DP-1598

IN SITU HIGH RESOLUTION GAMMA SPECTROMETRIC SURVEY OF BURIAL GROUND MONITORING WELLS

W. W. BOWMAN

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

Printed in the United States of America

Available from

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy A03; Microfiche A01

M26934

DP-1598
Distribution Category: UC-70

IN SITU HIGH RESOLUTION GAMMA SPECTROMETRIC SURVEY OF BURIAL GROUND MONITORING WELLS

W. W. BOWMAN

Approved by

T. V. Crawford, Research Manager
Environmental Sciences Division

Publication Date: September 1981

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

ABSTRACT

In situ high resolution gamma-ray spectrometry with an intrinsic germanium detector assembly of special design surveyed the burial ground monitoring wells to locate and identify gamma emitters that may have migrated from the burial trenches toward the water table. Gamma-ray spectra were acquired as a function of depth in each well and recorded on magnetic tape. These spectra were reduced by a series of computer programs to produce count rate versus depth profiles for natural and man-made activities. The original spectra and the profiles have been archived on magnetic tape for comparison with similar future surveys.

Large amounts of man-made activities were observed in some of the burial trenches; however, below the trench bottoms, only very low but detectable amounts of ^{60}Co and ^{137}Cs were observed in eleven wells. The highest level of man-made gamma activity observed below the trench bottoms has a count rate roughly equal to that observed for uranium daughter activities which are natural to the subsoil.

CONTENTS

IN SITU HIGH RESOLUTION GAMMA SPECTROMETRIC SURVEY OF BURIAL GROUND MONITORING WELLS

INTRODUCTION

One centrally located solid radioactive waste storage site is used to store all radioactive solid waste produced at Savannah River Plant as well as occasional special Department of Energy shipments from offsite. The original area of 76 acres began to receive waste in 1953 and was filled in 1972 when operations were shifted to an adjacent 119-acre site. The predominant storage mode for solid radioactive waste is burial in earthen trenches, hence the colloquial name "Burial Ground." The trenches are nominally 20 feet deep and 20 feet wide. The minimum soil cover is four feet, but it must be sufficient to reduce surface radiation to 6 mR/hr or less. Throughout this document, the term "burial ground" is used in reference to the original 76-acre storage site.

Extensive surveillance programs have been under way since startup of the waste storage site to monitor for possible migration of radionuclides from their storage locations.[1] To aid in this surveillance, four classes of wells have been installed in and around the burial ground as follows:

- Perimeter Wells. These wells are located outside the burial ground exclusion area and are typically four-inch-diameter steel pipes penetrating into the water table.

- Boreholes. These typically 1.25-inch-diameter steel pipes penetrate through waste emplacements to 50 feet and are not open to water.

- Trench Wells. These wells (1.5-inch-diameter steel pipes) penetrate to the bottoms of the burial trenches. They are open to water that has percolated through the waste on its way toward the water table (~45 feet) and has perched at the bottom of the trench.

- Grid Wells. Throughout the burial ground, 67 wells (4-inch-diameter steel casings) are located on ~200-foot grid spacings. These wells penetrate the mean water table ~10 feet and are open to ground water.

Surveys of trench wells show radioactivity in the perched water in the burial trenches, and the grid well water samples show very little of these activities in the water table. Therefore, these activities are removed from the perched water as it percolates toward the water table. Geiger counter scans of the boreholes show no indication of activity migration. However, these detectors have a high background because poor energy resolution precludes discrimination between natural and manmade activities. The grid wells were scanned with a 3 by 3 inch NaI detector; however, the resolution of this detector was not sufficient to adequately distinguish these activities. Excellent gamma-ray energy resolution is available with germanium detectors; however, use of these detectors in the field is complicated by the necessity of their operation at liquid nitrogen temperatures. Recently, intrinsic germanium detectors, cryostat, liquid nitrogen reservoir, and electronic packages have been configured that can pass through the larger-diameter wells. These configurations, called sondes, were developed for mineral and oil exploration. The first application of germanium detectors to in situ surveillance of the SRP burial ground is the subject of this report. This report documents a data base for future comparisons with similar surveys to measure migration rates of gamma activities in the critical region between the trench bottom and the water table.

SUMMARY

Figure 1 shows the burial ground and the location of the 54 grid wells surveyed with the intrinsic germanium detector assembly. The eleven wells which are circled are those which showed detectable quantities of man-made activities (seven wells with ^{137}Cs and four with ^{60}Co) below the burial trench bottoms. No other man-made gamma activities were observed below the trench bottoms. The highest level of man-made activity observed below the trench bottom is in Well A-3; the count rate is roughly equivalent to that from natural uranium daughter activities in the subsoil. Because the distributions of man-made activities in the soil are probably non-uniform, only relative comparisons of activity concentrations are possible.

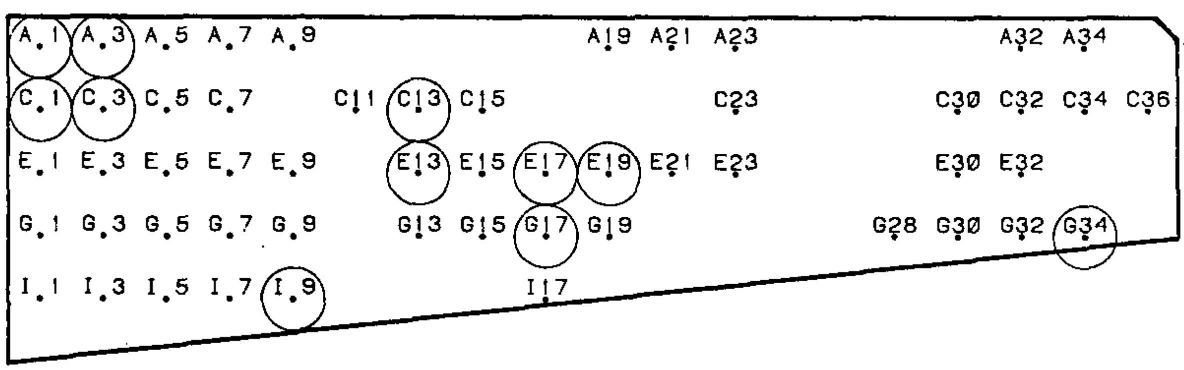


FIGURE 1. Monitoring Wells Surveyed in Burial Ground. Circled Wells Have Activity Below Trench Bottom

EQUIPMENT

The principal field equipment used in this survey includes: the germanium detector in the sonde (purchased from Princeton Gamma-Tech, Inc.), the data acquisition electronics, a travel trailer to protect the electronics, a motor generator unit to provide electrical power, and a hoist mechanism for automatically positioning the sonde at known depths in the monitoring wells.

Detector System

The outer stainless steel shell of the sonde (shown in Figure 2) is 3 inches in diameter and 65 inches long. In a vacuum chamber near the bottom of the sonde is the intrinsic germanium detector which is a closed-ended coaxial detector, 48 mm in diameter and 40 mm long. At 1332 keV, the detector has energy resolution of 2.0 keV and efficiency of 14.0% relative to a 3-by-3-inch NaI detector. The detector and the first stage of the preamplifier circuit are mounted to a cold finger which is connected to the liquid nitrogen reservoir. To provide the necessary clean vacuum for operation of the detector and insulation of the reservoir, molecular sieve material is packaged in contact with the reservoir. Wires carrying bias voltage to the detector and output signals from the first stage of the preamplifier are contained in a stainless steel tube that passes through the center of the liquid nitrogen reservoir to a connector ~3 feet from the bottom of the sonde (see Figure 3). A special electronics package containing the rest of the preamplifier and a circuit that generates the +3000 V detector bias voltage from standard (low voltage) preamplifier power, attaches to this connector (Figure 4). A stainless steel sleeve fits over the electronics package and seals to the lower portion of the sonde. A hoist cable mounting bracket and a 75-foot section of garden hose are flanged to the top of the sonde. Ninety-foot lengths of output signal and preamplifier power cables pass through the garden hose and attach to the connectors on the electronics package. The purpose of the garden hose and other sealed connections is to keep ground water out of the sonde and allow for boiloff of the liquid nitrogen.

Data Collection

The cables at the groundside end of the garden hose assembly attach to a spectroscopy amplifier that amplifies and shapes the detector output signals and provides power to the preamplifier in the sonde. A pulse height analyzer (Figure 5) sorts the amplified detector pulses by amplitude to generate a 4096 channel gamma-ray energy spectrum. The spectra acquired by the pulse height analyzer are recorded on magnetic tape for transport to the laboratory for computer analysis. Figure 6 shows the travel trailer that houses the groundside electronics and shows the motor-generator unit that provides electrical power.

