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216-B-5 Reverse Well Characterization Study

R. M. Smith
Earth Sciences Group
Environmental Monitoring Department

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216-B-5 REVERSE WELL CHARACTERIZATION STUDY

R. M. Smith

Earth Sciences Group
Environmental Monitoring Department

November 1980

Rockwell International

Rockwell Hanford Operations
Energy Systems Group
P.O. Box 800
Richland, Washington 99352

ABSTRACT

The processing of irradiated nuclear fuels at the Department of Energy's (DOE) Hanford Site produced large volumes of radioactive liquid waste. Some of this waste was disposed to the sediments underlying the Hanford Site by means of disposal facilities called "reverse wells." One such facility is the 216-B-5 reverse well. This reverse well was one of the first disposal sites used at Hanford, and was in service from 1945 to 1947.

An investigation of the 216-B-5 reverse well was conducted during 1979 and 1980. Wells were drilled around the reverse well and sediment samples were collected and analyzed in order to determine the spatial distribution of radionuclides sorbed on the sediments. These analyses were then used to map distributions of $^{239-240}Pu$, ^{137}Cs, and ^{90}Sr around the reverse well. The impact of the sorbed radionuclides on ground-water contamination was considered.

SUMMARY

The purpose of this study was to determine radionuclide distributions around the 216-B-5 Reverse Well. The reverse well was used for the disposal of alkaline, low-salt, radioactive liquid wastes from a plutonium recovery plant (B Plant) between 1945 and 1947. During this two year period, $\sim 3.1 \times 10^7$ ℓ of waste containing ~4.3 kg of plutonium were discharged to the disposal system.

The disposal system consisted of a settling tank and a 20-cm-diameter well. The waste was pumped to the 241-B-361 settling tank where the solids settled and the liquid overflowed into the reverse well. The reverse well was drilled to 92 m and perforated from 74 to 92 m below ground surface. The waste flowed down the reverse well, through the perforations, and was distributed into the sediments. Water level measurements made in 1947 and 1948 indicated that the reverse well penetrated the water table by as much as 3 m and the wastes were discharged to the saturated sediments in the unconfined aquifer.

Estimates of the plutonium content in the 241-B-361 settling tank were determined from analyses of sludge samples and from an in situ neutron activation study. The techniques agreed reasonably well and indicated that approximately half of the estimated plutonium inventory discharged to the system remained in the settling tank and the remainder overflowed into the reverse well.

Monitoring wells were drilled around the reverse well and settling tank to determine the radionuclide distributions sorbed on the sediments. Two wells drilled ~1 m from the settling tank showed that sediments around the tank were not contaminated and therefore the tank had not leaked. Three wells drilled to basalt and another well deepened to basalt were used to determine radionuclides distributions around the reverse well. Sediment samples collected from these wells were analyzed for $^{239-240}Pu$, ^{137}Cs, and ^{90}Sr from which contamination plumes were drawn. This work showed that $^{239-240}Pu$ and ^{90}Sr exceeding 10 nCi/g were limited to within 6 m from the reverse well. Levels of $^{239-240}Pu$ exceeding 100 nCi/g were

limited to a narrow (1 m) layer located at the position of the 1948 water table. The ^{137}Cs distribution indicated that ^{137}Cs moved laterally away from the reverse well in a silt layer in the unsaturated sediments, at the position of the 1948 water table, and at the basalt surface. A widespread layer of contamination located just above the basalt surface was revealed by gamma scintillation logging. A possible source of this contamination is the BY-Cribs located ~900 m north of the reverse well.

Studies of ground-water contamination near the reverse well indicate that the radionuclide levels are orders of magnitude less than drinking water standards. Therefore, the sorbed radionuclide plumes are causing no contamination problems in the ground water. The wells drilled in this study have been screened with stainless-steel screen to provide a representative ground-water monitoring system.

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INTRODUCTION

The disposal of radioactive liquid wastes has been a major concern at the Department of Energy's Hanford Site, located in southeastern Washington (Figure 1), since the processing of irradiated nuclear fuels began in 1944. These activities produced large volumes of radioactive liquid wastes which have been stored in and disposed to sediments underlying the Hanford Site. Initially, intermediate level, radioactive liquid wastes were disbursed to the sediments by means of waste disposal structures called reverse wells. The 216-B-5 reverse well is one of the first liquid waste disposal facilities used at Hanford.

The objective of this project was to determine radionuclide distributions around the 216-B-5 reverse well and associated 241-B-361 settling tank. This work was performed in support of the Long-Term Transuranic Defense Waste Program. This document reviews previous studies and reports the radionuclide distributions around the 216-B-5 reverse well as determined in the present study.

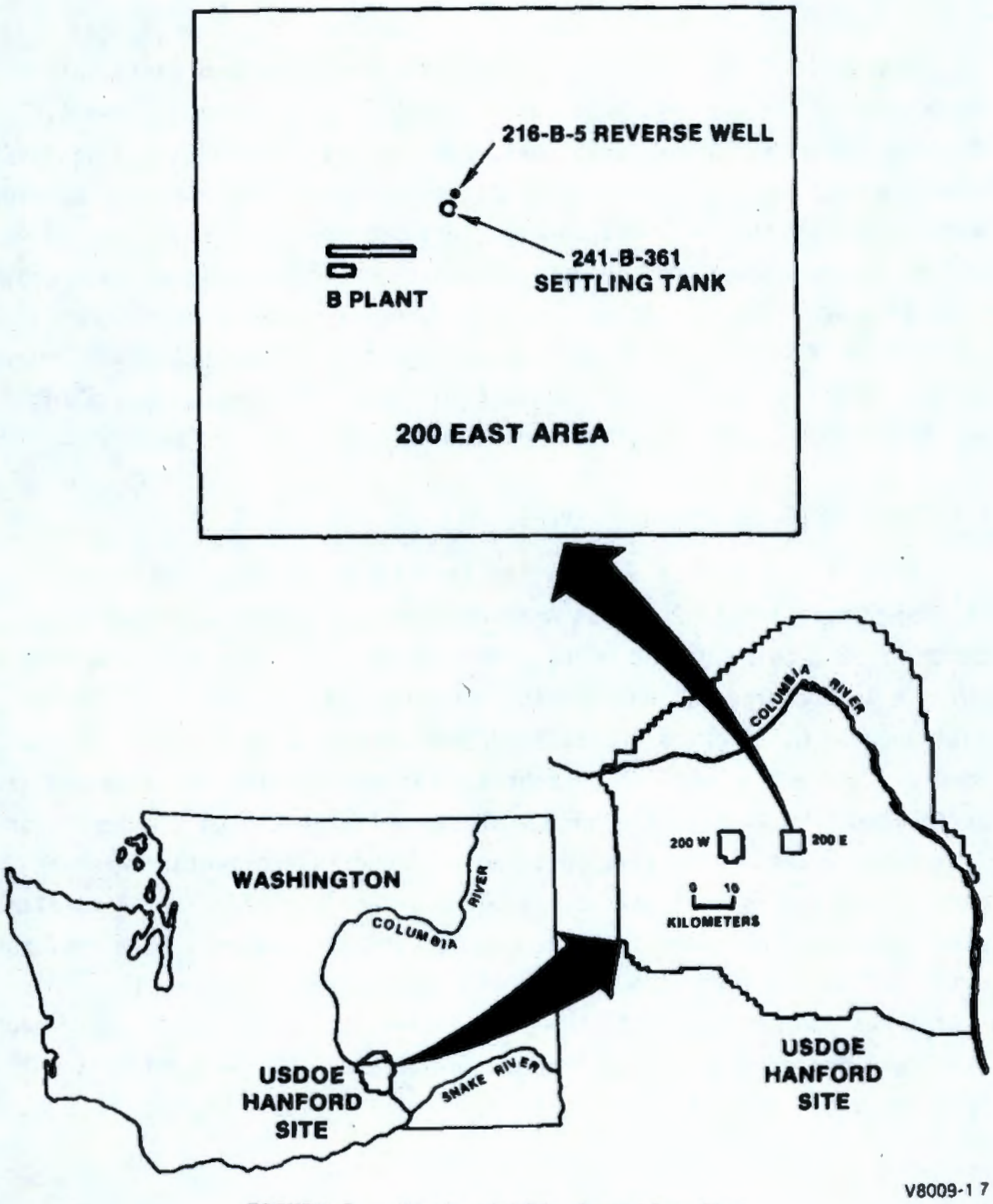


FIGURE 1. Hanford Site Location Map.

HISTORY OF THE 216-B-5 REVERSE WELL

The Hanford Site was selected for the production and purification of plutonium for military purposes under the U.S. Government's Manhattan Project during World War II (Groves, 1962). Radioactive liquid wastes generated during the separation of plutonium from irradiated nuclear fuels were initially stored or disposed of in three ways: highly radioactive liquid wastes were stored in underground tanks, intermediate level wastes were discharged to reverse wells, and low-level wastes were discharged to ponds. The 216-B-5 reverse well was designed and constructed to dispose of intermediate level liquid wastes from one of the separations plants (B Plant) which used the bismuth phosphate separation process.

CONSTRUCTION OF THE 216-B-5 REVERSE WELL

The 216-B-5 reverse well is located ∿370 m northeast of the 221-B (B Plant) building in 200 East Area (Figure 2) and was completed to a depth of 92 m below ground surface in October 1944. The well was drilled using a telescoping casing technique using 40 cm casing to 4 m, 30 cm casing to 31 m, 25 cm casing to 74 m, and 20 cm casing to 92 m. A diagram of the reverse well is presented in Figure 3. The 20 cm casing was perforated from 74 m to the bottom of the well, providing the means for distributing waste solutions into the surrounding sediments. Waste entered the reverse well at ∿3.7 m below ground surface. A 1.3-cm-diameter pipe (gageline) extended from the ground surface to within 15 m from the bottom of the well for the purpose of liquid level measurements. This system was operative only if the liquid levels in the reverse well reached the lower end of the pipe and therefore operated as a warning system to indicate that the reverse well was filling with liquid waste.

USE OF THE 216-B-5 REVERSE WELL

Low salt, alkaline, radioactive liquid wastes from cell washings collected in the 5-6 W cell located in the 221-B building and from the 224-B building were discharged to the 216-B-5 reverse well via the 241-B-361 settling tank. The reverse well was used from April 1, 1945 to September 20, 1947 (Brown and Ruppert, 1950; Battelle Staff, 1975). The wastes were discharged to the settling tank and overflowed to the reverse well. The system was designed to remove particulate material from the waste prior to discharge to the reverse well and thus reduce the chance of plugging the well. The estimated waste inventory discharged to the 241-B-361 settling tank and 216-B-5 reverse well is reported in Table 1.

TABLE 1. Estimated Waste Inventory Released to the 241-B-361 Settling Tank and 216-B-5 Reverse Well (Hanson et al., 1971).

	Amount Discharged			Total Amount Discharged	Total Decayed Amount (1979)
	1945	1946	1947		
Volume, ℓ	9.18×10^6	1.22×10^7	9.18×10^6	3.06×10^7	3.06×10^7
Pu, g	1.28×10^3	1.71×10^3	1.28×10^3	4.27×10^3	4.27×10^3
Beta, Ci	1.14×10^3	1.52×10^3	1.14×10^3	3.80×10^3	$<1.39 \times 10^2$
^{90}Sr, Ci	2.27×10^1	3.02×10^1	2.27×10^1	7.56×10^1	3.32×10^1
^{137}Cs, Ci	2.42×10^1	3.23×10^1	2.42×10^1	8.07×10^1	3.73×10^1
^{106}Ru, Ci	4.88×10^1	6.51×10^1	4.88×10^1	1.63×10^2	1.72×10^{-8}

The 216-B-5 reverse well was removed from service on September 19, 1947 when a water sample from well 299-E33-18, located 655 m north of the reverse well (Figure 2), indicated the presence of alpha contamination in ground water (Brown and Ruppert, 1950). Two days later, the waste that was being discharged to the reverse well was rerouted to the 216-7A and -7B cribs. Following the analysis of the first water sample from well 299-E28-18, a second water sample was collected and analyzed. The results of this analysis indicated that the first analysis was wrong and the ground water in that area was not contaminated with radionuclides. Analyses of additional samples supported the results of the second water analysis.

Drilling logs from wells drilled near the reverse well indicate that the water table at the 216-B-5 reverse well was ~90 m below ground surface in 1948. Since the reverse well was drilled to 92 m, this indicates that the reverse well penetrated the water table and radioactive liquid wastes were discharged directly into the saturated sediments below the water table. These findings provided the impetus for a full scale investigation of the 216-B-5 reverse well from 1947 to 1950. This study will be discussed in the section on previous studies.

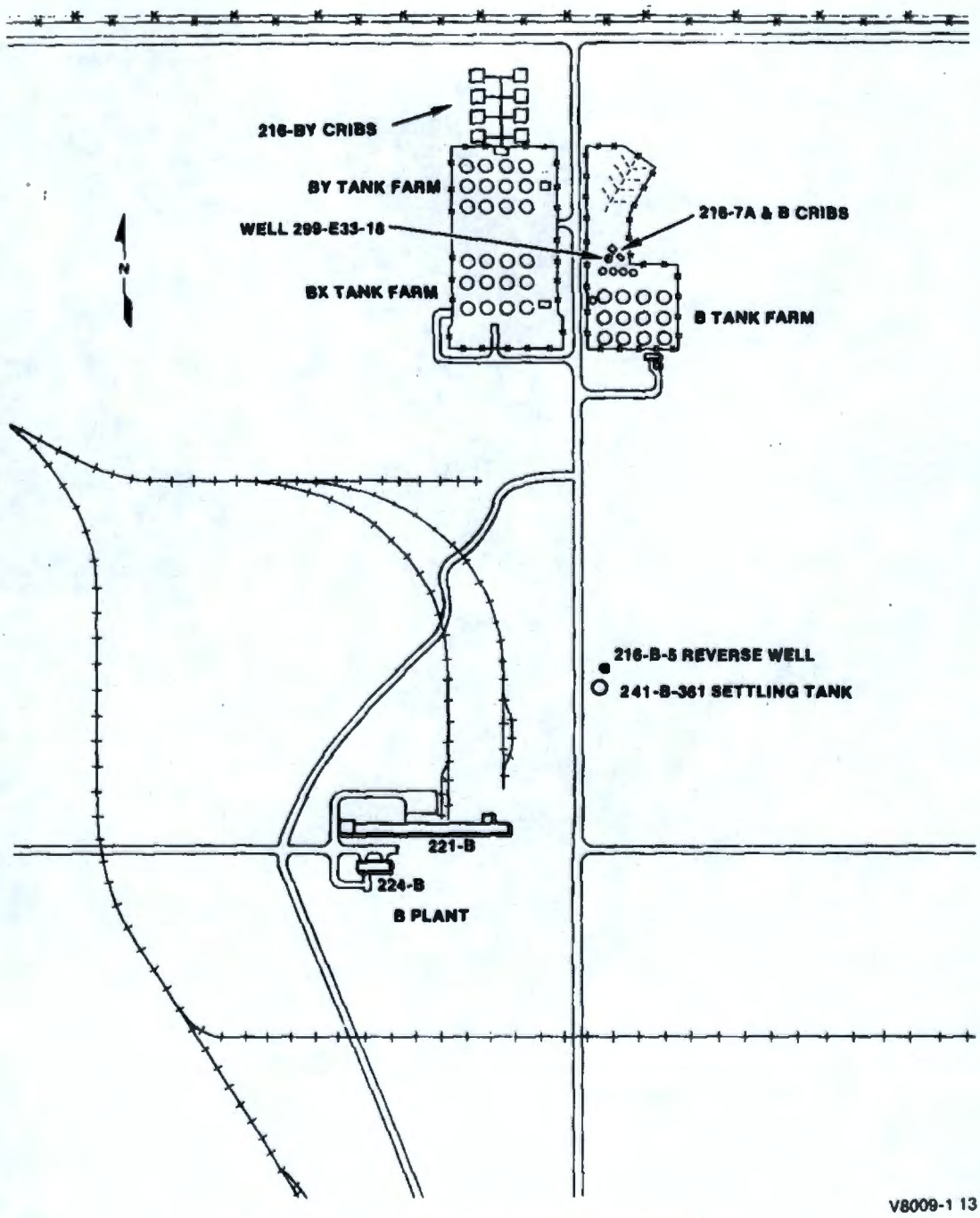


FIGURE 2. Reverse Well Location Map.

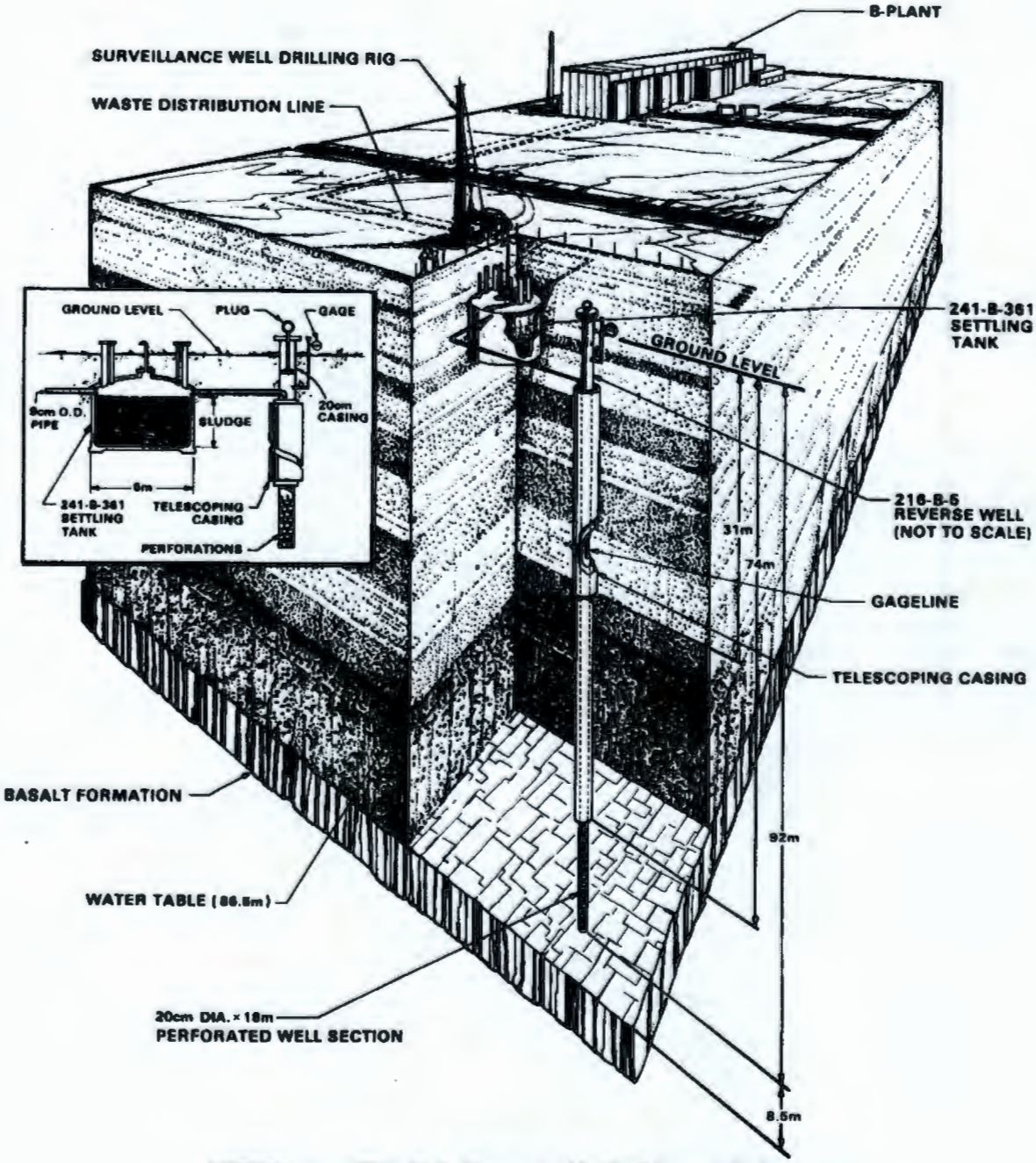


FIGURE 3. 216-B-5 Reverse Well Disposal System.

ENVIRONMENTAL CHARACTERISTICS

Climate, biology, geology, and hydrology have the potential for affecting radionuclide distributions around a disposal facility. Climate and biology, however, have little impact on the radionuclide distribution around the 216-B-5 reverse well because the waste release zone for the facility was from 74 to 92 m below the ground surface. Animal and plant intrusion into the radionuclide plume around the reverse well has been precluded by the depth of the plume. Climatic and biologic characteristics of the Hanford Site are discussed in an environmental impact statement for the site (ERDA Staff, 1975). Geology and hydrology were the major environmental factors which determined the distribution of radionuclides around the 216-B-5 reverse well.

GEOLOGY

The Hanford Site is underlain by three stratigraphic formations. They are in descending order: unconsolidated sediments of the Hanford Formation, semiconsolidated sediments of the Ringold Formation, and Yakima Basalt flows of the Columbia River Basalt Group (Tallman et al., 1979). A generalized geologic cross section for the Hanford Site is presented in Figure 4.

The basalts comprising the Columbia River Group are flood basalts that flowed from fissures in the ground in southeastern Washington, eastern Idaho, and northeastern Oregon. Numerous depressions formed in the basalt surface creating basins. The extent of the Columbia River Basalt and locations of major structural basins are presented in Figure 5. The Hanford Site is located in the Pasco Basin. Sediments transported into the Pasco Basin accumulated to form the Ringold Formation. Part of the Ringold Formation was eroded away and sediments comprising the Hanford Formation were deposited when catastrophic flooding occurred as ice-dammed lakes released large quantities of water during Pleistocene glaciation.

A geologic cross section for the area in the immediate vicinity of the 216-B-5 reverse well is presented in Figure 6. In this figure, the boundary between the Hanford Formation and the Ringold Formation is between the sand and pebble units as indicated by a solid line. The average particle size distributions of the major sediment units delineated in Figure 6 are presented in Table 2.

The 216-B-5 reverse well penetrated into the Ringold Formation sediments and the release point for the reverse well is limited to the Ringold sediments. The waste was released only to the silty sandy very coarse to fine pebble (abbreviated name, Table 2) unit. A sandy silt to pebbly sandy silt layer was also encountered at ∿78 m below ground surface in wells 299-E28-23, -24, and -25.

HYDROLOGY

The Hanford Site is underlain by many aquifers both confined and unconfined. The confined aquifers are located between basalt flows in interbed sediments or in porous interflow zones. The unconfined aquifer system is of immediate importance in this study because it is the release point for the 216-B-5 reverse well.

The unconfined aquifer is located on top of the upper basalt flow of the Columbia River Basalt Group in the glaciofluvial sediments which cover the Hanford site. The natural recharge area of the unconfined aquifer system is located at the foot of the Rattlesnake Hills and Yakima Ridge (Figure 7) and drains into the Yakima and Columbia Rivers (Bierschenk, 1959; ERDA Staff, 1975). Prior to the beginning of waste operations at Hanford, the water table contour map of the unconfined aquifer appeared as in Figure 7. Since flow paths are perpendicular to the water table contours, the direction of water flow in the unconfined aquifer beneath the separations areas was to the east in 1944. As a result of discharges of water to disposal facilities in the separations areas, the water table elevation increased. The December 1979 Hanford site water table map, presented in Figure 8 shows how the water table has changed. This indicates that water in the unconfined aquifer is generally flowing east and southeast except in regions near ground water mounds

caused by U and B ponds in 200 West and 200 East Areas, respectively. The 216-B-5 reverse well is located between these two ground water mounds in an area where the direction of ground water flow is difficult to determine. The change in water table elevations is <1 m in 200 East Area. The flat water table beneath 200 East Area indicates that the ground water flow is slow even though the aquifer is located in a highly permeable sediment unit. Past studies (Brown and Ruppert, 1950) indicate that the actual waste from the reverse well flowed to the southeast. The 1973 nitrate plume in the unconfined aquifer, presented in Figure 9, indicates that the ground water beneath 200 East area has flowed to the southeast in the past.

TABLE 2. Average Particle Size Distributions for the Major Sediment Units at the 216-B-5 Reverse Well.

Geologic Unit (Abbreviated Name)	Particle Size								
	Fine Coarse	Very Fine Pebble	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Silt & Clay
Very Coarse Sand to Very Coarse Pebble	18	20	25	15	8	5	4	2	3
Very Coarse to Coarse Sand	4	6	25	34	12	6	5	3	5
Pebbly Very Coarse to Coarse Sand	2	4	21	46	17	5	1	1	3
Slightly Silty Coarse to Medium Sand	0	2	9	27	34	18	5	2	3
Silty Sandy Very Coarse to Fine Pebble	7	13	24	28	14	5	3	2	4

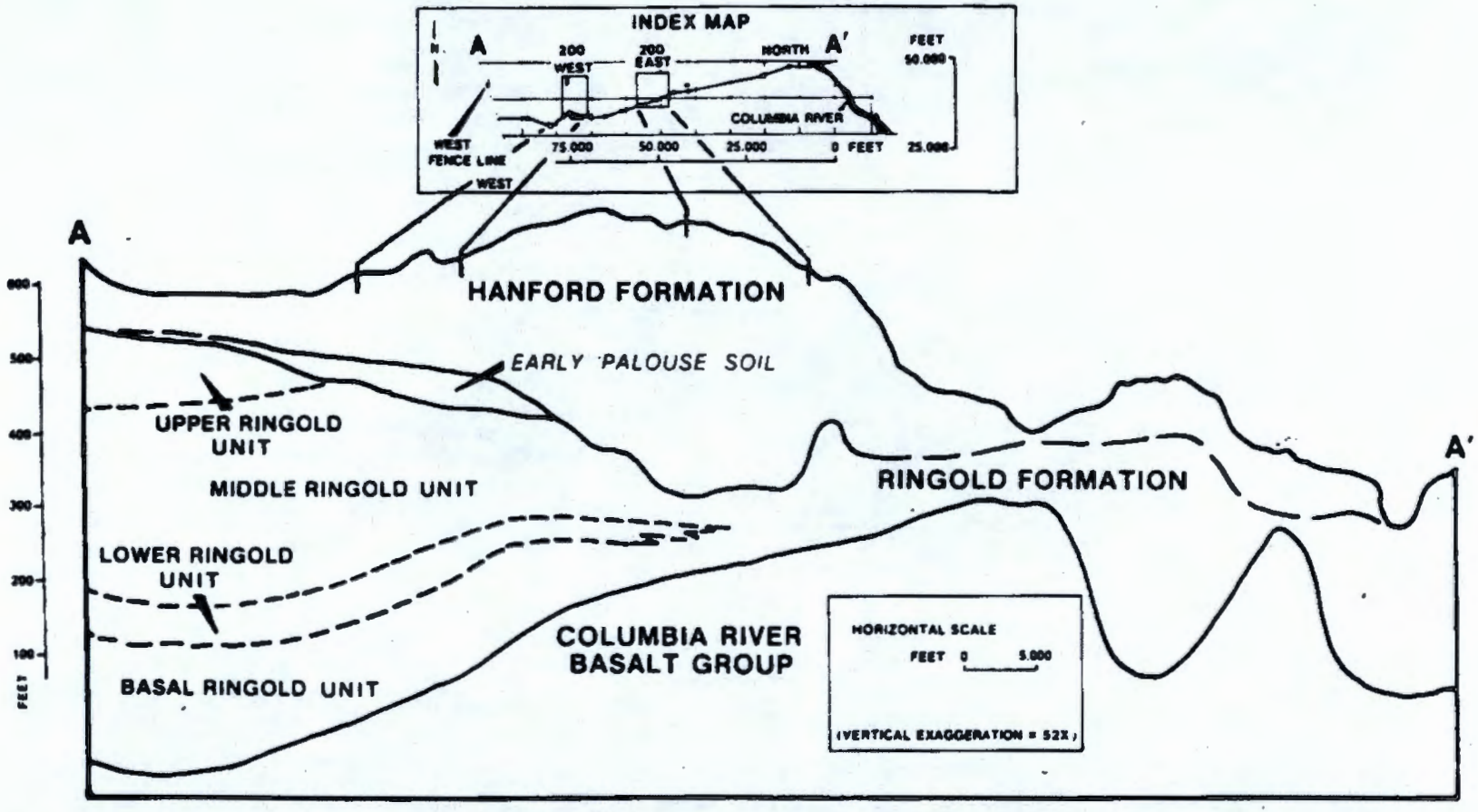


FIGURE 4. Generalized Hanford Geologic Cross Section (Tallman et al., 1979).

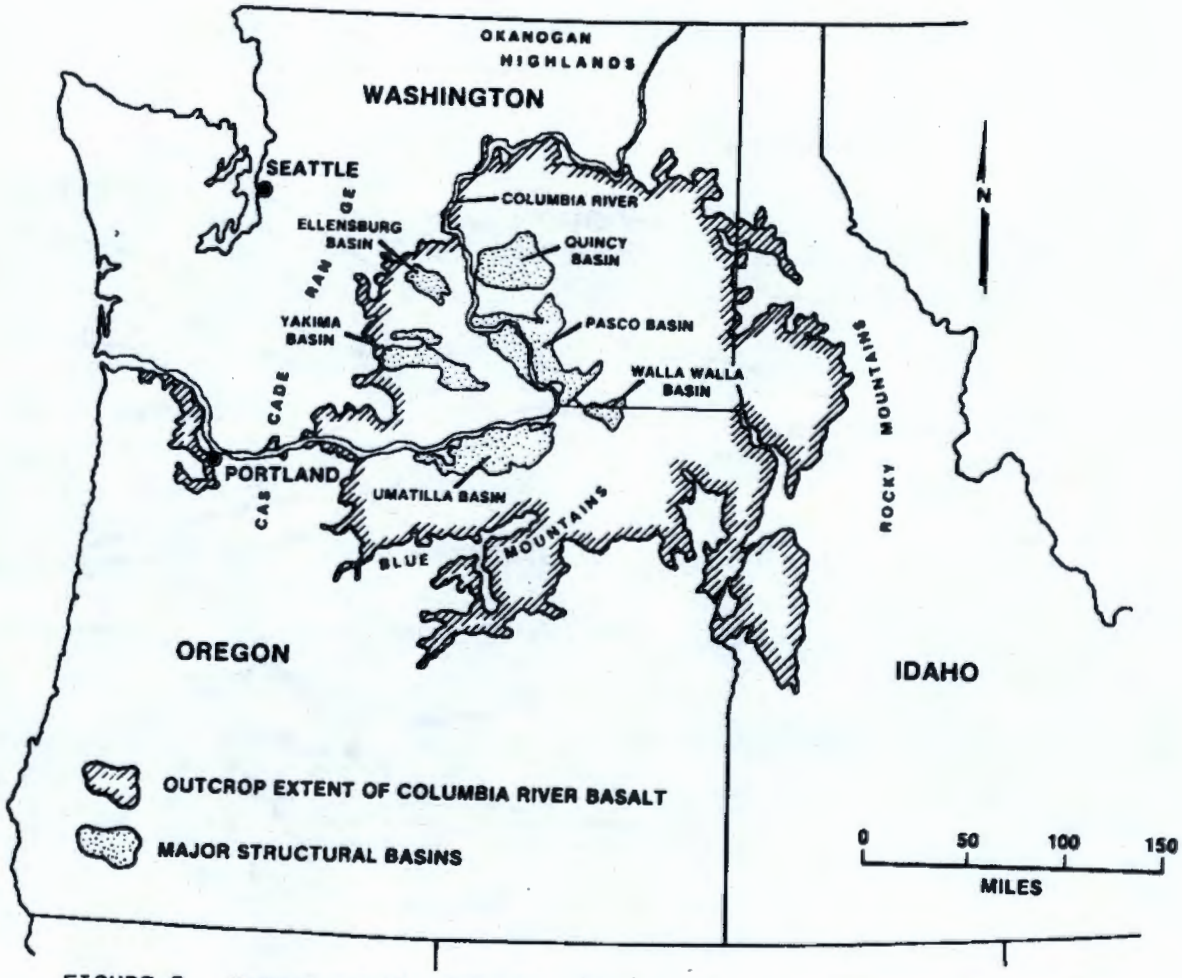


FIGURE 5. Extent of the Columbia River Basalt (Tallman et al., 1979).

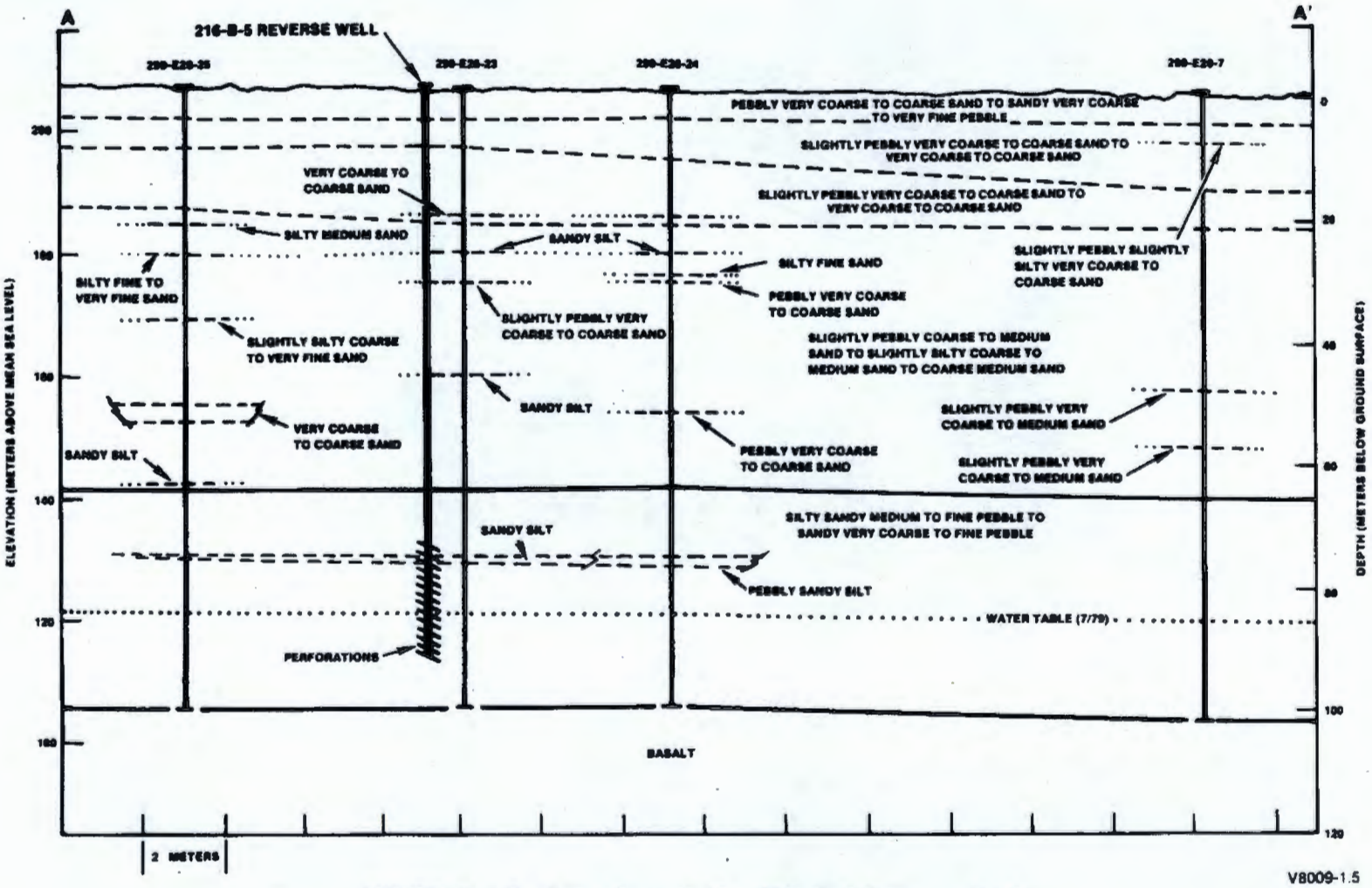


FIGURE 6. Geology Around the 216-B-5 Reverse Well.

