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216-S-1 and S-2 Mixed Fission Product Crib Characterization Study

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Environmental Technologies
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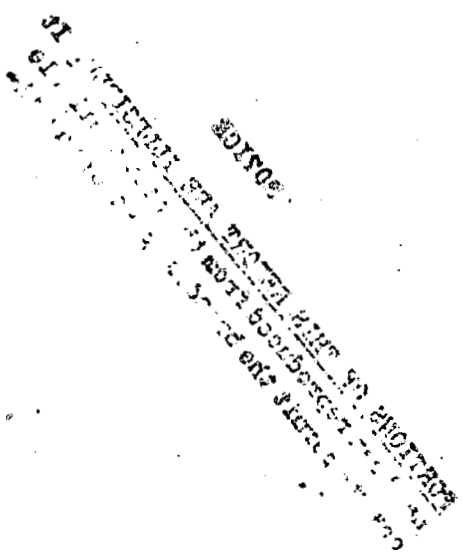

ABSTRACT

The 216-S-1 and 2 crib is an underground structure that was used for the disposal of radioactively contaminated liquid waste at the Hanford Site. The crib received acidic, intermediate level, mixed fission-product waste solutions from 1952 to 1956. The 1980 status of radioactive contaminants in the sediment beneath the crib was investigated. The results indicate that the radionuclide distributions are stable, with no evidence of significant translocations found since the late 1960's.

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EXECUTIVE SUMMARY

The 216-S-1 and 2 waste disposal crib, located on the Hanford Site, was studied in terms of present radionuclide distributions and environmental safety. This crib received $\sim 1.6 \times 10^8$ liters of waste containing $\sim 7.5 \times 10^5$ curies of mixed fission products from 1952 to 1956. Borehole scintillation and gamma spectroscopic profiles of monitoring wells in and around the crib were obtained during this study. Data from previous studies were examined and conclusions, which are based on the comparison of results from present and past studies, are reported.

The results of the study generally confirm the findings of previous studies with respect to the location and stability of radionuclides in the crib sediments. Most of the ^{137}Cs activity is generally restricted to a 10-meter zone beneath the crib bottom (i.e., 10 to 20 meters from the surface). Cesium-137 migrated deepest beneath the S-2 portion of the crib. Historically, ^{90}Sr was widespread beneath the crib, but its distribution in the unsaturated sediments was not determined in this study because in situ measurement of ^{90}Sr is not possible. However, the presence of ^{90}Sr and total beta activity in the saturated sediments beneath the crib was determined by analyzing sediment samples collected when monitoring wells were deepened.

Strontium-90 was detected below the water table in two localized areas beneath the crib. One of these areas is associated with a zone of contamination caused by the casing failure of a ground-water monitoring well within the crib in 1955. A similar cause is suspected, but could not be confirmed, for the other area. These areas appear to be stable and highly localized.

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CONTENTS

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INTRODUCTION

The U.S. Department of Energy's (DOE) Hanford Site is located in south-central Washington State (Figure 1). The site has served primarily as a plutonium production facility since its inception in 1943.

The chemical separation facilities at Hanford are located in the central portion of the site in two exclusion areas known as the 200 East and 200 West Separations Areas (see Figure 1).

Some low-level, liquid radioactive wastes from chemical processing operations are discharged to the ground via subsurface structures of various types. One type of subsurface disposal structure, known as a crib, is used for the underground dispersal and percolation of liquid waste into the sediments.

The 216-S-1 and 2 crib site is located in the 200 West Separations Area (see Figure 1). The crib received large volumes of acidic, mixed fission-product waste solutions from the Redox building (Figures 1 and 2).

The status of radionuclide distributions beneath the 216-S-1 and 2 crib was determined in this study in support of the Contaminated Soils and Sediments Program. The study provides information and data from which options for the permanent disposition of this site and similar sites may be developed.

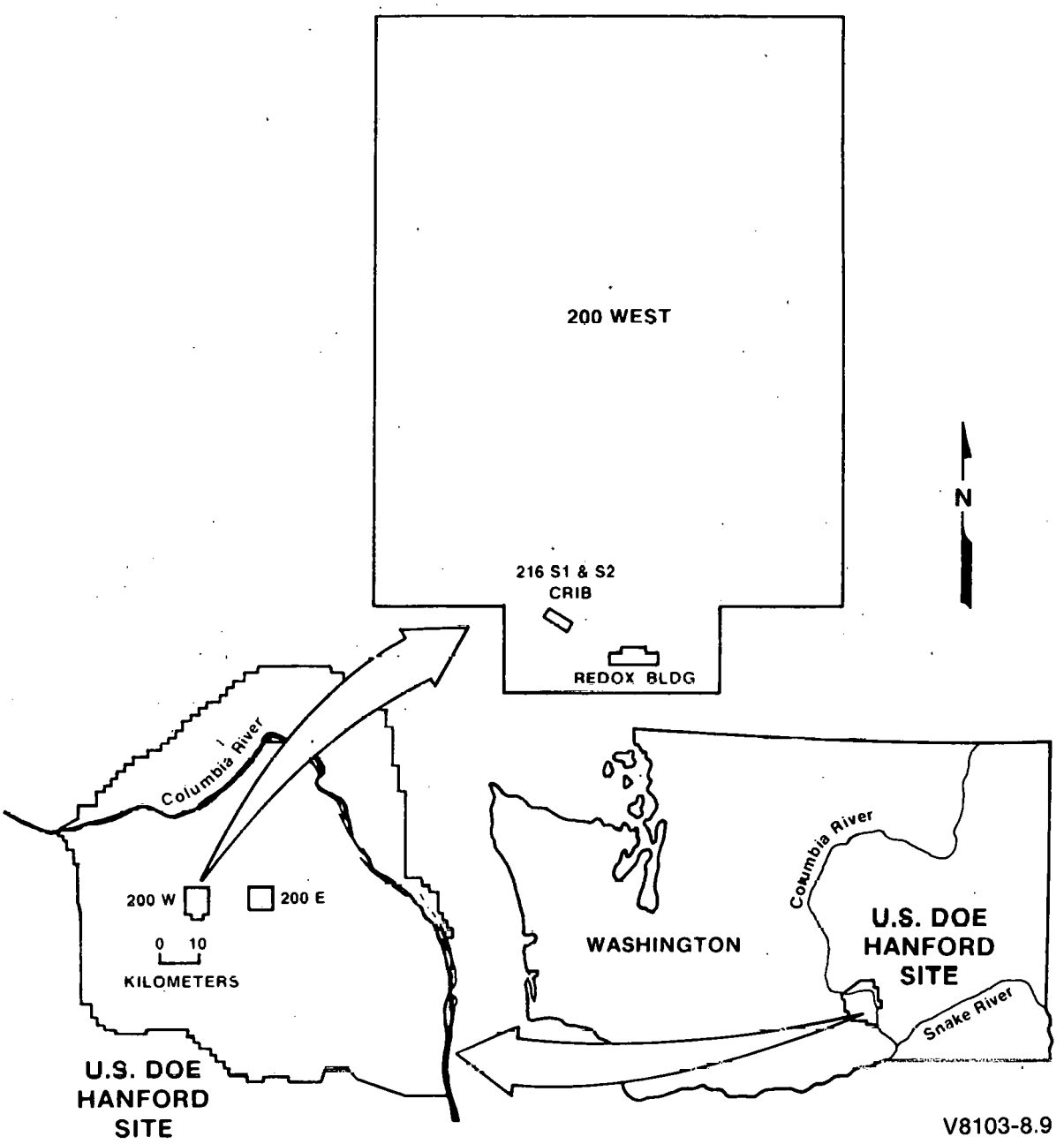

FIGURE 1. Location of the 216-S-1 and 2 Crib.

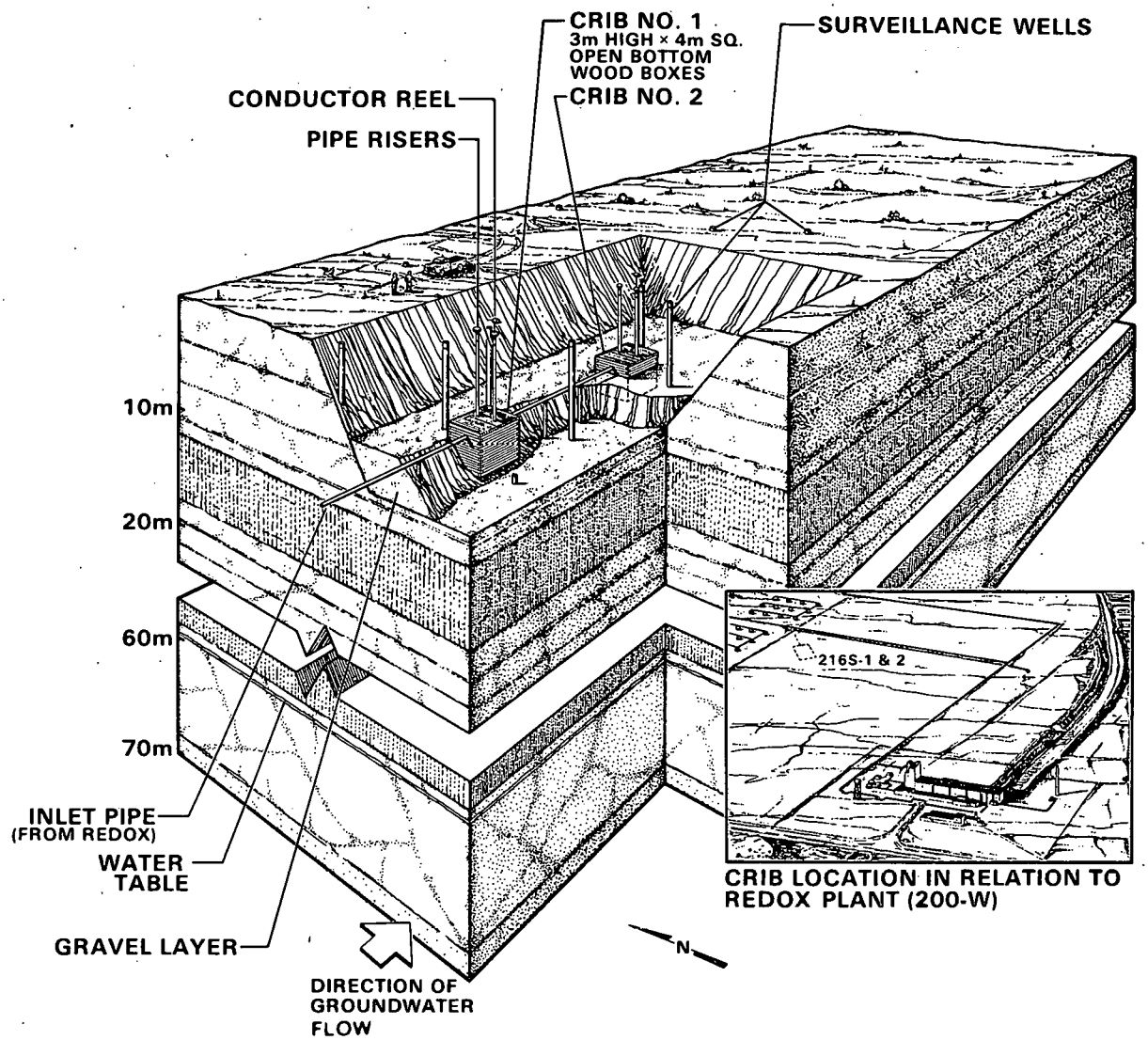

FIGURE 2. Block Diagram of the 216-S-1 and 2 Crib and Location Relative to Redox Plant.

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SITE HISTORY

The 216-S-1 and 2 crib was constructed in 1950 and 1951. Design of the crib is presented in Figures 2 and 3. The crib is located ∿430 meters northwest of the Redox building. The bottom of the excavation is ∿10 meters below grade with bottom dimensions of 12.2 by 27.4 meters and 45-degree side slopes (see Figure 3). The bottom 3 meters were filled with screened, crushed stone greater than 1.3 centimeters diameter. Two open-bottomed, square, wooden crib boxes, 3.7 meters on a side and 2.9 meters high, were placed 1.8 meters into the gravel layer. The crib boxes were constructed with 15- by 20-centimeter timbers and cross braces, as shown in Figure 3. The two crib boxes are connected in series with overflow from the S-1 box flowing into the S-2 box via a pipe.

Before the facility was put into service, three vadose zone (unsaturated) monitoring wells, 299-W22-1, -2, and -3, were drilled to a depth of 45 meters (Haney and Linderoth, 1959).

The 216-S-1 and 2 facility received waste from the cell drainage collection tank, D-1, and the condensate receiver tank, D-2, located in the Redox building. Table 1 presents the radionuclide inventory for the waste streams discharged to the 216-S-1 and 2 crib (Hanson et al., 1973). Monthly waste stream radionuclide inventories from the D-1 and D-2 tanks, respectively, are given in Ruppert and Heid, 1954; Paas and Heid, 1955; and Heid, 1956.

The average pH of D-1 and D-2 wastes was 2.1 (Rhodes, 1956). Waste was discharged to the crib in batches of about 19,000 liters at an average rate of 10 batches per day (Haney and Linderoth, 1959). The crib was in service from January, 1952 to January, 1956.

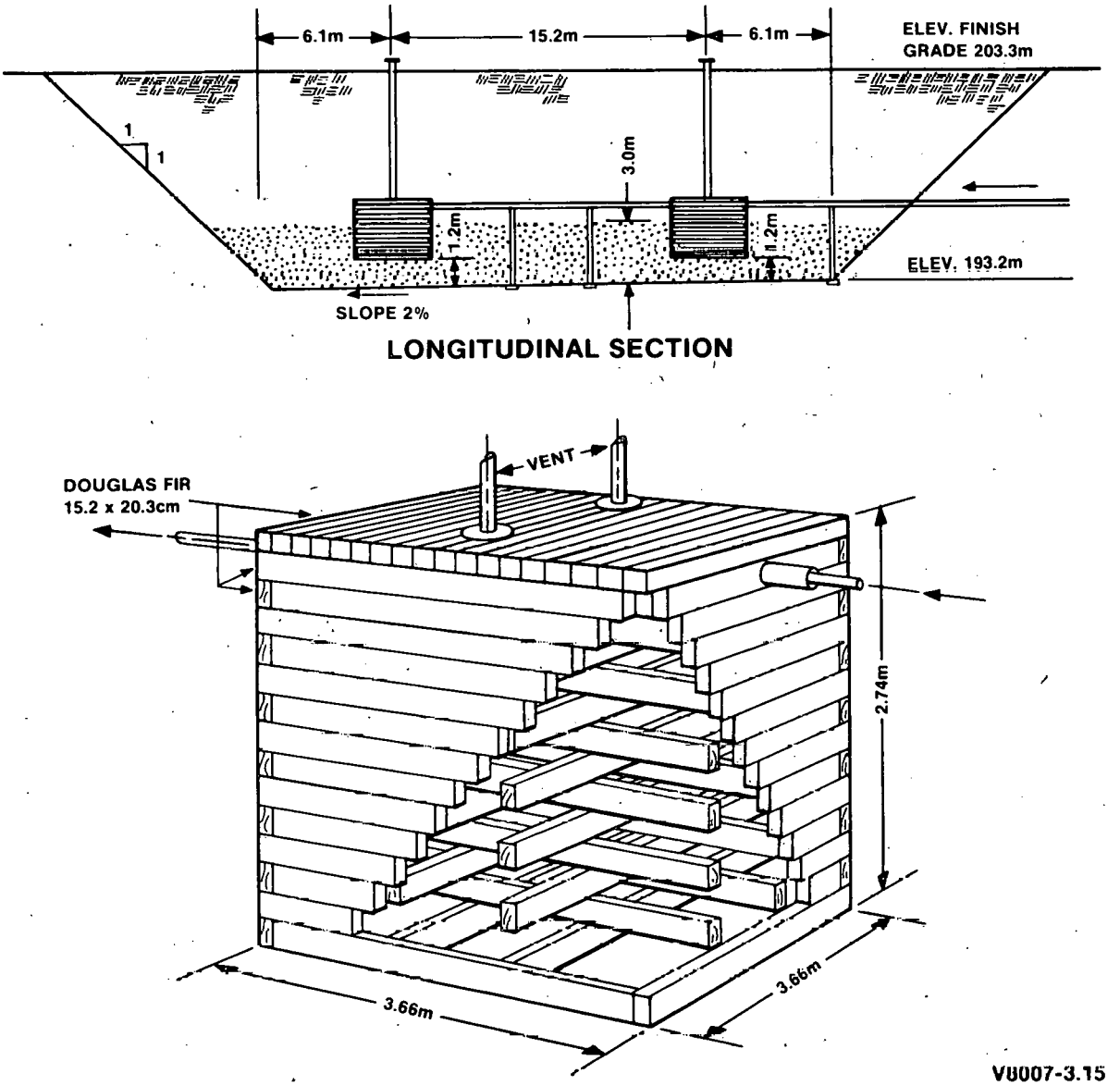

FIGURE 3. Construction Detail of 216-S-1 and 2 Crib.

TABLE 1. Radionuclide Inventory of Waste Discharged to the 216-S-1 and 2 Crib.*

Year	Volume, ℓ	Beta, Ci	^{90}Sr, Ci	^{137}Cs, Ci	^{106}Ru, Ci	^{60}Co, Ci	Pu, g	^{238}U, kg
1952	1.43E+7	5.56E+2	2.00E+0	2.00E+0	2.00E+0	-	8.00E+0	1.50E+1
1953	4.69E+7	4.53E+4	1.81E+2	1.51E+2	1.81E+2	6.00E-1	4.90E+1	9.30E+1
1954	4.92E+7	3.08E+5	1.23E+3	1.03E+3	1.23E+3	4.10E+0	4.44E+2	8.39E+2
1955	4.96E+7	3.96E+5	1.58E+3	1.32E+3	1.59E+3	5.30E+0	6.97E+2	1.32E+3
1956	2.50E+4	1.16E+2	1.00E+0	-	1.00E+0	-	2.00E+0	4.00E+0
Sum	1.50E+8	7.50E+5	3.00E+3	2.50E+3	3.00E+3	1.00E+1	1.20E+3	2.27E+2
Decay (1/81)	1.50E+8	<6.03E+4	1.58E+3	1.37E+3	5.15E-4	3.24E-1	1.20E+3	2.27E+3

*From Hanson et al., 1973.

Well 299-W22-3, one of the three original monitoring wells, was deepened from 45 to 93 meters and perforated from 63 to 93 meters in January 1955. This was done to provide a ground-water monitoring well for the crib. In June 1955, the well was found to contain liquid waste within 15 meters from the ground surface. Waste had flowed to the bottom of the well and into the saturated sediments through perforations in the casing. This indicated that the well casing had failed near the bottom of the crib. The leak occurred in the part of the well that contained new casing, and since the old casing had not failed in the previous 3-year period before the well was deepened, the casing failure was probably not due to the acidic waste corroding the casing. Another source of a casing failure is a weld in the casing. An examination of driller's logs for this well shows that two welds in the casing are located within 1 meter from the bottom of the crib. Either weld could have provided an entry point for wastes to flow into the well. Studies of the liquid contained in the well were conducted and will be presented in the "Previous Studies" section of this report. Early in August 1955, well 299-W22-3 was filled with sand, and within 6 months, the crib was removed from service.

Drilling of ground-water monitoring wells inside the crib did not resume until after the crib was removed from service. Therefore, no monitoring data regarding soil or ground-water radionuclide concentrations were obtained for this facility until the deep-well drilling program of 1955.

Ground-water monitoring data from 1956 to 1964 and concerning the 216-S-1 and 2 crib deal with analyses of ^{90}Sr concentrations in ground-water samples collected from well 299-W22-2, which monitors the crib. Reported ^{90}Sr concentrations in this well exceeded the Table 1 (controlled area) limit presented in ERDA Manual Chapter (MC) 0524 (ERDA, 1975) until 1961. Work by Raymond and McGhan (1967) indicated that ^{90}Sr concentrations under the crib in 1966 also exceeded the Table I limit.

Monitoring wells near the 216-S-1 and 2 crib have been studied using a gamma scintillation probe. Scintillation profiles have been prepared at various times from 1958 to the present for selected wells around waste disposal sites. These profiles are presented in Fecht et al., 1977, and in Additon et al., 1978.

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ENVIRONMENTAL CHARACTERISTICS

The environmental characteristics considered in this study are climate, biology, geology, and hydrology. These characteristics have the potential to affect radionuclide distributions around the 216-S-1 and 2 crib and will be discussed briefly. General characteristics for the Hanford Site are discussed in the environmental impact statement (ERDA, 1975).

CLIMATE

The three climatic factors that influence the radionuclide distributions at the 216-S-1 and 2 crib site are precipitation, temperature, and wind. The climate at Hanford is dry and mild with occasional high-velocity winds. The dry climate favors the deep-rooted plant species growing on the site and facilitates the upward movement of near-surface water by capillary action caused by evaporation of water at the ground surface. Both factors provide potential paths for the upward translocation of radionuclides near the ground surface. The occasional high-velocity winds can erode the surface sediments as evidenced by the many active sand dunes on the Hanford Site. Any radionuclides reaching the ground surface could be transported from the 216-S-1 and 2 crib site by the winds. A more detailed description of the Hanford climate is presented in the Hanford Site environmental impact statement (ERDA, 1975).

BIOLOGY

The Hanford Site is classified ecologically as a shrub-steppe grassland. The dominant vegetative type within the 200 Areas at Hanford, the sagebrush/cheatgrass community, surrounds the 216-S-1 and 2 crib site. The site has been cleared of living vegetation and is kept free of vegetation through annual herbicide applications, in order to inhibit migration of near-surface contamination to the ground surface by deep-rooting plants. This has been done routinely since 1978. Before the herbicide applications, there was some growth of tumbleweed

(*Salsola kali*), cheatgrass (*Bromus tectorum*), and gray rabbitbrush (*Chrysothamus nauseosus*) on the crib site. Currently, there are only a few small tumbleweeds and bursage (*Ambrosia acanthicarpa*) growing on the site. The area is surrounded by large rabbitbrush plants, tumbleweeds, bursage, cheatgrass, hoary aster (*Machaeranthera canescens*), tumblemustard (*Sisymbrium altissimum*), goat's beard (*Tragopogon* sp.) and a few bunch grasses, such as Indian ricegrass (*Oryzopsis hymenoides*).

Mammals traverse the crib site, but the lack of vegetative cover reduces the desirability of the site as a habitat for small mammals. The tracks of black-tailed jackrabbit (*Lepus californicus*), Nuttall's cottontail (*Sylvilagus nuttallii*), coyote (*Canis latrans*), and Great Basin pocket mouse (*Perognathus parvus*) have been seen on and near the crib site. Burrowing rodents represent potential dispersal agents for the near-surface radioactive materials at the crib site. These burrowing animals are also prey for coyotes and other carnivores that inhabit the Hanford Site.

Another potential biological transport mechanism for radionuclides from the crib site is represented by the harvester ant (*Pogonomyrmex owyheei*) colonies found inside the devegetated area. Harvester ants are a known food source of the side-blotched lizard (*Uta stansburiana*), which inhabits the Hanford Site. In addition, these insects have the potential to transport small amounts of radionuclides to the surface as a result of their tunneling activities, which can reach depths of 3 to 4 meters (Klepper et al., 1979).

GEOLOGY

Disposal of radioactive wastes to the ground is possible because waste-sediment interactions provide the necessary retention of radionuclides on the sediment column. The sediment column influences waste retention by chemical interactions with the radionuclides and by physical interactions with the liquid, resulting in lateral spreading of the waste. Knowledge of the geology beneath a crib is required to understand radionuclide distributions.

The Separations Area lies on a broad bar of sand and gravel deposited by flood waters from catastrophic Pleistocene floods. This flood bar is commonly known as the 200 Areas Plateau, and its surface and near-surface unconsolidated sands and gravels comprise the Hanford formation (Figure 4). At the 216-S-1 and 2 crib site, the Hanford formation sediments were underlain by the previous surface soil, known as early Palouse soil. This soil apparently was weathered, wind-blown sedimentary material from the underlying Ringold Formation.

Stratigraphic cross sections through the 216-S-1 and 2 crib are presented in Figures 5 and 6. A plan view map showing the cross sections and location of wells used to draw the geologic cross sections is presented in Figure 7. The following description of formations is adapted from Tallman et al. (1979).

Hanford Formation

The Hanford formation in the vicinity of the 216-S-1 and 2 crib site is generally about 40 meters deep. Because the Hanford formation resulted from multiple Pleistocene floods, the sedimentary deposits found within this formation are complex. There is a general decrease in coarseness downward, suggesting that the main, higher-velocity current of the later floods may have been closer to the 200 Areas Plateau than the main current of the earlier floods. Receding waters during waning flood stages created channels in some areas, which were filled by succeeding floods, leaving anomalous gravelly and very coarse sand layers deeper in the Hanford formation. Periods of low flow during these floods allowed the deposition of silt stringers that occur throughout the Hanford formation.

Early Palouse Soil

The fine sand and silt that underlie the Hanford formation appears to be a wind-blown deposit similar to the loess soil in areas of eastern Washington known as the Palouse. This early Palouse soil is approximately 5 to 8 meters thick in the 216-S-1 and 2 crib area and is thought to be wind-reworked and -redeposited fine-grained sand and silt of the underlying Ringold Formation sediments.

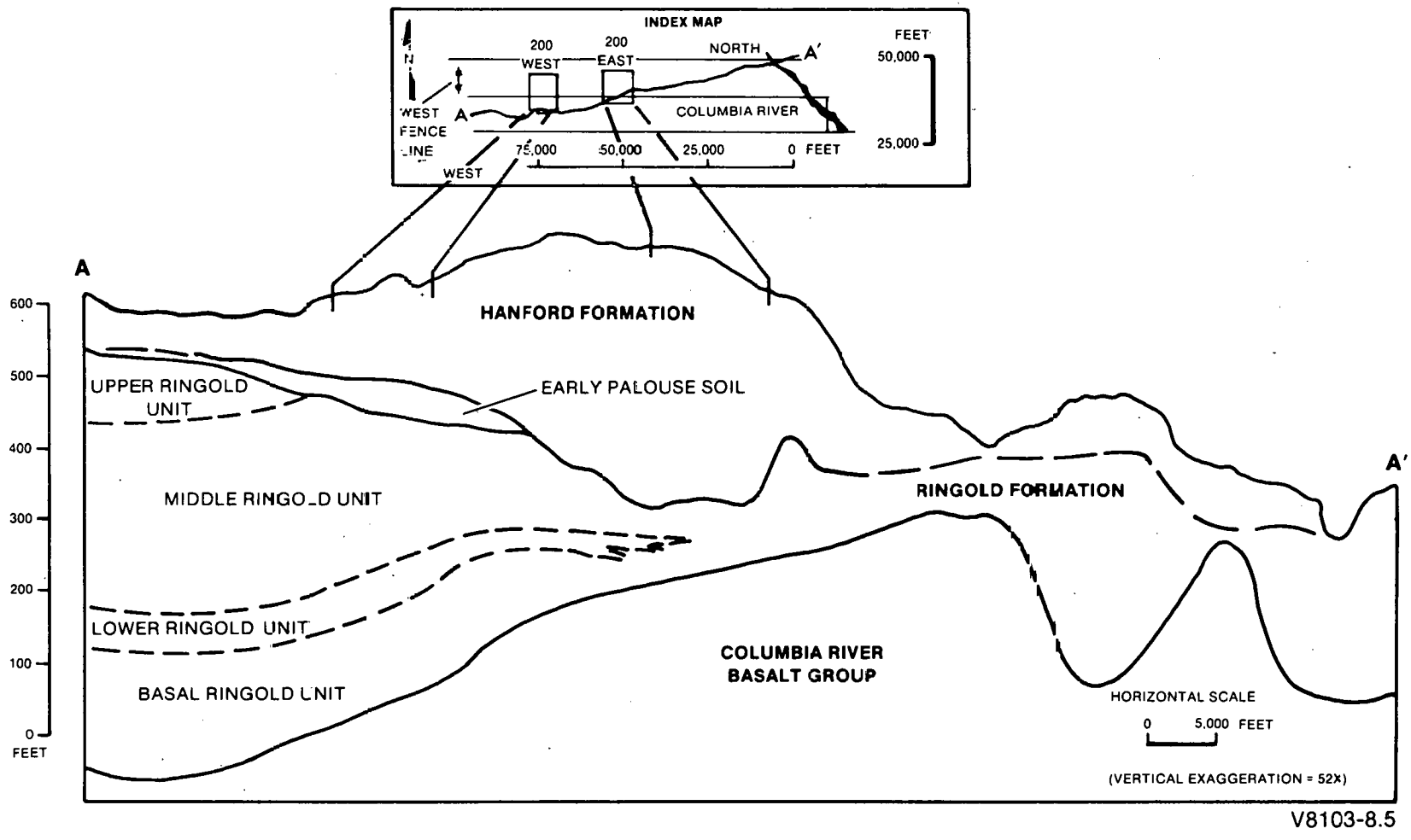

FIGURE 4. Geologic Crcss Section Through the Hanford Site (adapted from Tallman et al., 1979).

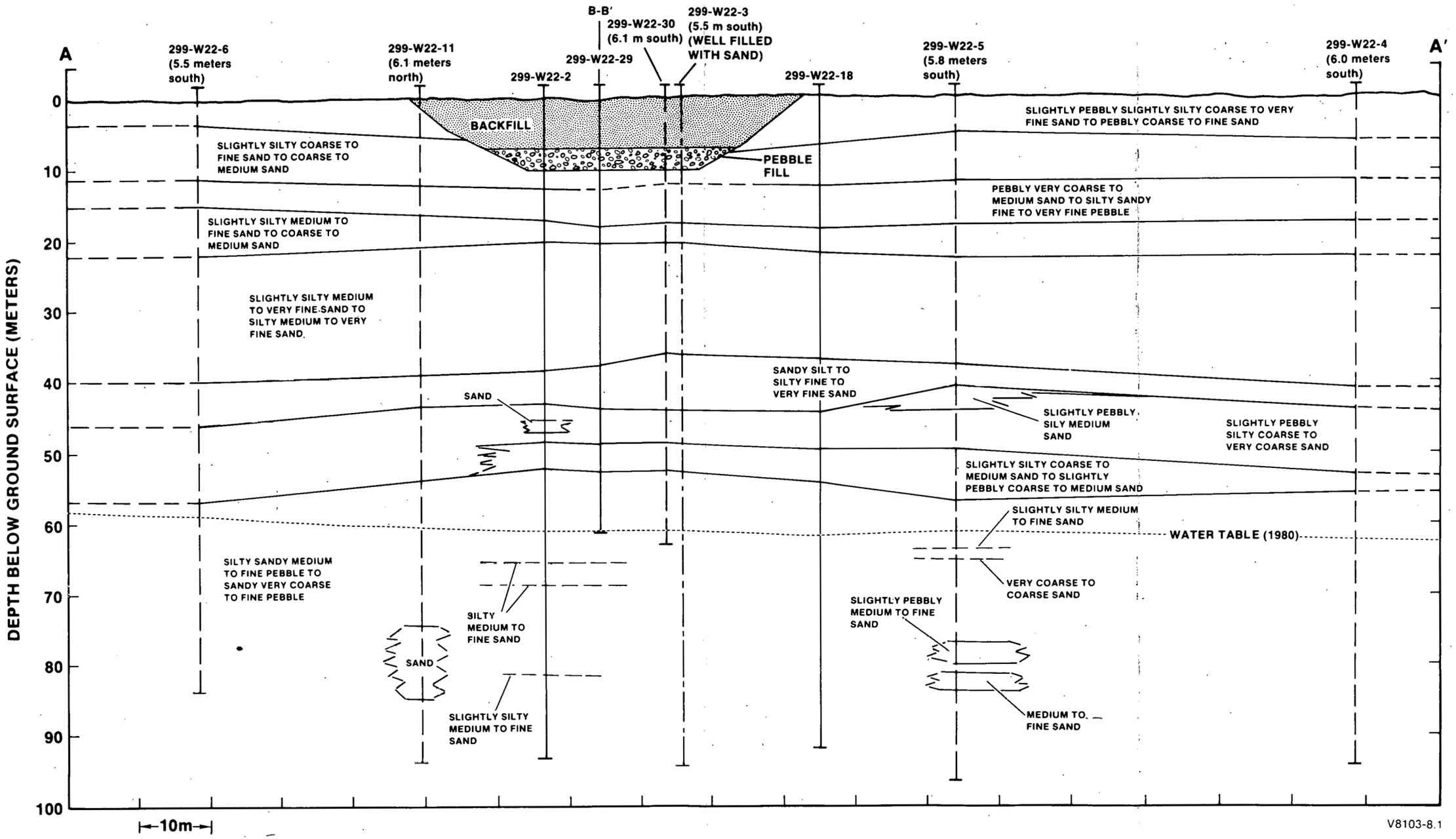

FIGURE 5. Stratigraphic Cross Section A to A' Through the 216-S-1 and 2 Crib.

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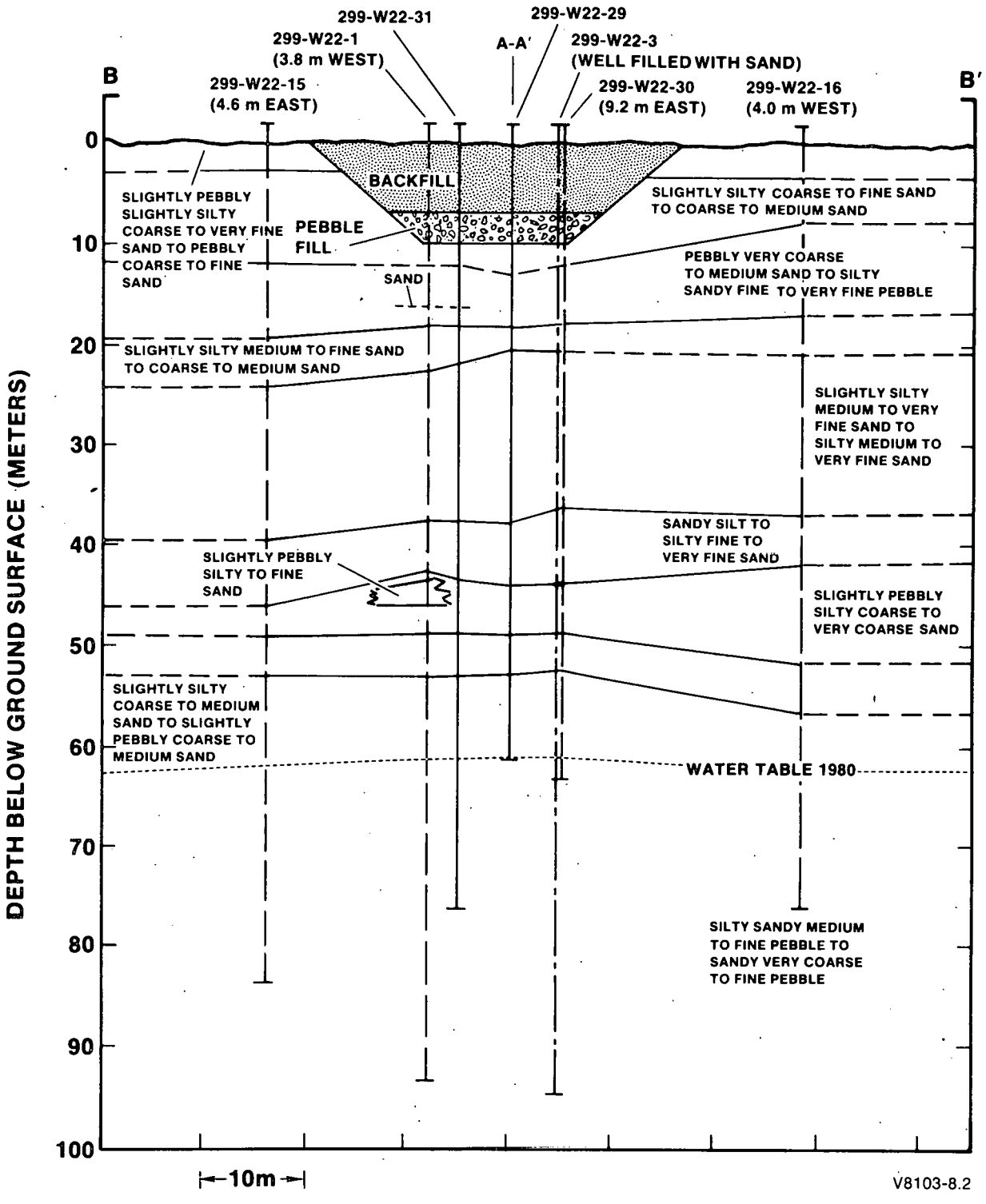

FIGURE 6. Stratigraphic Cross Section B to B' Through the 216-S-1 and 2 Crib.

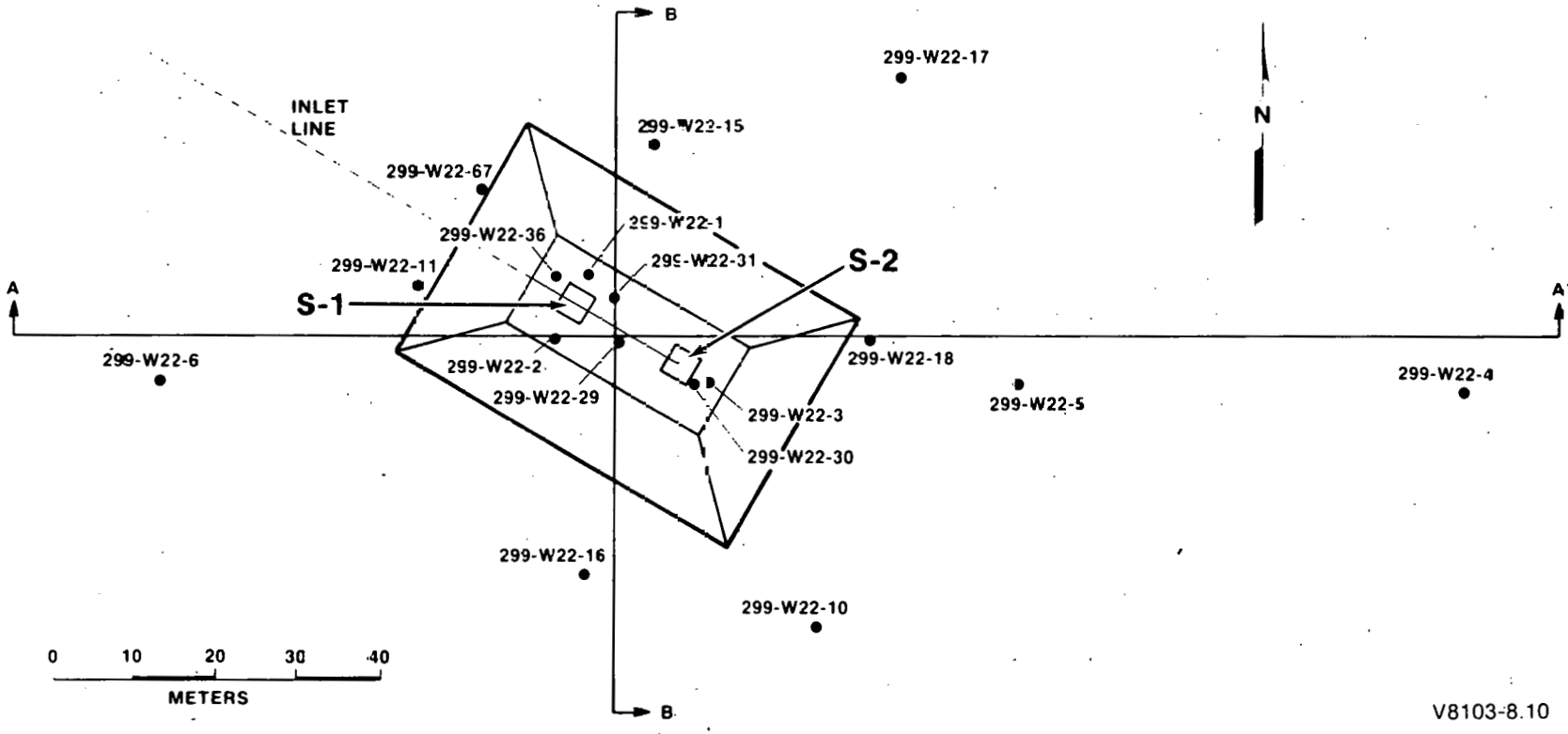

FIGURE 7. Plan View of the 216-S-1 and 2 Crib and Associated Monitoring Wells.

Upper Ringold

The sediments of the upper Ringold unit are about 5 meters thick beneath the 216-S-1 and 2 crib site. The surface of the upper Ringold has a well-developed caliche horizon. The upper Ringold sediments are medium-to-fine sands with silt and clay lenses. There are some areas with very coarse sand, pebbles, and cobbles but, generally, the fineness of the sedimentary material and the sharpness of the textural boundaries suggest a low-energy depositional environment.

Middle Ringold

At approximately 5 meters above the present water table (~55-meter depth), the lithology changes from the fine sediments of the upper Ringold unit to the coarse sediments of the middle Ringold unit. Beneath the 216-S-1 and 2 crib, the middle Ringold is generally a silty, sandy gravel. The middle Ringold extends from slightly above the water table (60 meters below ground surface) to almost 140 meters below ground surface in the 216-S-1 and 2 crib area. Since the deepest crib-monitoring wells do not extend deeper than 94 meters from the surface, the middle Ringold unit is the lowest stratigraphic unit of interest to this characterization study.

The middle Ringold unit consists of well-rounded pebbles and small cobbles with coarse-to-fine sand and silt. Sand and silt lenses ranging from 2.5 centimeters to 4.5 meters in thickness have been found. The large particle sizes and the particle roundness of the materials in this sedimentary unit suggest a high-energy depositional environment.

HYDROLOGY

The hydrology of the 216-S-1 and 2 crib site can be divided into the surface zone, the unsaturated zone (vadose zone), and the saturated zone below the water table. Only the vadose and saturated zones affect radionuclide distributions around the 216-S-1 and 2 crib significantly. High moisture infiltration rates and dry climate reduce the importance of surface hydrology (surface runoff) to a negligible level. The waste

discharged to the crib infiltrated into and flowed through ∿50 meters of the vadose zone to the water table. Approximately 10 column volumes (volume beneath the bottom of the crib to the water table) of waste were discharged to the crib, allowing the waste to percolate to the water table. The two hydrologic zones will be discussed separately.

Vadose Zone Hydrology

The rapid infiltration of precipitation and subsequent wetting of the vadose zone create the potential for water to reach wastes located in Hanford formation sediments. Depth of water penetration is a function of precipitation duration, intensity, and frequency. A long-term lysimeter study has been conducted at Hanford to assess likely precipitation penetration depths under near-natural conditions (Jones, 1978; Brown and Isaacson, 1977). The moisture content of sediments in the upper 12 meters of the lysimeters changed in response to fluctuations in precipitation and solar radiation at the ground surface (Jones, 1978). Therefore, the migration of radionuclides located in the upper 12 meters of the sediment profile can be affected by seasonal changes in moisture content in that portion of the profile. Nearly all of the precipitation entering the sediment profile is transported back to the atmosphere by evapotranspiration. This upward movement of moisture has the potential for transporting any radionuclides in solution toward the soil surface.

Moisture flow through the vadose zone is affected by layering of differing sediment types in the sediment column. Moisture flow is impeded at interfaces between sediment types because of reduced pore size (lower conductivity) and increased liquid-surface area interaction. The result of reduced flow at the interface is lateral spreading of the liquid. Such lateral spreading is desirable because the greater the volume of sediment through which the wastes must pass, the greater the sorptive capacity of the crib system.

Saturated Zone Hydrology

The hydrology of the unconfined and confined ground-water aquifers has been and continues to be important. Contamination of the unconfined aquifer under the Separation Areas has been studied (ERDA, 1975; Graham et al., 1981).

Artificial recharge areas such as cribs, ditches, and ponds have a significant local effect on ground-water directions and rates. Generally, however, the overall flow pattern from west to east to the Columbia and Yakima Rivers still prevails (Newcomb et al., 1972; Graham et al., 1981).

Waste water discharged to the 216-U-10 Pond, near the southwestern corner of the 200 West Area, has produced a ground-water mound that has a dominant influence on the unconfined ground-water flow (Figure 8). The decommissioning of U-Pond, presently under study, will result in a drop in water table elevations over a large extent of the 200 West Area, including the 216-S-1 and 2 crib site. The overall effect of this decommissioning would be the lowering of the hydraulic gradient, and hence, the slowing of ground-water transport rates from 200 West Area and the 216-S-1 and 2 crib site.