FIGURE 2. Intrinsic Germanium Detector Sonde

FIGURE 3. Liquid Nitrogen Reservoir in Sonde

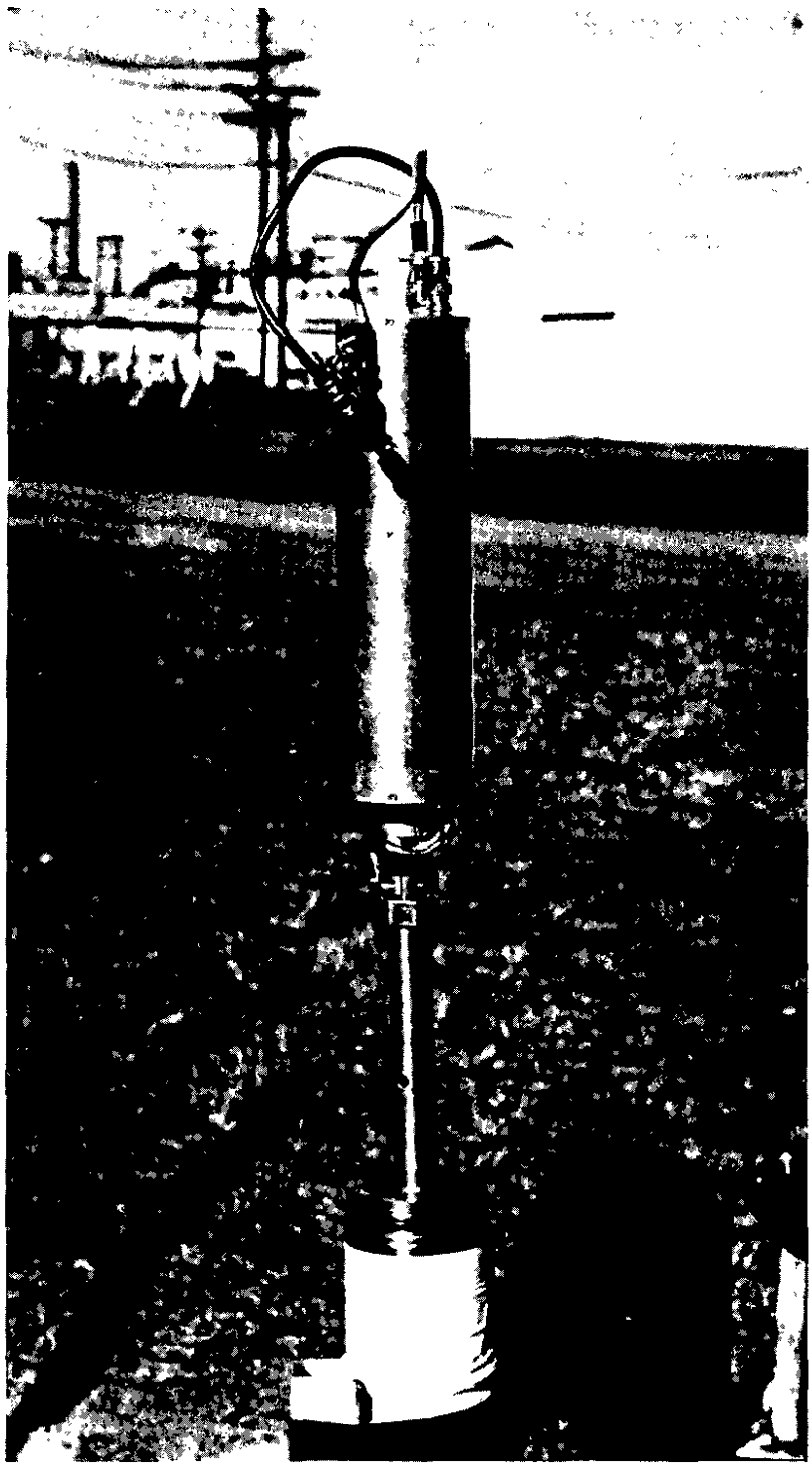


FIGURE 4. Special Electronics Package in Sonde

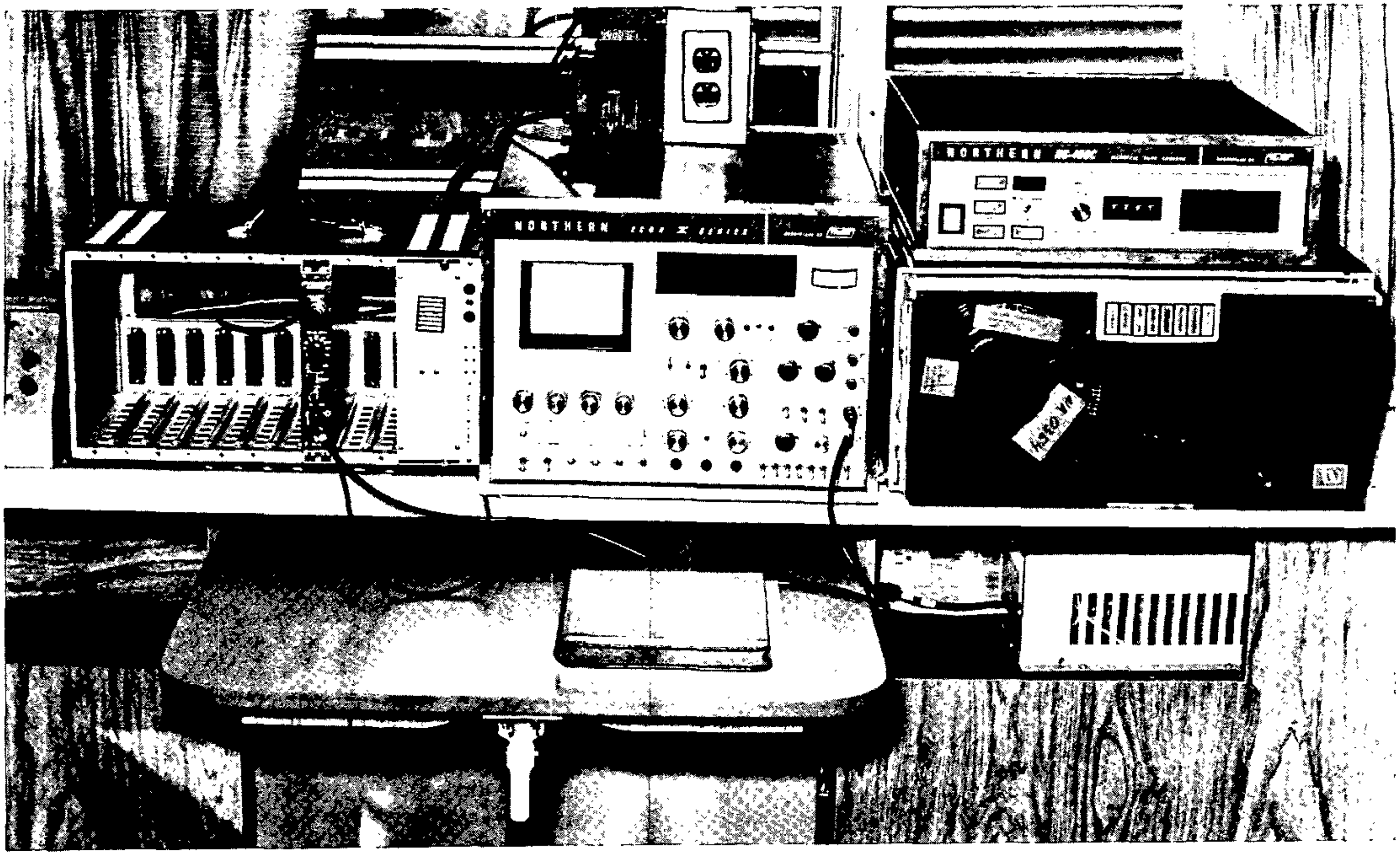


FIGURE 5. Data Acquisition Electronics

FIGURE 6. Field Electronics Trailer

Automated Hoist

Connected to the motor generator unit is the hoist mechanism for lowering the sonde into a well (Figure 7). A stainless steel cable attached to the mounting bracket at the top of the sonde passes up the well, around a metered pulley, through a limit switch, and finally wraps around a cylinder (Figure 8). The hoist cylinder is powered by a gear-reduced, variable-speed electric motor that receives its power from a solid-state dimmer switch in series with an interval timer. By variations in the dimmer switch and timer settings, sonde travel rates can be adjusted from 0.06 inch to ~9 feet per minute.

Operating Parameters

Typically, the sonde was operated at a drop rate of ~0.4 inch per minute, which permitted the sonde to travel 6 inches during the 1000-second spectrum acquisition time. By operating the pulse height analyzer in repeat/clear mode, the analyzer automatically records the spectrum at the end of 1000 seconds, clears its memory, and initiates acquisition of the next spectrum. Recording time is ~4 seconds. About 80 spectra were acquired over the 40-foot depth interval which is typical of most wells.

SURVEY PROCEDURES

Normal Operation

Under normal operations, one well was scanned automatically overnight. During the day shift, operators stopped the scan and moved the equipment to another well to prepare for the next overnight scan.

Because the reservoir contains only enough liquid nitrogen for ~30 hours of operation, the sonde was disconnected from the hoist and disassembled every day to allow filling of the reservoir. Before each well was scanned, a dummy sonde (made of a 6-foot section of 3-1/2 inch plastic pipe) was lowered into the well to locate the water table or any obstruction which might trap the sonde in the well. A clamp was placed on the hoist cable to trigger a limit switch (which would shut off the motor/generator) when the sonde reached either the obstruction or the water table. The reservoir was "topped off" with liquid nitrogen, and the sonde was reassembled and reattached to the hoist cable near the top of the well. The metered pulley was "zeroed" to read the initial depth of the detector from the top of the well casing. The sonde drop rate was measured (and adjusted, if necessary), and a fresh magnetic tape was loaded onto the tape transport unit while the

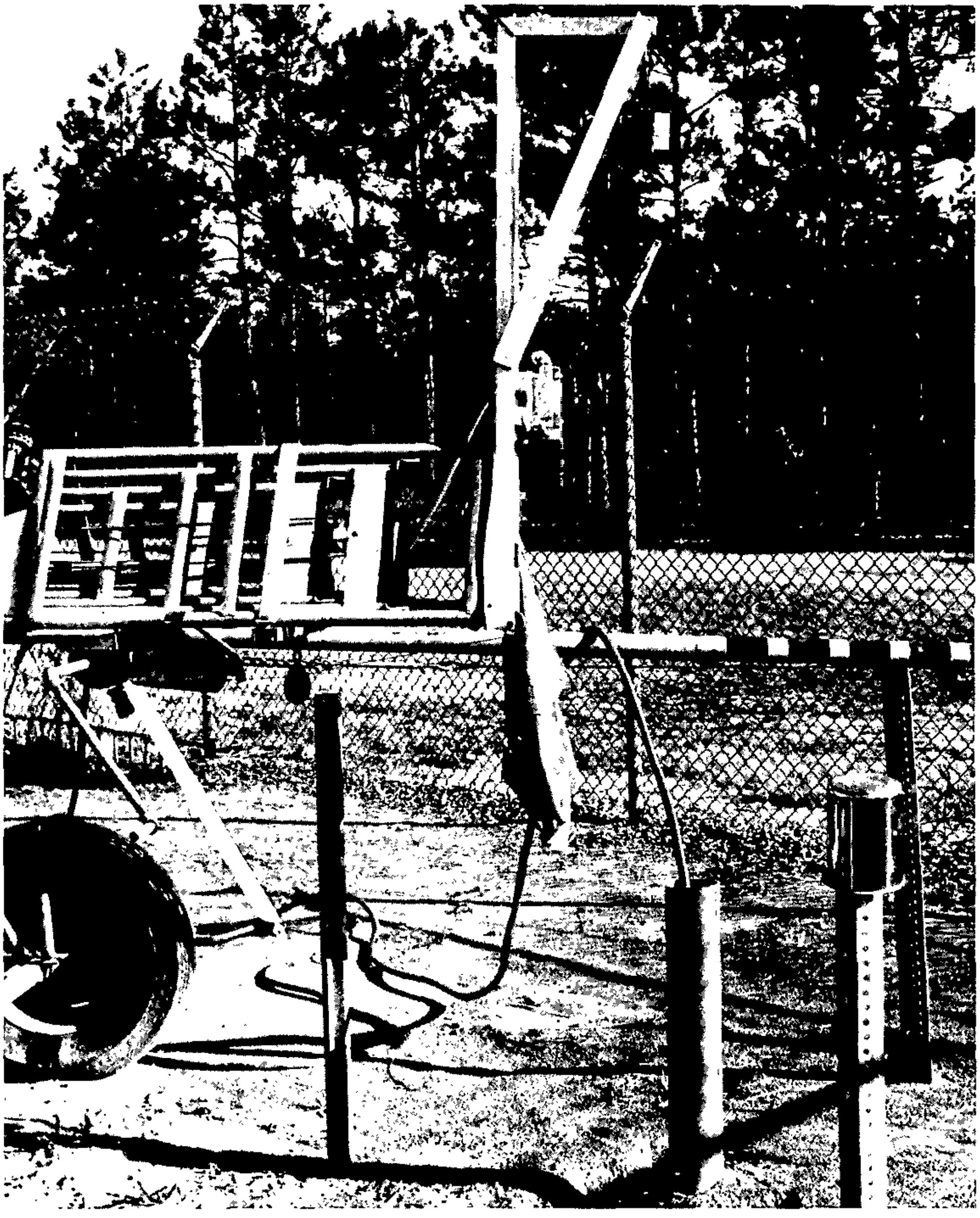


FIGURE 7. Hoist for Lowering Sonde into Well

FIGURE 8. Hoist Cylinder

system electronics came to equilibrium. The starting depth was recorded when the pulse height analyzer was placed in acquisition mode.

Correct operation of the system was verified by monitoring the drop rate through at least one data acquisition/recording cycle. The data acquired in the field for each well include: the magnetic tape with sequence-numbered gamma-ray spectra, and a data sheet listing well number, date, dummy sonde shutoff depth, magnetic tape number, rate of drop and stop values for the spectrum sequence number, metered pulley readings, and time of day. A remarks section was included on the data sheet to note possibly significant events.

Atypical Conditions

Several equipment and procedure modifications were introduced during this survey. These modifications are presented here to assist in the design of future surveys.

Originally, a small motor generator unit was used to provide electric power to the system. To maintain the frequency at 60 Hz, this unit had to operate at almost full throttle, which caused excessive wear and overheating under long-term continuous operation. The larger unit shown in Figure 7 operated satisfactorily at half throttle.

Some of the grid well casings are slightly bent or have small "ledges" which catch the sonde as it is lowered into the well. If the sonde were to "break loose" after the hoist unwound a length of slack cable, the cable could be broken by the falling sonde. To prevent this, a limit switch was initially installed in series with the hoist motor such that tension on the cable completed the circuit. However, when the sonde would catch, thereby breaking the hoist motor circuit, the pulse height analyzer continued to cycle, confusing the depth versus spectrum sequence number calibration. The cable clamp (positioned with the dummy sonde) arrangement described under normal operations eliminated this problem. The effect of the ledges was also reduced by attaching a tapered weight to the bottom of the sonde to help center the sonde in the well.

On two occasions, water leaked into the sonde, filled the liquid nitrogen reservoir, and submerged the special preamplifier/bias voltage electronics package. Damage to the components and the circuit boards were repaired by the vendor (requiring about six weeks). To prevent this from recurring, the dummy probe/cable clamp arrangement was installed, which keeps the sonde above the water table.

On another occasion, a small leak developed in the vacuum cryostat. After several weeks of operation, the molecular sieve became filled to capacity, which allowed the vacuum to degrade and increased the heat flow to the liquid nitrogen. During a well scan, the liquid nitrogen completely evaporated, and the molecular sieve material warmed up, which released the trapped air and pressurized the sonde. Because the end cap of the sonde is held in place by the vacuum and the pressure on the O-ring seal, the end cap detached and fell to the bottom of the well. The end cap was recovered using the spring-loaded device shown in Figure 9. Again the entire sonde had to be returned to the vendor for cleanup and repair.