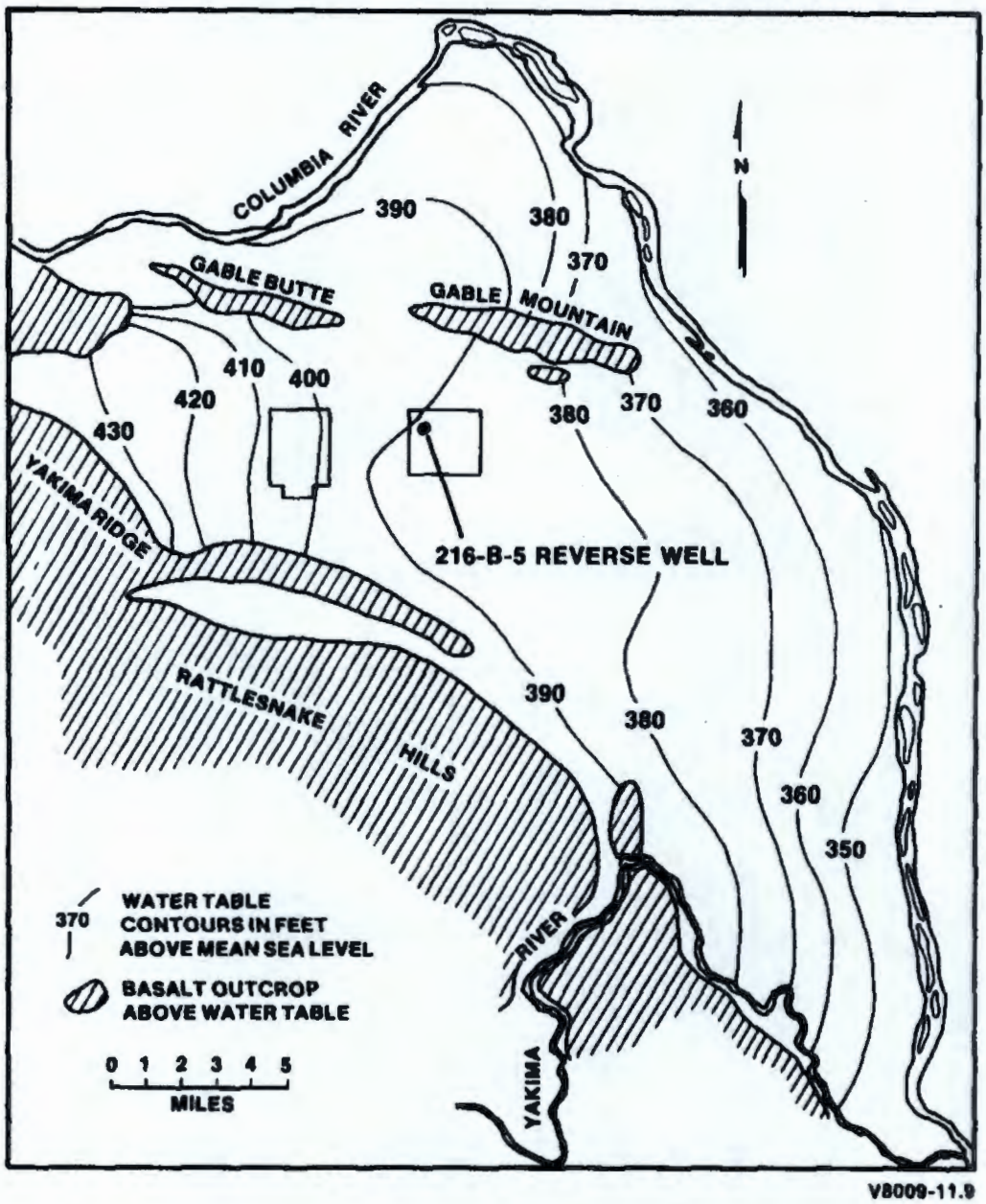


FIGURE 7. 1944 Hanford Water Table Map (ERDA Staff, 1975).

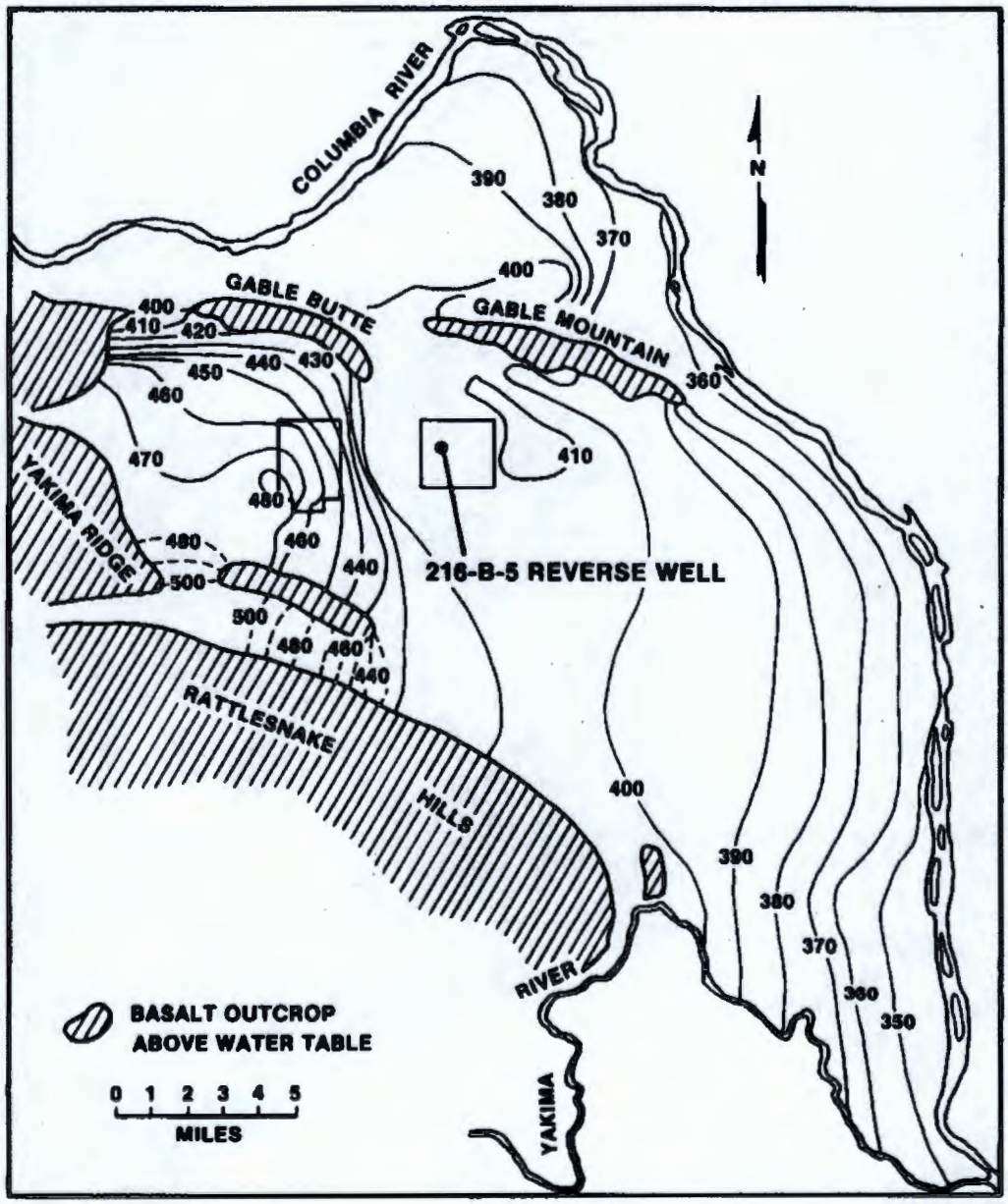


FIGURE 8. 1979 Hanford Water Table Map.

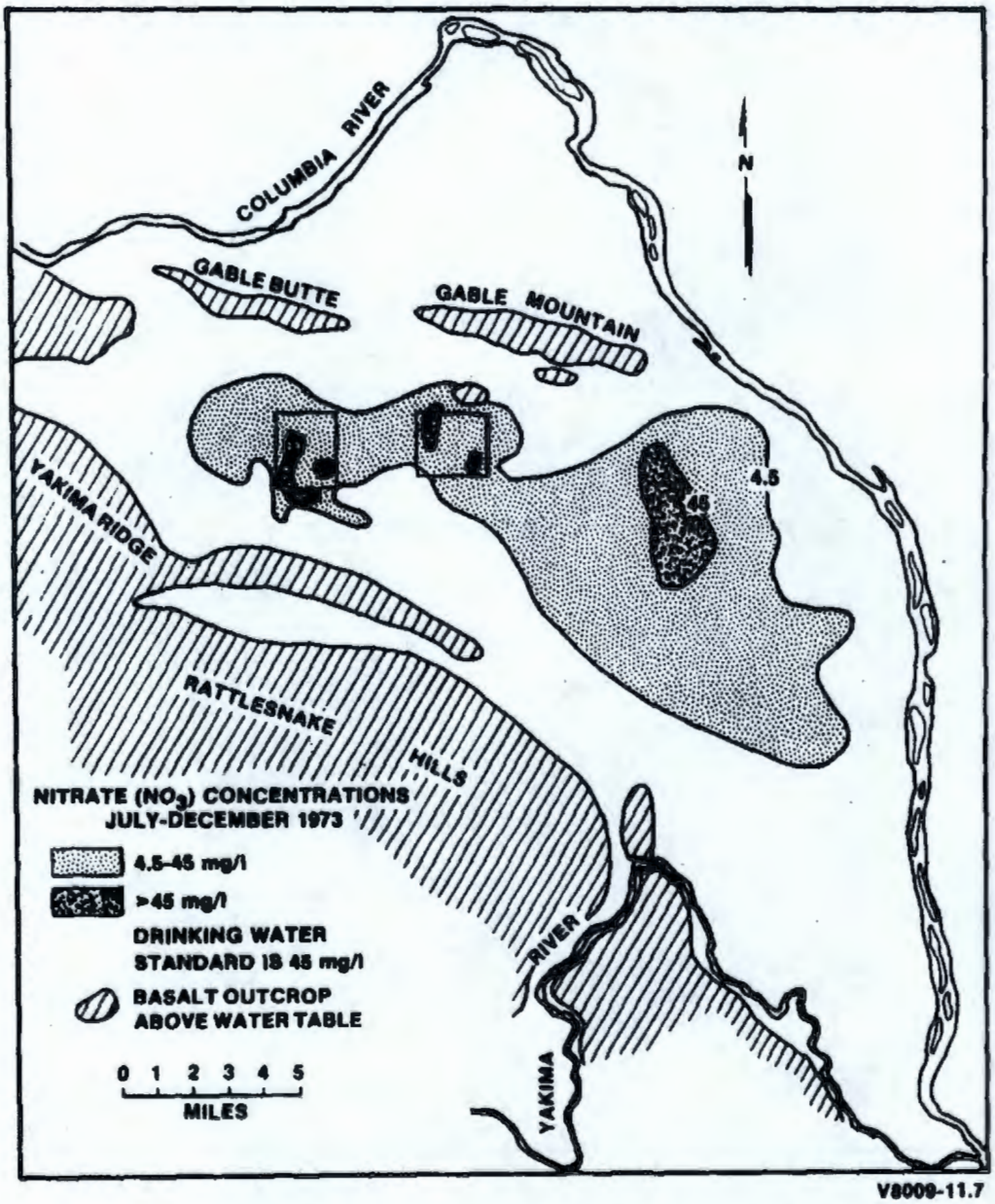


FIGURE 9. 1973 Nitrate Plume in the Unconfined Aquifer (ERDA Staff, 1975).

PREVIOUS STUDIES OF THE 216-B-5 REVERSE WELL SYSTEM

BROWN AND RUPPERT STUDIES

A study by Brown and Ruppert, designed to determine potential hazards from wastes discharged to ground, was developed in 1946 and implemented in 1947 and 1948 following the alleged discovery of alpha contamination in the ground water in well 299-E33-18 (Brown and Ruppert, 1948, Brown and Ruppert, 1950). Two major objectives of the study were to determine the spatial distribution of radionuclide contamination in the ground water and to predict the direction the contamination would migrate if it moved at all.

Eleven wells were drilled from November 1947 to May 1948 as part of an effort to determine the distribution of radionuclides in the ground water around the 216-B-5 reverse well. Nine of the wells are shown in Figure 10. The remaining two wells were drilled east of those shown in Figure 10 and were not required to delineate the radionuclide distributions around the reverse well. The wells were drilled 9 m into the saturated zone below the water table. Sediment and ground water samples were collected at the time of drilling and were analyzed for alpha and total beta-gamma contamination.

No radioactive contaminants were detected in any of the sediment samples collected from the 11 wells, but analyses of ground water samples indicated the presence of beta-gamma and alpha activity in the ground water. Brown and Ruppert (1950) presented ground water contamination plumes as a function of time for total fission product activity (beta-gamma) and total alpha activity from November 1, 1947 to July 1, 1949. These plumes are shown in Figure 11. An isopleth delineating the maximum permissible concentration (MPC) for ^{90}Sr in an uncontrolled zone 300 pci/ℓ (U.S. DOE Staff, 1977), was added to provide a reference. Strontium-90 has the lowest MPC of the common fission product contaminants. The November 1, 1947 contamination plumes were developed using contamination trends in water samples collected from each well extrapolated back to November 1. Therefore, the November 1, 1947 contamination plumes are best estimates of the plumes for that time. The large contamination lobes extending to the south

in the November 1, 1947 and July 1, 1948 fission product plumes were drawn as a result of analyses of water samples from well 299-E23-1 and the high permeability of the sediments in the area as determined from hydrologic testing. Analyses of water samples collected from well 299-E23-1 shortly after it was drilled (March 22, 1948) indicated that the ground water contained beta-gamma activity at the detection limit of the analysis. Therefore, when the authors extrapolated data back to November 1, 1947, they included well 299-E23-1 in the fission product plume. This is also the reason for drawing the lobe on the July 1, 1948 plume.

Several conclusions can be drawn from Figure 11. The area of the fission product contamination plume decreased with time. This was attributed to decay of short-lived radionuclides and dispersion and dilution of radionuclides in the ground water. By July 1, 1949, the lowest detectable fission product activity (20 pCi/ℓ) isopleth was <300 m from the 216-B-5 reverse well in the southeast direction and <150 m in the southwest direction. A southeast direction of ground water flow at the time of waste disposal to the reverse well is indicated by the shape of the fission product contamination plumes. Since no plutonium was detected in any of the water samples, the authors attributed the alpha contamination to uranium. The MPC for uranium and plutonium are 66,600 dis/min/ℓ and 11,100 dis/min/ℓ, respectively. The activity of the most concentrated alpha contamination isopleth was 400 dis/min/ℓ within 60 m from the reverse well. Therefore, the maximum alpha concentration in the alpha contamination plumes reported in Brown and Ruppert (1950) is at least ten times lower than the MPC for plutonium in an uncontrolled zone.

LARGE VOLUME WATER SAMPLING

In 1976, water samples from 3 of the 11 wells drilled for the first 216-B-5 reverse well study in 1947 and 1948 were pumped through a large volume water sampler developed at Battelle's Pacific Northwest Laboratory (PNL) (Weimer, 1978). This system is comprised of a series of filters arranged in parallel and three Al_2O_3 beds positioned in series. A diagram of this system is presented in Figure 12. Each set of filters consists of a 3.0 and a 0.04 μ filter. The filters remove particulates from

the water and the Al_2O_3 beds retain colloidal and charged ionic species. The results of the analyses presented in Table 3 indicate that the concentrations of all radionuclides measured were at least four orders of magnitude less than the maximum permissible concentrations for uncontrolled zones. The ability of the Al_2O_3 beds to retain radionuclides can be determined from analyses of individual Al_2O_3 beds. If the Al_2O_3 beds are doing an adequate job of retaining a particular radionuclide, bed 1 should retain most of the radionuclide, bed 2 should retain less, and bed 3 should retain the least amount of the radionuclide. This pattern existed for every radionuclide in the sample from well 299-E28-7, but not in those samples from wells 299-E28-1 and -5. The radionuclide concentrations from wells 299-E28-1 and -5 are generally lower than those for -7; the pattern is not followed when the radionuclide concentration is low. When the radionuclide concentrations in the samples from wells 299-E28-1 and -5 are at the level found in well -7, the retention of those radionuclides on the Al_2O_3 beds follows the pattern of decreasing retention from beds 1 to 3.

The past studies have been concerned with radionuclide contamination in the ground water while the present study is designed to examine the hydrologic, geologic, and chemical characteristics of the 216-B-5 reverse well contamination plume retained on the sediment. No previous work was designed to determine the actual distribution of radionuclides sorbed on the sediments. This is required before a decision concerning future disposition of the site can be made. This work will be presented in the remainder of this report.

TABLE 3. Radionuclide Concentrations (pCi/ℓ) in Ground Water Near the 216-B-5 Reverse Well, September 1976.

Radionuclide	MPC*	Filters			Al_2O_3 Beds			
		Well	3.0 μ	0.04 μ	Total	Bed 1	Bed 2	Bed 3
^{46}Sc	40,000	E28-1	0.021	-	0.042	0.020	0.016	0.006
		E28-5	-	-	0.001	0.001	-	-
		E28-7	Not Used	-	0.008	-	0.008	-
^{54}Mn	100,000	E28-1	0.021	-	0.059	0.018	0.017	0.024
		E28-5	0.031	-	0.072	0.024	0.021	0.027
		E28-7	Not Used	0.098	1.0	0.87	0.08	0.05
^{60}Co	50,000	E28-1	1.5	4.2	1.6	0.68	0.50	0.41
		E28-5	0.034	0.041	0.035	0.023	0.006	0.005
		E28-7	Not Used	5.2	0.49	0.19	0.18	0.12
^{65}Zn	100,000	E28-1	-	-	0.086	0.018	0.030	0.038
		E28-5	0.025	-	0.13	0.051	0.029	0.049
		E28-7	Not Used	0.13	1.1	0.93	0.14	0.07
$^{95}Zr,^{95}Nb$	100,000	E28-1	-	-	0.14	0.52	0.039	0.050
		E28-5	0.042	-	0.14	0.050	0.040	0.051
		E28-7	Not Used	0.22	3.6	3.19	0.23	0.23
^{106}Ru	10,000	E28-1	0.025	-	-	-	-	-
		E28-5	-	-	-	-	-	-
		E28-7	Not Used	-	0.28	0.28	-	-
^{137}Cs	20,000	E28-1	0.035	-	0.37	0.011	0.012	0.014
		E28-5	0.032	-	0.047	0.017	0.011	0.015
		E28-7	Not Used	1.1	1.5	1.19	0.20	0.14
^{152}Eu	60,000	E28-1	0.026	-	0.010	0.010	-	-
		E28-5	0.010	-	-	-	-	-
		E28-7	Not Used	-	-	-	-	-
^{238}Pu	5,000	E28-1	<0.00003	<0.00003	0.00009			
		E28-5	0.00009	<0.00001	<0.00007			
		E28-7	Not Used	0.002	0.0005			
$^{239-240}Pu$	5,000	E28-1	<0.00003	0.0002	0.0003			
		E28-5	0.0001	0.0002	0.0005			
		E28-7	Not Used	0.14	0.002			

*Maximum permissible concentration for uncontrolled areas.

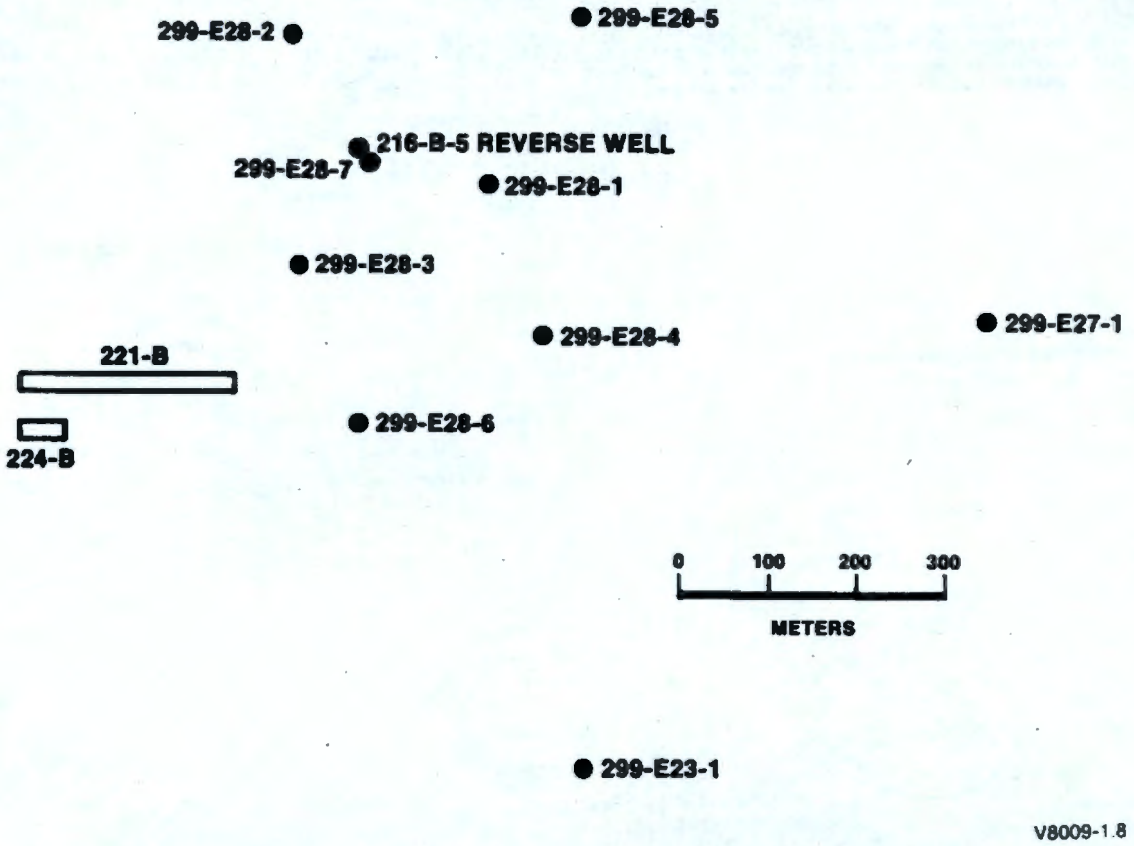


FIGURE 10. Well Location for the Brown and Ruppert Studies.

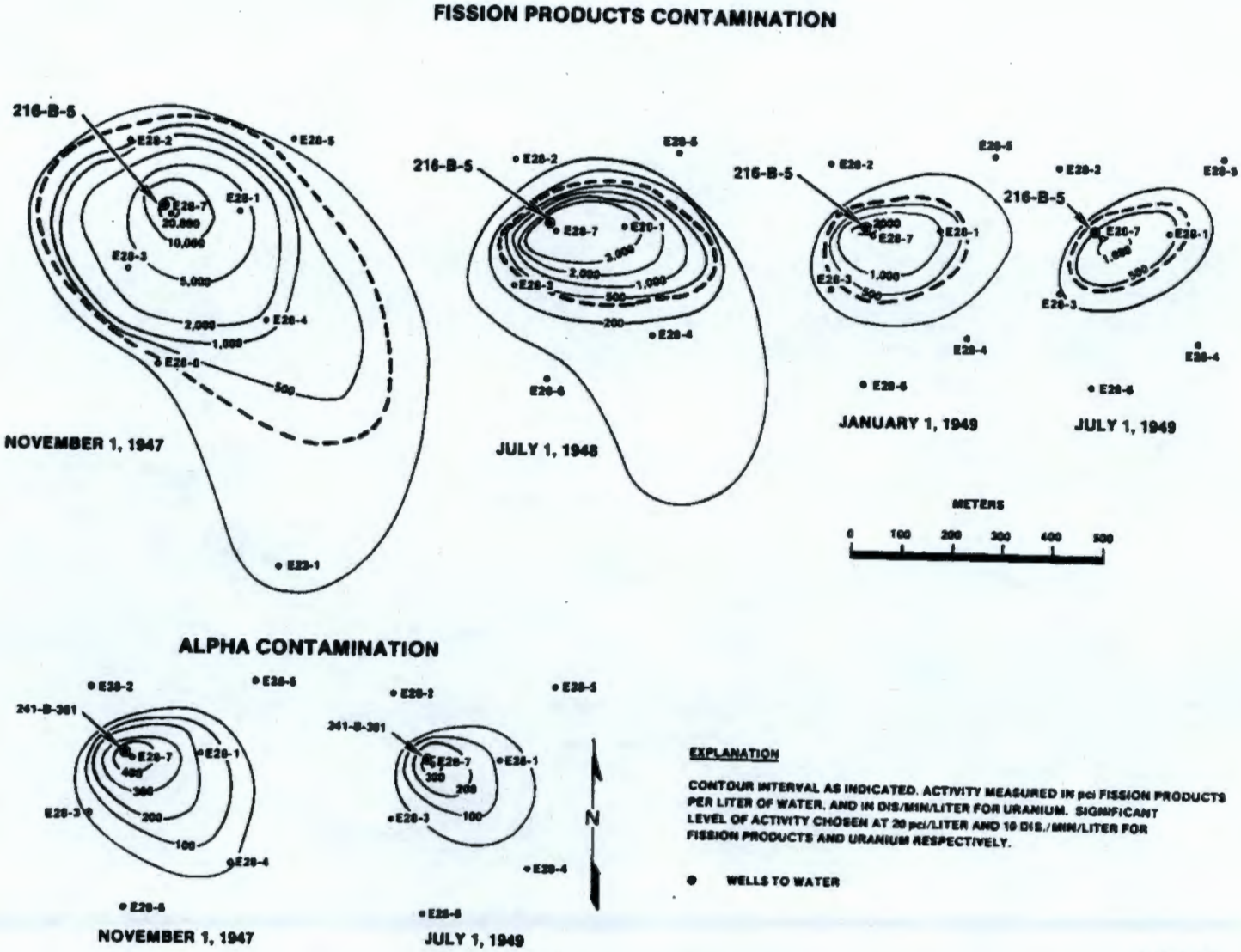


FIGURE 11. Radionuclide Distributions in the 216-B-5 Reverse Well (Brown and Ruppert, 1950).

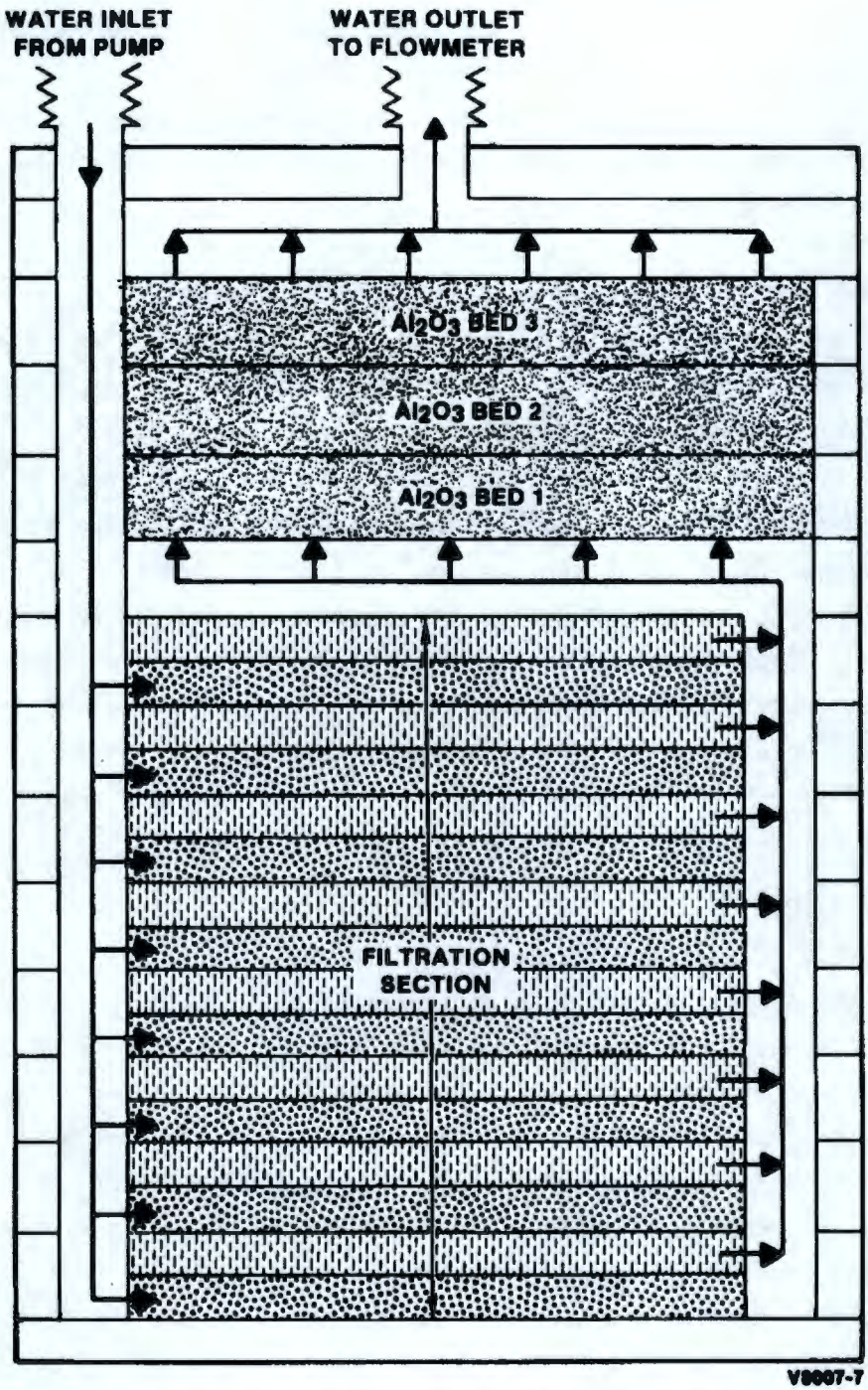


FIGURE 12. The Large Volume Water Sampler (Weimer, 1978).

216-B-5 REVERSE WELL CHARACTERIZATION PLAN

The primary objective of this study was to determine the distribution of radionuclides sorbed on the sediments around the 216-B-5 reverse well. Additional work was also performed to determine radionuclide concentrations in the ground water and the quantity of plutonium retained in the 241-B-361 settling tank.

METHODS AND MATERIALS

In order to determine the distribution of radionuclides sorbed on the sediments, five wells were drilled and one well was deepened. The locations of these wells are shown in Figure 13. Two wells, 299-E28-73 and 74, were drilled to a depth of 12.2 m on the north and south sides of the 241-B-361 settling tank to determine if the tank had leaked any radioactive liquid waste into the surrounding sediments. Well 299-E28-7 was deepened to basalt and wells 299-E28-23, -24 and -25 were drilled to basalt. The four deep wells were drilled to basalt in order to determine radionuclide distributions around the reverse well. The deep wells were drilled along a northwest-southeast transect because this was the reported direction of ground water flow in the area at the time waste was discharged to the reverse well.

Well Drilling

All wells drilled for this study were drilled using cable tool techniques and a drive barrel sampler (Price et al., 1979). When drilling in zones containing contaminated sediment, a temporary plastic "greenhouse" was constructed around the well head and all cables and drilling tools leaving the "greenhouse" were surveyed for radioactive contamination and cleaned if found to be contaminated. The "greenhouse" served as the outer containment to prevent release of radioactive material to the surrounding environment. The "greenhouse" was constructed to allow the driller to work outside the greenhouse while sampling personnel worked inside the "greenhouse" cleaning the cable and tools as they were lifted out of the well and collecting sediment samples. A split barrel sampler with a durable drive shoe and a spring steel sample retainer was used to drill through cobble

material below the water table. The drive shoe enabled the sampler to pass through cobble material without bending and the sample retainer prevented water saturated samples from falling out of the sampler.

Sediment Sampling

Sediment samples were collected throughout the entire length of each well at the time of drilling. These samples were then used to develop geologic cross sections and moisture profiles, and analyzed for radioactive contaminants. In the uncontaminated portion of each well, as determined using field survey instruments, two sediment samples were collected for moisture determinations every 0.8 m and two 500 mℓ samples were collected every 1.5 m for storage in a sediment library. Both types of samples were also collected at noticeable changes in sediment type or moisture content. In areas where radioactive contamination was detected using field survey instruments, sediment samples were collected at ∿0.6 m intervals. Contaminated sediment samples were subsampled and packaged for shipment at the drilling site. Subsamples were obtained from a well mixed sample (∿3 kg) by cone and quartering inside double plastic bags. From each contaminated sample collected, four ∿50 g subsamples were placed in plastic vials and two ∿500 g subsamples were placed in plastic, 500 mℓ bottles. The small subsamples were analyzed for $^{239-240}Pu$, ^{241}Am, ^{90}Sr, and gamma emitting radionuclides. The larger samples were used for gamma energy analyses (GEA) when a large sample size was required to detect low-level activity. The larger samples were also stored for possible future use.

Analytical Procedures

Granulometric Analyses. All uncontaminated sediment samples collected from the wells around the 216-B-5 reverse well were dry sieved using a Rotap shaker (Fecht and Price, 1977). A summary of these results was presented in Table 2. Approximately 150 g samples were shaken through a nest of 20.3-cm-diameter sieves. Nine size fractions, corresponding to the eight smallest particle sizes presented in Table 4, were collected. The silt and clay fraction in Table 4 was divided into two fractions which is why nine size fractions are reported in Table 2. These data were then used to develop geologic cross sections delineating the

major sediment lithologies. Prior to sieving, sediment samples were stored in glass jars with a mouth diameter of ~7 cm. Therefore, the quantity of material >7 cm was estimated at the time of drilling and reported in the well logs.

TABLE 4. Particle Size Nomenclature.

Particle Designation	Particle Diameter, mm
Boulder*	>256
Cobble*	
Large	256 - 128
Small	128 - 64
Pebble*	
Very Coarse	32 - 16
Coarse	32 - 16
Medium	16 - 8
Fine	8 - 4
Very Fine	4 - 2
Sand	
Very Coarse	2 - 1
Coarse	1 - 0.5
Medium	0.5 - 0.25
Fine	0.25 - 0.125
Very Fine	0.125 - 0.0625
Silt and Clay	<0.0625

*Gravel

Plutonium and Americium Analyses

Two laboratories, Rockwell Hanford Operations (Rockwell) and Eberline Instrument Corporation (Eberline) analyzed the sediment samples for $^{239-240}Pu$ and ^{241}Am. Both laboratories utilized a chemical extraction to remove the plutonium and americium from the sediment. This was followed by separation of plutonium from americium, analysis of plutonium by alpha energy analysis (AEA), and analysis of americium by AEA or GEA.

The Rockwell laboratory extracted plutonium and americium from the sediment with a mixture of concentrated nitric and hydrochloric acids. The sediment-acid mixture was boiled for one hour, cooled, and filtered. Plutonium and americium were precipitated and separated from solution, the precipitate dissolved, and then plutonium was separated from other actinides using an ion exchange separation. Plutonium was electrodeposited on a stainless steel planchet and analyzed by AEA. Americium was analyzed by GEA.

The Eberline procedure involved complete dissolution of the sediment sample in nitric and hydrofluoric acids. Plutonium and americium were separated using an ion exchange column and then electroplated on stainless steel planchets. The radionuclides were then analyzed by AEA. This technique is similar to that presented by Nessman et al. (1977).

Strontium Analyses

All ^{90}Sr analyses were conducted by Rockwell using the same chemical extraction as for plutonium and americium. The ^{90}Sr was separated from the extracted solution and beta assayed.

Gamma Energy Analyses

All analyses for gamma emmitting radionuclides were conducted by Rockwell. The samples were analyzed using a system consisting of three lithium drifted germanium (Ge(Li)) detectors and a 4000 channel analyzer. Samples were analyzed in plastic 20 or 500 mℓ containers depending on the radionuclide concentration.

