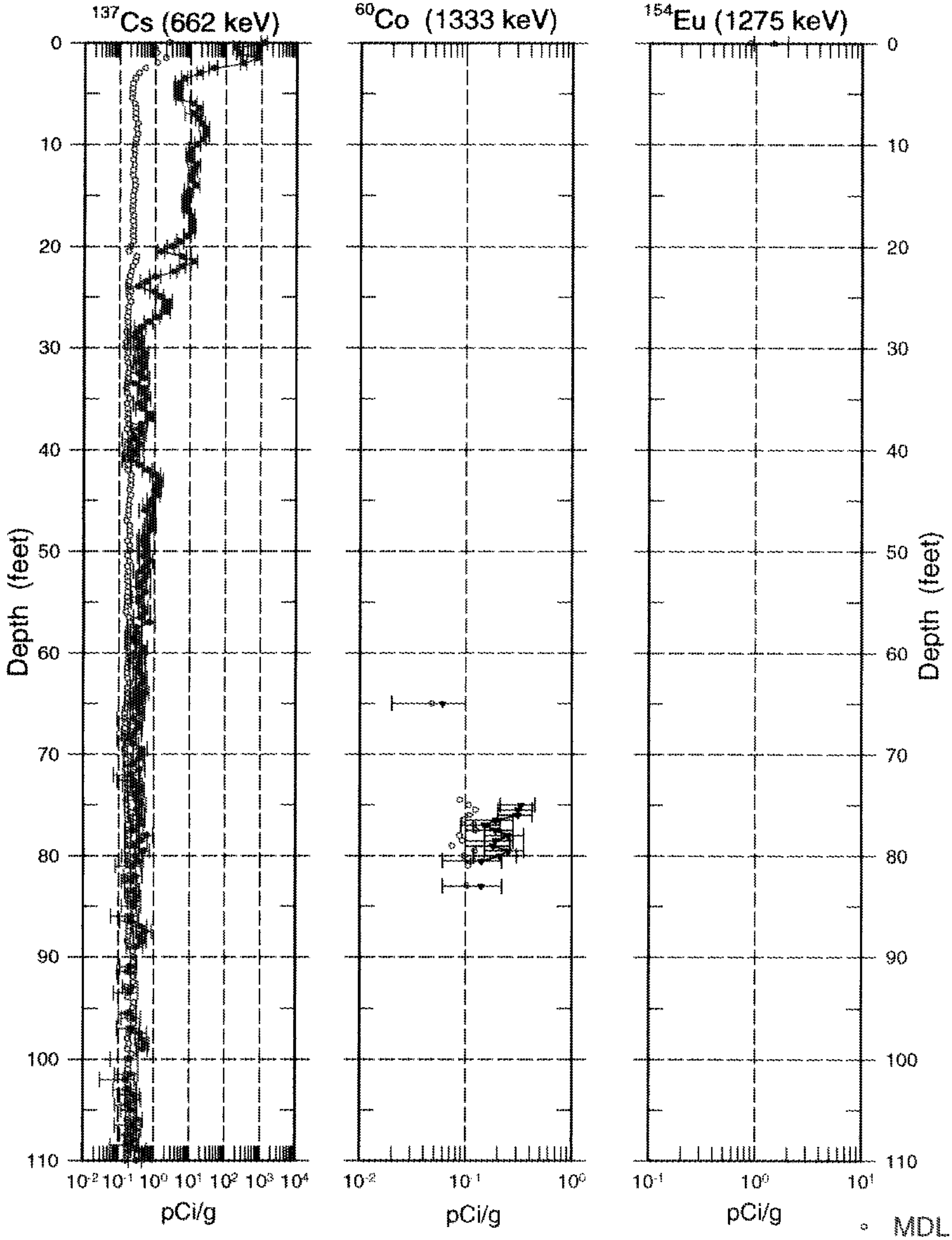
Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

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.

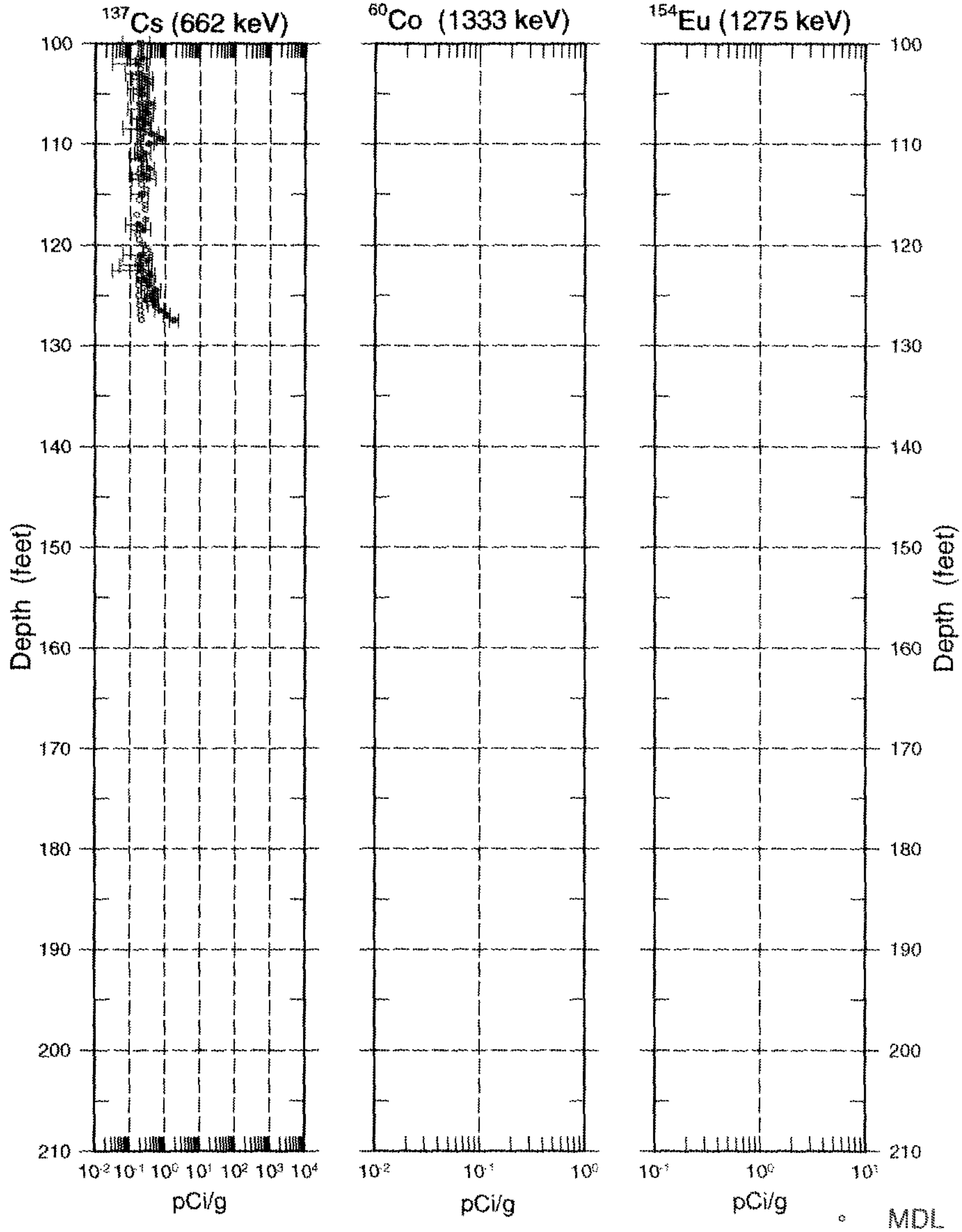
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with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

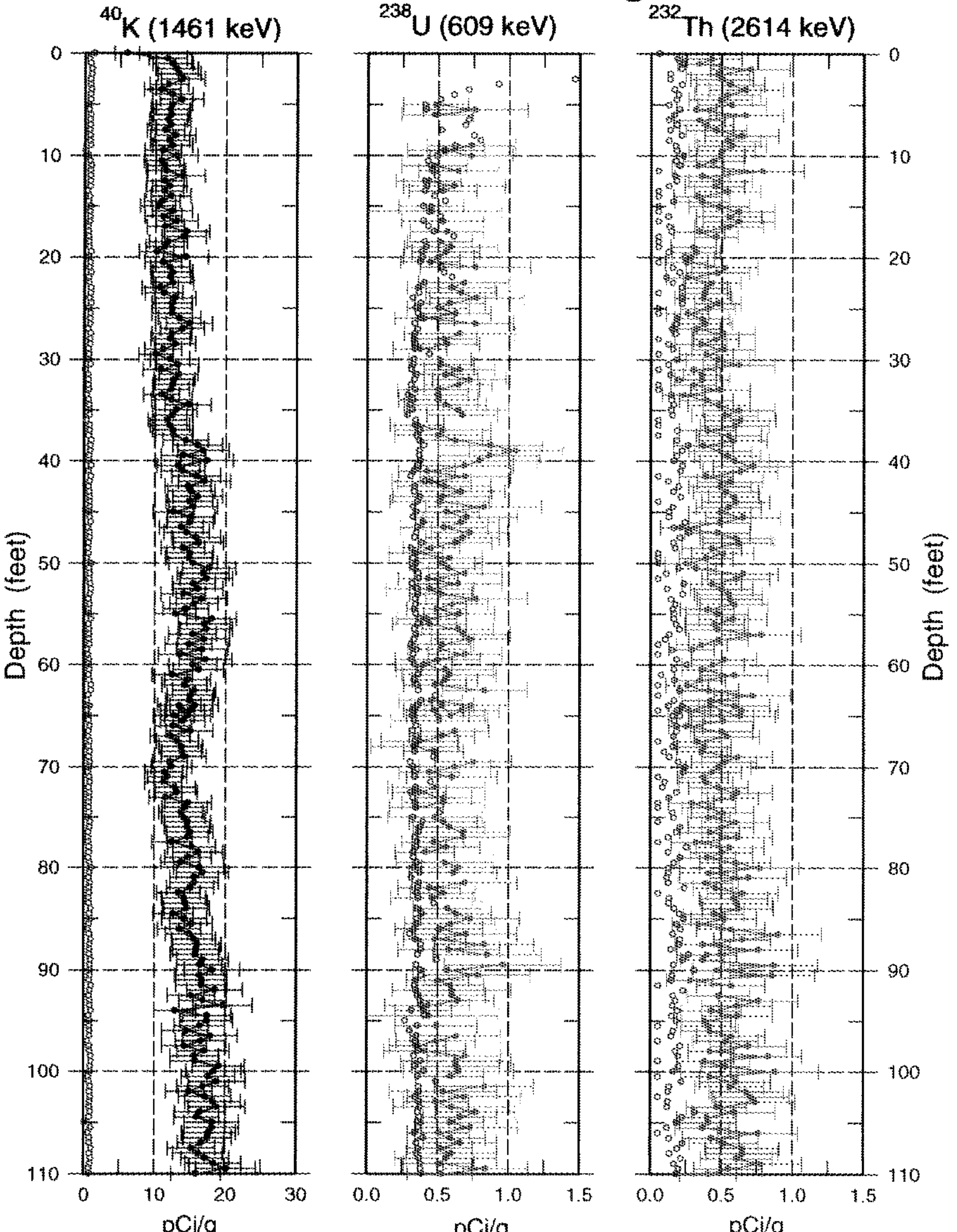
30-05-02
Man-Made Radionuclide Concentrations

