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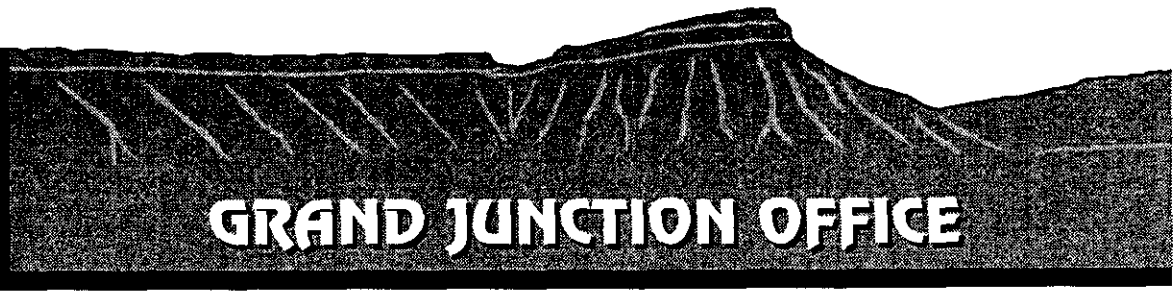
Vadose Zone Characterization Project at the Hanford Tank Farms

AX Tank Farm Report

August 1997



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United States Government **Department of Energy**
Grand Junction Office

memorandum

DATE: SEP 12 1997

SUBJECT: AX Tank Farm Report

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DOE-Richland

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Vadose Zone Characterization Project at the Hanford Tank Farms

AX Tank Farm Report

August 1997

Prepared for
U.S. Department of Energy
Richland Operations Office
Richland, Washington

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

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AX Tank Farm Report

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Executive Summary

The U.S. Department of Energy Grand Junction Office (DOE-GJO) was tasked by the DOE Richland Operations Office (DOE-RL) to perform a baseline characterization of the gamma-ray-emitting radionuclides that are distributed in the vadose zone sediments beneath and around the single-shell tanks (SSTs) at the Hanford Site. The intent of this characterization is to determine the nature and extent of the contamination from these radionuclides, to identify contamination sources when possible, and to develop a baseline of the contamination distribution against which future comparisons and characterizations can be compared.

This characterization project involves acquiring information regarding vadose zone contamination with borehole geophysical logging methods and documenting this information in a series of reports. Data from boreholes surrounding each tank are compiled into individual Tank Summary Data Reports. Four Tank Summary Data Reports were prepared for the tanks in the AX Tank Farm (DOE 1997c, 1997d, 1997e, and 1997f).

The data from each tank in a tank farm are compiled and summarized in a Tank Farm Report. This document is the Tank Farm Report for the AX Tank Farm. The Tank Farm Reports present models of the contamination plumes based on geostatistical analyses of the measured contamination distribution. In the AX Tank Farm, cesium-137 (^{137}Cs) was the main contaminant detected in the vadose zone. Other radionuclides such as cobalt-60 (^{60}Co), europium-154 (^{154}Eu), and antimony-125 (^{125}Sb) were also detected; however, these radionuclides were detected in small isolated occurrences and were not modeled. The visualizations show three-dimensional solid surface representations of the contamination viewed from several perspectives. The development of the geostatistical model and the visualizations is described in detail, and the limitations and inaccuracies of both the model and the visualizations are discussed. The visualizations show that the majority of the plumes of gamma-emitting contaminants are related to surface spills or pipeline leaks and not necessarily associated with tanks that are designated assumed leakers (tanks AX-102 and AX-104).

The potassium-40 (^{40}K) concentration data were modeled, and visualizations of ^{40}K concentrations greater than 13.5 pCi/g are presented. The data presented in the visualizations indicate that some areas of the AX Tank Farm are lower in ^{40}K content than others. Because low ^{40}K concentrations may indicate the presence of coarse-grained sediments, coarser-grained, and, therefore, more permeable sediments may be present in these areas. In regions where contamination from surface spills migrated to depths of more than 100 ft, the visualizations of the ^{40}K concentration data indicate coarser sediments.

Data acquired during this characterization project establish a baseline of the current vadose zone contamination conditions and present a limited assessment of the impacts of this contamination. This work can be used to help define a tank monitoring program and to determine the implications or impacts of the contamination. It may also be used to aid in the development of a more comprehensive characterization effort for this tank farm.