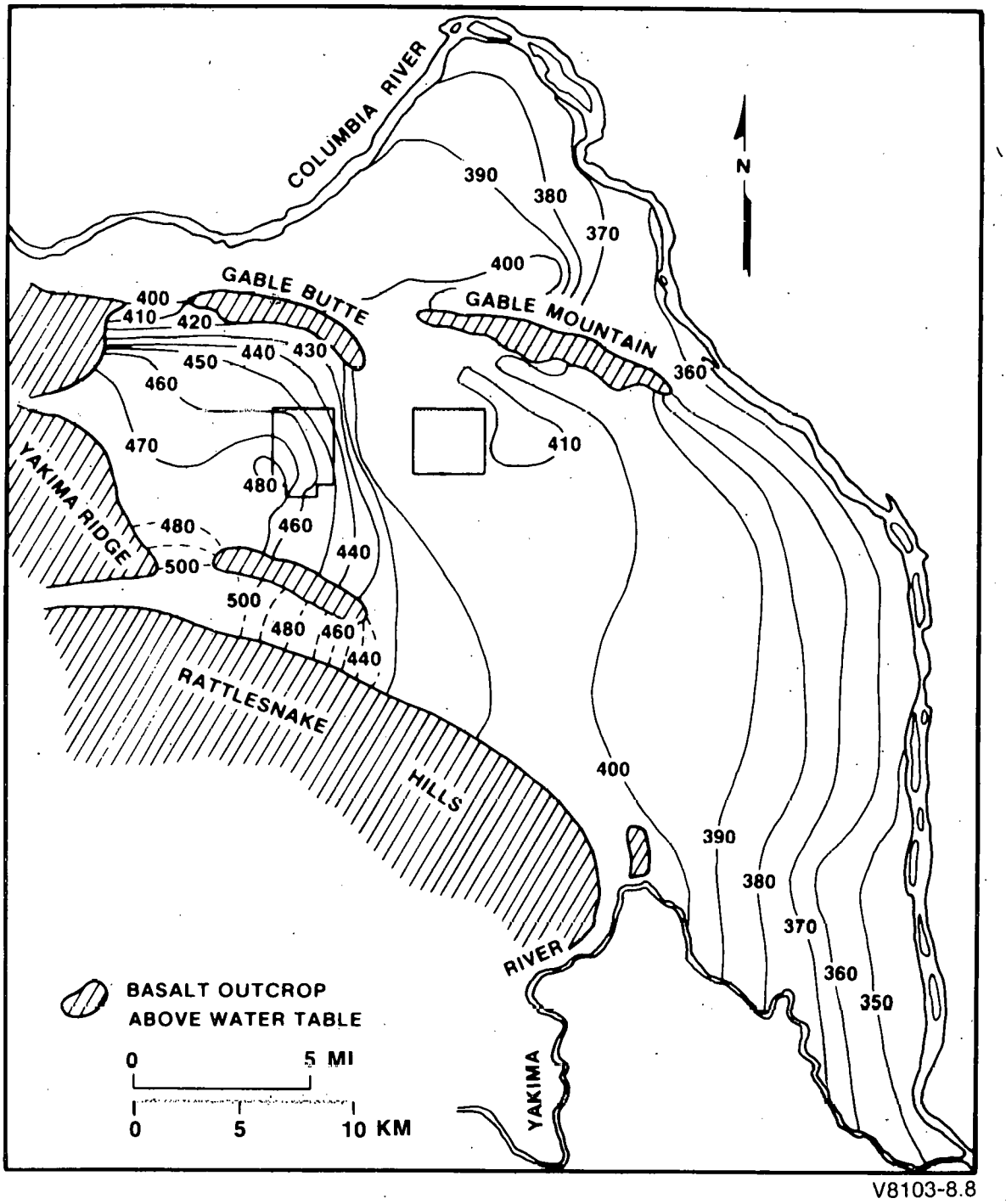

FIGURE 8. Ground-Water Elevations (Feet) Beneath the Hanford Site (1979).

PREVIOUS STUDIES

Two major studies and several minor studies of the 216-S-1 and 2 crib have been conducted. The two major studies involved the drilling of wells to determine the distribution of radionuclides in sediments beneath the crib. The minor studies involved laboratory sorption work using actual wastes discharged to the crib.

The first major study, conducted by Haney and Linderoth (1959), began in 1956 after the crib had been removed from service. The purpose of the study was to determine the spatial distribution of radionuclides in the sediments beneath the crib. The study used 10 monitoring wells, of which 2 wells, 299-W22-1 and -2, were drilled to 45 meters before the crib was put into service. Wells 299-W22-4 and -5 were drilled to the water table in August 1955. Wells 299-W22-1 and -2 were deepened to just more than 90 meters in June 1956. The remaining six wells, 299-W22-10, -11, -15, -16, -17, and -18, were drilled between May and August 1956. Altogether, 10 wells penetrated the water table. Their positions are shown in Figure 7. Hard-tool drilling techniques were used to drill wells for this study.

Sediment samples were collected every 0.7 meters in wells drilled after the crib was removed from service and in the deepened portions of wells 299-W22-1 and -2. Analyses of sediment samples were conducted over a 3-year period. All samples were analyzed for ^{90}Sr, ^{137}Cs, and total beta activity.

Haney and Linderoth (1959) reported ^{90}Sr, ^{137}Cs, total beta activity, and gamma scintillation probe data for the 11 wells. They also presented total beta distributions on two geologic cross sections through the cribs. Conclusions drawn from this study deal with ^{90}Sr and ^{137}Cs distributions beneath the cribs. They conclude that ^{137}Cs is "confined to the upper strata immediately under the crib site" while "^{90}Sr reaching the ground-water encompassed an area of about 10,000 ft^2," which is one-eighth of the area to which the waste had spread before reaching the water table.

In 1966, another field study of the 216-S-1 and 2 crib was conducted as part of a research program by Pacific Northwest Laboratory (PNL). The study's purpose was to evaluate the impact of the proposed Ben Franklin Dam on radionuclides stored in the vadose zone and on Hanford waste management techniques practiced at that time (Raymond and McGhan, 1967). Five additional wells, 299-W22-29, -30, -31, -36, and -67, were drilled at the 216-S-1 and 2 site. Four of these wells (all except well 299-W22-67) were located in the crib facility and penetrated the water table. Radionuclide distributions determined in this study and in the 1956 study are presented in Figure 9 (adapted from Brown, 1967).

In the 1966 study, it was indicated that some sediments near the water table contained up to 1.2×10^{3} μCi ^{90}Sr/g of sediment. The average ^{90}Sr concentration in the ground water beneath the cribs in 1966 was 5×10^{-5} μCi/mℓ. This level was five times greater than the maximum permissible concentration of 1×10^{-5} μCi/mℓ allowed in ERDA MC 0524. This level of contamination was localized in areas near the 216-S-1 and 2 crib and at no time was the ^{90}Sr limit in the ground water exceeded beyond the 200 West Area control zone boundary.

The 1966 study concluded that "most of the long-lived isotopes are confined within 100 feet of the ground surface." Raymond and McGhan (1967) assumed that an average ^{90}Sr concentration of 2×10^{-3} μCi/g in the 6-meter-thick sediment layer, which is located immediately above the water table, would represent a total of 4 curies of ^{90}Sr. They concluded that the "ground water will not change greatly from the presently observed values" with a 6-meter rise in the water table.

Sediment samples for the 1966 study were analyzed by direct scintillation counting in a well crystal with a 400-channel spectrum analyzer for the gamma-emitting isotopes. Strontium-90 analyses were made by soil fusion, chemical separation, and beta counting (Raymond and McGhan, 1967).

Brown (1967) reviewed the 1956 and 1966 studies and gamma scintillation data to determine the migration characteristics of radionuclides through sediments.

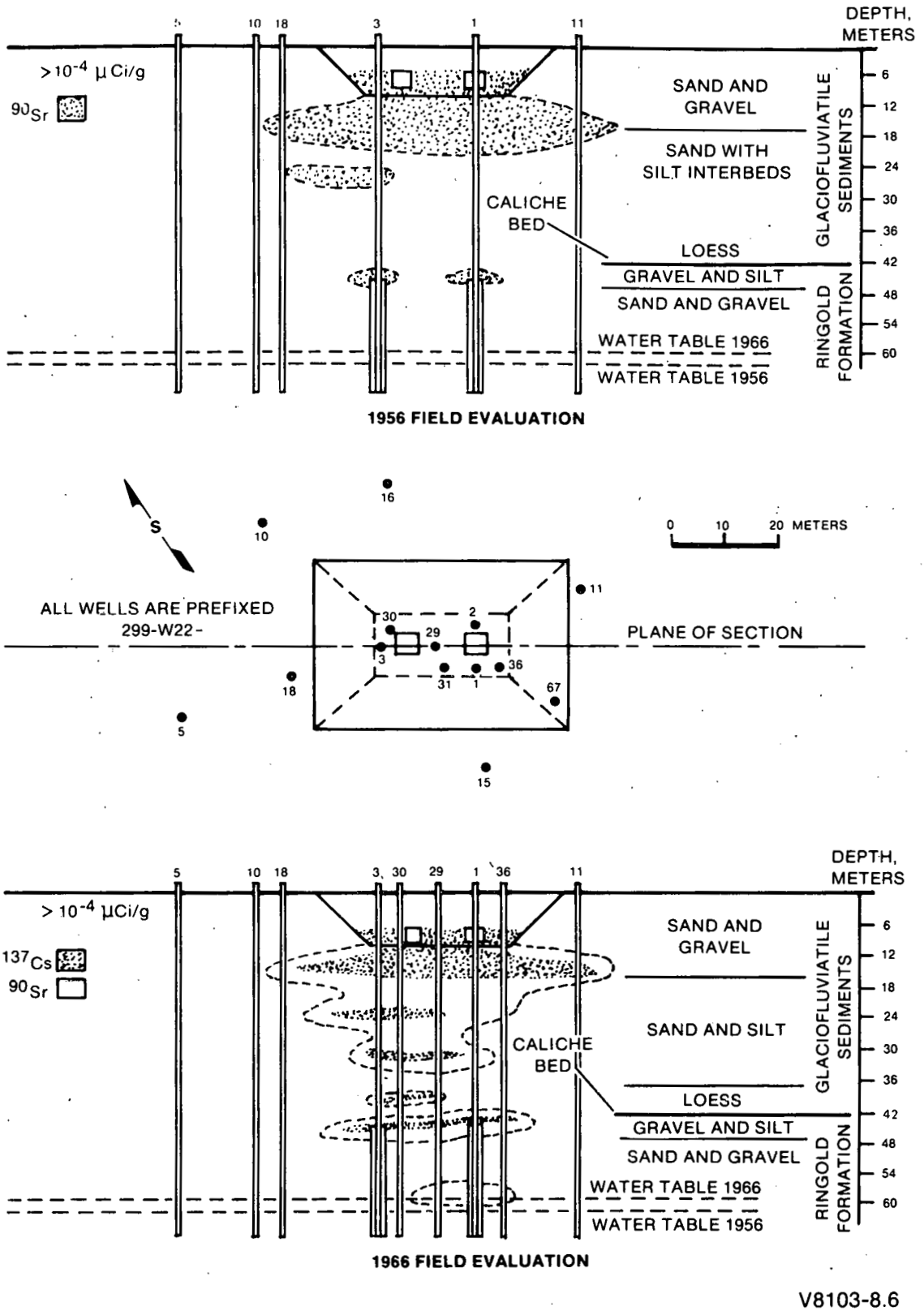

FIGURE 9. Results of the 1956 and 1966 216-S-1 and 2 Crib Field Evaluations.

All minor studies connected with the 216-S-1 and 2 crib were laboratory studies conducted in the 1950's. In 1951, D. W. Rhodes began to study sediments from the 200 Separations Area to determine sorption characteristics of sediments under various conditions. One well (299-W22-63) selected was located approximately 100 meters east of the Redox building. Rhodes conducted detailed radionuclide sorption work using sediments from this well.

In August 1955, the casing failure of well 299-W22-3 (see Site History) prompted a study to determine radionuclide sorption from water samples collected from this well. The ^{137}Cs and ^{90}Sr concentrations in the water samples, collected on October 20, 1955 from the well, were 0.113 μCi/mℓ and 0.223 μCi/mℓ, respectively. Rhodes passed a water sample collected from the well through a sediment column to determine the sorption characteristics of the radionuclides contained in the water. This work indicated that the ^{137}Cs breakthrough resulted in a C/C_o (input-to-output solution concentration ratio) of less than 2.6×10^{-4} after seven column volumes, while the 50% ^{90}Sr breakthrough occurred at two column volumes. This study prompted additional studies of the waste being discharged to the 216-S-1 and 2 crib.

Rhodes (1956) conducted work concerning radionuclide sorption from waste discharged to the 216-S-1 and 2 crib. The results indicated that greater than 90% of the ^{137}Cs was adsorbed by the soil while less than 10% of the ^{90}Sr was adsorbed. Rhodes determined that this poor sorption was due to the low pH (2.1) of the waste solution and the high salt concentrations of the D-1 tank waste. To obtain greater than 90% removal of the ^{90}Sr from the D-2 tank waste, it was necessary to raise the solution pH above 8. Addition of a phosphate salt as well as a pH increase was required before a 90% removal of ^{90}Sr was obtained from the D-1 tank waste. This study resulted in the following modifications in the waste disposal procedure: the D-1 waste was routed to the waste evaporator, the pH of D-2 waste was raised to about 8 before disposal, and the waste was discharged to a new crib (216-S-7). These modifications resulted in no change to ^{137}Cs sorption and increased ^{90}Sr sorption to greater than 90%.

The previous studies did not address the gamma-emitting radionuclide concentrations in the saturated sediments below the water table. Earlier gamma profiles were difficult to interpret because the non-sorbing ^{106}Ru gamma emitter was present where the waste solution migrated. As time progressed, however, ^{106}Ru-^{106}Rh decayed and the long-lived gamma emitters remained. More recent gamma profiles showed the presence of long-lived gamma-emitting radionuclides just above the water table. The speciation and concentration of this activity is discussed in this report.

In the 1967 study by Raymond and McGhan, elevated ^{90}Sr levels in the ground water beneath the crib were discussed. Strontium-90 levels have fluctuated, but according to ground-water monitoring data, have decreased since the 1967 study. This subject in addressed in the present study.

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CURRENT STUDY

INTRODUCTION

The objective of the current study was to define the radionuclide distributions beneath the 216-S-1 and 2 crib site and to determine the source of elevated ^{90}Sr concentration in the ground water beneath the site. Since previous studies have defined ^{90}Sr and ^{137}Cs concentrations between the crib bottom and the water table, particular attention was directed toward defining radionuclide distributions immediately above, at, and below the water table. This emphasis was especially appropriate in light of the continued elevated ^{90}Sr concentrations reported in the ground water.

The study involved the cleaning and/or deepening of selected monitoring wells in and around the 216-S-1 and 2 crib site, and obtaining downhole scintillation and gamma energy analysis profiles. Ground-water sampled and analyzed for selected radionuclides.

MATERIALS AND METHODS

A plan view of the 216-S-1 and 2 crib site, showing the location of the monitoring wells, is given in Figure 7. The experimental design of the current study included the use of these existing wells to investigate the radionuclide distributions in sediments beneath the crib. In order to obtain a better understanding of saturated-zone radionuclide distributions, it was decided to deepen wells 299-W22-29 and 299-W22-30. Well 299-W22-29 could not be deepened because the casing was bent, so well 299-W22-31 was substituted and deepened 14 meters. Well 299-W22-30 was deepened approximately 7 meters.

During the 1960's, sediment sifted into wells 299-W22-5 and -18 through perforations in the casing. These wells were cleaned to their original drill depths of more than 90 meters in May and June of 1980.

The wells were logged using borehole scintillation counting and gamma-ray spectrometer systems. Wells 299-W22-30 and -31 were relogged

after deepening. The two wells that were cleaned were relogged with the scintillation counting equipment only because no field-detectable activity was encountered.

Scintillation Logging

Scintillation logging of monitoring wells on the Hanford Site has been conducted since 1954. The equipment used for the present study was a Gearheart-Owen Industries Model 3200* logging system operated by PNL. This equipment uses a thallium-activated, sodium-iodide phosphor crystal detector. Equipment used for previous work was not the same as the equipment used in this study, but the end result was that all generations of equipment used detected gamma radiation with approximately the same sensitivity. Therefore, all gamma profiles presented are comparable.

The resulting gamma profiles represent the radiation intensity of gamma-emitting radionuclides. Since this intensity is a function of the energy of the gamma radiation emitted as well as the total amount of gamma radiation, the method is qualitative. Comparisons of successive loggings were made to determine changes in vertical radionuclide distributions, and changes in radiation intensity due to natural radioactive decay and/or redistributions of radionuclides in the sediment column (Additon et al., 1978).

Borehole Gamma Spectrometer

The borehole gamma spectrometry system consists of two different intrinsic germanium gamma-ray spectrometers with matched live time corrector/pulse pileup rejector systems, which feed into a pulse height analyzer. Results are recorded on cassette magnetic tape (Kay, 1980).

The entire unit is contained in a specially designed 2 1/2-ton, four-wheel drive, well-logging truck. A 230-meter cable is controlled by a hoist unit powered by the truck engine. Electrical instruments are powered from generating units on the truck.

The two detectors are Models 548 and 190 by Princeton Gamma-Tech Inc.* Each has a 12-hour capability on one charge of liquid nitrogen. The sensitivity of the two detectors differs greatly and, in addition, two lead shields may be added to each probe, giving four possible measuring configurations. The detectors are calibrated in a borehole calibration facility that consists of well casing surrounded by well-mixed sediments of known radionuclide contamination (Kay, 1980).

The probes are built to withstand water pressures up to a 30-meter depth with proper venting of the cryostat. Plastic bags, 90 meters long and sealed at the bottom, were used to cover the probes and cable while logging the wells below the water table to ensure that the probes would not become contaminated.

RESULTS

Scintillation Profiles

The scintillation profiles for the six wells drilled through the 216-S-1 and 2 crib site (299-W22-1, -2, -29, -30, -31, and -36) are given in Figures 10 through 15. Profiles for the peripheral wells (299-W22-5, -10, -15, -17, -18, and -67) appear in Figures 16 through 21. The scintillation profiles for wells 299-W22-5 and -18 are only given for the deeper profiles obtained after cleaning, since the profiles from the surface to the water table were unchanged from July 9, 1979 to June 9, 1980. For the two wells that were deepened (299-W22-30 and -31), the scintillation profiles are shown in Figures 22 and 23.

Saturation of the detection system occurs at a count rate of approximately 2.4×10^6 counts/min. The actual profile shape in areas where the capacity was exceeded cannot be inferred from these plots, since vertically adjacent points could represent count rates differing by orders of magnitude.

*Registered trade name.

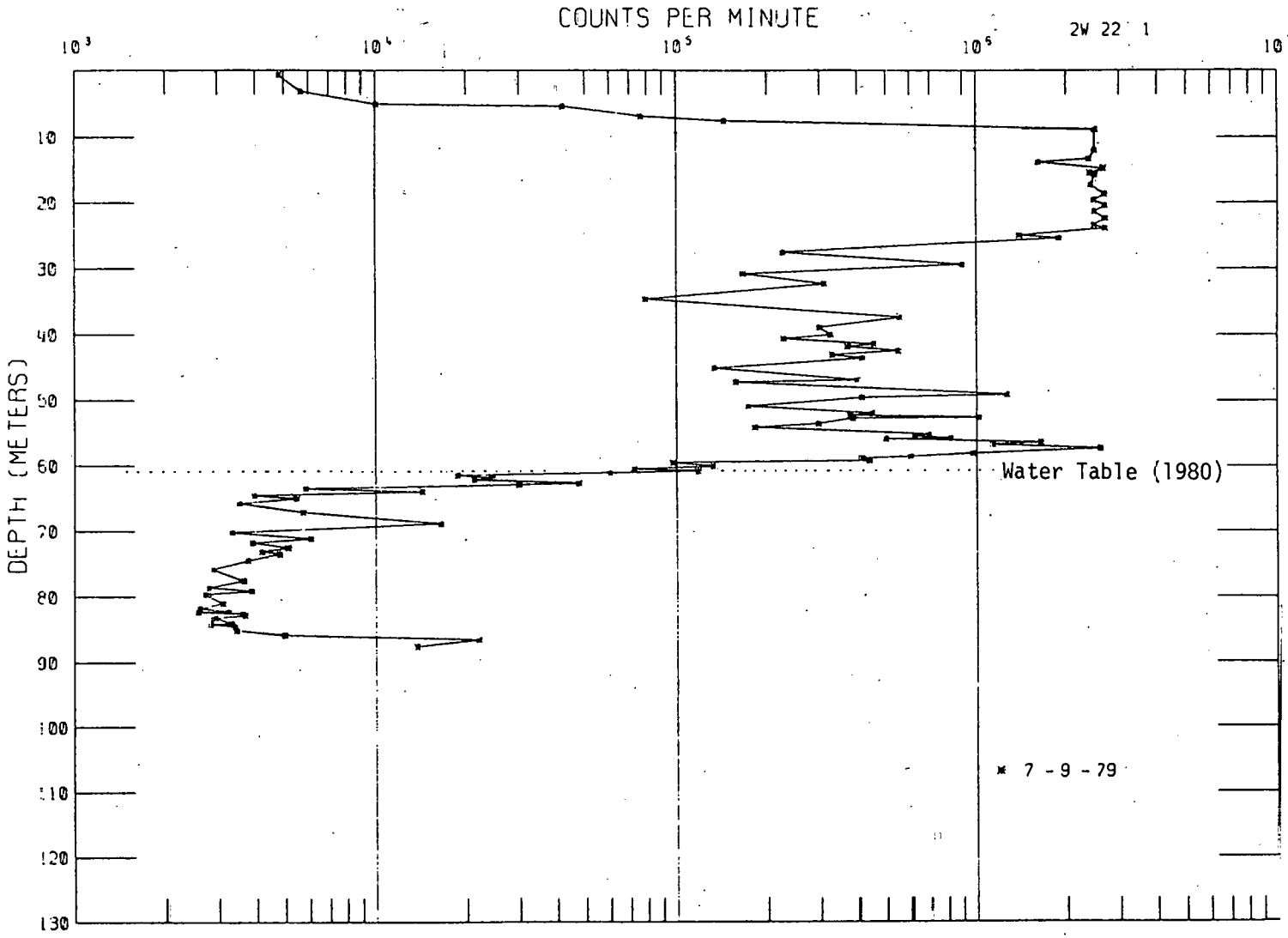


FIGURE 10. Scintillation Profile for Well 299-W22-1.

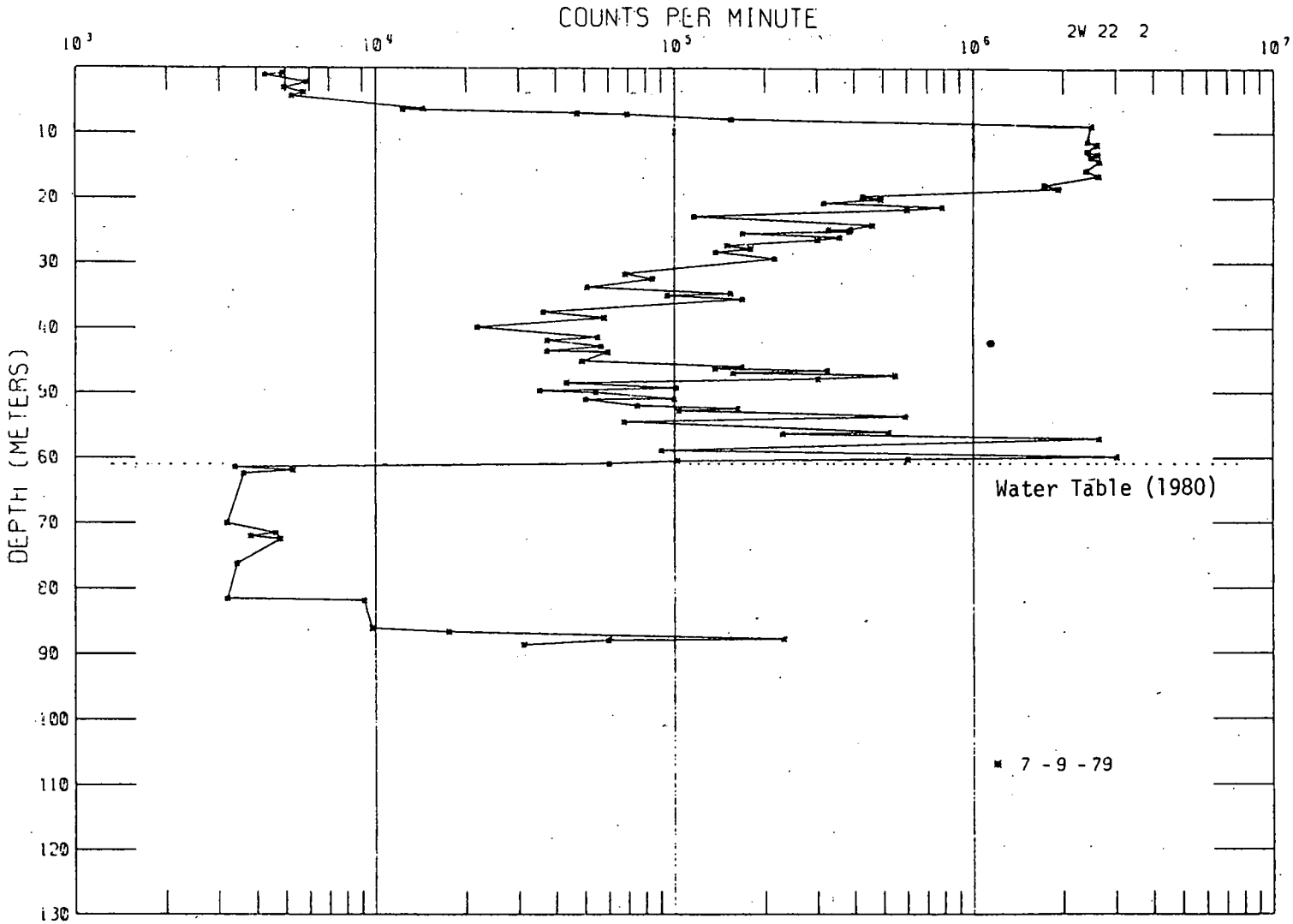


FIGURE 11. Scintillation Profile for Well 299-W22-2.

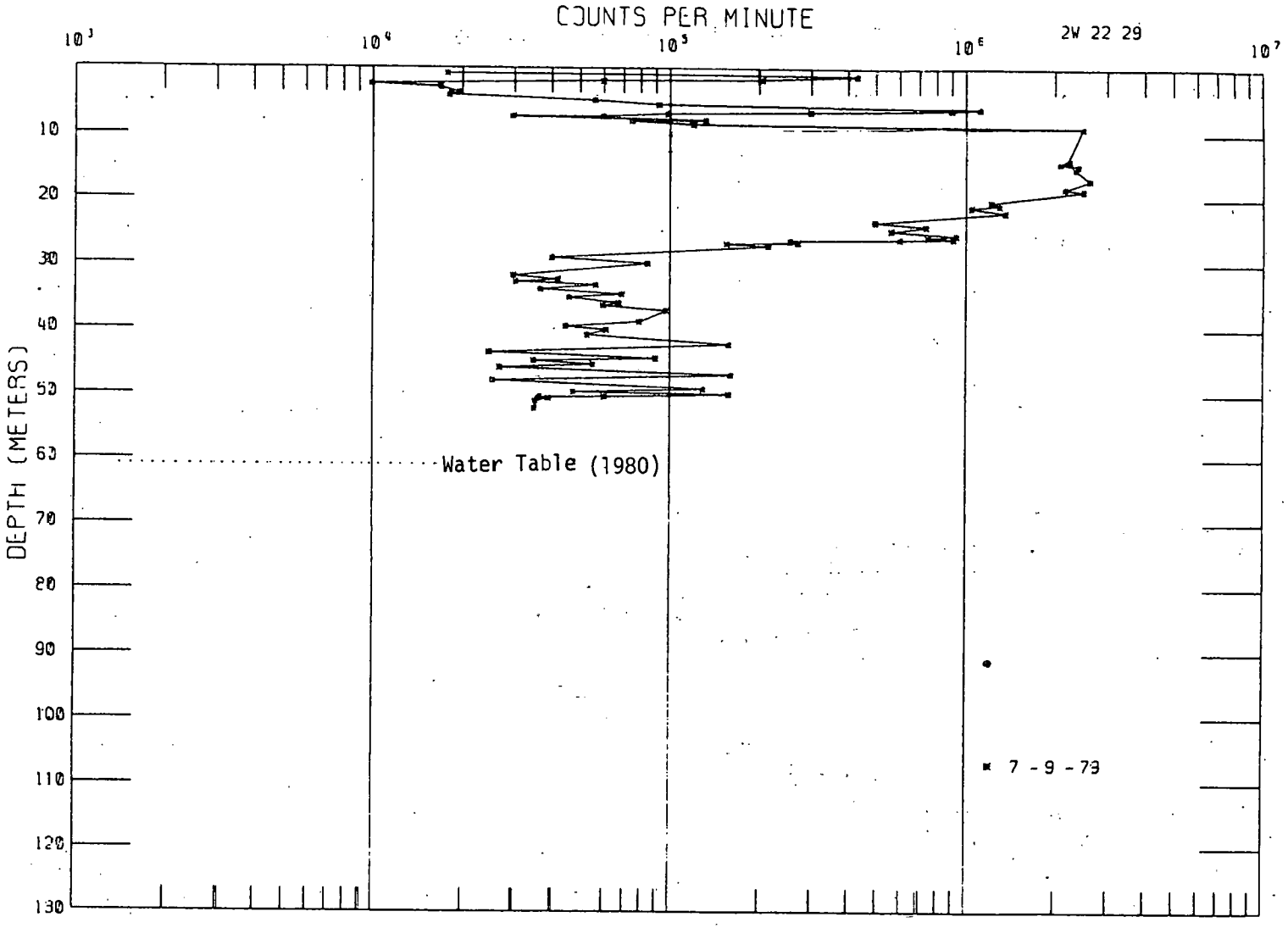


FIGURE 12. Scintillation Profile for Well 299-W22-29.

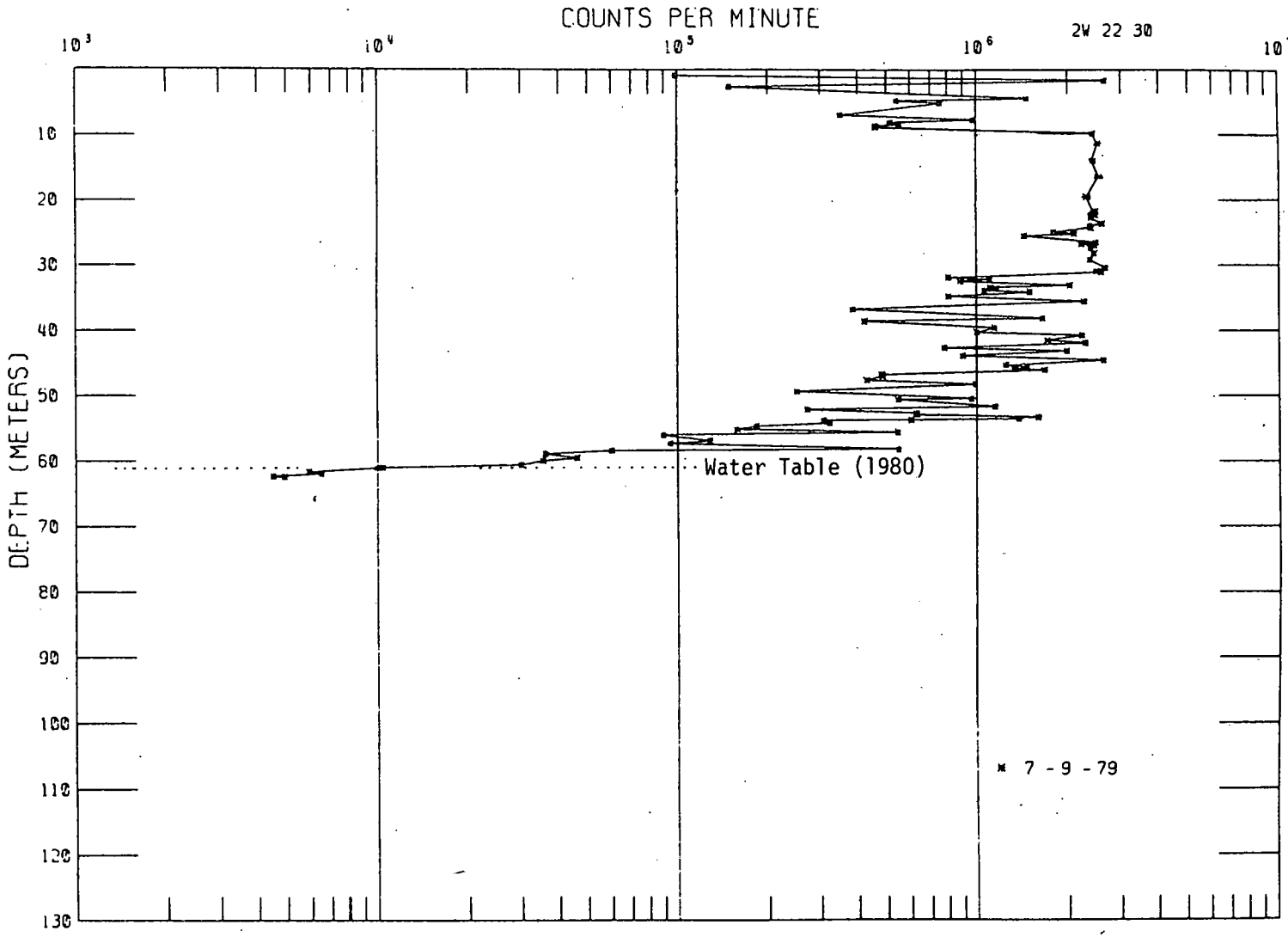


FIGURE 13. Scintillation Profile for Well 299-W22-30.

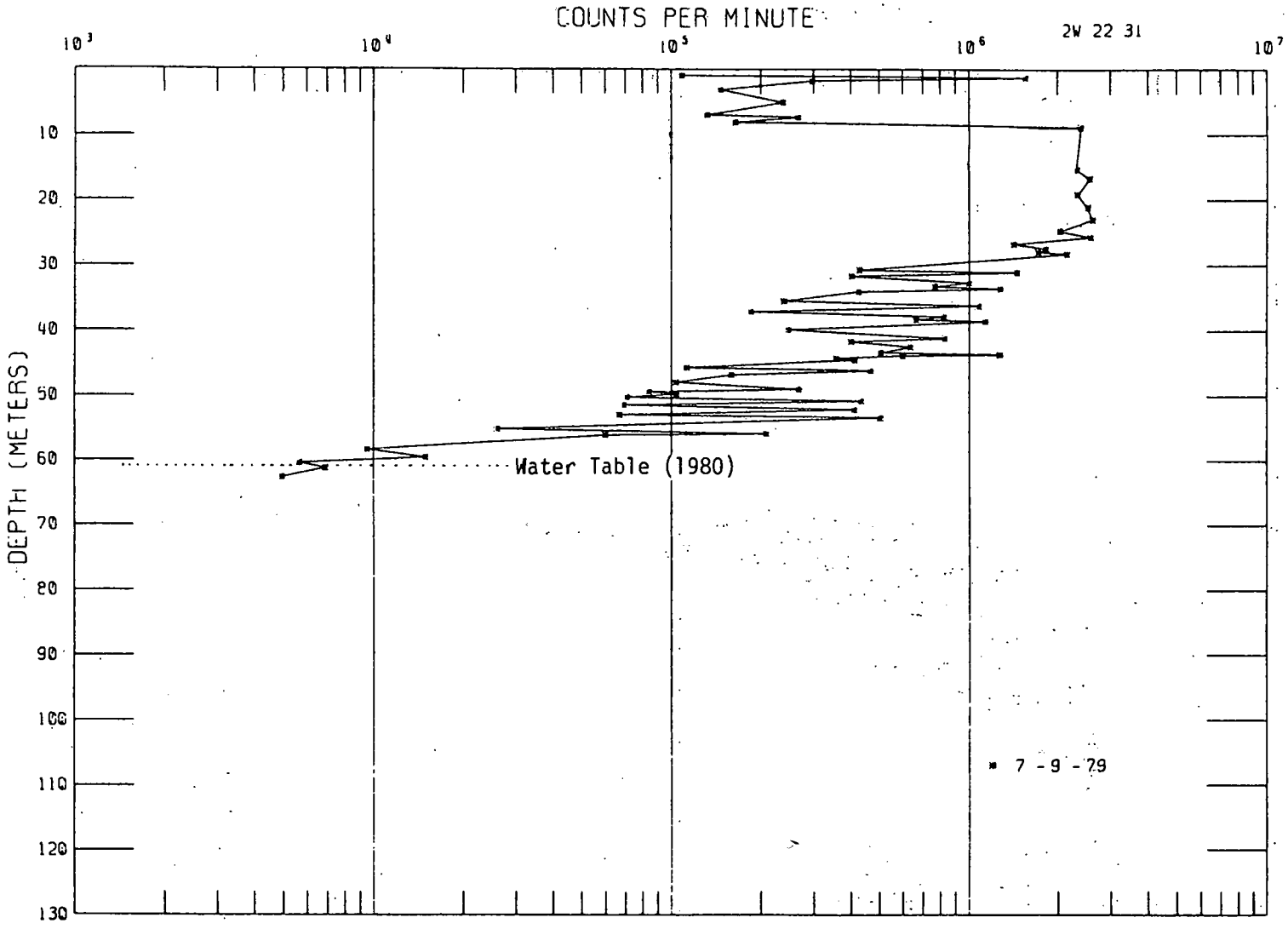


FIGURE 14. Scintillation Profile for Well 299-W22-31.

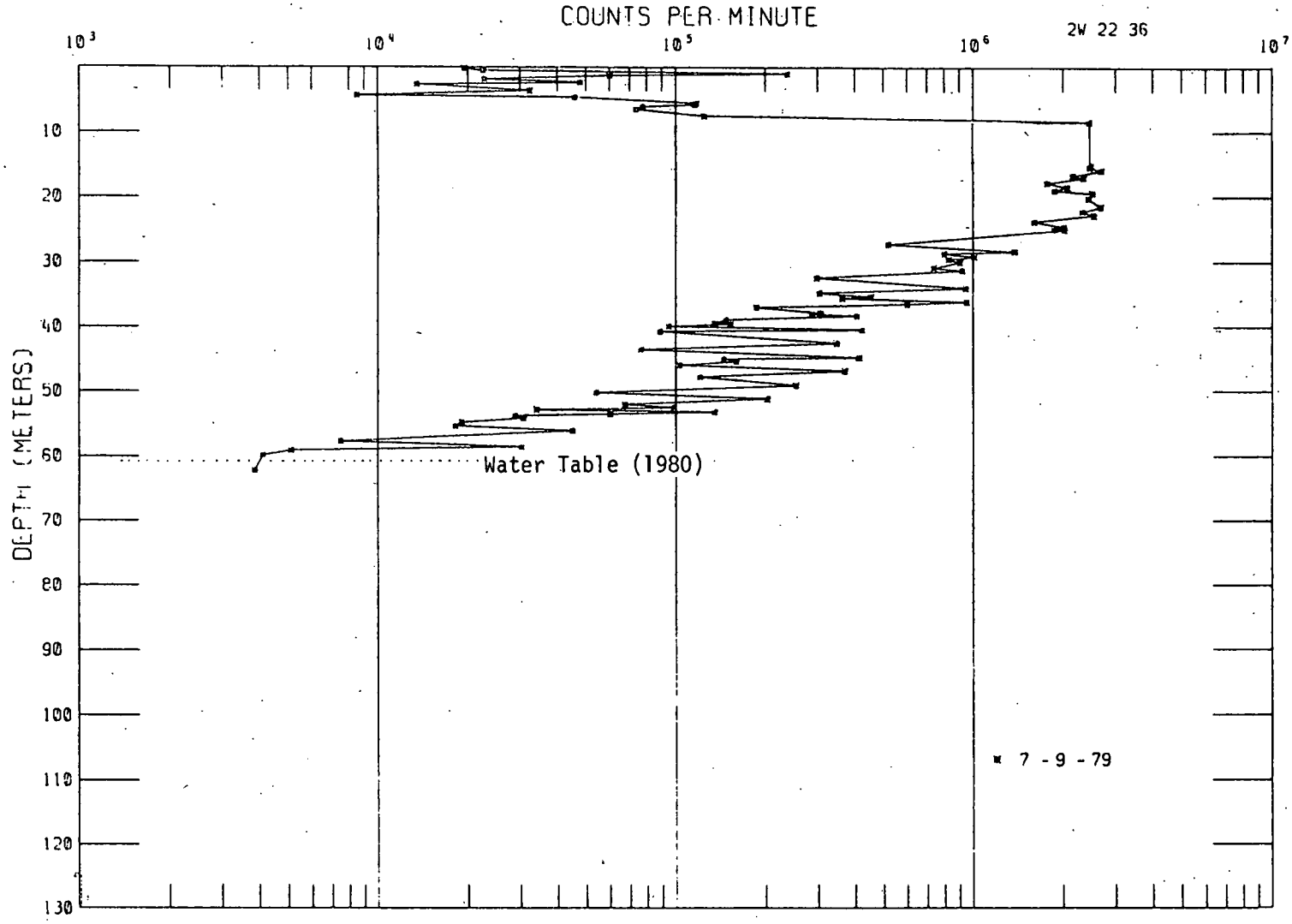


FIGURE 15. Scintillation Profile for Well 299-W22-36.

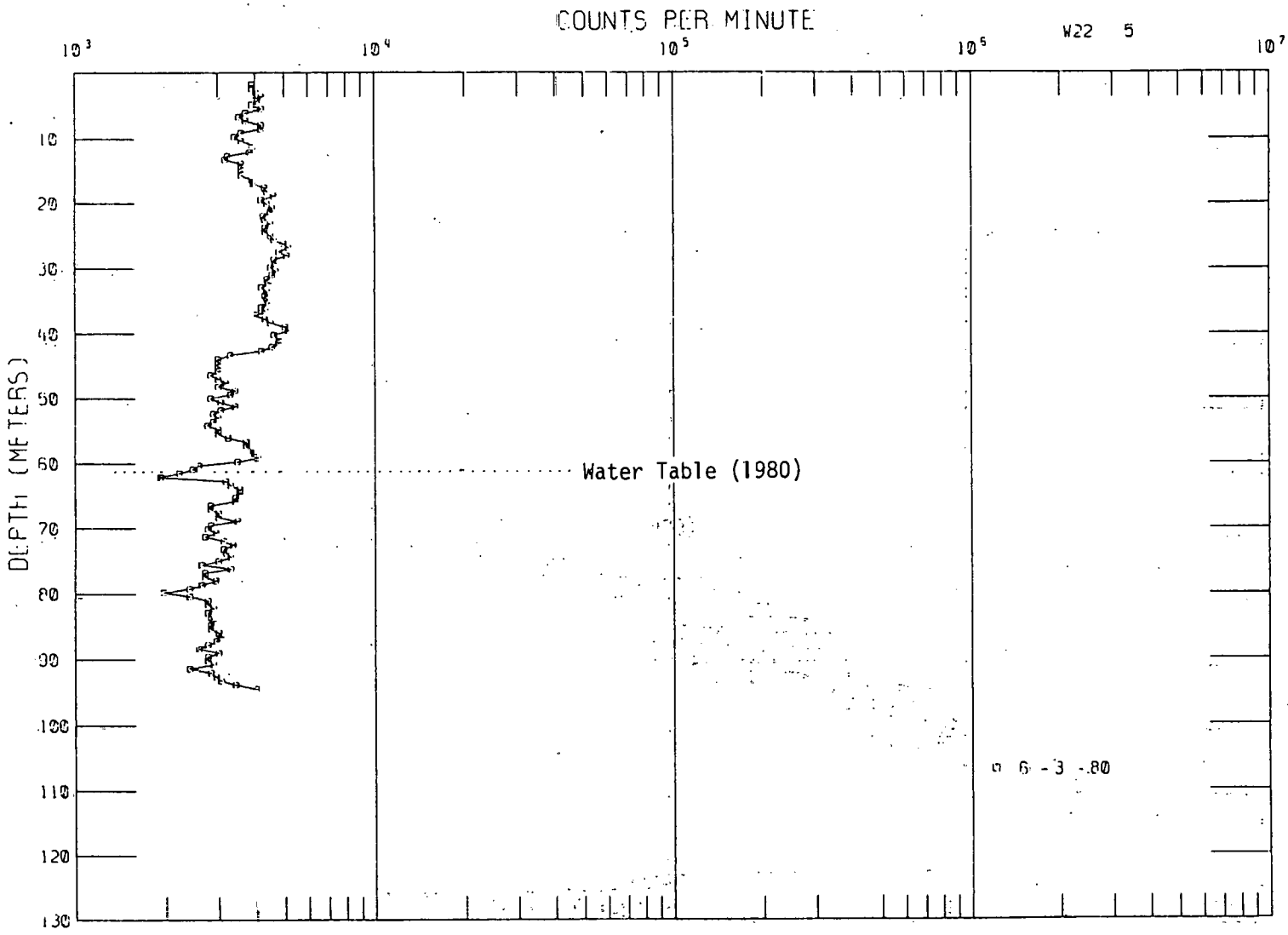


FIGURE 16. Scintillation Profile for Well 299-W22-5.