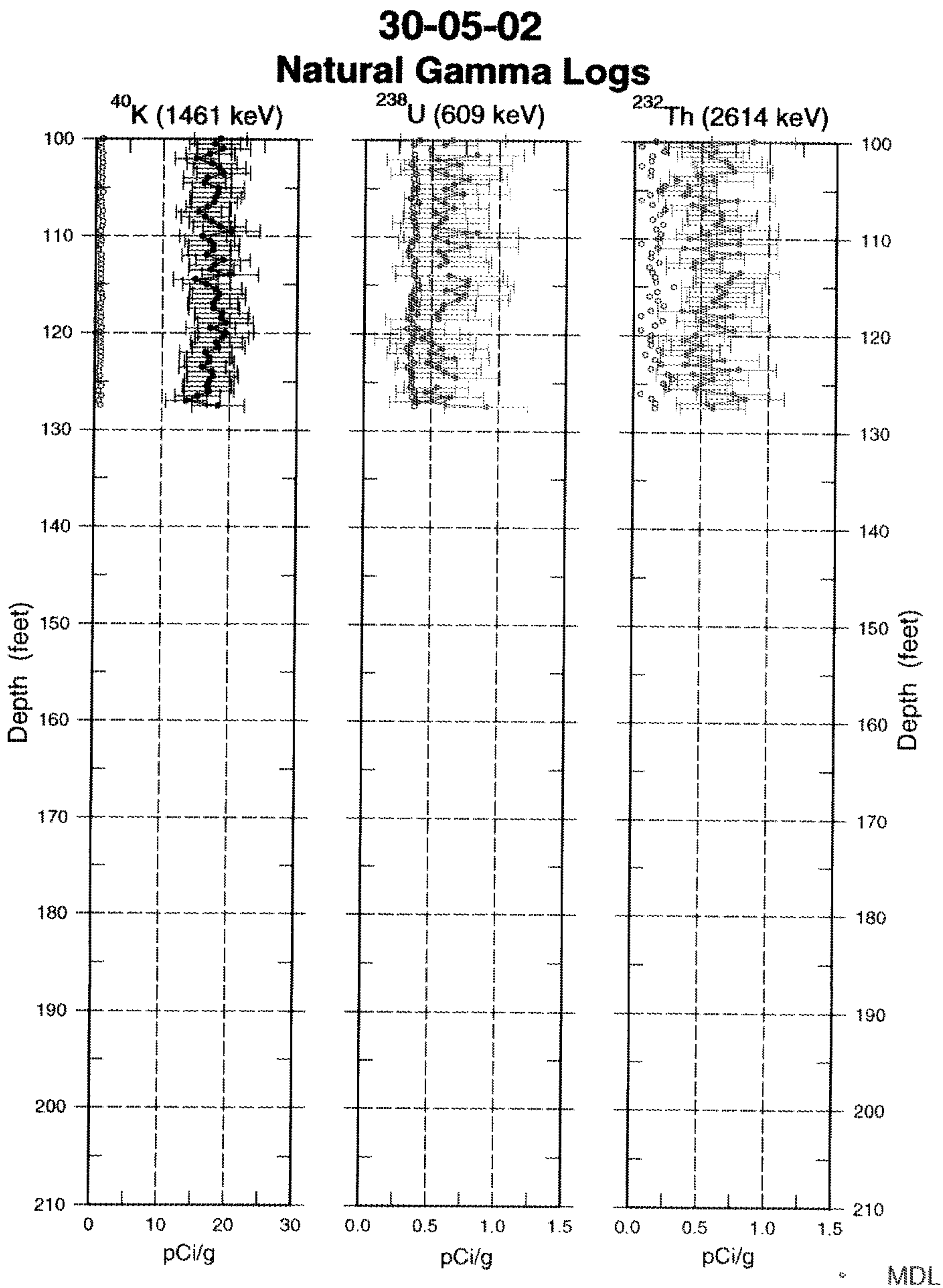


30-05-02
Man-Made Radionuclide Concentrations



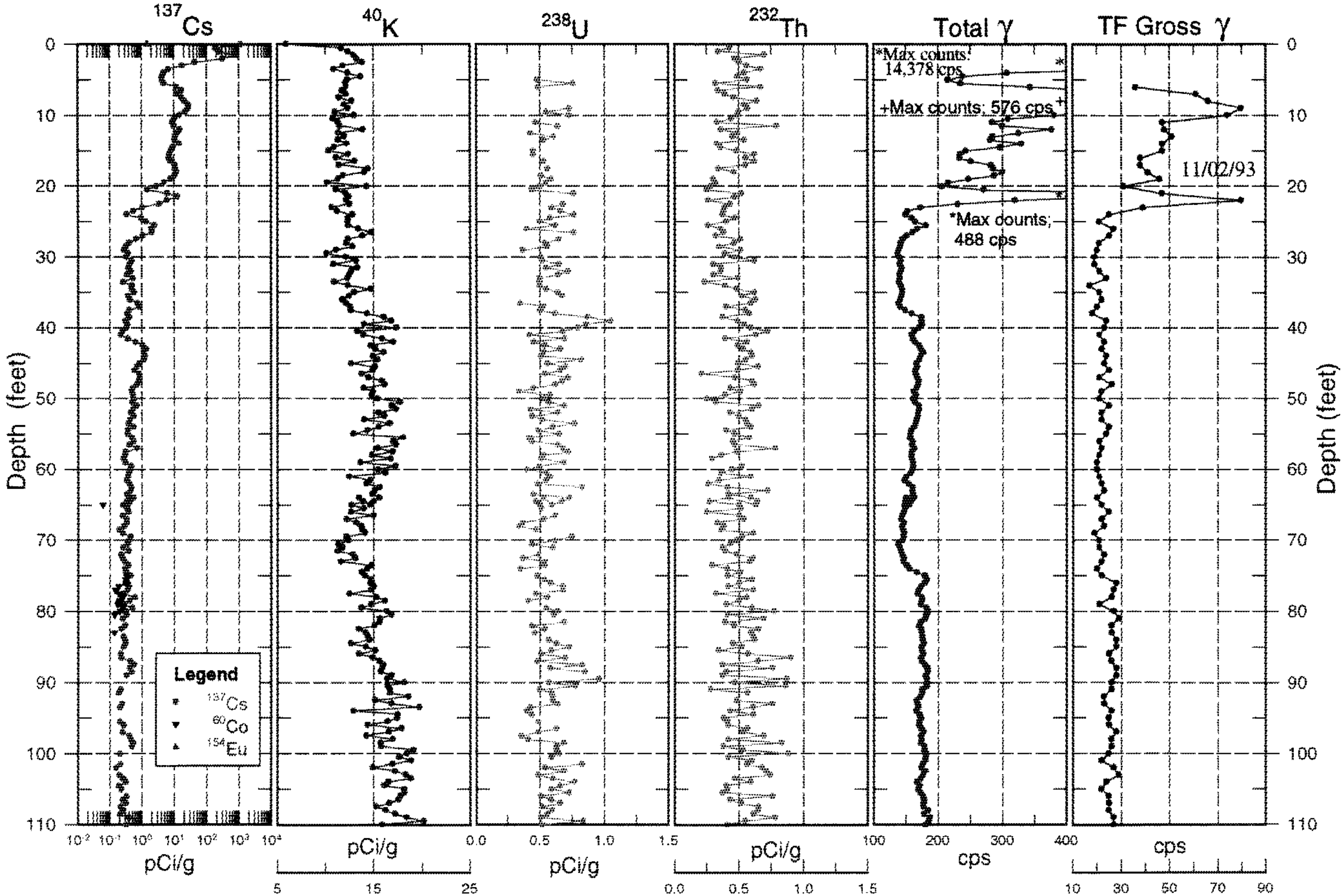
30-05-02
Natural Gamma Logs



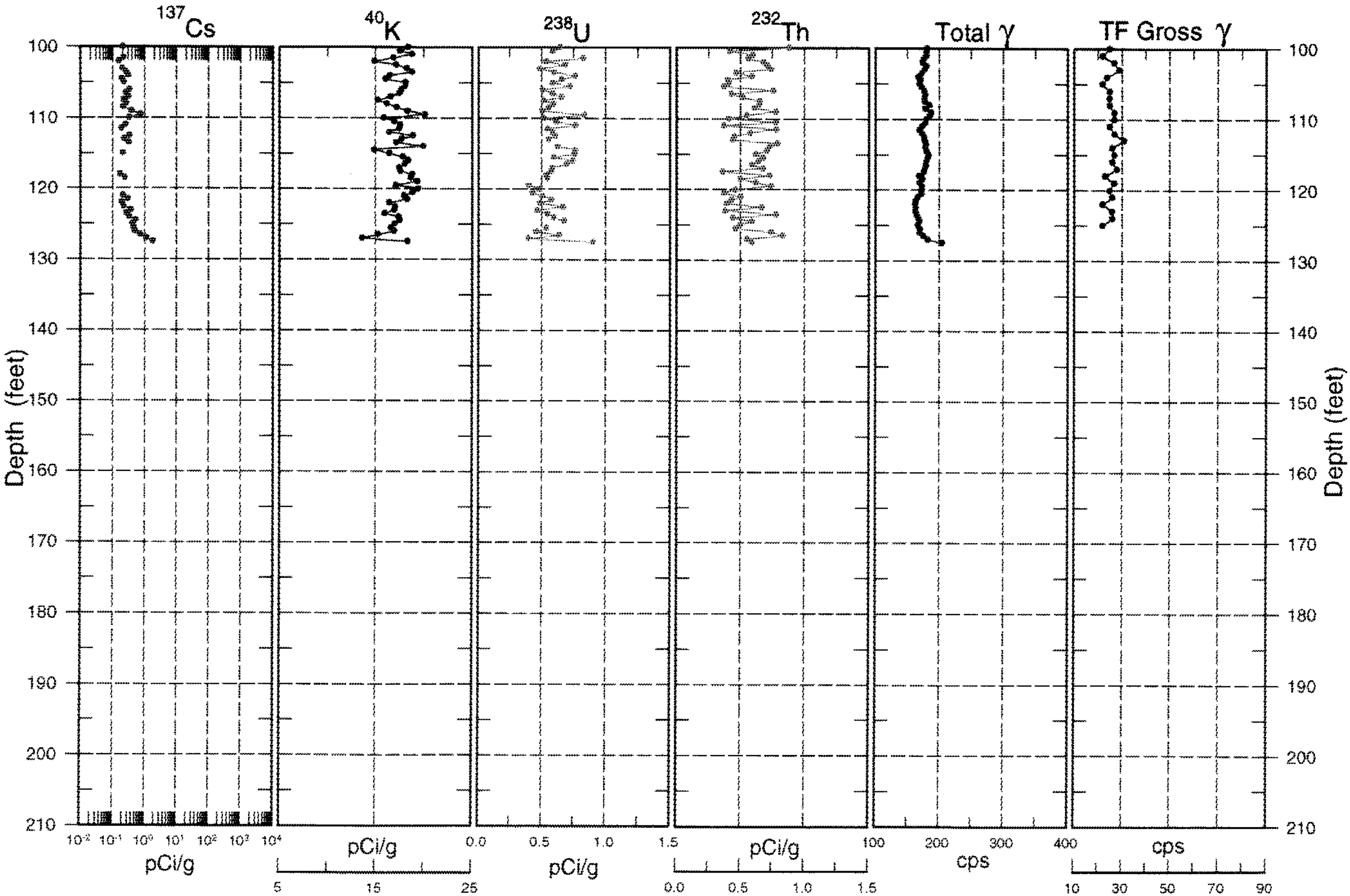


30-05-02
Natural Gamma Logs
40K (1461 keV)
238U (609 keV)
232Th (2614 keV)
Depth (feet)
100
110
120
130
140
150
160
170
180
190
200
210
0
10
20
30
0.0
0.5
1.0
1.5
pCi/g
MDL