Radionuclide Analyses of Water Samples

Water samples were filtered through a 0.1 μ filter prior to analysis. Analyses were conducted in the same manner as the sediment samples except the extraction step was not required.

Gamma Radiation Logging

Six wells around the 216-B-5 reverse well were logged in 1974 for gamma radiation. This work was performed by PNL using a Gearhart-Owen Model 3200 logging system. The system is based on a thallium-activated,

sodium iodide phospher crystal which produces photons when excited by gamma radiation. The photons are converted to an electrical current which is then used as a measure of the intensity of the gamma radiation reaching the detector. The system is qualitative and is used only for comparing relative levels of activity in a well at different times or depths in the well. A more detailed description of this system and earlier systems is presented in Fecht et al. (1977).

Sampling of the 241-B-361 Settling Tank

Two sludge samples were collected from the 241-B-361 settling tank using a ~0.5 m long split tube sampler. The entire sampler was transported to the laboratory before the sample was removed from the sampler.

The tank was also assayed using an in situ neutron activation technique described by Brodzinski (1979). Copper foils (plates) were suspended in a fiberglass access tube that extended from ground surface, through a riser in the settling tank, to the bottom of the tank. This is shown in Figure 14. The copper foils are suspended in the neutron field generated by fissioning plutonium (transuranic elements) in the sludge. The copper undergoes the reaction $^{63}Cu\ (n,\gamma)\ ^{64}Cu$. After a minimum 13 hour exposure, the foil is removed and the quantity of gamma emitting ^{64}Cu is determined using a specially constructed, low background NaI(Tl) detector system. The quantity of plutonium is determined using a previously established calibration curve. The copper is sensitive to neutrons produced within an ~1-m sphere from which an average plutonium concentration is determined.

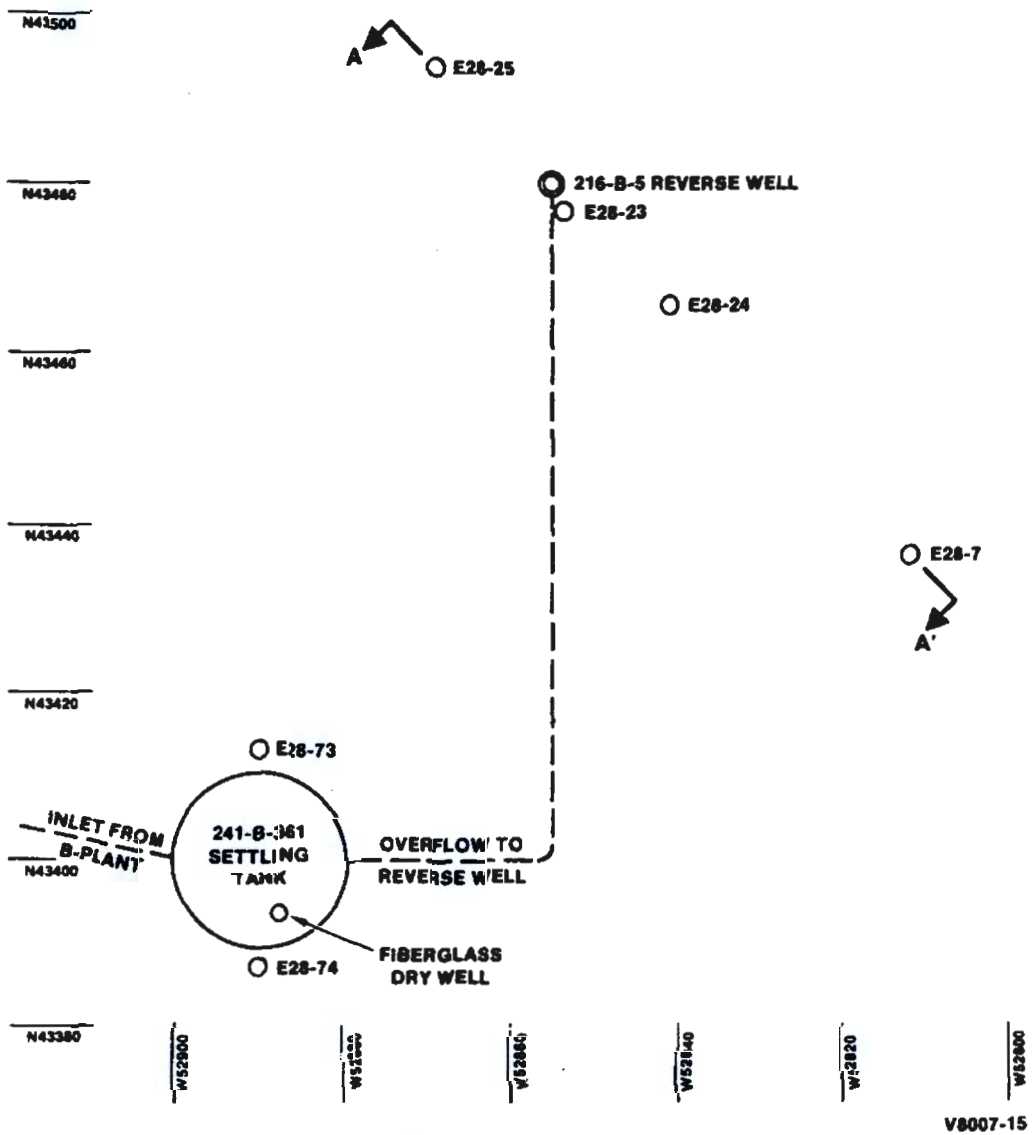


FIGURE 13. Well Locations for the Current Study.

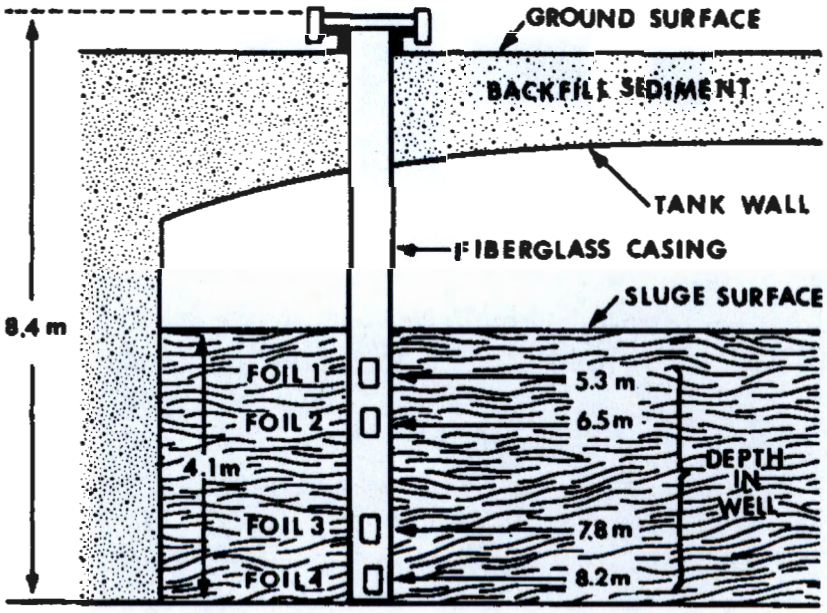


FIGURE 14. Foil Positions in the 241-B-361 Settling Tank.

RESULTS AND DISCUSSION

RADIONUCLIDE CONCENTRATIONS IN THE SEDIMENT

Radionuclide analyses of the sediment samples collected during drilling are graphically presented beside the geologic logs in Figures 15 through 18. The numerical results from which the concentration profiles were developed are presented in Appendix A. Cesium-137 was the only gamma-emitting fission product detected. The purpose of these figures is to show how radionuclide concentrations varied with changes in the sediment type and with changes in position of the water table.

The presence of cesium in the silt layer at approximately 78 m below the ground surface is indicative of sediment control of the distribution of radionuclides. A peak in cesium activity occurs in this silt layer in wells 299-E28-23 and -25 (Figures 16 and 18). The silt layer becomes more coarse in well 299-E28-24 (Figure 18), which may be the reason why cesium was not detected in this well at that position. The waste flowed laterally from the reverse well through the silt layer under conditions of unsaturated flow.

The waste remained in the silt layer and did not flow into the more coarse sediments above and below this layer because of the physical principles controlling movement of water in unsaturated sediments. Water flows through sediment as a result of potential energy gradients. The potentials primarily responsible for moisture flow in the unsaturated Hanford sediments are the matric potential (Ψm) and the gravitational potential (Ψg) (Baver et al., 1972; Jones, 1978). The gravitational potential is due to the position of the water in the earth's gravitational field and is determined by elevation in the sediment column. The matric potential is due to forces of attraction between the water and sediment particles and the surface tension of the water. Therefore, the matric potential is a function of the sediment type and moisture content of the sediment. The effect of sediment type and mositure content on the matric potential is presented in Figure 19. The curves presented in Figure 19 are desorption curves. By convention, the matric potential is negative and ranges from zero in a saturated sediment to a large negative value

in a dry sediment. Note in Figure 19 that the desorption curve for the clay is always to the right of the desorption curve for the sand. This means that, at the same moisture content, the clay will have a lower matric potential than the sand. This also means that, at the same matric potential (no potential gradient, therefore, no moisture flow), the clay will contain more water than the sand. Water flows from higher potential energy to lower potential energy. Therefore, water would flow into the silt layer (lower ψ_m) before it flowed into the more coarse surrounding sediment layers. The waste would not flow from the silt layer until the moisture content of that layer reached a high enough level to produce a matric potential that was greater than the matric potential of the surrounding sediments. This apparently did not occur because only the silt layer contained radioactive contamination in the vicinity of the 78-m depth.

Figures 16, 17, and 19 also show the influence of the position of the water table on the radionuclide concentration. The figures indicate peak radionuclide concentrations at the position of the water table in 1948. Peaks in strontium, cesium, and plutonium concentrations correspond to the position of the water table in 1948 in Figure 16. This indicates that the water released from the reverse well did not mix readily with the ground water and flowed laterally at the water table. The role of the present water table in determining the current radionuclide distribution is hard to define. Figure 16 indicates that concentrations of the four radionuclides reported greatly increase at the position of the present water table, while Figures 15, 17, and 18 do not indicate this pattern. It is likely that the reverse well filled with waste to the position of the 1948 water table or higher while it was being used. The volume of the reverse well in the 3-m interval between the 1948 water table position and the current water table position is only ~100 ℓ. Since the waste was discharged to the reverse well after the receiving tank in B Plant filled, large volumes of waste were discharged in batches. Therefore, the waste probably filled the interval between the two positions of the water table and flowed laterally through the perforations into the unsaturated sediments. Data for well 299-E28-24 (Figure 17)

shows the presence of cesium at the 82-m depth. This indicates that the waste may have been standing at the 82-m depth, or higher. Figure 16 also shows detectable levels of cesium and strontium at this depth. Therefore, the increase in activity at the present water table may be due to the lateral flow of waste from the reverse well into the unsaturated sediments at the time the reverse well was used.

Radionuclide concentrations for sediments collected from wells 299-E28-73 and -74 are presented in Appendix A. These results indicate that the sediments around the 241-B-361 settling tank are not contaminated and therefore, the settling tank has not leaked.

RADIONUCLIDE DISTRIBUTION IN THE SEDIMENT

The radionuclide concentration data presented in the previous section were used to map radionuclide distributions around the reverse well. The radionuclide distributions are presented in Figures 20 through 23. The distributions were drawn on a vertically exaggerated portion of the geologic cross section A-A' presented in Figure 6.

Figure 20 presents the field detectable beta-gamma activity. The influence of the silt layer at ~78 m below ground surface is indicated in this figure. The direction of ground water flow is also indicated by this figure. There was no field detectable beta-gamma activity below the water table in well 299-E28-25, 6 m from the reverse well, but well 299-E28-7, 19 m from the reverse well, did contain beta-gamma activity. This is consistent with a southeast direction of ground water flow. The cross section from A to A' is in the southeast direction as shown in Figure 13.

Figure 21 presents the ^{137}Cs distribution as determined using laboratory analyses. This figure shows the influence of the silt layer at 78 m below ground surface and the 1948 water table at ~90 m on the ^{137}Cs distribution. The highest ^{137}Cs concentration, 51.3 nCi/g, was detected in well 299-E28-23 at 86.6 m. The 10 nCi/g isopleth extends at least 6 m downflow to well 299-E28-24, but less than 6 m upflow to well 299-E28-25.

The ^{137}Cs activity which begins at 82 m below ground surface in wells 299-E28-23 and -24, indicates that the liquid level in the reverse well likely rose to the 82-m depth at times. The 0.1-nCi/g isopleth indicates that ^{137}Cs may have accumulated on the basalt surface and spread laterally along the impermeable boundary. This trend is indicated in both the upflow and downflow directions and will be discussed in the section on gamma scintillation logging.

Figure 22 presents the $^{239-240}Pu$ distribution. The plutonium distribution also shows evidence of the influence of the 1948 water table and the direction of ground water flow. The highest level of $^{239-240}Pu$ detected, 191 nCi/g, was located at a depth of 89.5 m in well 299-E28-23. This was the location of the 1948 water table. Plutonium contamination above 10 nCi/g is limited to a distance less than 6 m from the reverse well. All of the detectable plutonium contamination is below the present water table.

The waste discharged to the reverse well was alkaline, therefore, the plutonium would probably have existed as a solid in the form of a highly insoluble hydroxide polymer or oxide crystal (Cleveland, 1970), which would have sorbed onto the sediments by colloidal attraction and physical filtering. This mechanism was suggested by Ames (1974) in his detailed examination of plutonium sorption in sediments from the 216-Z-9 crib. This mechanism of plutonium retention by the sediments would account for the rapid decrease in plutonium concentration with distance from the reverse well. Other reports also note the large sorption capacity of the Hanford sediments for plutonium (Hajek, 1966; Healy, 1946; Rhodes, 1952; Routson, 1974; and Bensen, 1960).

Figure 23 presents the ^{90}Sr distribution. This distribution is similar to the other distributions in that it shows the influence of the 1948 water table and the direction of ground water flow. The lowest isopleth concentration presented was 0.1 nCi/g because this was the lowest concentration that the Rockwell laboratory could consistently detect. In comparing the ^{137}Cs and ^{90}Sr distribution, the volume of sediment contaminated by ^{90}Sr is less than that contaminated by ^{137}Cs. This is generally

not the case when ^{137}Cs and ^{90}Sr are released at the same activity because ^{137}Cs generally sorbs to greater extent than ^{90}Sr (Routson, 1978; Tamura, 1962).

McHenry (1957) studied the sorption of ^{90}Sr and ^{137}Cs on Hanford sediment from waste solutions generated in the bismuth phosphate separation process. These waste solutions were the same as those discharged to the 216-B-5 reverse well. His column experiments, using Hanford sediment, showed that the ratio of effluent ^{90}Sr concentration to influent ^{90}Sr concentration (C/C_0) was 0.013 after passage of five column volumes while the C/C_0 for ^{137}Cs was 0.25. This indicated that ^{90}Sr sorbed much more strongly than ^{137}Cs. McHenry attributed the greater ^{90}Sr sorption to the presence of phosphate (PO_4^{-3}) which would form a precipitate with ^{90}Sr (Ames et al., 1958).

Ames (1960) also showed that ^{90}Sr would also sorb strongly by means of a replacement reaction. Phosphate contained in the waste solution would form the highly insoluble mineral apatite. The calcium contained in this mineral can be replaced by ^{90}Sr resulting in ^{90}Sr occupying a position previously held by calcium. The precipitation of a strontium-phosphate solid phase is important because a large amount of ^{90}Sr remained in the 241-B-361 settling tank. This will be shown in the following section.

241-B-361 SETTLING TANK SLUDGE ANALYSIS

The 241-B-361 settling tank was sampled to determine radionuclide concentrations in the sludge for purposes of decommissioning the tank and also to determine what proportion of the estimated plutonium inventory remained in the tank. The results of analyses of sludge samples collected from the settling tank are presented in Table 5. This information indicates that the solids remaining in the tank are predominantly bismuth phosphate, which is consistent with the fact that the separations process used at B Plant, at the time the reverse well was in use, was the bismuth phosphate process. The results of the neutron activation technique for in situ determination of plutonium in the settling tank are presented in Table 6.

TABLE 5. Analysis of 241-B-361 Settling Tank Sludge.

Component	Solids, wt%	Liquids
Al^{+3}	<0.06	-
Bi^{+2}	10.3	8.05 E-5 M
Fe^{+3}	1.3	2.0 E-4 M
F^{-}	0.04	1.0 E-2 M
La^{+3}	3.2	3.0 E-4 M
Mg^{+2}	0.5	<9.0 E-5 M
Mn^{+2}	3.0	<2.0 E-5 M
$NaAlO_2$	0.04	<4.05 E-4 M
Na_2CO_3	-	1.90 E-1 M
$NaNO_2$	-	3.0 E-2 M
$NaNO_3$	-	1.07 E+0 M
NaOH	-	2.4 E-1 M
Na_3PO_4	-	1.0 E-2 M
Na_2SO_4	-	4.0 E-2 M
Ni^{+2}	-	<5.2 E-5 M
NO_3^{-}	2.0	-
PO_4^{-3}*	3.4	-
SiO_4	0.4	2.0 E-3 M
SO_4^{-2}	0.2	-
^{239}Pu	3.4 µCi/g	6.1 E-7 µCi/mℓ
^{137}Cs	1.4 µCi/g	2.5 E-3 µCi/mℓ
$^{89-90}Sr$	23 µCi/g	3.1 E-5 µCi/mℓ
^{238}U*	1.1 E-5 g/g	8.4 E-6 g/mℓ

*All valences.

Note: No pumpable liquids contained in the tank.
Particle Density - 3.93 g/cm^3
Bulk Density - 1.29 g/cm^3
Moisture Content - ~72 wt%
Volume - 1.20 E+5 ℓ

TABLE 6. Results of In Situ, Neutron Activation Analyses in the 241-B-361 Settling Tank.

Foil	Plutonium Concentration, nCi/g
1	54
2	555 ± 22
3	1430 ± 50
4	1085 ± 64

The results from both methods were used to calculate the quantity of plutonium contained in the settling tank. The sludge analyses indicate that there is ~2.4 kg of plutonium contained in the settling tank and the neutron activation technique indicates there is ~1.6 kg of plutonium. These two values are surprisingly close for two such different methods of estimating the plutonium concentration. These values indicate that approximately half of the estimated 4.3 kg of plutonium discharged to the system was retained in the 241-B-361 settling tank and the rest overflowed into the 216-B-5 reverse well.

There are other important facts to note in Table 5. Even though the plutonium concentration of the solids is 3.4 μCi/g, the solution concentration of plutonium, 6.1×10^{-7} μCi/mℓ, is less than the MPC for an uncontrolled zone, 5×10^{-6} μCi/mℓ, by an order of magnitude. Another important fact is the relationship between ^{137}Cs and ^{90}Sr concentrations in the solids and liquids. The ^{90}Sr concentration in the solids exceeds the ^{137}Cs concentration by ~1.5 orders of magnitude while the ^{137}Cs concentration in the liquids exceeds the ^{90}Sr concentration by almost 2 orders of magnitude. This indicates that ^{90}Sr precipitates from solution under the actual waste conditions much more than ^{137}Cs. Therefore, a larger portion of the ^{137}Cs inventory overflowed to the reverse well than the ^{90}Sr inventory. This could be part of the reason for the ^{137}Cs distribution being more extensive than the ^{90}Sr distribution shown in Figures 21 and 23.

The discovery that a large portion of the ^{137}Cs inventory was discharged to the reverse well, and that ^{137}Cs activity appears to have spread along the basalt surface, prompted the examination of wells around the reverse well to determine the contamination status of the sediments located near the basalt surface. This investigation was conducted using gamma scintillation logging for the total gamma activity.

GAMMA SCINTILLATION LOGGING

This work was performed to determine the contamination status of wells around the reverse well. The locations of those wells are shown in Figure 24. The total gamma profiles for six wells are presented in Figures 25 to 30. These profiles indicate the presence of low level gamma activity just above the basalt surface as did the ^{137}Cs distribution shown in Figure 21. This also means that the gamma activity has to reach these wells by flowing along the surface of the basalt. The results of gamma scintillation logging in four wells shown in Figures 25, 28, 29, and 30 shows that the gamma contamination is widespread along the basalt surface and a source of contamination other than the 216-B-5 reverse well is indicated.

The only large source of gamma contamination in the ground water in this area is a group of seven cribs (216-B-43 to 216-B-49) called the BY cribs, located ~900 m north of the reverse well (Figure 2). These cribs received ~3.4×10^7 ℓ of high salt waste containing ~13,000 Ci ^{90}Sr and ~3,800 Ci ^{137}Cs. These levels are two orders of magnitude higher than the ^{90}Sr and ^{137}Cs inventories discharged to the reverse well. Gamma logs collected previously, were studied to determine if the BY cribs could be the source of the widespread gamma contamination at the basalt surface. These logs are shown in Appendix B. These logs also indicate that the sediments located just above the basalt surface to the south and east of the BY cribs are contaminated with gamma-emitting radionuclides. The basalt surface slopes to the south from the BY cribs, and therefore, the contamination could flow south following the basalt surface. The contamination plume as drawn from total gamma logs is presented in Figure 31. The contamination level indicated by the gamma logs is low as shown by

Van Luik and Smith (1980). They report that for ^{137}Cs, the gamma detector's upper detection limit is ~10 nCi/g. At this concentration, the gamma detector peaks at ~2 x 10^6 to 4 x 10^6 counts per minute as evident in the logs for wells 299-E33-4 and -1. Since higher energy gamma radiation causes a greater response from the gamma detector, the 10 nCi/g limit is conservative for radionuclides that emit higher energy radiation than that emitted by ^{137}Cs. Therefore, the activity detected is not a significantly high level. An important observation is that the gamma activity may be migrating south. Evidence of this is indicated by the 1968 and 1976 gamma logs from well 299-E28-14 presented in Figures 32 and 33. This activity is still present in 1979, but at reduced levels from 1976 as indicated in Figure 30. This is important because it appears that a radionuclide front passed through the area. The contamination has not extended beyond well 299-E28-6, but close surveillance of this well is recommended. It is also recommended that the regional extent of this gamma plume be studied by logging selected wells using both the gamma scintillation system and a gamma spectrometer system using an intrinsic germanium detector with which in situ radionuclide analyses are possible.

GROUND WATER ANALYSIS

The radionuclide contamination of the ground water in the vicinity of the reverse well was presented in the large volume water sampling results presented in the "Past Studies" section. This work indicated that the levels of radionuclide activity were well below drinking water standards in three wells of which the closest to the reverse well was 19 m.

The work conducted by Brown and Ruppert (1950) showed how the distribution of ground water contamination changed with time. They showed that alpha contamination of the ground water was never a problem because all concentrations were at least an order of magnitude less than limit for drinking water. The beta-gamma activity plumes rapidly decreased in size with time after the reverse well was removed from service indicating that the source of activity had a short half life and remained in solution.

The lack of detectable beta-gamma activity on the sediment, even in areas where the ground water was contaminated to 20,000 pCi/ℓ, indicates that the activity was due to radionuclides that did not sorb on the sediment. This strongly suggests that a radionuclide such as ^{106}Ru was responsible for much of the activity in the early ground water contamination plumes (Routson, 1974).

Data from routine ground water monitoring programs are presented in Appendix D. The data presented are of questionable quality because of inadequate sampling systems. An example of an inadequate monitoring structure was well 299-E28-7. The pump used to collect samples for analysis was removed from the well in 1978 and was found to be contaminated with 5,000 counts per minute beta-gamma activity. This contamination was contained on rust inside the pump. When the well was deepened, the old well casing was removed and replaced with new casing. The lower 5 m of the casing was contaminated with 3,000 counts per minute beta activity (could not penetrate cloth tape). Tamura (1963) showed that two iron oxide containing minerals, goethite ($HFeO_2$) and limonite ($Fe_2O_3 \cdot xH_2O$), had a high specific sorption capacity for strontium. Therefore, the rust (iron oxide) from the iron casing would be a site for concentrating the ^{90}Sr. The presence of beta activity on the rust from the casing and little or no strontium in the sediment, indicates that the ^{90}Sr has been concentrated in the rust. The presence of this contamination could alter the solution chemistry producing erroneous radionuclide analyses. To prevent this from happening in the future, the wells drilled for this project will be developed to provide a system from which representative water samples can be collected. Stainless steel screen will be placed in each well, a sand pack added, and the casing pulled back to expose the screen. Representative water samples may then be collected from these wells to determine the radionuclide concentrations in the ground water in the immediate vicinity of the contamination plume.

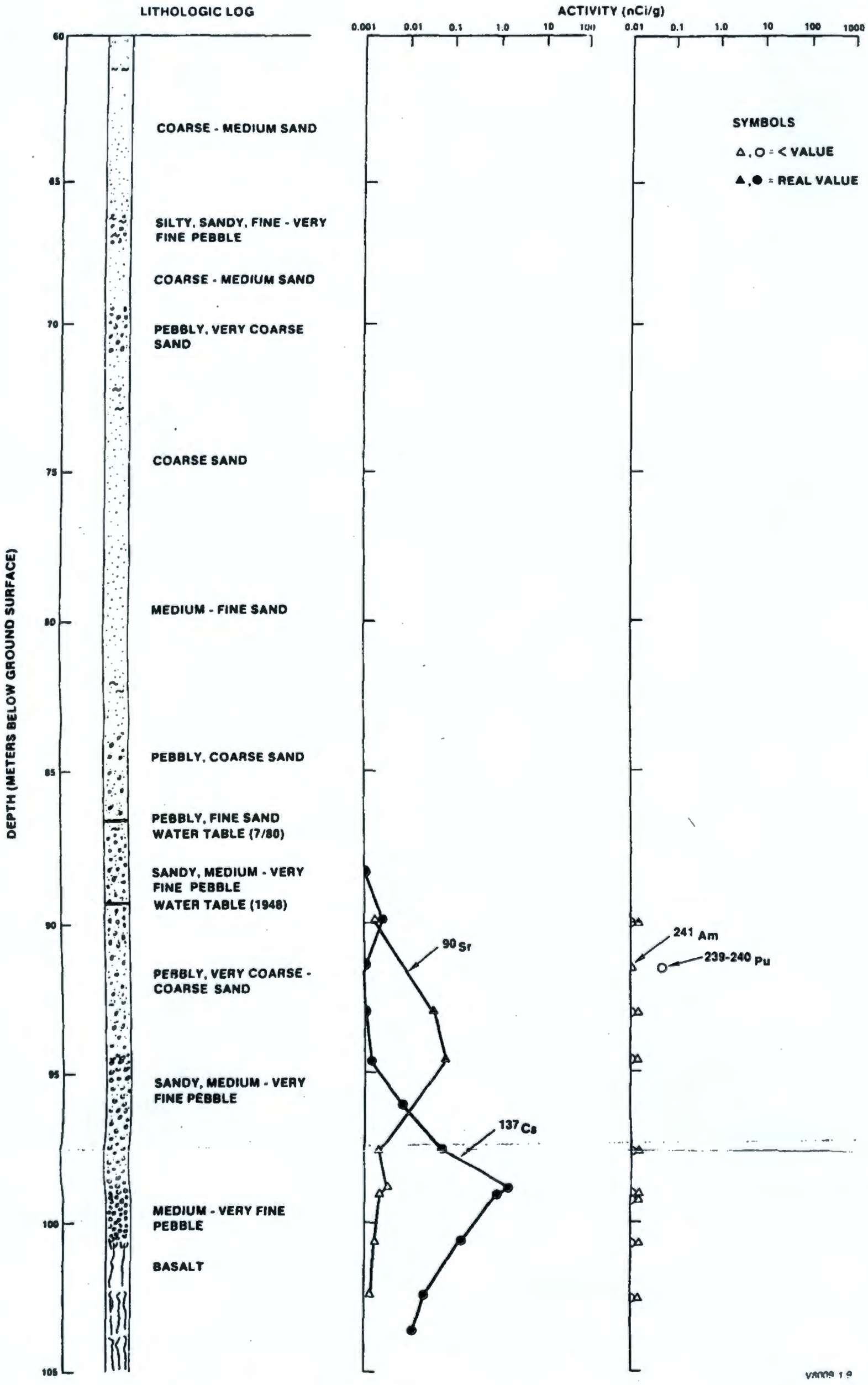


FIGURE 15. Geologic and Radionuclide Activity Logs for Well 299-E28-7.

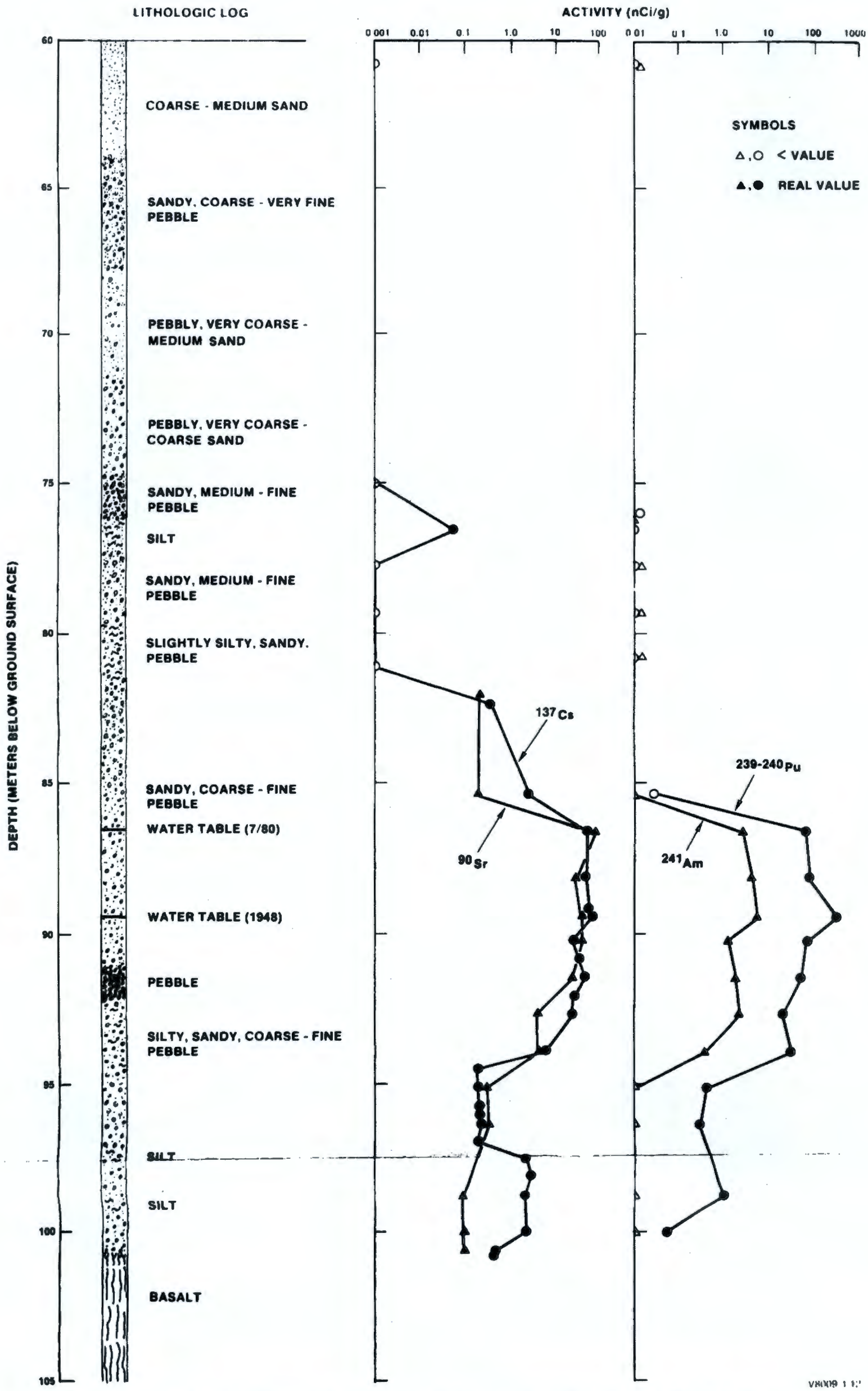


FIGURE 16. Geologic and Radionuclide Activity Logs for Well 299-E28-23.

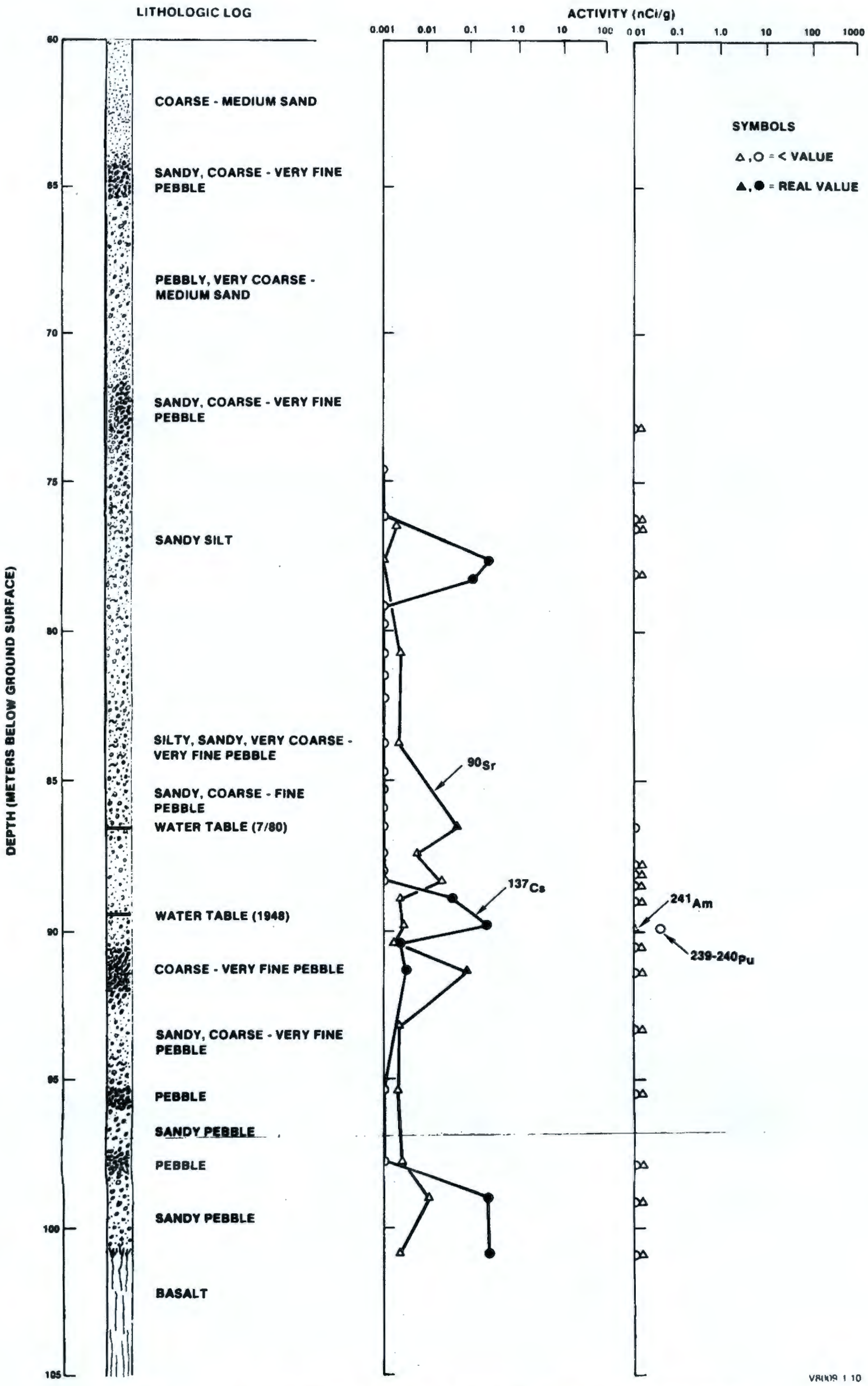


FIGURE 17. Geologic and Radionuclide Activity Logs for Well 299-E28-24.