Data Reduction

The raw data for each well (the gamma-ray spectra on magnetic tape and the operating parameters on the data sheet) were returned to the laboratory and reduced by computer. The data reduction scheme diagrammed in Figure 10 was executed on the Systems Engineering Laboratories Model SEL 32-77 computer system. All of the programs used in this scheme were developed for this survey except for the spectrum reduction program RAGS[2] which is a modified version of the code used for the NURE program.[3] The raw spectra are read by program TAPEDUMP and reformatted for temporary storage on disk. The operating parameters are inputted to program INP-GEN which generates for each spectrum a header record that is attached to the appropriate spectrum by program CORRELAT. The correlated spectra are compressed for archiving on magnetic tape using CORRSTOR; the reverse program STORCORR decompresses archived spectra and returns them to disk.

Each correlated spectrum is reduced to a list of photopeak channel numbers, energies, and areas by the RAGS program. The first execution of RAGS on the spectra from a well uses a default energy calibration. Using the known energies of gamma rays expected in the spectrum (usually from natural uranium, thorium, and potassium) and the photopeak channel numbers, more accurate calibrations can be inputted to program ECALP. ECALP maintains a file of energy calibrations as a function of date and time of spectrum acquisition; program RAGS always reads this file and uses the energy calibration most recent to the spectrum acquisition date and time to convert channel numbers to energy. A second run of program RAGS generates photopeak data lists to the printer and to a disk file named after the well.

After the energy calibration data have been verified, the photopeak data disk file is read by the primary output program PPLOT which sorts the data and provides a visual summary for selected activities observed in that well. Program PPLOT generates a printer plot of activity level for a specified nuclide versus well depth as shown by the example in Figure 11. The top and bottom lines title the plot as to identity of activity (natural uranium), type of plot (log plot), well number (A-3), and the photopeak energy range used (605.0 to 612.0 keV) to identify the activity. (A major gamma ray in the natural uranium decay series has an energy of 609.2 keV.) The two columns at the left list up to 51 of the data points plotted, i.e., well depth in feet on the X-axis, activity values in cpm (photopeak counts per minute) on the Y-axis. The X-axis is labeled at top and bottom in depth (feet); the Y-axis is labeled on the right as activity decade (e.g., 10**0 means 10^0 or 1, 10**4 means 10000). Intersections of the X-axis labeled depths and the Y-axis decades are represented by the +'s in the plot grid. To make the plot easier to read, periods are used to fill the area under the data points which are represented by asterisks. The number of asterisks for each depth represents the one-sigma range for that data point. Twenty feet corresponds to the nominal trench bottom. The plot resolution is 0.5 feet per X-axis column and a factor of 1.26 on the Y-axis (i.e., one-tenth of a log decade).

In this report, activity is expressed in units of photopeak counts per minute (cpm), which can be converted to units of specific activity (e.g., dpm/g) only by assuming the distribution of activity in the soil and the effects of gamma attenuation by the soil. Accurate efficiency calibration factors were obtained for the detector system using natural activation in the subsoil surrounding a calibration well drilled behind the laboratory building. Cores from this well were assayed in the Ultralow Level Counting Facility to measure specific activity in dpm/g. Spectra taken with the sonde at depths corresponding to the cores were combined with the core assays to yield dpm/g per cpm conversion factors. These factors are listed in Table 1 along with factors for man-made activities obtained by interpolation and application of decay scheme parameters. These factors (especially for the man-made activities) may not be applicable to the data contained in this report because the subsoil beneath the burial ground is probably not equivalent to that surrounding the calibration well, and the man-made activities are probably not distributed uniformly in the soil. In fact, the activity distribution in the trenches is undoubtedly not uniform, and man-made activities could be sorbed onto the inside surface of the casings. Application of these conversion factors would not be proper in these cases.

FIGURE 9. Detector Cap Retrieval Device

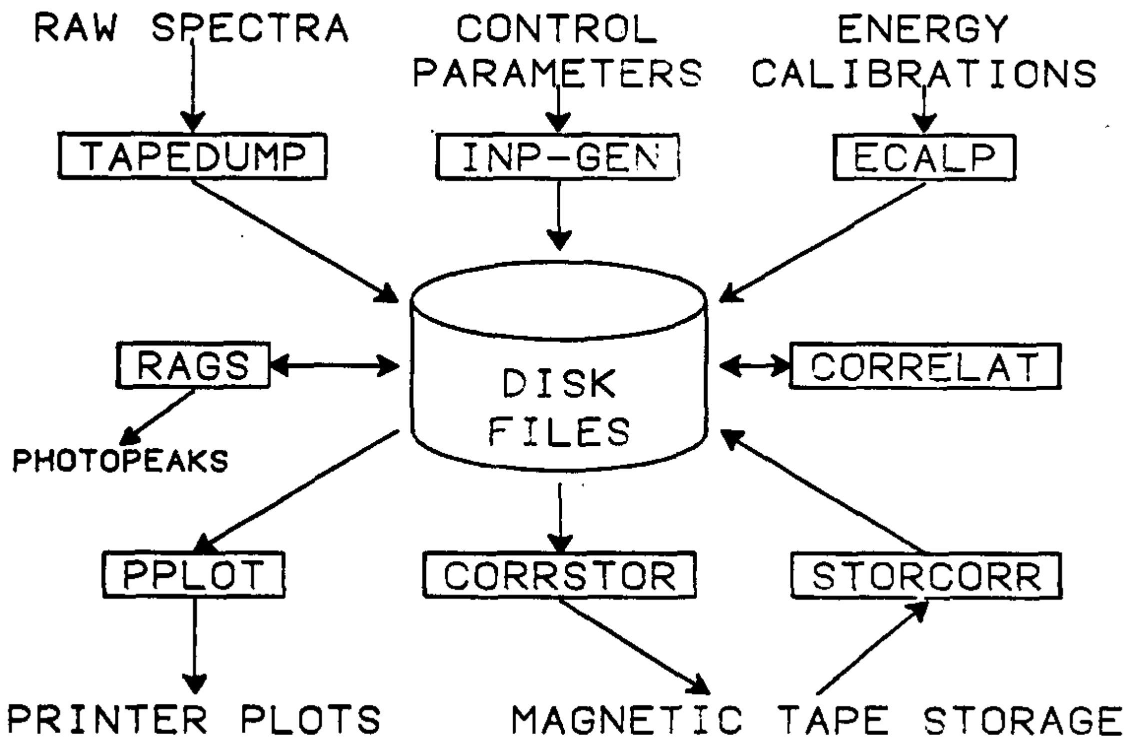


FIGURE 10. Borehole Probe Data Reduction

DEPTH FEET	ACTIVITY CPM
6.7	15.8
7.4	20.3
8.0	17.9
8.7	22.8
9.4	20.4
10.0	14.4
10.7	12.2
11.3	14.2
12.0	13.4
12.7	16.2
13.3	19.7
14.0	15.9
14.7	17.6
15.3	17.7
16.0	15.1
16.7	17.0
17.3	19.6
18.0	19.7
18.7	21.6
19.3	19.9
20.0	10.3
21.3	11.5
22.7	10.2
23.3	13.3
24.0	18.0
24.6	14.9
26.0	10.8
26.6	13.5
27.3	14.9
28.0	11.8
28.6	17.5
32.0	11.1
33.3	13.1
34.0	13.6
34.6	16.9
35.3	11.4
36.0	12.6
36.6	12.1
37.3	11.4
40.6	9.2
41.9	9.1
42.6	12.6
43.3	9.0
43.9	8.7
44.6	13.8
45.3	11.1
45.9	10.8
46.6	12.1
47.3	12.3
47.9	16.6
48.6	15.4

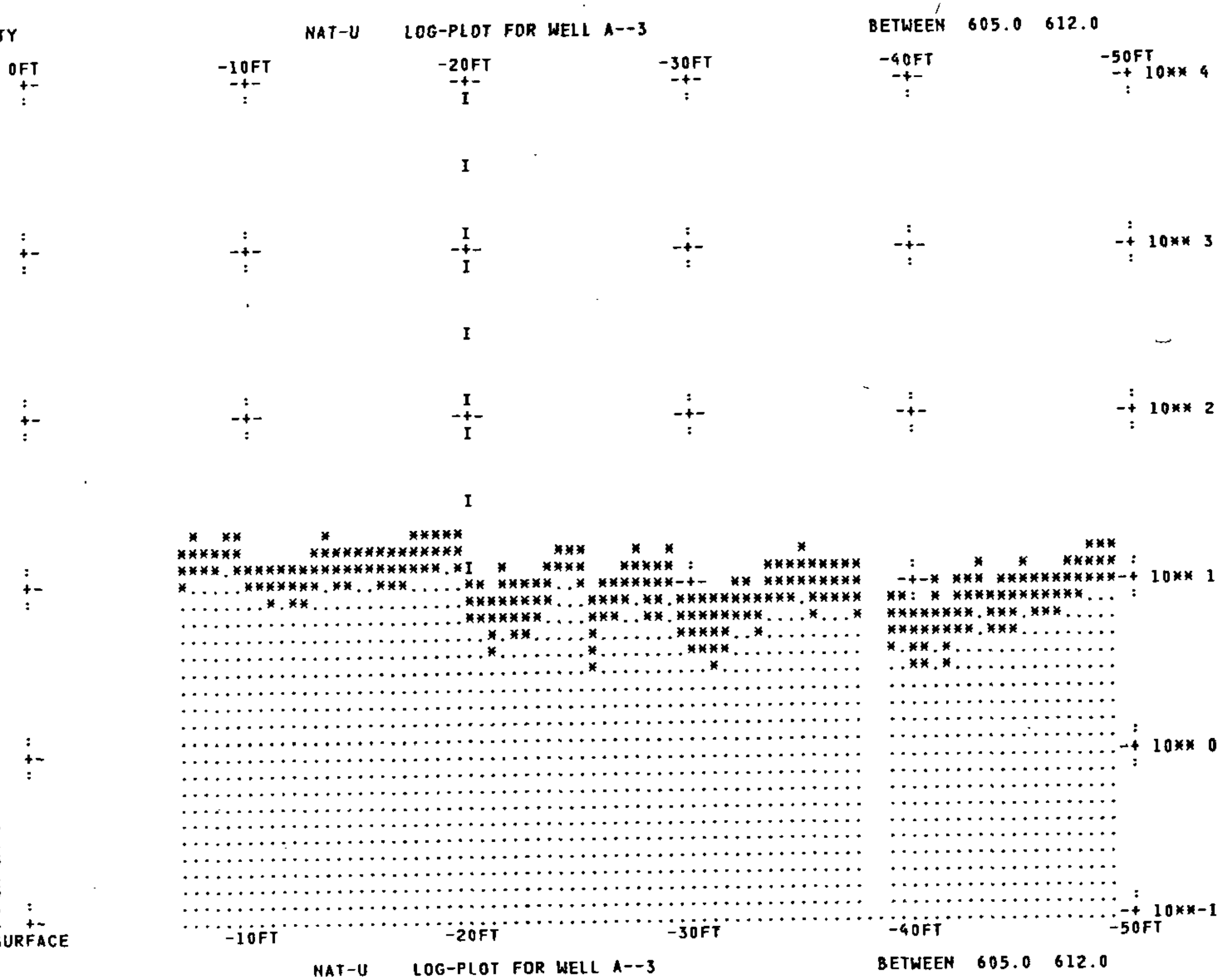


FIGURE 11. Log Plot for Natural Uranium in Well A--3

TABLE 1

Conversion Factors for Observed Radionuclides

Radionuclide	Conversion Factor*
^{40}K	244.
^{60}Co	25.7
^{137}Cs	20.3
^{212}Pb (Thorium Daughter)	14.3
^{214}Bi (Uranium Daughter)	37.3

* Units are pCi/gram soil per count/min assuming uniform distribution of radionuclide in soil equivalent to that surrounding the calibration well.

RESULTS

Microfiche containing printer plot profiles for natural and all man-made activities detected in all burial ground grid wells are available at SRL. Throughout the burial ground, the natural activities, uranium, thorium, and potassium, were observed as expected. The only man-made activities observed were ^{60}Co, ^{137}Cs, and ^{154}Eu.