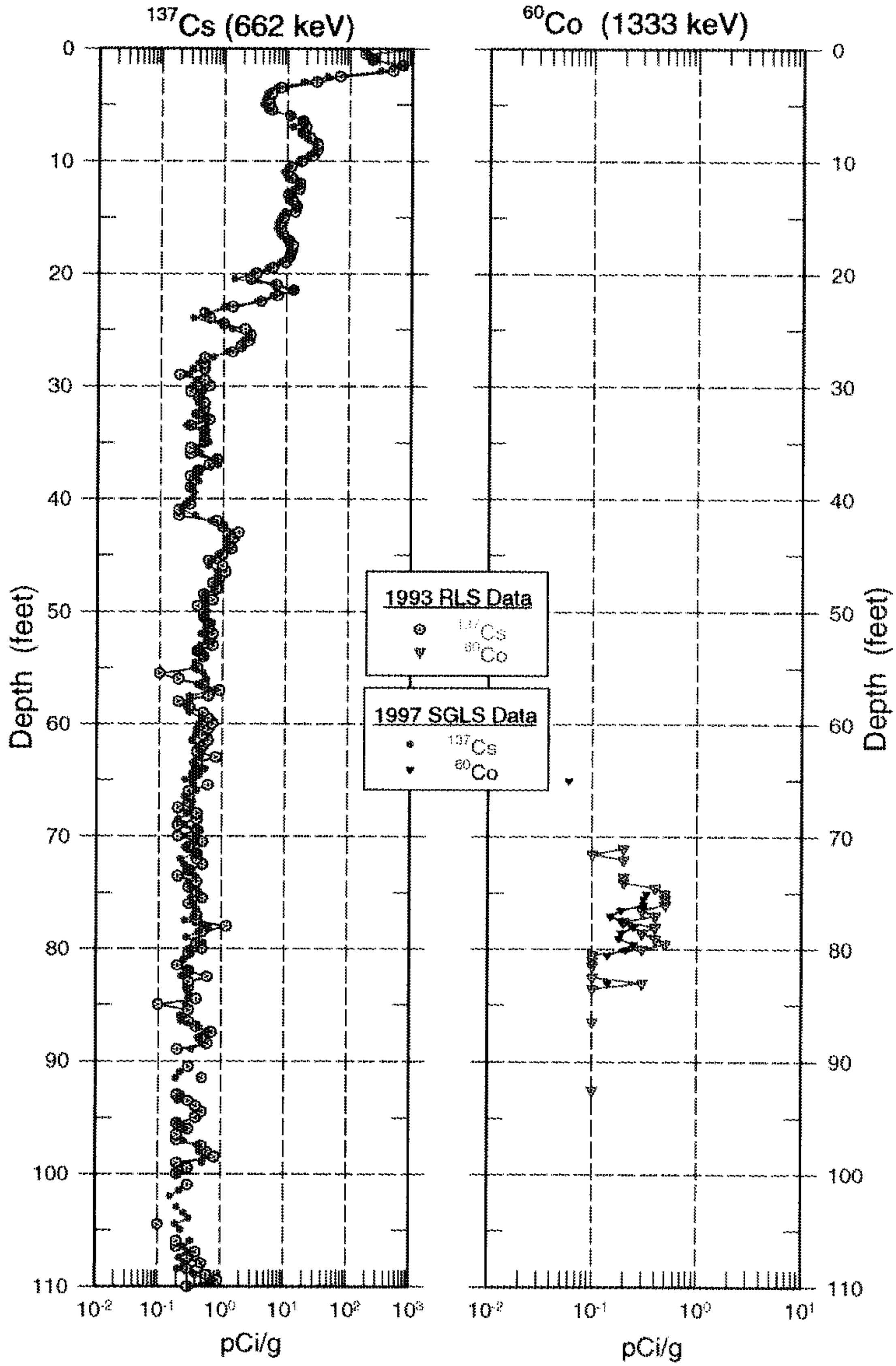
30-05-02 Combination Plot



30-05-02 Combination Plot



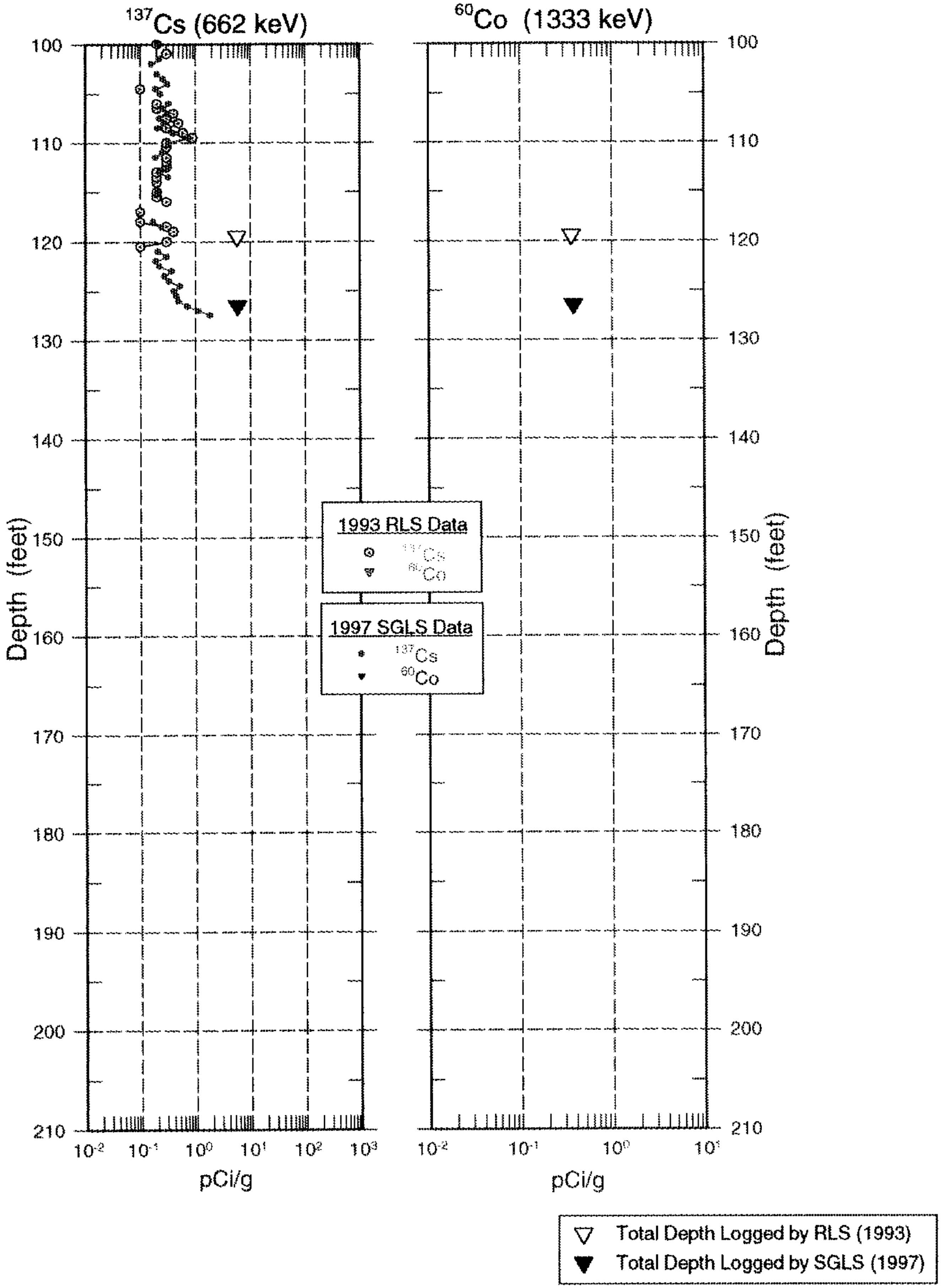
30-05-02
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



30-05-02

Man-Made Radionuclide Concentrations

1993/1997 Spectral Gamma Data Comparison



Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole 30-06-09

Borehole Information

Farm :	C	**Tank :**	C-106	**Site Number :**	299-E27-85
N-Coord :	42,932	**W-Coord :**	48,302	**TOC Elevation :**	645.40
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 to a depth of 100 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 :**	2/3/97	**Logging Engineer:**	Alan Pearson		
Start Depth, ft.:	0.0	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	35.0	**MSA Interval, ft. :**	.5	**Log Speed, ft/min.:**	n/a		

Log Run Number :	2	**Log Run Date :**	2/4/97	**Logging Engineer:**	Bob Spatz		
Start Depth, ft.:	98.5	**Counting Time, sec.:**	100	**L/R :**	L	**Shield :**	N
Finish Depth, ft. :	34.0	**MSA Interval, ft. :**	.5	**Log Speed, ft/min.:**	n/a		

Log Event A

Borehole 30-06-09

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 two 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, and U-235 were detected in this borehole. The presence of Cs-137 was measured almost continuously from the ground surface to a depth of 52.5 ft. Measurable Cs-137 contamination was also detected from 54 to 72.5 ft, at 91.5 ft, and at the bottom of the logged interval (97 to 98.5 ft). The presence of Co-60 was detected from 22 to 22.5 ft and at 74.5 ft. U-235 contamination was detected at the ground surface.

The K-40 concentration values increase from 37.5 to 39.5 ft, then become variable from 41 to 71 ft. The K-40 concentrations increase gradually from 72 to 80 ft, then remain elevated to the bottom of the logged interval.

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

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

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.

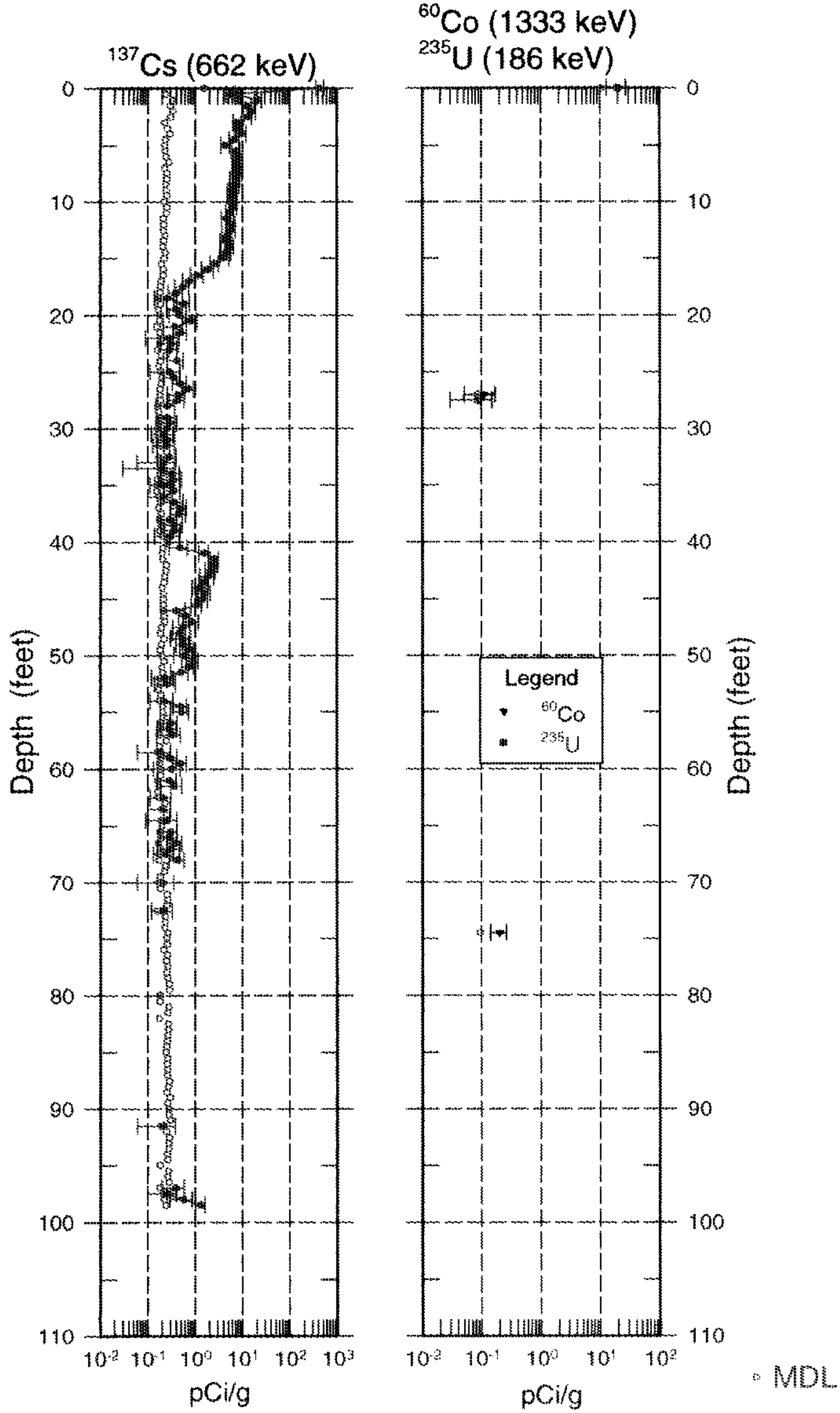
Uncertainty bars on the plots show the statistical uncertainties for the measurements as 95-percent confidence intervals. Open circles on the plots give the MDL. The MDL of a radionuclide represents the lowest concentration at which positive identification of a gamma-ray peak is statistically defensible.

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.