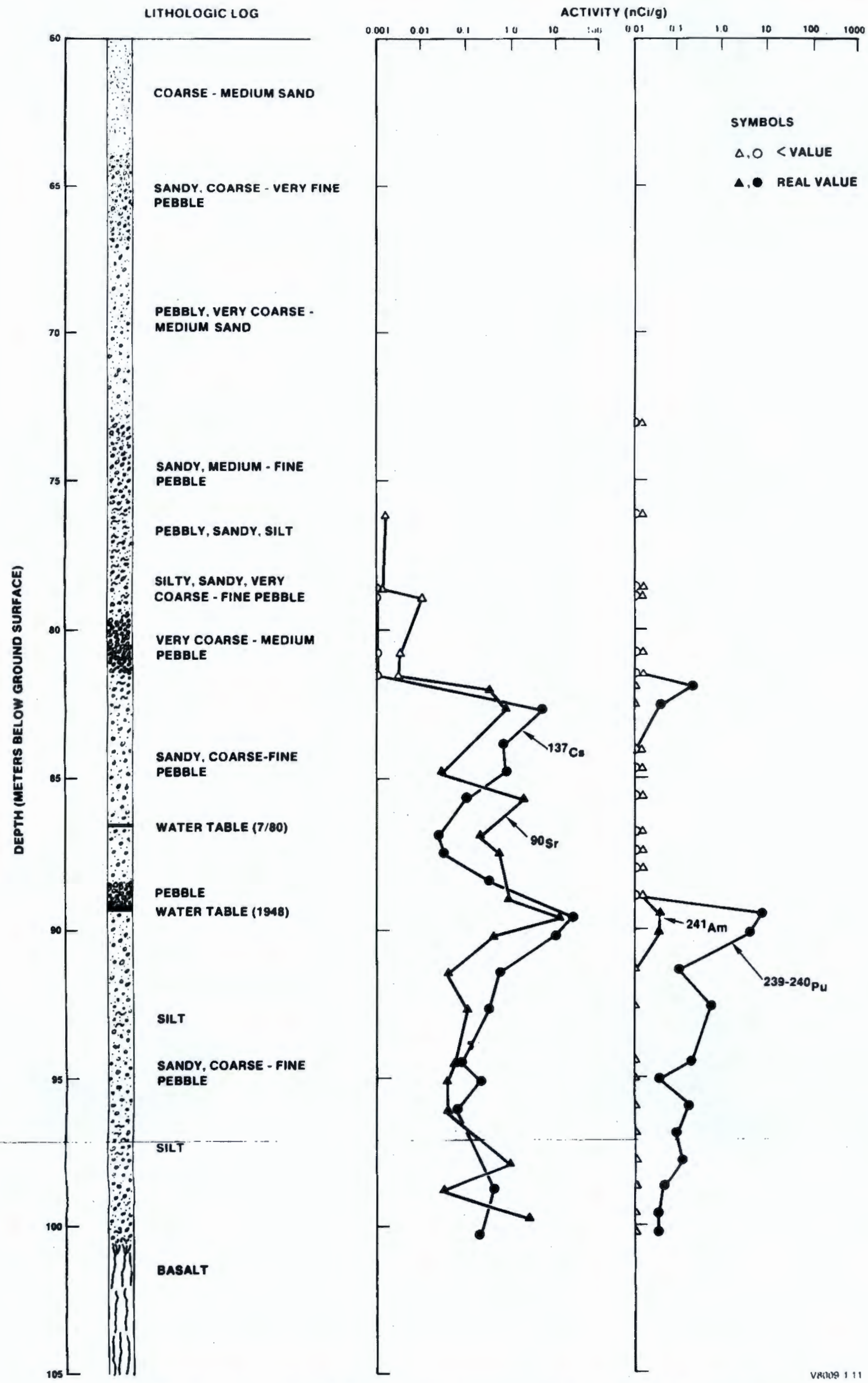


FIGURE 18. Geologic and Radionuclide Activity Logs for Well 299-E28-25.

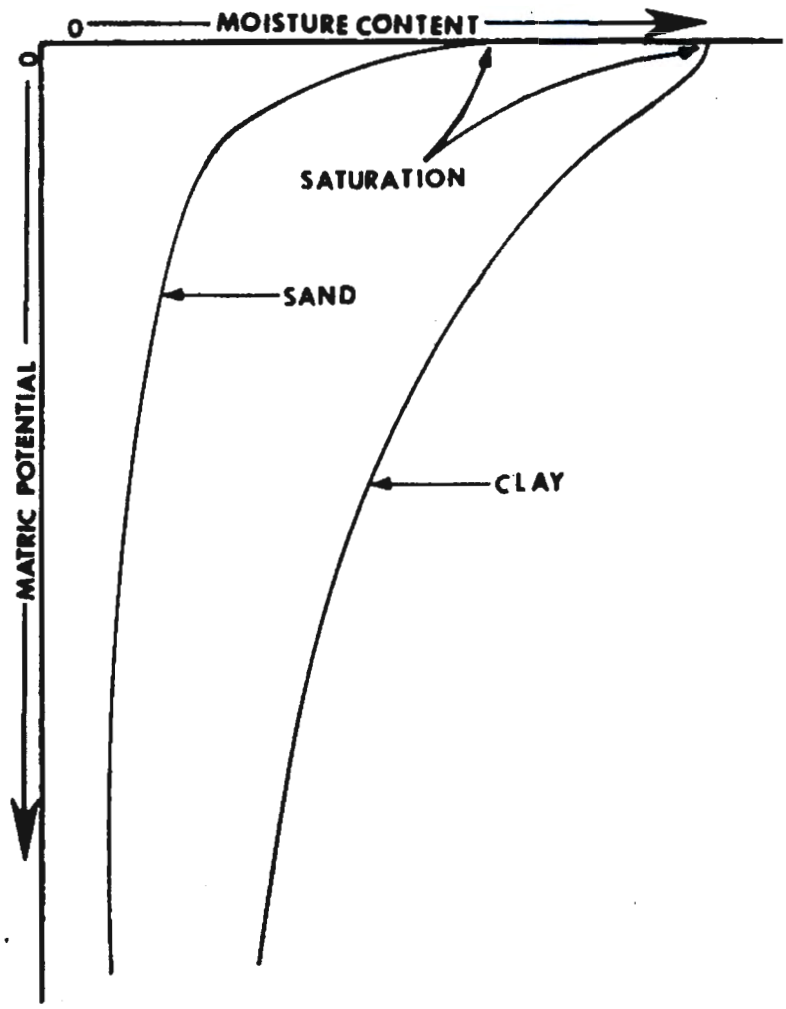


FIGURE 19. Hypothetical Desorption Curves.

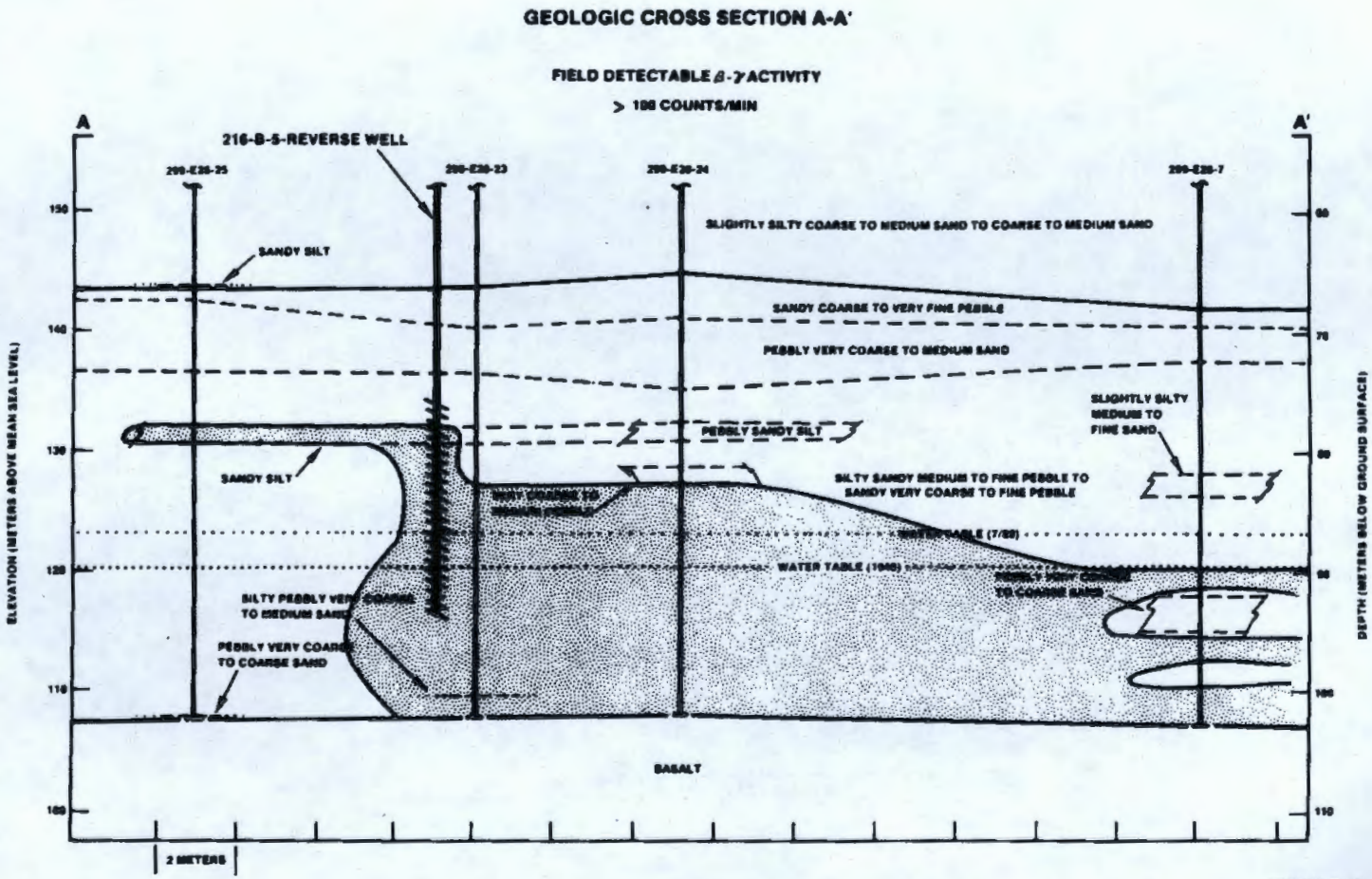


FIGURE 20. Field Detectable Beta-Gamma Distribution.

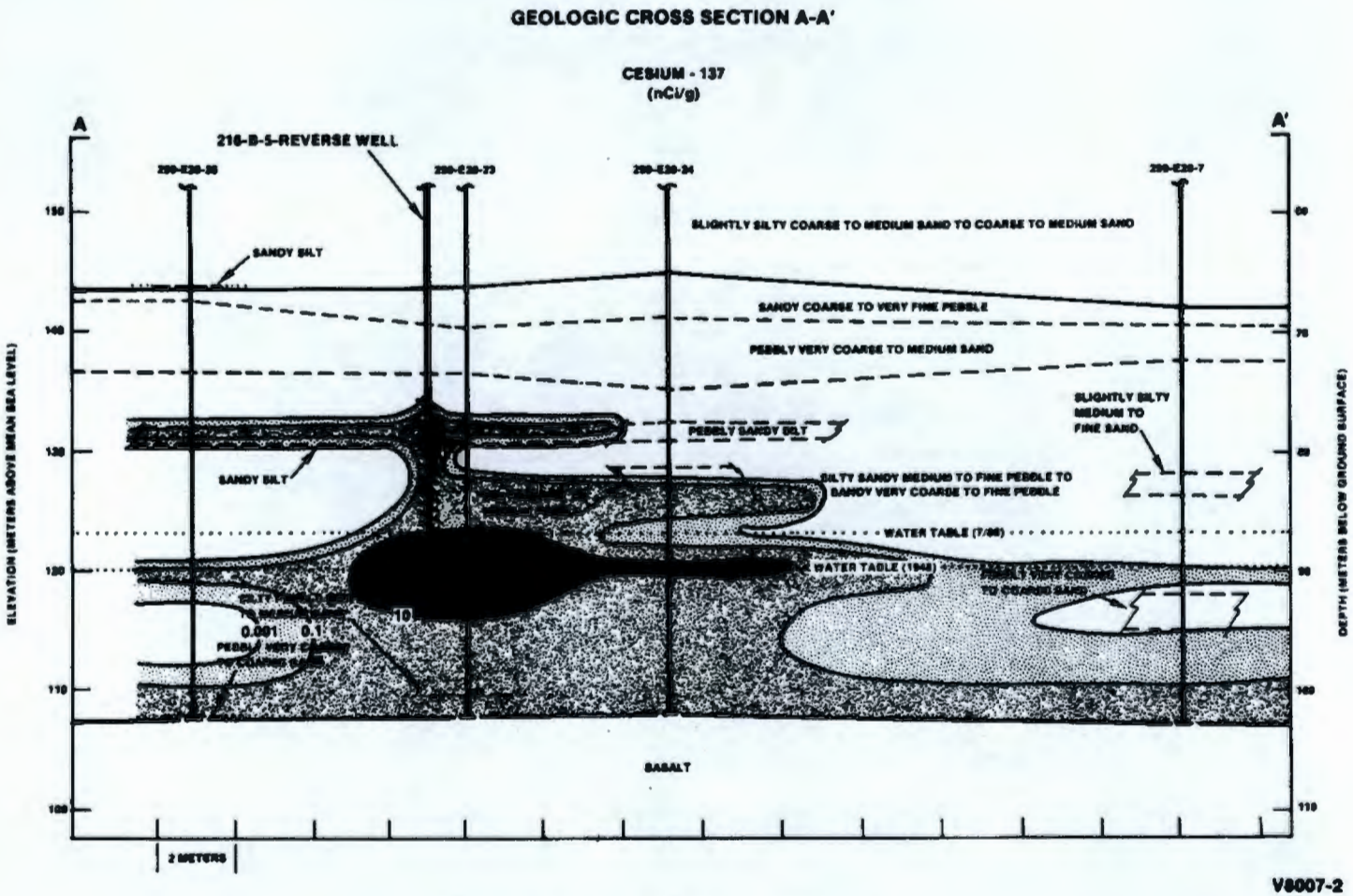


FIGURE 21. ^{137}Cs Distribution.

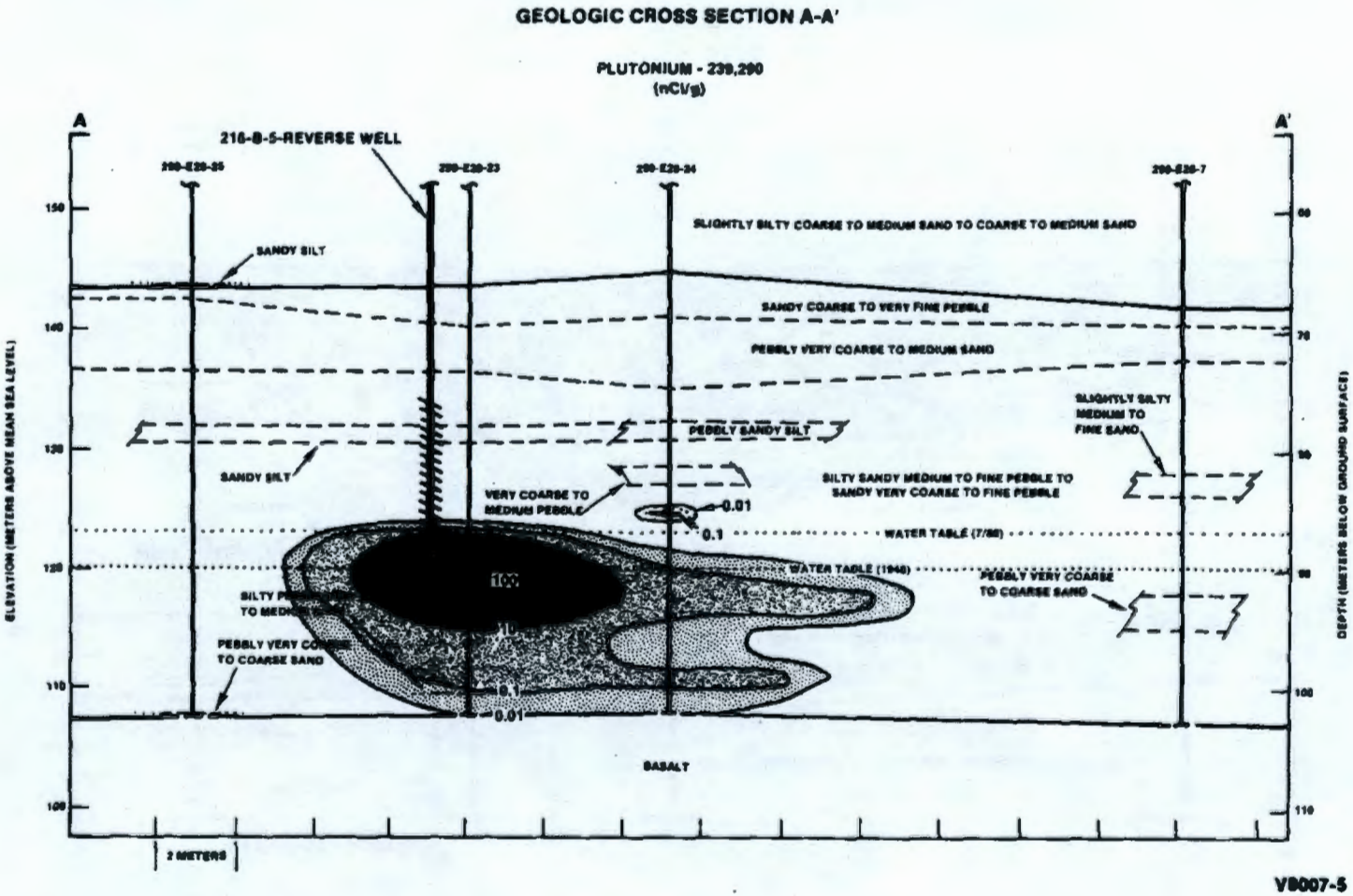


FIGURE 22. 239-240Pu Distribution.

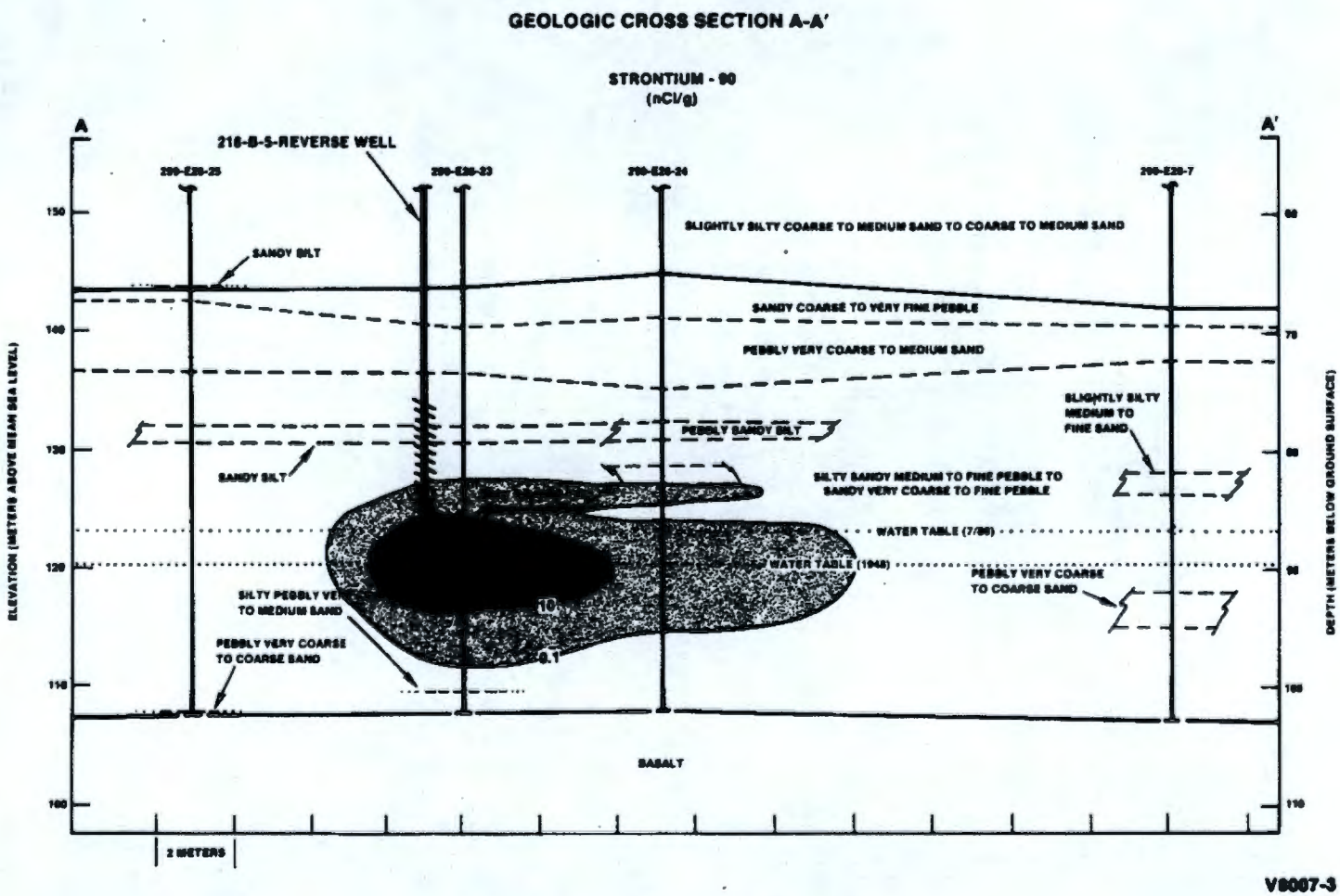


FIGURE 23. ^{90}Sr Distribution.

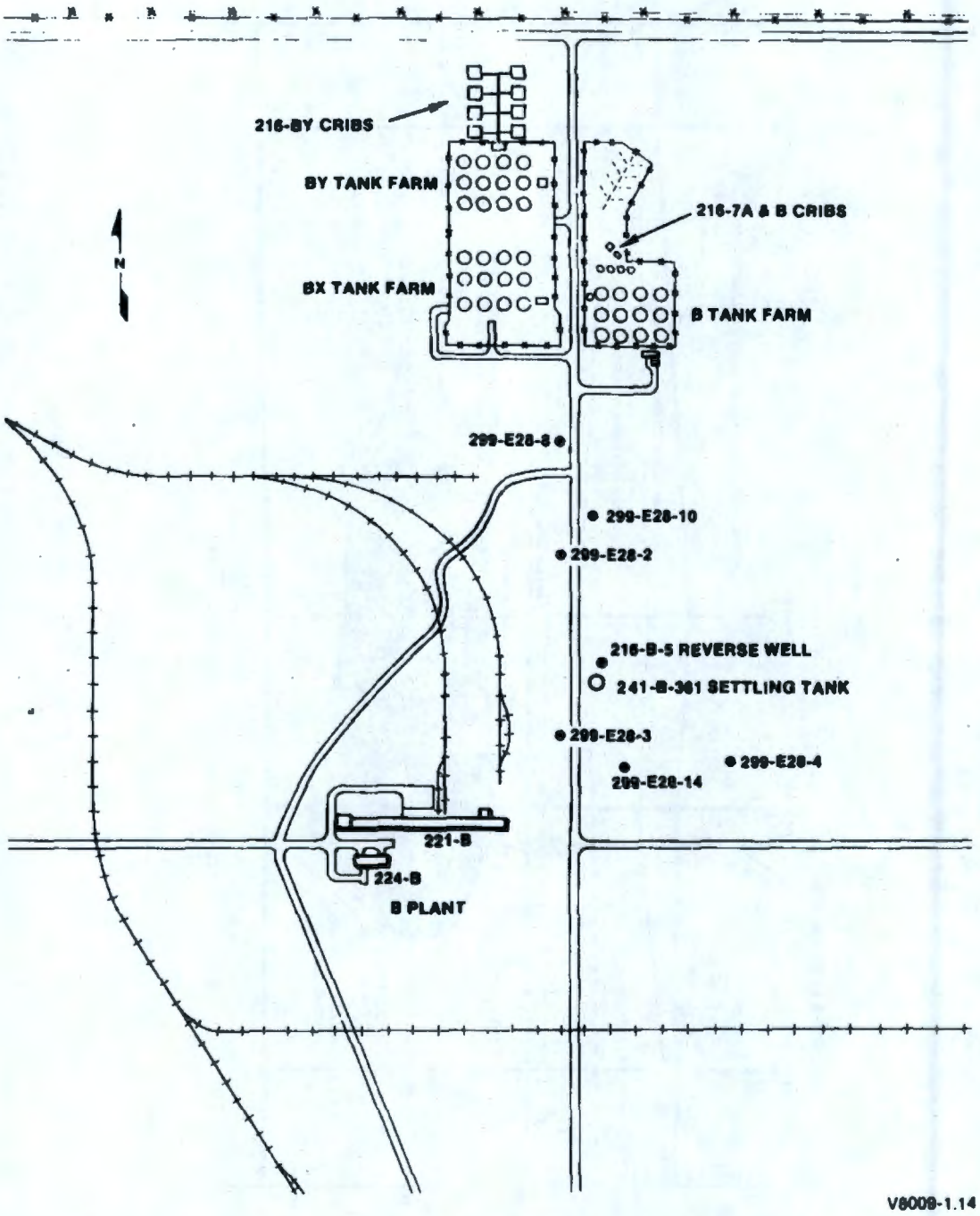


FIGURE 24. Location Map for Well Logged for Total Gamma Activity.

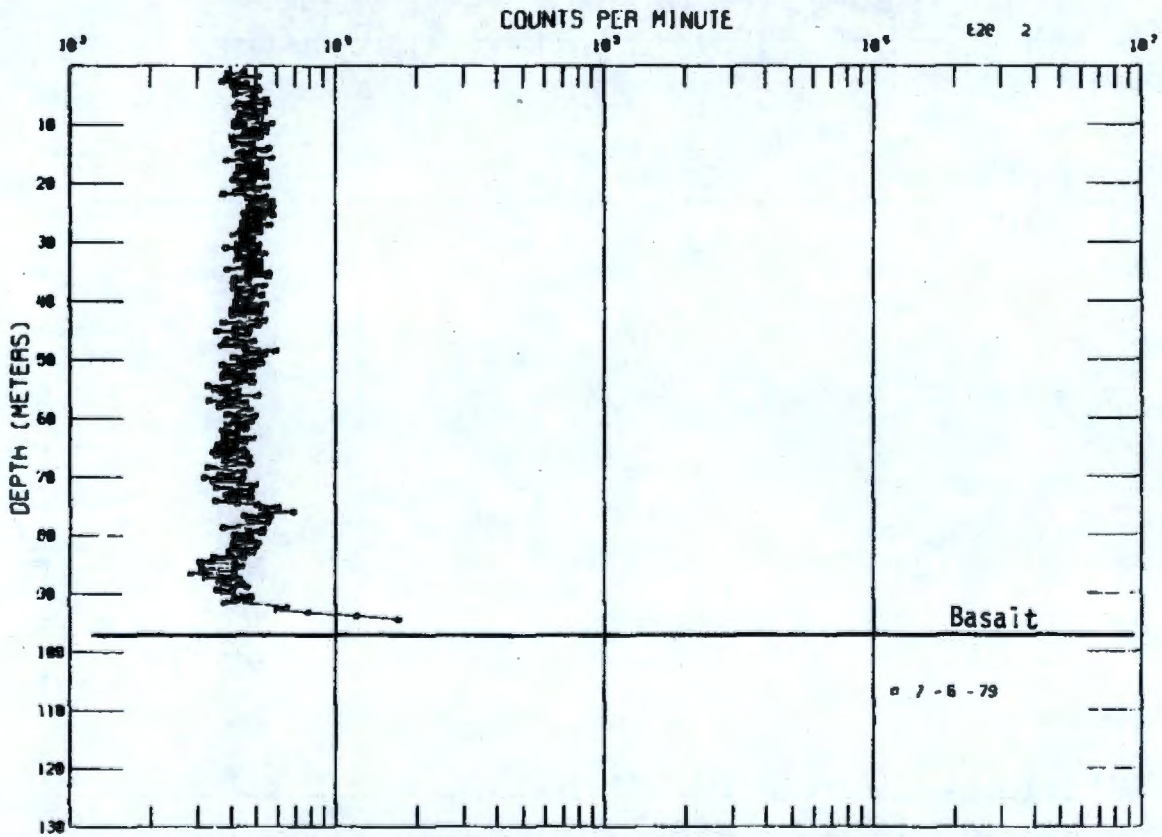


FIGURE 25. Gamma Activity for Well 299-E28-2.

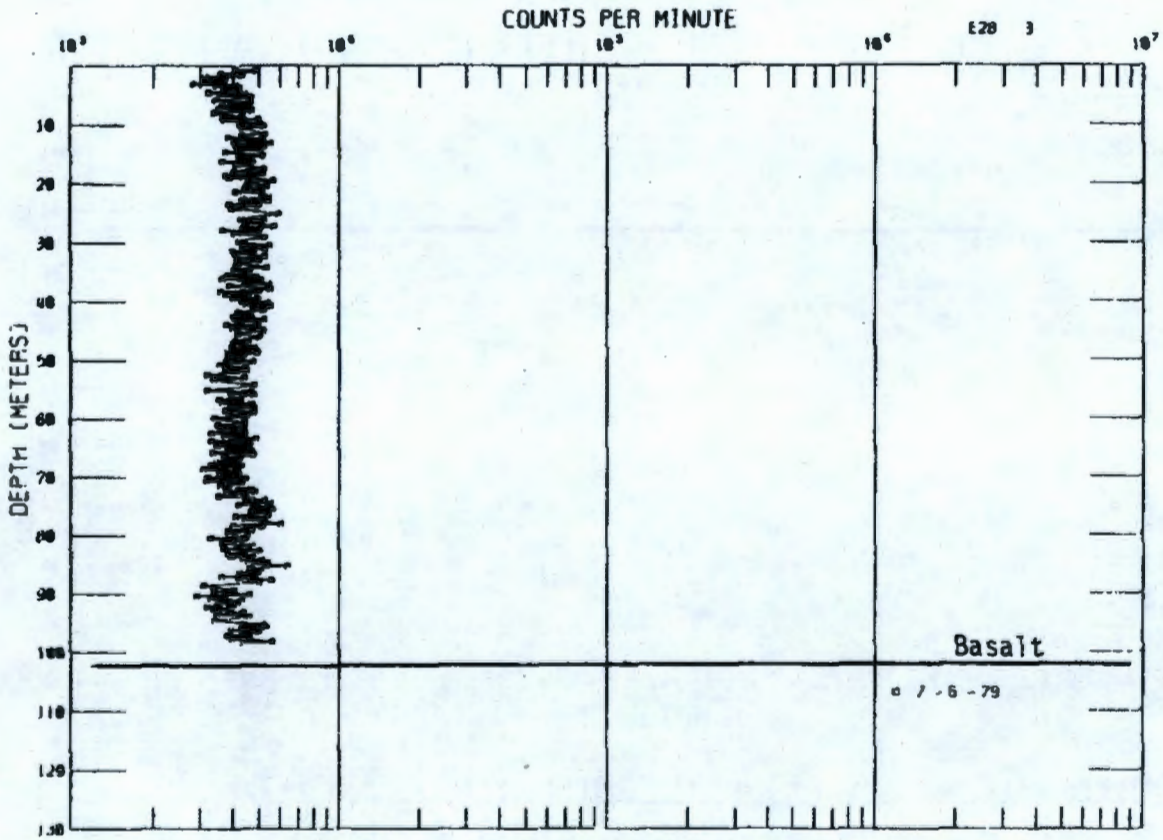


FIGURE 26. Gamma Activity for Well 299-E28-3.

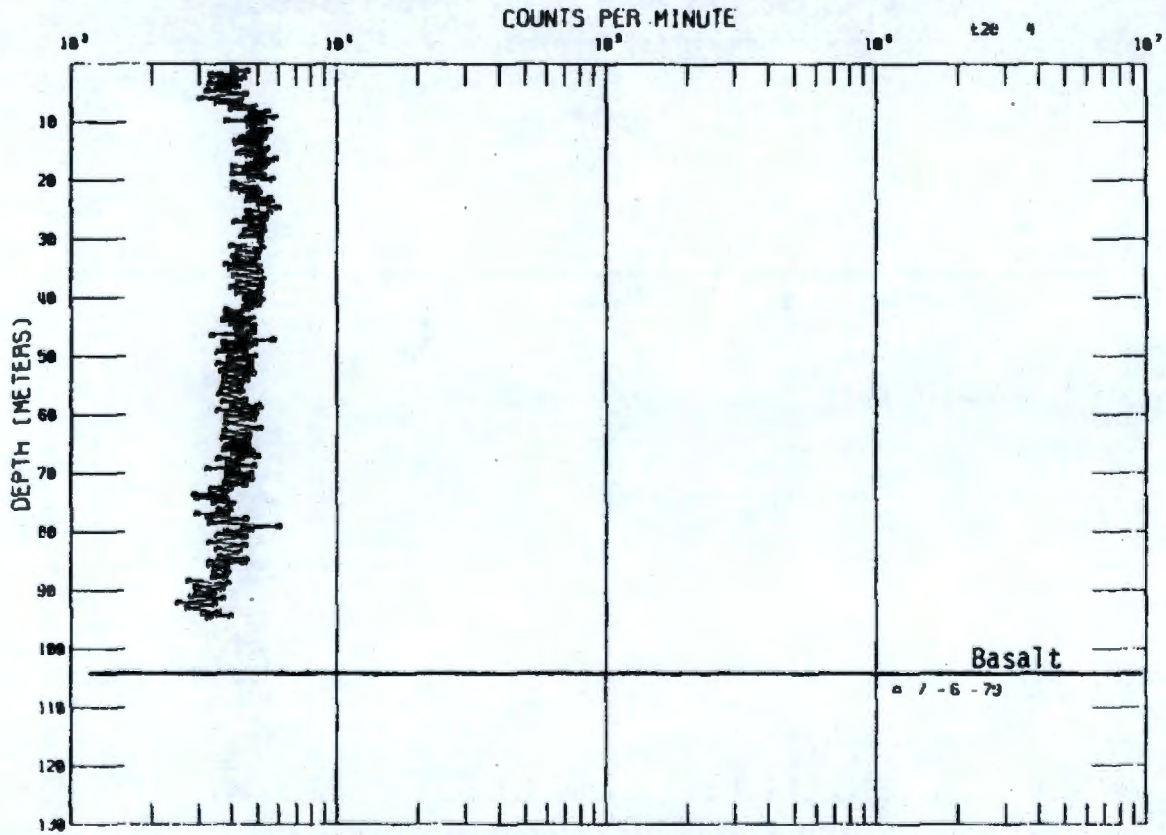


FIGURE 27. Gamma Activity for Well 299-E28-4.