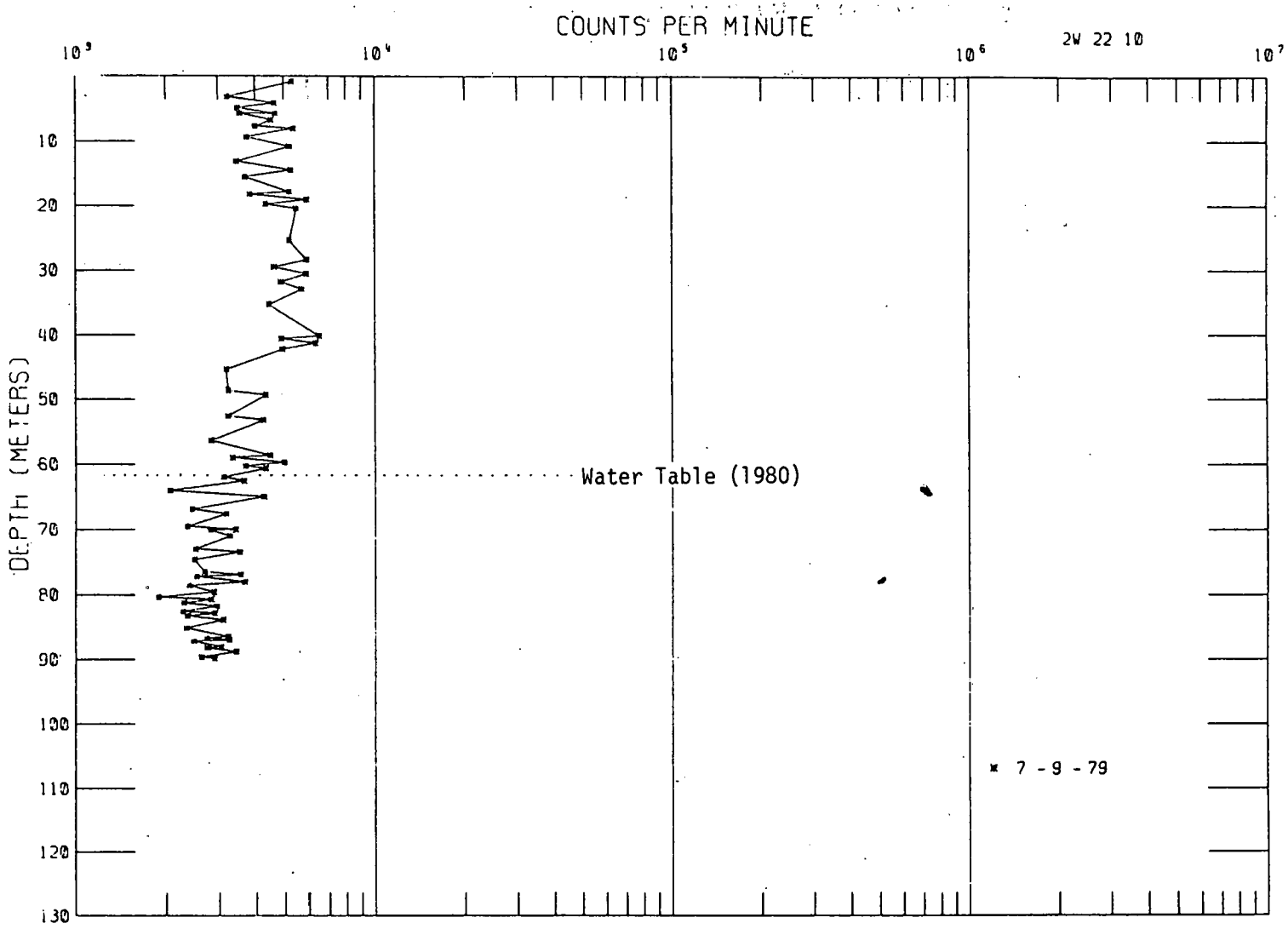


FIGURE 17. Scintillation Profile for Well 299-W22-10.

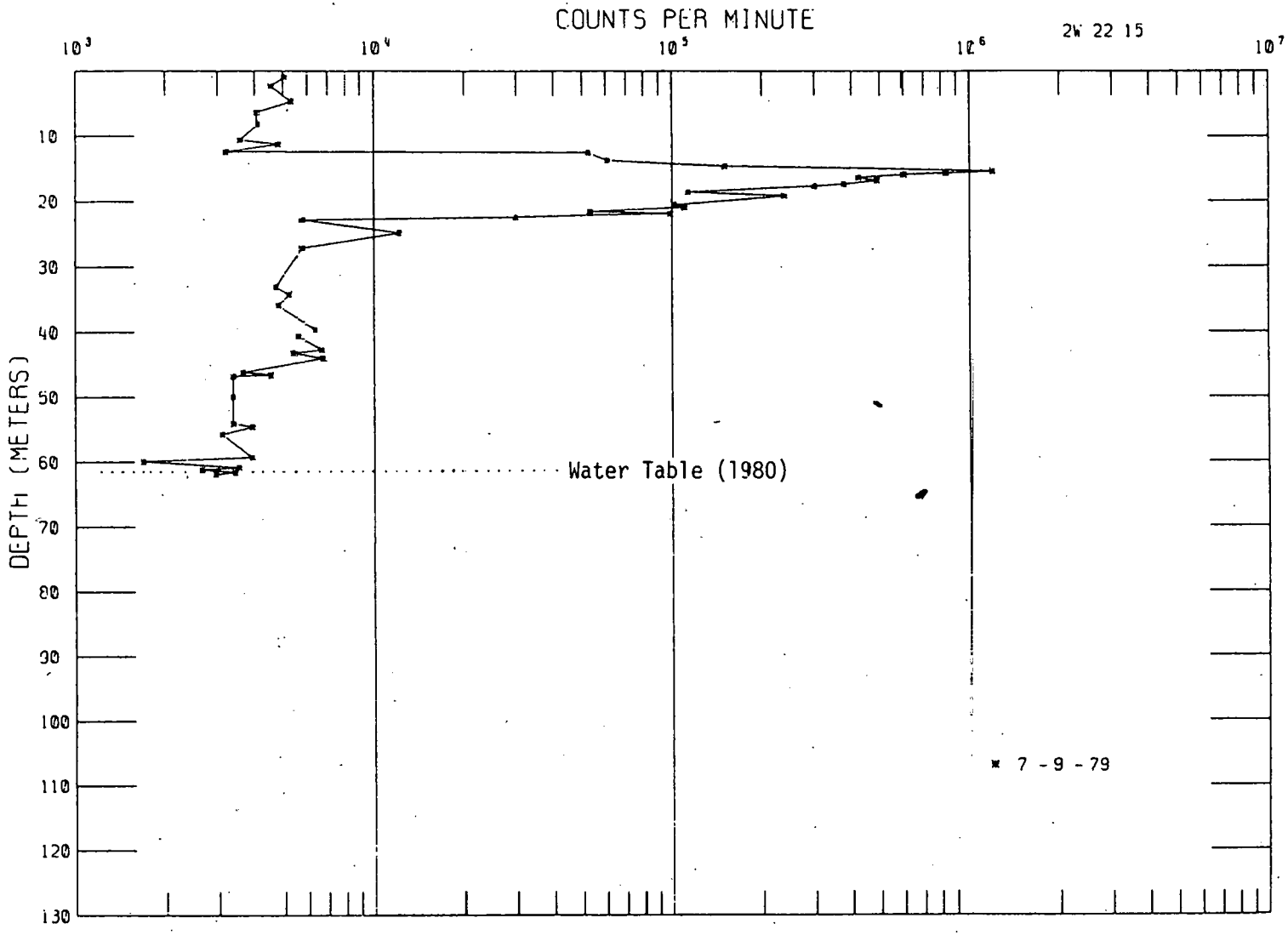


FIGURE 18. Scintillation Profile for Well 299-W22-15.

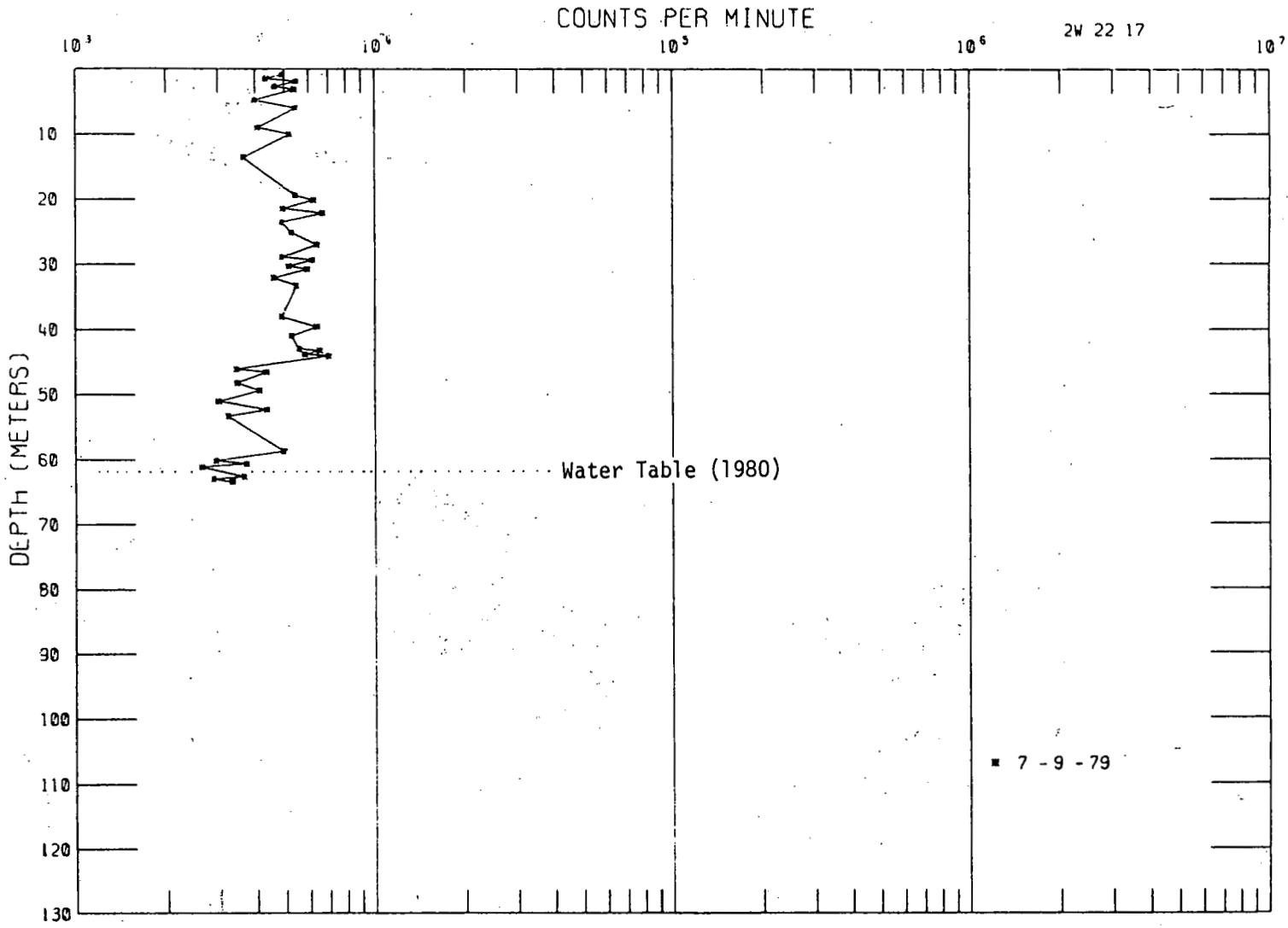


FIGURE 19. Scintillation Profile for Well 299-W22-17.

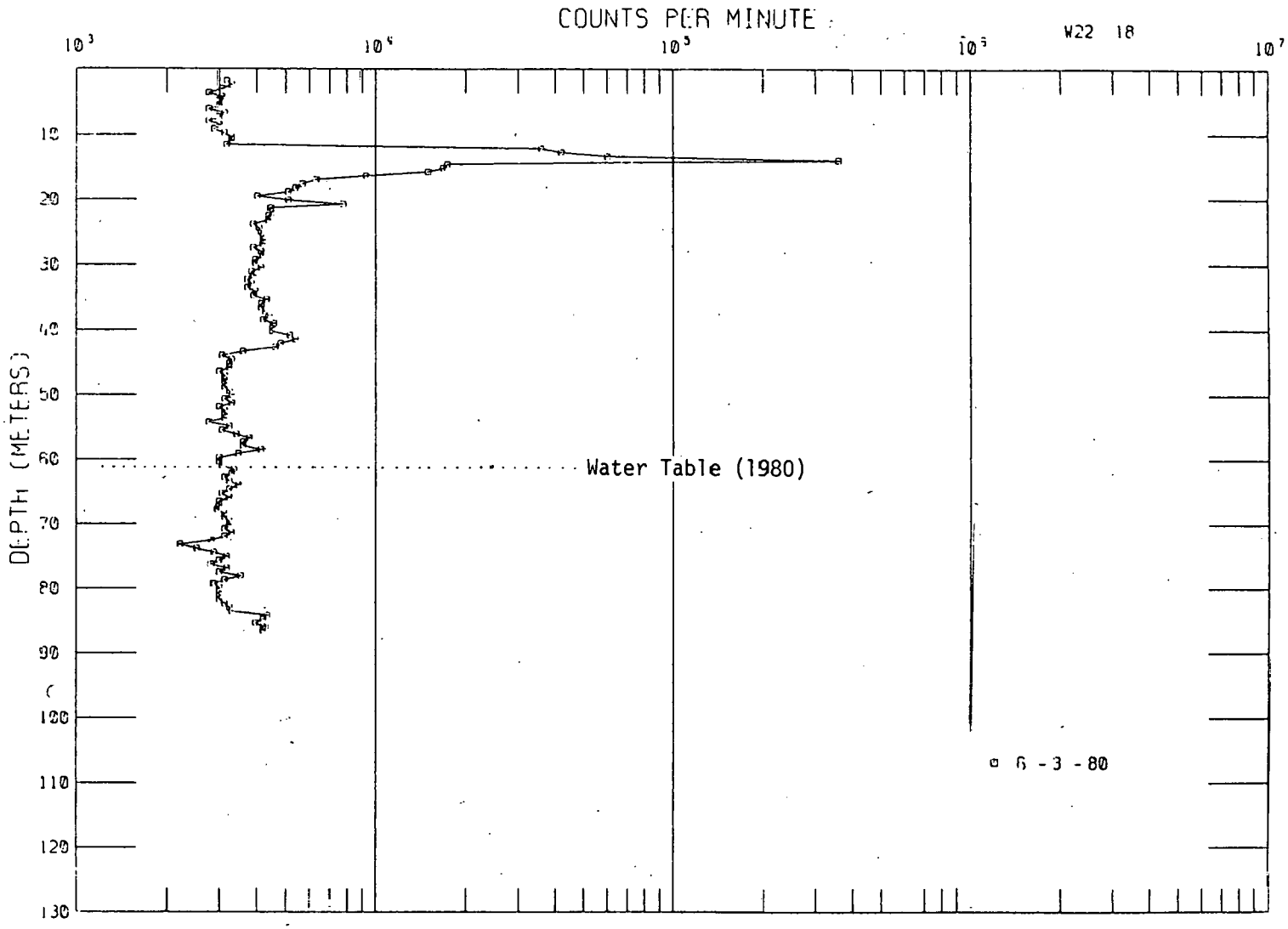


FIGURE 20. Scintillation Profile for Well 299-W22-18.

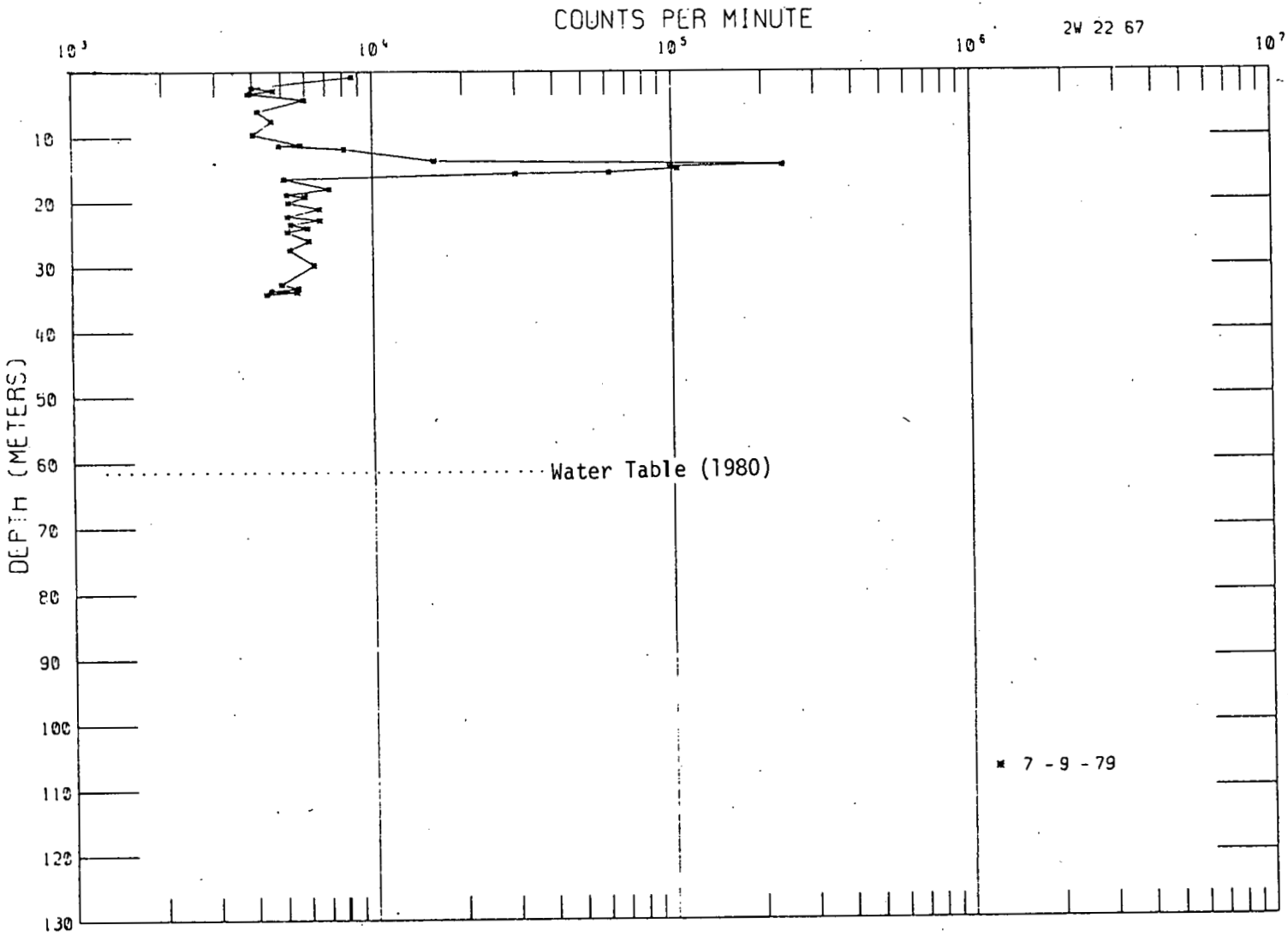


FIGURE 21. Scintillation Profile for Well 299-W22-67.

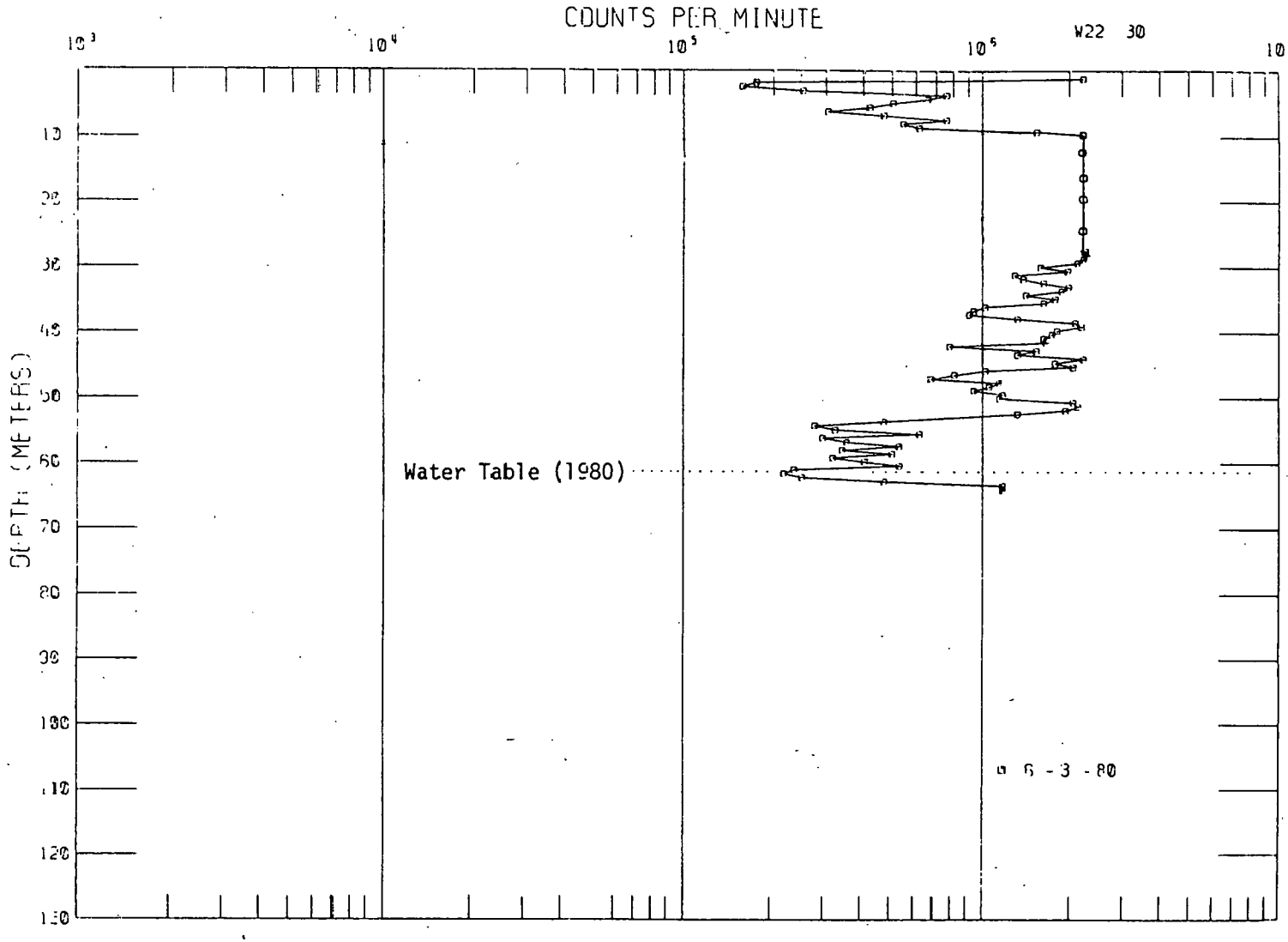


FIGURE 22. Scintillation Profile for Well 299-W22-30 After Deepening.

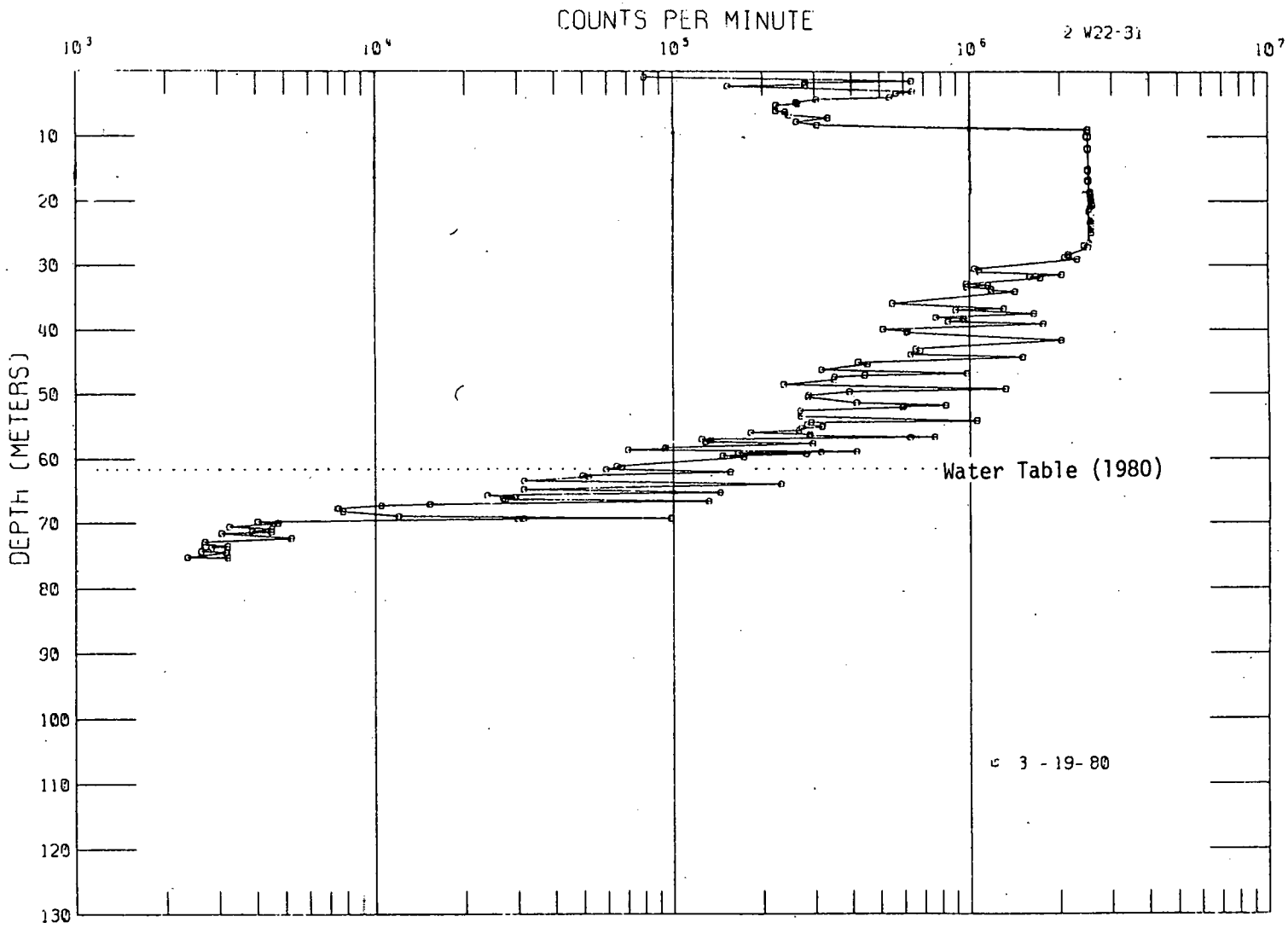


FIGURE 23. Scintillation Profile for Well 299-W22-31 After Deepening.

Gamma Spectrometer Results

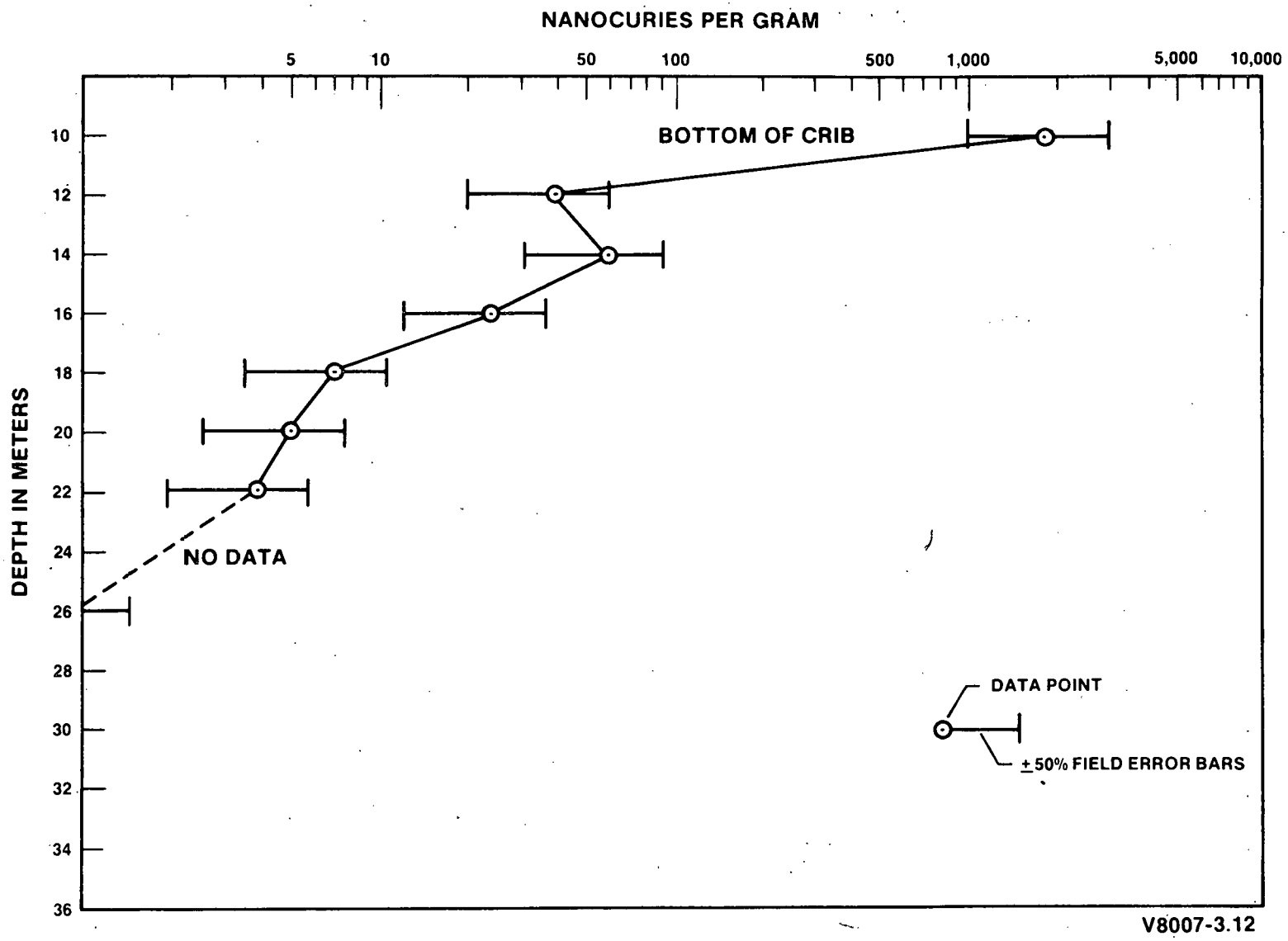
The gamma spectrometer data are given in Appendix A. The equipment used to obtain these data was calibrated in units of microcuries per liter (μCi/ℓ) of sediment. To convert these concentrations from a volume basis to a weight basis, a mean density of Hanford sediments, 1.7 g/cm^3, was used (Routson and Fecht, 1979).

Wells were generally logged at 2-meter intervals. Where no gamma activity was detectable, 4-meter intervals were used. Cesium-137 concentrations greater than 10 nCi ^{137}Cs/g were detected in wells 299-W22-1, -2, -29, -30, -31, and -36 (Figures 24 through 29). The greatest concentrations were located at the crib bottom and rapidly decreased below that zone. The difference between the shapes of the peaks in this region for the gamma spectroscopic plots and the corresponding scintillation profiles is attributable to at least four related factors:

- Differences in sensitivity between the two detector systems
- Differences in the effective sampling volume "seen" by the two detector systems
- Difference in intensity due to a selective energy versus a comprehensive, all-energy gamma scan
- The different sample spacings.

The effect of sample spacing differences was investigated by remeasuring the activity peaks associated with the crib bottom at closer sampling intervals for wells 299-W22-30 and -36 (the well with the deepest extent of higher ^{137}Cs concentrations, and the well with the highest "crib-bottom" ^{137}Cs peak, respectively).

The results, illustrated in Figures 30 and 31, show that in well 299-W22-30 the actual peak was missed with the 2-meter interval (it was also unmeasurable), while in well 299-W22-36 the peak was accurately described.



FIGJRE 24. Cesium-137 Profile for Well 299-W22-1.

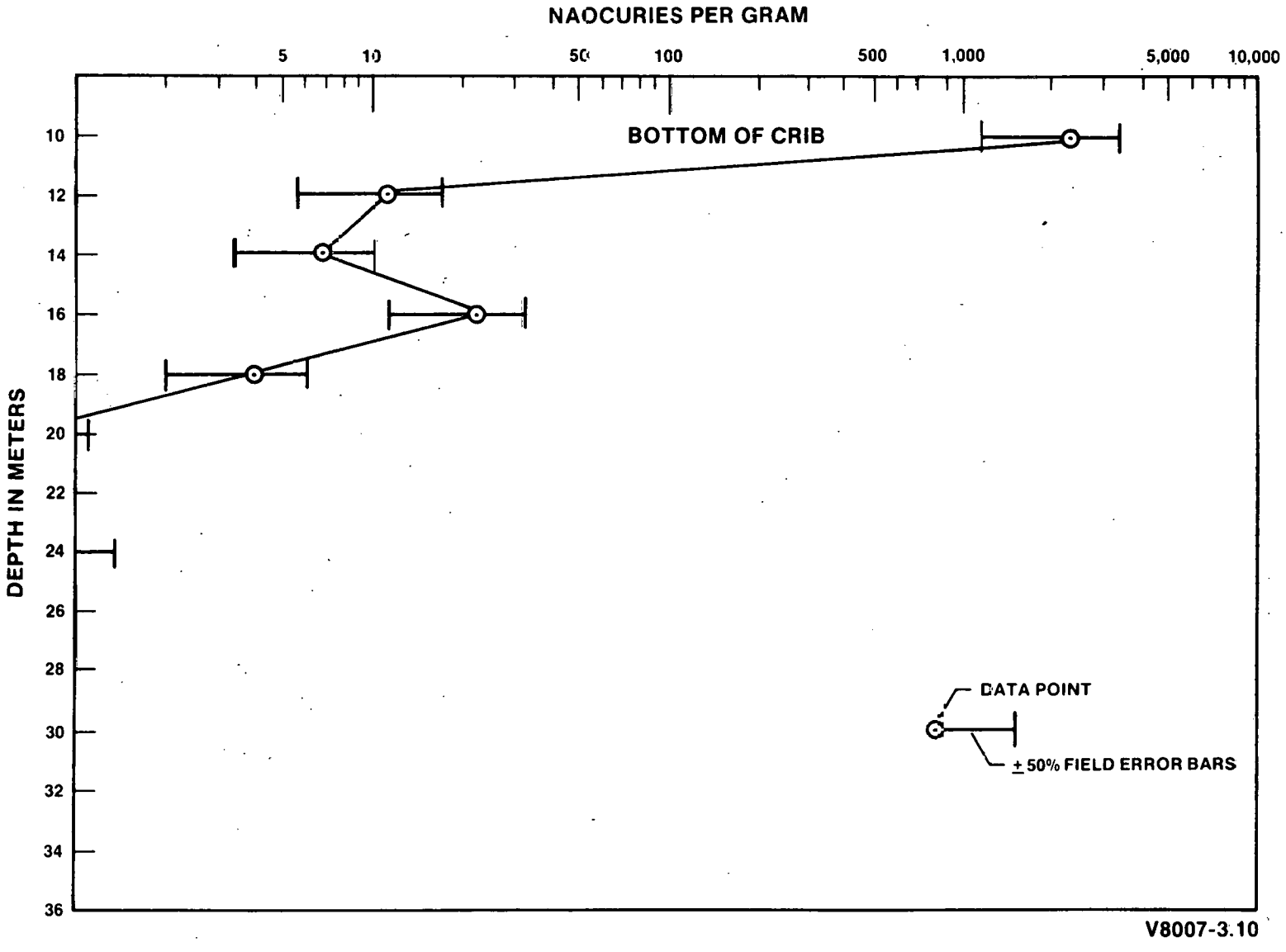


FIGURE 25. Cesium-137 Profile for Well 299-W22-2.

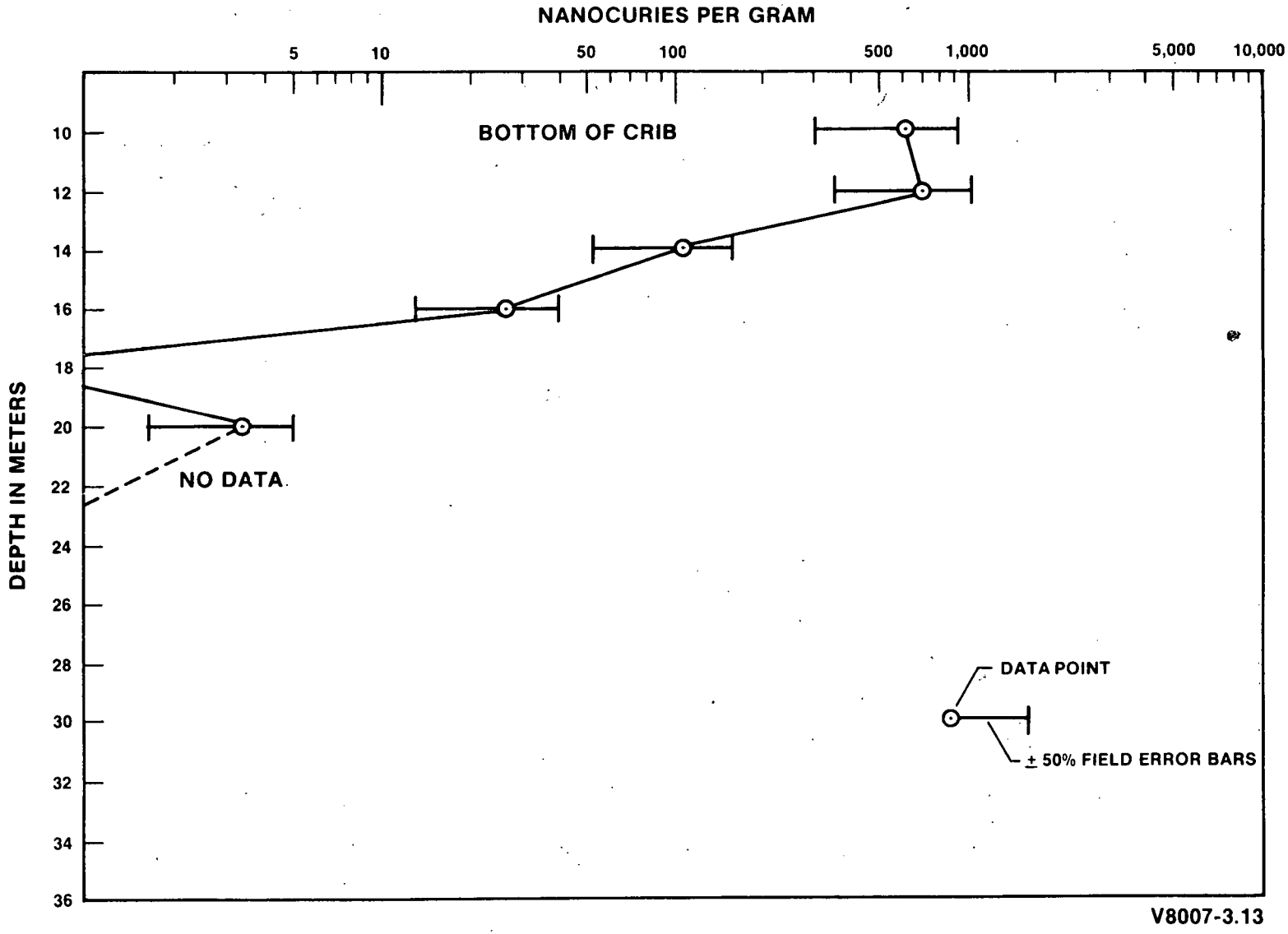


FIGURE 26. Cesium-137 Profile for Well 299-W22-29.

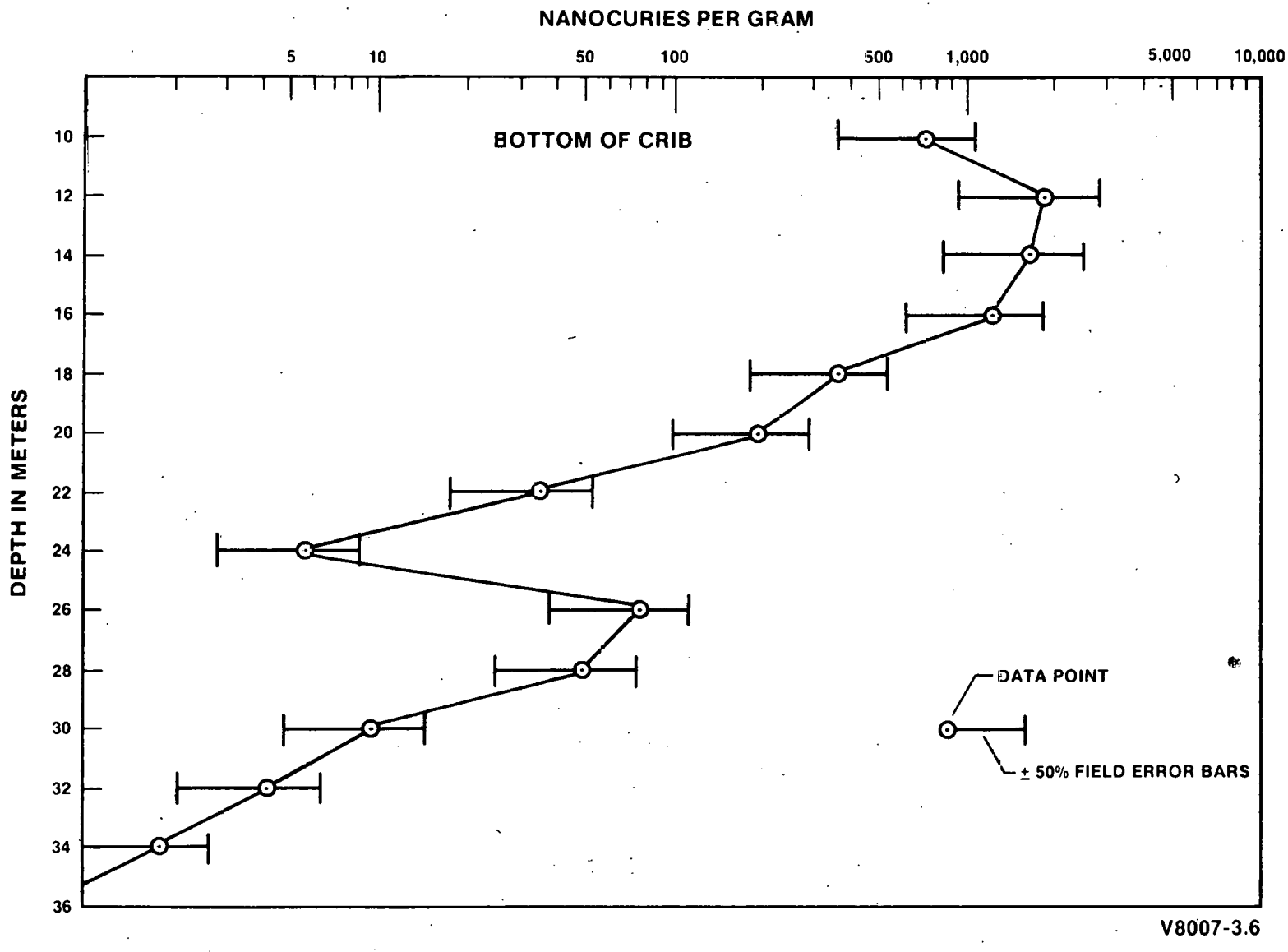


FIGURE 27. Cesium-137 Profile for Well 299-W22-30.