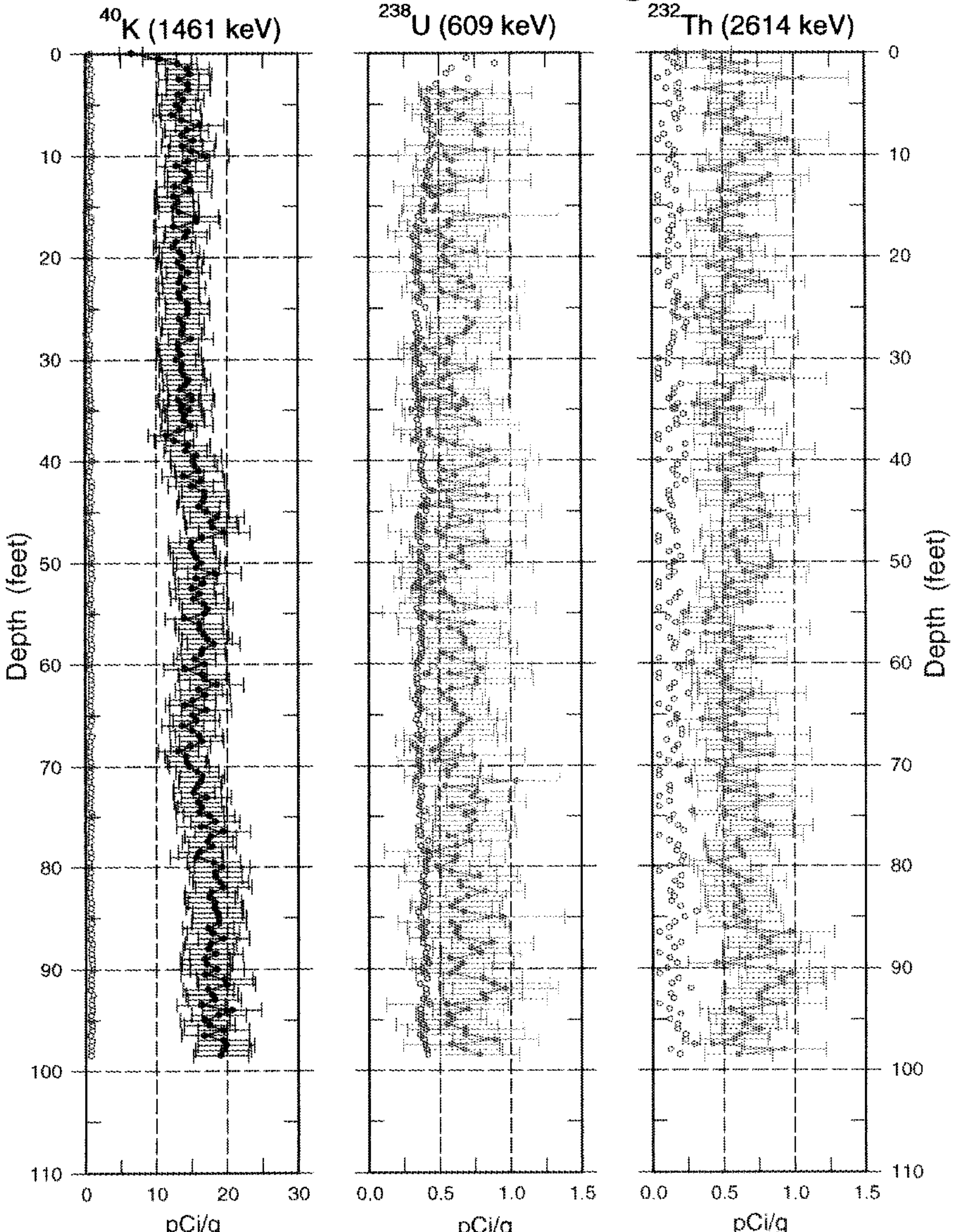
An additional log plot compares spectral gamma data collected with the Radionuclide Logging System

(RLS) in 1993 with spectral gamma data collected with the SGLS in 1997. Uncertainty bars and MDLs are not included on these plots.

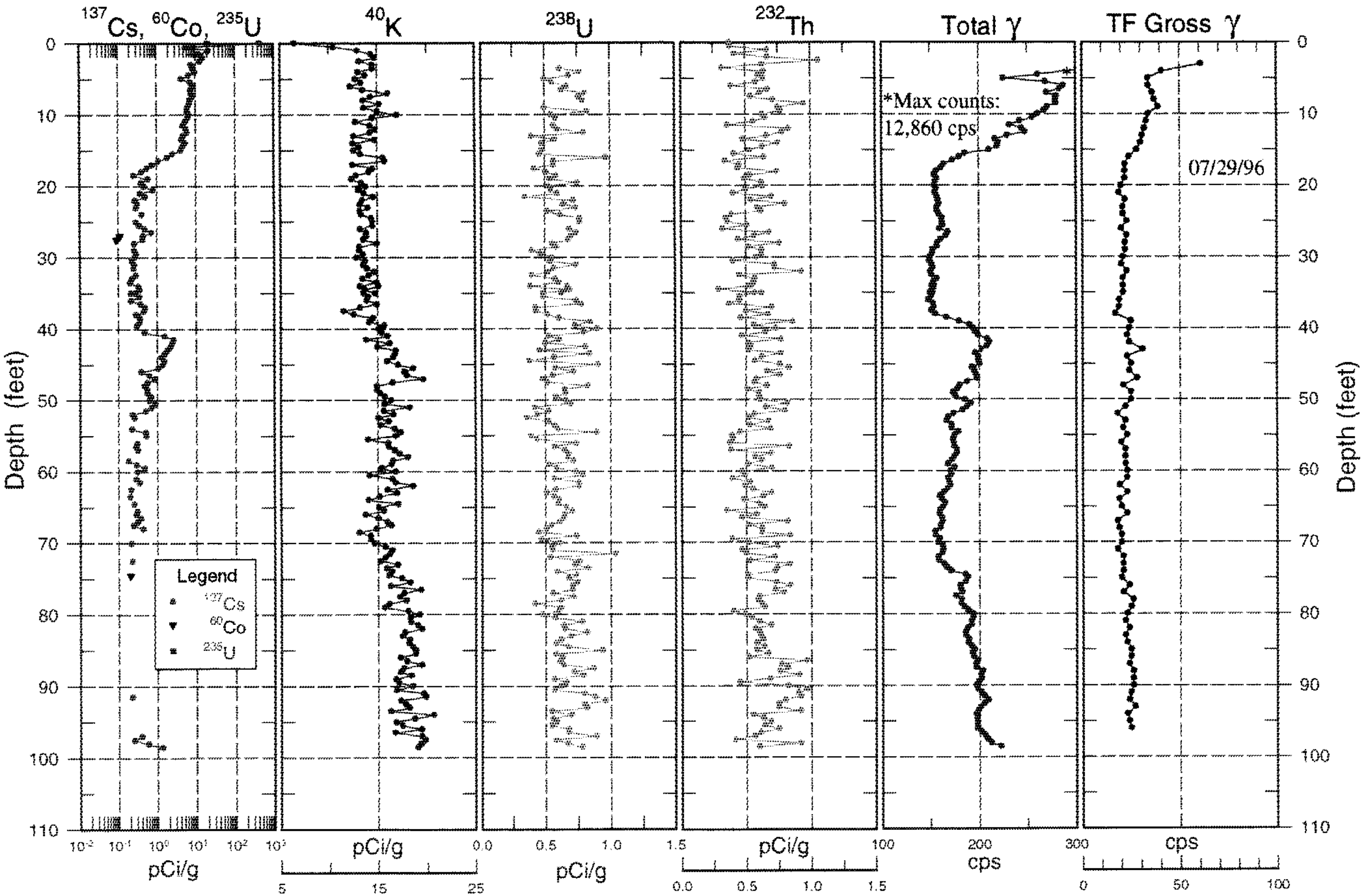
30-06-09
Man-Made Radionuclide Concentrations



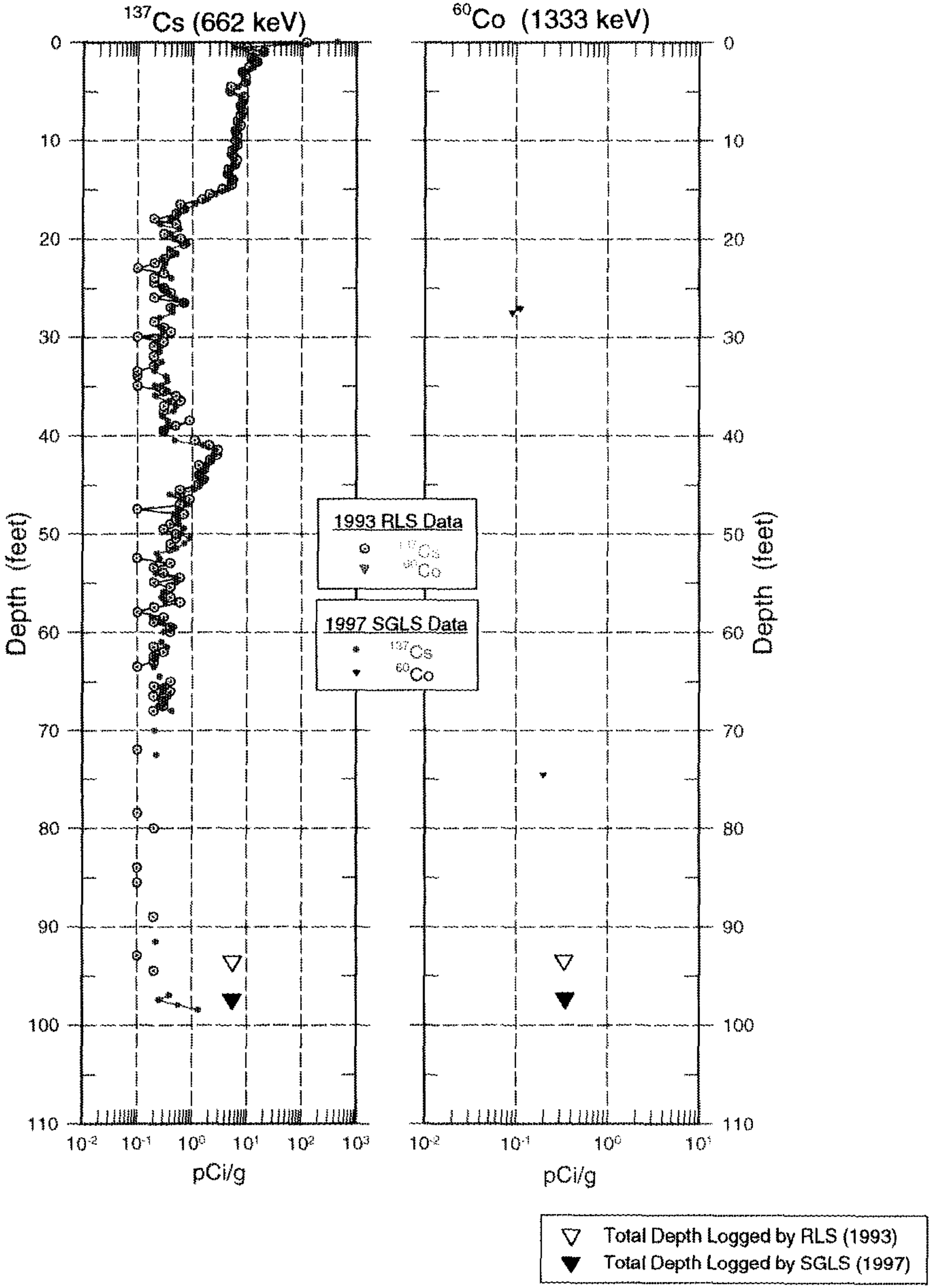
30-06-09
Natural Gamma Logs



30-06-09 Combination Plot



30-06-09
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



MACTEC ENVIRONMENTAL RESTORATION SERVICES, LLC

Spectral Gamma-Ray Borehole Log Data Report

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. : .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. : .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. : .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. : .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. : .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 were detected at the ground surface.

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 and C-106.