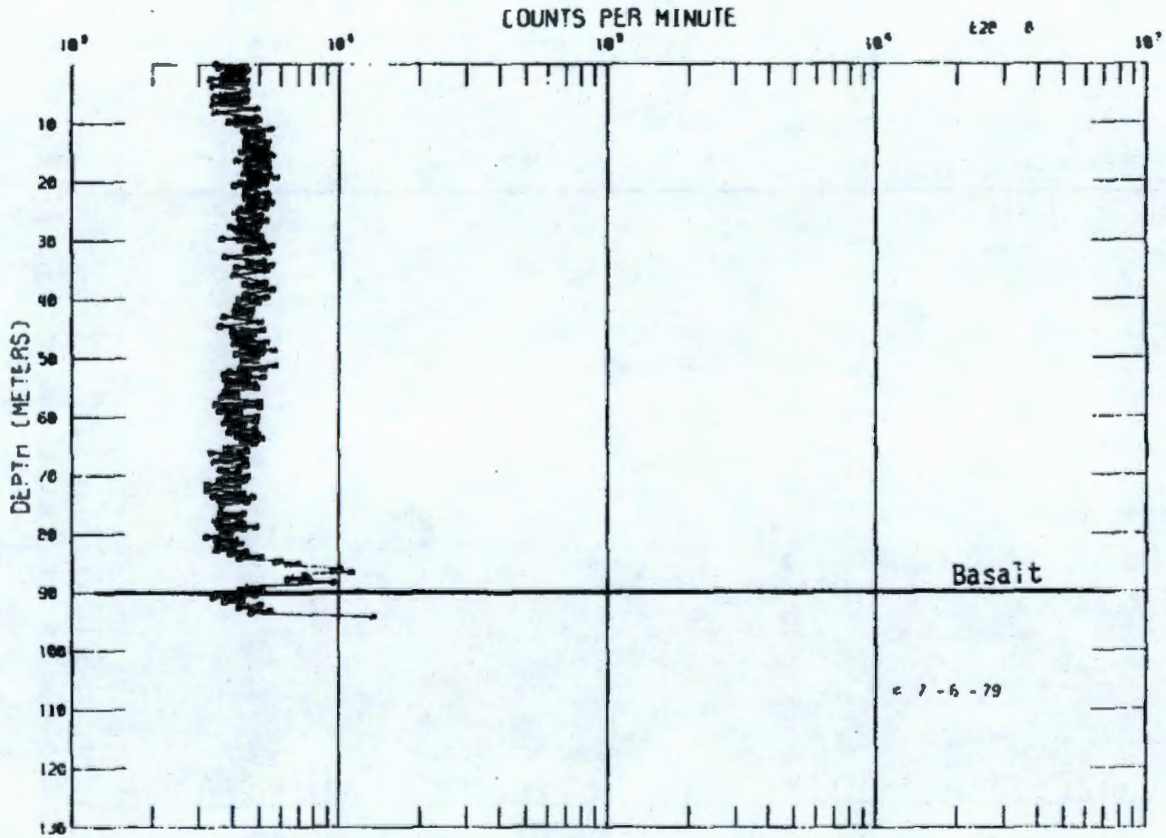


FIGURE 28. Gamma Activity for Well 299-E28-8.

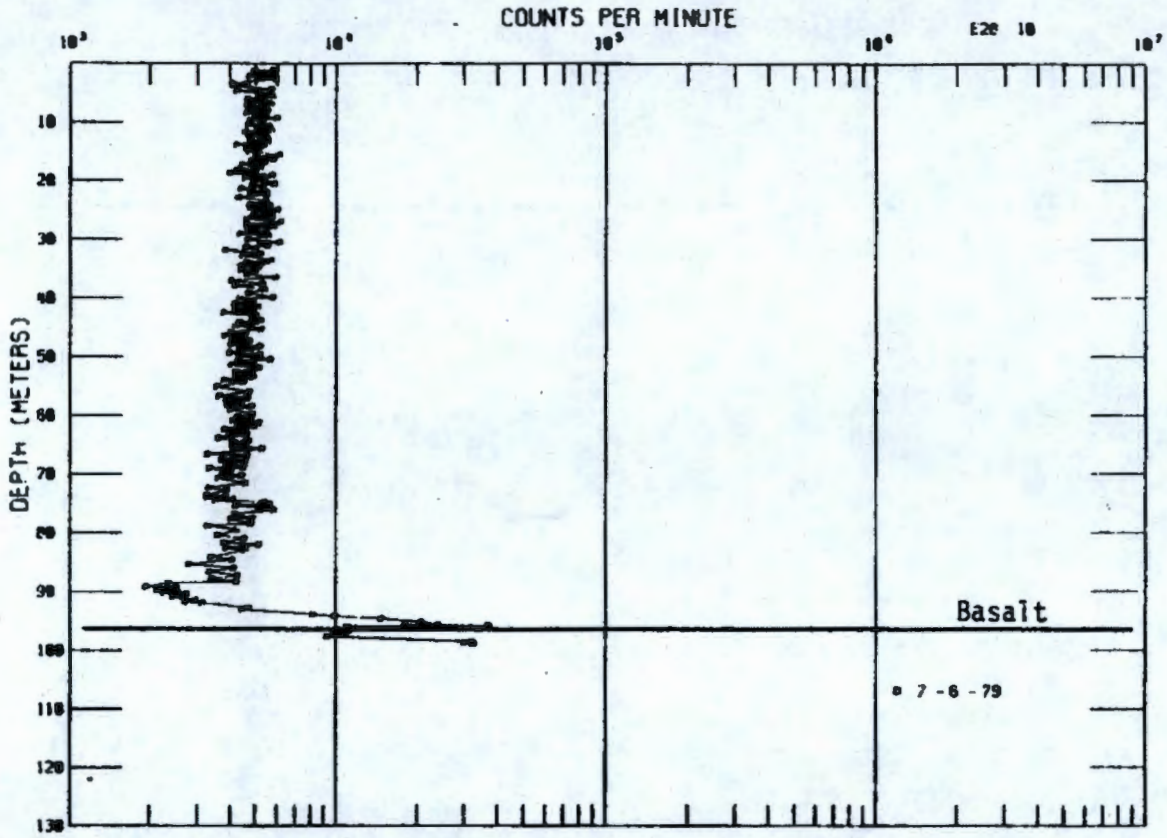


FIGURE 29. Gamma Activity for Well 299-E28-10.

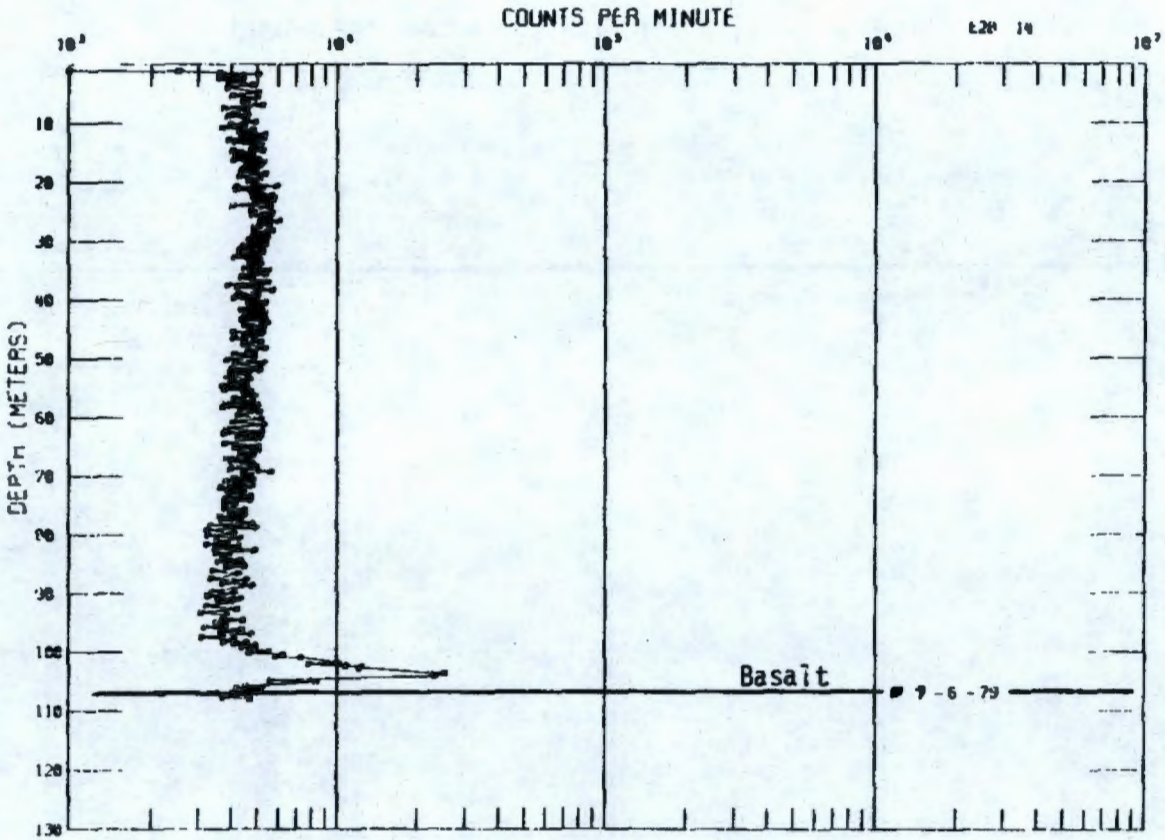


FIGURE 30. Gamma Activity for Well 299-E28-14.

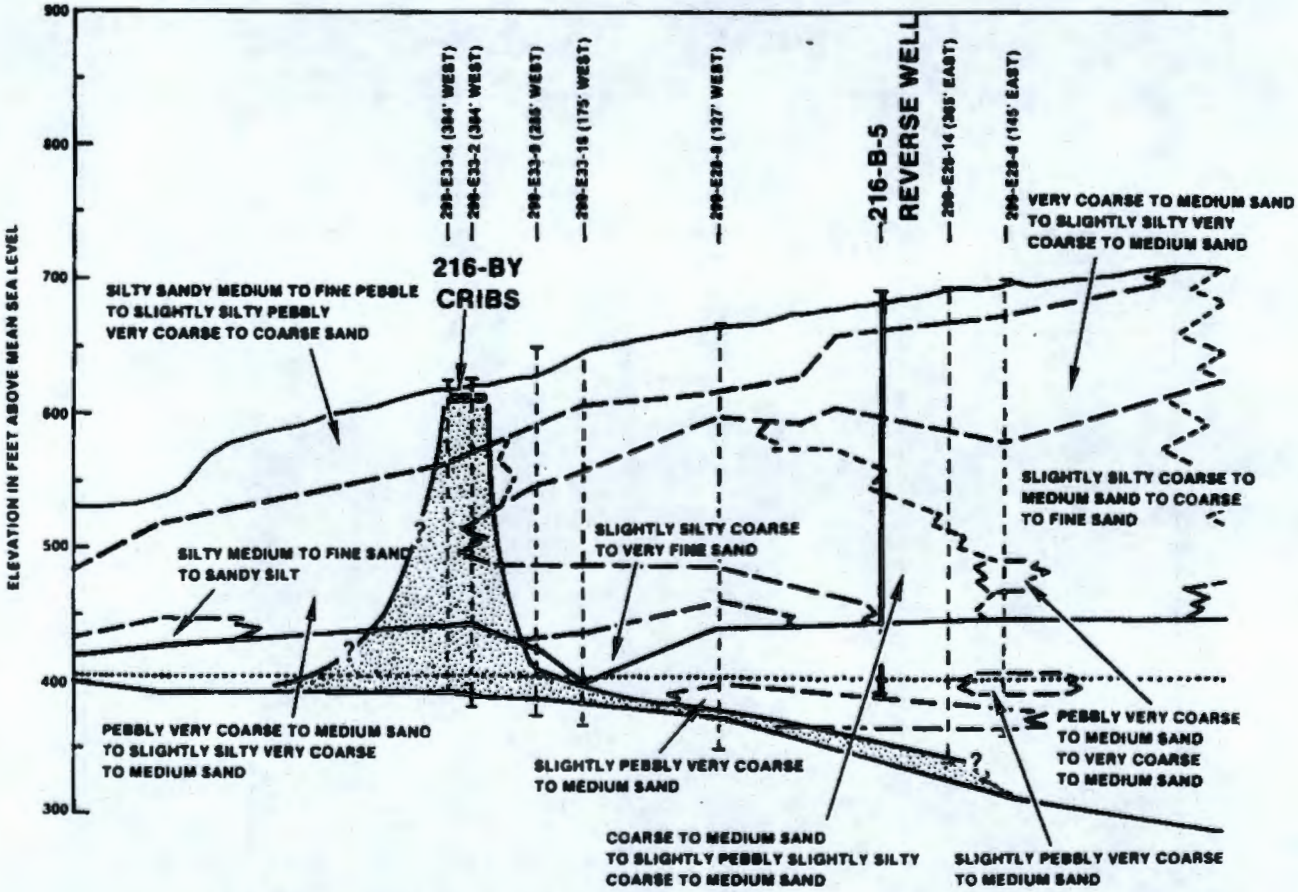


FIGURE 31. Proposed Gamma Contamination from the BY-Cribs.

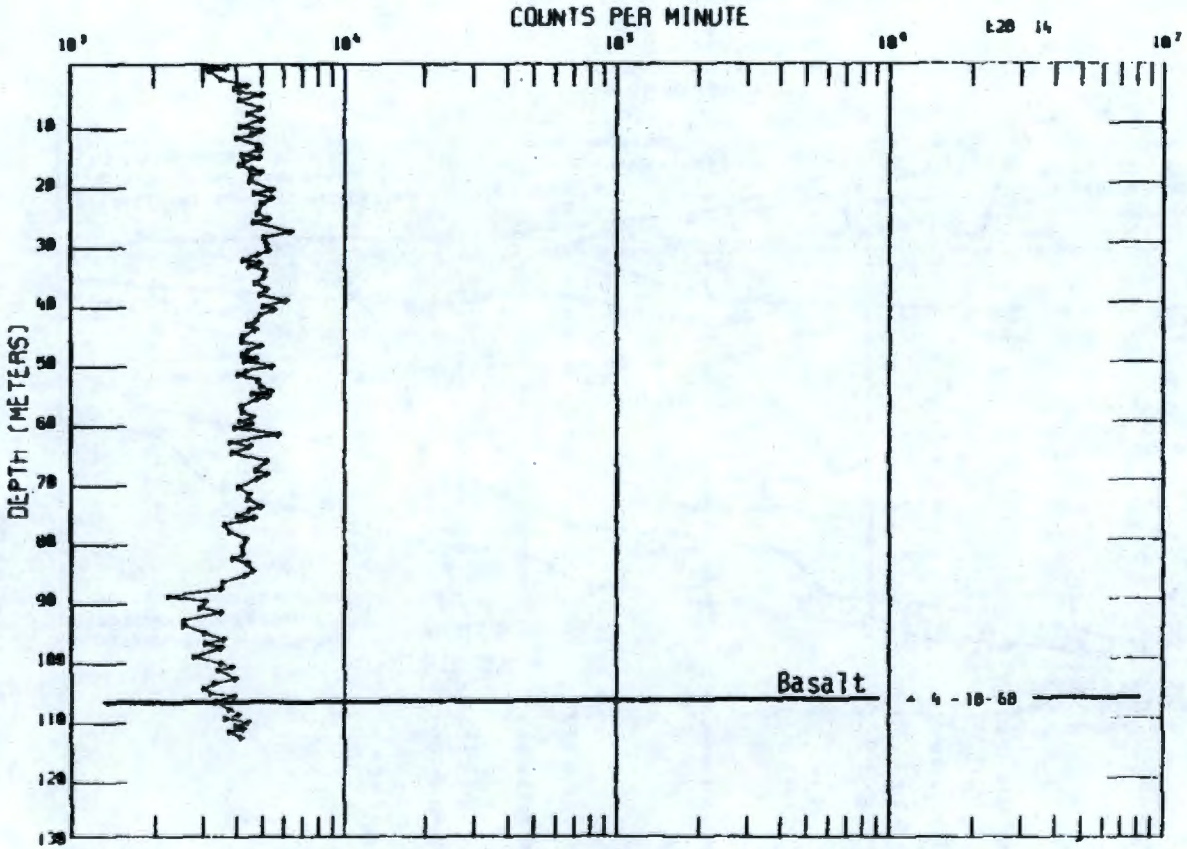


FIGURE 32. Gamma Activity for Well 299-E28-14, 1968.

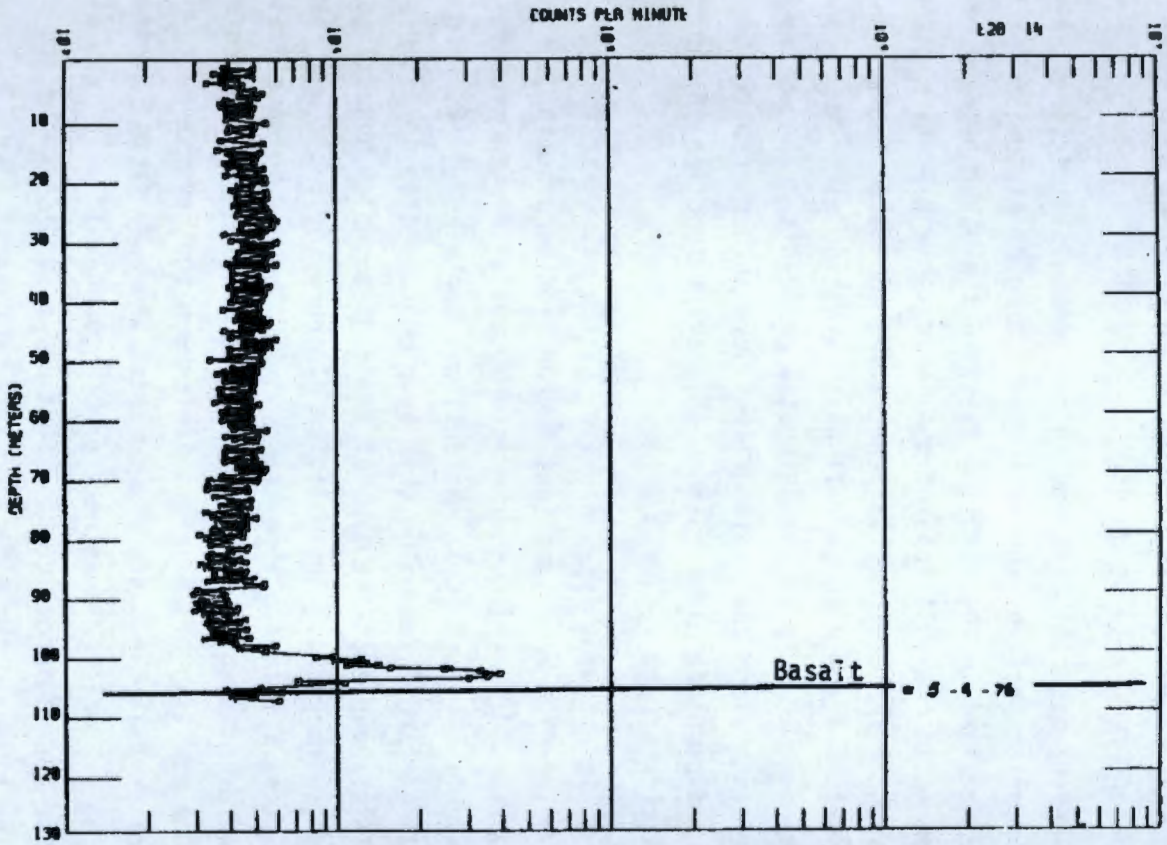


FIGURE 33. Gamma Activity for Well 299-E28-14, 1976.

CONCLUSIONS

The current radionuclide distributions in the saturated sediments below the water table and in the unsaturated sediments above the water table were delineated. Several important conclusions were drawn from the results presented in this document.

Analyses of material retained in the 241-B-361 settling tank indicate that approximately half of the estimated 4.3 kg of plutonium discharged to the system remained in the settling tank and the other half overflowed to the reverse well. Calculations of the water table elevation using the depth of standing water in wells penetrating the water table, indicated that the bottom of the reverse well penetrated the water table and wastes were discharged directly to the saturated sediments. The wastes flowed into the sediments and the radionuclides were sorbed onto the sediments, producing radionuclide distributions that are a function of the physical characteristics of the system.

Changes in sediment type, position of the water table, and direction of ground-water flow were important factors influencing the distributions of radionuclides discharged to the reverse well. A predominant silt layer, through which the reverse well was drilled, contained ^{137}Cs when the more coarse sediment above and below the layer contained no detectable ^{137}Cs activity. This shows that the type of sediment to which a waste solution is discharged is important. The position of the water table was also shown to be important for controlling the distribution of radionuclides. Radionuclides were retained in the highest concentrations on the sediment located at the position of the water table when the reverse well was in use. This indicates that the waste flowed laterally away from the reverse well along the water table. The direction of ground-water flow was also shown to influence the radionuclide distributions as indicated by the elongated shape of the plume in the direction of ground-water flow.

The radionuclide distributions indicate that most of the radionuclide contamination exceeding 10 nCi/g is sorbed on the sediment located within 6 m from the reverse well along a southeast-northwest cross section. The ^{137}Cs contamination is the only exception to this because a 1-m-thick layer

exceeding 10 nCi/g extends beyond 6 m in the direction of ground water flow. The ^{137}Cs distribution indicates that ^{137}Cs flowed to the basalt surface and then flowed laterally. In order to determine the lateral extent of this contamination, gamma scintillation logging of existing wells located around the reverse well was conducted.

Gamma logging showed that sediments distributed over a broad area and located just above the basalt surface were contaminated with low-level gamma contamination. Examination of previously collected gamma logs indicated that a possible source of this contamination could be the BY cribs located ~900 m north of the reverse well. This work also indicates that the contamination may be moving in a southeasterly direction.

Ground-water analyses of three wells located near the reverse well show that the radionuclide concentration of the ground water is orders of magnitude lower than the MPC for an uncontrolled zone. This indicates that the equilibrium between the radionuclides sorbed on the sediment and the radionuclides in the water yields insignificant levels of contamination in the ground water.

The results presented in this report elicit several recommendations for future work. To accurately monitor the ground water in the area, the wells drilled for this study should be screened using stainless steel screens and the casing pulled back to ensure adequate exchange of ground water between the well and the aquifer and also to prevent sampling problems caused by rusting of the casing. These wells should then be sampled periodically to determine that the ground water contamination remains low. The broad contamination plume at the basalt surface should be investigated as to its distribution, source or sources, radionuclide identity and concentration, and to develop a monitoring plan if required.

In conclusion, the radionuclides sorbed on the sediments at concentrations exceeding 10 nCi/g have remained close to the reverse well and are yielding equilibrium solution concentrations orders of magnitude less than limits for uncontrolled zones. Therefore, the contamination which has resulted from past use of the reverse well poses no threat to the surrounding environment.

APPENDIX A

RADIONUCLIDE ANALYSES OF SEDIMENT SAMPLES

Well 299-E28-7

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
88.4	Rockwell	7.91E-4	-	-	-
89.9	Rockwell	2.30E-3	<1.6E-3	6.37E-2	<3.8E-4
	Eberline	-	-	3.23E-4	4.15E-5
91.4	Rockwell	1.89E-4	-	-	-
93.0	Rockwell	7.57E-5	3.59E-2	5.33E-2	<3.6E-4
	Eberline	-	-	9.17E-4	3.09E-5
94.5	Rockwell	1.23E-3	6.85E-2	2.07E-2	2.66E-1
96.0	Rockwell	7.56E-3	-	-	-
97.5	Rockwell	6.51E-2	2.03E-3	4.42E-3	<4.6E-4
	Eberline	-	-	6.24E-6	1.83E-5
98.9	Rockwell	1.21E0	3.85E-3	7.62E-2	<1.7E-3
	Eberline	-	-	6.08E-4	7.21E-5
99.1	Rockwell	9.35E-1	<2.5E-3	1.35E-3	2.29E-3
	Eberline	-	-	1.56E-3	9.88E-5
100.6	Rockwell	1.27E-1	1.45E-3	2.05E-3	<4.2E-4
	Eberline	-	-	1.25E-3	2.54E-4
102.1	Rockwell	3.93E-2	<1.1E-3	1.84E-3	<7.0E-4
	Eberline	-	-	5.15E-4	5.83E-5
103.6	Rockwell	1.36E-2	-	-	-

Well 299-E28-23

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
3.1	Rockwell	1.18E-4	-	-	-
	Eberline			2.74E-5	5.10E-6
24.4	Rockwell	1.31E-4	-	-	-
	Eberline	-	-	1.39E-5	6.20E-5
42.7	Rockwell	1.10E-4	-	-	-
	Eberline	-	-	8.20E-6	2.36E-6
61.1	Rockwell	1.36E-4	-	-	-
	Eberline	-	-	-1.54E-6	4.80E-6
73.2	Rockwell	<2.40E-5	-	-	-
74.7	Rockwell	<2.10E-5	-	-	-
76.2	Eberline	-	-	1.39E-5	4.62E-6
76.5	Rockwell	6.68E-2	-	-	-
	Eberline	-	-	3.12E-3	2.81E-5
77.7	Rockwell	1.88E-4	-	-	-
	Rockwell	2.09E-4	-	-	-
	Eberline	-	-	3.11E-5	1.17E-5
79.3	Rockwell	1.16E-4	-	-	-
	Eberline	-	-	3.26E-6	4.89E-6
80.8	Rockwell	<2.20E-5	-	-	-
	Rockwell	1.06E-4	-	-	-
	Eberline	-	-	1.57E-5	2.42E-6
82.0	Rockwell	-	2.09E-1	-	-
82.3	Rockwell	3.63E-1	-	-	-
	Rockwell	4.16E-1	-	-	-
	Eberline	-	-	4.81E-4	3.10E-5
83.8	Eberline	-	-	9.39E-4	1.75E-4
85.3	Rockwell	1.80E0	1.45E-1	2.65E-2	<1.6E-3
86.6	Rockwell	5.13E+1	6.03E+1	7.02E+1	1.33E0
	Rockwell	4.51E+1	-	-	-
88.1	Rockwell	3.08E+1	2.19E+1	7.50E+1	2.19E0
	Rockwell	3.07E+1	-	-	-
89.2	Rockwell	4.40E+1	-	-	-
89.5	Rockwell	4.90E+1	3.41E+1	1.91E+1	2.54E0
	Rockwell	3.63E+1	-	-	-

Well 299-E28-23 (Continued)

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
90.2	Rockwell	2.33E+1	2.57E+1	4.95E+1	9.92E-1
	Rockwell	2.22E+1	-	-	-
90.8	Rockwell	2.10E+1	-	-	-
91.4	Rockwell	2.79E+1	1.65E+1	3.85E+1	1.14E0
92.1	Rockwell	1.65E+1	-	-	-
	Rockwell	1.91E+1	-	-	-
92.7	Rockwell	1.58E+1	3.70E0	1.27E+1	1.34E-1
93.3	Rockwell	1.14E+1	-	-	-
93.9	Rockwell	5.04E0	6.32E0	1.81E+1	2.84E-1
94.5	Rockwell	2.30E-1	-	-	-
	Rockwell	1.66E-1	-	-	-
	Eberline	-	-	7.14E0	1.13E-1
95.1	Rockwell	1.62E-1	2.02E-1	3.38E-1	<1.6E-3
	Rockwell	1.81E-1	-	-	-
	Eberline	-	-	2.95E-1	4.74E-3
95.7	Rockwell	1.24E-1	-	-	-
96.0	Rockwell	2.80E-1	-	-	-
96.3	Rockwell	2.57E-1	1.56E-1	2.73E-1	<1.3E-3
	Rockwell	1.27E-1	-	-	-
96.9	Rockwell	2.58E-1	-	-	-
97.5	Rockwell	1.57E0	-	-	-
	Rockwell	1.19E0	-	-	-
98.2	Rockwell	1.86E0	-	-	-
	Rockwell	1.77E0	-	-	-
98.8	Rockwell	1.21E0	8.41E-2	9.52E-1	-
	Rockwell	1.59E0	-	-	-
100.0	Rockwell	1.59E0	8.35E-2	5.48E-2	<1.8E-3
	Eberline	-	-	2.70E-1	4.40E-3
100.6	Rockwell	3.50E-1	9.05E-2	-	-
	Eberline	-	-	3.29E-2	5.89E-4
100.7	Rockwell	4.83E-1	-	-	-
	Rockwell	3.67E-1	-	-	-

Well 299-E28-24

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
15.2	Eberline	-	-	5.96E-7	5.98E-6
51.8	Eberline	-	-	7.44E-6	9.10E-7
73.2	Eberline	-	-	4.16E-6	3.83E-6
76.2	Rockwell	-	1.21E-3	1.45E-3	<4.8E-4
	Eberline	-	-	1.41E-5	6.05E-6
	Eberline	-	-	2.48E-5	3.83E-6
78.6	Rockwell	<5.7E-5	<3.5E-3	4.3E-4	<5.3E-4
	Rockwell	-	-	1.33E-2	<4.4E-4
	Eberline	-	-	8.43E-4	1.35E-4
78.9	Rockwell	<5.2E-5	1.24E-2	1.93E-3	<5.1E-4
80.8	Rockwell	1.40E-4	3.38E-3	1.81E-3	<8.3E-4
	Rockwell	-	<2.6E-3	2.93E-3	<5.5E-4
	Eberline	-	-	1.59E-3	1.08E-4
81.5	Rockwell	<4.8E-5	2.09E-3	8.9E-4	<1.6E-4
	Eberline	-	-	1.69E-3	2.11E-5
82.0	Rockwell	-	2.09E-1	1.08E-1	<4.7E-3
	Rockwell	-	1.63E-1	1.49E-1	1.04E-2
82.6	Rockwell	5.27E0	8.36E-1	1.98E-2	<9.4E-4
	Rockwell	-	1.01E0	6.00E-3	<6.7E-4
	Eberline	-	-	3.63E-2	5.77E-4
83.8	Rockwell	6.47E-1	2.54E-3	1.15E-1	<5.2E-4
84.7	Rockwell	6.65E-1	2.51E-2	1.37E-3	<8.6E-4
	Rockwell	-	2.30E-2	7.95E-2	<6.2E-3
85.7	Rockwell	8.85E-2	1.62E0	9.91E-4	<8.4E-4
	Eberline	-	-	1.52E-3	6.62E-6
86.9	Rockwell	2.37E-2	1.70E-1	1.73E-3	<8.2E-4
	Rockwell	-	7.93E-2	<3.0E-3	<7.6E-3
87.5	Rockwell	4.11E-2	3.97E-1	9.8E-4	<9.9E-4
	Eberline	-	-	2.49E-3	4.24E-5
88.1	Rockwell	-	3.17E-1	6.82E-3	<6.4E-4
88.4	Rockwell	2.93E-1	4.36E-1	5.69E-2	<1.1E-3
	Rockwell	3.44E-1	-	-	-
89.0	Rockwell	-	8.28E-1	2.11E-3	<2.4E-3
	Rockwell	-	8.14E-1	8.67E-3	<5.0E-4
	Eberline	-	-	4.46E-3	9.30E-5
89.6	Rockwell	1.60E+1	8.83E0	8.43E0	3.16E-2
	Rockwell	1.00E+1	1.35E+1	2.28E0	3.64E-2
	Eberline	-	-	4.72E0	5.48E-2

Well 299-E28-24 (Continued)

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
90.2	Rockwell	7.56E0	6.66E-1	2.34E0	4.05E-2
	Rockwell	8.25E0	9.23E-1	1.37E0	2.71E-2
	Eberline	-	-	2.47E0	4.93E-2
91.4	Rockwell	4.08E-1	4.54E-2	2.42E-1	3.94E-3
	Eberline	-	-	7.63E-2	1.80E-3
92.7	Rockwell	1.94E-1	1.30E-1	5.18E-1	9.08E-3
	Rockwell	-	7.79E-2	5.03E-1	8.42E-3
	Eberline	-	-	5.50E-1	1.17E-2
94.5	Rockwell	7.56E-2	6.15E-1	1.41E-1	<7.7E-4
	Rockwell	-	4.56E-2	4.46E-2	<7.3E-4
	Eberline	-	-	1.65E-1	3.72E-3
95.1	Rockwell	1.60E-1	3.12E-2	4.70E-2	<4.6E-4
96.0	Rockwell	6.26E-2	3.71E-2	1.21E-1	<5.0E-4
96.8	Rockwell	-	1.60E-2	4.06E-2	<6.7E-4
	Eberline	-	-	9.66E-2	1.80E-3
97.8	Rockwell	-	9.16E-1	1.19E-1	<8.1E-4
98.8	Rockwell	3.05E-1	2.52E-2	4.70E-2	<5.6E-4
	Eberline	-	-	4.66E-2	7.57E-4
99.7	Rockwell	-	1.63E0	3.42E-2	<7.1E-4
100.3	Rockwell	1.16E-1	1.84E-2	3.58E-2	<6.3E-4
	Rockwell	-	1.12E-2	3.69E-2	2.58E-3
	Eberline	-	-	3.40E-2	5.17E-4

Well 299-E28-25

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
1.5	Eberline	-	-	6.30E-6	5.59E-6
15.2	Rockwell	<2.4E-5	-	-	-
33.5	Eberline	-	-	7.43E-6	4.49E-6
51.8	Rockwell	<2.2E-5	-	-	-
61.1	Eberline	-	-	5.29E-6	5.53E-6
73.2	Eberline	-	-	8.94E-7	9.61E-6
74.7	Rockwell	<5.7E-5	-	-	-
76.2	Rockwell	<1.9E-5	-	-	-
76.5	Rockwell	-	<1.4E-3	2.87E-3	<1.5E-3
	Eberline	-	-	2.19E-5	9.43E-6
77.7	Rockwell	1.35E-1	<9.3E-4	7.32E-4	<6.6E-4
	Eberline	-	-	8.95E-4	1.39E-4
78.3	Rockwell	9.87E-2	-	-	-
79.3	Rockwell	1.07E-4	-	-	-
	Rockwell	1.15E-4	-	-	-
79.9	Rockwell	<2.0E-5	-	-	-
	Rockwell	<5.2E-5	-	-	-
80.8	Rockwell	<7.6E-5	<1.4E-3	-	-
	Rockwell	<1.8E-5	-	-	-
81.5	Rockwell	<1.9E-5	-	-	-
82.3	Rockwell	<1.8E-5	-	-	-
83.8	Rockwell	<3.9E-5	<1.2E-4	-	-
84.7	Rockwell	<8.9E-5	-	-	-
85.3	Rockwell	1.25E-4	-	-	-
85.9	Rockwell	7.18E-5	-	-	-
86.6	Rockwell	<2.3E-5	<1.6E-3	1.59E-1	<4.7E-4
	Rockwell	-	5.63E-2	4.11E-2	<3.7E-4
	Eberline	-	-	4.21E-4	7.96E-5
87.5	Rockwell	5.45E-4	6.94E-3	4.21E-4	-
	Rockwell	5.40E-4	-	-	-
88.1	Rockwell	1.49E-4	-	-	-
	Rockwell	2.04E-4	-	-	-
	Eberline	-	-	2.37E-4	9.98E-6

Well 299-E28-25 (Continued)

Depth, m	Laboratory	^{137}Cs, nCi/g	^{90}Sr, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
88.4	Rockwell	1.31E-4	2.37E-2	3.04E-2	<4.8E-4
	Rockwell	1.70E-4	-	-	-
89.0	Rockwell	3.84E-2	<1.6E-3	8.71E-2	<5.1E-4
	Eberline	-	-	3.56E-3	1.47E-4
89.9	Rockwell	1.53E-1	<2.4E-4	4.99E-2	<3.9E-4
	Rockwell	1.90E-1	-	-	-
90.5	Rockwell	1.72E-3	<1.4E-3	1.14E-3	<4.2E-4
	Rockwell	2.36E-3	-	-	-
	Eberline	-	-	7.68E-4	5.28E-5
91.4	Rockwell	2.56E-3	8.01E-2	2.15E-2	<4.2E-4
	Rockwell	3.57E-3	-	-	-
	Eberline	-	-	7.75E-4	2.70E-5
93.3	Rockwell	-	1.47E-3	1.79E-3	<4.7E-4
95.4	Rockwell	1.26E-4	1.48E-3	8.26E-3	<7.0E-4
	Eberline	-	-	5.45E-4	9.81E-6
97.8	Rockwell	4.92E-4	<1.6E-3	2.65E-3	<4.0E-4
99.1	Rockwell	1.35E-1	1.04E-2	2.66E-3	<5.2E-4
	Eberline	-	-	1.20E-3	1.00E-4
100.9	Rockwell	1.57E-1	<1.6E-3	3.63E-3	<4.9E-4
	Eberline	-	-	3.20E-4	3.14E-5