Summary data from all 67 grid wells are listed in Table 2. Thirteen of these wells could not be surveyed (as indicated in Table 2) because of collapsed or severely bent casings, liners which restrict the inside well diameter, or permanently mounted pump ports. Of the 54 wells which could be scanned, 32 showed only natural activities, i.e., ^{40}K and the daughters in the uranium and thorium decay series. Twenty-two wells showed man-made gamma activities, e.g., ^{60}Co, ^{137}Cs, and ^{154}Eu. No other man-made gamma activities were observed in this survey. Below the bottom of the burial trenches (nominally about 25 feet down from the tops of the grid well casings), detectable levels of ^{137}Cs were observed in 7 wells and 4 wells showed ^{60}Co. No ^{154}Eu was observed below 25 feet. The printer plot activity profiles for these activities in these wells are reproduced in Figures 12 through 22. Although these activities were observed below the trench bottoms, typical count rates for the natural activities range as follows: 10 to 100 cpm for the 239-keV gamma from the ^{212}Pb daughter in the natural thorium series, 10 to 70 cpm for the 609-keV gamma from the ^{214}Bi daughter in the natural uranium series, and 0.5 to 50 cpm for ^{40}K.

The relatively small amounts of activity observed in Wells E-17, G-17, and G-34 below 25 feet (see Figures 18, 20, and 21) may be the result of contamination during the installation of the well because very large amounts of ^{60}Co and/or ^{137}Cs were observed in these wells above 25 feet (i.e., in the burial trench).

For the other wells, the activity levels below 25 feet are small, except for Well A-3 (see Figure 13). A second survey of this well reproduced the shape and depth of the activity profile. Well I-9 was surveyed three times. The original scan indicated a small amount of ^{137}Cs at 30 feet. The second scan (Figure 22) of the well (designated as I++9 in the microfiche) encountered a slight obstruction at 33 feet, and no activity was observed at 30 feet. The third scan (designated as I**9) was begun at 25 feet and showed a weak band of ^{137}Cs at 36-38 feet (Figure 23). The depth calibration used with the original scan was assumed to be in error. Other wells were rescanned to verify the depth calibration, and no other errors were detected.

TABLE 2. Summary of Manmade Activities Observed in Burial Ground

SUMMARY OF MAN-MADE ACTIVITIES

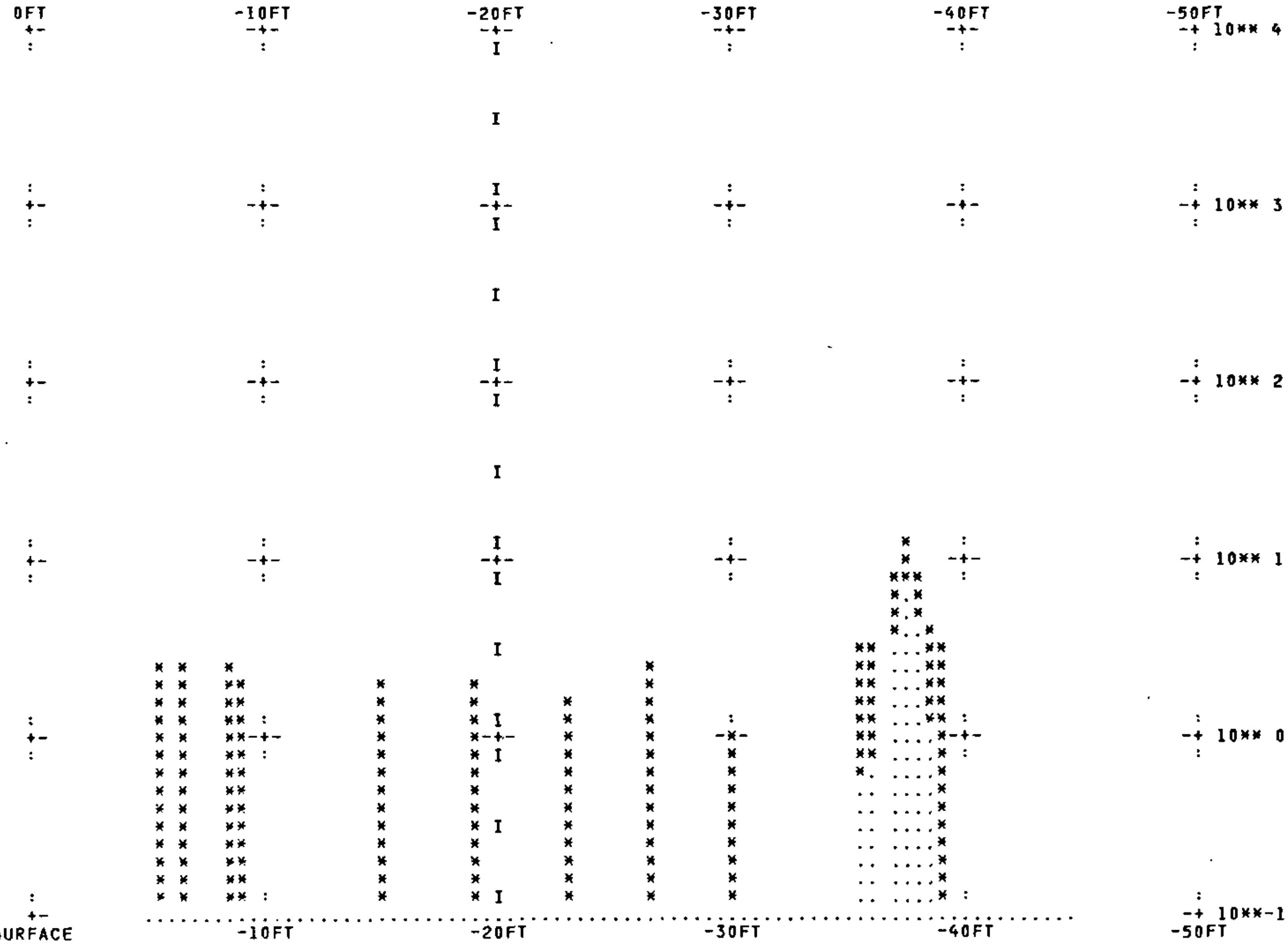
WELL	SCANNED START-STOP FT - FT	CS-137 MAXIMUM FT	CS-137 MAXIMUM CPM	CS-137 BELOW 25 FT	CS-137 BELOW 25 CPM	CO-60 MAXIMUM FT	CO-60 MAXIMUM CPM	CO-60 BELOW 25 FT	CO-60 BELOW 25 CPM	EU-154 MAXIMUM FT	EU-154 MAXIMUM CPM	EU-154 BELOW 25 FT	EU-154 BELOW 25 CPM	COMMENT
A--1	5.0-45.0	37.1	12.1	37.1	12.1	.0	.0	.0	.0	.0	.0	.0	.0	
A--3	6.0-46.0	37.3	64.4	37.3	64.4	.0	.0	.0	.0	.0	.0	.0	.0	
A--5	8.0-50.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A--7	3.5-16.5	17.3	60.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A--9	5.3-36.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-11	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
A-19	2.5-29.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-21	4.0-33.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-23	5.6-41.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-32	3.5-45.5	3.2	7.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-34	5.6-53.6	21.6	46.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
A-36	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
C--1	5.6-44.1	17.2	4.8	43.6	4.7	.0	.0	.0	.0	.0	.0	.0	.0	
C--3	6.8-35.4	27.9	5.0	27.9	5.0	.0	.0	.0	.0	.0	.0	.0	.0	
C--5	5.5-29.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C--7	7.5-38.6	19.0	10000.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C--9	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
C-11	6.4- 4.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C-13	8.3-48.3	.0	.0	.0	.0	36.2	22.4	36.2	22.4	.0	.0	.0	.0	
C-15	10.0-49.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C-17	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
C-19	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
C-21	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
C-23	6.5-47.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C-30	8.3-41.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C-32	4.4-35.6	3.9	20.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
C-34	2.8-47.1	10.9	2250.0	.0	.0	.0	.0	.0	.0	11.0	670.0	.0	.0	
C-36	3.5-25.6	.0	.0	.0	.0	10.0	10000.0	.0	.0	.0	.0	.0	.0	
E--1	4.0-37.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E--3	5.7-33.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E--5	5.0-49.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E--7	7.0-39.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E--9	3.0-36.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E-13	11.0-54.8	.0	.0	.0	.0	30.6	14.8	30.6	14.8	.0	.0	.0	.0	
E-15	4.0-43.1	8.4	151.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	

Table 2 (Continued)

WELL	SCANNED START-STOP FT - FT	CS-137 MAXIMUM FT	CS-137 MAXIMUM CPM	CS-137 BELOW 25 FT	CS-137 BELOW 25 CPM	CO-60 MAXIMUM FT	CO-60 MAXIMUM CPM	CO-60 BELOW 25 FT	CO-60 BELOW 25 CPM	EU-154 MAXIMUM FT	EU-154 MAXIMUM CPM	EU-154 BELOW 25 FT	EU-154 BELOW 25 CPM	COMMENT
E-17	2.0-47.2	.0	.0	.0	.0	9.0	10000.0	42.8	4.7	.0	.0	.0	.0	
E-19	4.0-40.5	6.9	39.2	38.2	3.4	.0	.0	.0	.0	.0	.0	.0	.0	
E-21	5.0-47.3	5.0	9.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E-23	6.3-38.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E-30	4.8-41.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E-32	4.0-42.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
E-34	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
E-36	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
G--1	4.0-39.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G--3	4.2-49.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G--5	4.6-53.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G--7	7.6-38.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G--9	3.5-46.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-13	1.0-51.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-15	6.0-50.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-17	5.5-46.3	10.1	1780.0	37.6	8.9	11.5	21.8	.0	.0	.0	.0	.0	.0	
G-19	4.5-45.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-21	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
G-23	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
G-28	1.0-35.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-30	3.0-24.5	11.6	130.0	.0	.0	17.6	116.0	.0	.0	11.1	20.0	.0	.0	
G-32	3.5-34.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
G-34	2.8-47.4	3.3	240.0	.0	.0	13.0	10000.0	26.2	5.2	.0	.0	.0	.0	
G-36	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
I--1	6.8-28.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
I--3	10.8-50.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
I--5	5.0-27.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
I--7	7.0-47.5	15.1	10.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
I--9	5.0-50.1	10.6	9.7	37.2	10.1	.0	.0	.0	.0	.0	.0	.0	.0	
I-13	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
I-15	.0- .0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	UNABLE TO PASS PROBE
I-17	5.9-41.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	

DEPTH ACTIVITY CS-137 LOG-PLOT FOR WELL A--1 BETWEEN 658.0 663.9

FEET	CPM
5.5	1.6
6.5	1.4
8.5	1.6
9.0	1.3
15.0	1.2
19.0	1.2
22.6	1.2
26.1	1.5
29.6	0.4
35.1	2.2
35.6	2.6
36.6	7.1
37.1	12.1
37.6	8.0
38.1	3.0
38.7	1.9