1.0 Introduction

The AX Tank Farm is located in the east-central portion of the 200 East Area of the Hanford Site (Figure 15-1). This tank farm consists of four 1,000,000 gallon (gal) single-shell tanks (SSTs) that were constructed to store high-level radioactive waste generated by chemical processing of irradiated uranium reactor fuel. This waste was generated primarily at the Plutonium-Uranium Extraction Plant (PUREX), which is located about 1,500 feet (ft) south-southwest of the AX Tank Farm. These four tanks presently contain a total of 906,000 gal of waste. Two of the tanks in the AX Tank Farm, tanks AX-102 and AX-104, are listed in Hanlon (1997) as "assumed leakers." These tanks are estimated to have leaked a total of 11,000 gal of high-level radioactive liquid into the vadose zone sediments; however, the accuracy of these estimates is unknown.

In 1994, the Department of Energy Richland Office (DOE-RL) requested the DOE Grand Junction Office (DOE-GJO), Grand Junction, Colorado, to conduct a baseline characterization of contamination of gamma-emitting radionuclides in the vadose zone at all the Hanford Site SST farms by conducting spectral gamma-ray logging of boreholes that surround the tanks. Existing monitoring boreholes in the AX Tank Farm were logged with high-purity intrinsic germanium (HPGe) spectral gamma-ray logging systems (SGLSs) to produce an assay of the gamma-emitting radionuclides in the sediments surrounding the boreholes. Radionuclide concentration logs for individual boreholes were compiled and presented in four individual Tank Summary Data Reports (DOE 1997c, 1997d, 1997e, and 1997f). These log data were used to develop a three-dimensional model of the distribution of contamination in the vadose zone around the AX Tank Farm tanks that is presented in this report in the form of three-dimensional color visualizations of contaminant distribution.

The AX Tank Farm Preliminary Report (DOE 1997b) was completed in April 1997 for the Hanford Tanks Initiative (HTI) per their request. The preliminary report provided HTI with details regarding data acquisition and geologic model development, without the details regarding geologic, operational, and historical information that are provided in this report. The visualizations presented in the preliminary report are the same visualizations presented in this report.

2.0 Purpose and Scope

2.1 Purpose of the Project

The purpose of this baseline characterization is to quantify the gamma-emitting contamination distribution within the vadose zone sediments surrounding the SSTs. The gamma-ray signatures of the radionuclides that are present in the sediments can be detected through existing steel-cased boreholes that surround the tanks. An integral objective of this characterization project is to confirm the sources of contamination, when possible.

One objective of this characterization project is to compile acquired data into a baseline. Acquired borehole log data are baseline measurements of the contamination concentrations around the individual boreholes and constitute the initial baseline of the contamination distribution within the AX Tank Farm. This baseline consists not only of the individual borehole logs or the log database, but also of the contamination distribution model. These data can be used for future comparisons of radionuclide migration studies that may aid in identifying and/or quantifying new tank leaks.

Another objective of this project is to provide more site-specific geologic information by generating logs of the naturally occurring potassium-40 (^{40}K), uranium-238 (^{238}U), and thorium-232 (^{232}Th) (KUT) concentrations, which can be used to identify changes in the lithology that can influence contaminant migration. These KUT data are correlated with similar data from nearby groundwater monitoring wells, as well as with historical data recorded during monitoring borehole construction.

2.2 Scope of the Project

The primary scope of this project involves logging existing vadose zone monitoring boreholes with spectral gamma logging equipment. Since no new boreholes were drilled in the AX Tank Farm during the course of this project, the acquisition of data and evaluation of the vadose zone contamination are affected by the areal distribution and depths of the existing boreholes. These boreholes extend 100 to 125 ft down into the vadose zone, while the groundwater is approximately 280 ft below the ground surface.

A major portion of this project involves assessment of historical or existing data, such as the gross gamma logs, drilling logs, groundwater monitoring information, tank-leak documentation, and tank operations information. This information was reviewed and is presented in this report to promote understanding of the present conditions at the AX Tank Farm as determined from the spectral gamma log data.

This project is limited in scope to passive spectral gamma-ray logging data acquisition methods. As a result, radionuclides that do not decay with the emission of gamma-ray photons are not assayed, nor are other regulated chemical constituents that may have been present in the tank waste and leaked into the vadose zone.