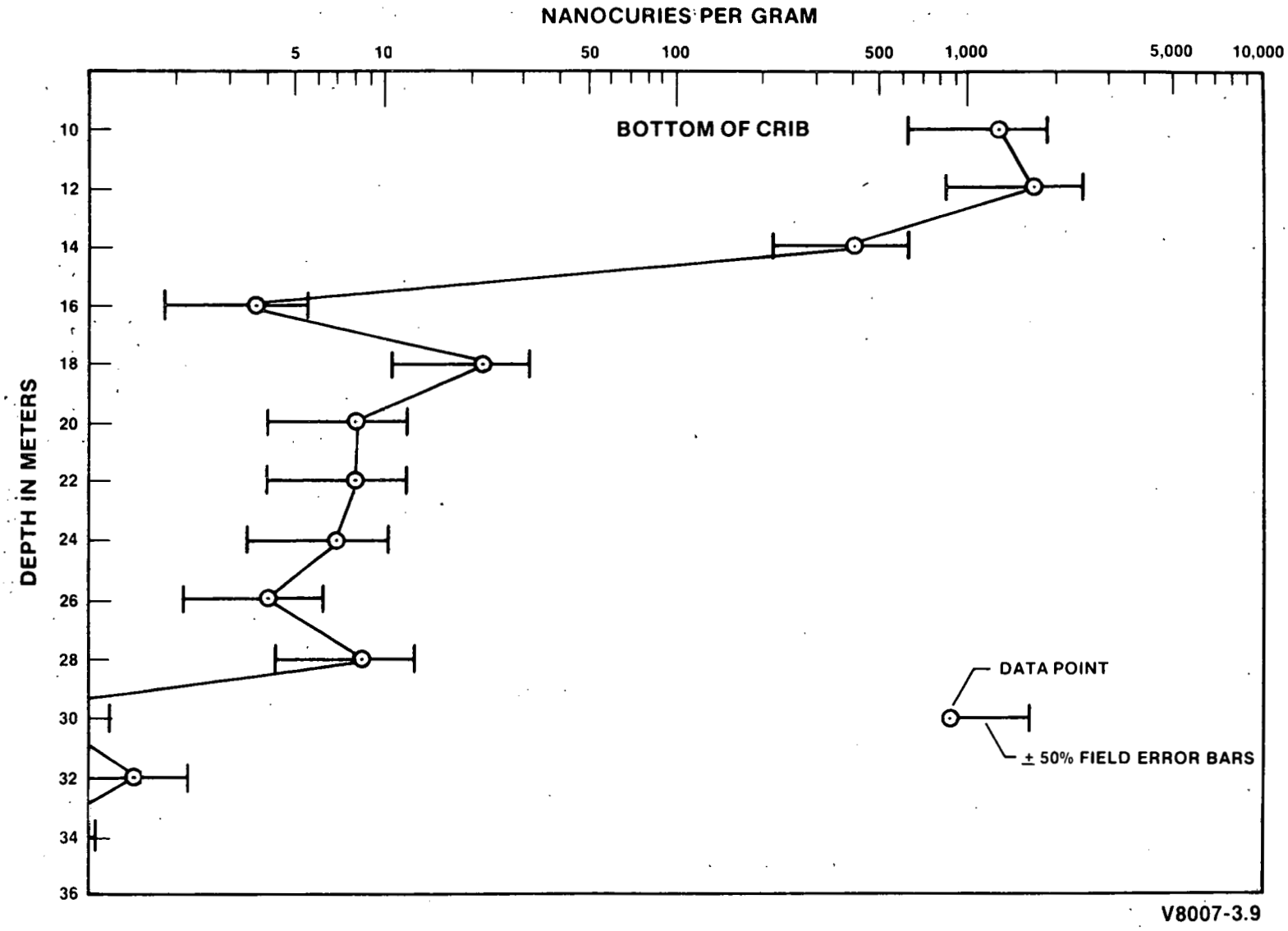


FIGURE 28. Cesium-137 Profile for Well 299-W22-31.

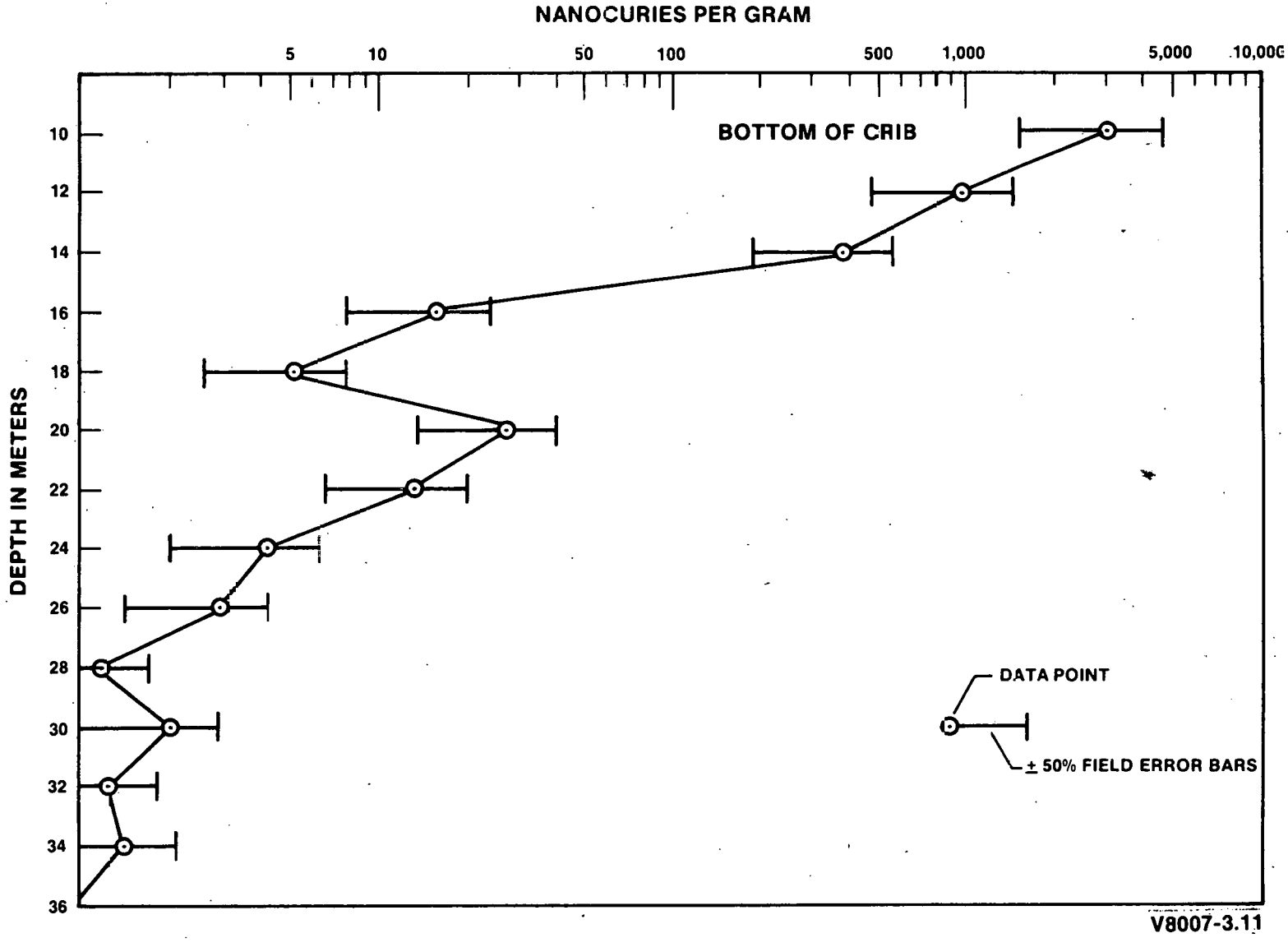


FIGURE 29. Cesium-137 Profile for Well 299-W22-36.

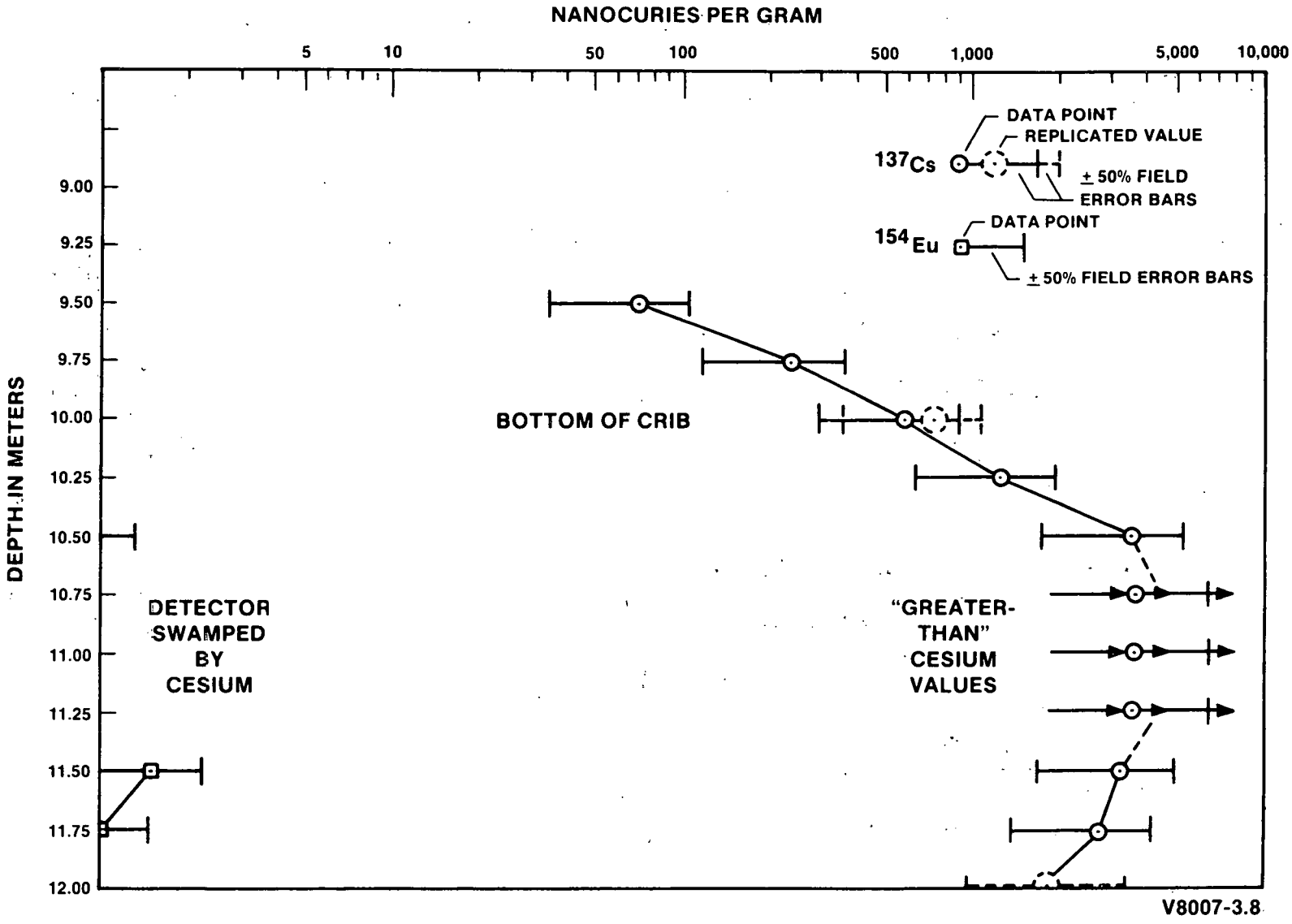


FIGURE 30. Crib Bottom Detail, Well 299-W22-30, for ^{137}Cs and ^{154}Eu.

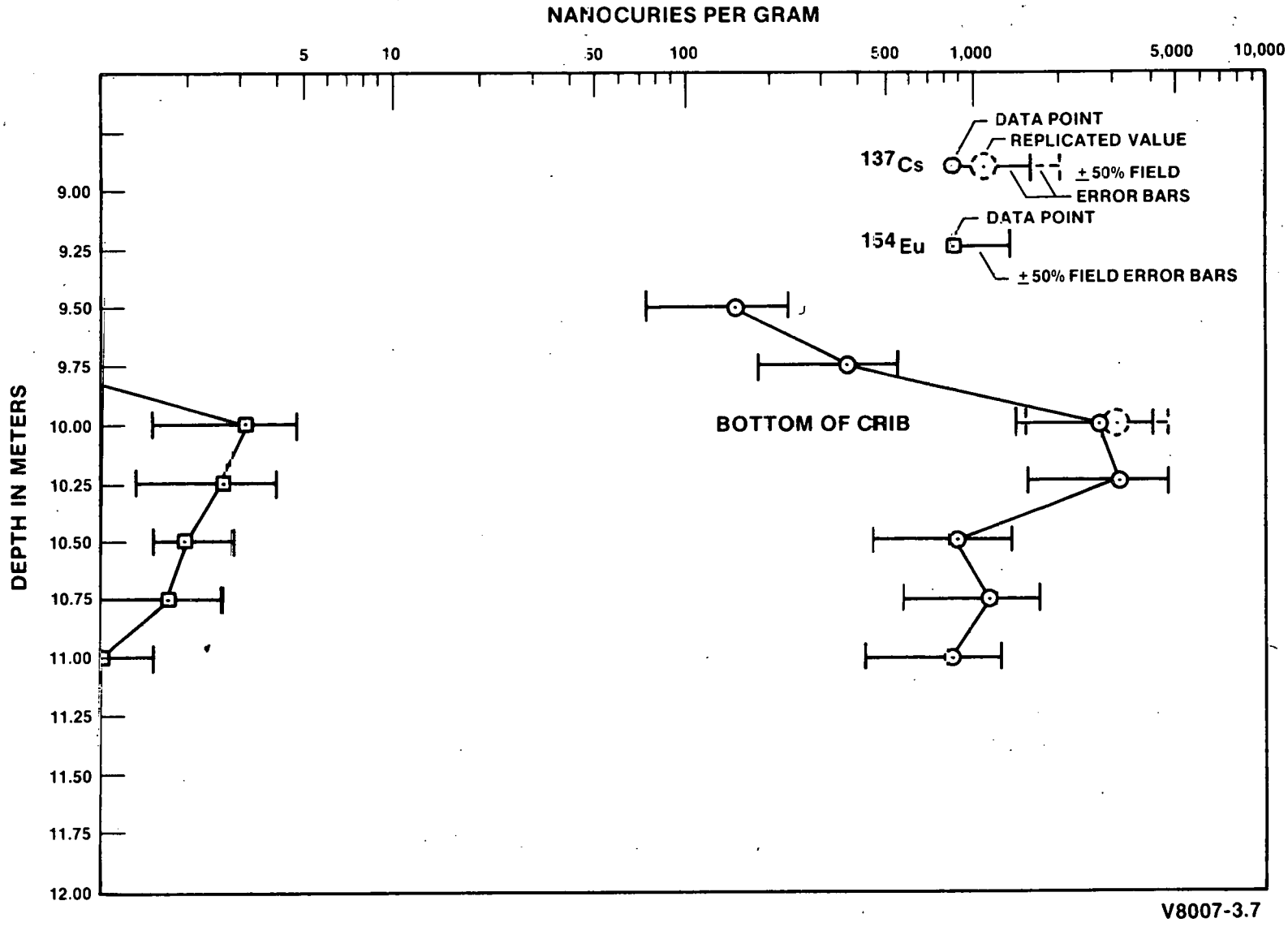


FIGURE 31. Crib Bottom Detail, Well 299-W22-36, for ^{137}Cs and ^{154}Eu.

Europium-154 concentration profiles follow the basic shape of the ^{137}Cs profiles (see Figure 31). Figure 30 shows the detector is unable to measure other energies, while the counter is swamped at one energy. This effect also increases the threshold level for the detection of significant counts at other energy levels while one energy level is receiving high count inputs. High ^{137}Cs concentrations will mask low concentrations of other radionuclides or, if high enough, ^{137}Cs levels make the detection of other radionuclides impossible.

To determine approximate sensitivity differences between the two logging methods, scintillation and gamma spectroscopic logs from well 299-W22-36 were compared. The data indicated that there was approximately a thousandfold difference in the sensitivities of the two methods. In Figure 32, ^{137}Cs concentrations (determined by gamma spectroscopy) are plotted versus total gamma activity (determined by gamma scintillation) for well 299-W22-36. It is apparent from this figure that the scintillation probe becomes overloaded at approximately 10 nCi/g ^{137}Cs. This overload occurs at $\geq 2.4 \times 10^6$ counts/min; above this level, the probe shows no additional response to increased gamma activity.

Scintillation profiles detail contamination levels from natural background to significant levels, while gamma spectroscopic profiles allow greater detail at higher contamination levels. Therefore, the two methods are complementary in defining the extent of gamma-emitting radionuclide contamination. The gamma spectroscopic method, in addition, allows the detailing of contamination plumes in terms of individual radionuclide concentrations.

Ground-Water Sampling

Ground-water samples were collected in January and June of 1980. The first sampling involved well 299-W22-30 shortly after it was deepened. The second sampling involved wells 299-W22-1, -2, -5, -10, -18 and -31 (see Figure 7 for well locations). Samples were collected using weighted polyethylene bottles, which were lowered into the well. These two samplings were conducted as a survey of the ground-water quality in and near the 216-S-1 and 2 crib site. Results appear in Table 2.

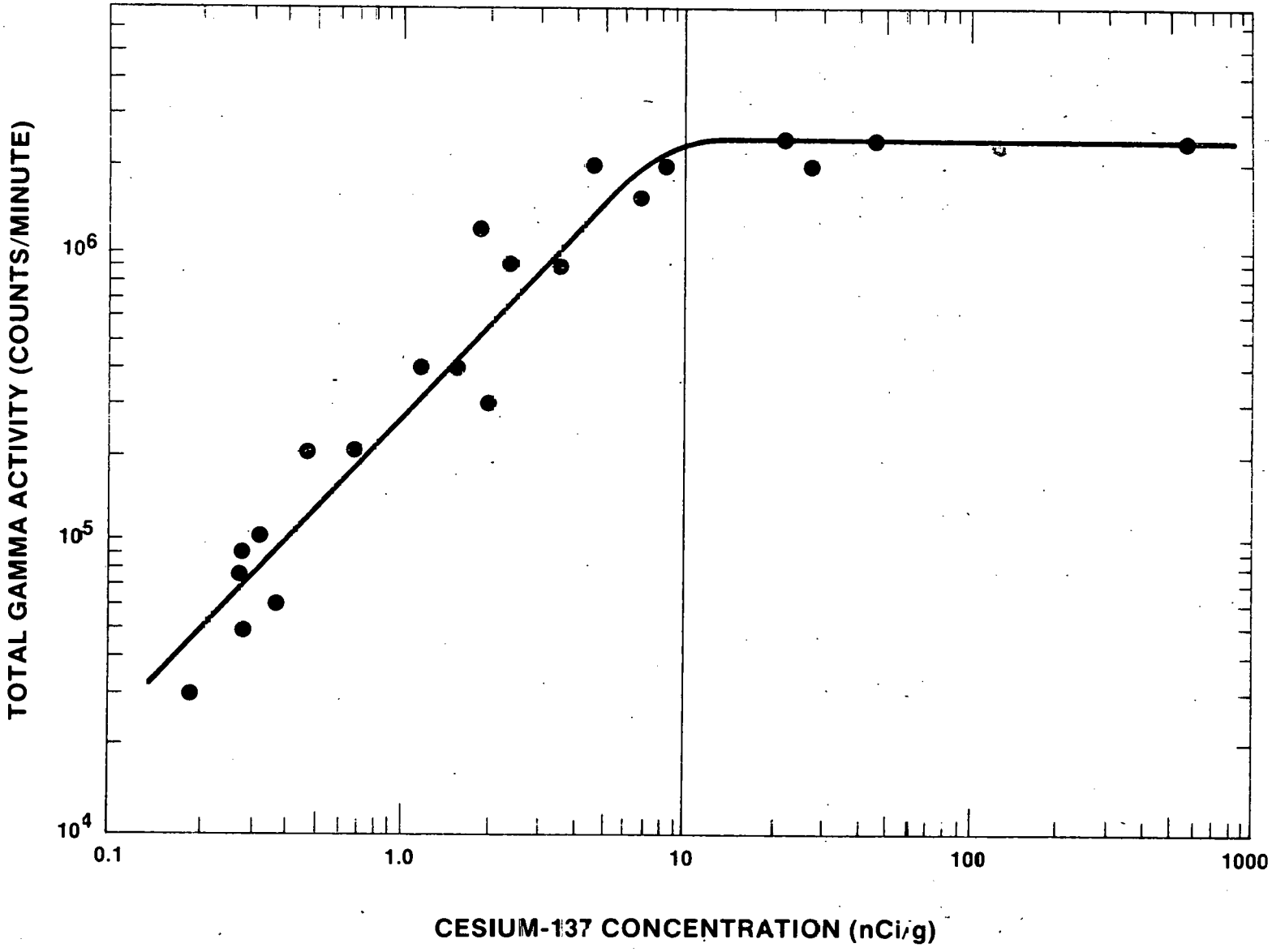


FIGURE 32. Cesium-137 Activity (IG) Versus Total Gamma Activity (Scintillation) for Well 299-W22-36.

TABLE 2. Current Study 216-S-1 and 2 Crib Site Ground-Water Radionuclide Contamination Levels (in pCi/ℓ).

Well (299-W22-)	Total α	Total β	^{90}Sr
1	<17	7,100	
2	<17	170	
5	<17	<75	
10	<17	<75	
18	<17	<75	
30	<17	6,230 ± 220*	3,030 ± 70*
31	<17	4,200	

*Standard deviation for 3 sample results.

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DISCUSSION

SCINTILLATION PROFILES

The scintillation profile results obtained in this study are directly comparable with the corresponding profiles obtained previously. The differences in the profiles may be attributed to ^{106}Ru-^{106}Rh decay, differences in scintillation detector sensitivities, and small errors in depth measurement. The results of radioactive decay are the most obvious as illustrated in profiles from well 299-W22-2 presented in Figure 33 (Additon et al., 1978).

The 1958 profile, shown in Figure 33, appears to have saturated the probe from the 10- to 30-meter depth, and perhaps also at the 42- to 43- and 52- to 55-meter depths. The striking difference between the 1963 profile and the two earlier profiles reflects the result of ^{106}Ru decay.

Scintillation profiles for well 299-W22-2 (presented in Figures 11, 33, and 34) illustrate a phenomenon that is especially evident in the later profiles representing the longer-lived gamma-emitting radionuclides. Activity decreases rapidly below the zone immediately beneath the crib structure, but increases again at about 47 meters, 53 meters, and 56 to 60 meters. The peaks nearer 60 meters, which appear to be strong enough to have saturated the scintillation probe, are at the water table. The activity at 90 meters, when the saturated zone directly above is at natural background levels, presents another interpretive problem. These evidences of gamma contamination in the saturated sediments below the water table are also reflected in the scintillation profile for well 299-W22-1 (see Figure 8), but not in the profiles for wells 299-W22-29, -30, -31, and -36 (see Figures 12 through 15).

High contamination levels were encountered below the water table in well 299-W22-30. Field instrument readings of 20,000 to 40,000 counts/min of beta-gamma activity were encountered slightly below the water table and continued to be present 7 meters deeper to the point where drilling was abandoned. Since well 299-W22-30 is located only a few meters from

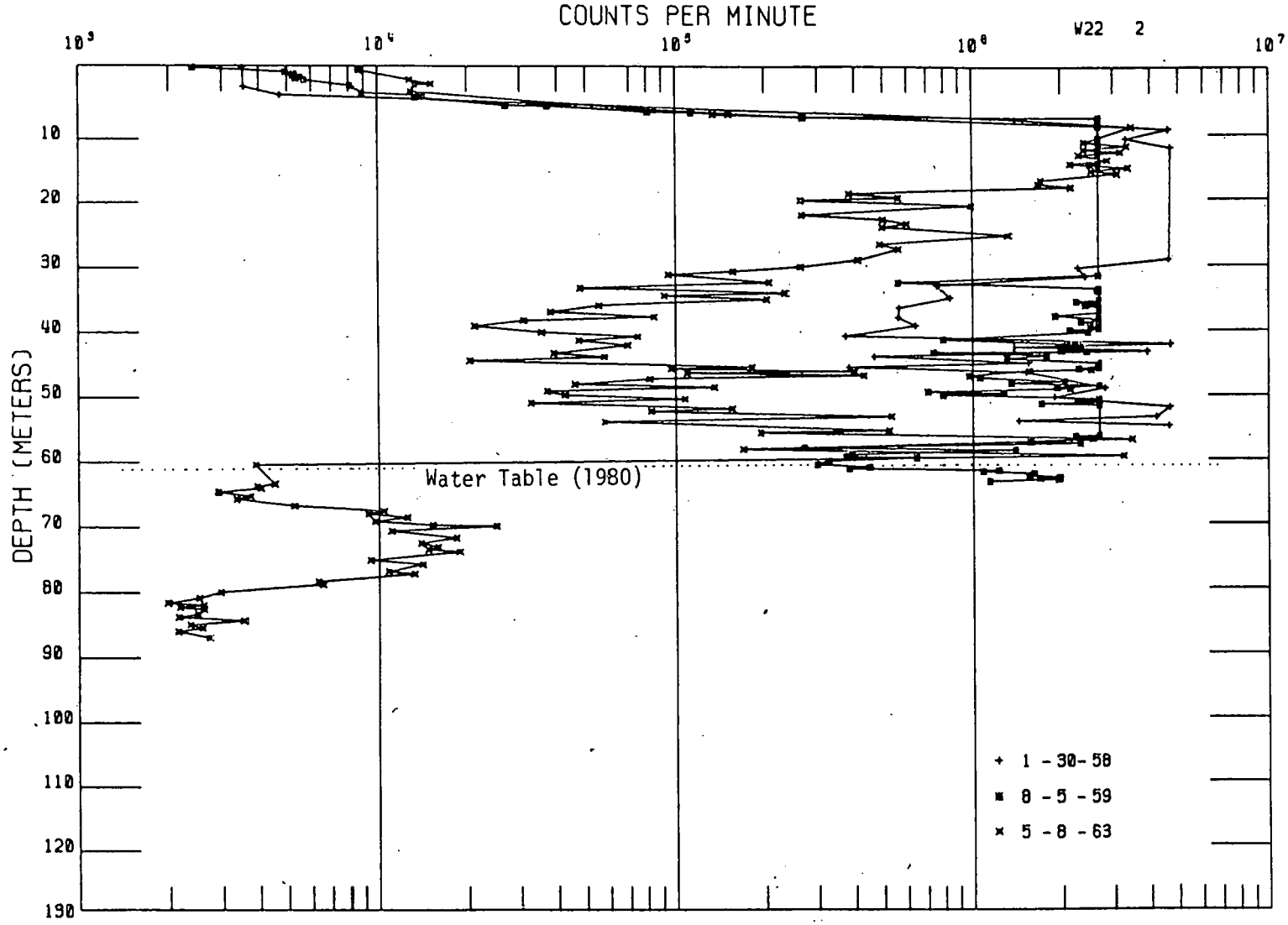

FIGURE 33. Well 299-W22-2 Scintillation Profiles for the Years 1958, 1959, and 1963.

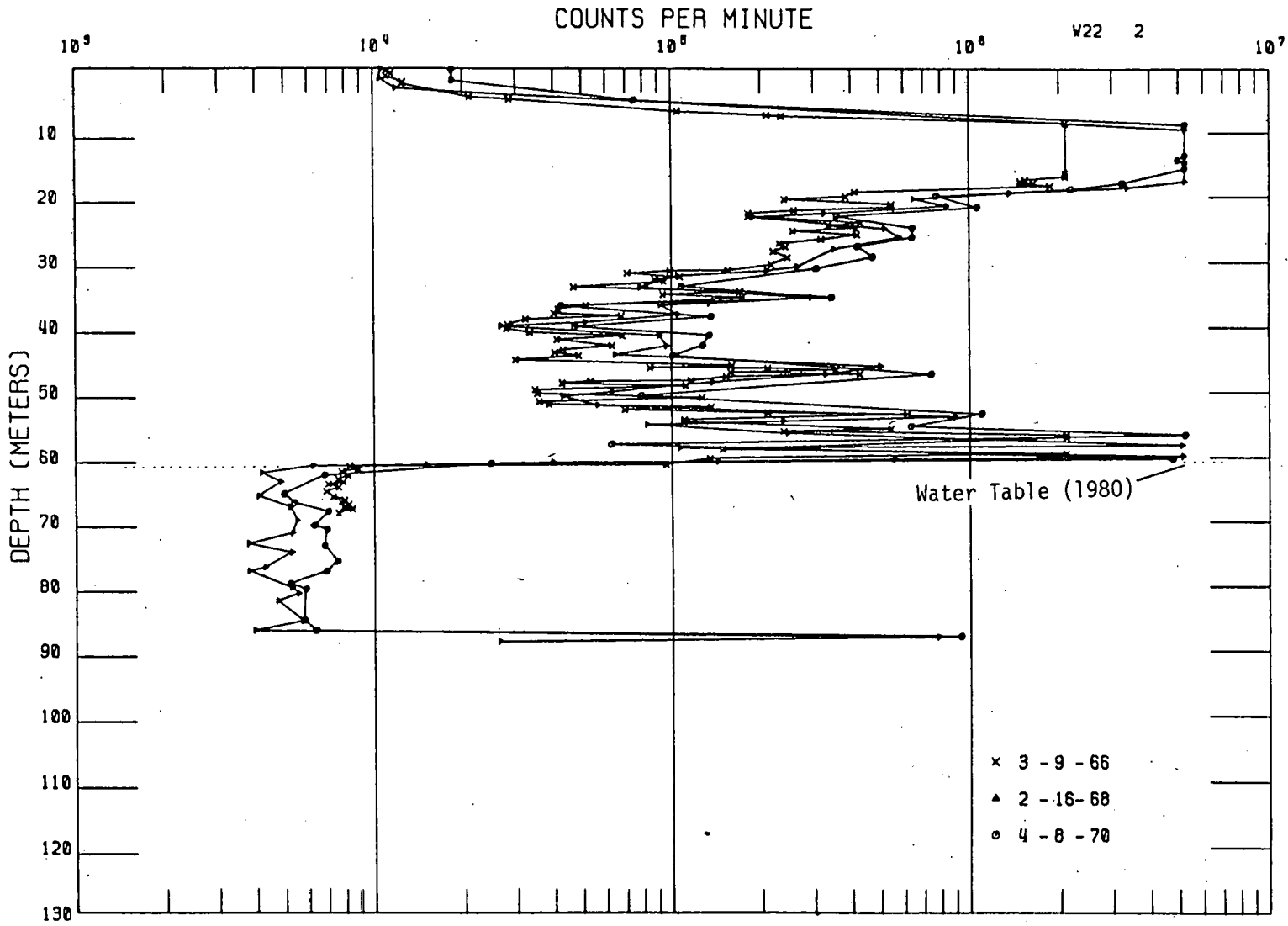

FIGURE 34. Well 299-W22-2 Scintillation Profiles for the Years 1966, 1968, and 1970.

well 299-W22-3, which leaked waste directly from the crib into the ground water (see "Site History"), the source of this activity was identified as the 299-W22-3 well leak. Further work on well 299-W22-30 would not have added any insight into the problem identified in the 299-W22-1 and -2 scintillation profiles and, therefore, drilling was discontinued.

Analyses of sediment samples from well 299-W22-31 revealed that extremely low levels of ^{137}Cs contamination existed at or below the water table. Sediment samples collected at 1.5-meter intervals from 62.5 to 76 meters were counted with a gamma spectrometer. The results are presented in Table 3.

TABLE 3. Concentrations of ^{137}Cs on Sediments in Well 299-W22-31.

Depth, m	^{137}Cs, nCi/g
64	0.0019
65.5	0.0325
67	0.0031
68.5	0.0023
70	0.0019
71.5	0.0008
73	0.0008
74.5	0.0011
76	0.0012

The deepened wells were relogged with the scintillation probe. Figure 35 compares the 299-W22-31 profiles before and after the well was deepened 14 meters. The entire lower portion of the contamination profile has moved down with the casing. A peak remains at the bottom of the crib near the 10-meter depth, indicating that the sediments at the bottom of the crib contain high levels of contamination. The zone of high contamination, from about 19 to 30 meters on the postdeepening profile, largely represents actual sediment contamination. If the

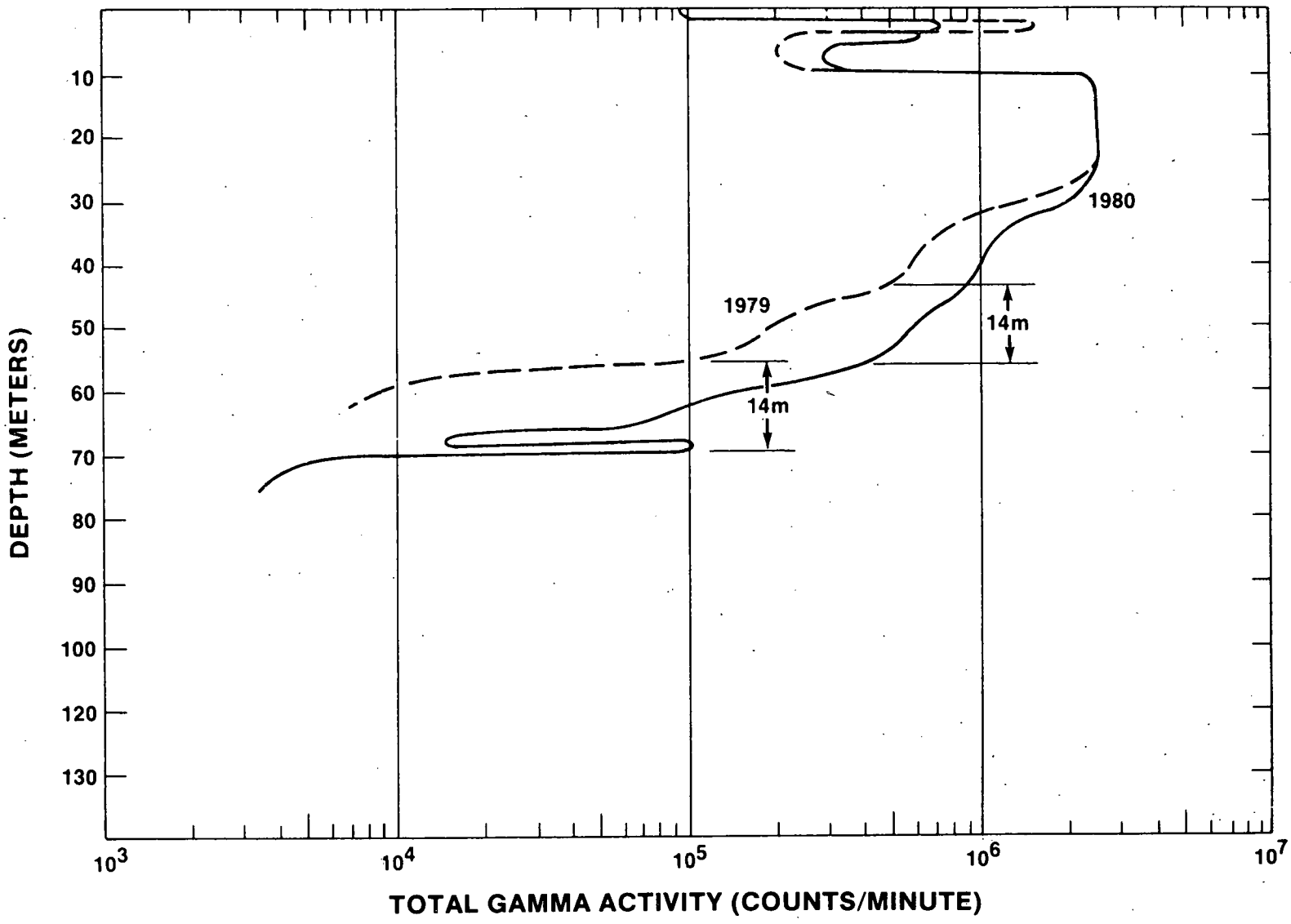

FIGURE 35. Comparison (Overlay) of the Well 299-W22-31 Scintillation Profiles Obtained Before and After the Well was Deepened Fourteen Meters.

9-meter activity peak also exists on the casing, it is not separable from the surrounding sediment contamination at 22 to 23 meters.

The former 2-meter activity peak, which represents the shallow burial of contaminated drilling samples from the 1956 well-drilling, probably became split between the remaining peak representing contaminated sediment and the increased activity at about 16 meters below ground surface.

Below 40 meters, these profiles are offset 14 meters, which suggests that much of the measurable gamma contamination in this region is located on the well casing. Similar comparisons may be made for the corresponding well 299-W22-30 profiles before and after deepening.

Wells 299-W22-1 and -2 were in place during the entire life of the crib, which allowed casing contact with the acidic waste. In 1956, just before the crib was removed from service, wells 299-W22-1 and -2 were deepened from approximately 45 to 90 meters. Therefore, the areas of casing in contact with waste may be expected to show zones of high activity at their new depths. The gamma profiles for wells 299-W22-1 and -2 (see Figures 10 and 11) from the surface to 45 meters represent actual sediment activity since new, clean casing was driven to this depth. The increased activity associated with the 10-meter depth before the well was deepened should, therefore, be located at about 55 meters following deepening of the well. Wells 299-W22-1 and -2 exhibit just such activity peaks near 55 and 60 meters.

Examination of the driller's logs for wells 299-W22-1 and -2 provides further evidence of the hypothesis that the 55- to 60-meter gamma scintillation activity is located on the well casings. When well 299-W22-1 was deepened, low-level contamination was detected at the 46-meter depth. This low level of contamination decreased to at or near background levels (200 to 500 counts/total beta-gamma) as drilling proceeded to the water table. In the well 299-W22-2 deepening, no mention was made of contamination until the 80-meter depth was approached. Summaries of these two driller's logs have been prepared and are given in Appendix B. Laboratory radiological analyses, performed as part of the

Raymond and McGhan (1967) study, showed that in the 55- to 60-meter zone, no ^{137}Cs levels exceeded 0.1 nCi/g for any of the other wells that were drilled through the crib (see Figure 7).

RADIONUCLIDE DISTRIBUTIONS

Results from the gamma spectroscopic logging were used to map radionuclide distributions beneath the crib. The ^{137}Cs distributions, drawn on geologic cross sections A-A' and B-B' (see Figure 7), are presented in Figures 36 and 37. Europium-154, the only other gamma-emitting radionuclide detected in significant quantities, was detected just below the bottom of the crib at concentrations less than 10 nCi/g.

Both cross sections indicated that ^{137}Cs concentrations are highest at and just below the bottom of the crib and gradually decrease with depth. The plumes showed that the radioactive waste has migrated the deepest beneath the S-2 portion of the crib. This may be because this was the lowest point in the crib. Well 299-W22-3 was present when the crib was in operation and waste could have flowed down the annulus between the borehole and the casing. Both situations could be a factor in the ^{137}Cs distribution shown. The small zones of contamination between 1 and 10 nCi/g at 58 to 60 meters in wells 299-W22-1 and -2 are the result of well deepening discussed in the "Results" section. These contamination zones are suspected to be associated with the casing and not the sediments.

The presence of ^{60}Co, ^{154}Eu, and ^{125}Sb in well 299-W22-1 at the 57- to 60-meter depth, while undetectable directly above and below this zone, suggests a transport mechanism other than waste liquid flow. As described previously, sediment interactions with the waste should result in general decreases in radionuclide concentrations with depth. Zones of higher radionuclide concentration, corresponding to silt stringers or other zones of finer particulate materials are likely. Moreover, the effect of the presence of the water table as a neutralizing and reducing barrier is unknown as far as the solubility of ^{60}Co, ^{154}Eu, or ^{125}Sb is concerned. It is not known why these three radionuclides are present near the water table in well 299-W22-1 or why detectable amounts of

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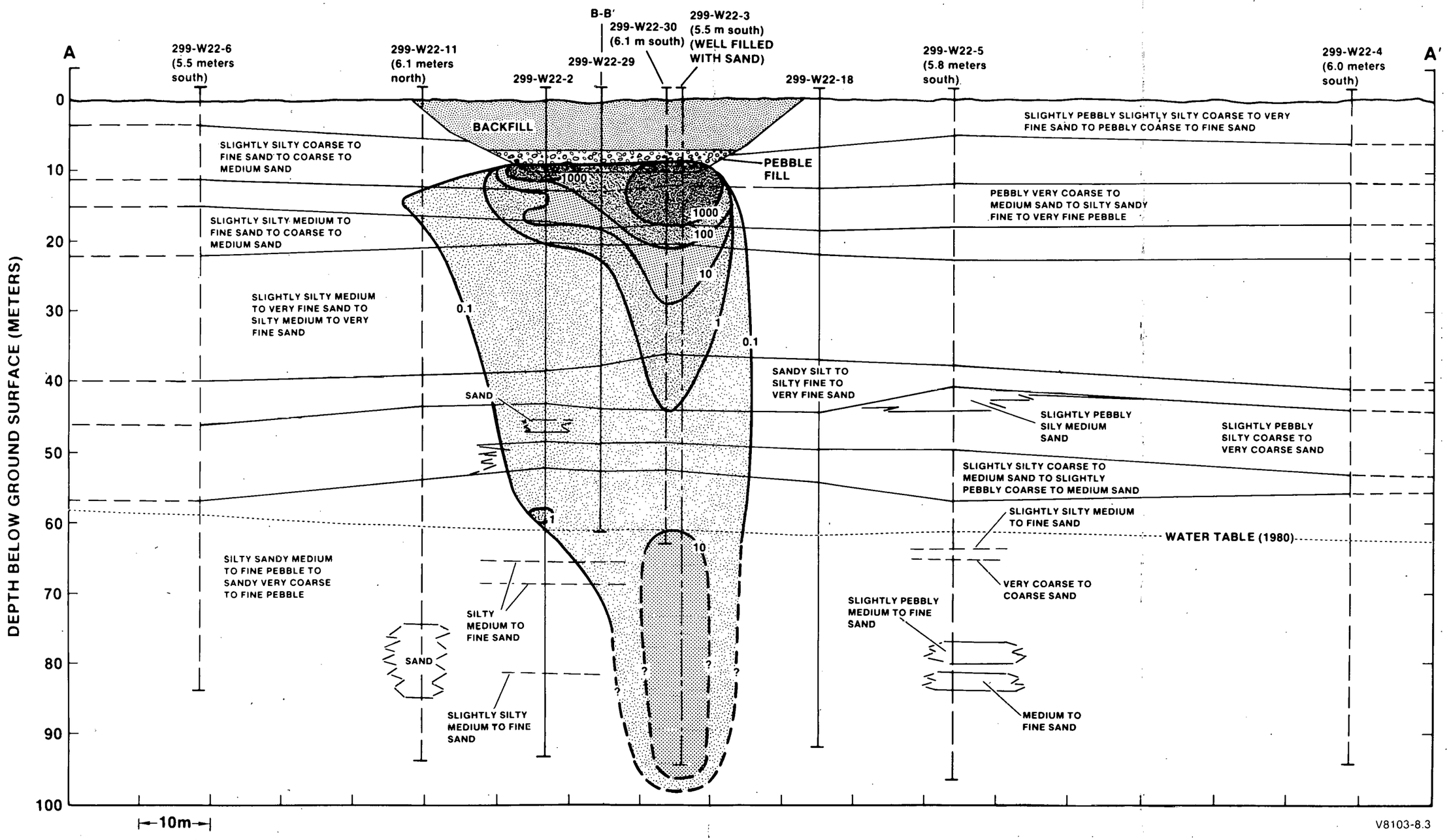

FIGURE 36. Cesium-137 Distribution (nCi/g) Beneath the 216-S-1 and 2 Crib, A to A'.