Log Plot Notes:

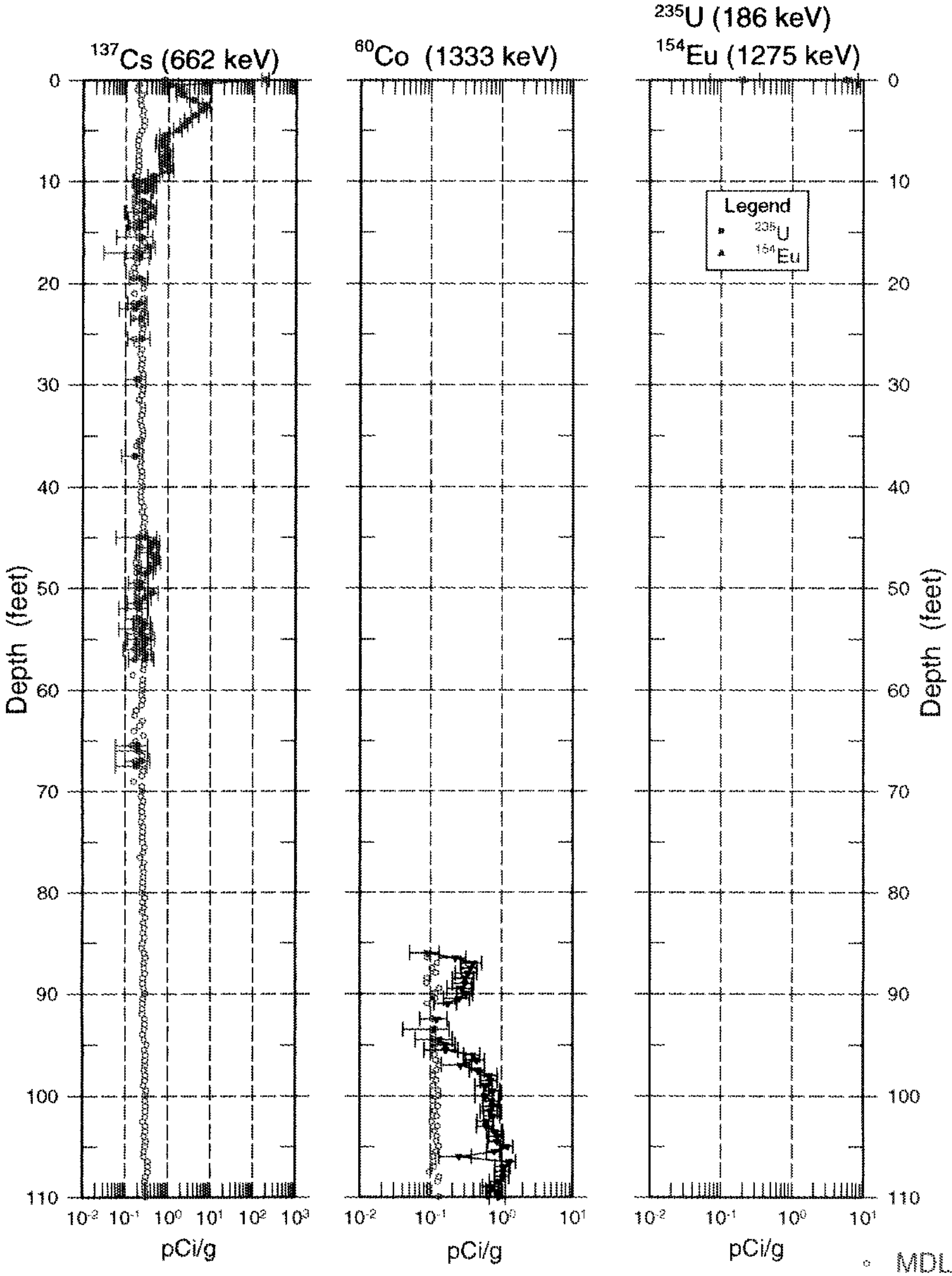
Separate log plots show the man-made and the naturally occurring radionuclides. The natural radionuclides can be used for lithology interpretations. The headings of the plots identify the specific gamma rays used to calculate the concentrations.

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.

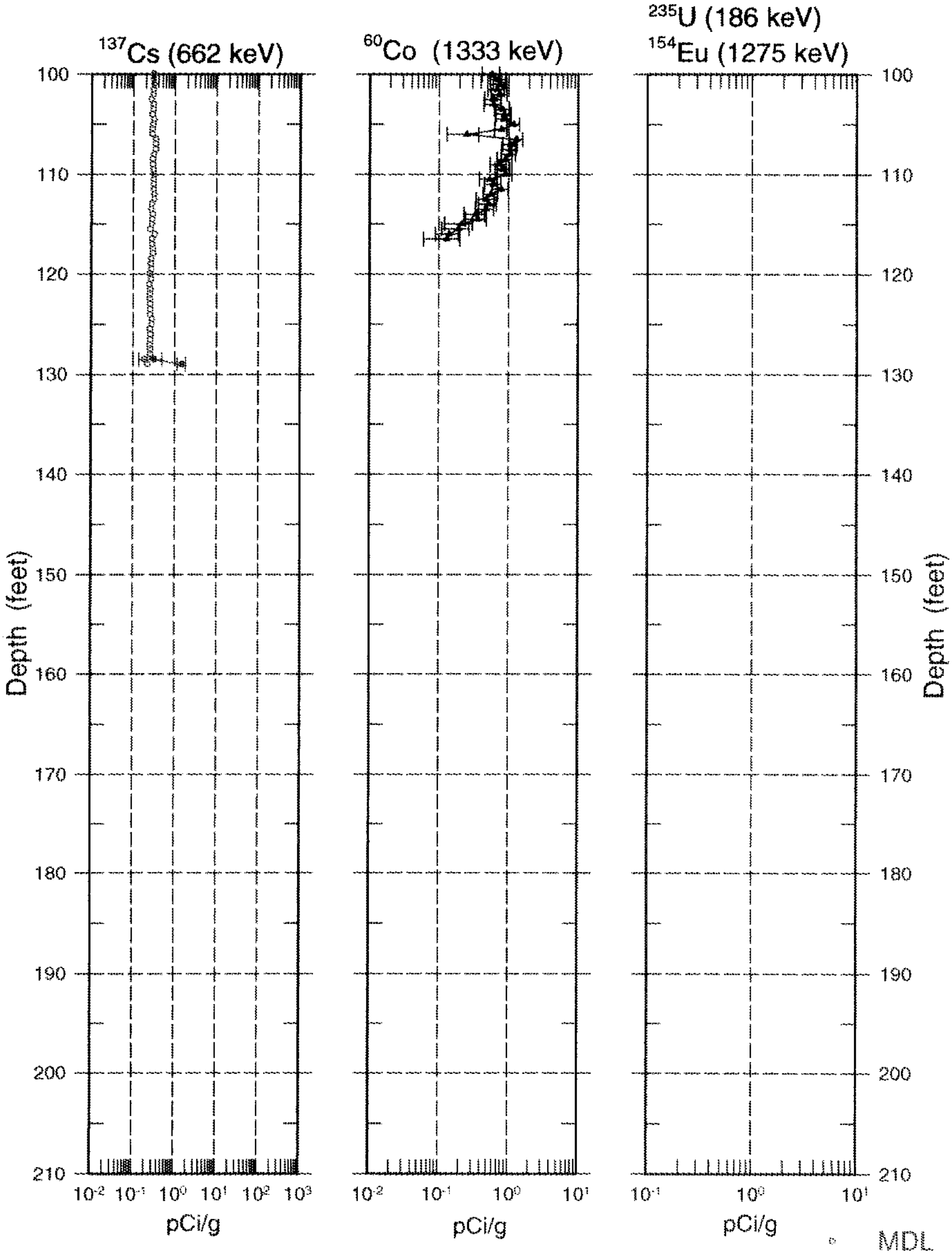
An additional log plot compares spectral gamma data collected with the Radionuclide Logging System (RLS) in 1993 with spectral gamma data collected with the SGLS in 1997. Uncertainty bars and MDLs are not included on these plots.