The scope of this project includes preparation of reports that document the results of the logging investigations and identify the quality of the data in terms of precision and accuracy as well as quality assurance. Documentation regarding procedures, instrument calibration, quality assurance, and data analysis methods has been prepared (DOE 1994a, 1994b, 1995c, 1995d, 1995e, 1995f, 1995g, 1995h, 1995i, 1996c, 1996d, 1996e, 1996f, 1996g). All reports and the log data are available from Hanford databases. These data along with quantified uncertainties are available for decision makers to use in the future.

2.3 Regulatory Basis

The operation and eventual closure of the SST farms are regulated by both Federal and State laws. The mixed waste in the SSTs is regulated through the Resource Conservation and Recovery Act of 1976 (RCRA) and the Washington Hazardous Waste Management Act of 1976 (HWMA) for the hazardous waste component, and through the Atomic Energy Act of 1954 (AEA) as amended for the radioactive waste component (DOE 1996b). For purposes of this vadose zone characterization project, RCRA and the HWMA are the environmental laws of primary importance.

Under RCRA and the HWMA, the Washington State Department of Ecology (Ecology) regulates the SSTs as hazardous waste storage-tank systems under Washington Administrative Code (WAC) 173-303 (DOE 1996b). Because the SSTs are a treatment, storage, and/or disposal (TSD) unit, they are part of the larger Hanford Facility that consists of all TSD units at the Hanford Site.

TSD units of the Hanford Facility are regulated as either interim status or final status units. A final status permit, *Dangerous Waste Portion of the Resource Conservation and Recovery Act Permit for the Treatment, Storage, and Disposal of Dangerous Waste* (Ecology 1994), was issued for the Hanford Facility in 1994. Under a negotiated permitting approach, additional TSD units will be added to this permit as the units are evaluated through the RCRA permitting process. Eventually all TSD units of the Hanford Facility, which will continue dangerous waste management, will be converted from interim status to final status and included in the permit (Ecology 1994). TSD units that will not be used for continued dangerous waste management, such as the SSTs, will be closed under interim status rather than converted to final status.

According to the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1996), also known as the Tri-Party Agreement or TPA, closure of the SSTs will be pursuant to WAC 173-303-610. DOE is required to remove or decontaminate all waste residues, contaminated containment system components, contaminated soils, and contaminated equipment at the time of closure; closure of the SSTs as landfills is allowed if all the contaminated soil cannot be practicably decontaminated or removed (DOE 1996b). In either case, characterization of the nature and extent of the leaked waste is needed to evaluate remedial action alternatives for closure of the soils contaminated by waste leaked from the SSTs. Without appropriate data on the nature and extent of contamination, it will not be possible to develop or assess the risk associated with various closure options for the SSTs.

In addition to providing necessary information to support closure of the SSTs, the vadose zone characterization will provide a baseline of gamma-ray activity in boreholes of the SSTs. Newly acquired spectral gamma-ray data can be compared to this baseline to help identify any new or continuing leaks. Monitoring of the SSTs is required under a number of regulations and interim status requirements of RCRA. The existence of a defensible baseline will reinforce the effectiveness of future monitoring activities.

2.4 Purpose of the Report

This report documents the results of the spectral gamma logging characterization at the AX Tank Farm. The data were originally reported in individual Tank Summary Data Reports. Visualizations of the cesium-137 (^{137}Cs) contamination distributions (based on the empirical model) that correlate the individual borehole logs in three dimensions are also presented. The visualizations are useful for identifying contamination plumes, developing relationships between the plumes, and determining the sources of the contamination. Section 9.0, "Development of the Visualizations," documents the model development, identifies assumptions and model parameters, and explains the uncertainties associated with the model.

A significant portion of this report presents background information regarding the logging equipment and spectral gamma log data, geologic information, and historical information regarding tank farm operations. Sections 4.0, "Geology and Hydrology," and 5.0, "Review of Tank Farm History," present brief descriptions of the geology and hydrology in the vicinity of the AX Tank Farm, tank construction, waste constituents, and operational histories for each tank in the AX Tank Farm. Section 6.0, "Adjacent Waste Site Information," includes descriptions of waste sites adjacent to the AX Tank Farm area. Sections 7.0, "Spectral Gamma-Ray Logging Measurements," and 8.0, "Log Data Results," describe the logging equipment, data acquisition and processing, and preparation of the log data presentations. Discussions regarding the development of the contamination plume modeling and visualizations are presented in Section 9.0, "Development of the Visualizations." The visualizations of the contamination plumes in the AX Tank Farm are discussed on a tank-by-tank basis in Section 10.0, "Discussion of Results." Section 15.0, "Figures for the AX Tank Farm," contains figures in the order they are presented in the report text.