Well 299-E28-73

Depth, m	Laboratory	^{137}Cs, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
1.5	Rockwell	3.35E-4	-	-
3.1	Rockwell	1.26E-4	-	-
4.6	Rockwell	9.37E-5	-	-
6.1	Rockwell	1.16E-4	-	-
7.6	Rockwell	<7.40E-5	-	-
	Eberline	-	7.15E-6	6.47E-6
9.1	Rockwell	1.77E-4	-	-
10.7	Rockwell	1.05E-4	-	-
12.8	Rockwell	<8.30E-5	-	-
	Eberline	-	1.12E-5	4.45E-6

Well 299-E28-74

Depth, m	Laboratory	^{137}Cs, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
1.5	Rockwell	9.25E-5	-	-
3.1	Rockwell	1.28E-4	-	-
4.6	Rockwell	1.17E-4	-	-
6.1	Rockwell	1.25E-4	-	-
7.6	Rockwell	<6.1E-5	-	-
	Eberline	-	1.85E-5	-5.04E-6
9.1	Rockwell	1.42E-4	-	-
10.7	Rockwell	1.36E-4	-	-
12.7	Rockwell	<7.1E-5	-	-
	Eberline	-	7.88E-5	1.24E-6

Well 299-E28-73

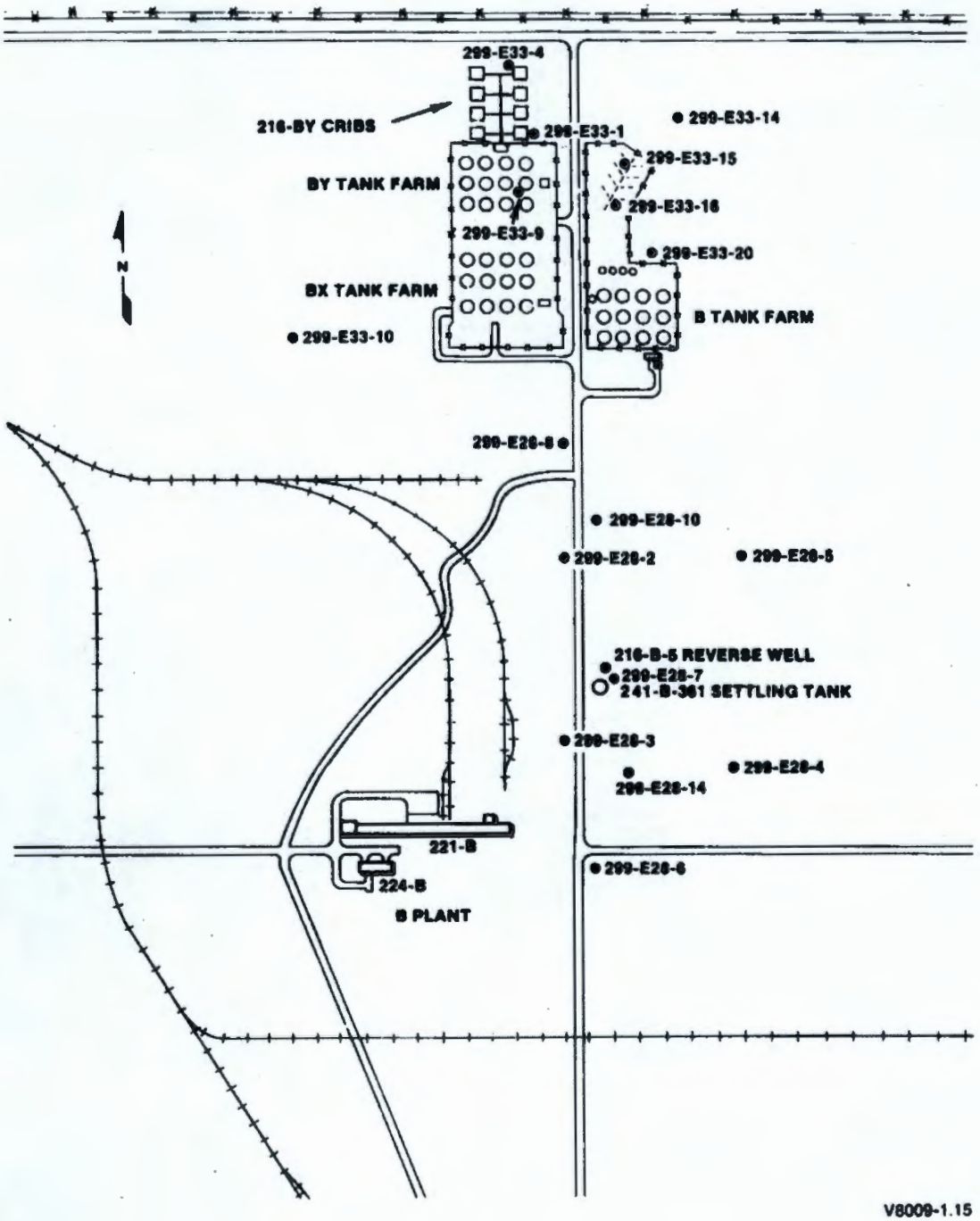
Depth, m	Laboratory	^{137}Cs, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
1.5	Rockwell	3.35E-4	-	-
3.1	Rockwell	1.26E-4	-	-
4.6	Rockwell	9.37E-5	-	-
6.1	Rockwell	1.16E-4	-	-
7.6	Rockwell	<7.40E-5	-	-
	Eberline	-	7.15E-6	6.47E-6
9.1	Rockwell	1.77E-4	-	-
10.7	Rockwell	1.05E-4	-	-
12.8	Rockwell	<8.30E-5	-	-
	Eberline	-	1.12E-5	4.45E-6

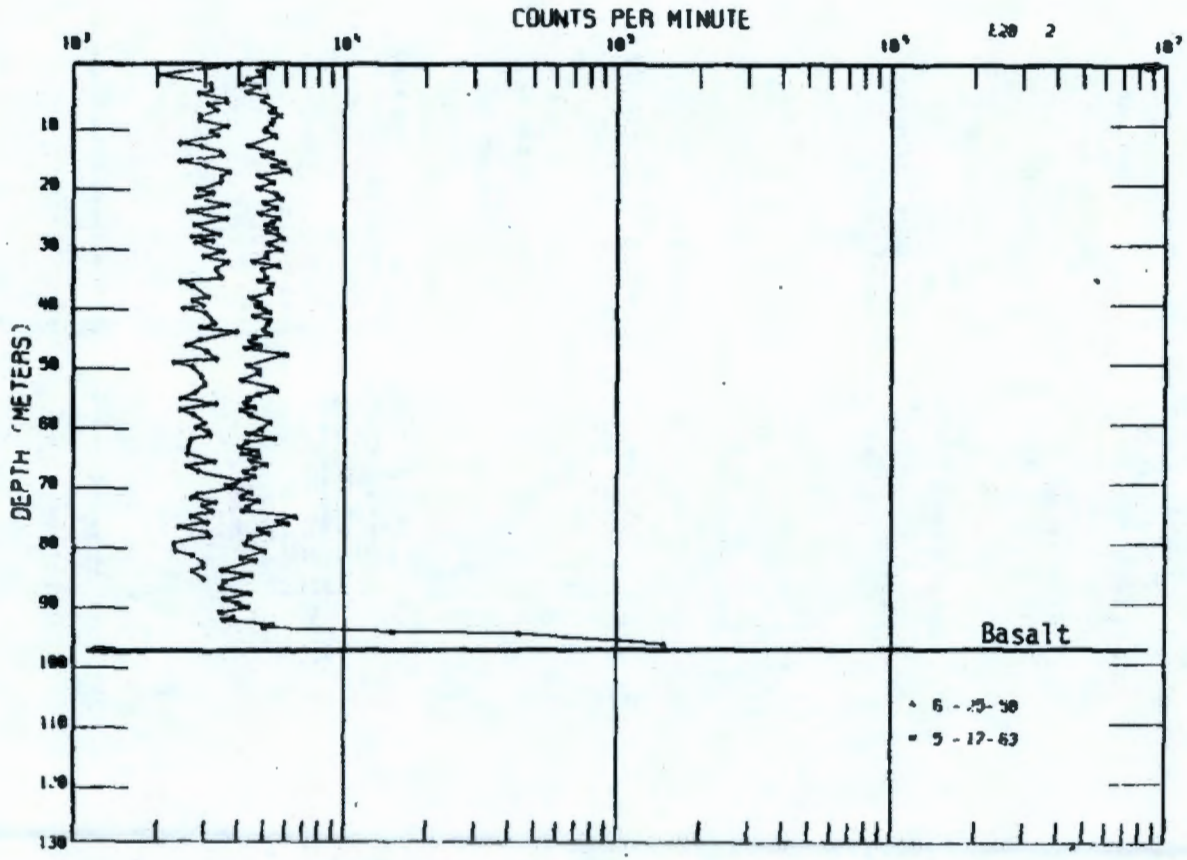
Well 299-E28-74

Depth, m	Laboratory	^{137}Cs, nCi/g	$^{239-240}Pu$, nCi/g	^{241}Am, nCi/g
1.5	Rockwell	9.25E-5	-	-
3.1	Rockwell	1.28E-4	-	-
4.6	Rockwell	1.17E-4	-	-
6.1	Rockwell	1.25E-4	-	-
7.6	Rockwell	<6.1E-5	-	-
	Eberline	-	1.85E-5	-5.04E-6
9.1	Rockwell	1.42E-4	-	-
10.7	Rockwell	1.36E-4	-	-
12.7	Rockwell	<7.1E-5	-	-
	Eberline	-	7.88E-5	1.24E-6

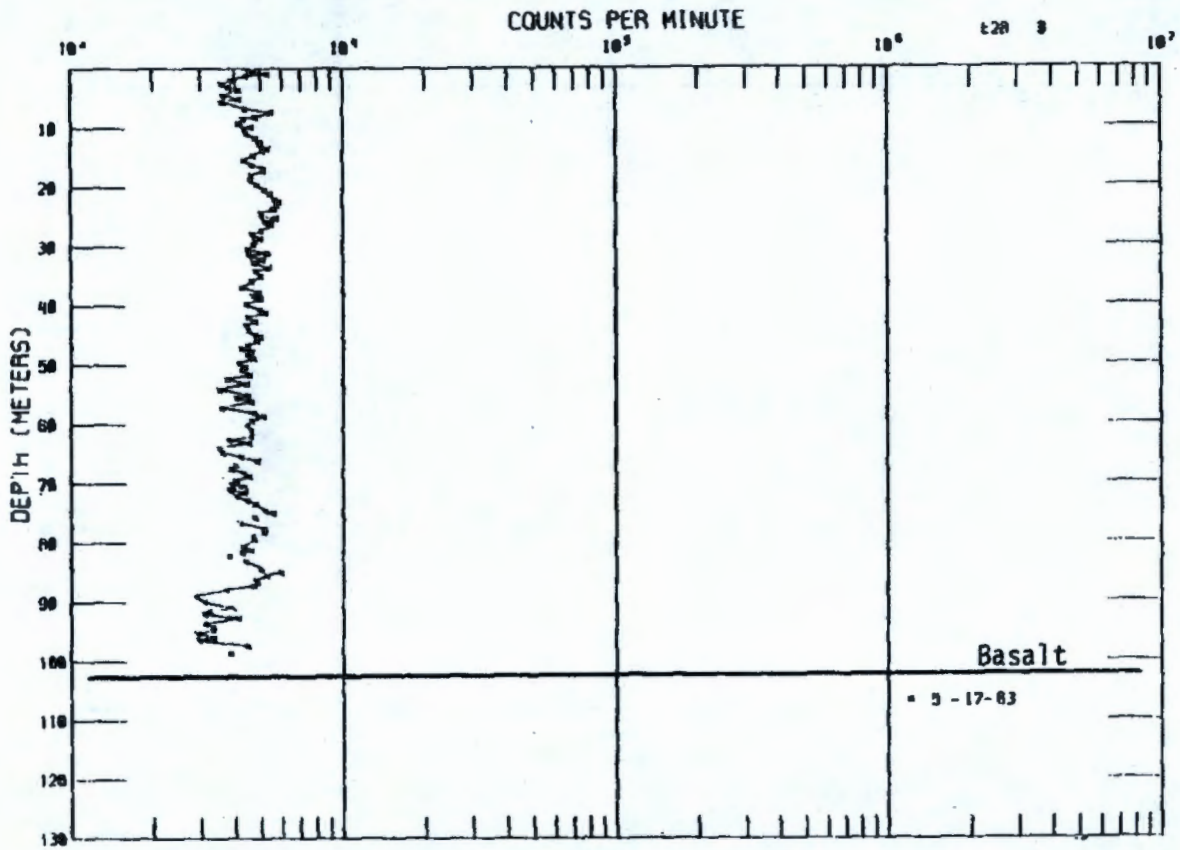
APPENDIX B

GAMMA SCINTILLATION LOGS

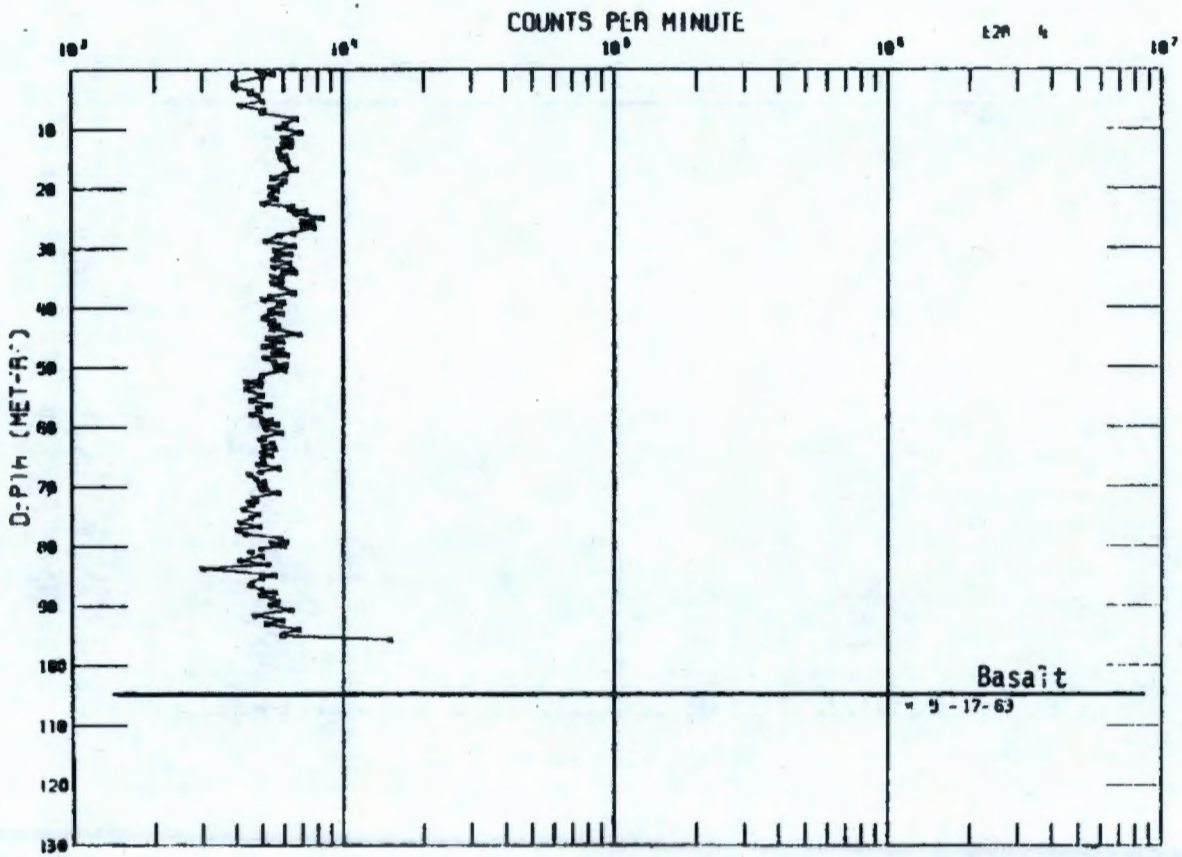

299-E33-4
216-BY CRIBS
299-E33-1
299-E33-14
299-E33-15
BY TANK FARM
299-E33-16
299-E33-9
299-E33-20
N
BX TANK FARM
B TANK FARM
299-E33-10
299-E28-8
299-E28-10
299-E28-2
299-E28-5
216-B-5 REVERSE WELL
299-E28-7
241-B-361 SETTLING TANK
299-E28-3
299-E28-4
299-E28-14
221-B
299-E28-6
224-B
B PLANT
V8009-1.15



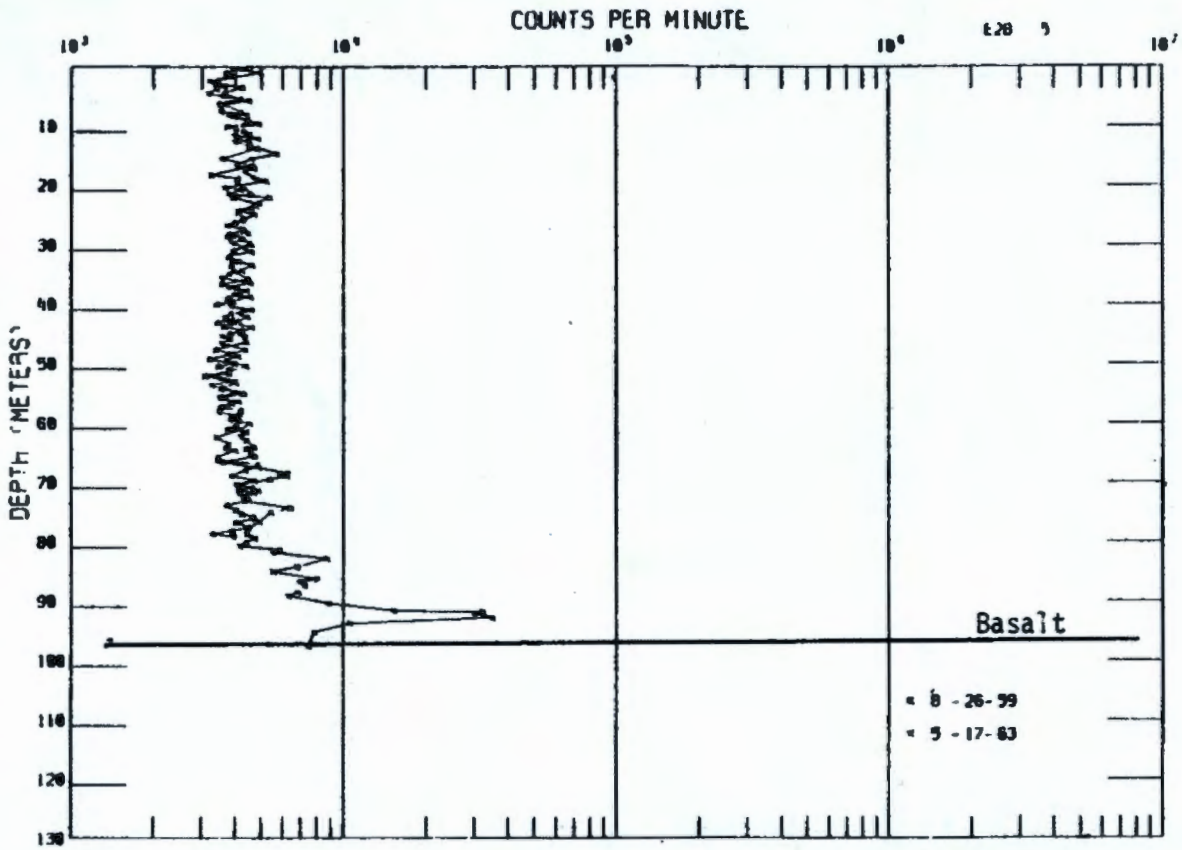
Well 299-E28-2



Well 299-E28-3



Well 299-E28-4



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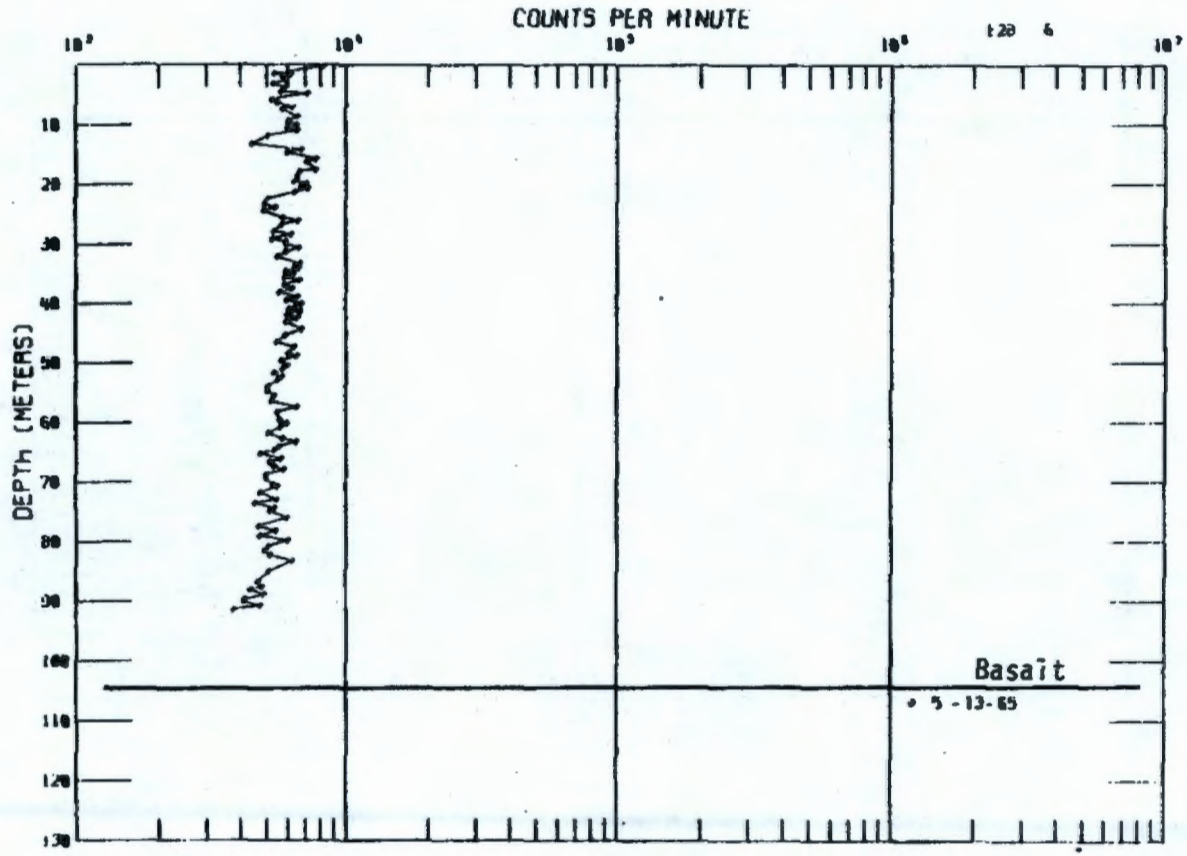

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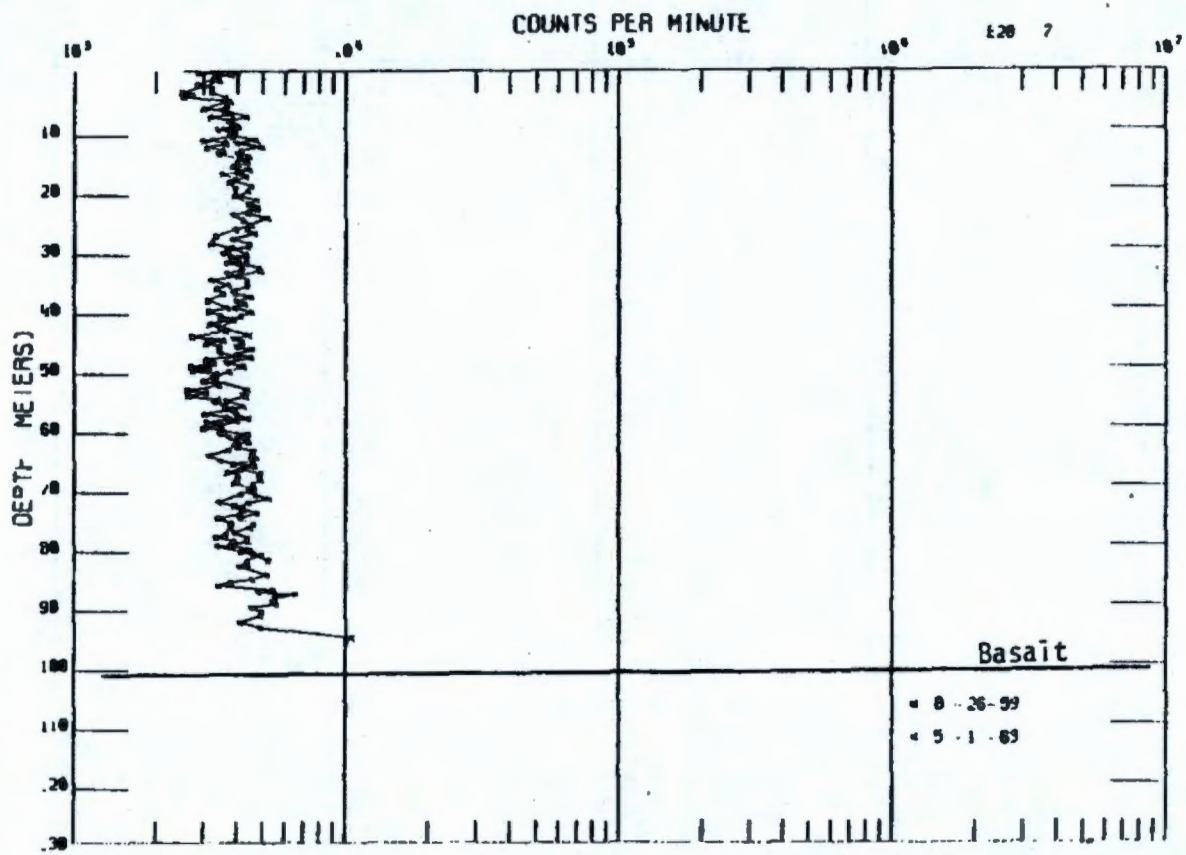
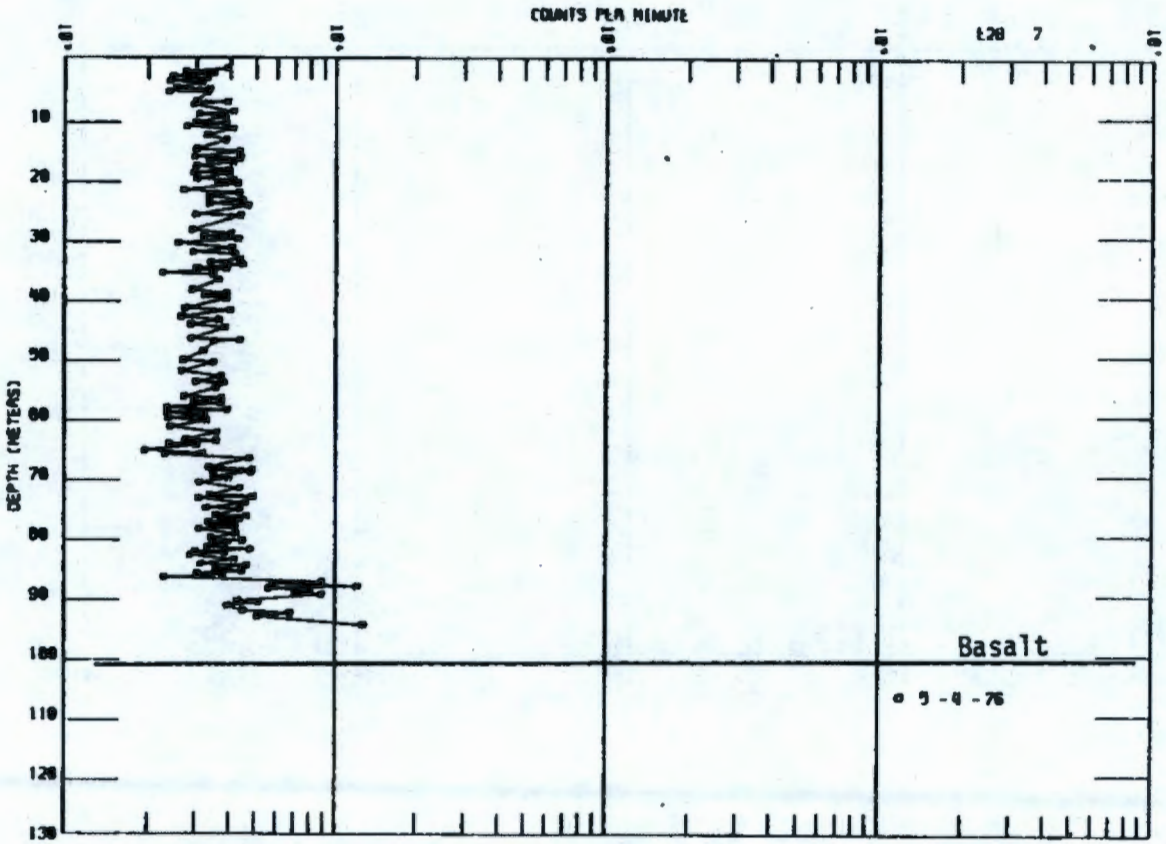
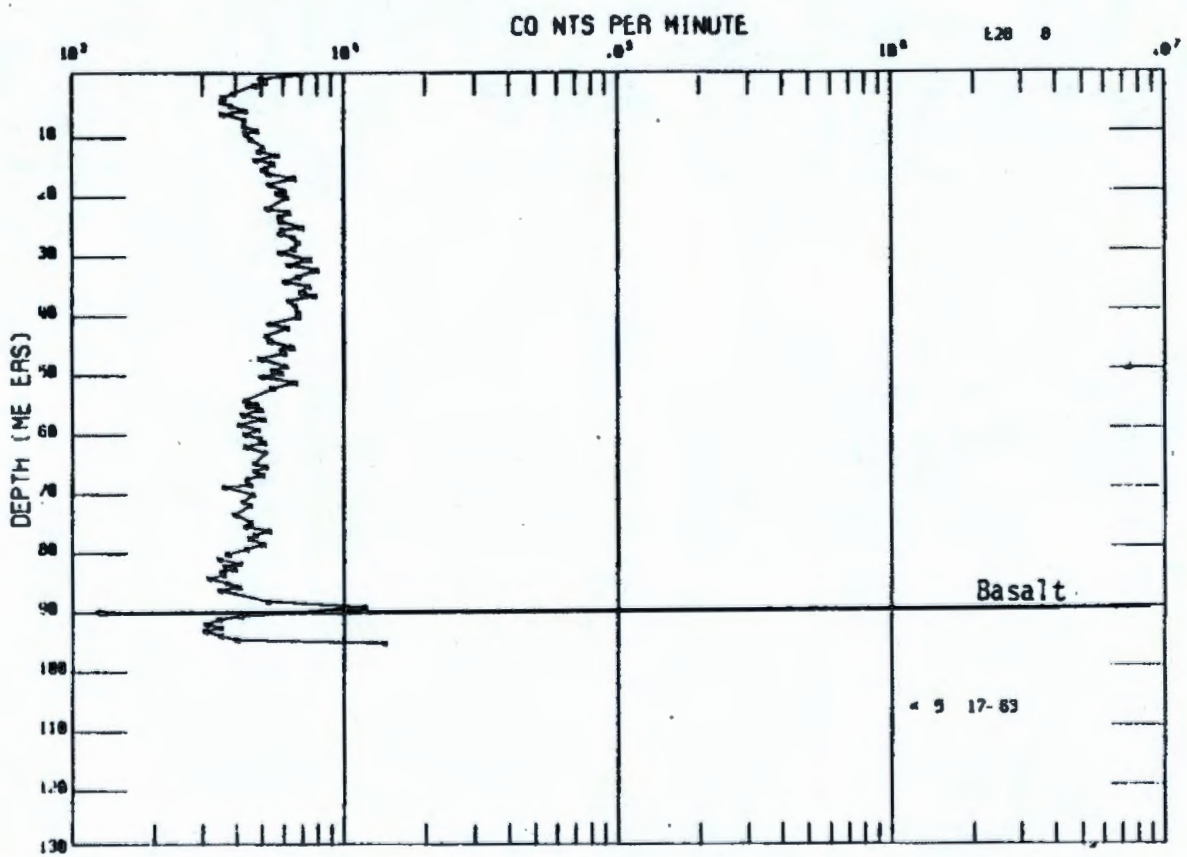