30-06-10
Man-Made Radionuclide Concentrations

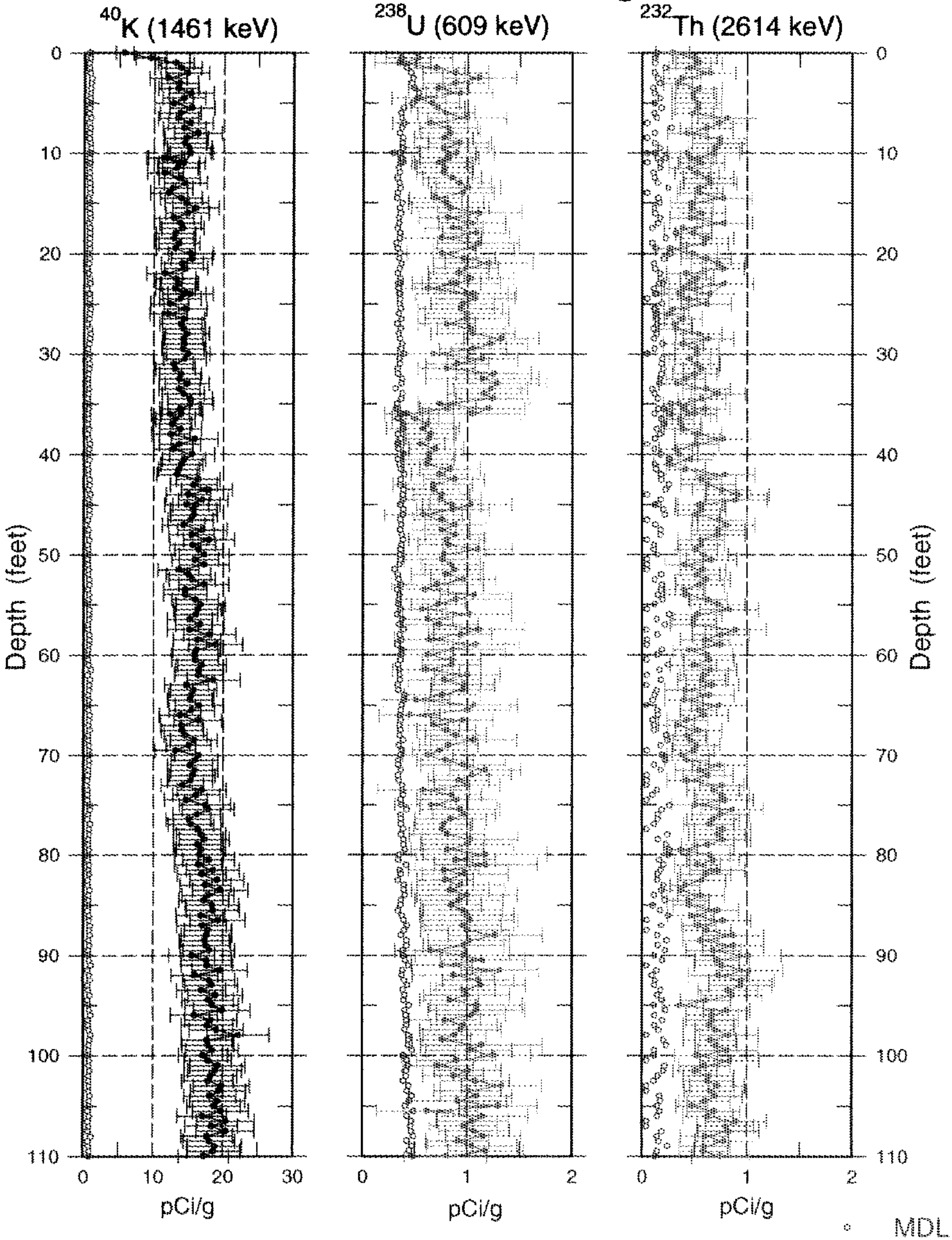


30-06-10

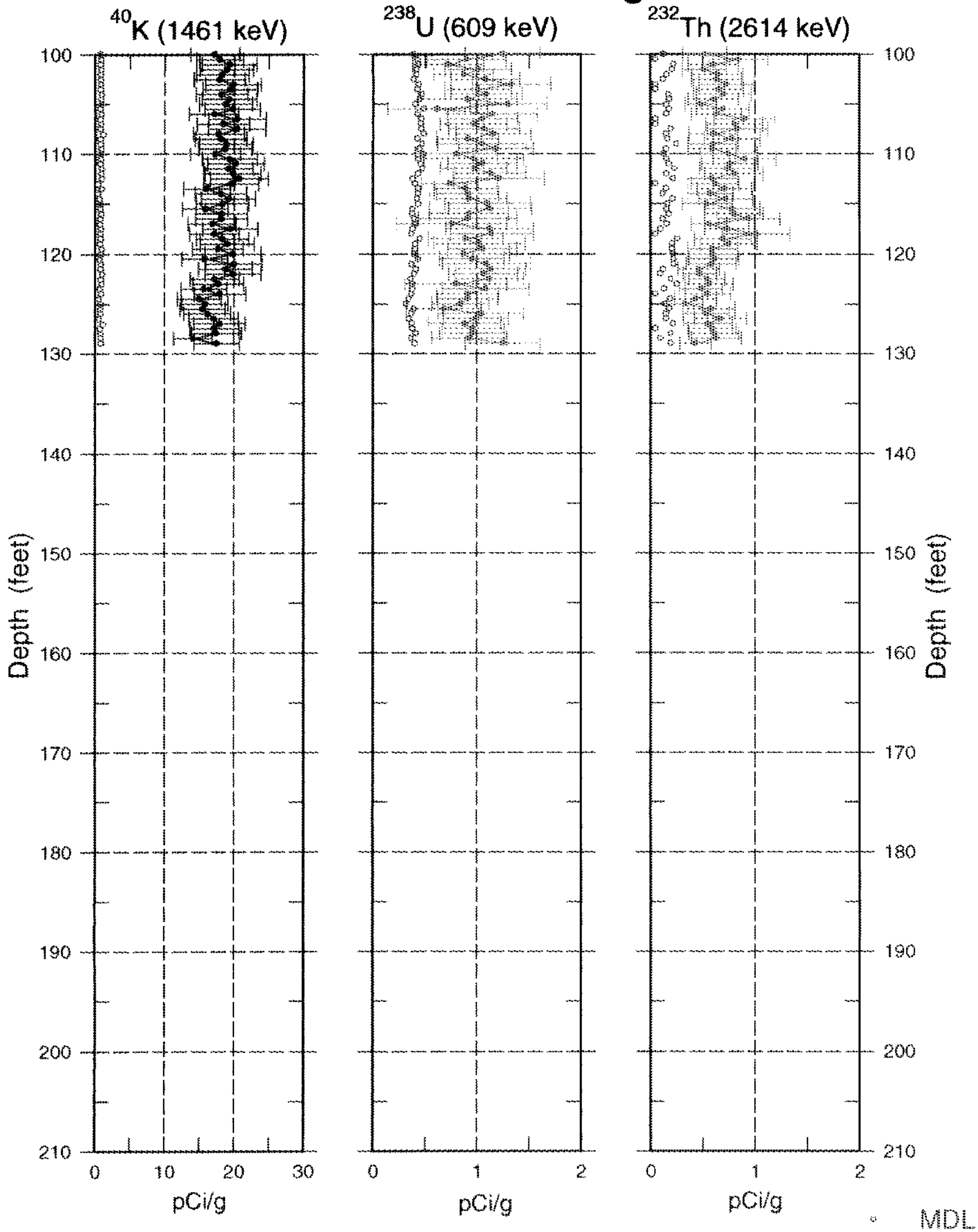
Man-Made Radionuclide Concentrations



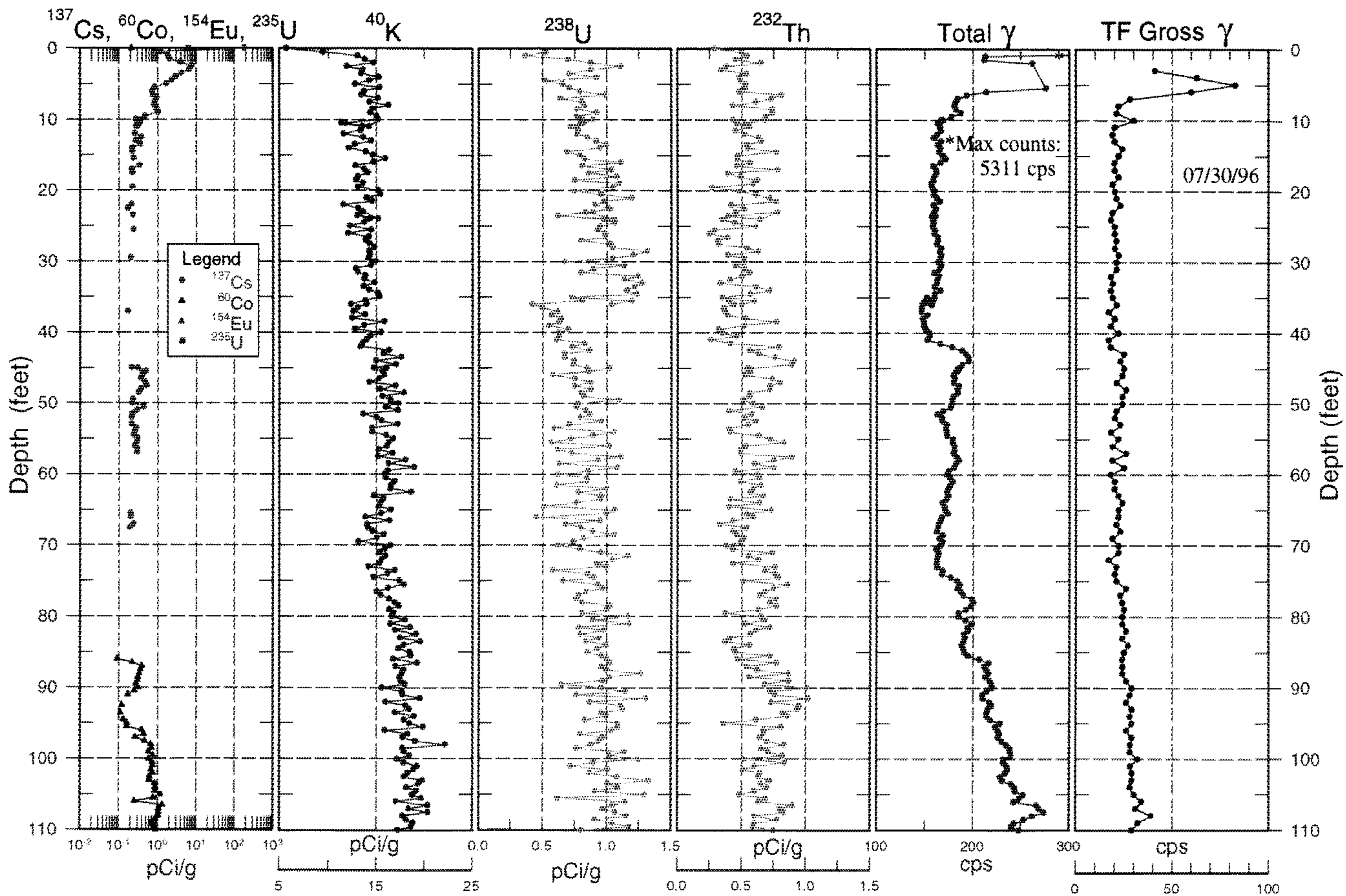
30-06-10
Natural Gamma Logs



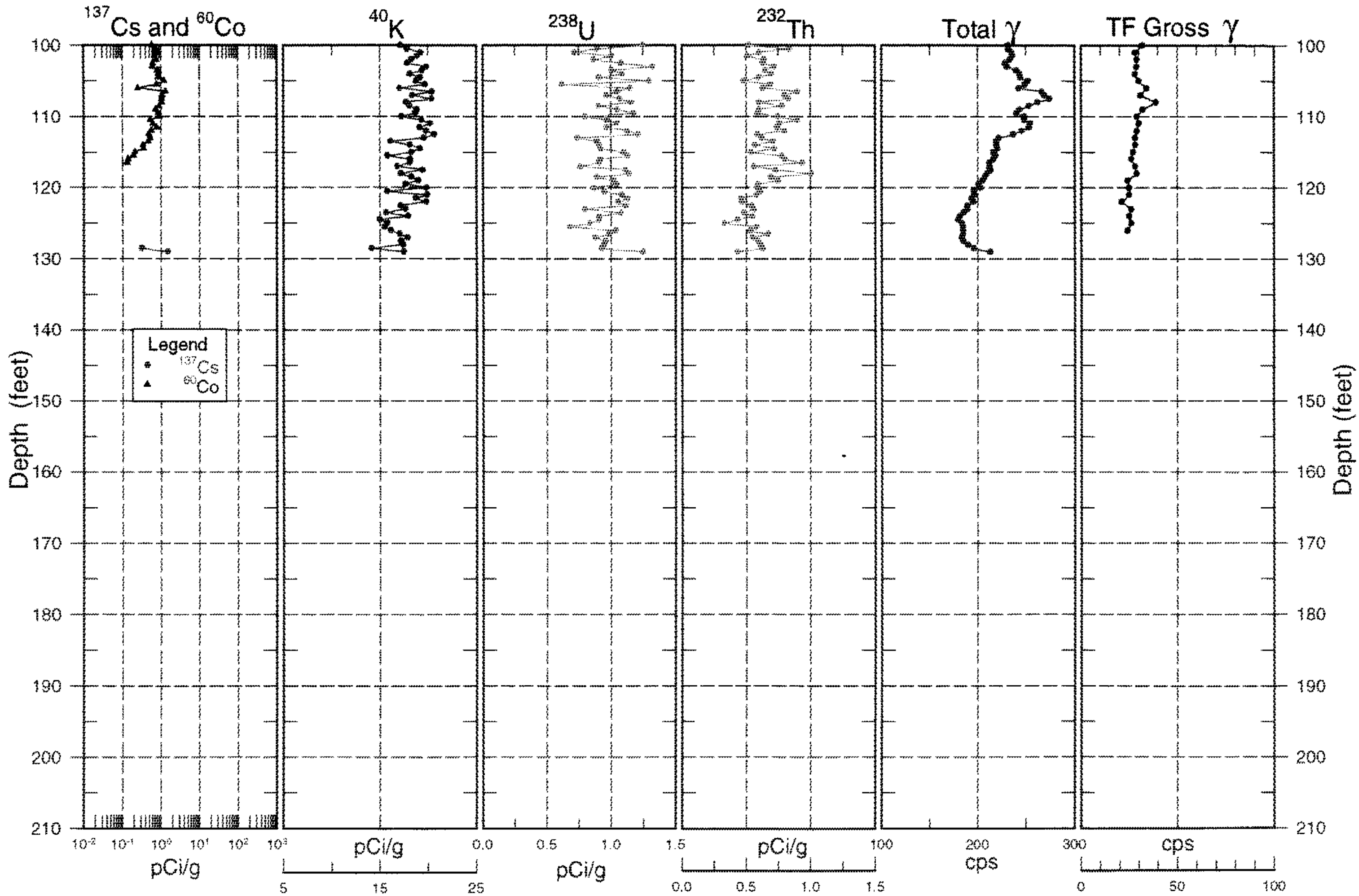
30-06-10
Natural Gamma Logs



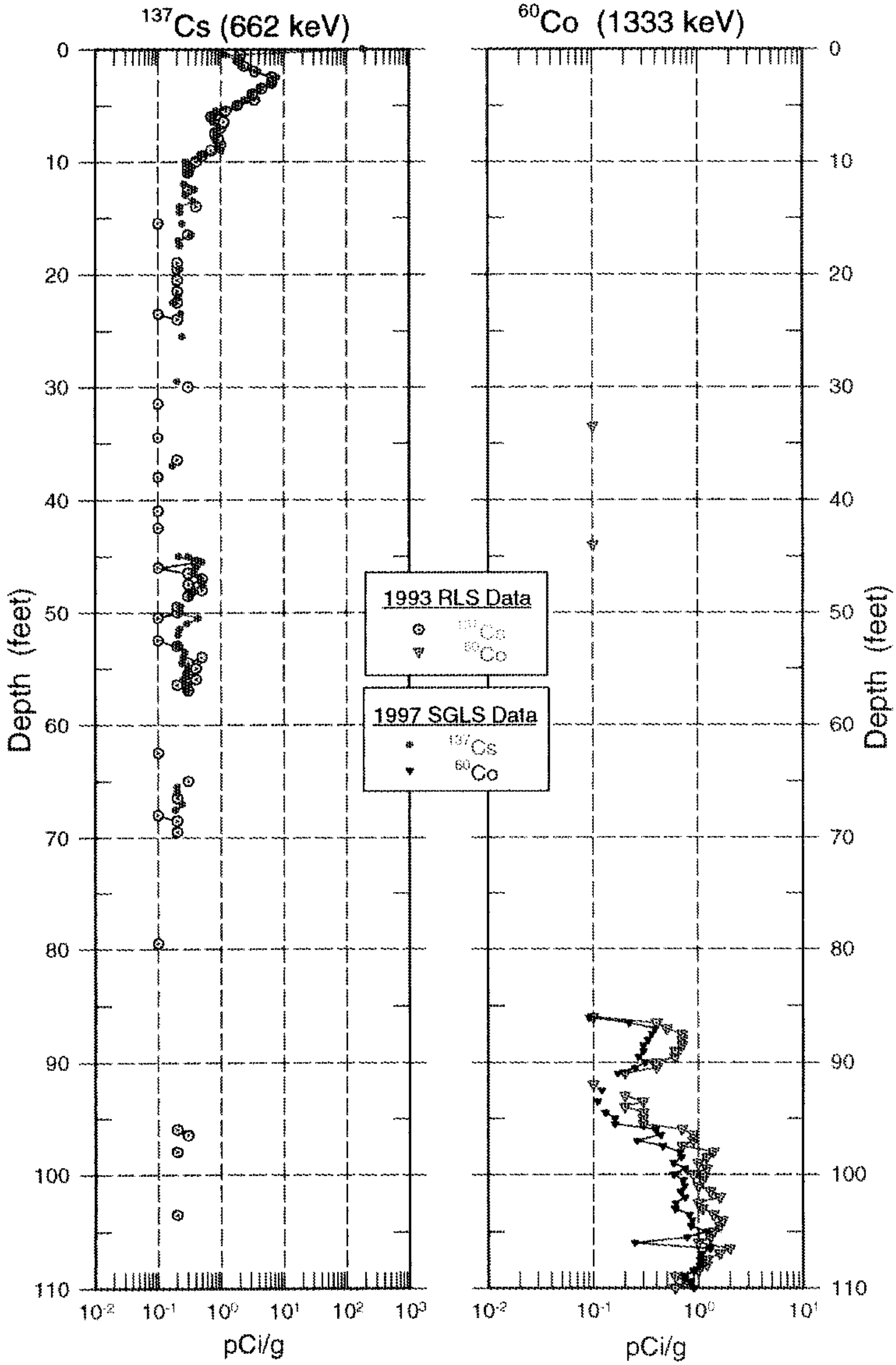
30-06-10 Combination Plot



30-06-10 Combination Plot



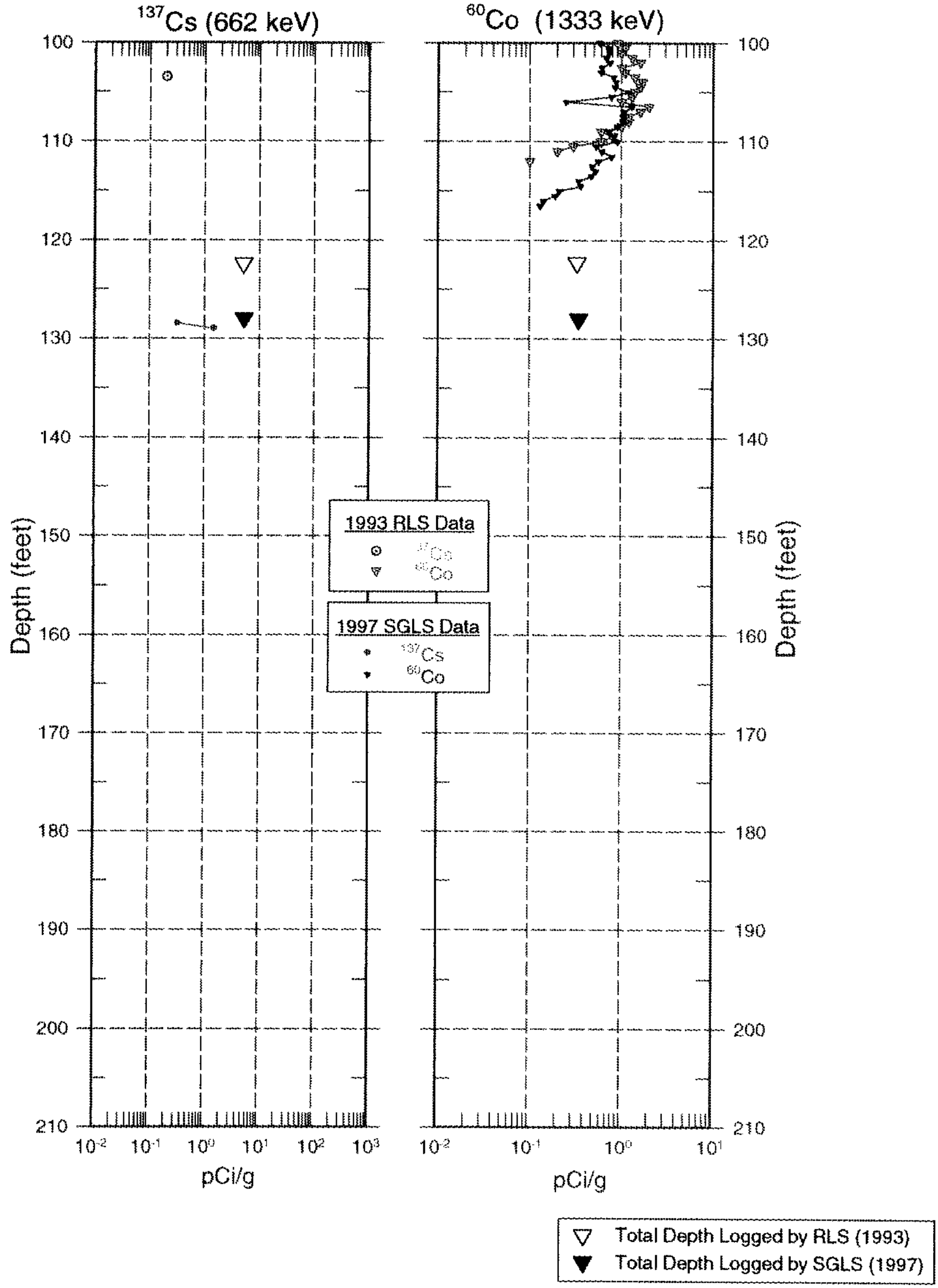
30-06-10
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison



30-06-10

Man-Made Radionuclide Concentrations

1993/1997 Spectral Gamma Data Comparison



mactec-ers
MACTEC ENVIRONMENTAL RESTORATION SERVICES, LLC

Spectral Gamma-Ray Borehole
Log Data Report

Log Event A

Borehole 30-06-12

Borehole Information

Farm : C
Tank : C-106
Site Number : 299-E27-86
N-Coord : 42,976
W-Coord : 48,260
TOC Elevation : 644.74
Water Level, ft : None
Date Drilled : 8/31/74

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 August 1974 to a depth of 100 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 : 1/27/97
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. : .5
Log Speed, ft/min.: n/a

Log Run Number : 2
Log Run Date : 1/28/97
Logging Engineer: Alan Pearson
Start Depth, ft.: 17.0
Counting Time, sec.: 100
L/R : L
Shield : N
Finish Depth, ft. : 66.0
MSA Interval, ft. : .5
Log Speed, ft/min.: n/a

Log Run Number : 3
Log Run Date : 1/29/97
Logging Engineer: Alan Pearson
Start Depth, ft.: 99.5
Counting Time, sec.: 100
L/R : L
Shield : N
Finish Depth, ft. : 65.0
MSA Interval, ft. : .5
Log Speed, ft/min.: n/a

Log Run Number : 4
Log Run Date : 1/29/97
Logging Engineer: Alan Pearson
Start Depth, ft.: 30.0
Counting Time, sec.: 100
L/R : L
Shield : N
Finish Depth, ft. : 15.0
MSA Interval, ft. : .5
Log Speed, ft/min.: n/a

Borehole 30-06-12