3.0 Radionuclides of Interest

Radionuclide contamination distributions and their impacts or implications relative to contamination sources are the primary focus of this project. Although an assay of all radionuclides in the vadose zone is desirable, the technology used in this project (passive gamma logging) allows only an assay of gamma-emitting radionuclides.

The radionuclide contamination in the vadose zone can be considered to present both a short-term occupational exposure risk to operations workers and a long-term risk to the public and the environment. The types of possible risks depend on a variety of factors that are specific to each radionuclide, including the decay half-life of the nuclide, its mobility in the vadose zone (and ultimately in the groundwater), and its specific activity and/or biological toxicity.

Long-term human health risks arise primarily from a potential pathway whereby an individual is exposed by ingesting contaminated groundwater and from a pathway involving direct exposure of an individual to contaminated sediment that is uncovered or otherwise brought to the surface in the distant future, after the end of an institutional control period. Long-term risk scenarios are

usually evaluated by using vadose zone contaminant-transport modeling to produce performance assessments that estimate potential doses for different pathways. Radionuclides of concern would be those with long half-lives and those that are mobile in the vadose zone and could contribute to groundwater contamination.

Short-term risk scenarios involve inhalation of radionuclides or direct exposure to workers during remediation or other operations that would uncover or bring the vadose zone contamination to the surface in the near future. The radionuclides of concern are those that are easily suspended in air and the high specific-activity radionuclides that present an exposure problem. Boothe (1996) presents a review of the radionuclide inventory of the tank wastes and the risk levels associated with each radionuclide.

The information in the following sections was obtained from a variety of sources, including National Low-Level Waste Management Program documents (Rudin and Garcia 1992a, 1992b; Rudin et al. 1992), nuclear physics references including Lederer and Shirley (1978), GE (1989), Erdtmann and Soyka (1979), and Hanford Site contractor documents including Dresel et al. (1995) and Johnson (1993).

3.1 Cesium-137 (^{137}Cs)

^{137}Cs is one of the highest specific-activity radionuclides in the tank wastes and is present at high concentrations. This radionuclide is a man-made isotope that originated as a high-yield fission product and accounted for a high percentage of the total radioactivity in irradiated fuel assemblies. ^{137}Cs was a major component of the process waste stream generated by the plutonium and uranium separations processes.

^{137}Cs has a half-life of 30.2 years and is the longest-lived high-yield fission product. It decays with the emission of beta particles (511 and 1176 kilo-electron-volts [keV]) to produce barium-137 (^{137m}Ba), which in turn produces a 661.6-keV gamma-ray photon with an intensity of 84.62 gamma photons per 100 decays of ^{137}Cs (Erdtmann and Soyka 1979). As a result of the gamma photon emission, ^{137}Cs is easily detected and quantified with HPGe spectral gamma-ray detection equipment. The minimum detectable level (MDL) of ^{137}Cs for the SGLS when logging with 100-second (s) counting times is about 0.1 picocurie per gram (pCi/g).

Because of its relatively long half-life and high concentration in the tank waste, ^{137}Cs is the most abundant radionuclide in the vadose zone around the SSTs. ^{137}Cs is reported to have a high sorptive capacity in sediment. However, in the presence of competing positive ions such as the dissolved radioactive salts present in the SSTs, the sorption of ^{137}Cs decreases (Carboneau et al. 1994b). At low concentrations, ^{137}Cs is more strongly adsorbed to the sediment, particularly if pH values are greater than 4.0, as is typical of the Hanford sediment.

^{137}Cs is absorbed by humans and animals through the digestive tract and behaves chemically in the body similar to potassium (Carboneau et al. 1994b). The EPA-mandated maximum contaminant level (MCL) for ^{137}Cs in drinking water is 200 picocuries per liter (pCi/L).

3.2 Cobalt-60 (^{60}Co)

^{60}Co is generated in nuclear reactors by neutron activation of stable ^{59}Co. ^{60}Co occurs in relatively high concentrations in the cladding of irradiated reactor fuel elements and was present in the waste stream products sent to the SSTs from the plutonium and uranium separation processes. ^{60}Co was originally present in the tanks at significant activities, but much of the ^{60}Co has since decayed away because it has a short half-life of 5.27 years.