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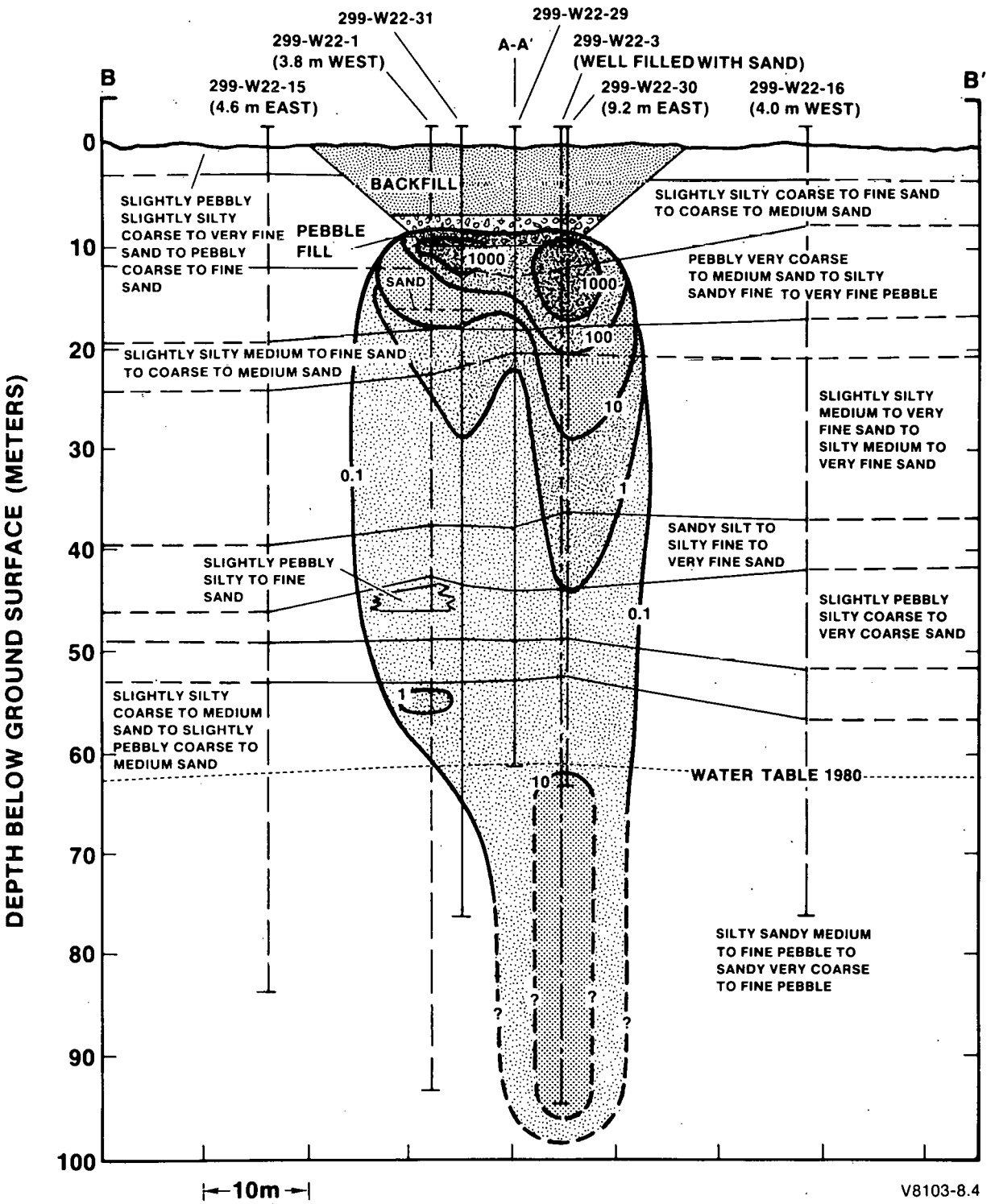

FIGURE 37. Cesium-137 Distribution (nCi/g) Beneath the 216-S-1 and 2 Crib, B to B'.

these same nuclides are absent near the water table in the other three wells logged to this depth, including well 299-W22-2. Each of these three radionuclides may remain soluble, hence water transportable, over a range of acidity and oxidation-reduction conditions. Antimony, however, readily bonds to iron or steel corroding in an acid solution (Pourbaix, 1966).

Antimony was not detected elsewhere in the crib because of counting interference from increased concentrations of ^{137}Cs and because of its absence (due to decay or sediment interactions) where concentrations of ^{137}Cs were low. The data of Raymond and McGhan (1967) showed antimony levels as high as 2,500 nCi/g at the bottom of the crib (well 299-W22-29) falling off to levels of less than 1 nCi/g 5 meters further down in the sediments. The presence of ^{125}Sb at this particular location in well 299-W22-1 is, therefore, suggestive of antimony plating on the well casing where acid-waste corrosion was the most intense.

In wells 299-W22-1 and -2, the spectra observed for the ^{137}Cs peaks near the water table were clean, exhibiting all the features expected from a single source near the detector. This observation is consistent with the idea that the ^{137}Cs contamination observed at this depth is on the well casing only.

Gamma contamination retained on the saturated sediments below the water table in well 299-W22-30 is a result of the 299-W22-3 well leak (see "Site History") in 1955. The extent of that leak is unknown and, therefore, was drawn using dashed lines. The sorption characteristics of radionuclides are similar in the saturated and vadose zones; it is unlikely that the zone contaminated at greater than 10 nCi/g presently extends more than 20 meters from well 299-W22-3. In the saturated zone, the maximum ^{137}Cs contamination level measured on the sediment was 34 nCi/g. The waste solution entering the saturated sediments less than 3 meters from well 299-W22-30 contained 113 nCi ^{137}Cs/mℓ. Vadose zone results for well 299-W22-30 showed that, at the crib/sediment interface, at least a fiftyfold concentration of the incoming solution occurred (from 113 to greater than 6,000 nCi/mℓ) over the 4-year active life of the crib. In well 299-W22-29, this concentration factor appears to have

been about 10. It is not likely that this concentration factor was exceeded during the short time (as much as 7 months) that well 299-W22-3 leaked. An estimated maximum ^{137}Cs concentration within the plume surrounding well 299-W22-3 would, therefore, be on the order of 1,000 nCi/mℓ or about 600 nCi/g of sediment. Finding ^{137}Cs concentration reduced by one order of magnitude within 3 meters from the contaminant source is consistent with vadose zone results.

In well 299-W22-30, ^{137}Cs concentrations ranged from less than 1 to nearly 7 nCi/g between 30 and 46 meters. From 46 meters to the water table, ^{137}Cs concentrations persisted near 1 nCi/g. This indicates that ^{137}Cs did migrate to the water table at this site.

Cesium-137 was found to be the predominant gamma-emitting radionuclide in the 216-S-1 and 2 crib site sediments. Amounts of ^{154}Eu and ^{60}Co found were generally at activities four to five orders of magnitude less than the ^{137}Cs values.

The distribution coefficient (K_d) for ^{137}Cs in sediments below the water table at the 216-S-1 and 2 crib site is approximately 300. At a soil contaminant concentration of 10 nCi ^{137}Cs/g and under saturated conditions, assuming that the water has access to all of the cesium, the concentration of ^{137}Cs in the ground water could be as high as 0.03 nCi/mℓ.

This is less than the ERDA MC 0524 limit of 0.4 nCi/mℓ for soluble ^{137}Cs concentration in waters disposed in a controlled area. From these very rough calculations, it may be seen that a 10-nCi/g ^{137}Cs soil contamination level in controlled area sediments presents no threat to percolating waters or to saturated zone ground water, should the site become inundated. In addition, as ^{137}Cs-contaminated water passes through the uncontaminated sediments outside the controlled area, it may be expected that the ^{137}Cs will be retained by these sediments through adsorptive (cation exchange) processes.

In the previous section, an approximate relationship between the intensity of the scintillation profile peaks and the ^{137}Cs concentration of the sediments was developed that suggested that zones of increased (greater than 10 nCi ^{137}Cs/g) contamination were restricted to areas

directly below the crib. The gamma spectrometer profiles, shown in Figures 10 through 23, confirm this view of the vertical extent of the ^{137}Cs contamination.

GROUND-WATER CONTAMINATION

The water-table elevation under the 216-S-1 and 2 crib site is presently influenced by liquid discharges to U-Pond (Figure 38). Since ground-water flow paths are perpendicular to water-table contours, Figure 38 suggests a general southeast direction of ground-water flow from the 216-S-1 and 2 crib site.

To interpret the meaning of the total beta and ^{90}Sr levels reported in the past and the water analyses conducted in the current study, contamination histories for wells near the crib site and west of the crib site were investigated. In addition, analyses of water samples from wells down-gradient from the 216-S-1 and 2 crib site were compared with samples from wells at similar distances but not down-gradient from U-Pond. The locations of wells for which water quality histories exist are shown in Figure 39. A summary of water quality data from wells monitoring the 216-S-1 and 2 crib are presented in Tables 4, 5, 6, and 7.

Initially, ground-water samples from well 299-W22-2 (see Table 6) appeared to have higher beta and ^{90}Sr concentrations than ground-water samples from well 299-W22-1 (see Table 4). Activities in well 299-W22-2 seem to have stabilized, with a gradual activity decrease before 1970, and have been in a nearly steady state since that time. The limit (ERDA MC 0524) for soluble ^{90}Sr discharges to controlled areas is 10 pCi/mℓ. Since 1960, well 299-W22-2 ground water has been below this limit.

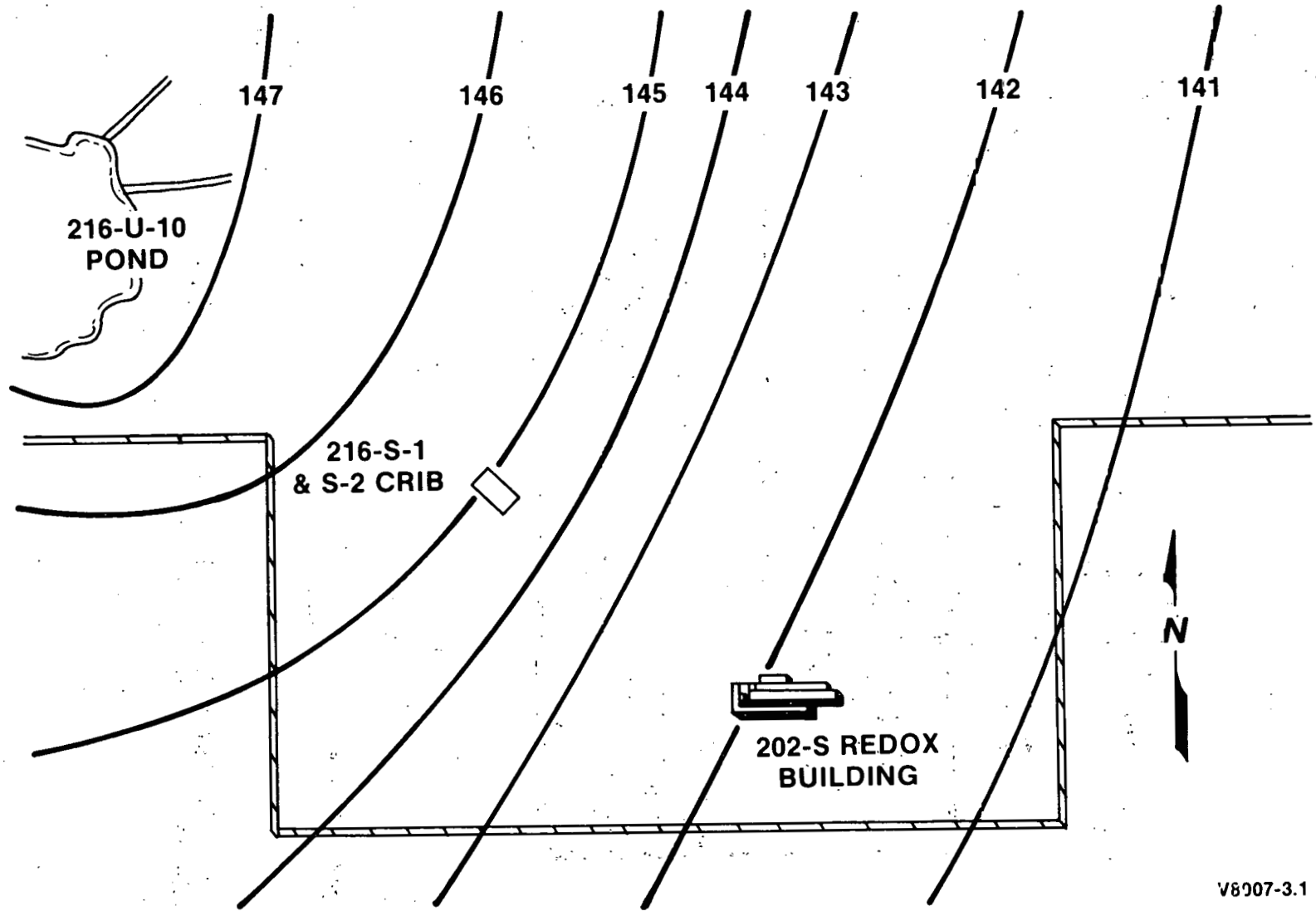

FIGURE 38. Water-Table Elevation (Meters) in the 216-S-1 and 2 Crib Vicinity.

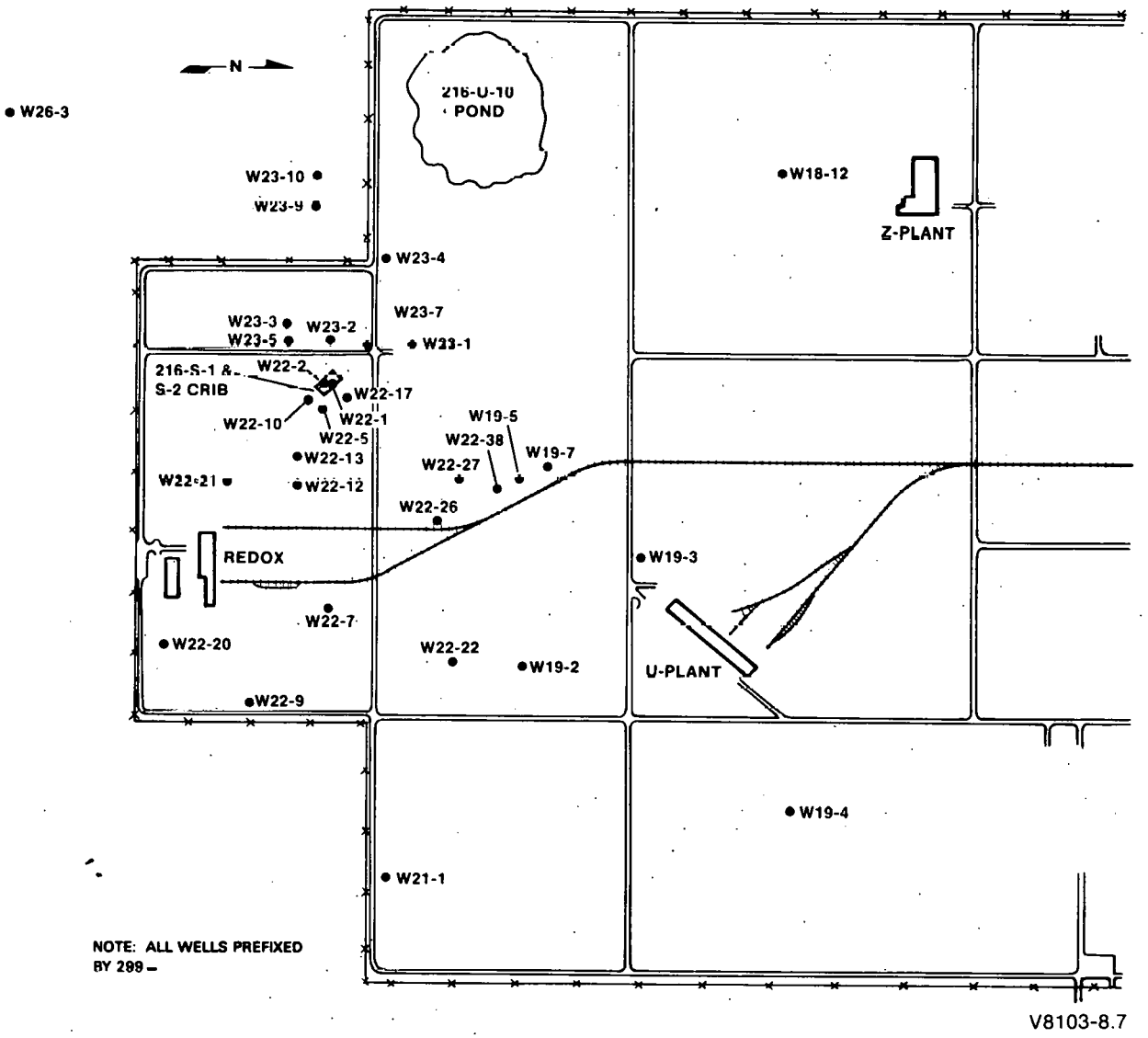

FIGURE 39. Water Wells in the 216-S-1 and 2 Crib Vicinity for Which Contamination Histories are Available.

TABLE 4. Well 299-W22-1 Ground-Water Monitoring, 1961 to 1977.

Time Period	Concentrations in pCi/mℓ				
	Total β		^{90}Sr		^{3}H
	Average[a]	Maximum[b]	Average[a]	Maximum[b]	
Jul - Dec, 1961	0.24				
Jan - Jun, 1962	0.28				
Jan - Jun, 1963	2.4				1400
Jan - Dec, 1963	4.0				1000
Jan - Dec, 1964	90.0	160.0	42	48	400
Jul - Dec, 1966	350.0				
Aug - Sep, 1970	47.0	49.0	20	21	
Oct - Dec, 1970	30.0	32.0	18	22	
Jan - Mar, 1971	52.0	56.0	27	32	
Apr - June, 1971	55.0	78.0	24	25	
Jul - Sep, 1971	41.0	50.0	20	22	
Oct - Dec, 1971	38.0	55.0	20	22	
Jan - Mar, 1974	10.0	15.0	9.5	11	
Apr - June, 1974	14.0	16.0	15[c]	21[c]	
Jul - Aug, 1974	23.0	27.0	21	21	
Oct - Dec, 1974	21.0	23.0	19	21	
Jan - Mar, 1975		29.0		25[d]	
Apr - Jun, 1975	25.0	28.0	18	20	
Jul - Sep, 1975	18.0	20.0	16	23	
Oct - Dec, 1975	23.0	27.0	30[c]	37[c]	
Jan - Mar, 1976	29.0	34.0	20	21	
Apr - June, 1976	28.0	33.0	22	25	
Aug - Sep, 1976	21.0	24.0	15	19	
Nov - Dec, 1976	16.0	18.0	13	15	
Jan - Feb, 1977	28.0	41.0	18	23	

[a]Average of the monthly values for the indicated months.

[b]Maximum of the monthly values for the indicated months.

[c]Apparent data discrepancy, more ^{90}Sr than Total β.

[d]No average computed since 1 of 3 values was <0.08 for Total β - probably an error.

TABLE 5. Well 299-W22-1 Ground-Water Monitoring, 1977 to 1979.

Time Period	Concentrations in pCi/mℓ						
	Total β	^{90}Sr	^{106}Ru	^{137}Cs	^{60}Co	Total α	^{3}H
May 1977	14.0	15.0	0.3	<0.02	<0.06	0.04	630
Aug 1977	24.0	17.0	0.6	<0.02	<0.02	0.07	1400
Nov 1977	23.0	16.0	0.9	<0.02	<0.02	0.07	1500
Feb 1978	28.0	14.0	0.8	<0.02	<0.02	0.08	2800
May 1978	31.0	20.0	0.5			0.07	2300
Jul 1978	27.0	17.0	0.2			0.02	240
Nov 1978	6.4	3.5	0.2			<0.02	260
Feb 1979	24.0	18.0		*		0.08	6700
May 1979	6.3	3.1		*		<0.02	430
Jul 1979	22.0	17.0		*		<0.02	1000
Oct 1979	16.0	15.0				<0.02	690

*No significant gamma contamination detected.

Ground-water samples from well 299-W22-1, on the other hand, have exceeded this 10-pCi ^{90}Sr/mℓ limit since 1964. From 1961 through 1963, the total beta activity levels were similar to those reported for well 299-W22-2. During 1963, total beta levels increased tenfold over the values of the previous 2 years. During 1964, an average twentyfold increase occurred over the average 1963 total beta levels. The latter half of 1966 saw a fourfold increase over the 1964 average total beta level. The next available data, in 1970, show that average levels had dropped to one-tenth of the 1966 levels. Since that time, the beta and ^{90}Sr data suggest a steady state, with perhaps a slight decreasing trend the last 2 years.

TABLE 6. Well 299-W22-2 Ground-Water Monitoring Results, 1959 to 1980.

Time Period	Concentrations in pCi/mℓ						
	Total β		^{90}Sr		Total α	^{106}Ru	^{3}H
	Average[a]	Maximum[b]	Average[a]	Maximum[b]			
Jan - Mar 1959	920.0[c]			2.1			
Jul - Sep 1959			0.82				
Oct - Nov 1959			1.2				
Jan - Mar 1960			0.84				
Apr - Jun 1960				9.7[d]			
Jul - Sep 1960				1.0			
Oct - Dec 1960				0.21			
Jan - Jun 1961				0.60			
Jul - Dec 1961	1.9[c]			0.60			
Jan - Jun 1962	2.0[c]			0.34			
Jan - Jun 1963	4.5[c]		3.1[c]				740
Jan - Dec 1964	1.4	2.2					1100
Aug - Sep 1970	0.32	0.45	0.09	0.10			
Oct - Dec 1970	0.28	0.38	0.12	0.14			
Jan - Mar 1971	0.74	0.92	0.34	0.48			
Apr - Jun 1971	0.67	0.88	0.28	0.41			
Jul - Sep 1971	0.45	0.41	0.19	0.20			
Oct - Dec 1971	0.36	0.38	0.14	0.17			
Jan - Mar 1974	0.19	0.27	0.13	0.17			
Apr - Jun 1974	0.18	0.22	0.12	0.12			
Jul - Aug 1974	0.14	0.16	0.10	0.14			
Nov 1974[e]	0.37[c]		0.07[c]				
Jan 1975	0.16[c]		0.12[c]				
Mar 1975	0.19[c]		0.11[c]				
May 1975	0.14[c]		0.07[c]				
Jul 1975	0.11[c]		0.06[c]				
Sep 1975	0.13[c]		0.09[c]				
Nov 1975	0.12[c]		0.12[c]				
Jan 1976	0.15[c]		0.09[c]				
Mar 1976	0.28[c]		0.14[c]				
May 1976	0.30[c]		0.22[c]				
Nov 1976	0.17[c]		0.13[c]				
Jan 1977	0.23[c]		0.17[c]				
Nov 1978	0.18[c]		0.10[c]		<0.02	0.16	870
Jun 1980	0.17[c]				<0.02		

[a]Average of the monthly values for the indicated months.

[b]Maximum of the monthly values for the indicated months.

[c]Only one reading reported for months given.

[d]High value after bailing and reperforating well.

[e]Bimonthly sampling program started.

TABLE 7. Recent Water Quality Sampling Results for Seven 216-S-1 and 2 Crib Site Monitoring Wells.

Well	Time Period	Concentrations in pCi/mℓ			
		Total α	Total β	^{90}Sr	^{137}Cs
299-W22-31	Jun 1980	<0.02	4.2		
299-W22-30	Dec 1979	<0.02	0.19[a]		
	Jan 1980		62.3[b]	30.3[b]	
299-W22-18	Jan 1980	<0.02	<0.08		
299-W22-17	Dec 1979	<0.02	<0.08	0.003	[c]
299-W22-16	Jun 1977	<0.02	<0.08		
	Jun 1978		<0.08		
299-W22-10	Dec 1979	<0.02	<0.08	0.008	[c]
	Mar 1980	<0.02	<0.08	0.010	[c]
	May 1980	<0.02	<0.08		[c]
299-W22-5	Dec 1979	<0.02	<0.08	0.011	[c]
	Jun 1980	<0.02	<0.08		

[a] Before deepening.

[b] After deepening.

[c] No significant gamma contamination detected.

The great increase in activity during the mid-1960's in well 299-W22-1 was not matched by a similar trend in well 299-W22-2. A survey of available total beta activity data (Appendix C) for wells west of, or near, well 299-W22-1 was conducted with the following results.

- Wells west of the crib site (299-W22-1 through -10 as listed in Figure 39) are considered to be generally upgradient in terms of the ground-water flow direction. Of these wells, only well 299-W22-4 showed elevated total beta activities in the late 1960's. In 1969, these levels were near 0.1 pCi/mℓ, which is at or near the lower limit of detection.

- Wells in or near the crib site for which histories were available included 299-W22-2, -5, -10, and -17. None of the histories for these wells included the time period of interest. However, in three wells the drainage of beta activity from the crib after deactivation is documented by sharp decreases in the beta activity. Well 299-W22-5 showed an initial beta activity increase after drilling from 10^{-3} to more than 10^{4} pCi/mℓ over a very short period of time, which may be explained by the use of water in the drilling operation. Subsequently, beta activities in these wells are declining at order-of-magnitude-per-year rates.

This information does not explain the total beta activity increase for well 299-W22-1 during the mid-1960's.

A survey of other wells (see Figure 39) was conducted. Total beta increases and decreases in the mid- to late 1950's, were found in wells 299-W19-2, 299-W22-7, -9, -12, -13, -20, and -21; this corresponds to active use of the 216-S-1 and 2 crib. These wells extend from the northeast through the southeast from the 216-S-1 and 2 crib site. Wells 299-W22-12 and -13 monitored the 216-S-7 crib, which replaced the 216-S-1 and 2 crib. The histories for these two wells show two peaks, (1) perhaps in response to the last of the 216-S-1 and 2 beta activity discharges and (2) in response to 216-S-7 discharges.

Wells in which total beta levels increased or decreased in the mid- to late 1960's include 299-W19-3, which monitors the 216-U-1 and U-2 crib complex southwest of U-Plant; 299-W19-5, which monitors the 216-S-23 crib; and 299-W22-21, -22, -26, -27, and -38, which monitor the 216-S-13, 216-U-12, 216-S-9, and 216-S-23 crib. In each case, the dates during which these cribs discharged beta activity included the time period in question, so no relationship between total beta activity peaks in these wells and in well 299-W22-1 is indicated.

The elevated total beta and ^{90}Sr values in well 299-W22-1 waters may be the result of a well leak shortly after this well was deepened in 1956. The 1980 total beta level in well 299-W22-30, which is located

in contaminated sediments, was approximately four times higher than the October 1979 total beta concentration for well 299-W22-1. Soluble ^{90}Sr levels are roughly comparable between well 299-W22-30 and -1, suggesting the presence of comparable amounts of ^{90}Sr on the sediments at these two locations. The elevated total beta activity in well 299-W22-31 probably is related to its close physical proximity to well 299-W22-1. A well-casing failure sometime after the crib was decommissioned could have resulted in the slow drainage of some ^{137}Cs depleted waste liquid directly to the ground-water in well 299-W22-1. It has been shown that ^{137}Cs sorption from the waste solution was not affected by the low pH, while ^{90}Sr sorption was increased by increases in solution pH as well as by the addition of a phosphate buffer (Rhodes, 1956). At present, this appears to be the most plausible explanation for the excess ^{90}Sr in well 299-W22-1 compared with all surrounding wells within the crib, except the well that was near a known well leak. In each of these wells, the difference in ^{137}Cs levels detected could be a function of the time the waste solution was in contact with the sediments of the crib before the leak occurred.

The important findings of this ground-water contamination survey were that elevated activity in the ground water directly under the crib has not been detected in recent water samplings in peripheral crib monitoring wells. In addition, the elevated ^{90}Sr and total beta levels in the well 299-W22-1 ground water appear to be stable and decreasing with time. There is no reason to suppose that future ground-water concentrations of beta- or gamma-emitting radionuclides resulting from the 216-S-1 and 2 crib will exceed currently observed levels.

SUMMARY AND CONCLUSIONS

The 216-S-1 and 2 crib site was studied to determine the 1980 radionuclide distributions in the crib sediments. Special attention was given to the evidences for contamination near, at, and below the water table.

Methods used included scintillation and gamma spectroscopic borehole logging systems. Two wells were deepened to allow a better definition of gamma-emitting radionuclide concentrations at and below the water table. Data obtained were analyzed and compared with data available from past monitoring activities, and previous field and laboratory studies concerning the 216-S-1 and 2 crib site.

Distributions of ^{137}Cs, the only gamma-emitting radionuclide widely distributed at levels greater than 10 nCi/g, were drawn on two geologic cross sections. Cesium-137 concentrations were highest at and just below the bottom of the crib and decreased rapidly with depth. The deepest penetration of ^{137}Cs was beneath the S-2 portion of the crib. Cesium-137 activity between 1 and 10 nCi/g was detected at approximately 60 meters in two original monitoring wells, but this was attributed to contamination fixed on the casing and not on the sediments. A zone of contamination exceeding 10 nCi/g was detected in the saturated sediments directly beneath the crib. The source of this contamination was a monitoring well that failed near the bottom of the crib and allowed waste to enter directly into the saturated sediments below the water table. This contamination was limited to within 20 meters laterally from the release point.

Scintillation profile comparisons indicated that, except for ^{106}Ru decay, there has been little change in the total gamma radiation profiles since 1958. Differences in these profiles since the late 1960's appear to reflect only random and systematic errors and provide no evidence for translocations of the gamma-emitting radionuclides since 1958.

Examination of scintillation profiles from the deepened wells indicated that some contamination was fixed on the well casing and was moved deeper into the profile by driving the casing deeper. This could produce erroneous interpretation of borehole logging data if not taken into consideration. In the future, wells that require deepening, if passing through zones of contamination, should be deepened by using a smaller-diameter casing inserted inside the original casing. In this way, any contamination fixed on the casing remains in place and is not moved deeper into the profile.

Since gamma spectroscopic results show that the greater part of the gamma activity in this crib comes from ^{137}Cs, the results of the scintillation probe were compared with ^{137}Cs. Note that these two methods do not see the same effective volumes, and differ in sensitivity. This comparison showed that when the scintillation probe is saturated at about 2.4×10^6 counts/min, the corresponding ^{137}Cs concentration is approximately 10 nCi/g. Only the 10-meter zone directly below the crib was found to be contaminated with ^{137}Cs greater than 10 nCi/g, except for a well near the S-2 portion of the crib, where ^{137}Cs at that concentration of 10 nCi/g was found to have penetrated to 20 meters beneath the crib bottom. The reason for the difference is most likely that the bottom of the 216-S-1 and 2 crib excavation was sloped (2%) toward and past this well, causing more of the waste solution to percolate in this lower part of the excavated area.

At this time, two wells (229-W22-1 and -30) show elevated beta activity levels in the ground water. Well 299-W22-30, with the highest beta levels, is located in the area contaminated by wastes that entered directly into the ground water during the 299-W22-3 well-casing leak of 1955. The other had very high beta activity levels in the late 1960's, which were not matched by earlier beta activity levels or by contemporary beta levels found in the ground water of other nearby wells. A cause for this two-orders-of-magnitude increase in total beta activity, 10 years after crib deactivation must, thus, be found in the 216-S-1 and 2 crib itself. A well-casing failure some time after crib deactivation may

have been responsible, with subsequent slow leakage of waste or sediment. The only conclusion that may be drawn from the available data is that these elevated beta contamination levels have been stable since 1970, and appear to be slowly decreasing, especially over the last several years. During 1979, several water samples from well 299-W22-1 contained ^{90}Sr levels below the applicable water discharge standard for controlled areas. The lower beta contamination levels consistently found in nearby crib monitoring wells show that this is a highly localized phenomenon that does not extend beyond the crib boundaries.

Similarly, in well 299-W22-30, the elevated contamination levels resulting from the 1955 well leak are not found in other wells either in or near the crib. The waste liquids that entered the ground water through this failed well casing should have interacted with the saturated zone sediments the same as with the vadose zone sediments. Migration of radionuclides in either the vadose or the saturated zone is a function of initial concentration in solution, solution flow rate, and the nature of the sediments in terms of particle size, mineralogy, and cation exchange capacity. This means that the extent of significant ^{137}Cs contamination around this well is probably restricted to a distance of less than 10 meters away from the source. No evidence for elevated total beta levels for nearby ground-water monitoring wells was found. The conclusion drawn from these results is that present migration rates from these contaminated zones may be considered insignificant, since elevated total beta contamination values cannot be found in nearby monitoring wells.

The presence of contaminated sediments 2 to 4 feet below ground surface presents a potential for plant or animal intrusion. For this reason, herbicides have been applied to the site annually to prevent plants from growing on the site. At this time, there is no evidence of plant or animal penetration into the waste and the near-surface contamination is posing no radiological control problems.

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APPENDIX A

BOREHOLE GAMMA ENERGY ANALYSIS RESULTS

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TABLE A-1. Well 299-W22-1 Borehole Gamma Energy Analysis Results, 2-15-80.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.41	<0.25	<0.016	0.9967	<0.031	<0.077	600	IG 190[a]
400	<0.015	<0.018	<0.001	0.6681	<0.0011	<0.0052	600	IG 548[a]
600	<0.016	<0.018	<0.001	0.6040	<0.0007	<0.0057	600	IG 548[a]
800	<0.015	<0.017	<0.001	0.0878	<0.0002	<0.0008	600	IG 548[a]
1000	<140	<140	<1.5	2142	<0.30	<0.7692	600	IG 190[b]
1200	<200	<130	<1.4	2844	<0.60	<2.335	600	IG 190[b]
1400	<42	<58	<1.0	701.1	<0.16	<0.4733	600	IG 190[b]
1600	<2.8	<1.4	<0.083	6.329	<0.044	<0.12	600	IG 190[a]
1800	<5.2	<2.6	<0.13	36.80	<0.052	<0.15	600	IG 190[a]
2000	<2.7	<1.5	<0.077	13.89	<0.040	<0.11	600	IG 190[a]
2200	<1.8	<1.1	<0.052	13.65	<0.031	<0.777	600	IG 190[a]
2400	<1.3	<0.93	<0.039	11.66	<0.031	<0.077	600	IG 190[a]
2600	<0.85	<0.66	<0.030	7.158	<0.031	<0.077	600	IG 190[a]
2800	<1.2	<0.89	<0.034	14.54	<0.031	<0.077	600	IG 190[a]
3000	<0.49	<0.30	<0.016	1.330	<0.031	<0.077	600	IG 190[a]
3200	<0.49	<0.35	<0.018	2.407	<0.031	<0.077	600	IG 190[a]
3400	<0.41	<0.26	<0.016	1.180	<0.031	<0.077	600	IG 190[a]
3600	<0.41	<0.20	<0.016	0.5596	<0.031	<0.077	600	IG 190[a]
3800	<0.55	<0.39	<0.018	2.024	<0.031	<0.077	600	IG 190[a]
4000	<0.029	<0.028	<0.001	1.537	<0.006	<0.0016	600	IG 548[a]
4200	<0.041	<0.033	<0.001	1.853	<0.0014	<0.0021	600	IG 548[a]
4400	<0.031	<0.027	<0.001	1.284	<0.0011	<0.0024	600	IG 548[a]
4600	<0.017	<0.019	<0.001	0.8559	<0.0002	<0.0012	600	IG 548[a]
4800	<0.015	<0.019	<0.001	0.7709	<0.0003	<0.0007	600	IG 548[a]
5000	<0.016	<0.021	<0.001	0.6220	<0.0004	<0.0010	600	IG 548[a]
5200	<0.013	<0.012	<0.001	0.3091	<0.0002	<0.0007	600	IG 548[a]
5400	<0.009	<0.006	<0.001	0.0536	<0.0002	<0.0007	600	IG 548[a]
5600	<0.010	<0.006	<0.001	0.0615	<0.0002	<0.0007	600	IG 548[a]

[a] Without Lead Shielding.

[b] With Lead Shielding.

TABLE A-2. Well 299-W22-1 Borehole Gamma Energy Analysis Results, Near and Below Water Table, 2-15-80.

Depth, cm	Concentration, μCi/ℓ Soil							Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu	^{125}Sb		
5200	<0.059	<0.057	<0.0014	0.7758	<0.001	<0.003	<0.030	300	IG 548[a]
5400	<0.039	<0.043	<0.0010	0.4813	<0.001	<0.003	<0.030	300	IG 548[a]
5550	<0.12	<0.10	<0.0028	1.716	<0.002	<0.012	<0.053	200	IG 548[a]
5600	<1.30	<0.63	<0.030	10.24	<0.008	<0.102	<0.30	30	IG 548[a]
5700[b]	-	-	-	-	-	-	-	-	-
5900	<0.060	<0.035	<0.0025	0.2521	0.0031	0.028	<0.030	600	IG 548[a]
6000[c]	<0.057	<0.036	<0.0025	0.1798	0.0035	0.018	0.060	600	IG 548[a]
6100[d]	<0.011	<0.068	<0.0005	0.0219	0.0005	0.0067	0.013	3000	IG 548[a]
6200	<0.029	<0.016	<0.0017	<0.0008	<0.0005	<0.0015	<0.034	600	IG 548[a]
6300[d]	<0.021	<0.092	<0.0008	0.0013	<0.0005	<0.0016	<0.005	600	IG 548[a]
6400	<0.023	<0.010	<0.0008	<0.0008	<0.0005	<0.0016	<0.006	600	IG 548[a]
6600	<0.021	<0.010	<0.0008	<0.0006	<0.0005	<0.0016	<0.006	600	IG 548[a]
6800	<0.026	<0.013	<0.0008	<0.0006	<0.0005	<0.0018	0.024	600	IG 548[a]
7000	<0.021	<0.010	<0.0008	<0.0006	<0.0005	<0.0016	<0.006	600	IG 548[a]
7200	<0.021	<0.010	<0.0008	<0.0006	<0.0005	<0.0016	<0.006	600	IG 548[a]
7400	<0.021	<0.008	<0.0008	<0.0006	<0.0005	<0.0016	<0.005	600	IG 548[a]
7600	<0.020	<0.009	<0.0008	<0.0006	<0.0005	<0.0015	<0.005	600	IG 548[a]

[a]Without Lead Shielding.

[b]Detector Overloaded.

[c]Water Attenuation Correction applied to all radionuclides below 5950 centimeters (approximately 195 feet), for water inside the casing.

[d]Data from 2-28-80.

TABLE A-3. Well 299-W22-2 Borehole Gamma Energy Analysis Results, 5-8-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.41	<0.15	<0.16	<0.014	<0.031	<0.077	600	IG 190[a]
400	<0.41	<0.16	<0.016	<0.014	<0.031	<0.077	600	IG 190[a]
600	-	-	-	-	-	-	-	-
800	<0.41	<0.17	<0.016	<0.014	<0.031	<0.077	600	IG 190[a]
1000	<160	<170	<1.7	3907	<0.16	0.690	600	IG 190[b]
1200	<1.0	<0.65	<0.026	19.17	0.068	0.075	3000	IG 190[a]
1400	<2.0	<1.3	<0.058	11.55	<0.031	<0.10	600	IG 190[a]
1600	<4.6	<0.61	<0.12	38.29	<0.053	<0.168	600	IG 190[a]
1800	<0.90	<0.61	<0.026	6.768	<0.031	<0.077	600	IG 190[a]
2000	<0.49	<0.30	<0.016	1.228	<0.031	<0.077	600	IG 190[a]
2200	<0.45	<0.21	<0.016	0.3888	<0.031	<0.077	600	IG 190[a]
2400	<0.41	<0.31	<0.016	1.536	<0.031	<0.077	600	IG 190[a]
2600	<0.45	<0.29	<0.016	0.9621	<0.031	<0.077	600	IG 190[a]
2800	<0.41	<0.21	<0.016	0.5405	<0.031	<0.077	600	IG 190[a]
3000	<0.41	<0.19	<0.016	0.4663	<0.031	<0.077	600	IG 190[a]
3200	<0.41	<0.16	<0.016	0.2286	<0.031	<0.077	600	IG 190[a]
3400	<0.41	<0.16	<0.016	0.1082	<0.031	<0.077	600	IG 190[a]
3600	<0.41	<0.16	<0.016	0.4149	<0.031	<0.077	600	IG 190[a]
3800	<0.41	<0.16	<0.016	0.1569	<0.031	<0.077	600	IG 190[a]
4000	<0.41	<0.16	<0.016	0.0550	<0.031	<0.077	600	IG 190[a]
4200	<0.41	<0.16	<0.016	0.1699	<0.031	<0.077	600	IG 190[a]
4400	<0.41	<0.16	<0.016	0.1119	<0.031	<0.077	600	IG 190[a]
4600	<0.41	<0.17	<0.016	0.1569	<0.031	<0.077	600	IG 190[a]
4800	<0.41	<0.16	<0.016	0.2330	<0.031	<0.077	600	IG 190[a]
5000	<0.41	<0.16	<0.016	0.0963	<0.031	<0.077	600	IG 190[a]
5200	<0.41	<0.16	<0.016	0.1633	<0.031	<0.077	600	IG 190[a]
5400	<0.41	<0.16	<0.016	0.2432	<0.031	<0.077	600	IG 190[a]
5600	<0.16	<0.11	<0.006	0.4193	<0.012	<0.031	1500	IG 190[a]

[a] Without Lead Shielding.

[b] With Lead Shielding.

TABLE A-4. Well 299-W22-2 Borehole Gamma Energy Analysis Results, 2-15-80.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
3400	<1.1	<0.43	<0.045	0.1295	<0.087	<0.21	600	IG 190[a]
3600	<1.1	<0.45	<0.045	0.3958	<0.087	<0.21	600	IG 190[a]
5600	<1.1	<0.47	<0.045	0.4233	<0.087	<0.21	600	IG 190[a]
5800	<1.3	<0.55	<0.047	0.3734	<0.087	<0.21	600	IG 190[a]
5960[b]	<3.37	<2.43	<0.093	11.05	<0.118	<0.28	600	IG 190[a]
6000	<1.68	<0.70	<0.071	0.2647	<0.118	<0.28	600	IG 190[a]
6200	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
6400	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
6600	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
6800	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
7000	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
7200	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
7400	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
7600	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
7800	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
8000	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
8200	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]
8300	<1.68	<0.70	<0.071	<0.063	<0.118	<0.28	600	IG 190[a]

[a]Without Lead Shielding.

[b]Water Attenuation Correction applied to all radionuclides below 5950 centimeters (approximately 195 feet), for water inside the casing.

TABLE A-5. Well 299-W22-5 Borehole Gamma Energy Analysis Results, 6-7-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
400	<0.0092	<0.0037	<0.0005	<0.0002	<0.0002	<0.0C07	600	IG 548
800	<0.0080	<0.0035	<0.0003	<0.0002	<0.0002	<0.0C08	600	IG 548
1200	<0.0081	<0.0037	<0.0003	<0.0002	<0.0002	<0.0C07	600	IG 548
1600	<0.0080	<0.0035	<0.0004	<0.0003	<0.0002	<0.0C07	600	IG 548
2000	<0.0089	<0.0038	<0.0003	<0.0002	<0.0002	<0.0C07	600	IG 548
2400	<0.012	<0.0037	<0.0003	<0.0002	<0.0002	<0.0C07	600	IG 548
2800	<0.0097	<0.0040	<0.0004	<0.0002	<0.0002	<0.0C07	600	IG 548
3200	<0.0091	<0.0039	<0.0003	<0.0003	<0.0002	<0.0C08	600	IG 548
3600	<0.0098	<0.0039	<0.0003	<0.0003	<0.0002	<0.0006	600	IG 548
4000	<0.0001	<0.0041	<0.0003	<0.0003	<0.0002	<0.0C07	600	IG 548
4400	<0.0072	<0.0034	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
4800	<0.0079	<0.0033	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
5200	<0.0086	<0.0033	<0.0004	<0.0002	<0.0002	<0.0007	600	IG 548
5600	<0.0073	<0.0032	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548

*Without Lead Shielding.

TABLE A-6. Well 299-N22-10 Borehole Gamma Energy Analysis Results, 6-8-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
400	<0.011	<0.0036	<0.0002	<0.0002	<0.0002	<0.0007	600	IG 548
800	<0.0099	<0.0038	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
1200	<0.0085	<0.0034	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
1600	<0.0087	<0.0036	<0.0002	<0.0002	<0.0002	<0.0007	600	IG 548
2000	<0.0090	<0.0040	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
2400	<0.0095	<0.0041	<0.0004	<0.0003	<0.0002	<0.0007	600	IG 548
2800	<0.0097	<0.0043	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
3200	<0.0095	<0.0043	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
3600	<0.0089	<0.0042	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
4000	<0.0097	<0.0042	<0.0003	<0.0002	<0.0002	<0.0009	600	IG 548
4400	<0.012	<0.0035	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
4800	<0.0081	<0.0031	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
5200	<0.0078	<0.0034	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
5600	<0.0081	<0.0034	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548

*Without Lead Shielding.

TABLE A-7. Well 299-W22-15 Borehole Gamma Energy Analysis Results, 5-22-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
400	<0.010	<0.0035	<0.0003	<0.0003	<0.0002	<0.0006	600	IG 548
800	<0.0076	<0.0042	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
1200	<0.0080	<0.0034	<0.0004	<0.0002	<0.0002	<0.0006	600	IG 548
1400	<0.014	<0.0065	<0.0004	<0.0004	<0.0003	<0.0008	600	IG 548
1500	<0.083	<0.039	<0.0020	<0.0020	<0.0008	<0.0024	600	IG 548
1600	<0.047	<0.023	<0.0012	<0.0011	<0.0005	<0.0015	604	IG 548
2000	<0.027	<0.013	<0.0007	<0.0007	<0.0003	<0.0014	600	IG 548
2400	<0.010	<0.0045	<0.0004	<0.0003	<0.0002	<0.0007	600	IG 548
2800	<0.0093	<0.0041	<0.0003	<0.0003	<0.0003	<0.0006	600	IG 548
3200	<0.0093	<0.0043	<0.0003	<0.0002	<0.0003	<0.0008	600	IG 548
3600	<0.0095	<0.0048	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
4000	<0.0093	<0.0052	<0.0003	<0.0003	<0.0003	<0.0007	600	IG 548
4400	<0.0093	<0.0039	<0.0004	<0.0002	<0.0002	<0.0007	600	IG 548
4800	<0.0090	<0.0031	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
5200	<0.0070	<0.0031	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
5600	<0.0076	<0.0030	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548

*Without Lead Shielding.