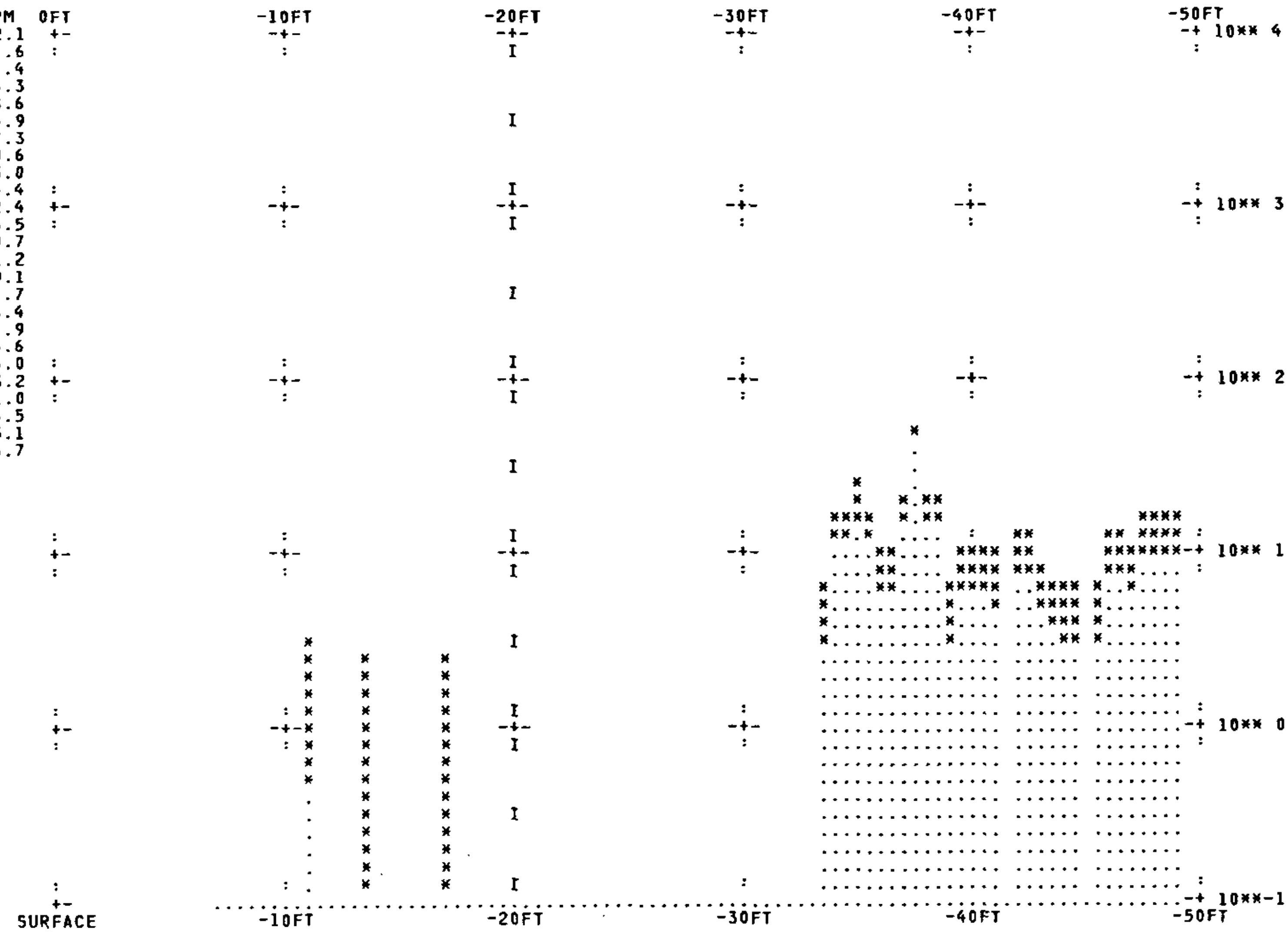


CS-137 LOG-PLOT FOR WELL A--1 BETWEEN 658.0 663.9

FIGURE 12. Log Plot for ^{137}Cs in Well A--1

DEPTH ACTIVITY   CS-137   LOG-PLOT FOR WELL A--3   BETWEEN 658.0 663.9

FEET	CPM
10.7	2.1
13.3	1.6
16.7	1.4
33.3	6.3
34.0	18.6
34.6	24.9
35.3	17.3
36.0	10.6
36.6	23.0
37.3	64.4
37.9	22.4
38.6	6.5
39.3	10.7
39.9	11.2
40.6	9.1
41.9	11.7
42.6	8.4
43.3	6.9
43.9	6.6
45.3	6.0
45.9	13.2
46.6	11.0
47.3	16.5
47.9	15.1
48.6	16.7



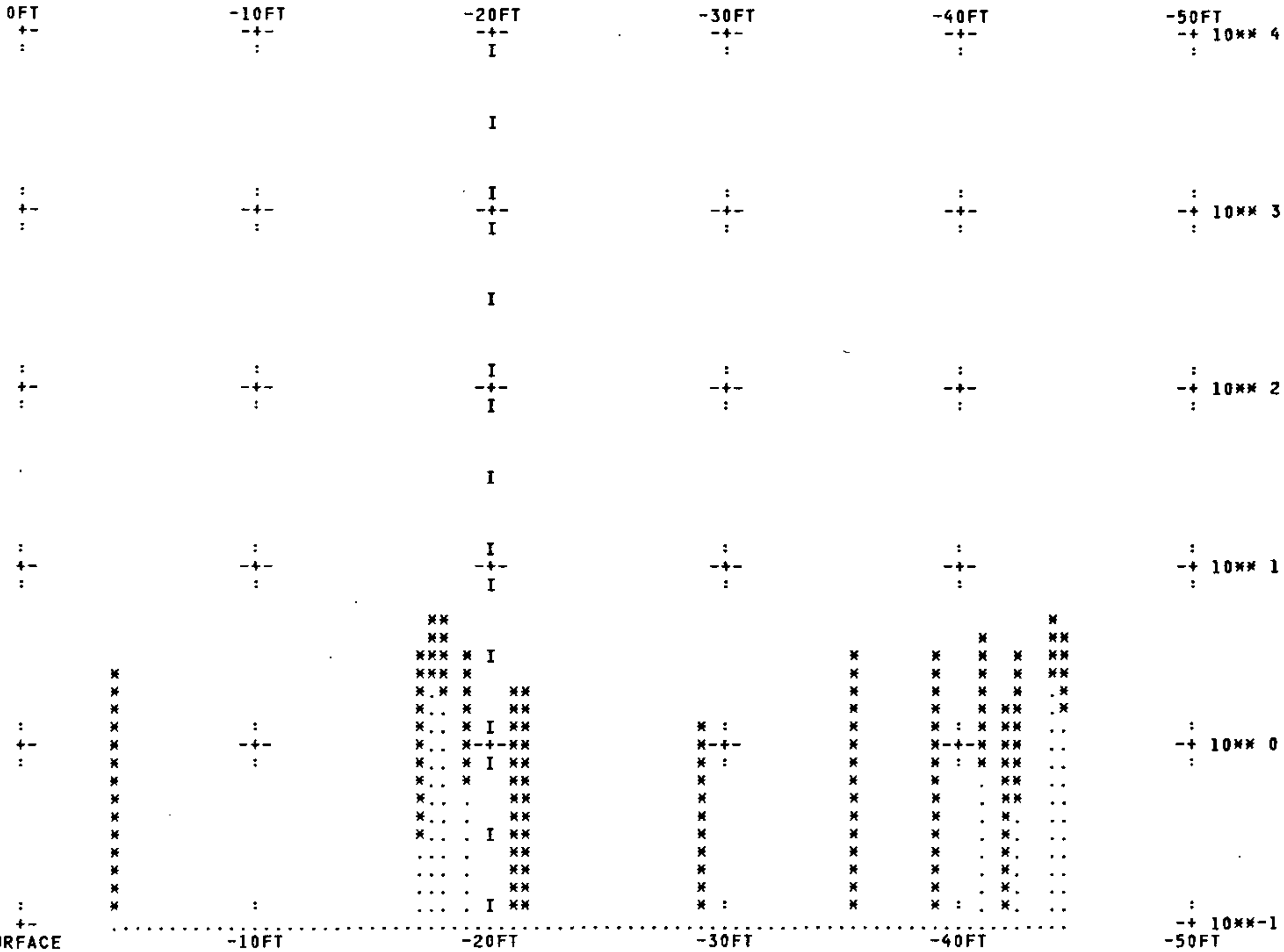
CS-137   LOG-PLOT FOR WELL A--3   BETWEEN 658.0 663.9

FIGURE 13. Log Plot for ^{137}Cs in Well A--3

DEPTH ACTIVITY

CS-137 LOG-PLOT FOR WELL C--1 BETWEEN 658.0 663.9

FEET	CPM
4.0	1.3
16.6	2.1
17.2	4.8
17.7	4.0
18.8	2.3
21.0	0.9
28.7	0.6
35.3	2.1
38.6	2.0
40.8	3.0
41.9	0.7
42.5	2.2
43.6	4.7
44.1	3.4



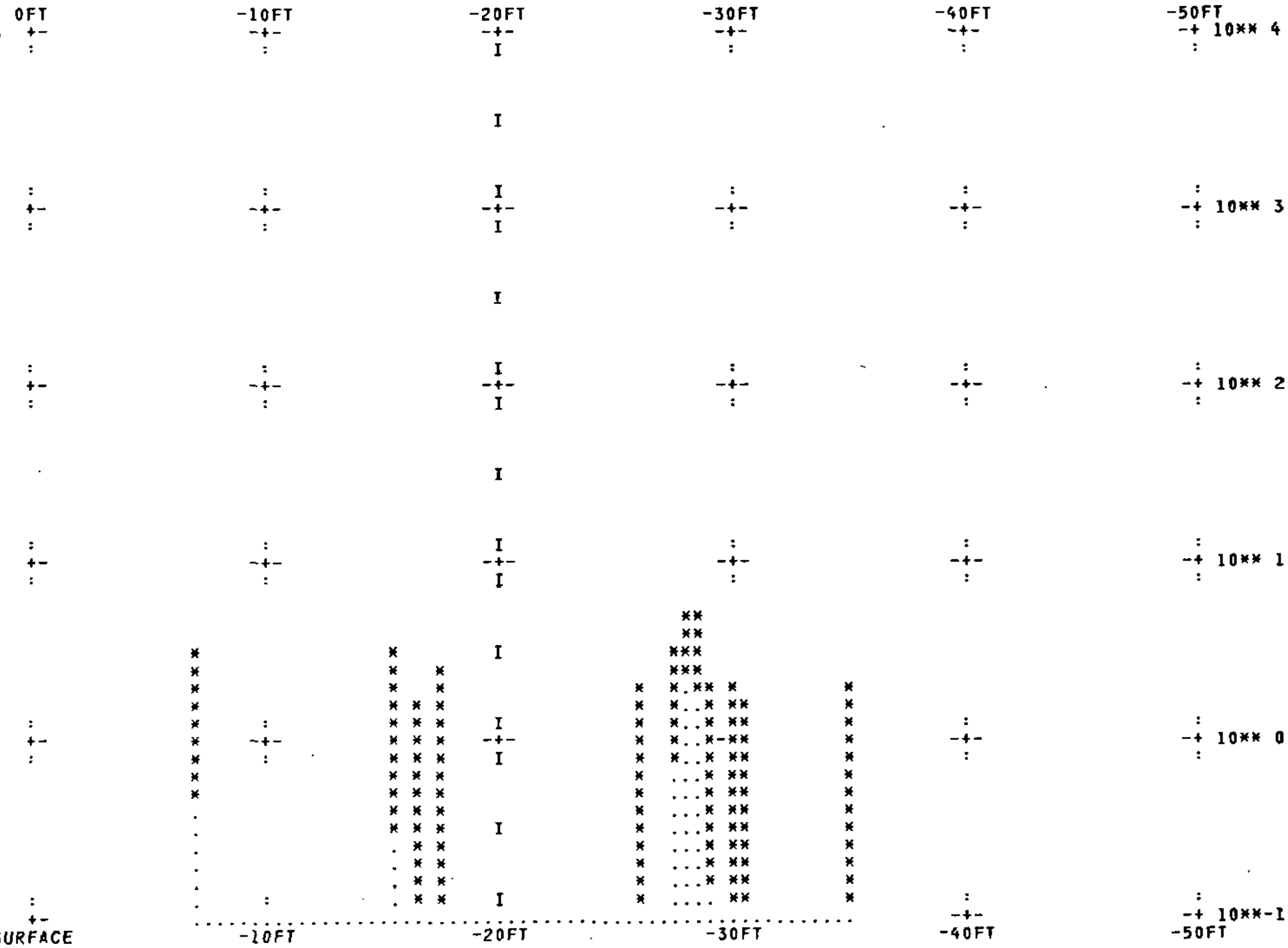
CS-137 LOG-PLOT FOR WELL C--1 BETWEEN 658.0 663.9