^{60}Co decays via beta emission to create stable nickel-60 (^{60}Ni). About 95 percent of the beta particles emitted during the decay of ^{60}Co have energies equal to or below 314 keV, but beta particle energies as high as 1,480 keV can be generated. During the decay to stable ^{60}Ni, ^{60}Co also emits two high-energy gamma rays: one at 1173 keV and the other at 1333 keV. The production of these gamma rays occurs in 99.8 and 99.9 percent of decays, respectively (Erdtmann and Soyka 1977). These gamma rays make the presence of ^{60}Co easy to detect and quantify with passive gamma measurement equipment. The MDA of ^{60}Co is about 0.15 pCi/g with the present logging acquisition rates utilized for this vadose zone characterization project.

The human exposure risk for ^{60}Co is relatively high because it emits relatively high-energy beta particles and gamma rays during decay and because it has a high specific activity (1.1×10^3 curies per gram [Ci/g]).

Adams (1995) provides a good review of studies on the mobility of ^{60}Co in soils and sediment, including laboratory experiments and actual site investigations. The ability of soil and sediment to retain ^{60}Co is quantified by the solid/liquid partition or the solid versus aqueous ratio (in micrograms of cobalt per gram of sediment) and is designated as K_d. The K_d value for ^{60}Co is reported to vary more than 4 orders of magnitude and is strongly dependent on the type of sediment in which it was measured or calculated (Adams 1995).

Measurements of vadose zone contamination distribution at Hanford (Brodeur et al. 1993) suggest ^{60}Co is more mobile in the vadose zone than europium or antimony, and it is much more mobile than ^{137}Cs. However, this mobility may be a result of the chemical properties of the effluent in which the ^{60}Co was released at the Hanford crib sites. The mobility of ^{60}Co discharged to the Hanford cribs may differ from the mobility of ^{60}Co resulting from waste tank leakage because of differences in the chemical properties of the wastes discharged to each of these facilities.

When ^{60}Co comes in contact with groundwater, most of it will become fixed in the soil and it does not migrate appreciably from the original source site. ^{60}Co is generally immobile and does not present a long-term health-and-safety risk from a groundwater pathway because of its short half-life. The EPA-mandated MCL for ^{60}Co in drinking water is 100 pCi/L.

^{60}Co is considered an exposure risk to workers because of the intense gamma rays emitted during decay but does not need to be considered in long-term performance assessments because of its short half-life. Nevertheless, this contaminant is monitored in the vadose zone because it can be mobile and because it is easily detected and assayed. Monitoring contamination plumes for

changes in ^{60}Co concentrations may indicate changing conditions of a plume that are due to remobilization from precipitation infiltration, new tank releases, or changes merely reflecting the decay rate of ^{60}Co.

3.3 Europium-154 (^{154}Eu)

Europium radionuclides in the tank wastes include the isotopes ^{152}Eu and ^{154}Eu. Of these isotopes, only ^{154}Eu was detected in the AX Tank Farm, where it was detected near the ground surface in a few thin zones of contamination. ^{154}Eu originates from the activation of europium-153 (^{153}Eu), which is a fission product. ^{154}Eu is not as abundant in the irradiated fuel or the processing waste streams as ^{137}Cs, but it is present in irradiated fuel at high enough concentrations that it contributes a significant amount to the total radiation flux from the fuel.

^{154}Eu decays by emission of a beta particle to stable gadolinium-154 (^{154}Gd) and has a half-life of only 8.59 years. The most intense gamma rays emitted during decay include 123 keV (40.5 percent), 723 keV (19.7 percent), 1004 keV (17.6 percent), and 1274 (35.5 percent) (Erdtmann and Soyka 1979).

Few references were found describing the mobility of europium in the vadose zone sediment. Monitoring results at approximately 50 crib sites at Hanford showed that europium is more mobile than ^{137}Cs but not as mobile as ^{60}Co (Brodeur et al. 1993). However, this conclusion is based strictly on a comparison of the contaminant distribution patterns at the crib sites, which may differ considerably from the distribution patterns at the SSTs in terms of types and concentrations of waste and how the effluent was released to the vadose zone.

^{154}Eu has not been detected in the unconfined aquifer beneath the 200 Areas (Dresel et al. 1995; Johnson 1995), indicating that it is retained in the vadose zone sediment at the Hanford Site.

^{154}Eu presents short-term exposure risks because of the gamma radiation, but it is not considered a long-term risk because of its relatively short half-life. The EPA-mandated MCL for ^{154}Eu in drinking water is 200 pCi/L.