TABLE A-8. Well 299-W22-17 Borehole Gamma Energy Analysis Results, 5-23-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
400	<0.0087	<0.0038	<0.0003	<0.0004	<0.0002	<0.0007	600	IG 548
800	<0.0079	<0.0034	<0.0005	<0.0002	<0.0002	<0.0006	600	IG 548
1200	<0.0079	<0.0035	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
1600	<0.0092	<0.0037	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
2000	<0.0095	<0.0039	<0.0003	<0.0004	<0.0002	<0.0007	600	IG 548
2400	<0.010	<0.0040	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
2800	<0.0093	<0.0041	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
3200	<0.0096	<0.0040	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
3600	<0.010	<0.0041	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
4000	<0.010	<0.0040	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
4400	<0.0089	<0.0039	<0.0003	<0.0003	<0.0002	<0.0006	600	IG 548
4800	<0.0074	<0.0031	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
5200	<0.0080	<0.0035	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
5600	<0.0056	<0.0023	<0.0002	<0.0002	<0.0002	<0.0004	600	IG 548

*Without Lead Shielding.

TABLE A-9. Well 299-W22-18 Borehole Gamma Energy Analysis Results, 5-24-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
400	<0.0082	<0.0033	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
800	<0.0075	<0.0033	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
1200	<0.0074	<0.0033	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
1400	<0.056	<0.026	<0.0014	<0.0014	<0.0006	<0.0017	600	IG 548
1600	<0.012	<0.0055	<0.0003	<0.0004	<0.0002	<0.0007	600	IG 548
2000	<0.0093	<0.0037	<0.0003	<0.0005	<0.0002	<0.0008	600	IG 548
2400	<0.0087	<0.0040	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
2800	<0.0094	<0.0041	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
3200	<0.0092	<0.0037	<0.0003	<0.0002	<0.0002	<0.0008	600	IG 548
3600	<0.0088	<0.0038	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
4000	<0.0001	<0.0042	<0.0004	<0.0002	<0.0002	<0.0007	600	IG 548
4400	<0.0069	<0.0030	<0.0002	<0.0002	<0.0002	<0.0005	600	IG 548
4800	<0.0054	<0.0023	<0.0002	<0.0002	<0.0002	<0.0005	600	IG 548
5200	<0.0076	<0.0032	<0.0002	<0.0002	<0.0002	<0.0006	600	IG 548
5600	<0.0075	<0.0034	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548

*Without Lead Shielding.

TABLE A-10. Well 299-W22-29 Borehole Gamma Energy Analysis Results, 5-4-79.

Depth, cm	Concentration, µCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.82	<0.31	<0.032	0.1394	<0.062	<0.15	600	IG 190[a]
400	<0.41	<0.16	<0.016	0.0560	<0.031	<0.077	600	IG 190[a]
600	-	-	-	-	-	-	-	-
800	<0.41	<0.16	<0.016	0.014	<0.031	<0.077	600	IG 190[a]
1000	<510	<760	<0.65	1031	<0.16	<0.46	600	IG 190[b]
1200	<650	<710	<5.7	1185	0.479	1.168	600	IG 190[b]
1400	<380	<300	<5.7	177.7	0.337	<0.60	600	IG 190[b]
1600	<6.7	<5.5	<0.10	44.36	<0.024	0.1342	4000	IG 190[b]
1800	<1.3	<0.53	<0.032	<0.074	<0.031	<0.077	600	IG 190[a]
2000	<0.65	<0.54	<0.019	5.686	<0.031	<0.077	600	IG 190[a]
2200	-	-	-	-	-	-	-	-
2400	<0.74	<0.35	<0.024	0.670	<0.031	<0.077	600	IG 190[a]
2600	<0.41	<0.22	<0.016	0.381	<0.031	<0.077	600	IG 190[a]
2800	<0.41	<0.16	<0.016	0.133	<0.031	<0.077	600	IG 190[a]
3000	<0.41	<0.16	<0.016	0.186	<0.031	<0.077	600	IG 190[a]
3200	<0.41	<0.17	<0.016	0.065	<0.031	<0.077	600	IG 190[a]
3400	<0.41	<0.16	<0.016	0.111	<0.031	<0.077	600	IG 190[a]
3600	<0.41	<0.16	<0.016	0.178	<0.031	<0.077	600	IG 190[a]
3800	<0.41	<0.17	<0.016	0.177	<0.031	<0.077	600	IG 190[a]
4000	<0.41	<0.17	<0.016	0.118	<0.031	<0.077	600	IG 190[a]
4200	<0.41	<0.16	<0.016	0.253	<0.031	<0.077	600	IG 190[a]

[a]Without Lead Shielding.

[b]With Lead Shielding.

TABLE A-11. Well 299-W22-30 Borehole Gamma Energy Analysis Results, 5-2-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.14	<0.16	<0.006	0.314	<0.001	<0.002	600	IG 548[a]
400	<0.14	<0.33	<0.006	1.811	<0.001	<0.002	600	IG 548[a]
600	<0.14	<0.34	<0.006	2.227	<0.001	<0.002	600	IG 548[a]
800	<0.14	<0.41	<0.005	0.8893	<0.001	<0.002	600	IG 548[a]
1000	<90	<98	<0.97	1213	<0.16	<0.46	600	IG 190[a]
1200	<300	<200	<3.4	3219	<0.21	2.118	600	IG 190[a]
1400	<190	<150	<2.1	2844	<0.16	<0.64	600	IG 190[a]
1600	<130	<120	<1.5	2120	<0.16	<0.51	600	IG 190[a]
1800	<33	<53	<0.47	621.8	<0.16	<0.46	600	IG 190[a]
2000	<22	<38	<3.0	332.0	<0.16	<0.46	600	IG 190[a]
2200	<17	<17	<0.30	59.64	<0.16	<0.46	600	IG 190[a]
2400	<0.55	<0.65	<0.010	9.660	<0.031	<0.077	600	IG 190[b]
2600	<17	<25	<0.30	132	<0.16	<0.46	600	IG 190[a]
2800	<17	<21	<0.30	84.39	<0.16	<0.46	600	IG 190[a]
3000	<0.98	<0.90	<0.015	16.21	<0.031	<0.077	600	IG 190[b]
3200	<0.49	<0.37	<0.010	7.240	<0.031	<0.077	600	IG 190[b]
3400	<0.41	<0.38	<0.010	3.065	<0.031	<0.077	600	IG 190[b]
3600	<0.41	<0.15	<0.010	1.319	<0.031	<0.077	600	IG 190[b]
3800	<0.41	<0.29	<0.010	1.734	<0.031	<0.077	600	IG 190[b]
4000	<0.74	<0.70	<0.010	10.38	<0.031	<0.077	600	IG 190[b]
4200	<0.41	<0.39	<0.010	2.997	<0.031	<0.077	600	IG 190[b]
4400	<0.74	<0.82	<0.011	11.16	<0.031	<0.077	600	IG 190[b]
4600	<0.41	<0.29	<0.010	1.600	<0.031	<0.077	600	IG 190[b]
4800	<0.41	<0.28	<0.010	1.402	<0.031	<0.077	600	IG 190[b]
5000	<0.41	<0.36	<0.010	2.603	<0.031	<0.077	600	IG 190[b]
5200	<0.12	<0.15	<0.003	1.639	<0.009	<0.023	2000	IG 190[b]
5400	<0.41	<0.21	<0.010	0.6334	<0.031	<0.077	600	IG 190[b]
5600	<0.41	<0.21	<0.010	0.5299	<0.031	<0.077	600	IG 190[b]

[a]With Lead Shielding.

[b]Without Lead Shielding.

TABLE A-12. Well 299-W22-30 Borehole Gamma Energy Analysis Results, 2-15-80.

Depth, cm	Concentration, μCi/ℓ						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs[a]	^{60}Cc	^{154}Eu		
5600	<1.4	<0.66	<0.054	0.5299[b]	<0.10	<0.26	500	IG 190[c]
5700	<0.14	<0.67	<0.054	1.066	<0.10	<0.26	500	IG 190[c]
5800	<1.4	<0.75	<0.054	1.402	<0.10	<0.26	500	IG 190[c]
5900	<1.4	<0.67	<0.054	0.8080	<0.10	<0.26	500	IG 190[c]
6000[d]	<1.8	<0.95	<0.069	1.079	<0.12	<0.31	500	IG 190[c]
6100	<1.8	<0.83	<0.069	0.464	<0.12	<0.31	500	IG 190[c]
6200	<1.8	<0.85	<0.069	0.652	<0.12	<0.31	500	IG 190[c]
6300	<2.0	<1.42	<0.069	3.004	<0.12	<0.31	500	IG 190[c]
6324	<40.0	<19.4	<11.4	20.03	<0.61	<1.7	100	IG 190[c]
6459	<1250	<59.3	<3.81	49.52	<1.6	<4.1	50	IG 190[c]
6500	<387	<19.4	<1.05	54.69	<0.61	<1.6	100	IG 190[c]
6600	<36.3	<16.8	<0.88	57.98	<0.61	<1.6	100	IG 190[c]
6729	<10.6	<5.3	<0.27	5.839	<0.10	<0.26	600	IG 190[c]

[a]Cs-137 Contamination Correction Factor applied as a constant for all logged depths (approximately 1.428 c/s).

[b]Value from readings of 5/2/79, used to correct for ^{137}Cs contamination.

[c]Without Lead Shielding.

[d]Water Attenuation Correction applied to all radionuclides below 5950 centimeters (approximately 195 feet), for water inside the casing.

TABLE A-13. Well 299-W22-31 Borehole Gamma Energy Analysis Results, 5-16-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.008	<0.004	<0.001	0.0003	0.0002	<0.0006	600	IG 548[a]
400	<0.008	<0.004	<0.0003	0.0004	0.0002	<0.0006	600	IG 548[a]
600	<0.008	<0.005	<0.0003	0.0003	0.0002	<0.0006	600	IG 548[a]
800	<0.011	<0.012	<0.0003	0.0012	<0.0002	<0.0006	600	IG 548[a]
1000	<406	<220	<16	3376	<0.45	<1.199	600	IG 190[b]
1200	<32	<25	<0.47	66.56	<0.18	0.5680	600	IG 190[b]
1400	<33	<27	<0.55	104.2	<0.23	0.6153	600	IG 190[b]
1600	<4.6	<2.5	<0.11	40.80	<0.049	0.1478	600	IG 190[a]
1800	<2.3	<1.3	<0.065	11.99	<0.037	0.1478	600	IG 190[a]
2000	<2.4	<1.3	<0.070	8.626	<0.040	<0.098	600	IG 190[a]
2200	<2.3	<1.2	<0.070	6.582	<0.037	<0.10	600	IG 190[a]
2400	-	-	-	-	-	-	-	-
2600	<0.65	<0.36	<0.018	1.624	<0.019	<0.046	1000	IG 190[a]
2800	<0.41	<0.17	<0.018	1.505	<0.031	<0.077	600	IG 190[a]
3000	<0.41	<0.29	<0.016	1.238	<0.031	<0.077	600	IG 190[a]
3200	<0.41	<0.27	<0.016	0.9488	<0.031	<0.077	600	IG 190[a]
3400	-	-	-	-	-	-	-	-
3600	<0.022	<0.020	<0.0005	0.7081	0.0004	0.0021	600	IG 548[a]
3800	<0.023	<0.024	<0.0005	0.9794	0.0004	0.0021	600	IG 548[a]
4000	<0.035	<0.023	<0.0006	0.9609	0.0004	0.0023	600	IG 548[a]
4200	<0.25	<0.23	<0.010	1.592	0.019	<0.046	600	IG 190[a]
4400	<0.019	<0.021	<0.0007	0.8213	<0.0006	0.0024	600	IG 548[a]
4600	<0.033	<0.023	<0.0008	1.089	0.0005	0.0040	600	IG 548[a]
4800	-	-	-	-	-	-	-	-
5000	<0.010	<0.013	<0.0002	0.7661	0.0002	0.0017	1415	IG 548[a]
5200	-	-	-	-	-	-	-	-
5400	<0.015	<0.019	<0.0004	0.7475	0.0002	0.0019	600	IG 548[a]
5600	<0.032	<0.021	<0.0008	0.6393	<0.0002	0.0048	600	IG 548[a]

[a]Without Lead Shielding.
[b]With Lead Shielding.

TABLE A-14. Well 299-W22-31 Borehole Gamma Energy Analysis Results, 2-15-80.

Depth, cm	Concentration, μCi/ℓ						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
5400	<0.070	<0.062	<0.0042	1.324	<0.0008	<0.005	300	IG 548[a]
5600	<0.25	<0.16	<0.011	5.546	<0.0015	<0.012	200	IG 548[a]
5700	<0.13	<0.10	<0.0062	1.032	<0.0023	<0.100	100	IG 548[a]
5800	<0.022	<0.020	<0.0013	0.1914	<0.0005	<0.0015	600	IG 548[a]
6000[b]	<0.029	<0.038	<0.0020	0.3772	<0.0006	<0.0018	600	IG 548[a]
6200	<0.058	<0.057	<0.0039	0.5561	<0.0012	<0.014	252	IG 548[a]
6400	<0.021	<0.010	<0.0013	0.1415	<0.0005	<0.0015	600	IG 548[a]
6600	<0.026	<0.032	<0.0022	0.4287	<0.0005	<0.0015	600	IG 548[a]
6800	<0.019	<0.010	<0.0006	0.0126	<0.0005	<0.0015	600	IG 548[a]
7000	<0.019	<0.009	<0.0006	0.0074	<0.0005	<0.0015	600	IG 548[a]
7200	<0.019	<0.008	<0.0006	0.0017	<0.0005	<0.0015	600	IG 548[a]
7400	<0.019	<0.008	<0.0006	0.0005	<0.0005	<0.0015	600	IG 548[a]
7560	<0.019	<0.008	<0.0006	0.0005	<0.0005	<0.0015	600	IG 548[a]

[a]Without Lead Shielding.

[b]Water Attenuation Correction applied to all radionuclides below 5950 centimeters (approximately 195 feet), for water inside the casing.

TABLE A-15. Well 299-W22-36 Borehole Gamma Energy Analysis Results, 5-9-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Co	^{154}Eu		
200	<0.41	<0.16	<0.016	0.057	<0.031	<0.077	600	IG 190[a]
400	<0.41	<0.16	<0.016	0.083	<0.031	<0.077	600	IG 190[a]
600	<0.41	<0.17	<0.016	0.190	<0.031	<0.077	600	IG 190[a]
800	<0.41	<0.16	<0.016	0.025	<0.031	<0.077	600	IG 190[a]
1000	<230	<210	<16	5214	0.483	4.121	600	IG 190[b]
1200	<54	<85	<0.66	1632	<0.16	0.710	600	IG 190[b]
1400	<33	<53	<0.46	633.0	<0.16	<0.40	600	IG 190[b]
1600	<15	<12	<0.25	26.74	<0.16	<0.36	600	IG 190[b]
1800	<0.63	<0.69	<0.021	8.749	<0.031	<0.077	600	IG 190[a]
2000	<2.5	<1.8	<0.065	46.53	<0.031	<0.077	600	IG 190[a]
2200	<1.4	<1.2	<0.033	22.59	<0.031	<0.077	600	IG 190[a]
2400	<0.58	<0.57	<0.016	7.131	<0.031	<0.077	600	IG 190[a]
2600	<0.49	<0.47	<0.016	4.883	<0.031	<0.077	600	IG 190[a]
2800	<0.41	<0.34	<0.016	1.923	<0.031	<0.077	600	IG 190[a]
3000	<0.41	<0.43	<0.016	3.343	<0.031	<0.077	600	IG 190[a]
3200	<0.41	<0.33	<0.016	2.084	<0.031	<0.077	600	IG 190[a]
3200	<0.41	<0.33	<0.016	2.084	<0.031	<0.077	600	IG 190[a]
3400	<0.41	<0.34	<0.016	2.390	<0.031	<0.077	600	IG 190[a]
3600	<0.41	<0.29	<0.016	1.474	<0.031	<0.077	600	IG 190[a]
3800	<0.41	<0.25	<0.016	1.100	<0.031	<0.077	600	IG 190[a]
4000	<0.082	<0.064	<0.003	0.2717	<0.006	<0.015	3000	IG 190[a]
4200	<0.018	<0.018	<0.001	0.6954	<0.001	<0.001	600	IG 548[a]
4400	<0.009	<0.011	<0.001	0.3101	<0.001	<0.001	600	IG 548[a]
4600	-	-	-	-	-	-	-	-
4800	<0.015	<0.015	<0.001	0.4579	<0.001	<0.001	600	IG 548[a]
5000	<0.009	<0.012	<0.001	0.2811	<0.001	<0.001	600	IG 548[a]
5200	<0.009	<0.018	<0.001	0.2874	<0.001	<0.001	600	IG 548[a]
5400	<0.008	<0.018	<0.001	0.1777	<0.001	<0.001	600	IG 548[a]
5600	<0.012	<0.012	<0.001	0.3615	<0.001	<0.001	600	IG 548[a]

[a]Without Lead Shielding.

[b]With Lead Shielding.

TABLE A-16. Well 299-W22-67 Borehole Gamma Energy Analysis Results, 5-2-79.

Depth, cm	Concentration, μCi/ℓ Soil						Time, s	Detector*
	^{144}Ce	^{106}Ru	^{134}Cs	^{137}Cs	^{60}Cc	^{154}Eu		
400	<0.0089	<0.0037	<0.0003	0.0004	<0.0003	<0.0007	600	IG 548
600	<0.0079	<0.0034	<0.0003	<0.0002	<0.0002	<0.0006	600	IG 548
800	<0.0081	<0.0031	<0.0003	<0.0003	<0.0002	<0.0006	600	IG 548
1000	<0.0079	<0.0033	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
1400	<0.032	<0.016	<0.0008	<0.0008	<0.0004	<0.0011	600	IG 548
1600	<0.0085	<0.0035	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
1800	<0.0090	<0.0039	<0.0003	<0.0002	<0.0002	<0.0007	600	IG 548
2000	<0.010	<0.0041	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
2200	<0.0089	<0.0049	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
2400	<0.0097	<0.0038	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
2600	<0.0096	<0.0047	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548
2800	<0.0090	<0.0040	<0.0003	<0.0003	<0.0003	<0.0007	600	IG 548
3000	<0.0098	<0.0047	<0.0003	<0.0003	<0.0003	<0.0007	600	IG 548
3200	<0.0094	<0.0037	<0.0003	<0.0003	<0.0002	<0.0007	600	IG 548

*Without Lead Shielding.

APPENDIX B

DRILLING LOG DIGESTS

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TABLE B-1. Well 299-W22-1 Drilling Log Digest.

Date	Depth, m	Observations	
		Lithological	Radiological
1/11/52	1.5	Backfill	
1/14/52	10.4	Sandy Silt	
	11.6	Gravel	
	13.4	Fine Sand, Silt	
	14.6	Sand	
1/15/52	16.8	Coarse Sand, Gravel, Some Silt	
	18.3	Coarse Sand, Silt	
	19.8	Sandy Silt	
	30.5	Heavy Silt	
1/16/52	32.0	Sandy Silt, Heavy Silt	
	39.6	Sandy Silt, Clay	
	43.6	Clay	
	45.1	Gravel	
	45.7	Gravel, Sand, Silt	
5/21/56	46.3	Gravel, Sand, Silt	3000 Counts
	49.4	Coarse Sand	
	50.0	Coarse Sand	800 Counts
	50.6	Coarse Sand	400 Counts
5/22/56	52.4	Coarse Sand	500 Counts
	53.0	Fine Sand, Coarse Sand	200 Counts
	53.6	Sand, Silt	500 Counts
	54.9	Coarse Gravel	400 Counts
5/23/56	57.9	Coarse Gravel	400 Counts
5/29/56	64.9	Gravel, Silt	Water Table

TABLE B-2. Well 299-W22-2 Drilling Log Digest.

Date	Depth, m	Observations	
		Lithological	Radiological
12/7/51	1.5	Backfill	
	8.2	Gravel Pack	
	10.4	Sand, Silt	
	12.2	Gravel, Sand, Very Little Silt	
	14.3	Sand, Silt	
	41.1	Heavy Silt, Sand	
5/9/56	46.3	Gravel, Sand	
	50.0	Sand, Some Silt	
5/10/56	51.8	Sand, Silt, Fine Gravel	
	56.7	Sand, Gravel, Little Silt	
5/11/56	60.4	Sand, Gravel	
5/14/56	62.8	Sand, Gravel	Water Table Level
5/16/56	71.3	Sand, Gravel	Contamination Very Low
5/18/56	80.5	Sand, Gravel	Higher Contamination
	81.0	Sand, Gravel	Higher Contamination
	81.7	Sand, Gravel	Contamination Down, Very Low
5/21/56	84.1-87.1	Sand, Gravel	Background, No Further Radiological Observations

APPENDIX C

TOTAL BETA CONCENTRATION HISTORIES

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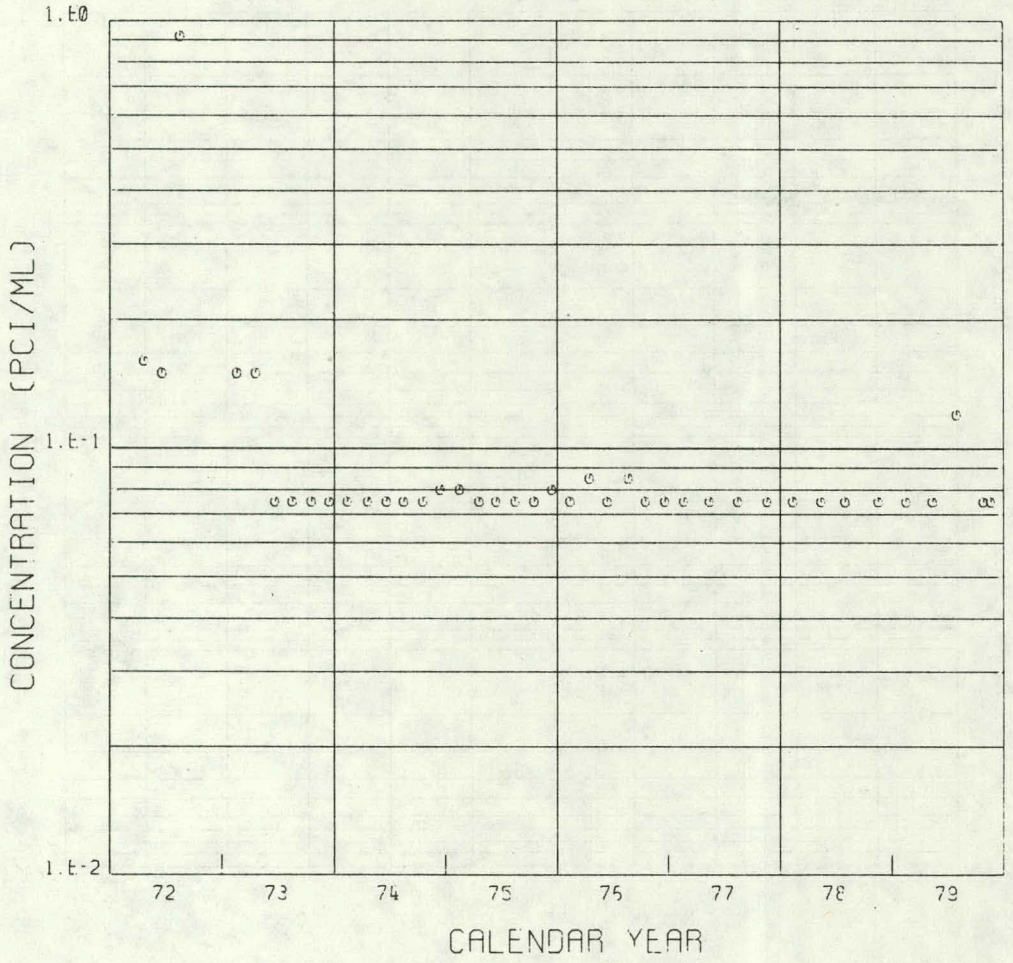
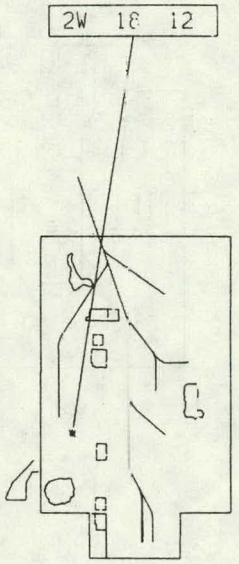
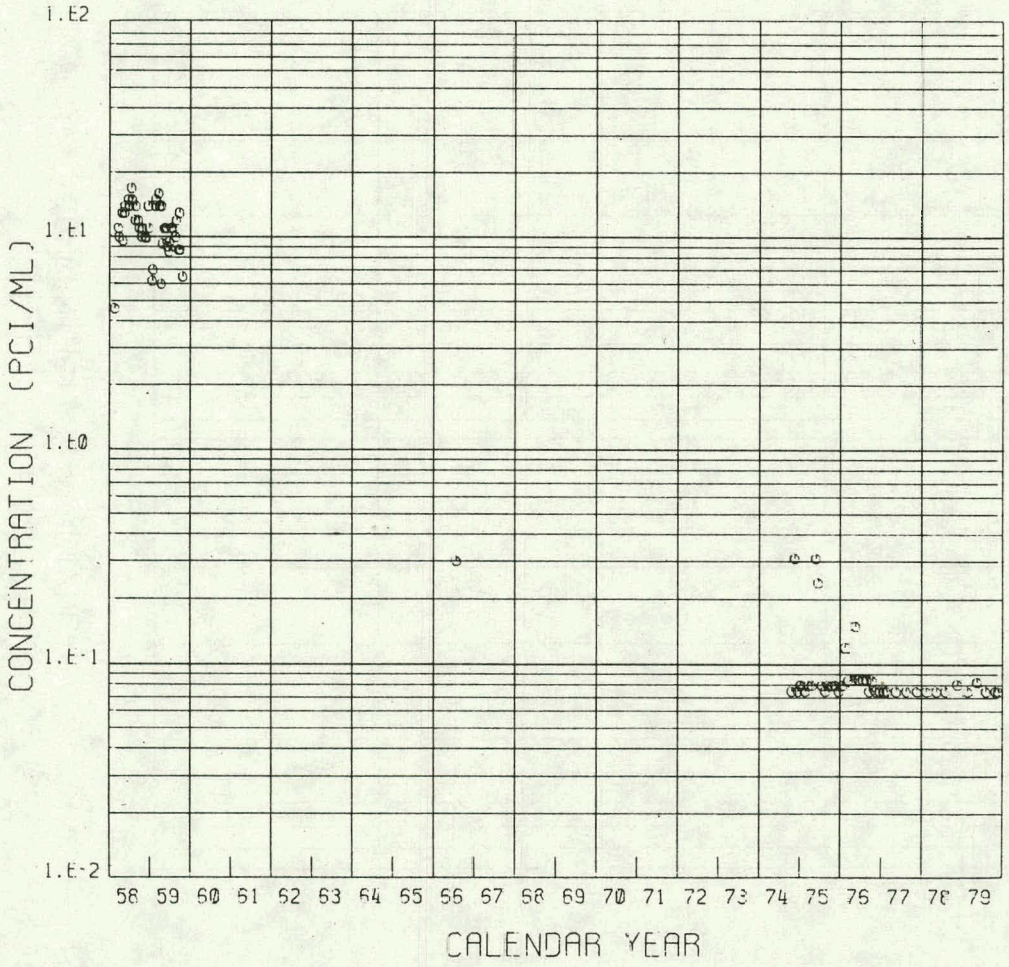
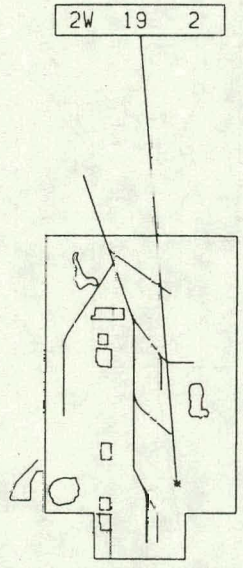




200 WEST AREA

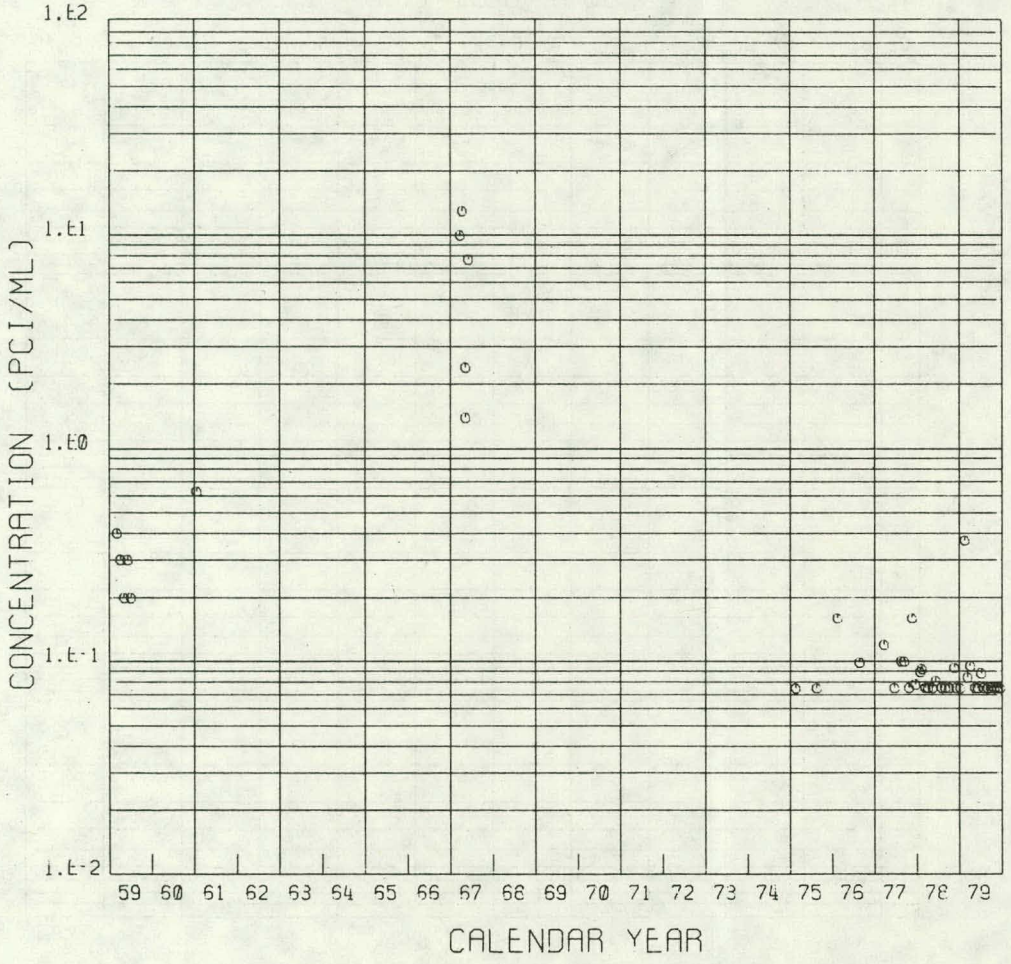
FIGURE C-1. Well 299-W18-12 Total Beta Concentration History.

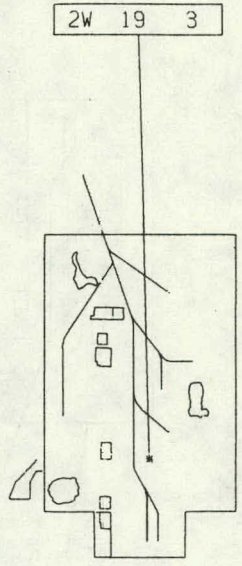




200 WEST AREA

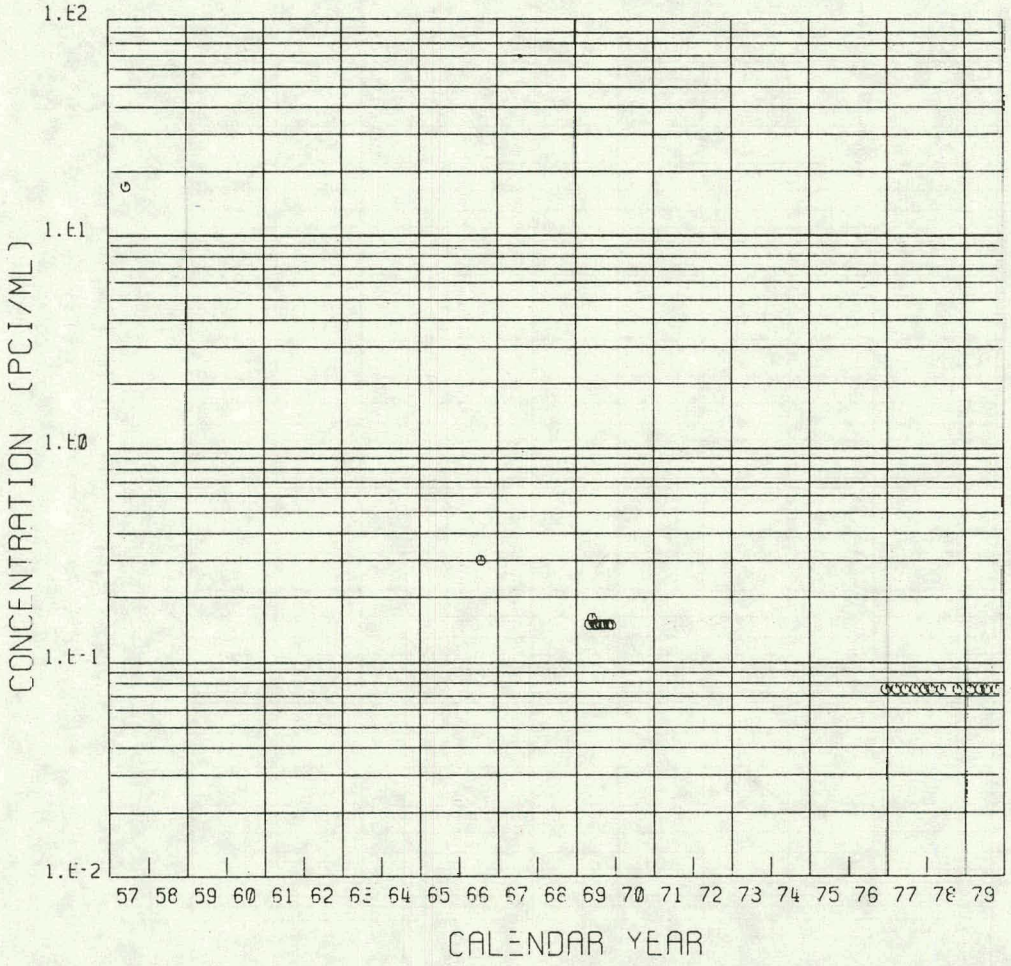
FIGURE C-2. Well 299-W19-2 Total Beta Concentration History.

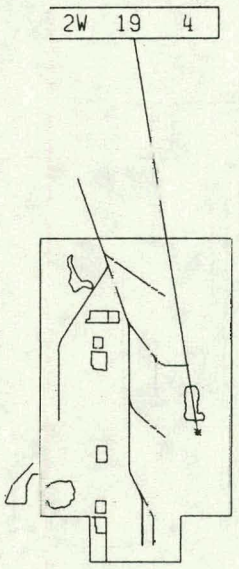




200 WEST AREA

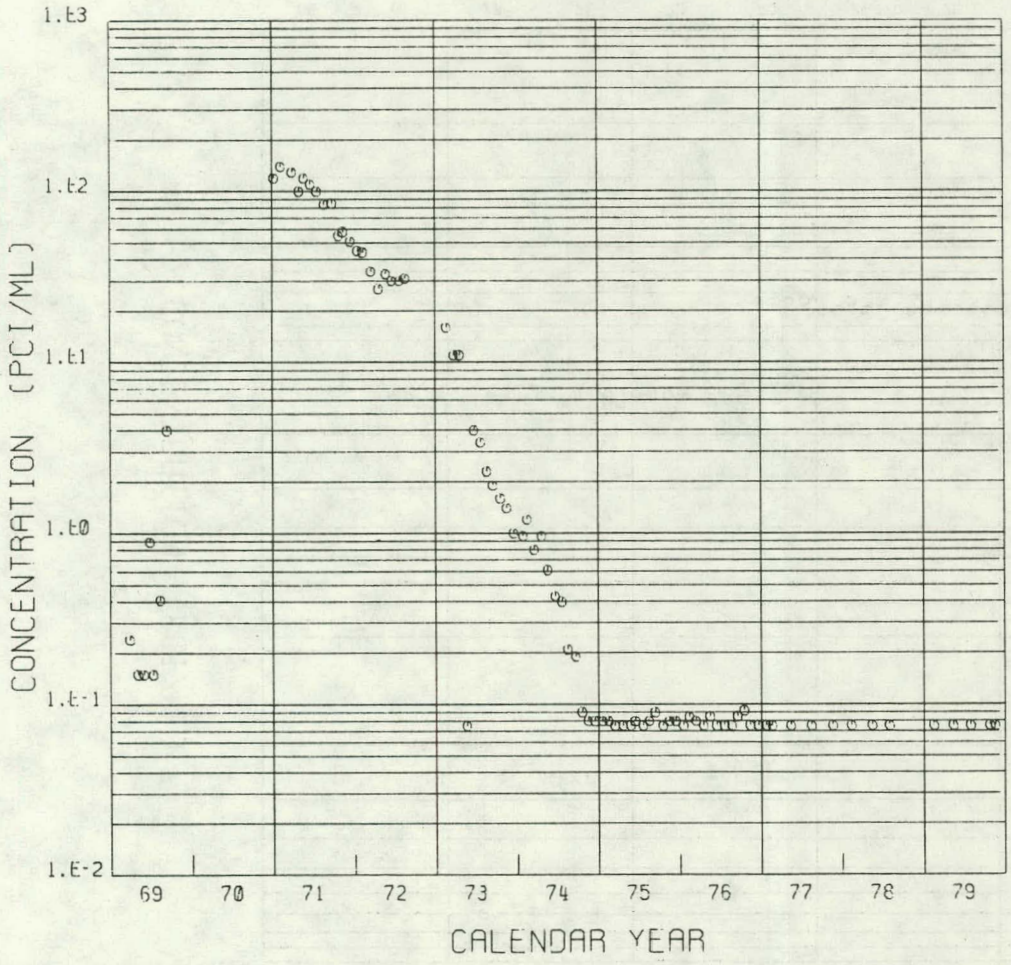
FIGURE C-3. Well 299-W19-3 Total Beta Concentration History.





200 WEST AREA

FIGURE C-4. Well 299-W19-4 Total Beta Concentration History.



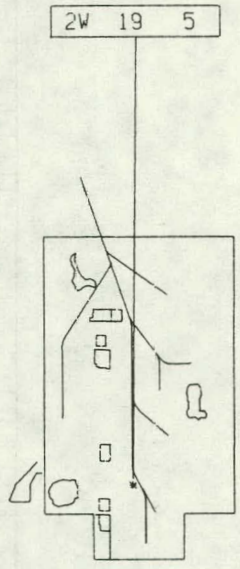


FIGURE C-5. Well 299-W19-5 Total Beta Concentration History.

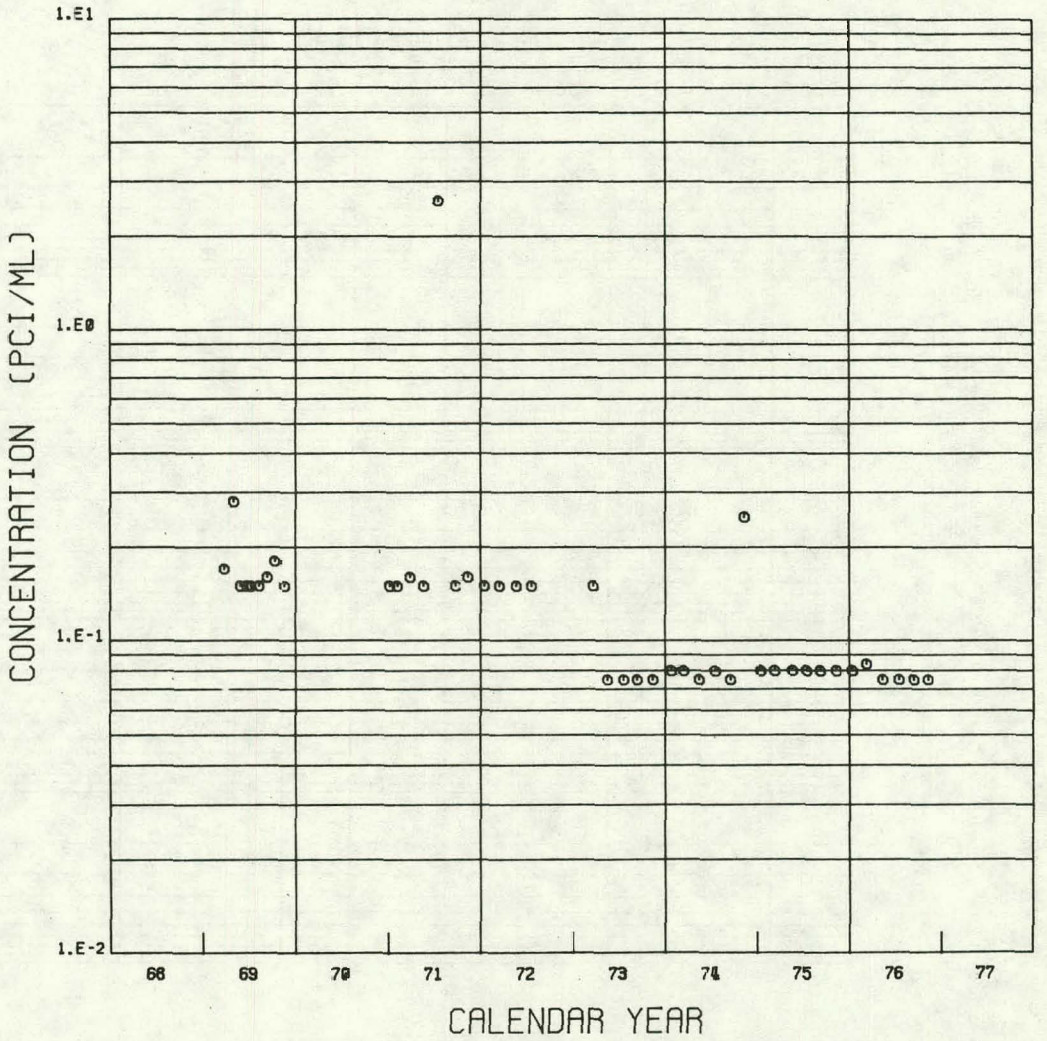
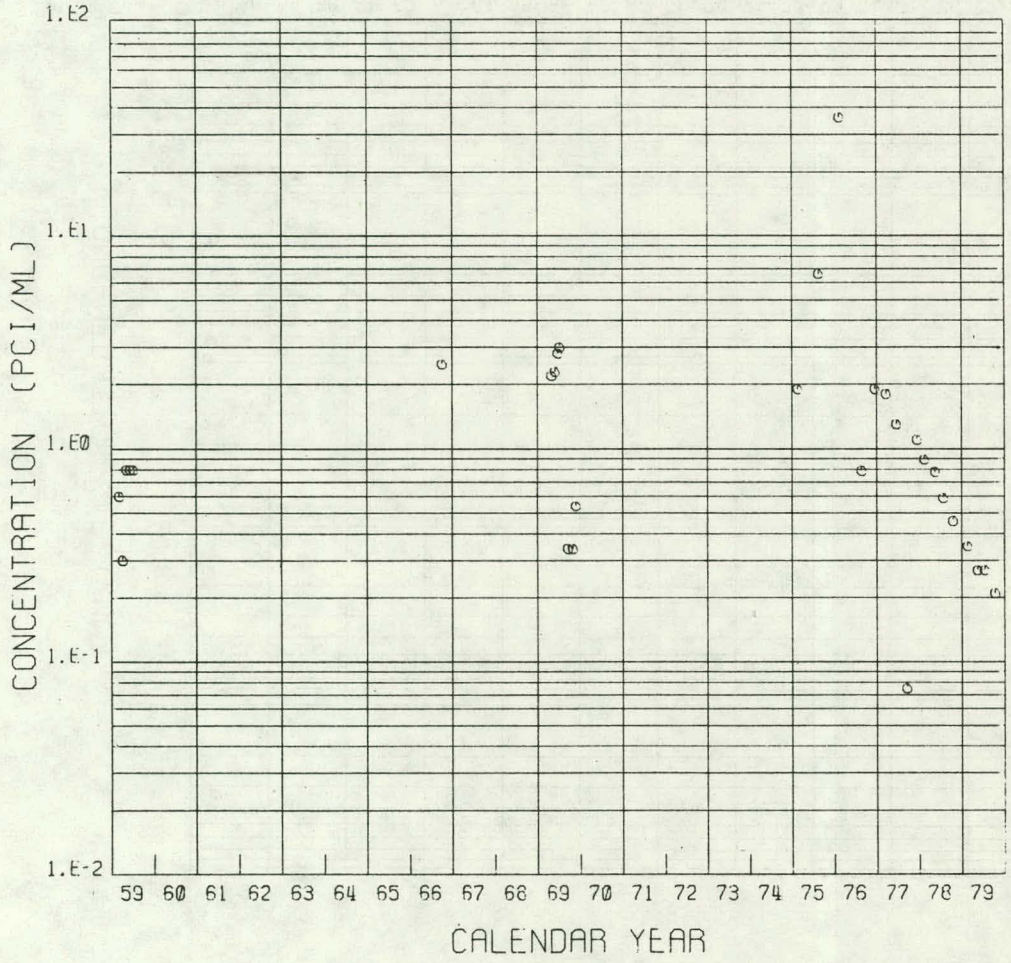
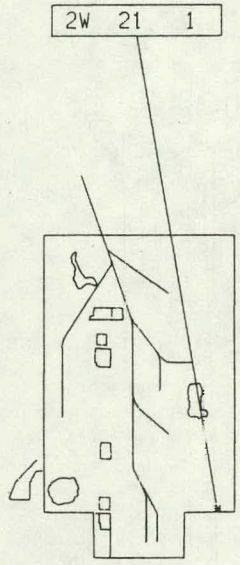


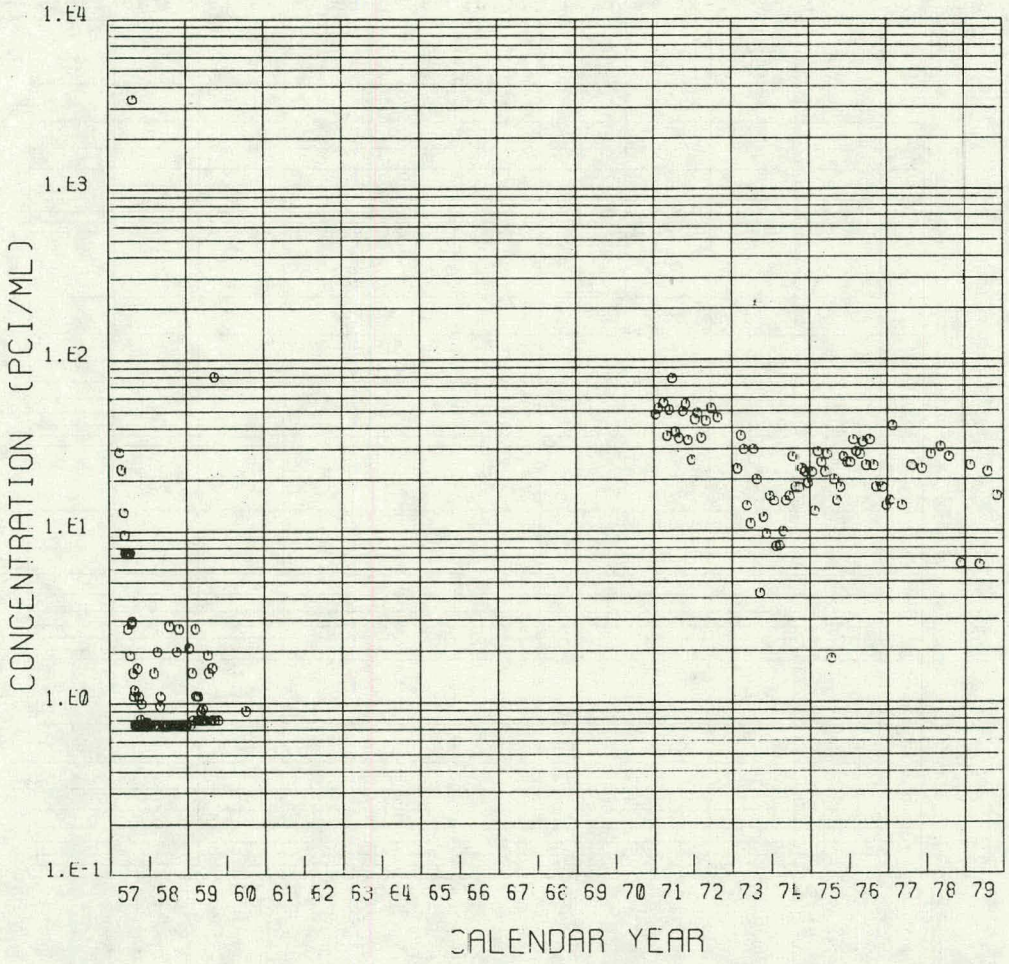
FIGURE C-6. Well 299-W19-7 Total Beta Concentration History.