FIGURE 14. Log Plot for ^{137}Cs in Well C--1

DEPTH ACTIVITY

CS-137 LOG-PLOT FOR WELL C--3 BETWEEN 658.0 663.9

FEET	CPM
6.8	2.3
15.3	2.1
16.3	0.7
17.3	1.8
25.9	1.0
27.4	2.4
27.9	5.0
28.4	4.2
28.9	1.4
29.9	1.2
30.4	0.7
34.9	0.9

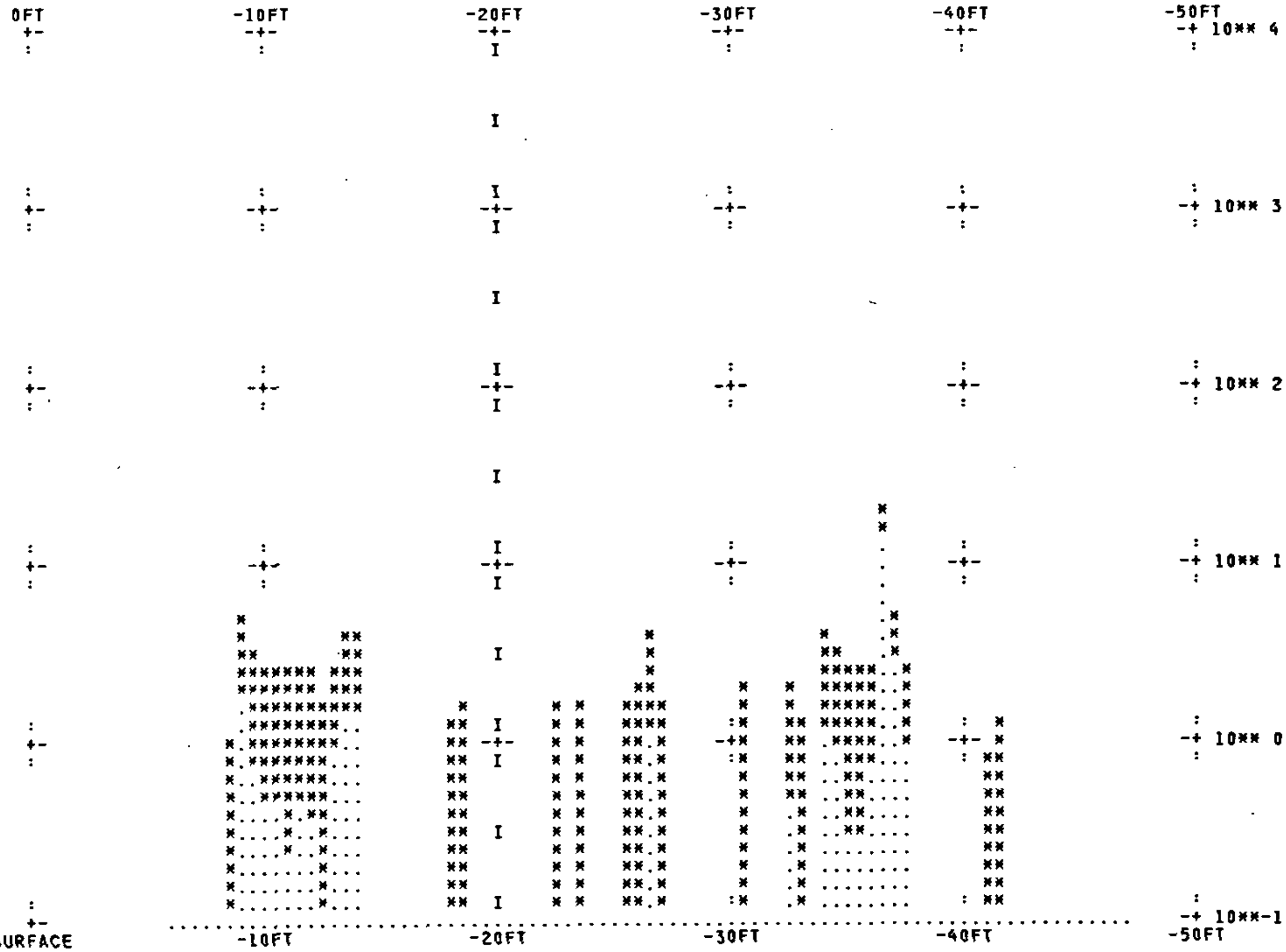


CS-137 LOG-PLOT FOR WELL C--3 BETWEEN 658.0 663.9

FIGURE 15. Log Plot for ^{137}Cs in Well C--3

DEPTH ACTIVITY CO-60 LOG-PLOT FOR WELL C+13 BETWEEN 1328.0 1335.0

FEET	CPM
8.3	0.5
8.9	4.1
9.4	2.5
10.0	2.0
10.6	1.6
11.2	2.0
11.8	1.9
12.3	1.1
12.9	2.3
13.5	3.7
17.6	0.8
18.2	0.8
22.2	0.9
23.4	0.7
25.1	0.7
25.7	1.4
26.3	3.2
26.9	0.9
30.4	1.2
32.1	1.6
32.7	0.6
33.8	3.1
34.4	2.8
35.0	1.8
35.6	2.1
36.2	22.4
36.7	5.1
37.3	2.3
40.8	0.4
41.4	0.7



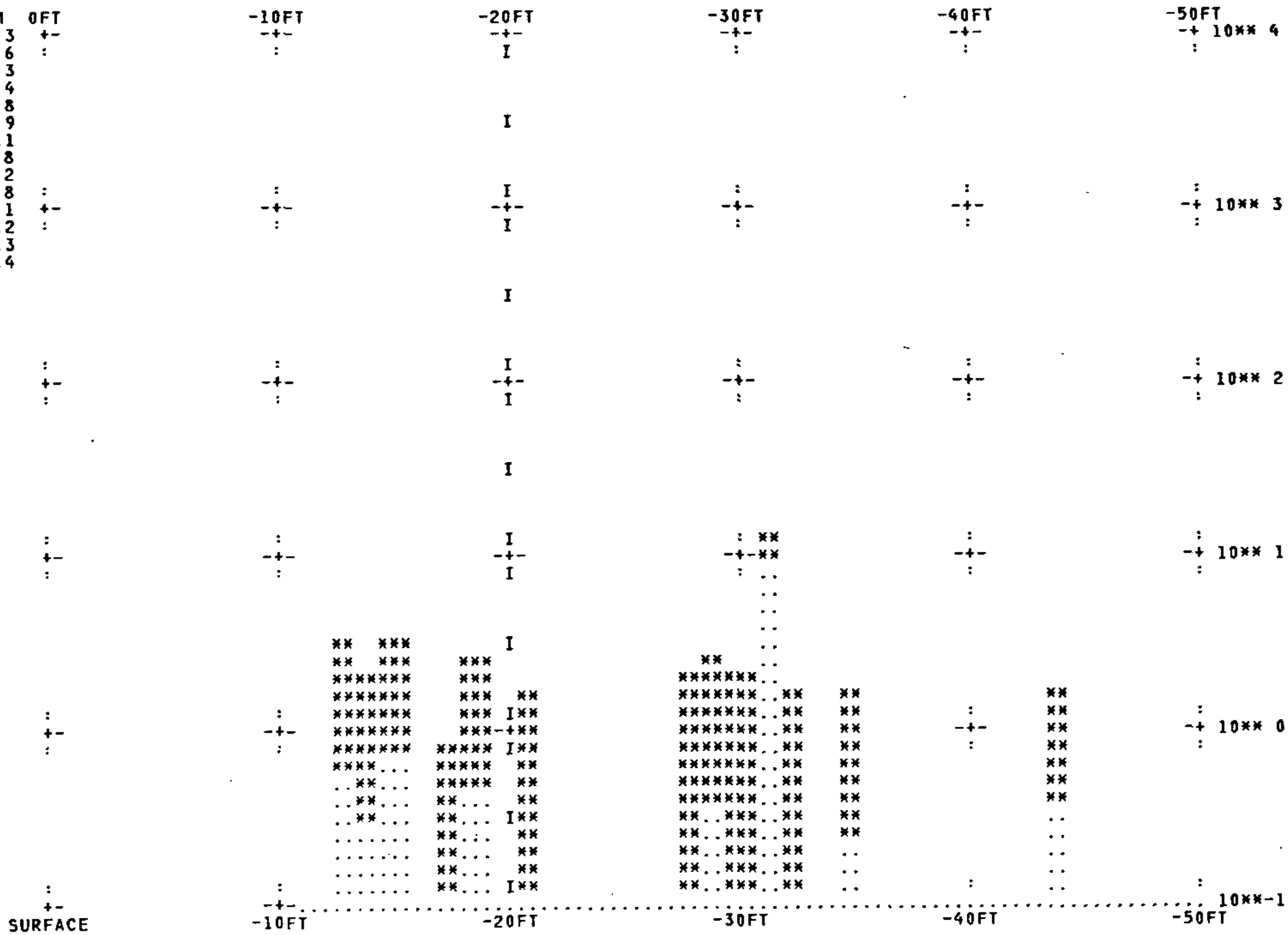
CO-60 LOG-PLOT FOR WELL C+13 BETWEEN 1328.0 1335.0

FIGURE 16. Log Plot for ^{60}Co in Well C+13

CO-60 LOG-PLOT FOR WELL E-13 BETWEEN 1328.0 1335.0

DEPTH ACTIVITY

FEET	CPM
12.2	2.3
13.3	1.6
14.5	2.3
16.8	0.4
17.9	1.8
20.2	0.9
27.1	1.1
28.3	1.8
29.4	1.2
30.6	14.8
31.8	1.1
34.1	1.2
43.3	1.3
51.3	0.4

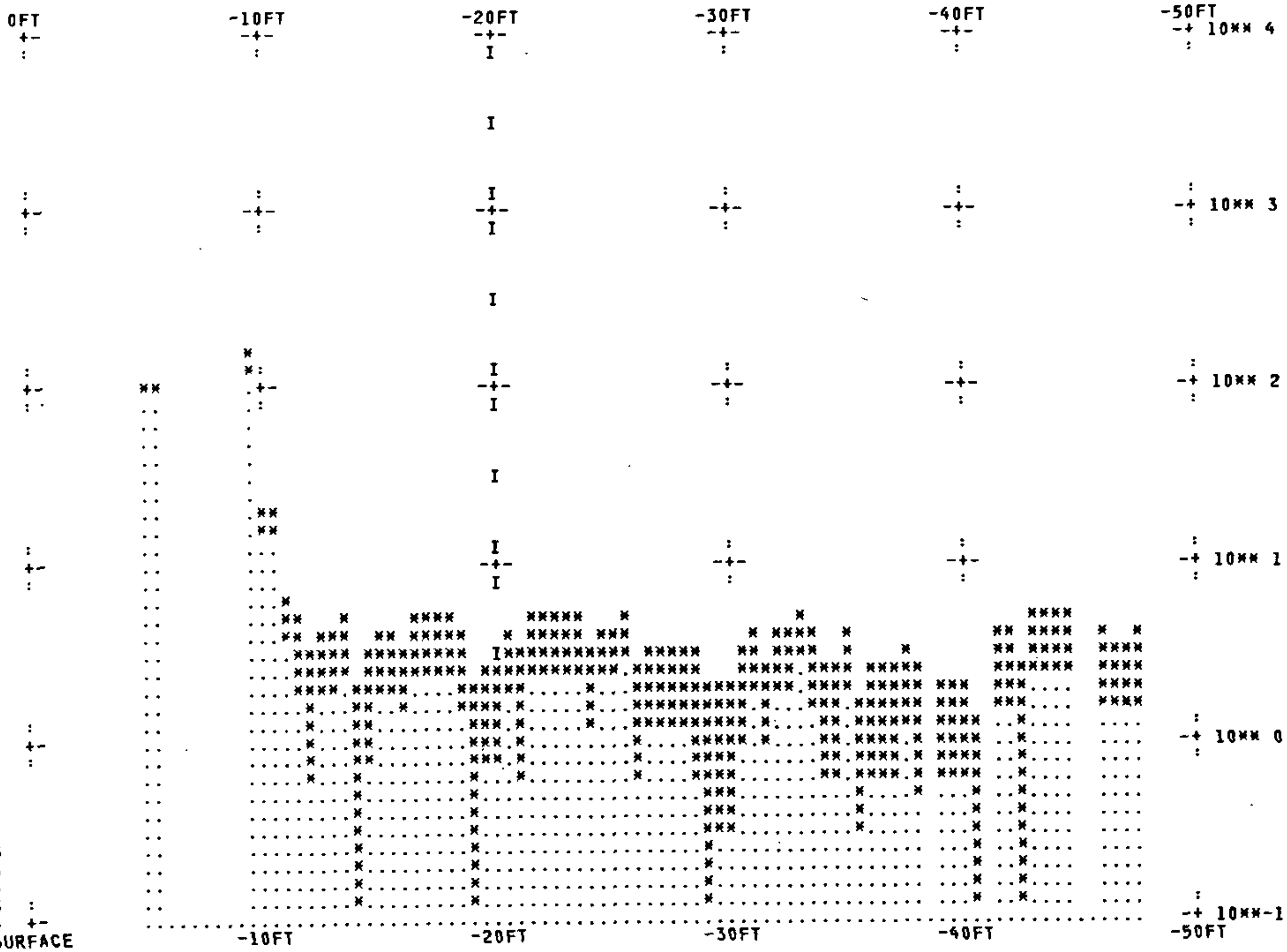


CO-60 LOG-PLOT FOR WELL E-13 BETWEEN 1328.0 1335.0

FIGURE 17. Log Plot for ^{60}Co in E-13

DEPTH ACTIVITY CO-60 LOG-PLOT FOR WELL E+17 BETWEEN 1328.0 1335.0

FEET	CPM
5.0	124.9
9.4	174.9
10.0	21.6
10.6	6.6
11.3	4.1
11.9	2.5
12.5	3.6
13.1	4.8
14.4	2.3
15.0	3.7
15.7	3.1
16.3	4.9
16.9	4.8
17.6	4.6
18.2	3.4
19.4	2.1
20.1	4.0
20.7	2.2
21.3	4.9
23.2	4.8
23.9	2.9
24.5	4.3
25.1	5.2
25.7	1.9
26.4	2.9
27.0	3.0
27.6	2.7
28.3	2.2
29.5	1.4
30.2	2.5
30.8	3.7
31.4	2.3
32.0	3.9
32.7	5.1
33.3	3.3
33.9	2.0
34.6	3.7
35.8	2.0
36.5	1.9
37.1	2.8
37.7	1.8
39.0	1.7
39.6	1.6
41.5	3.3
42.1	1.5
42.8	4.4
43.4	4.5
44.0	4.6
45.9	3.4
46.5	3.3
47.2	3.4