Well 299-E28-7



Well 299-E28-7



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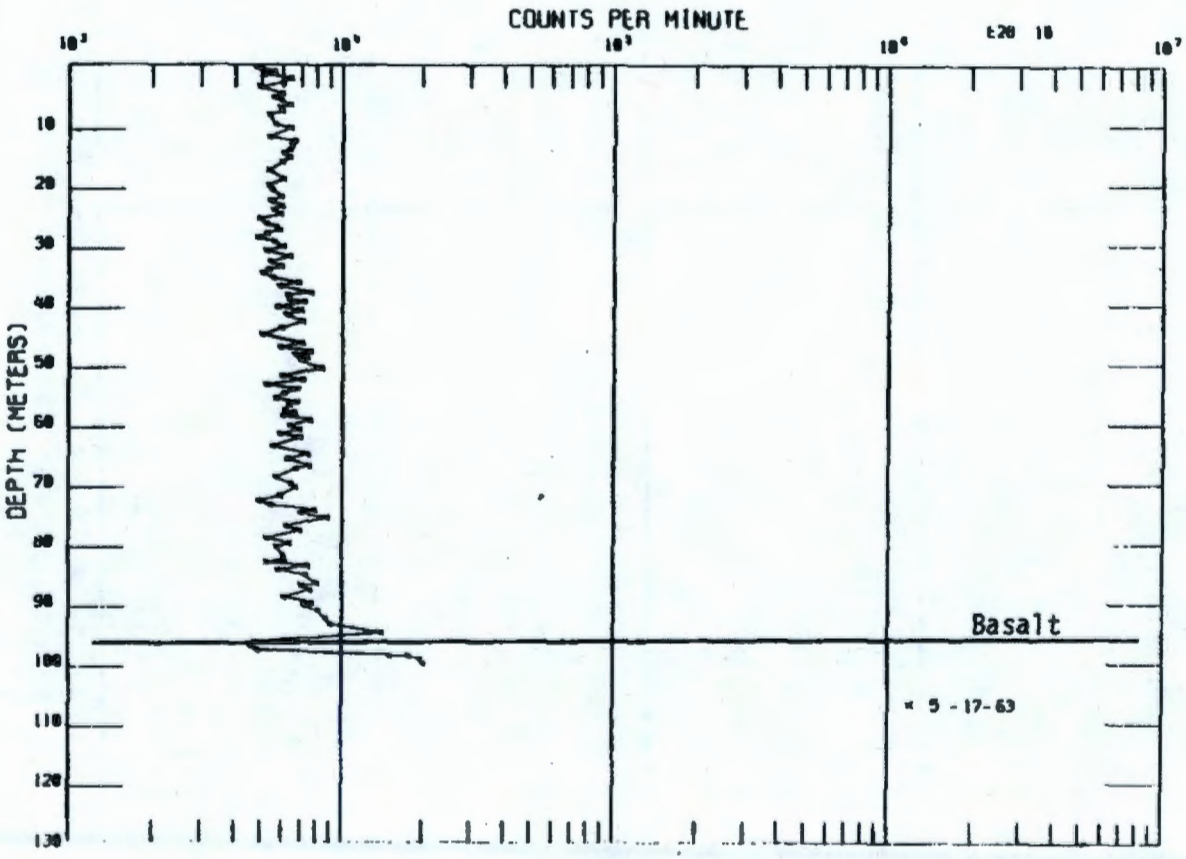
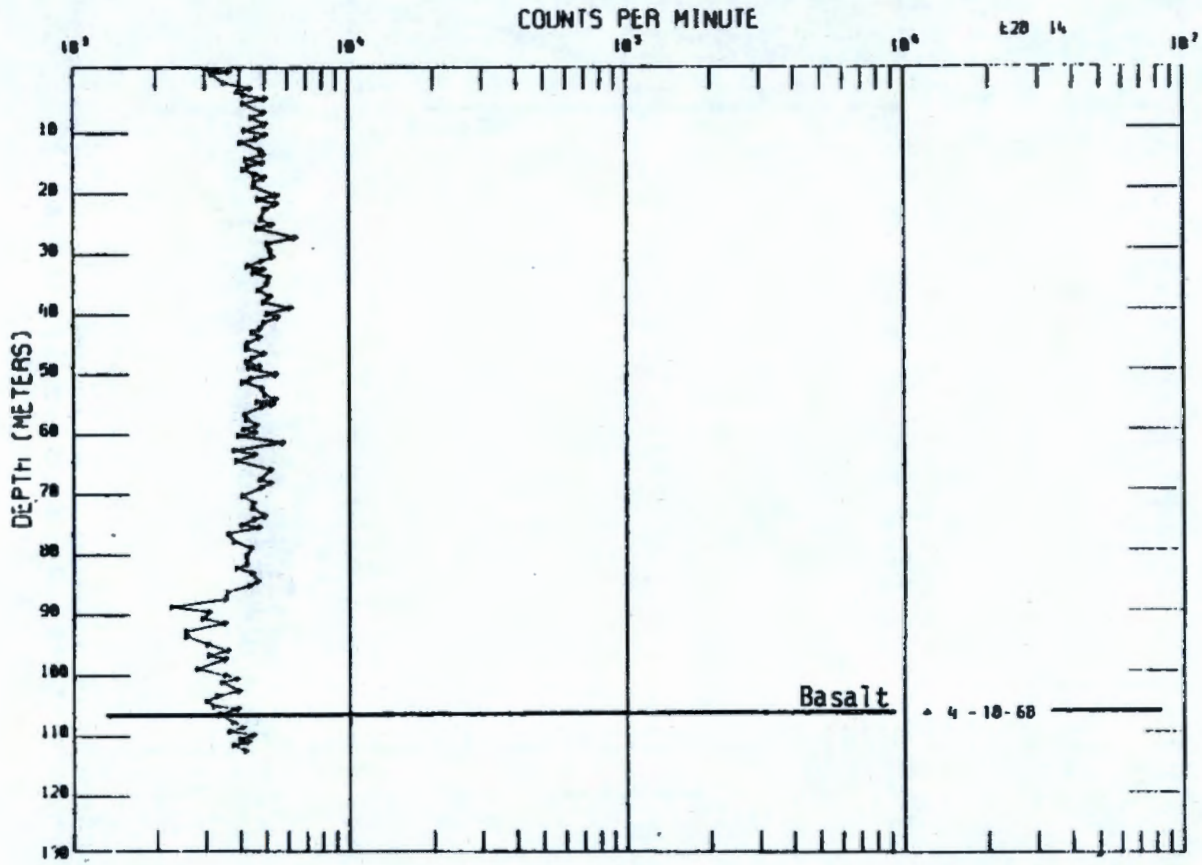
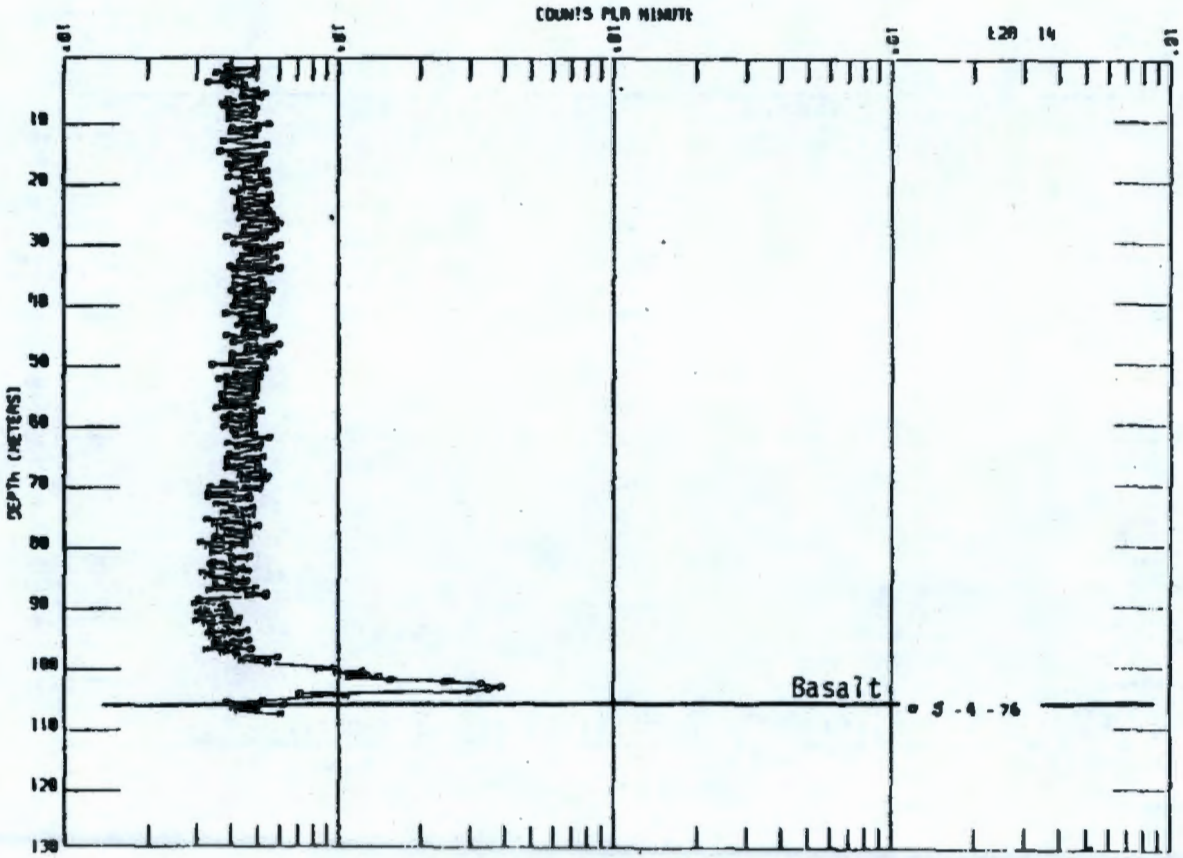


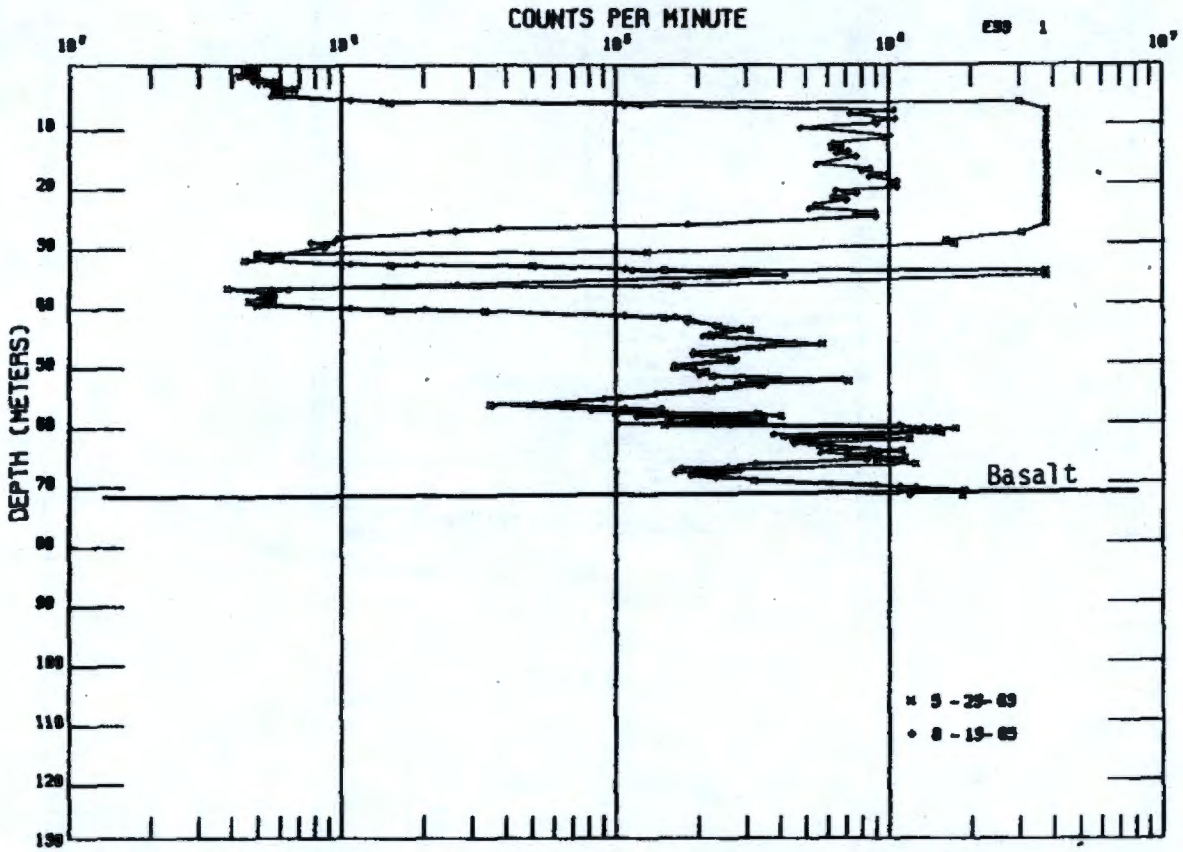
Well 299-E28-8



Well 299-E28-10



Well 299-E28-14



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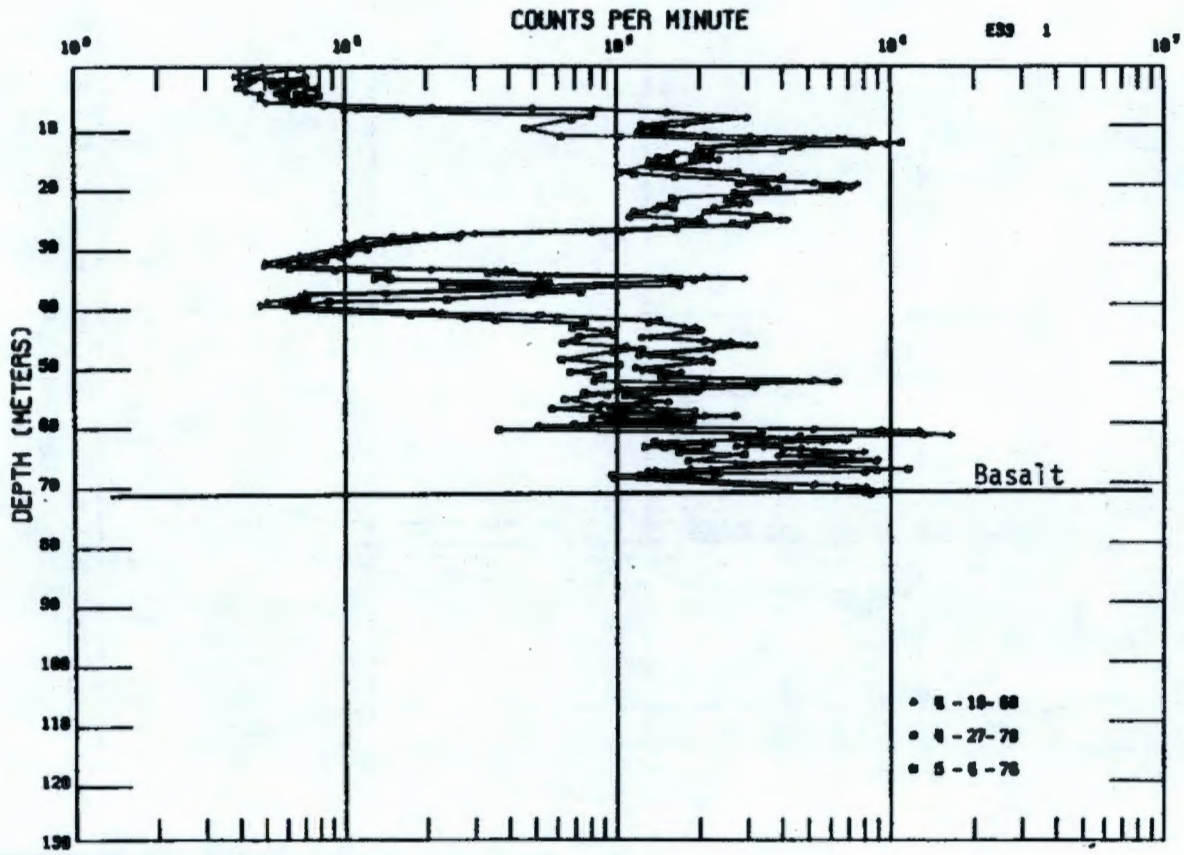
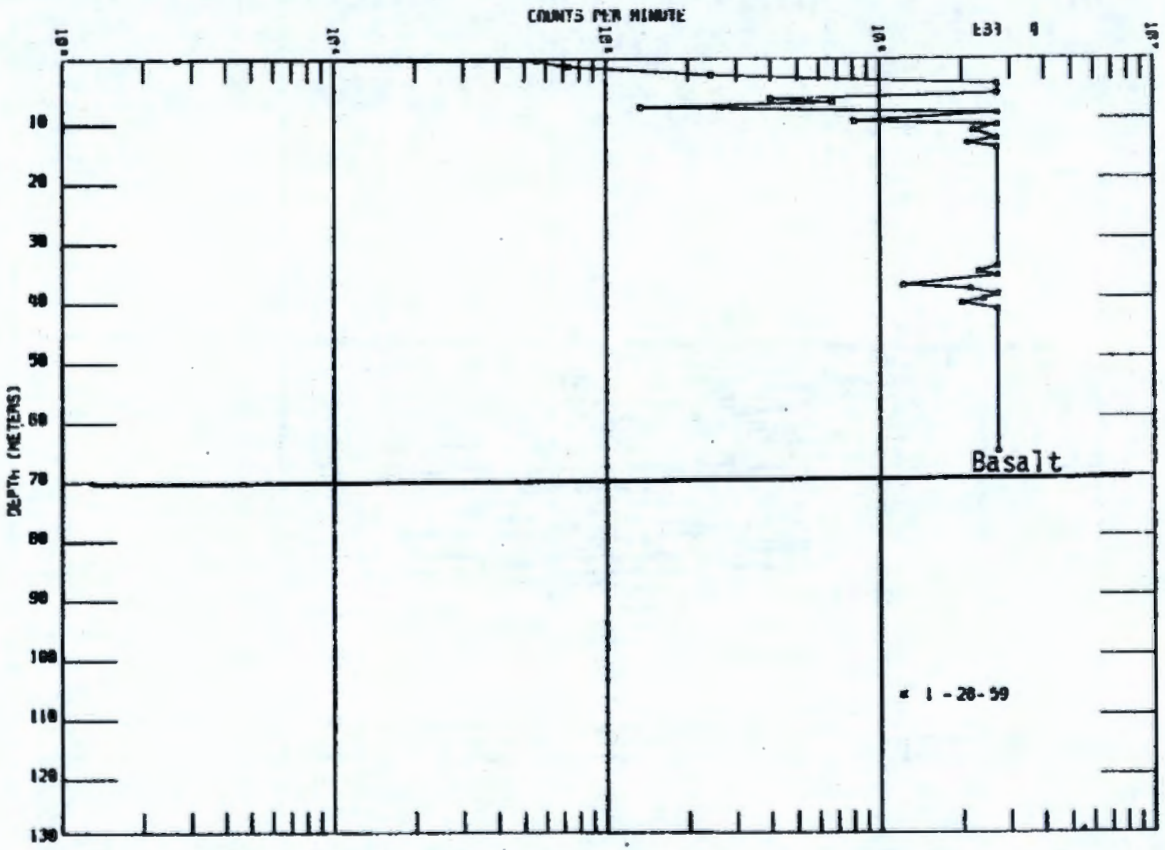
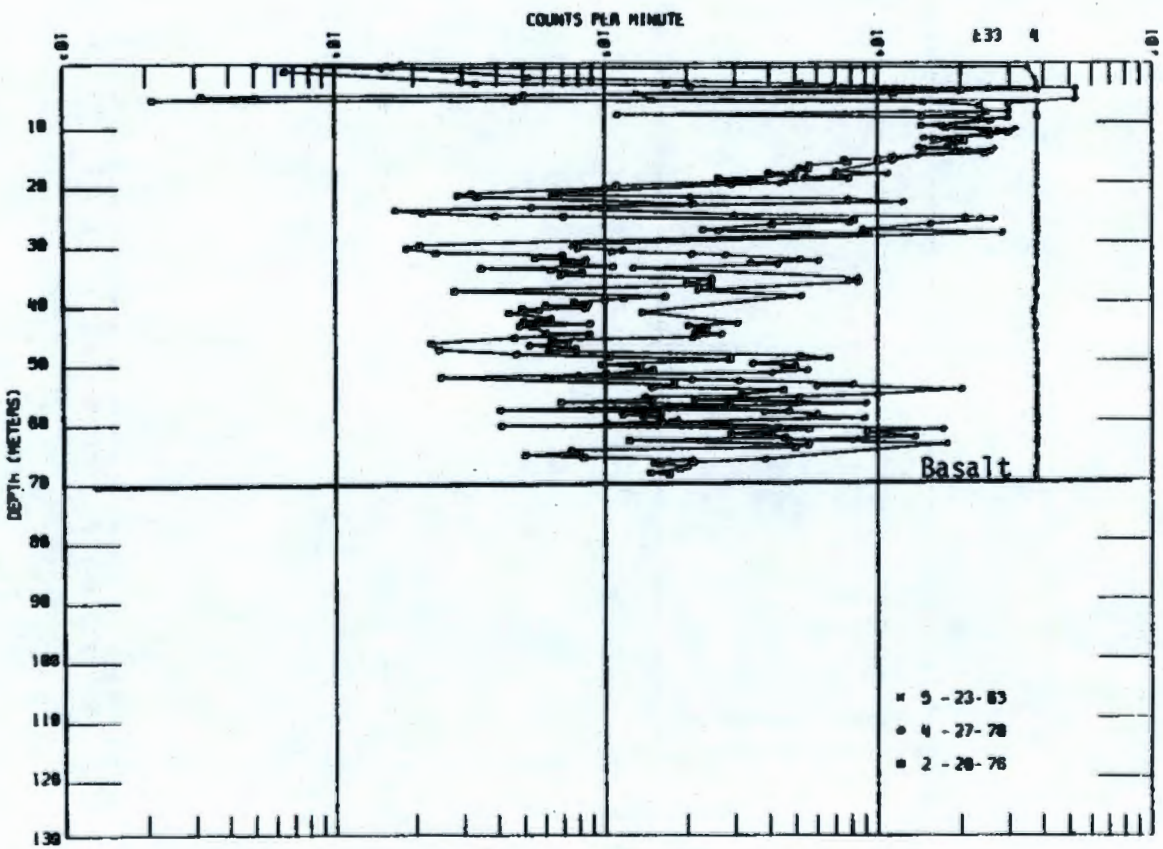