200 WEST AREA

FIGURE C-7. Well 299-W21-1 Total Beta Concentration History.



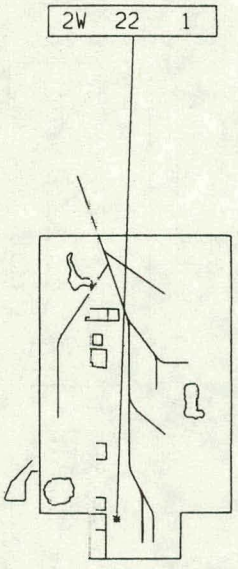


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FIGURE C-8. Well 299-W22-1 Total Beta Concentration History.

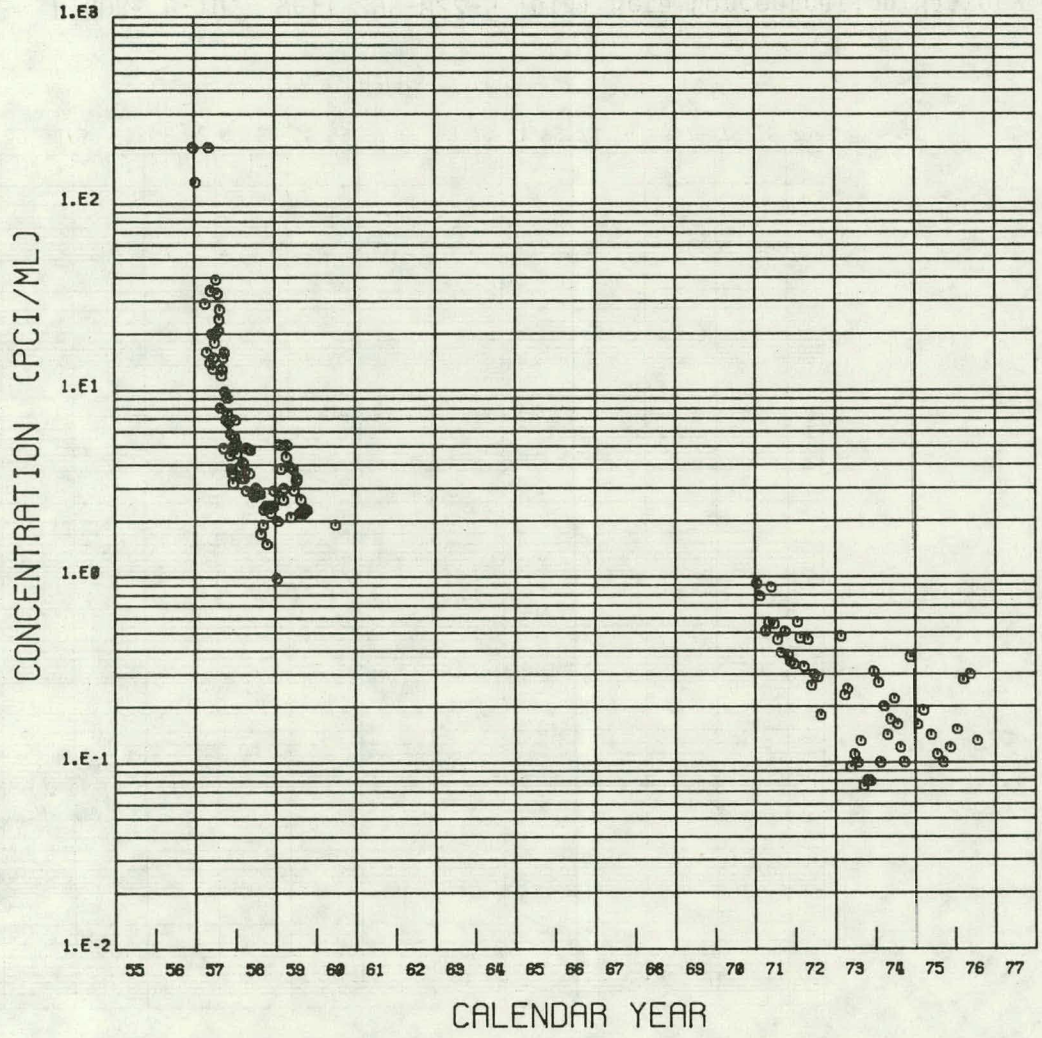
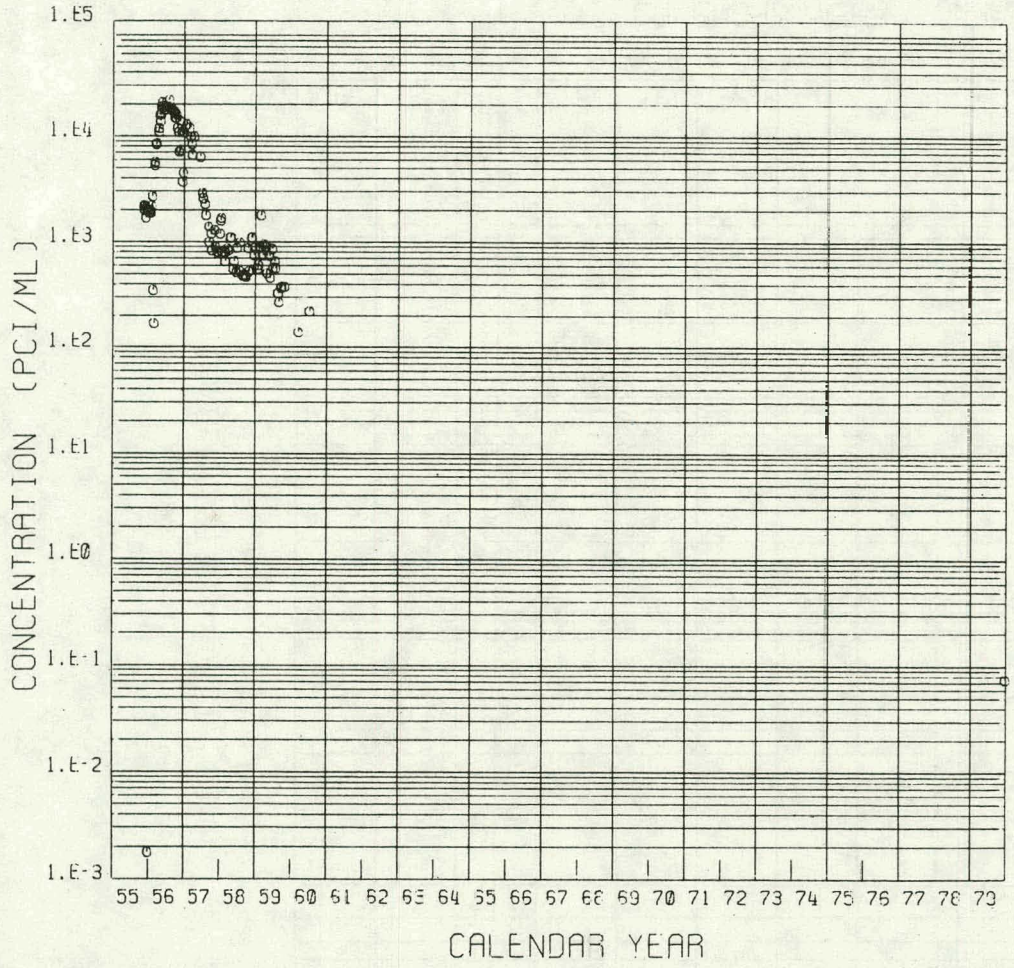


FIGURE C-9. Well 299-W22-2 Total Beta Concentration History.



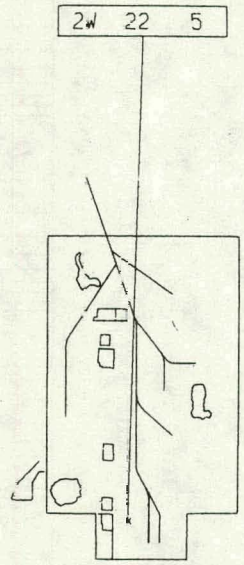


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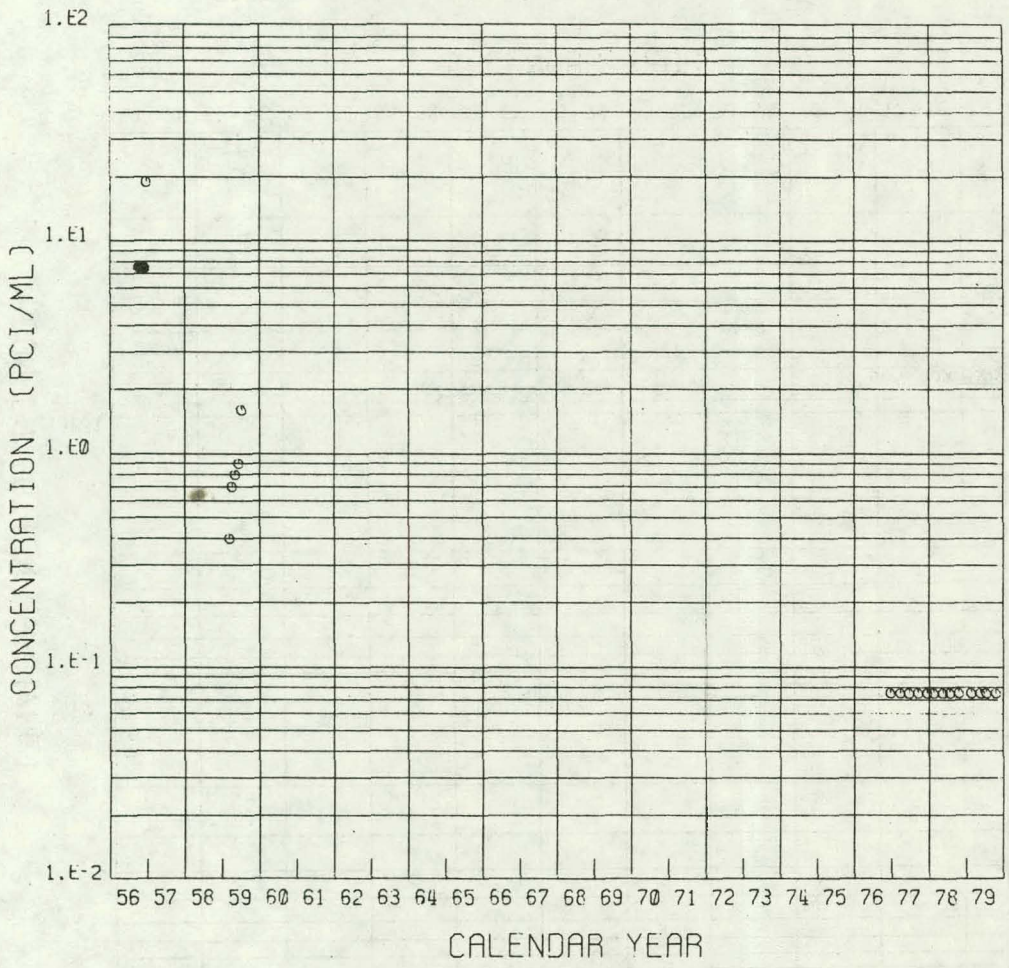
FIGURE C-10. Well 299-W22-5 Total Beta Concentration History.



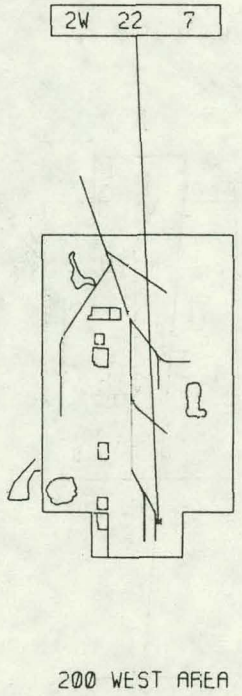
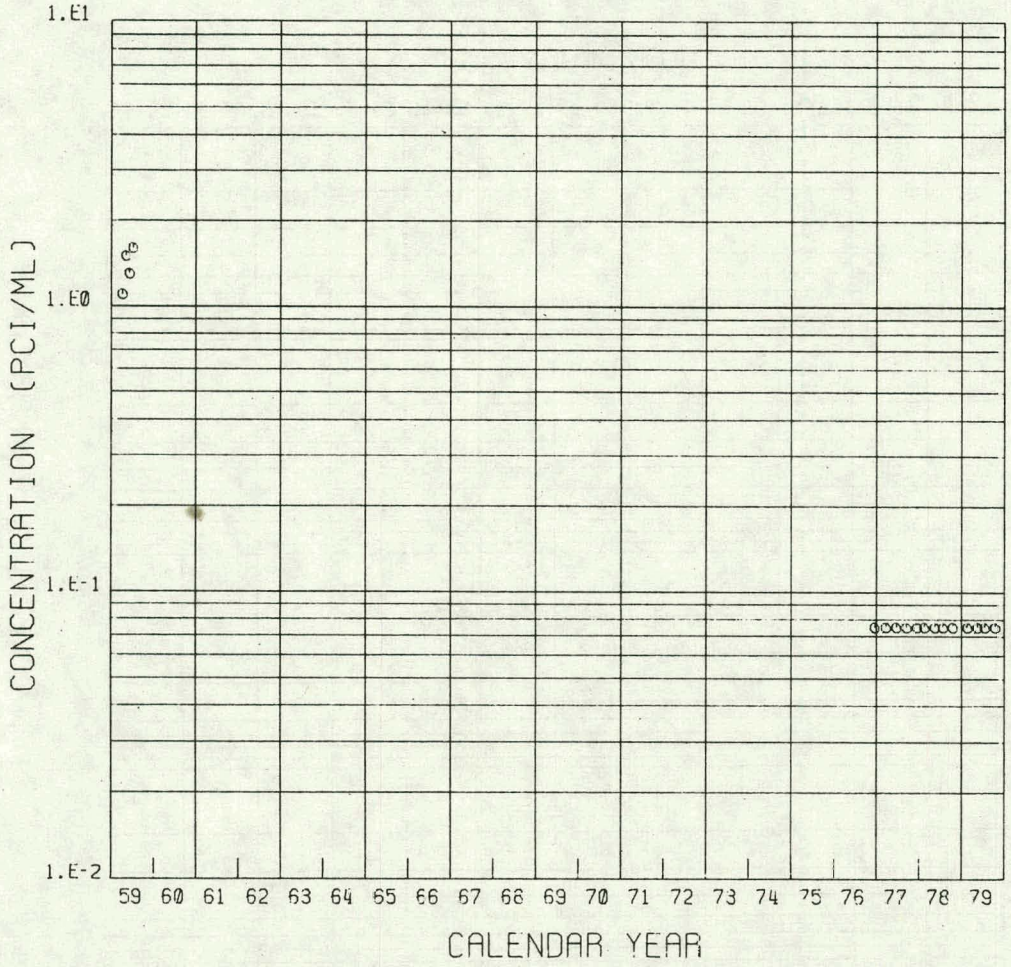
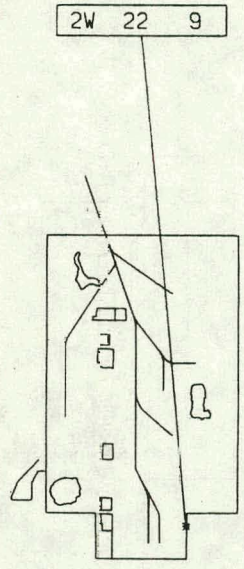


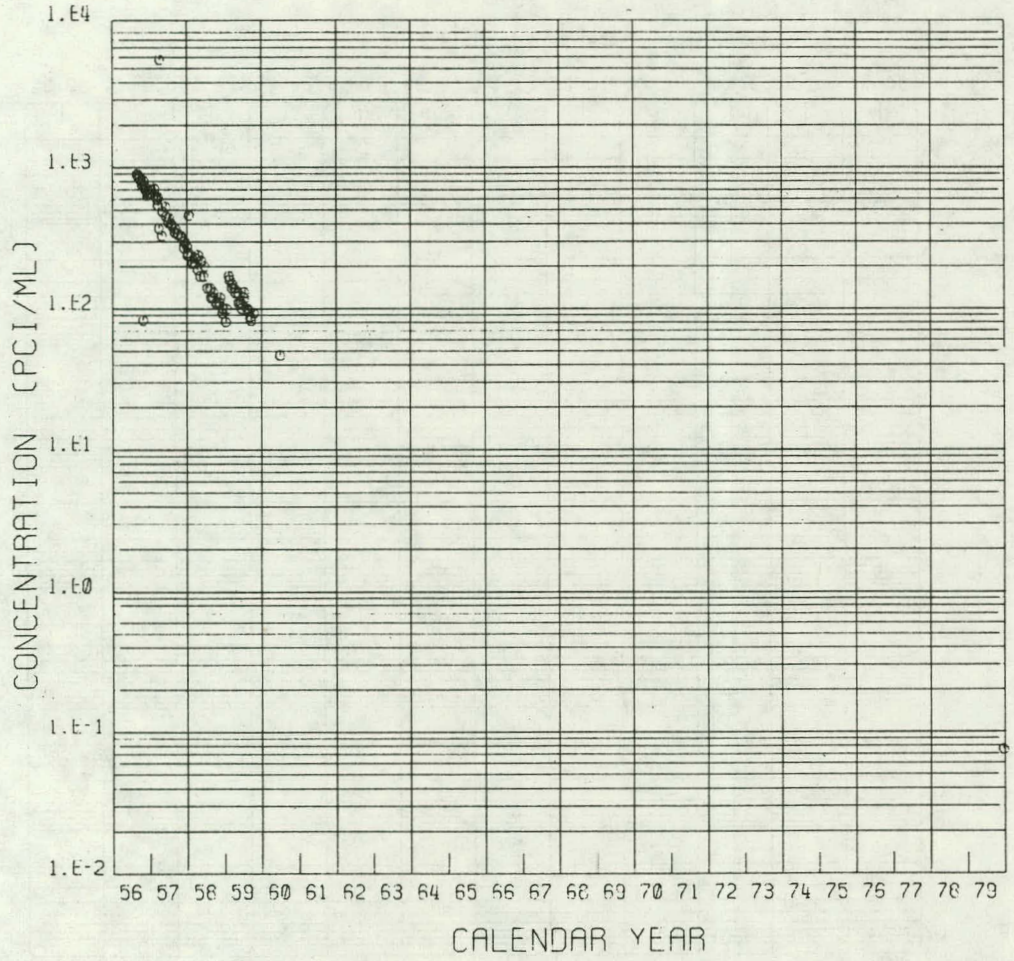
FIGURE C-11. Well 299-W22-7 Total Beta Concentration History.

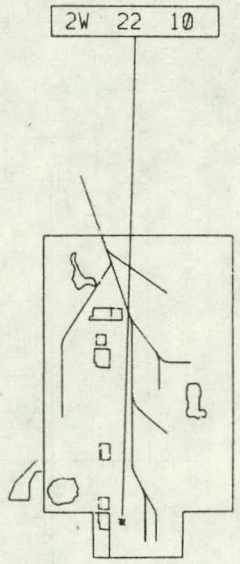




200 WEST AREA

FIGURE C-12. Well 299-W22-9 Total Beta Concentration History.





200 WEST AREA

FIGURE C-13. Well 299-W22-10 Total Beta Concentration History.

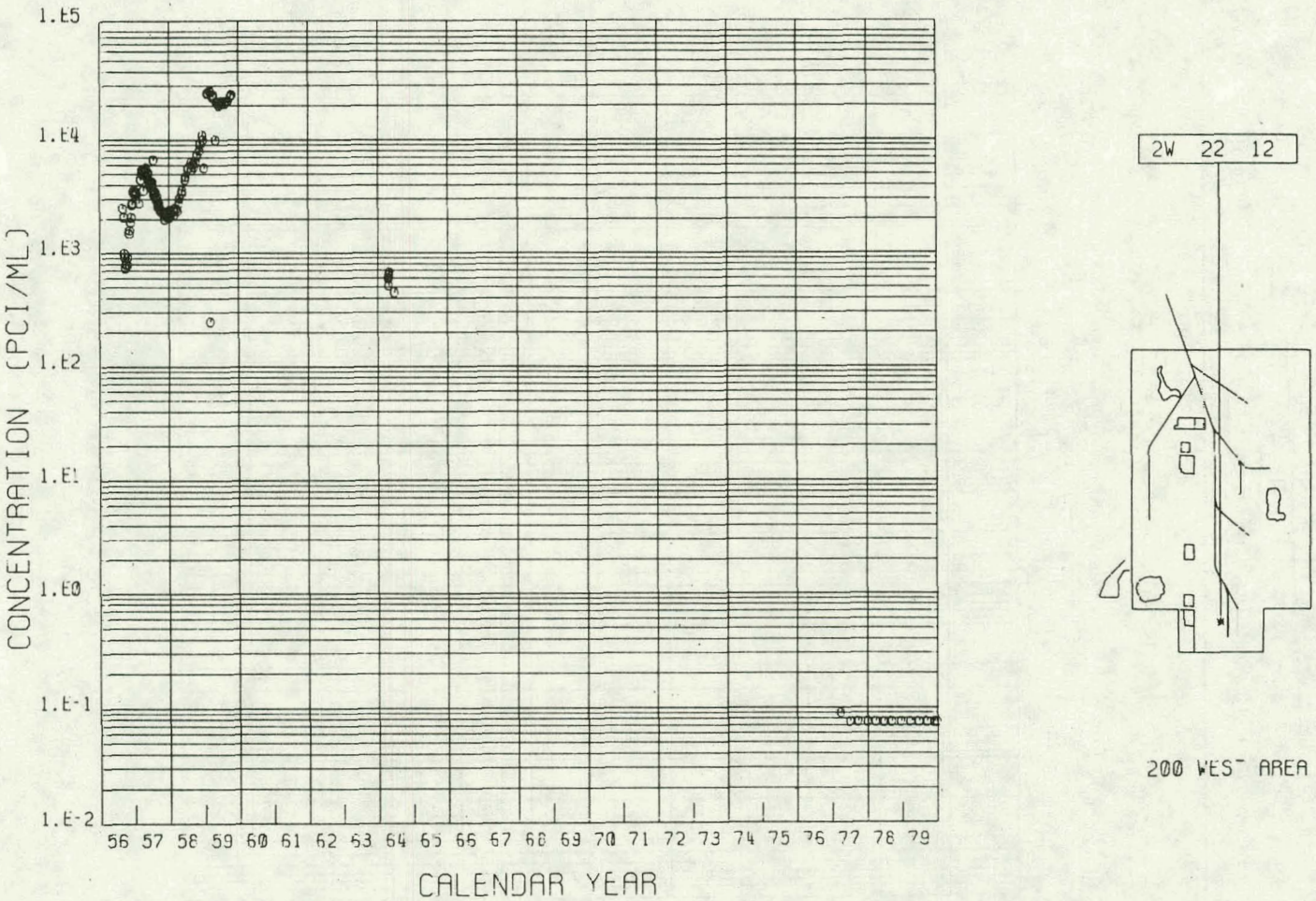


FIGURE C-14. Well 299-W22-12 Total Beta Concentration History.

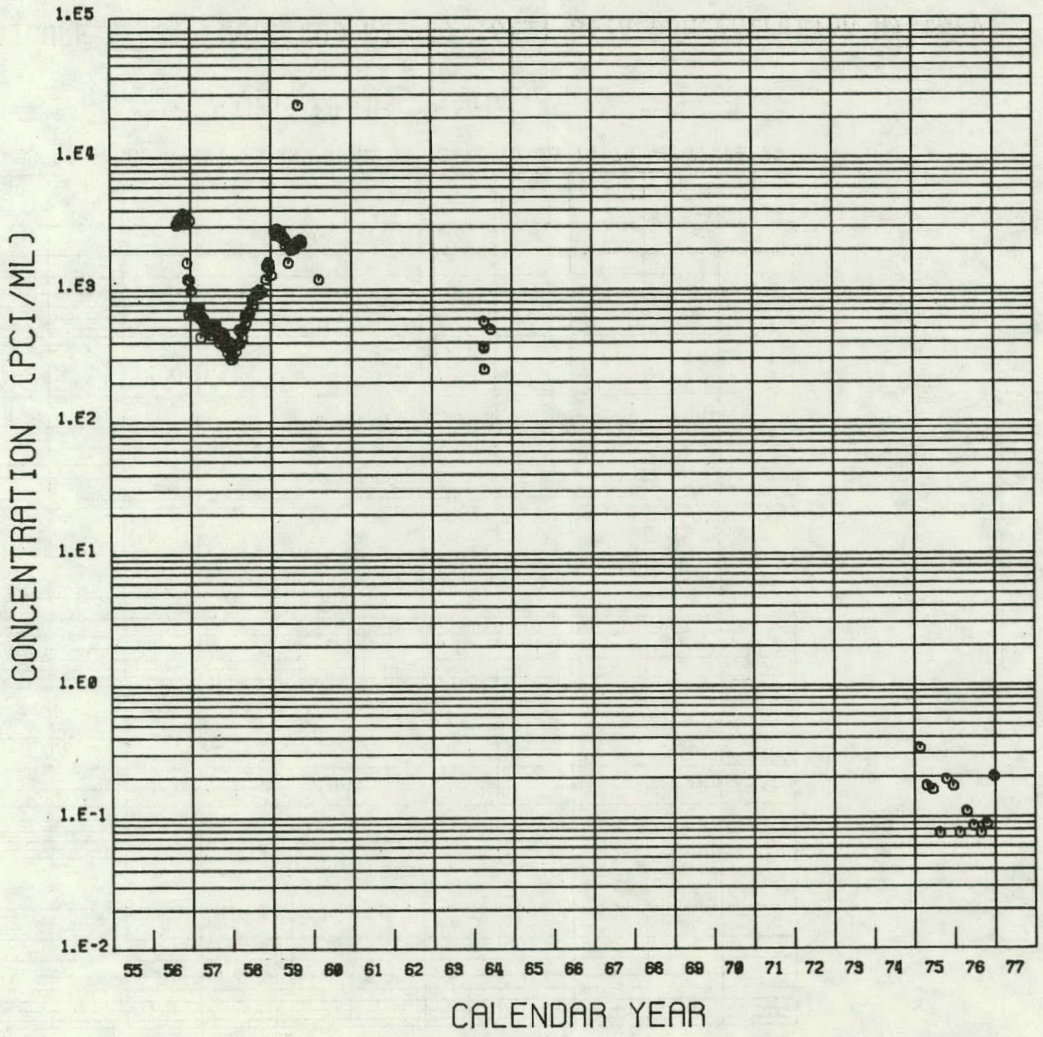
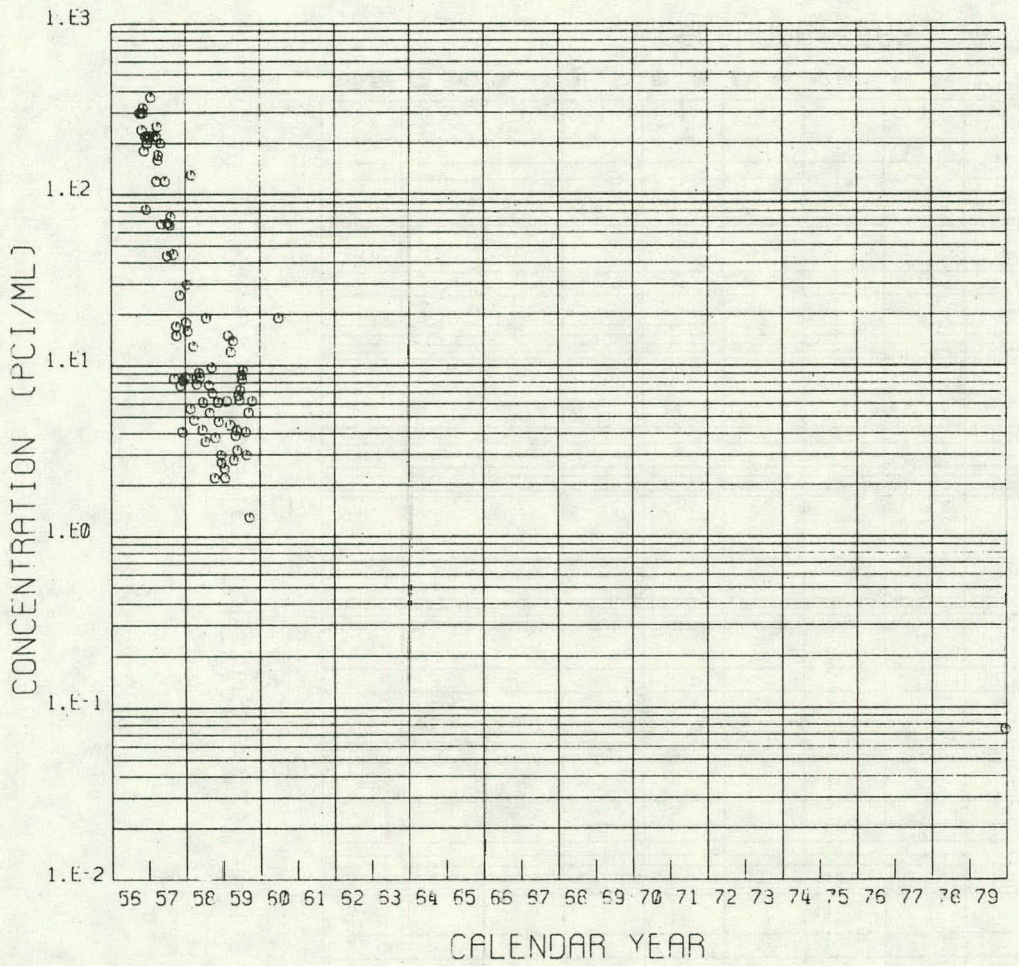


FIGURE C-15. Well 299-W22-13 Total Beta Concentration History.



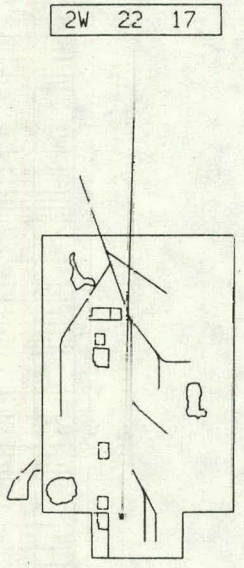
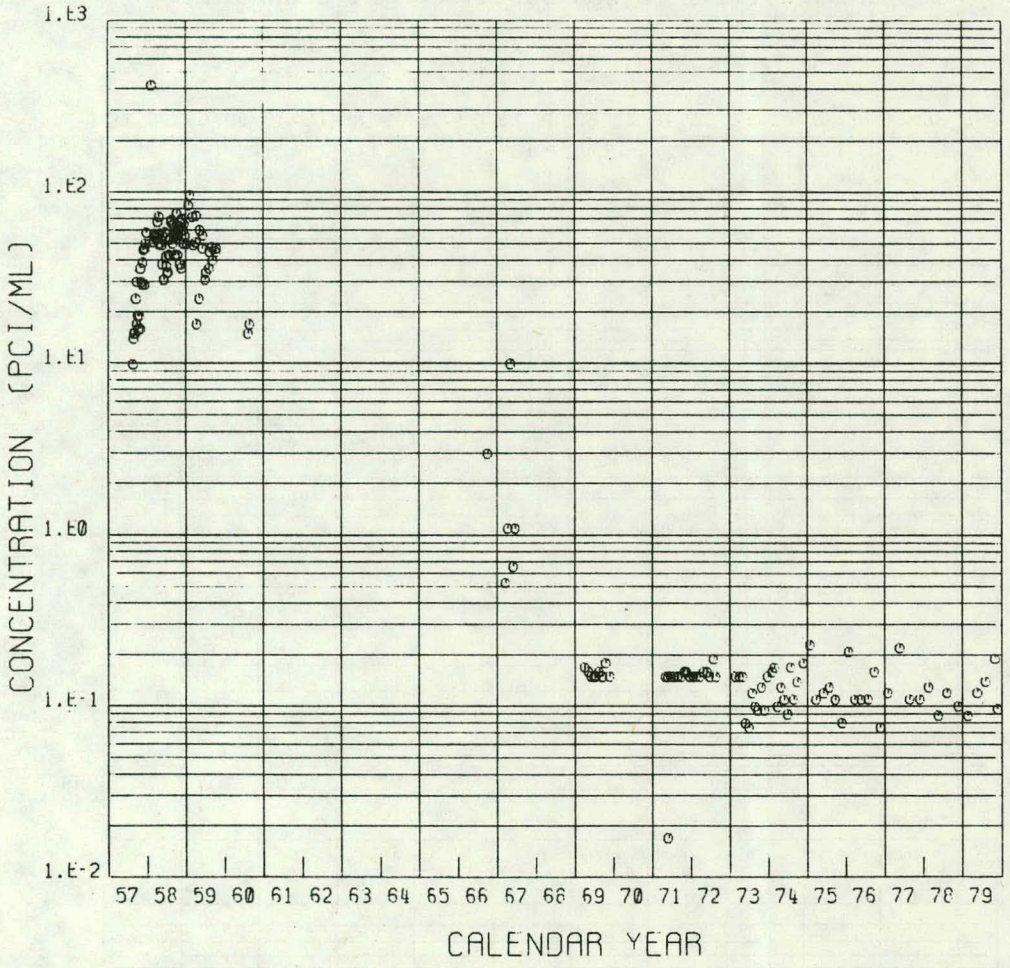


FIGURE C-16. Well 299-W22-17 Total Beta Concentration History.



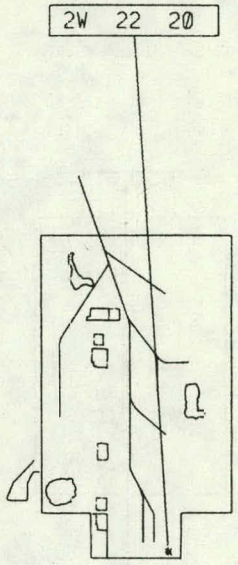


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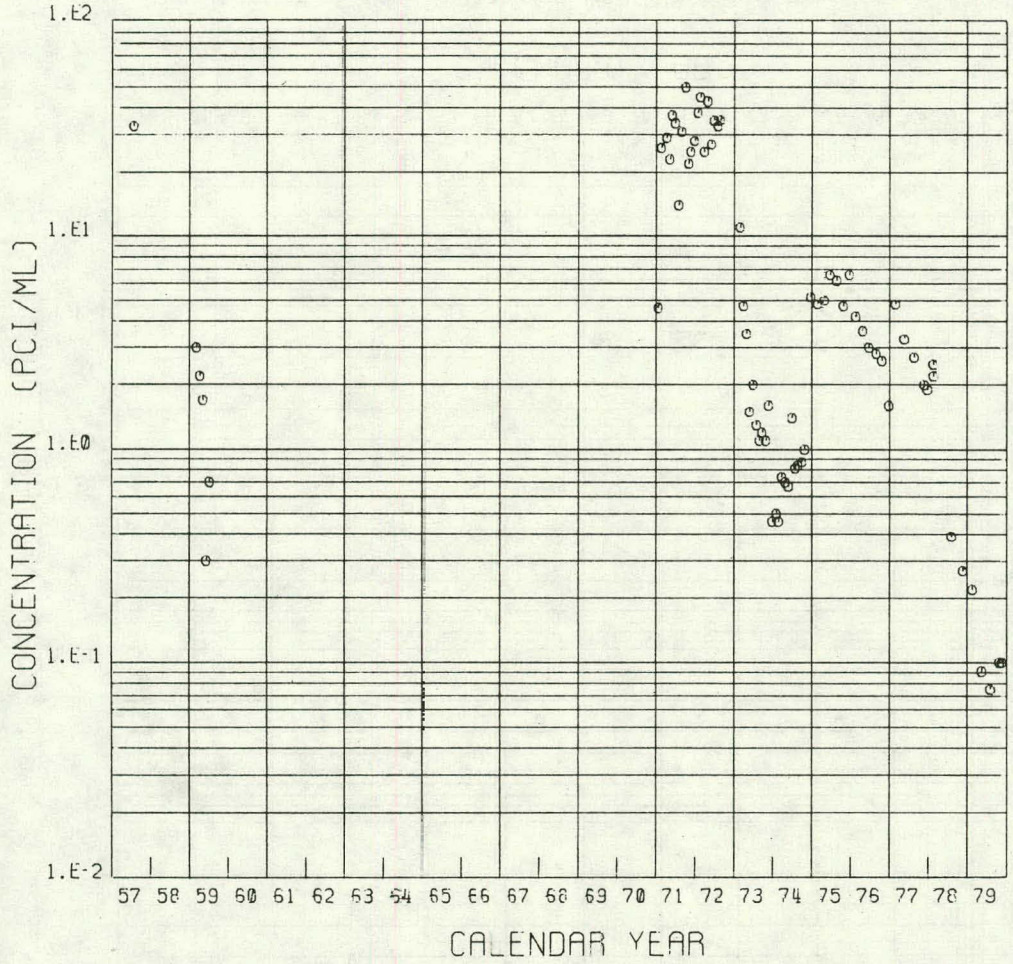
FIGURE C-17. Well 299-W22-20 Total Beta Concentration History.



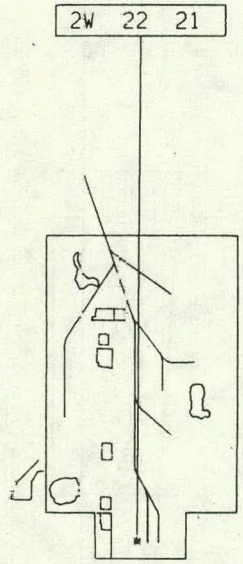


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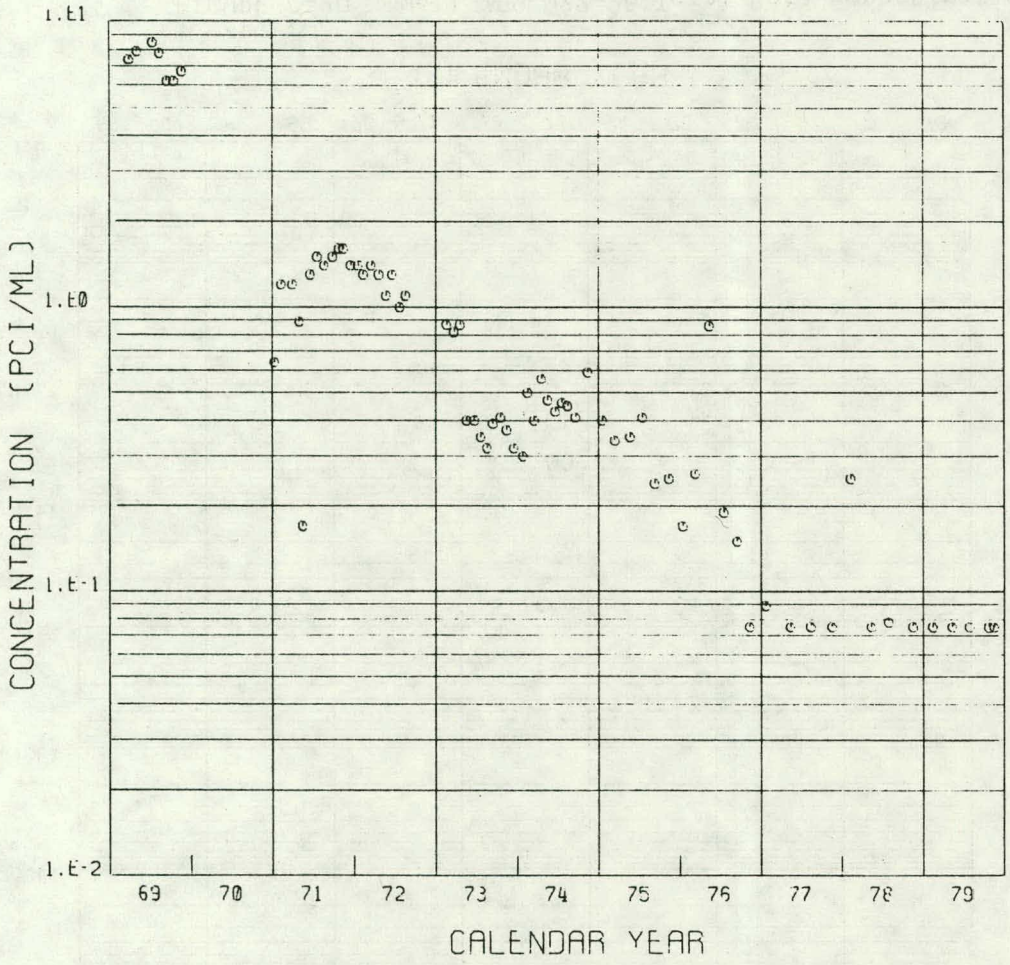
FIGURE C-18. Well 299-W22-21 Total Beta Concentration History.