Log Event 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 four log runs. Three log runs were required to log the length of the borehole. A fourth log run was performed as an additional quality assurance check on a segment of one of the primary 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 and Co-60 were detected in this borehole. Cs-137 contamination was measured continuously from the ground surface to a depth of 31.5 ft, 34 to 35 ft, 43 to 45.5 ft, 48.5 to 65 ft, and 99 to 99.5 ft. Several isolated concentrations of Cs-137 were detected between 66 and 80 ft. The presence of Co-60 was measured continuously from 19.5 to 22.5 ft and intermittently from 90 ft to the bottom of the logged interval. Isolated concentrations of Co-60 were detected at 25.5, 27.5, and 34 ft.

The K-40 concentration values increase at about 38 ft, then become slightly variable from 41 to 80 ft. The K-40 concentrations increase at about 80 ft and generally remain elevated to the bottom of the logged interval. A peak is shown on the U-238 plot at depth of 48.5 ft.

It was not possible to identify any of the 609-keV peaks used to derive the U-238 concentrations between the ground surface and 1 ft. This occurred because high gamma-ray activity associated with the nearby Cs-137 peak (661 keV) created an elevated Compton continuum extending to the 609-keV region, causing the MDL to exceed the measured U-238 concentration.

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

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.

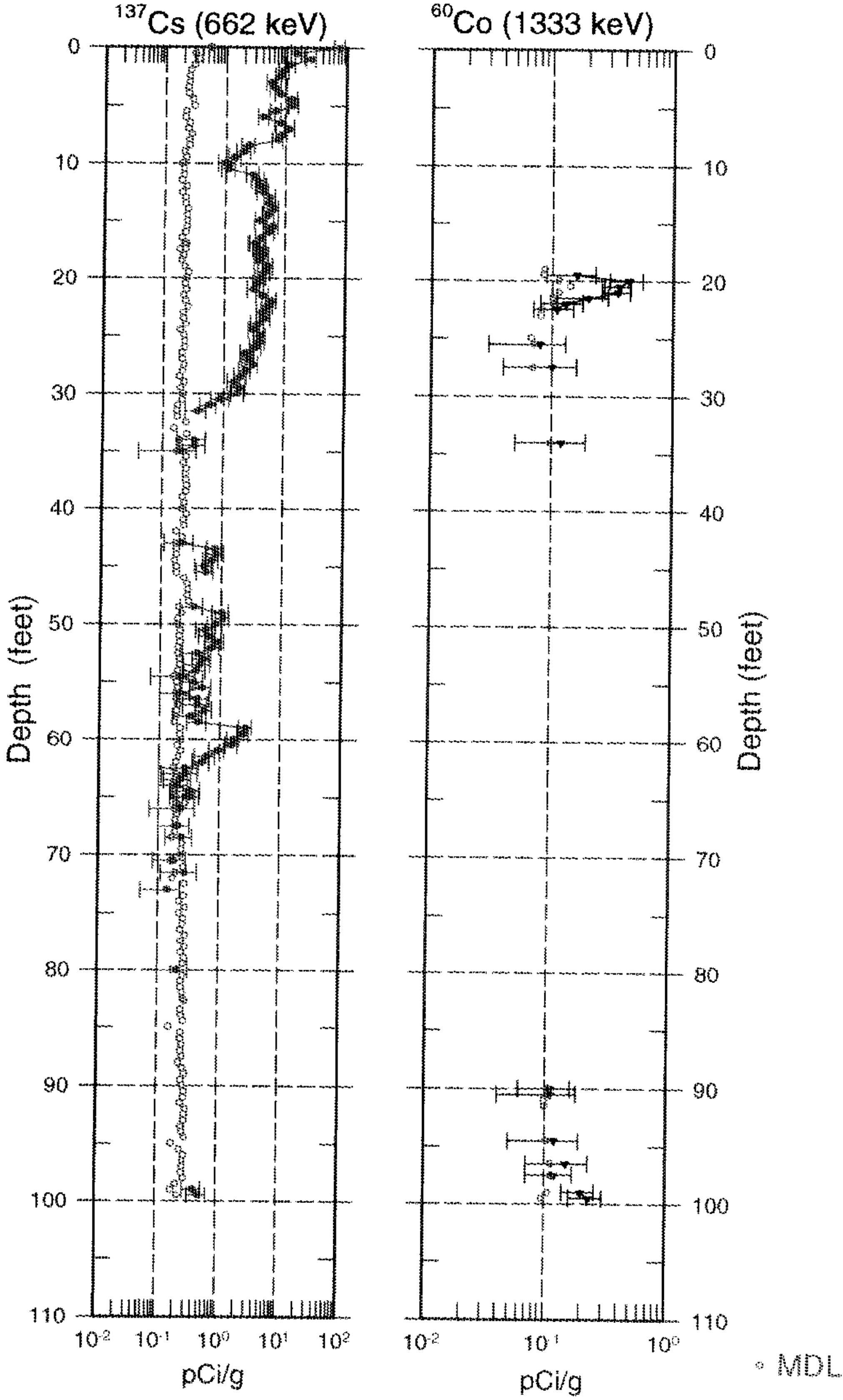
A combination plot includes the man-made and natural radionuclides, the total gamma derived from the spectral data, and the Tank Farms gross gamma log. The gross gamma plot displays the latest available digital data. No attempt has been made to adjust the depths of the gross gamma logs to coincide with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

The interval between 15 and 30 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.