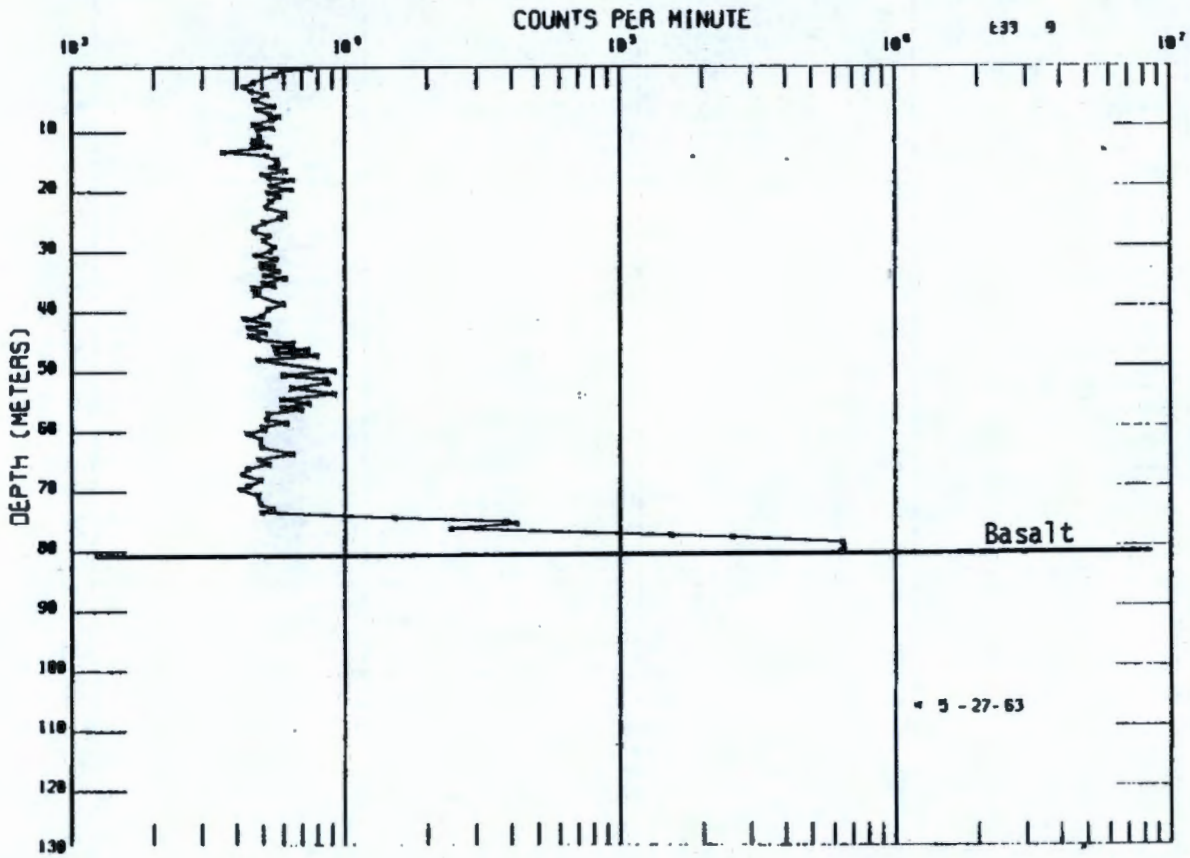
Well 299-E33-1



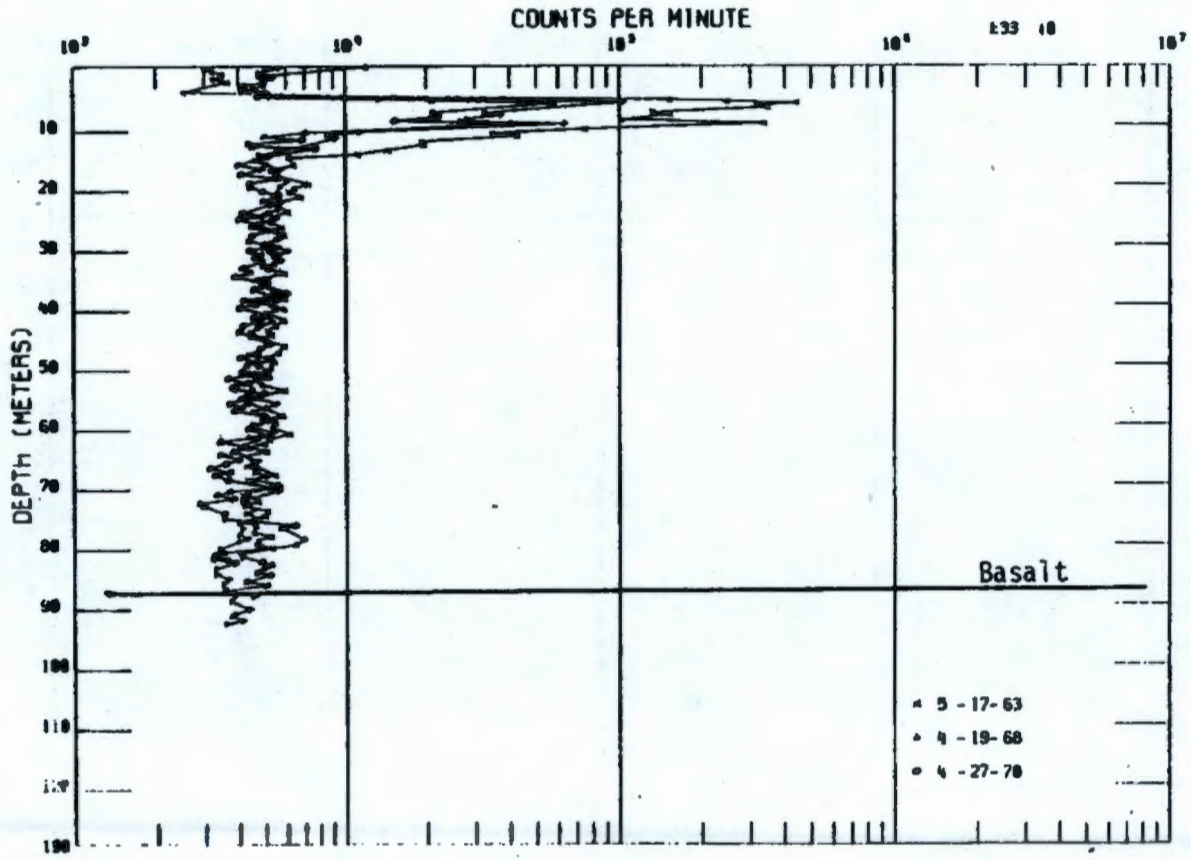
Well 299-E33-1



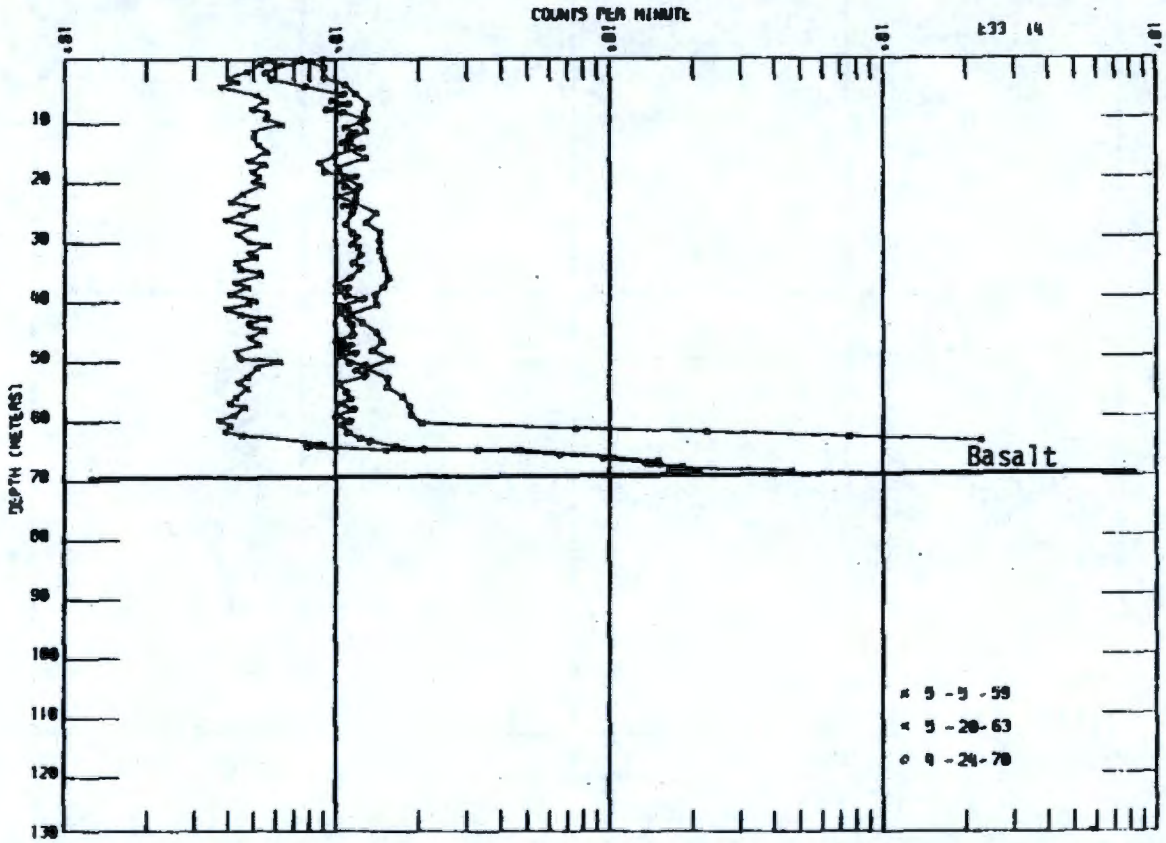
Well 299-E33-4



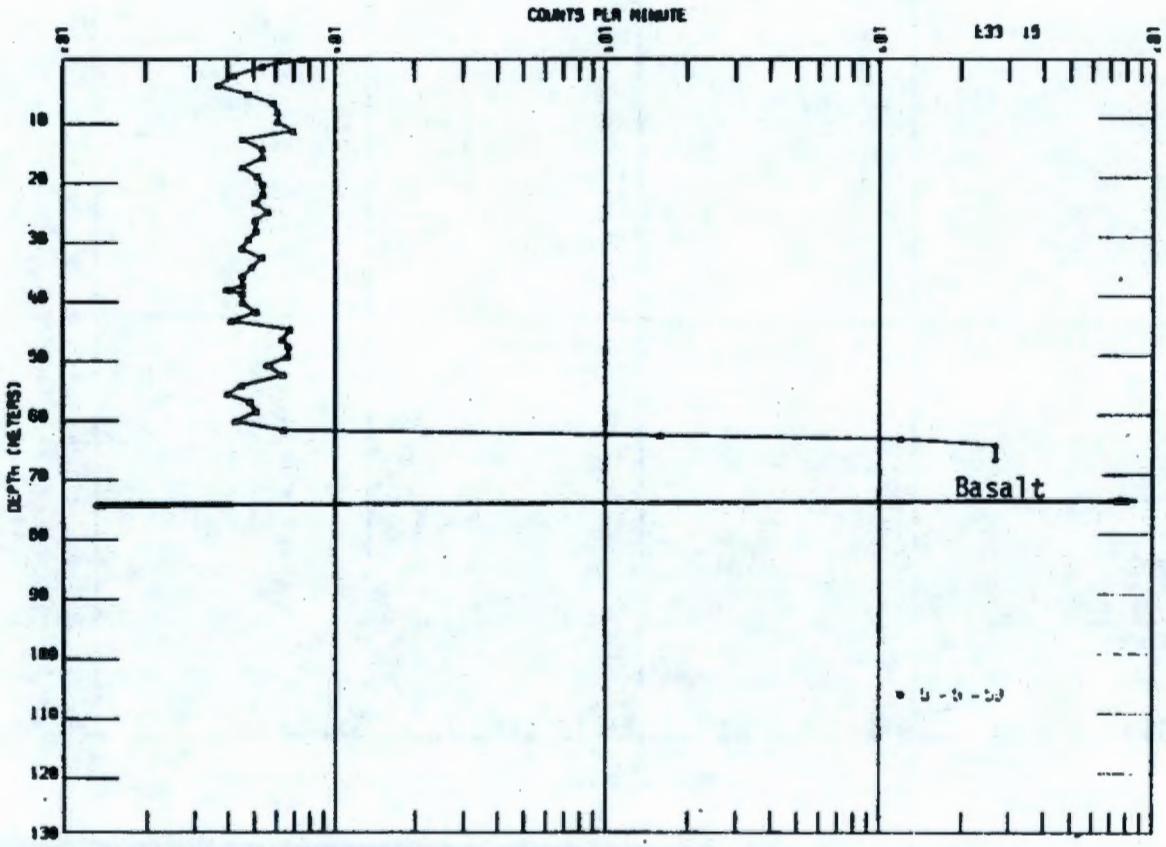
Well 299-E33-9



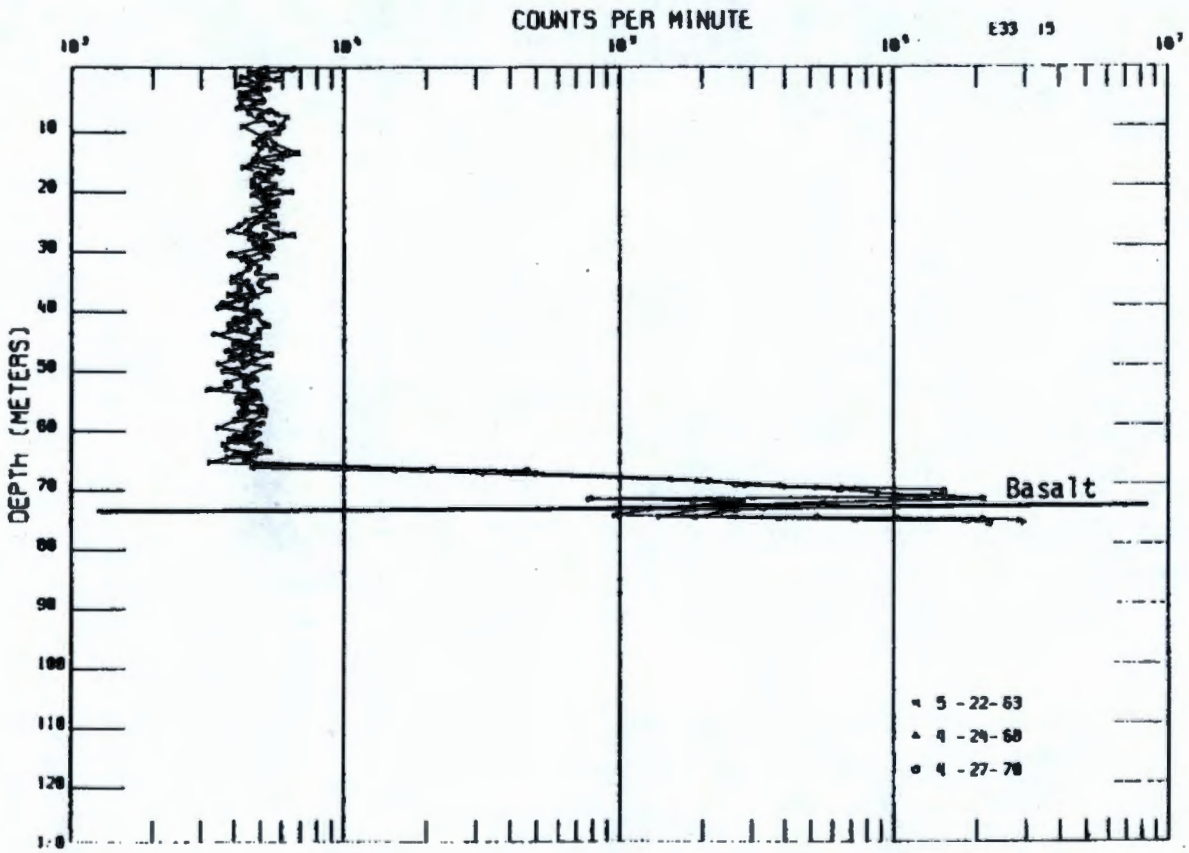
Well 299-E33-10



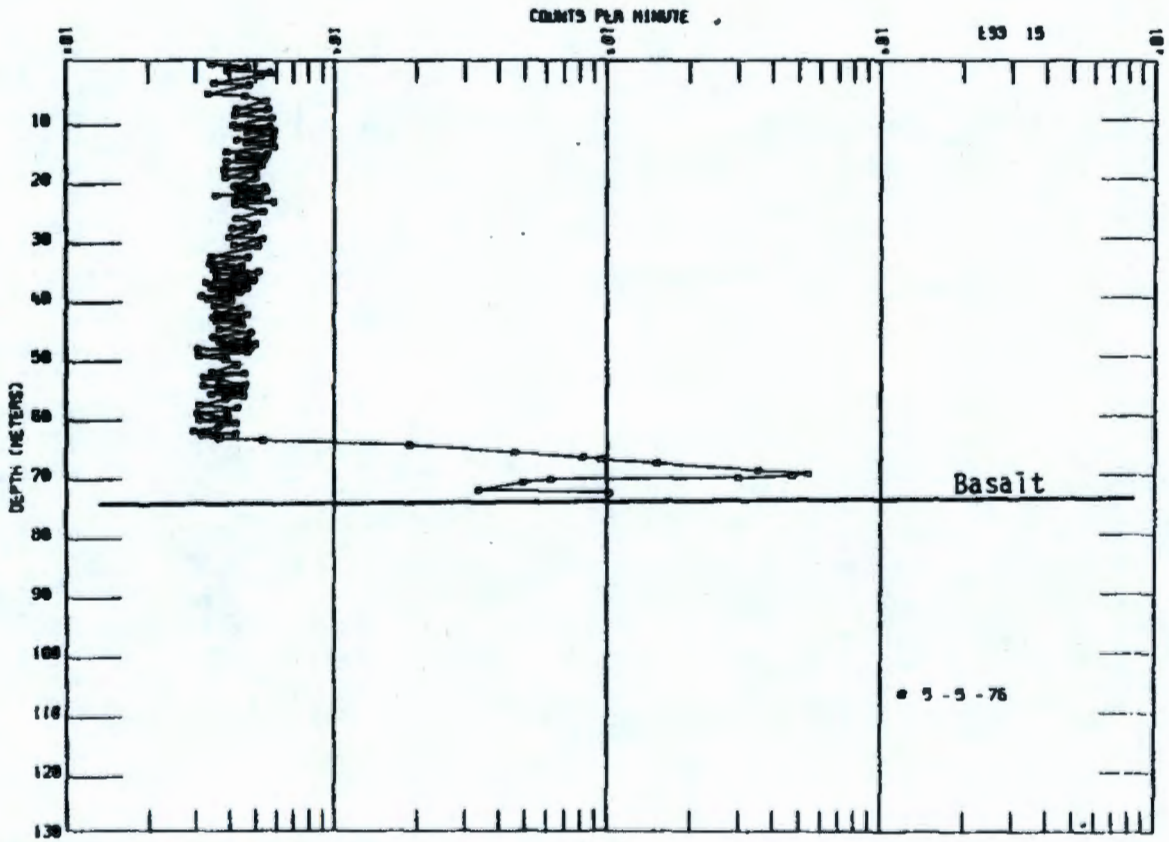
Well 299-E33-14



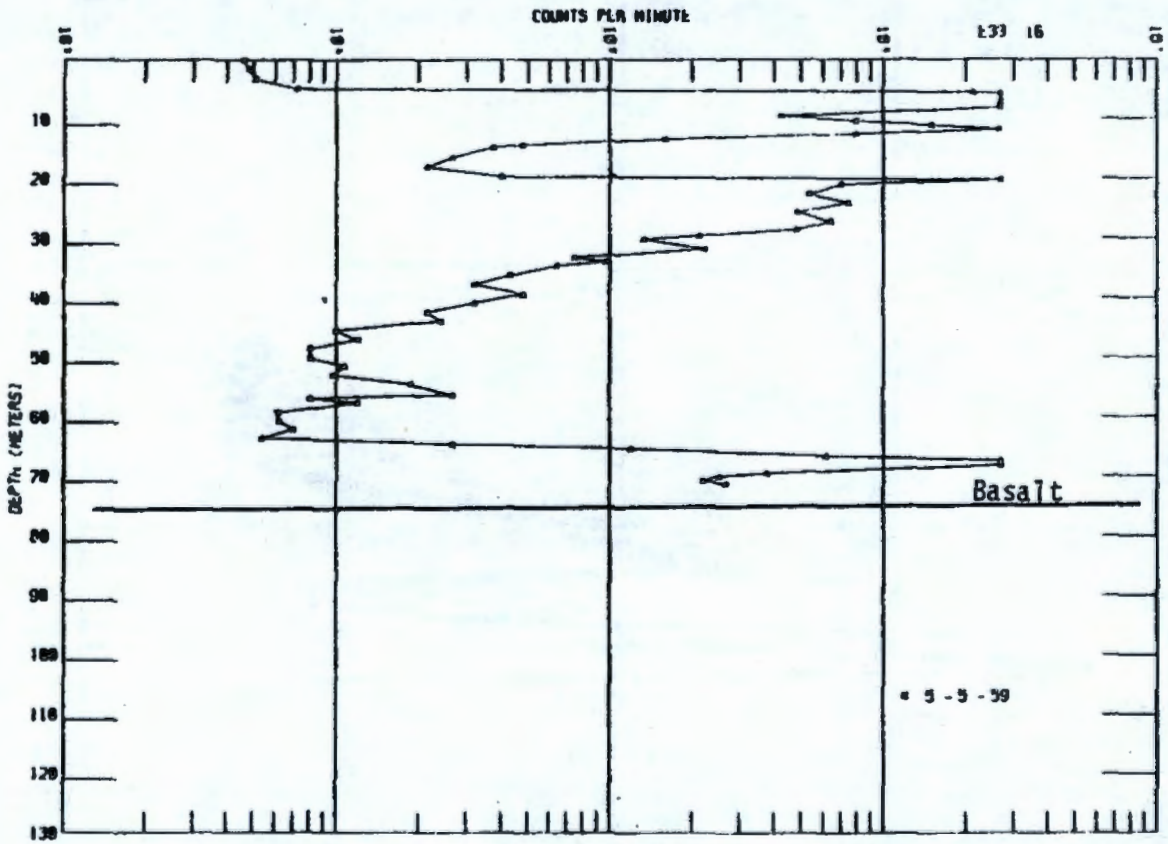
Well 299-E33-15



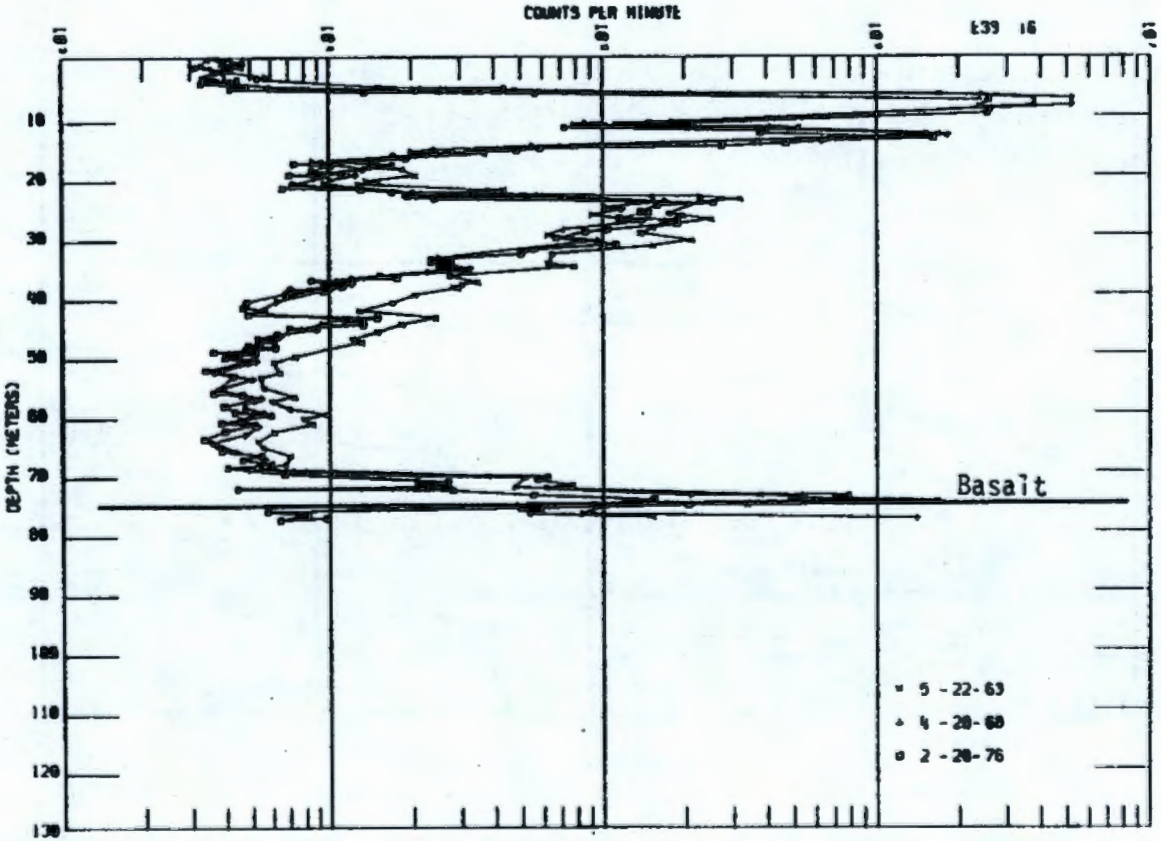
Well 299-E33-15



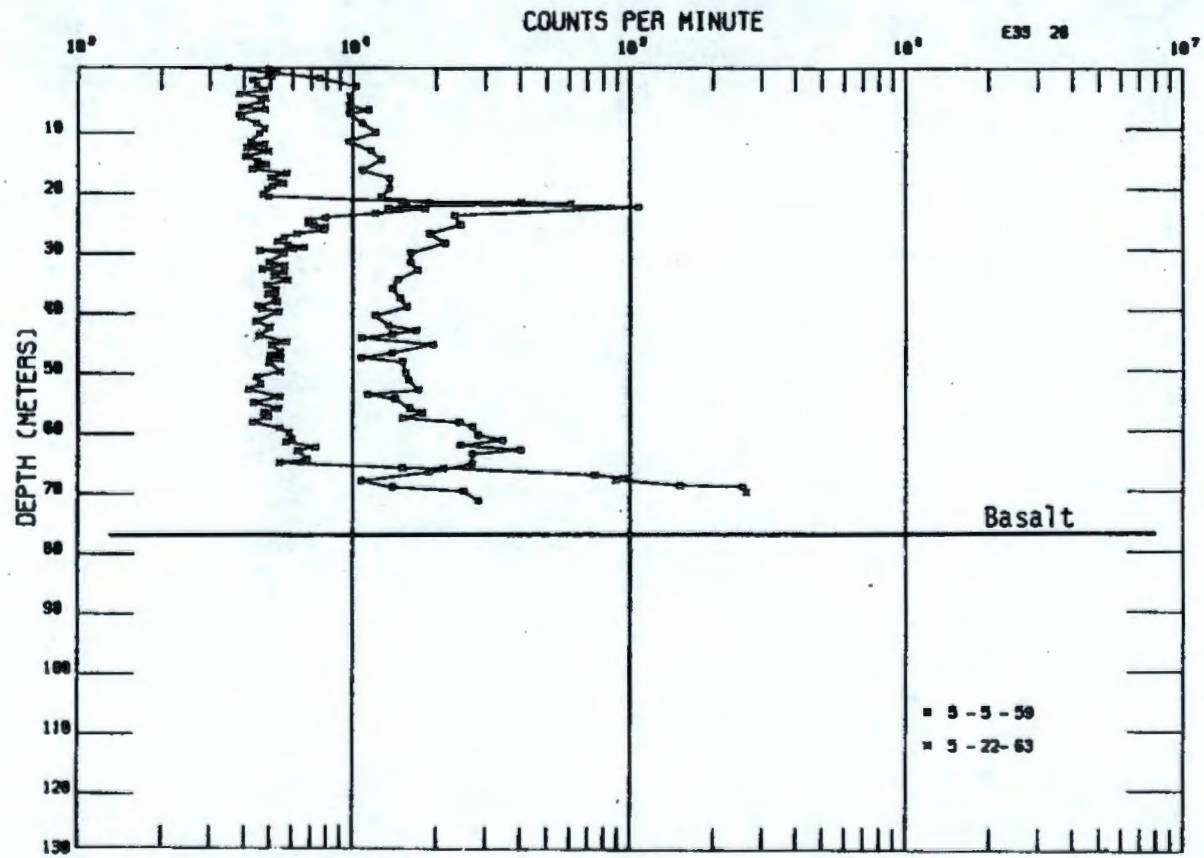
Well 299-E33-15



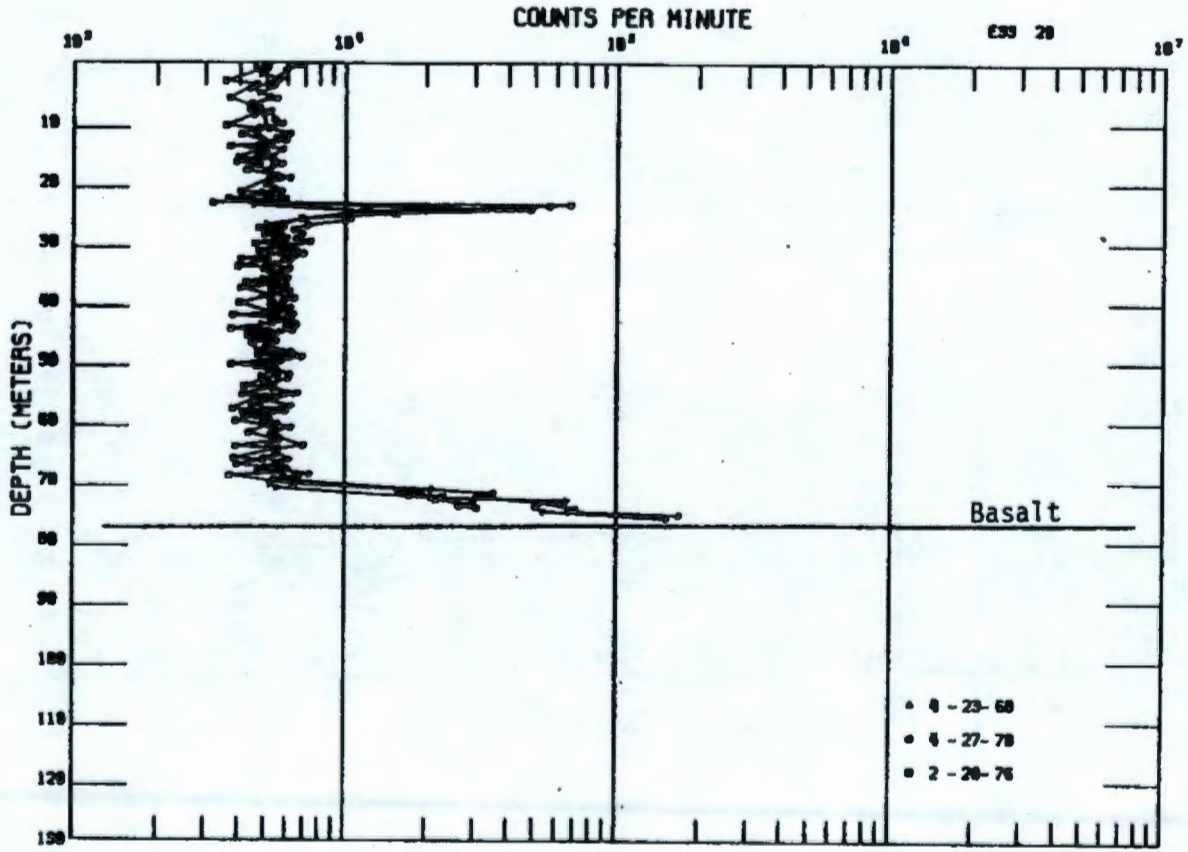
Well 299-E33-16



Well 299-E33-16



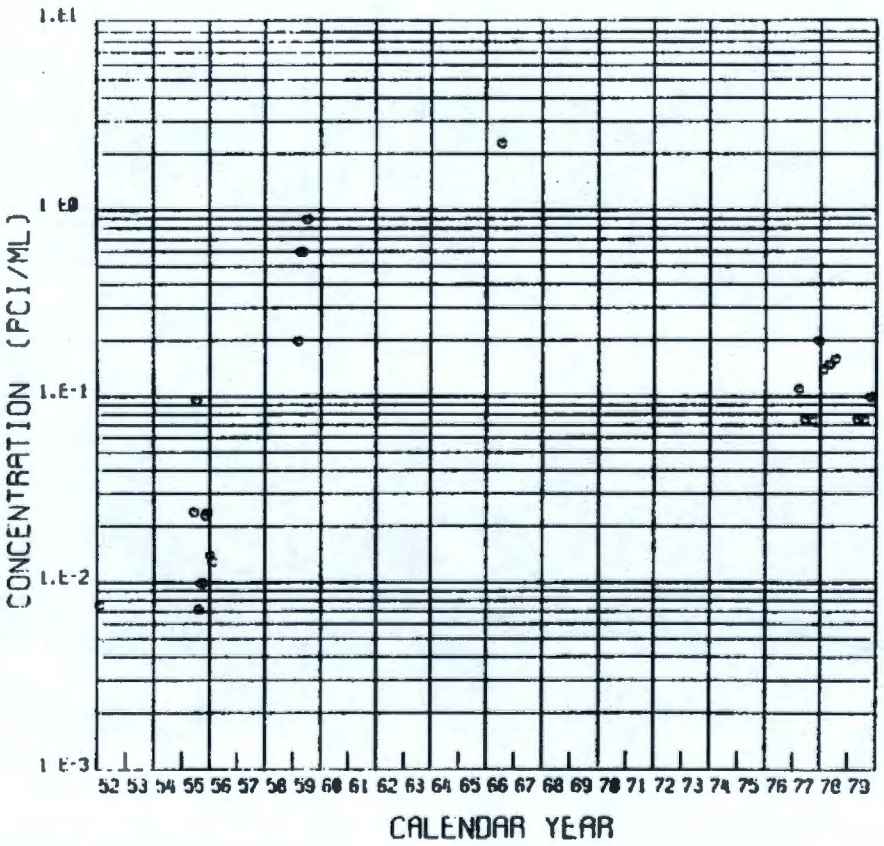
Well 299-E33-20

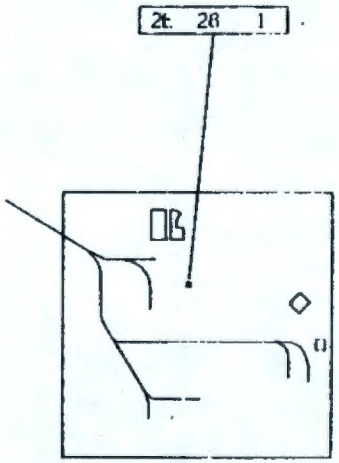


Well 299-E33-20

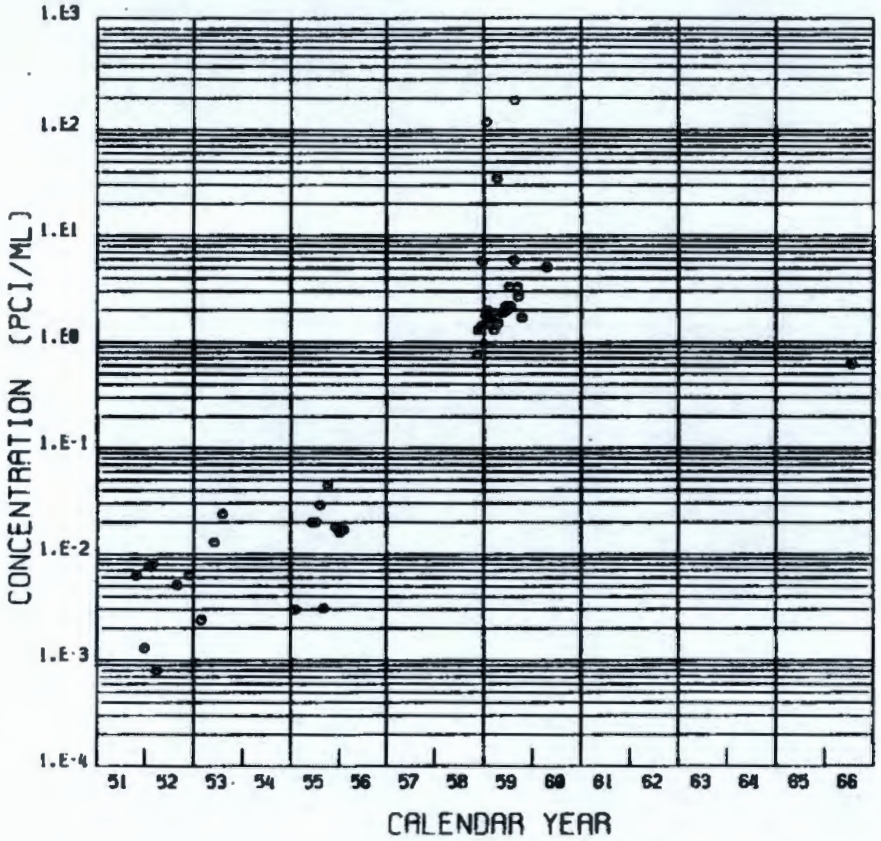
APPENDIX C

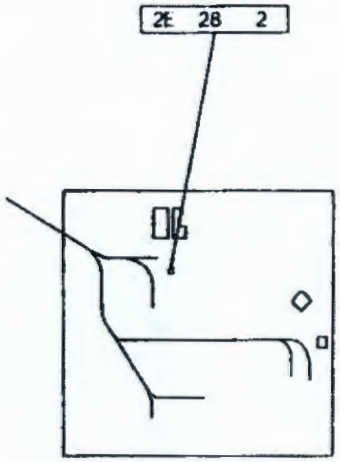
GROUND WATER MONITORING DATA





Well 299-E28-1





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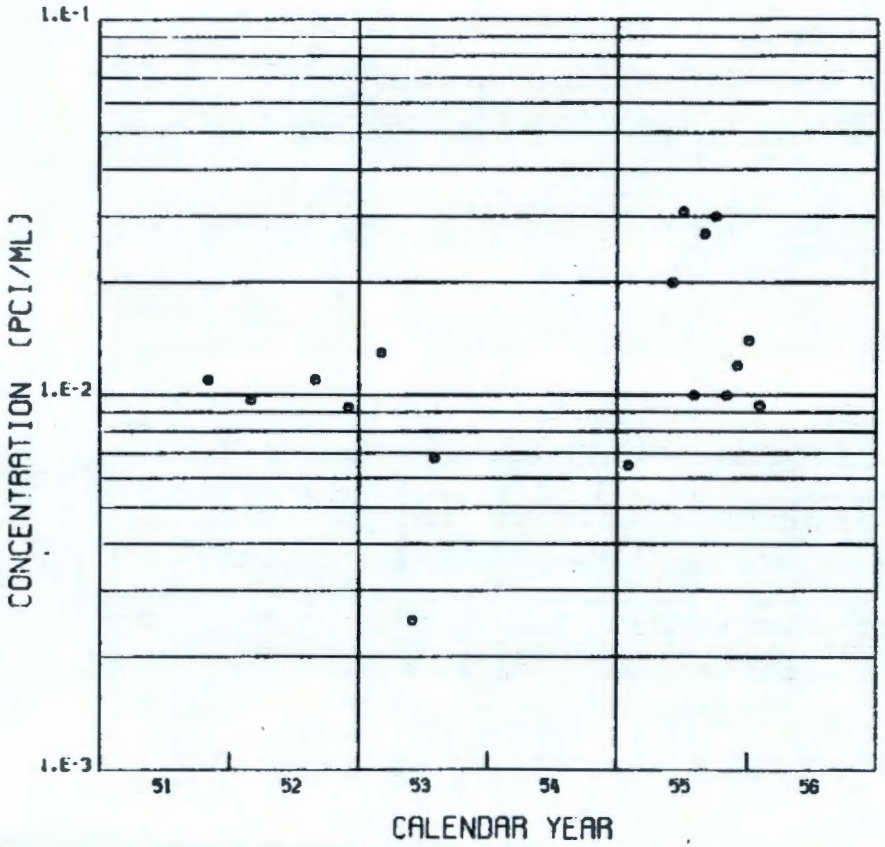
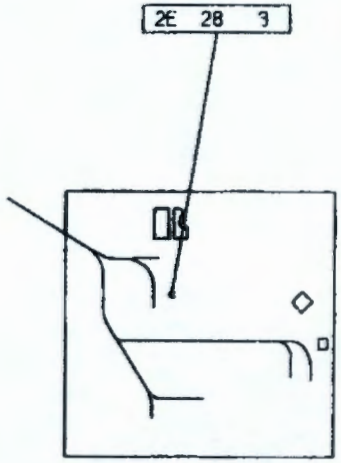
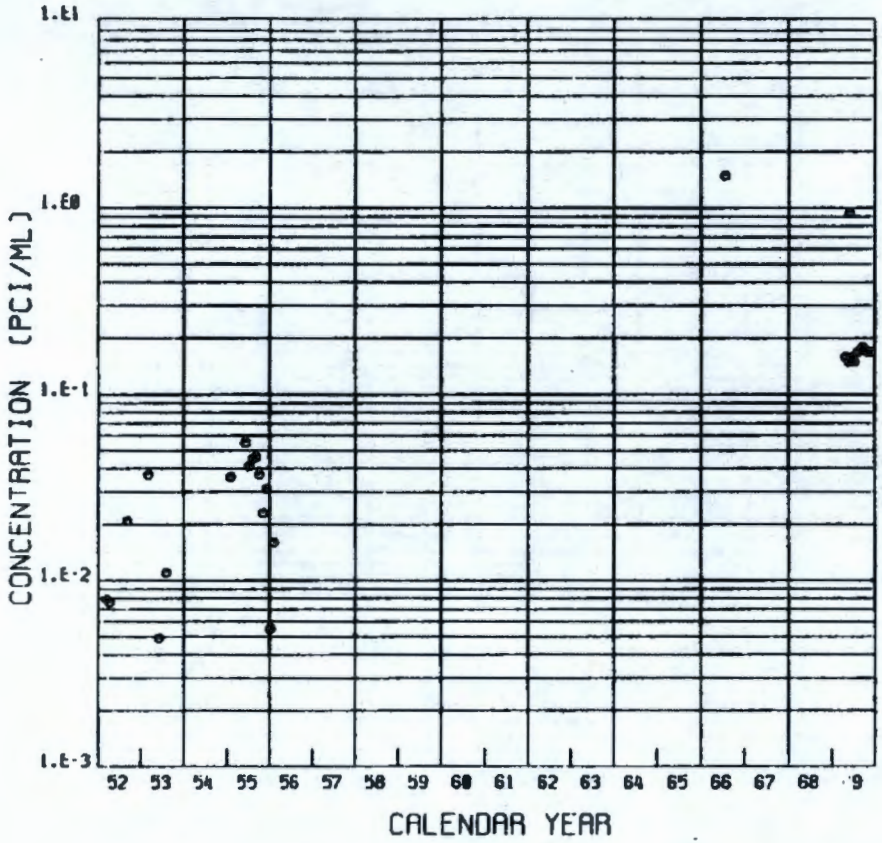
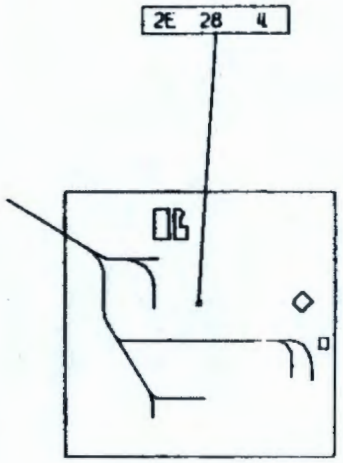


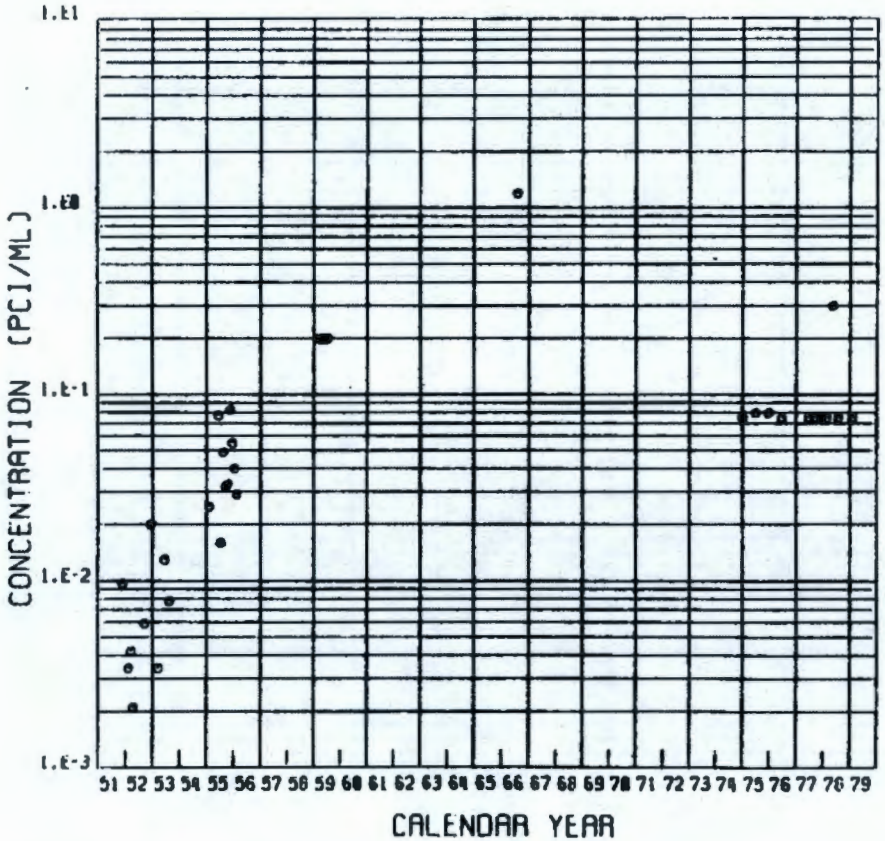


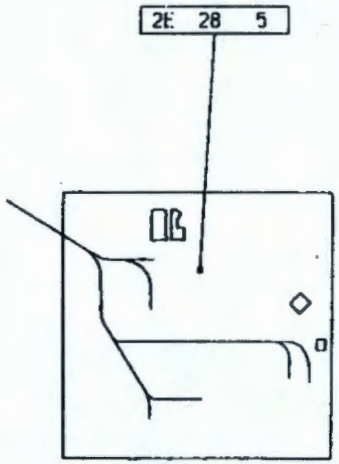
Well 299-E28-3



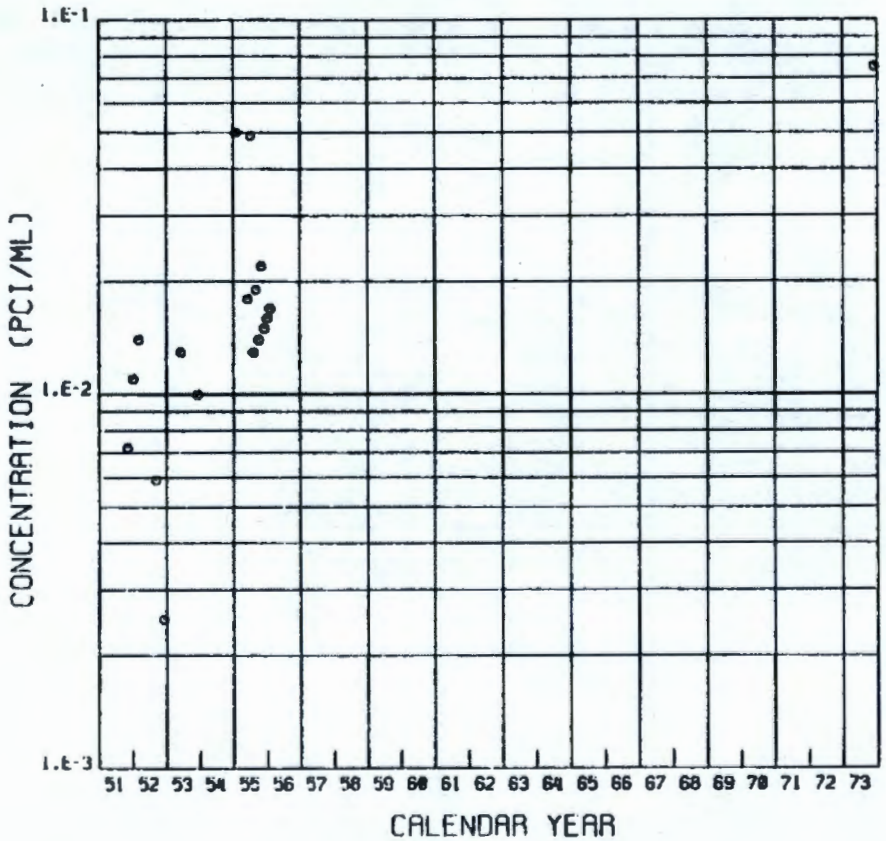


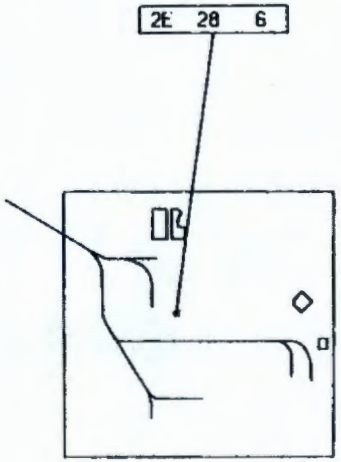
Well 299-E28-4



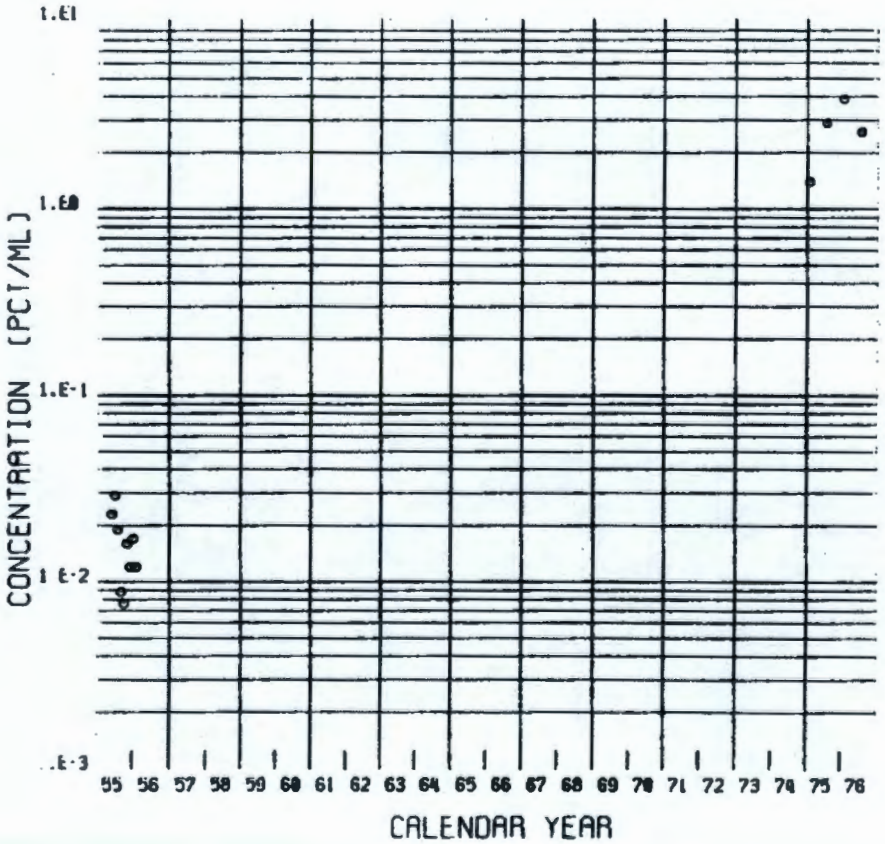


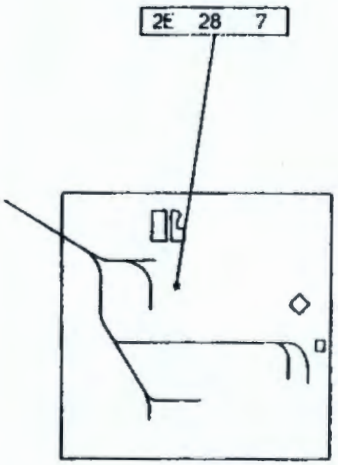
Well 299-E28-5





Well 299-E28-6





Well 299-E28-7

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