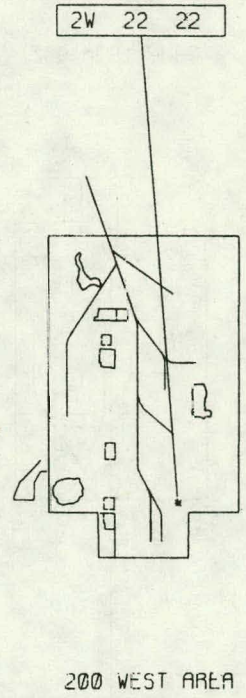
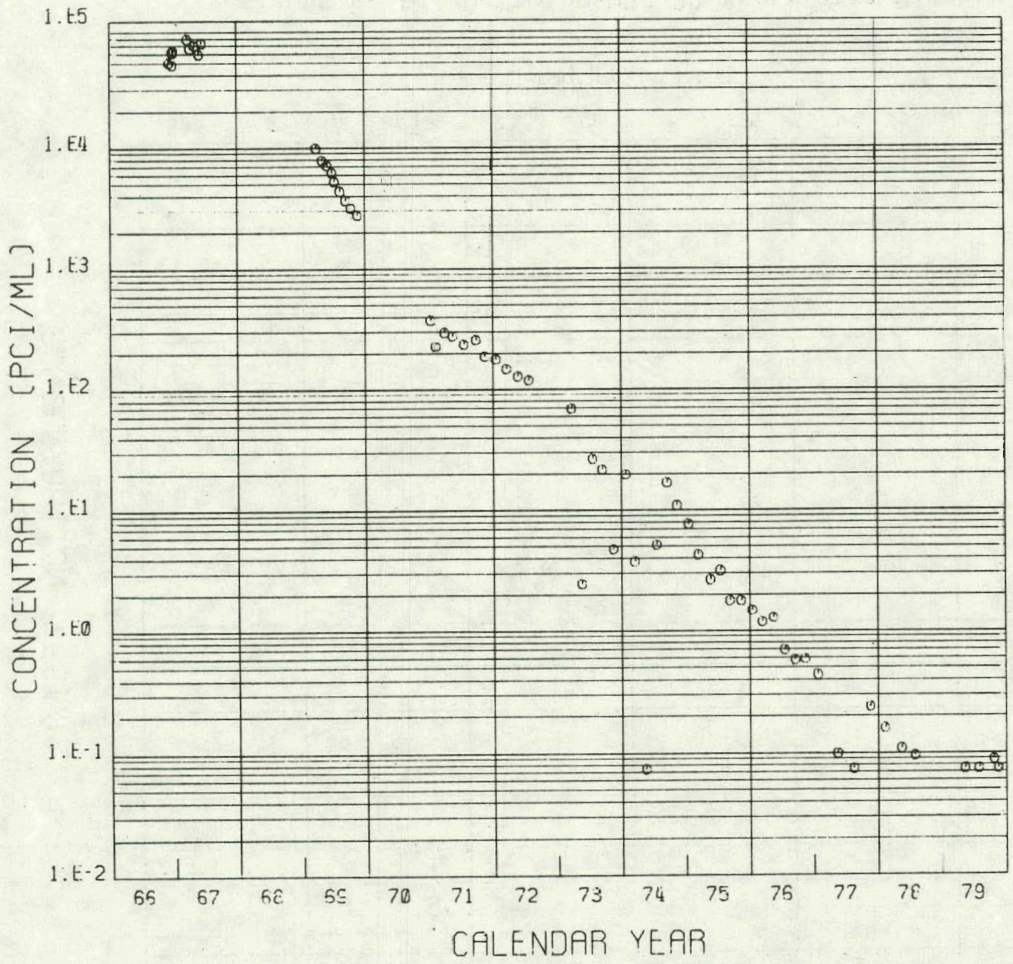


FIGURE C-19. Well 299-W22-22 Total Beta Concentration History.



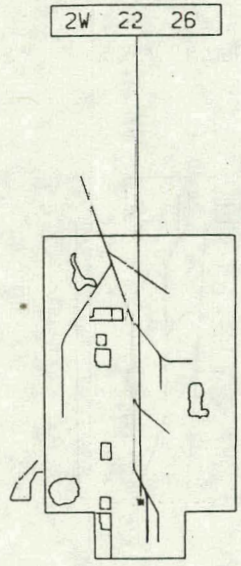
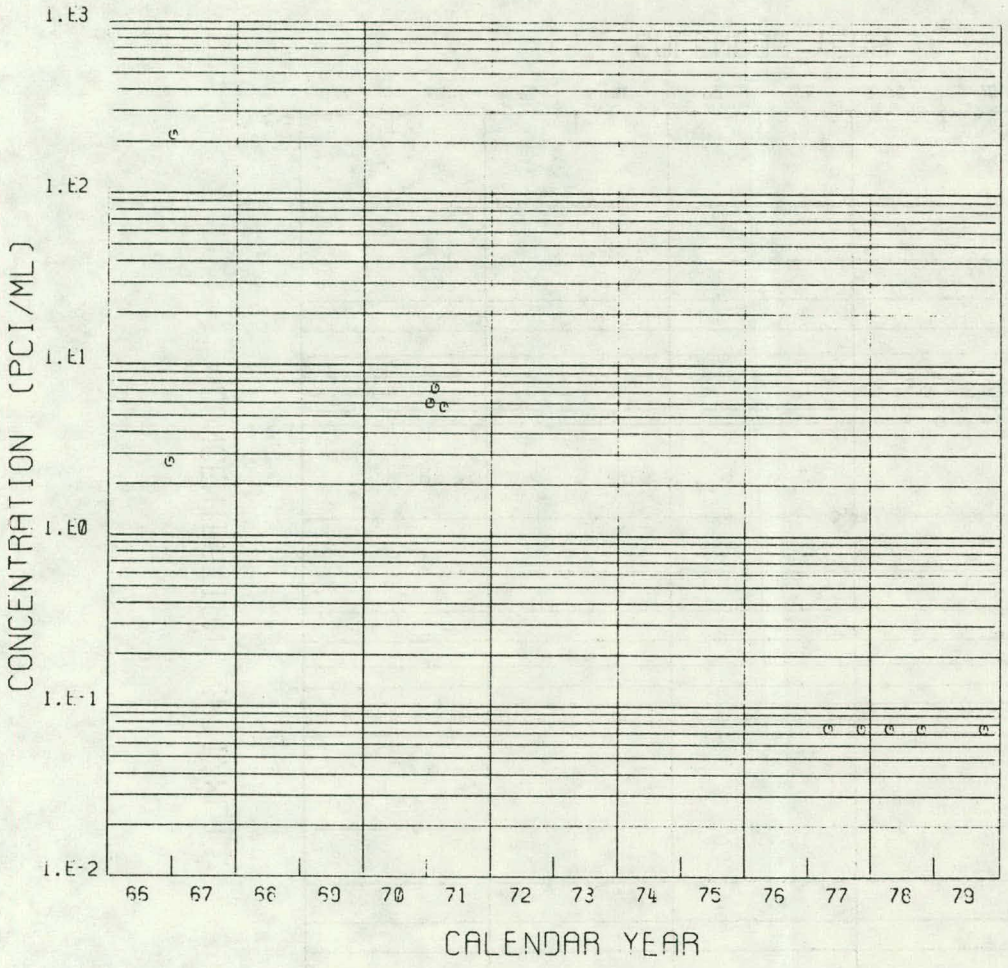


FIGURE C-20. Well 299-W22-26 Total Beta Concentration History.



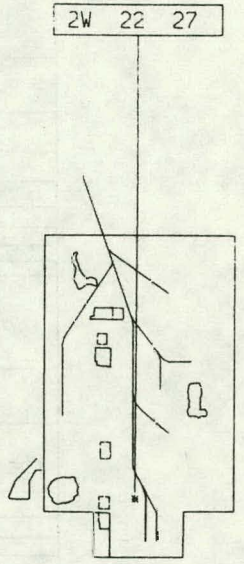


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FIGURE C-21. Well 299-W22-27 Total Beta Concentration History.

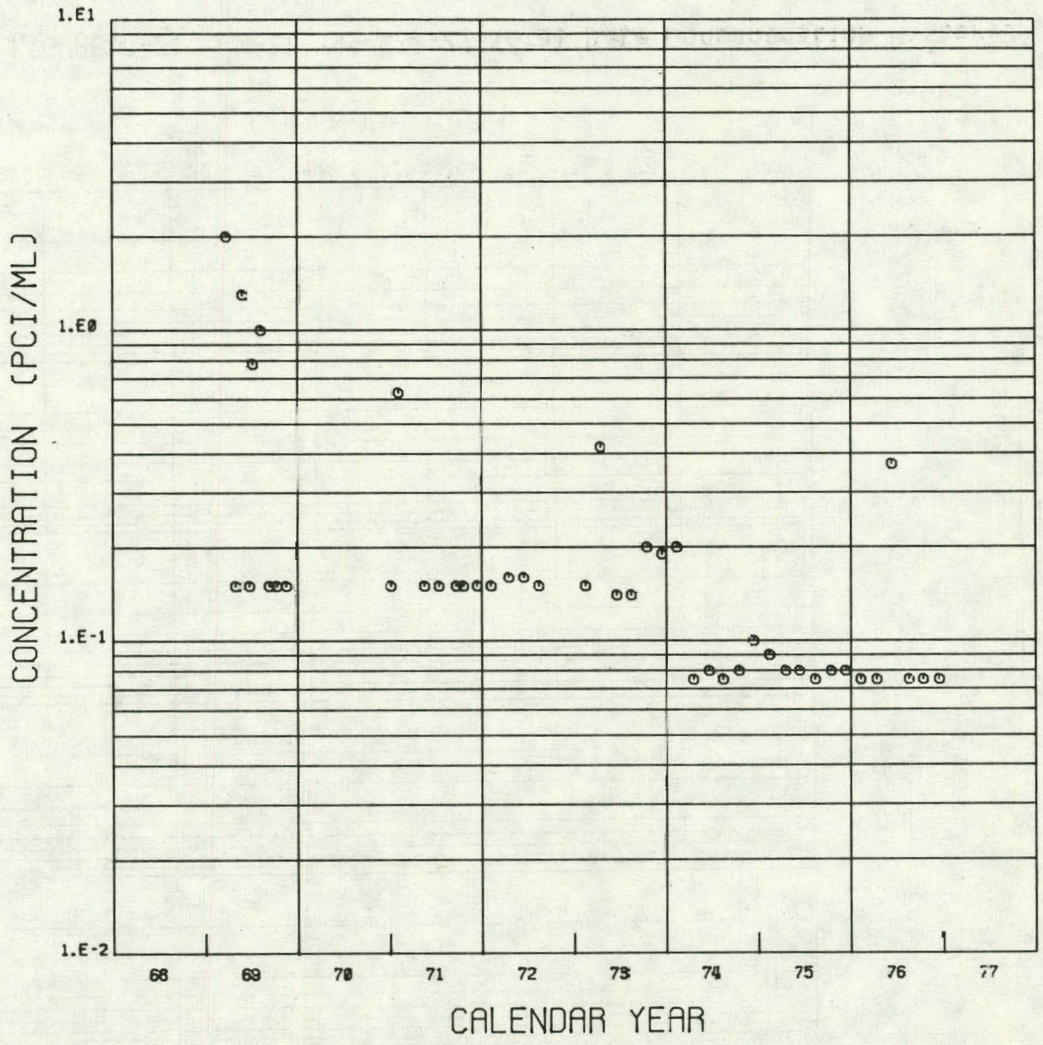
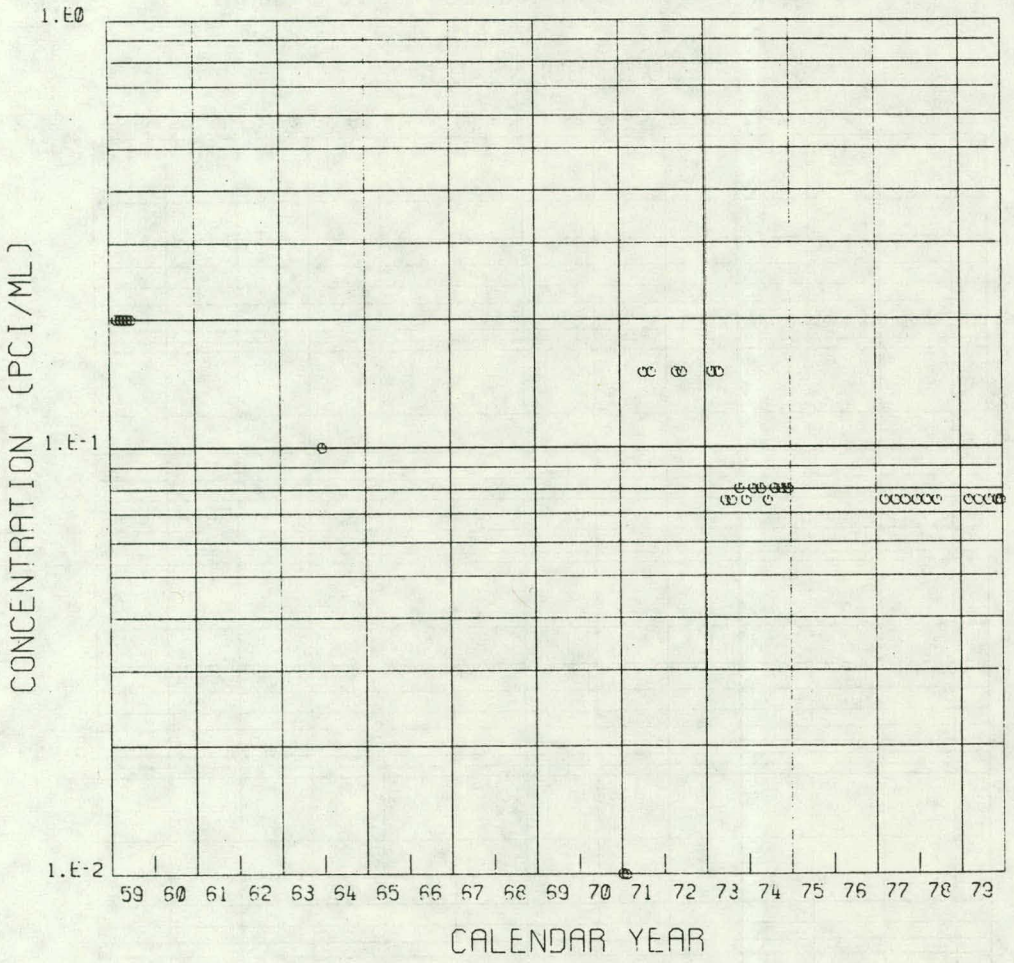


FIGURE C-22. Well 299-W22-38 Total Beta Concentration History.



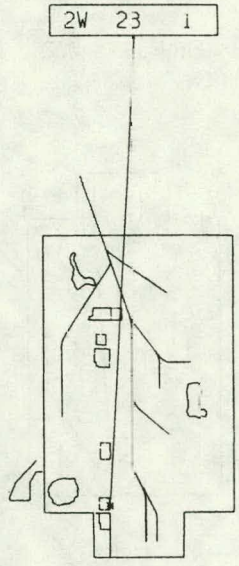


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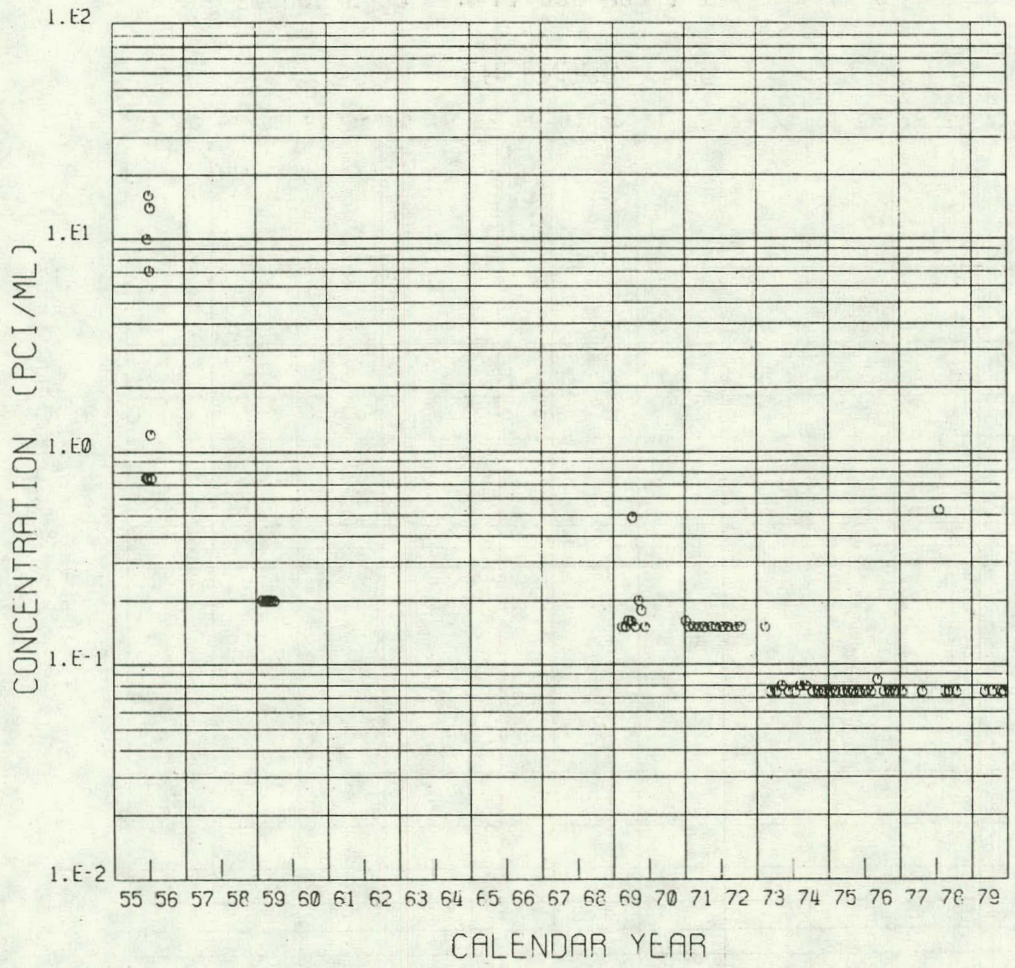
FIGURE C-23. Well 299-W23-1 Total Beta Concentration History.



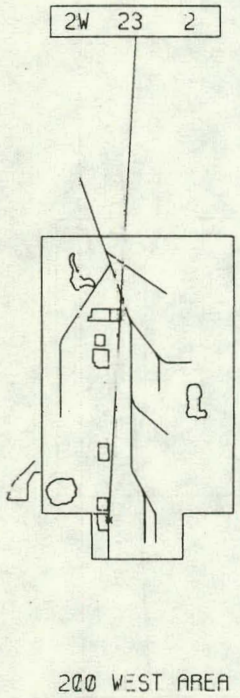
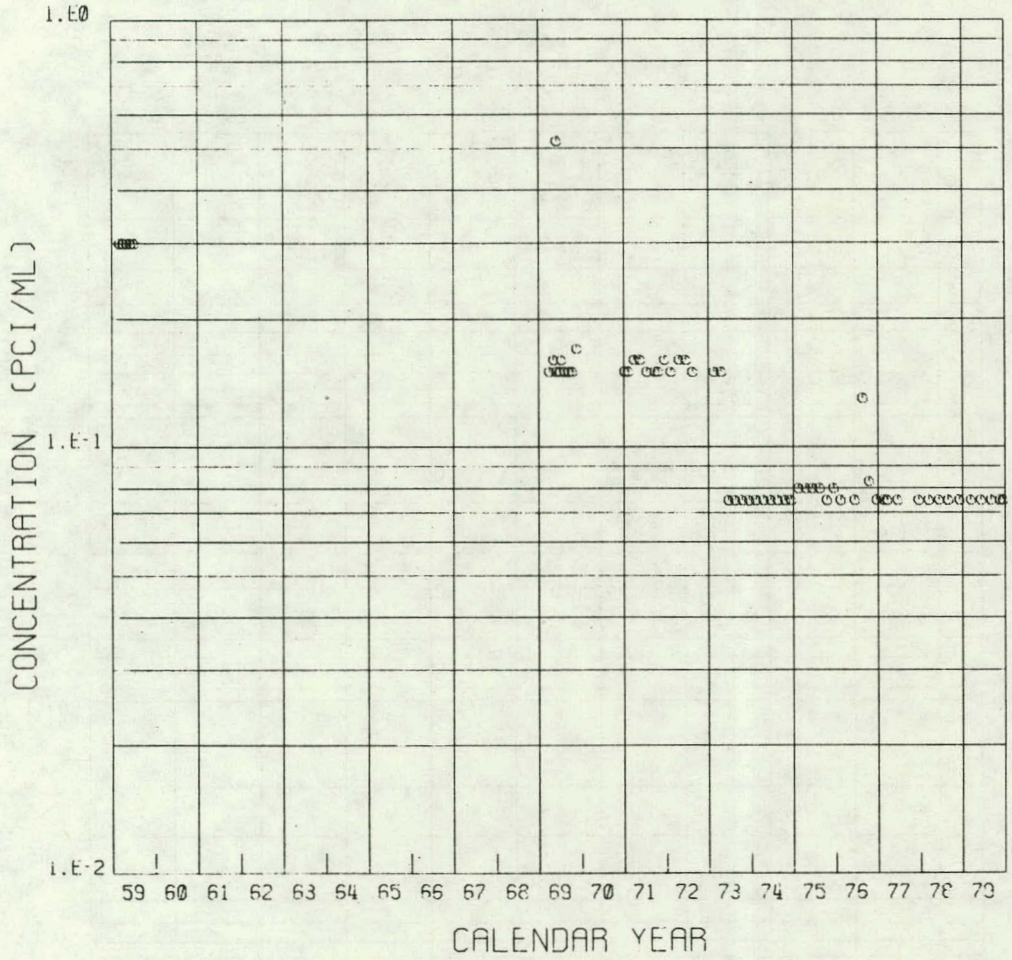


FIGURE C-24. Well 299-W23-2 Total Beta Concentration History.



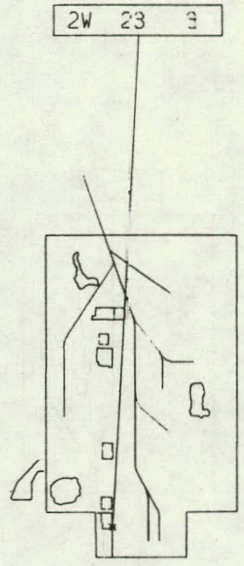


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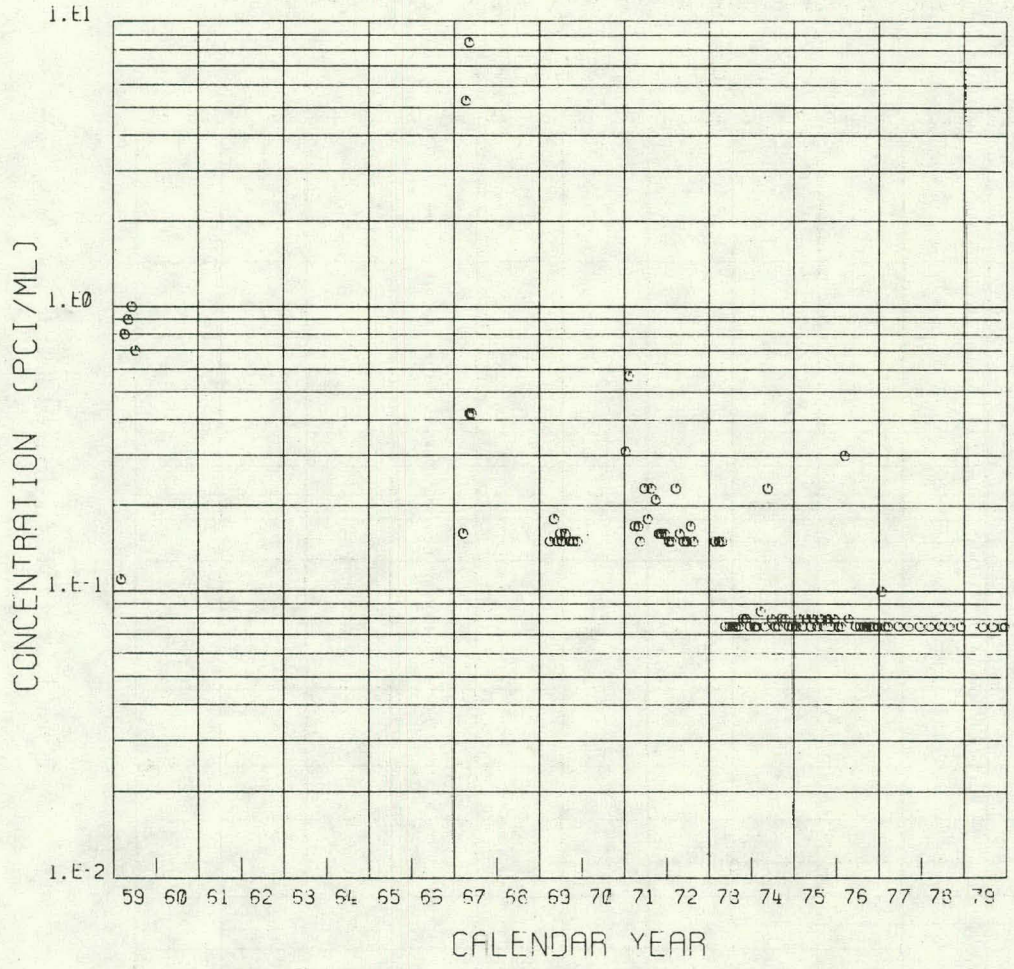
FIGURE C-25. Well 299-W23-3 Total Beta Concentration History.



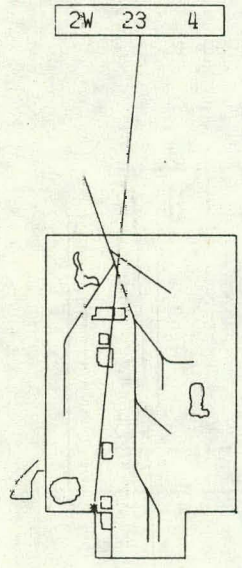


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FIGURE C-26. Well 299-W23-4 Total Beta Concentration History.

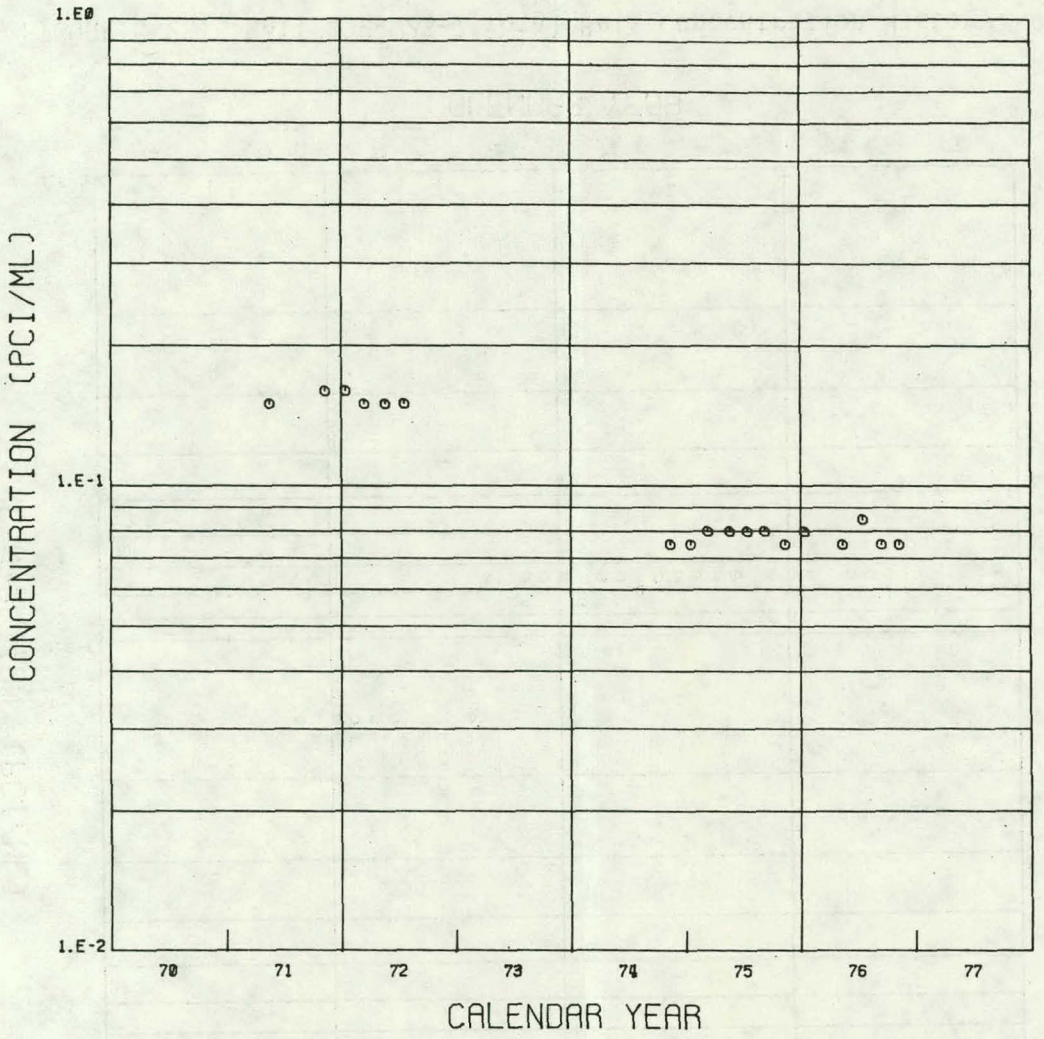


FIGURE C-27. Well 299-W23-5 Total Beta Concentration History.

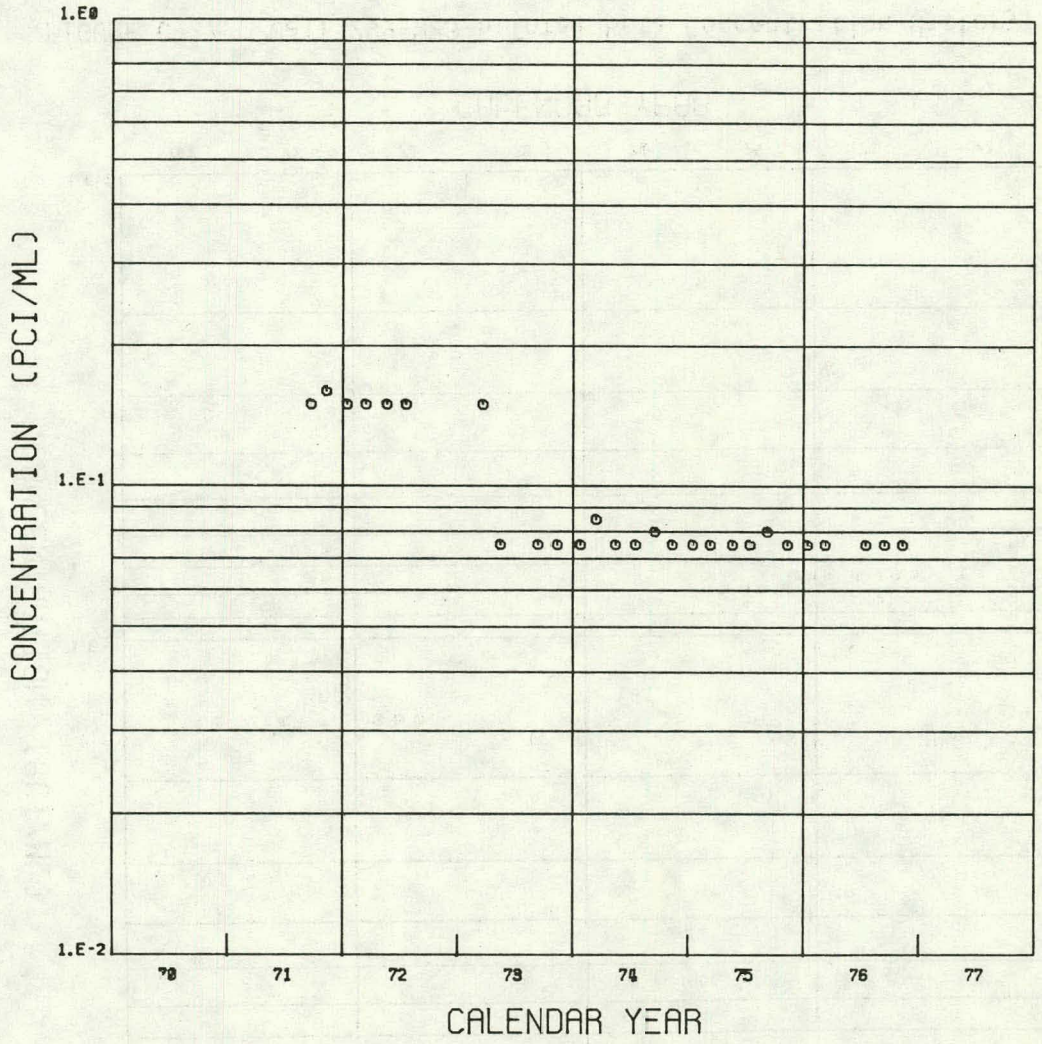
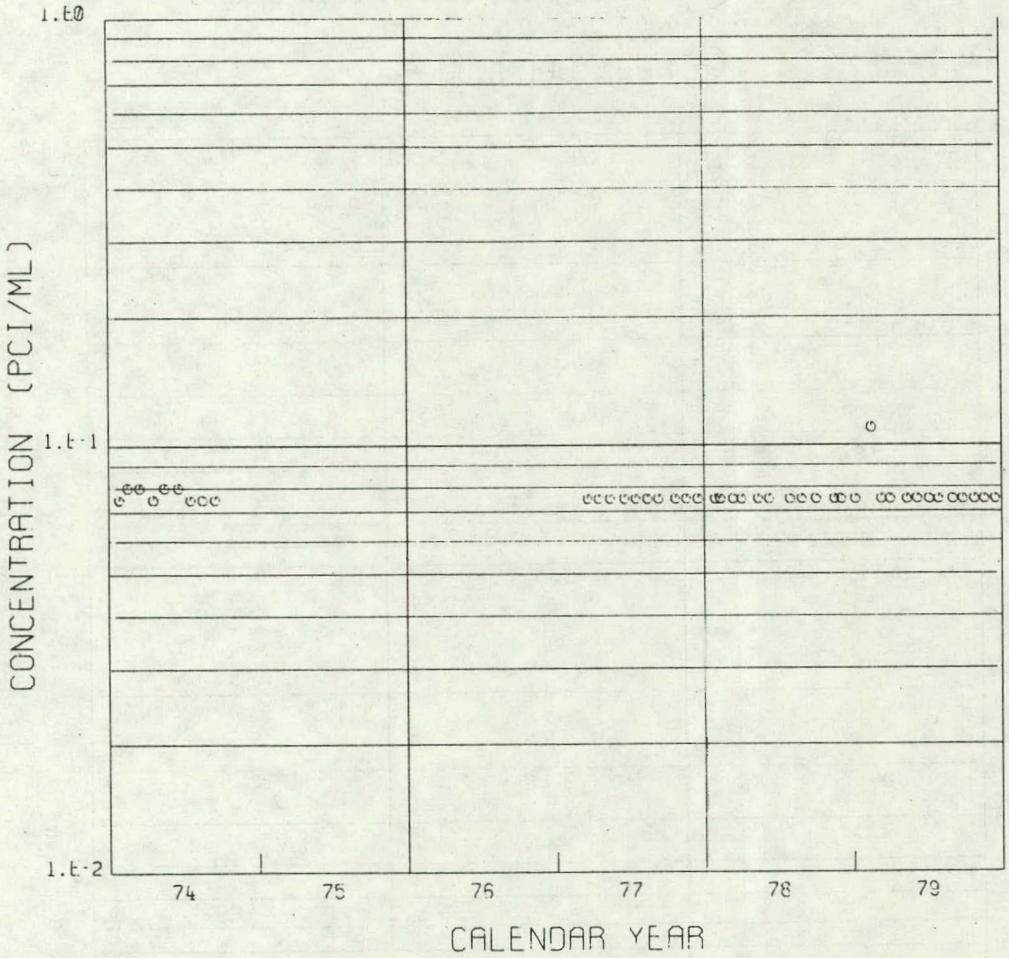


FIGURE C-28. Well 299-W23-7 Total Beta Concentration History.



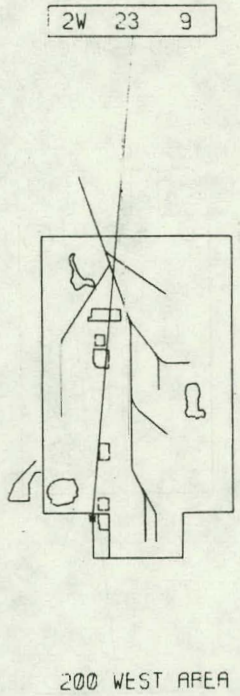
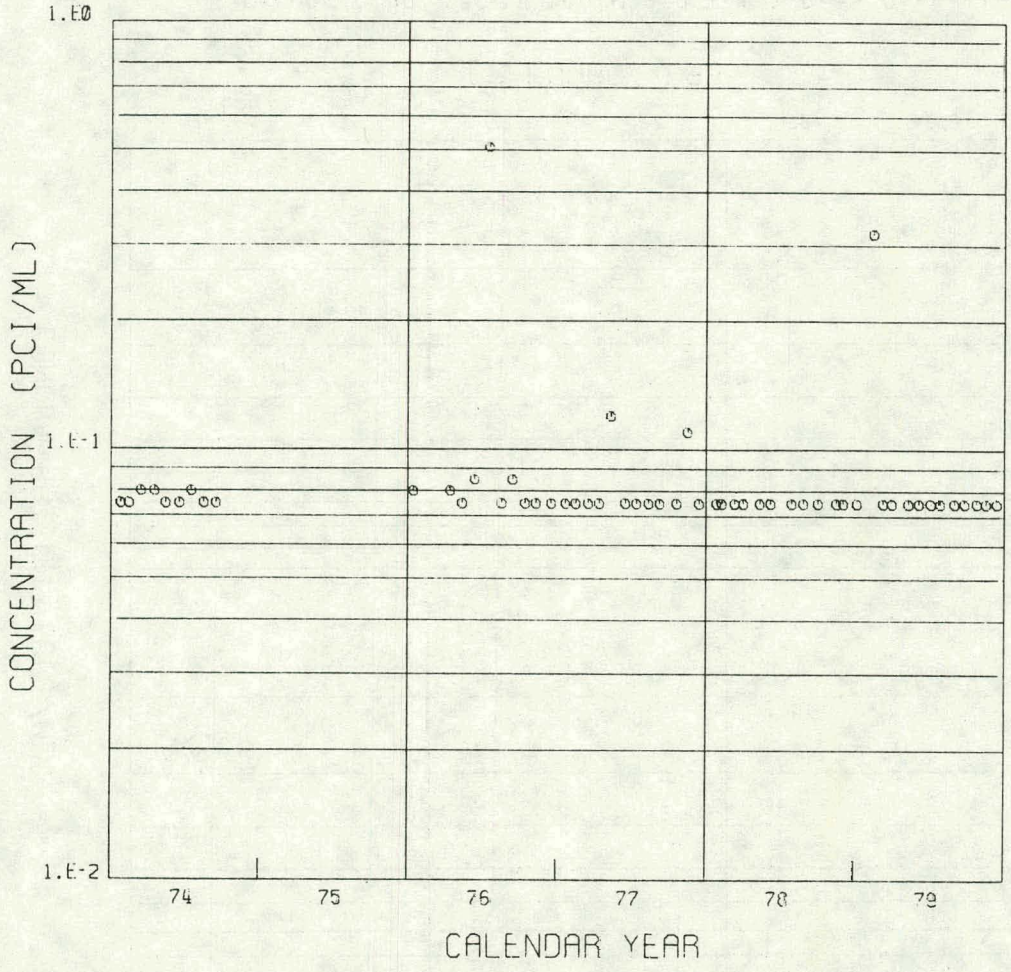


FIGURE C-29. Well 299-W23-9 Total Beta Concentration History.



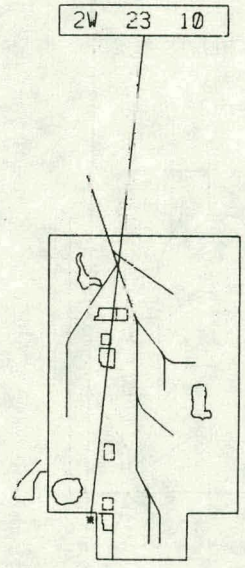
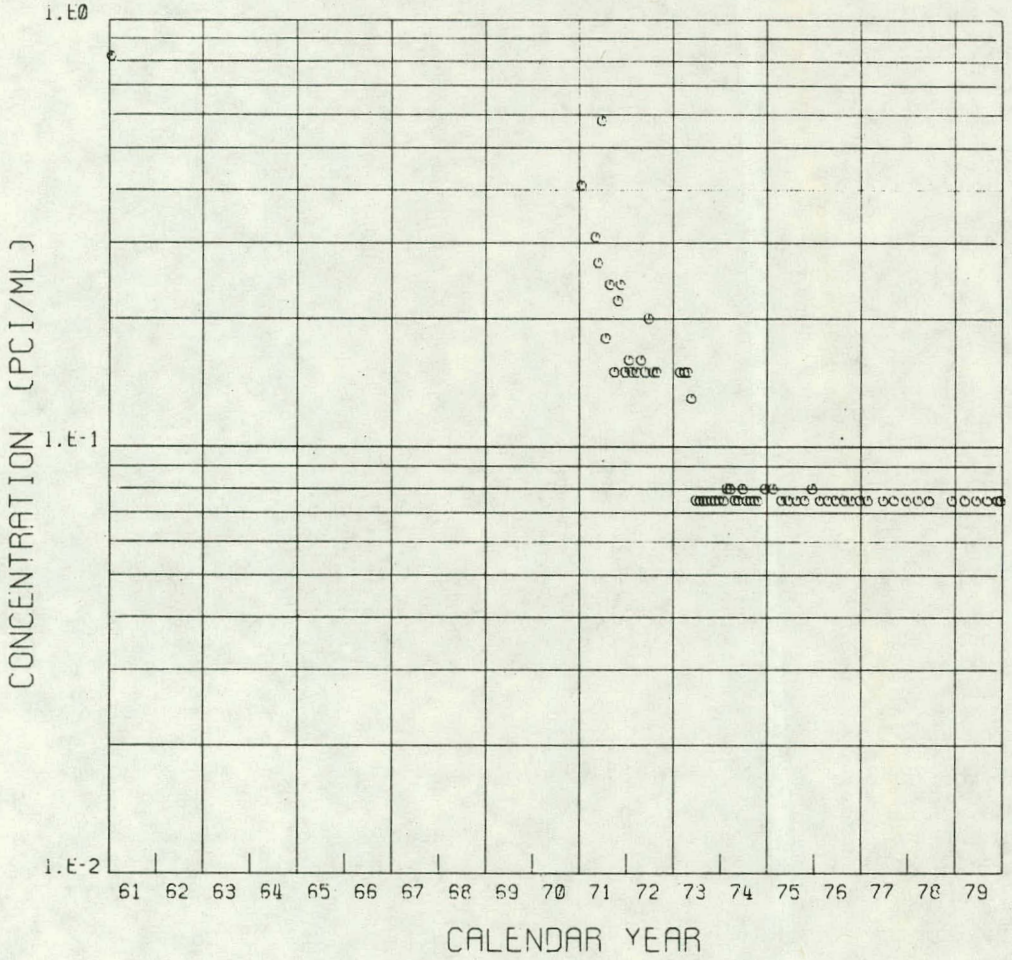


FIGURE C-30. Well 299-W23-10 Total Beta Concentration History.



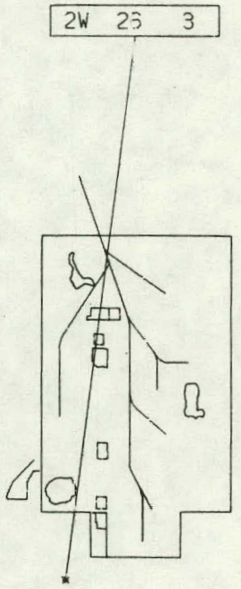


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FIGURE C-31. Well 299-W26-3 Total Beta Concentration History.

Rockwell Hanford Operations (continued)

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