3.4 Strontium-90 (^{90}Sr)

^{90}Sr is similar to ^{137}Cs because it is also a high-yield fission product with a half-life of 29 years. Unlike ^{137}Cs, ^{90}Sr decays with the emission of a beta particle but no gamma-ray photons. ^{90}Sr decays to yttrium-90 (^{90}Y), which has a short half-life (64 hours), and to stable zirconium-90 (^{90}Zr). The beta particle emitted in the decay of ^{90}Y has a high maximum energy (2.2 million-electron-volts [MeV]) and is usually associated with the parent radionuclide ^{90}Sr.

Some beta particles from ^{90}Sr are so energetic that when present in the subsurface at high concentrations (greater than about 2,000 pCi/g), bremsstrahlung or braking radiation may be measured in a borehole with the gamma-ray detectors. Bremsstrahlung is characterized in a gamma-ray spectrum by a low-energy continuum that decreases in intensity with increasing energy, in a log-linear manner, and covers an energy range from the x-ray region to about

300 keV. If ^{90}Sr is present at about 2,000 pCi/g or greater, it can be positively identified but not readily quantified with the spectral gamma-ray detection equipment.

The quantity of ^{90}Sr generated in a reactor increases linearly with the fuel fission rate, and essentially all the ^{90}Sr produced still remains in the fuel when it is extracted from the reactor and processed. At the time of processing, ^{90}Sr represents only about 0.05 percent of the total fission product activity but accounts for 20 percent of the total remaining radioactivity after 100 years.

Strontium is a divalent (Sr^{2+}) element that mimics the chemistry of calcium. It forms an ionic bond with negatively charged elements and is easily dissolved in water. When released into the sediment, dissolved in liquid effluent, it will readily adsorb onto sediment grains or clay particles and can replace Ca^{2+} in $CaCO_3$.

^{90}Sr is dissolved easily during the fuel dissolution process, the first stage of fuel rod processing, and it stays in solution throughout the separation process. Consequently, ^{90}Sr is always a component in the effluent waste products of the separation processes, and ^{90}Sr is the second most abundant radionuclide in the tank waste material (^{137}Cs is the most abundant).

^{90}Sr has a large K_d value for clay or organic soil, but the K_d value is much less than for ^{137}Cs (Carboneau et al. 1994a). The ^{90}Sr K_d value for sand or loam sediment typical of the Hanford formation is about 1 order of magnitude lower than the K_d value for clay soil. ^{90}Sr is also sensitive to the presence of calcium, and it apparently can replace calcium in carbonate sediment. This chemical relationship has particular significance where calcium carbonate rich zones are present in the Hanford formation and Ringold Formation sediments, as these zones may effectively inhibit the vertical migration of ^{90}Sr. ^{90}Sr retention in soil increases with an increasing pH value.

^{90}Sr is a significant health risk because it replaces calcium and is deposited in bone material, where it becomes fixed. Once deposited in the body, damage is caused by the high-energy beta radiation emitted during decay.

In groundwater, ^{90}Sr tends to stay in soluble form and migrates farther than other fission products such as ^{137}Cs. ^{90}Sr is often a risk-limiting radioisotope because of the relatively high mobility of ^{90}Sr in both the vadose zone sediment and the groundwater and because of its high health risk relative to other nuclides. The EPA-mandated MCL for ^{90}Sr in drinking water is 8 pCi/L.

3.5 Antimony-125 (^{125}Sb)

^{125}Sb is a fission product originating from slow neutron fission of uranium-235 (^{235}U) or plutonium-239 (^{239}Pu). Because its yield is low, ^{125}Sb does not account for a large percentage of the total fission product. The half-life of ^{125}Sb is 2.8 years.

^{125}Sb decays with the emission of a beta particle to tellurium-125 (^{125}Te), which is stable. Gamma rays emitted during the decay of ^{125}Sb include 428 keV (29.6 percent), 600 keV (18 percent), and 636 keV (11 percent) (Erdtmann and Soyka 1979).

^{125}Sb is an important radionuclide for vadose zone characterization and monitoring work because it can be abundant, it is easily measured, and it is more mobile than some of the other gamma-emitting radionuclides. It poses minimal risk because of its generally low abundance, but it is easily monitored and tracked for contaminant migration studies because it is a gamma-emitter.

No information was available on the mobility of ^{125}Sb either in vadose zone sediment or in groundwater. Brodeur et al. (1993) observed that ^{125}Sb was more mobile than ^{137}Cs, and it was detected deeper in the vadose zone than ^{137}Cs. ^{125}Sb was detected in the AX Tank Farm near the ground surface in boreholes 11-02-12 and 11-03-02.