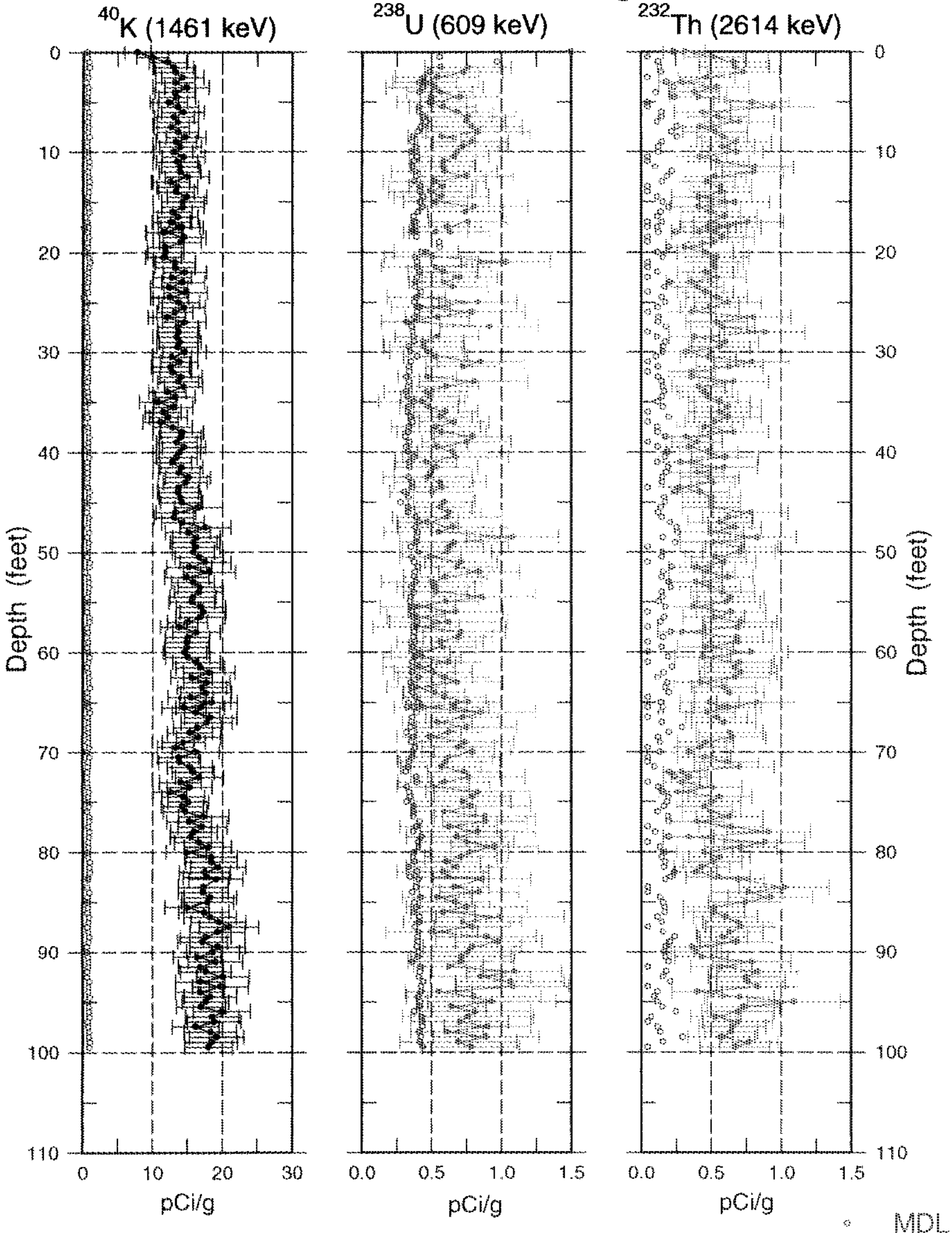
An additional log plot compares spectral gamma data collected with the Radionuclide Logging System (RLS) in 1993 with spectral gamma data collected with the SGLS in 1997. A separate plot was generated from this data that includes the Cs-137, Co-60, and K-40 concentrations detected between 10 and 40 ft plotted on a linear scale to provide a more detailed quantitative comparison of the data. Uncertainty bars and MDLs are not included on either plot.

30-06-12

Man-Made Radionuclide Concentrations



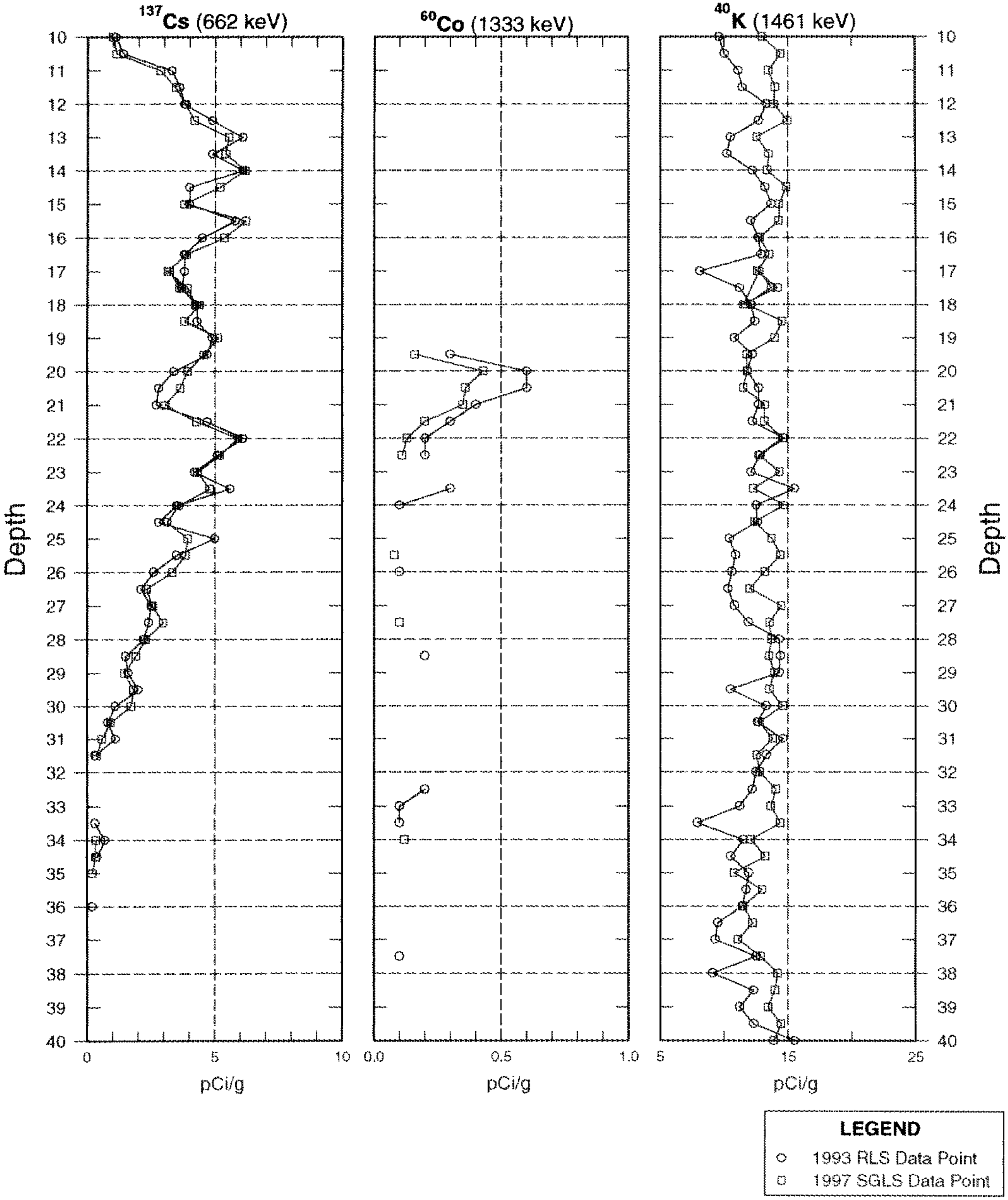
30-06-12
Natural Gamma Logs



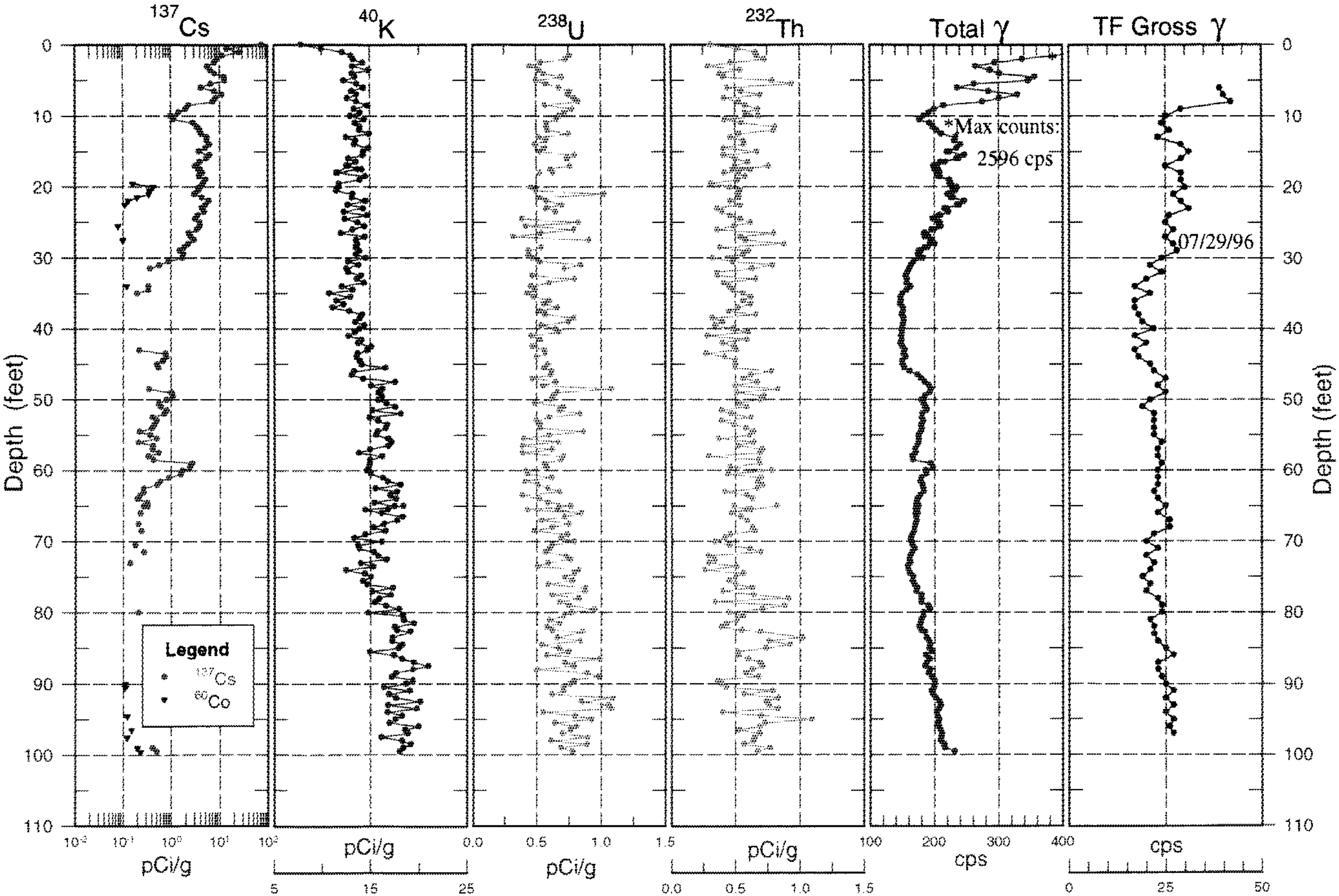
30-06-12

Man-Made and Natural Gamma Logs

1993/1997 Spectral Gamma Data Comparison



30-06-12 Combination Plot



30-06-12
Man-Made Radionuclide Concentrations
1993/1997 Spectral Gamma Data Comparison