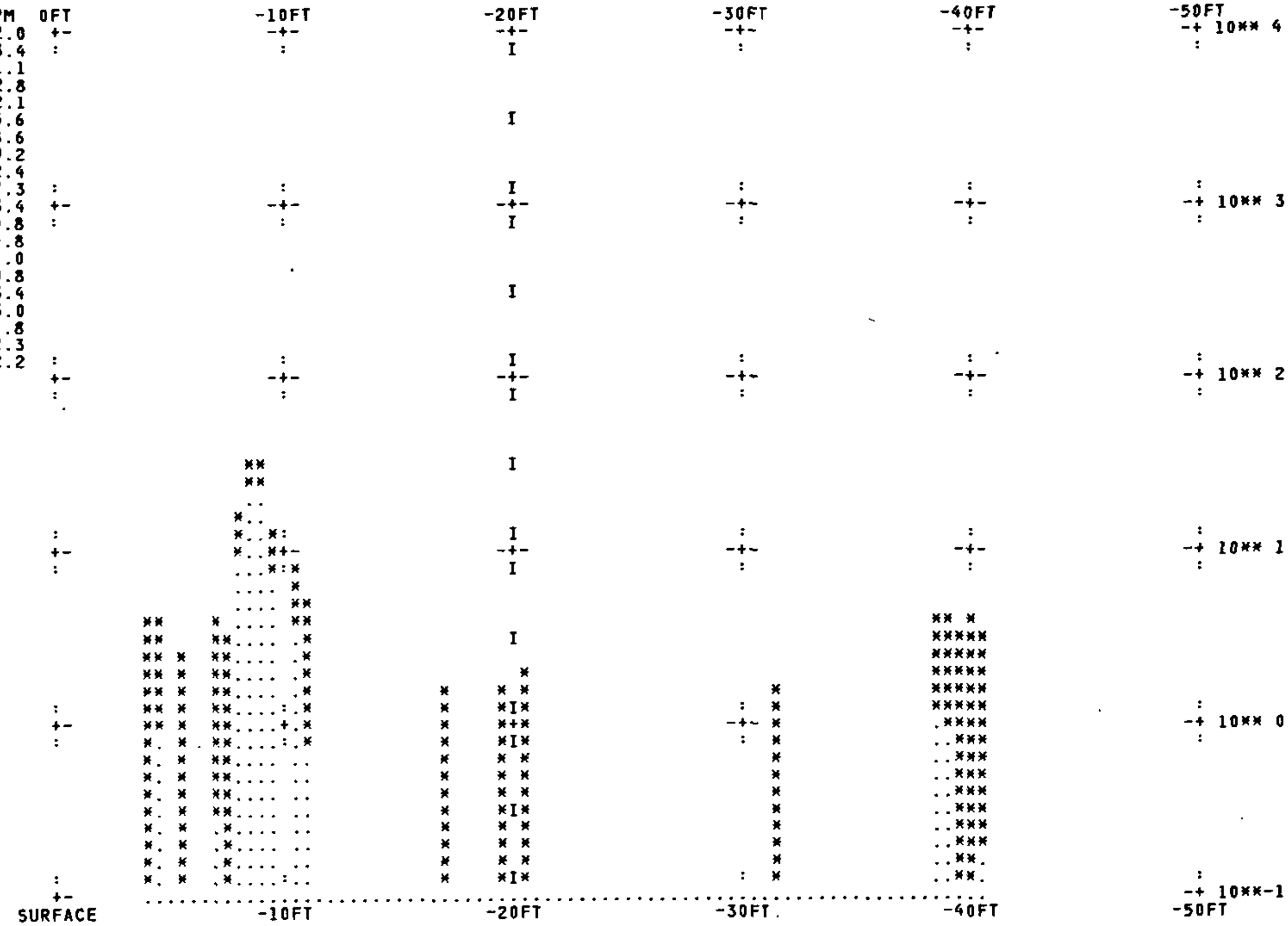
CO-60 LOG-PLOT FOR WELL E+17 BETWEEN 1328.0 1335.0

FIGURE 18. Log Plot for ^{60}Co in Well E+17

DEPTH ACTIVITY

CS-137 LOG-PLOT FOR WELL E-19 BETWEEN 658.0 663.9

FEET	CPM
4.0	2.0
4.4	3.4
5.3	1.1
6.7	2.8
7.1	2.1
8.0	15.6
8.5	38.6
8.9	39.2
9.4	12.4
10.3	7.3
10.7	3.4
17.0	0.8
19.3	0.8
20.2	1.0
31.5	0.8
38.2	3.4
38.7	3.0
39.1	1.8
40.0	2.3
40.5	2.2

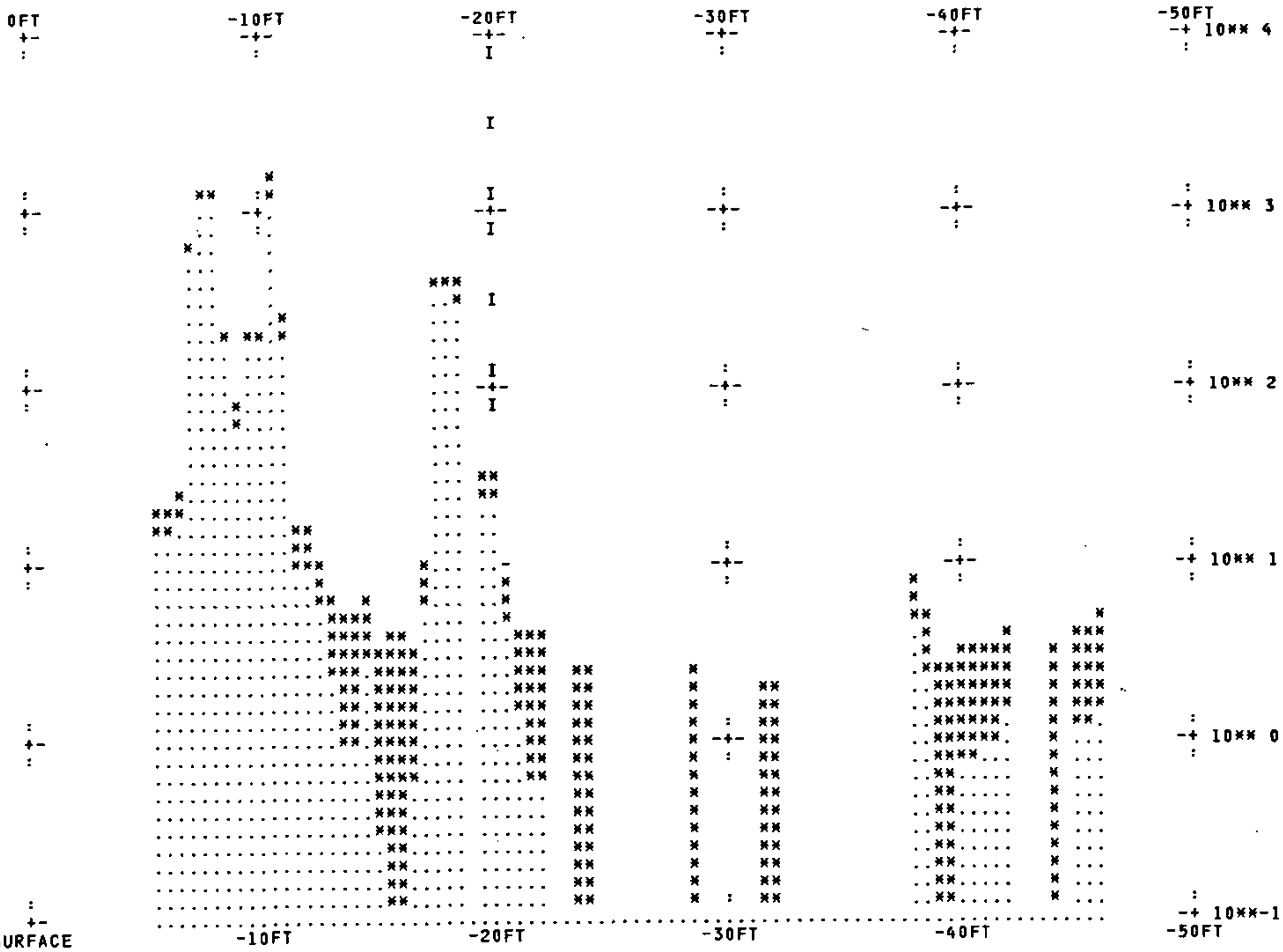


CS-137 LOG-PLOT FOR WELL E-19 BETWEEN 658.0 663.9

FIGURE 19. Log Plot for ^{137}Cs in Well E-19

DEPTH ACTIVITY CS-137 LOG-PLOT FOR WELL G-17 BETWEEN 658.0 663.9

FEET	CPM
5.5	23.1
6.1	28.8
6.8	773.8
7.5	1591.8
8.1	244.8
8.8	88.3
9.5	238.2
10.1	1780.5
10.8	284.4
11.5	16.2
12.1	10.8
12.8	5.5
13.5	3.6
14.2	6.0
14.8	2.0
15.5	2.4
16.2	2.4
16.8	11.0
17.5	542.8
18.2	447.2
19.5	36.4
20.2	8.3
20.8	3.7
21.5	2.7
23.5	1.2
28.2	1.1
31.5	1.1
37.6	8.9
38.2	4.8
38.9	1.3
39.6	2.5
40.2	2.5
40.9	2.7
41.6	3.2
43.6	2.0
44.9	3.5
45.6	4.4
46.3	8.0