^{125}Sb presents a short-term exposure risk because it can be inhaled. The EPA-mandated MCL for ^{125}Sb in drinking water is 300 pCi/L.

3.6 Technetium-99 (^{99}Tc)

^{99}Tc is an abundant fission product that is long-lived and is generally mobile in the environment. It is an important radionuclide in long-term risk assessments and can result in high calculated risk values.

^{99}Tc has a fission yield from fissionable isotopes of uranium and plutonium of about 6 percent (out of 200 percent), which is equivalent to that of ^{137}Cs. As a result, it is as abundant in terms of mass content as ^{137}Cs in effluent streams and SST wastes at Hanford. However, ^{99}Tc is present in the tank waste at a lower curie content (by many orders of magnitude) because ^{137}Cs has a much higher specific activity.

^{99}Tc has a half-life of 2.1×10^5 years, which is one of the reasons for its high risk rating in long-term performance assessments. It decays by 293-keV beta emission to stable ruthenium-99 (^{99}Ru) without the emission of gamma rays that are detectable with the logging system; therefore, it cannot be detected or assayed through the boreholes.

The mobility of ^{99}Tc in soil is highly dependent on its chemical form, which is governed by the oxidation-reduction potential of the soil. According to Rudin et al. (1992), if sufficient reducing conditions exist in the sediment, technetium will precipitate out of solution as a sulfide or hydrated oxide. If oxidizing conditions exist, technetium will be present as a pertechnetate ion, which studies have shown will migrate at a rate of 88 percent of the groundwater velocity or greater.

The EPA-mandated MCL for ^{99}Tc in drinking water is 900 pCi/L. ^{99}Tc is highly mobile in the groundwater at Hanford and has been detected in groundwater samples obtained in monitoring wells near the AX Tank Farm (refer to Section 4.5 of this report).

3.7 Uranium

Uranium isotopes are long-lived and can be mobile in both the groundwater and vadose zone. Boothe (1996) lists uranium isotopes as a groundwater hazard that should be included in a performance assessment.

Uranium isotopes in tank wastes primarily include ^{238}U and ^{235}U, with minute quantities of ^{232}U, ^{233}U, ^{234}U, and ^{236}U. Uranium isotopes in the irradiated fuel elements are separated from the fission and activation products in chemical processes. Consequently, waste effluent sent to the SSTs usually does not contain much uranium.

^{238}U, by far the most abundant uranium isotope in the waste, occurs naturally in the Earth's crust and is assayed for stratigraphic correlation purposes. It decays through a long and complex decay chain that results in the emission of alpha and beta particles as well as gamma rays. ^{238}U has a long half-life (4.7×10^9 years) and is easily assayed by gamma spectroscopy methods when in secular equilibrium with its short-lived, gamma-emitting daughter products bismuth-214 (^{214}Bi) and lead-214 (^{214}Pb).

When ^{238}U is not in secular equilibrium[1] with its post-radium daughter products, such as when uranium is chemically separated from them, it can be assayed with gamma spectroscopy methods with the 1001-keV gamma ray from the second daughter product metastable protactinium (^{234m}Pa). This gamma ray is not as intense as the gamma rays from ^{214}Bi and ^{214}Pb, but, when necessary, the logging data acquisition parameters can be enhanced to obtain adequate assay statistics.

^{235}U, the second most abundant uranium isotope, is the fissile isotope present in enriched reactor fuel. It is also long-lived, with a half-life of 7.0×10^8 years. The presence of ^{235}U can be detected with an intense low-energy gamma ray of 185.7 keV at 54 photons per 100 decays (Erdtmann and Soyka 1979). Although photons at this energy are indistinguishable from those emitted at the same energy from other nuclides, the existence of ^{235}U can be confirmed with other gamma rays if necessary.

The chemistry and geochemistry of uranium have been widely studied, and the behavior of uranium in the vadose zone and in groundwater is well known. Uranium can exist in several oxidation states, and the uranium-oxygen system is one of the most complex oxide systems. Uranium is one of the more mobile radionuclides at Hanford, and a large quantity of water will flush it through the vadose zone sediments. An extensive uranium/technetium-contaminated groundwater plume associated with uranium recovery operations at U Plant in the Hanford Site 200 West Area is undergoing remediation through a pump and treat system. This system removes the contaminants with an ion-exchange column.