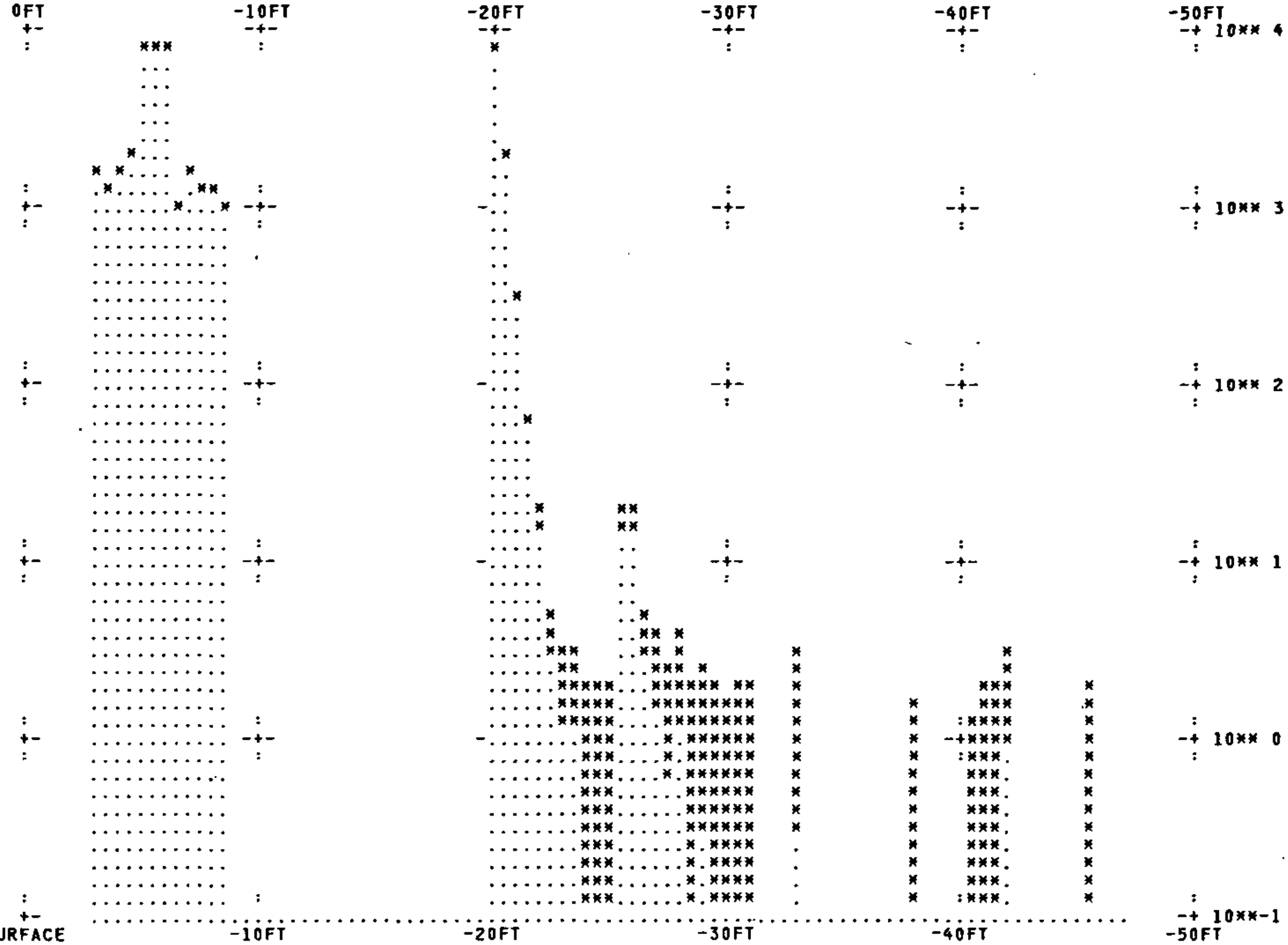


CS-137 LOG-PLOT FOR WELL G-17 BETWEEN 658.0 663.9

FIGURE 20. Log Plot for ^{137}Cs in Well G-17

DEPTH ACTIVITY CO-60 LOG-PLOT FOR WELL G-34 BETWEEN 1328.0 1335.0

FEET	CPM
2.8	1904.7
3.3	1565.7
3.9	1914.1
4.4	2522.4
5.0	9134.0
5.5	11827.5
6.1	1207.1
6.6	2017.1
7.1	1594.4
7.7	1657.4
8.2	1309.5
19.7	9074.0
20.2	2392.8
20.7	409.2
21.3	83.4
21.8	23.7
22.4	5.4
22.9	2.6
23.5	2.9
24.0	1.3
24.6	1.3
25.1	21.6
25.6	23.5
26.2	5.2
26.7	3.5
27.3	2.0
27.8	3.3
28.4	1.4
28.9	1.8
29.4	1.1
30.0	0.9
30.5	1.1
32.7	2.0
37.6	0.7
40.3	0.5
40.9	1.3
41.4	1.2
42.0	2.9
45.2	1.4

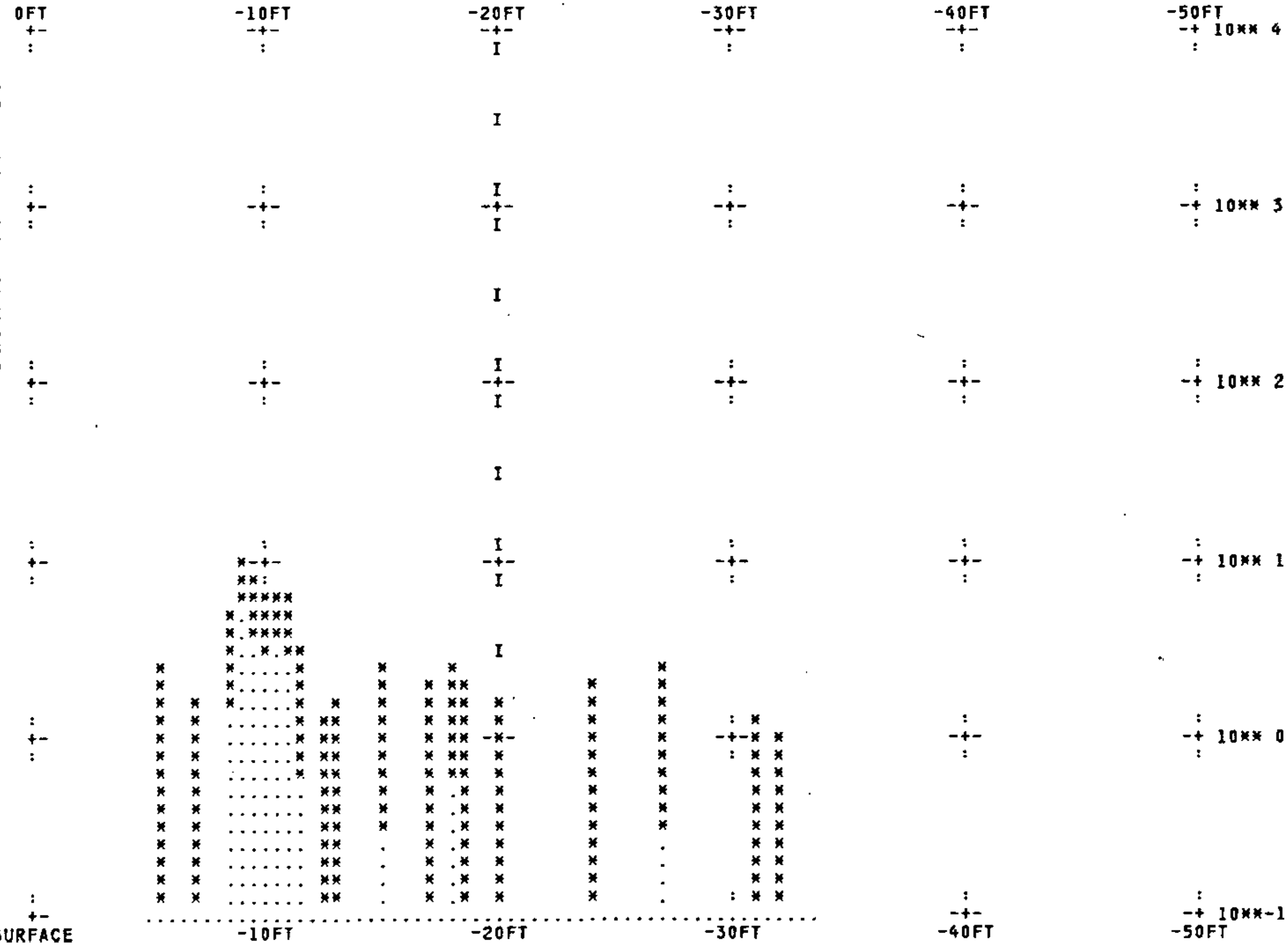


CO-60 LOG-PLOT FOR WELL G-34 BETWEEN 1328.0 1335.0

FIGURE 21. Log Plot for ^{60}Co in Well G-34

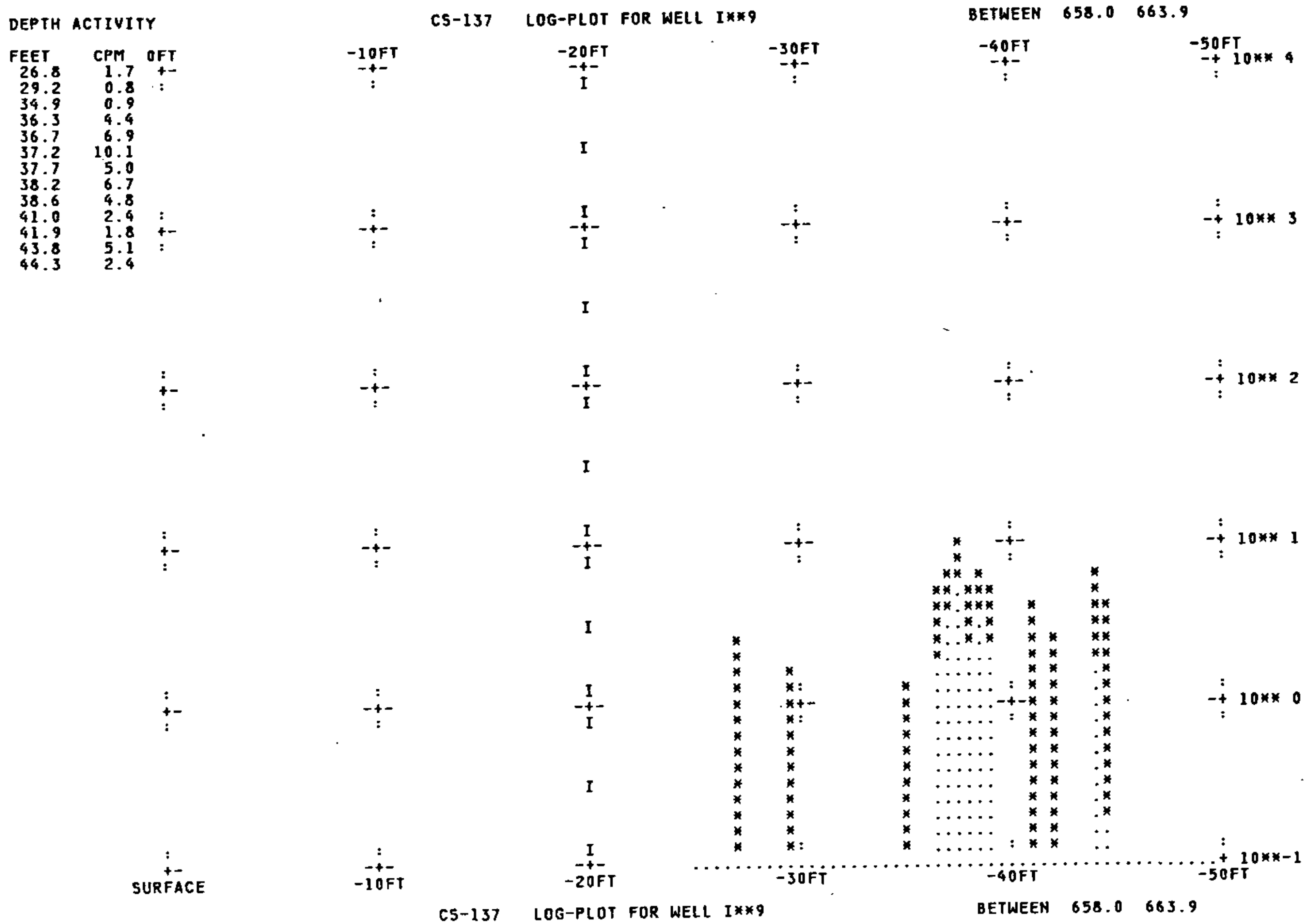
DEPTH ACTIVITY CS-137 LOG-PLOT FOR WELL I++9 BETWEEN 658.0 663.9

FEET	CPM
5.5	1.3
7.0	0.7
8.1	4.2
8.6	9.3
9.1	7.3
9.6	5.7
10.1	7.0
10.6	5.8
11.2	2.5
12.2	0.6
12.7	0.6
14.8	1.9
16.8	1.2
17.9	2.1
18.4	1.3
19.9	0.9
23.6	1.2
26.7	1.8
30.8	0.8
31.8	0.5



CS-137 LOG-PLOT FOR WELL I++9 BETWEEN 658.0 663.9

FIGURE 22. Log Plot for ^{137}Cs in Well I++9



FEET	CPM
26.8	1.7
29.2	0.8
34.9	0.9
36.3	4.4
36.7	6.9
37.2	10.1
37.7	5.0
38.2	6.7
38.6	4.8
41.0	2.4
41.9	1.8
43.8	5.1
44.3	2.4

FIGURE 23. Log Plot for ^{137}Cs in Well I**9

REFERENCES

1. Final Environmental Impact Statement, Waste Management Operations, Savannah River Plant. USERDA Report ERDA-1537 (1977).

2. W. W. Bowman. "Rapid Analysis of Germanium Spectra." Nucl. Instrum. Methods 96, 135 (1971).

3. R. C. Hochel, W. W. Bowman, and C. W. Zeh. A High-Capacity Neutron Activation Analysis Facility. USDOE Report DP-1546, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC (1980).