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[1]A condition of equlibrium in which the rate of decay of the parent radionuclide is exactly matched by the rate of decay of each intermediate daughter radionuclide.

In terms of a long-term performance assessment, uranium is often one of the higher risk radionuclides for groundwater contamination. The proposed EPA-mandated MCL for uranium in drinking water is 20 micrograms per liter (μg/L).

3.8 Plutonium, Americium-241 (^{241}Am), Iodine, Neptunium-237 (^{237}Np), and Ruthenium-106 (^{106}Ru)

Other nuclides and elements of interest and/or concern with this project include plutonium, ^{241}Am, iodine, ^{237}Np, and ^{106}Ru. None of these nuclides or elements were detected in the vadose zone at the AX Tank Farm; however, a short summary of each is provided.

Plutonium isotopes are an inhalation exposure risk. These isotopes are reported to be strongly adsorbed onto the sediment, but in some cases, organic compounds may enhance their mobility (Carboneau and Garcia 1994). Several plutonium isotopes are present in small quantities in the tank waste, and most can be detected and assayed to some degree with gamma spectroscopy measurements if these isotopes are present at high enough concentrations.

^{241}Am has a long half-life (433 years) and can be mobile under low pH conditions. It has an intense gamma ray with an energy of 59.5 keV, which is too low in energy to be detected and assayed with the SGLS. ^{241}Am decays by alpha particle emission to ^{237}Np, which is more mobile than americium. Both of these nuclides may pose a high long-term risk mainly because of the mobility of neptunium (Winberg and Garcia 1995).

^{237}Np is produced from the decay of ^{241}Am, and ^{237}Np is produced in a reactor by fast neutron interactions with ^{238}U and subsequent decay to ^{237}Np. ^{237}Np emits a gamma ray with an energy of 311 keV and can be detected with the SGLSs to a lower level of about 2.0 pCi/g. The presence of ^{237}Np would be an indication that ^{241}Am might also be present.

Most of the iodine isotopes generated in nuclear reactors are short lived and may be a short-term exposure problem. However, iodine-129 (^{129}I) is a long-lived isotope with a half-life of 1.6×10^7 years that is mobile in the vadose zone and groundwater, and it can be a significant long-term risk. ^{129}I cannot be detected with gamma spectroscopy equipment. This isotope does emit an x ray during decay that can be detected with another type of photon detector. The EPA-mandated MCL for ^{129}I in drinking water is 1 pCi/L.

^{106}Ru is a fission product that was abundant in the nuclear waste. ^{106}Ru decays to rhodium-106 (^{106}Rh), which in turn immediately decays to palladium-106 (^{106}Pd) and emits intense gamma rays at 512 keV and 622 keV. When the waste was first placed in the tanks, ^{106}Ru was a major contributor to the total gamma flux of the waste. However, because ^{106}Ru has a half-life of only 368 days, it has now decayed to low levels and is probably not detectable. ^{106}Ru was thought to have been a primary target nuclide for vadose zone leak-detection schemes, but spectral gamma data show that in many cases, ^{137}Cs, ^{60}Co, or ^{238}U, and not ^{106}Ru were detected with the gross gamma logging systems. The EPA-mandated MCL for ^{106}Ru in drinking water is 30 pCi/L.

4.0 Geology and Hydrology

The geology of the Hanford Site has been described in detail in numerous documents. The following sections are summaries of information presented in Price and Fecht (1976), Caggiano and Goodwin (1991), Delaney et al. (1991), Lindsey et al. (1992), and Lindsey et al. (1994).

4.1 Regional Geology

The Hanford Site is located in the Pasco Basin, which is a physical and structural depression in the Columbia Plateau created by tectonic activity and folding of the Columbia River basalts. The Pasco Basin is bounded on the north by the Saddle Mountains; on the west by the Umtanum Ridge, the Yakima Ridge, and the Rattlesnake Hills; and on the south by Rattlesnake Mountain and the Rattlesnake Hills. All these uplifts are major structural anticlines within the basalt basement rock. The eastern boundary of the Pasco Basin is a structural monocline with the bedrock dipping to the west and covered with the sediment that constitutes the Palouse Slope. The Hanford Site is underlain by Miocene Age basalt of the Columbia River Basalt Group and Miocene to Pleistocene suprabasalt sediments. Figure 15-2 shows the position of the Hanford Site 200 East and West Areas within the Pasco Basin.

4.1.1 Stratigraphy of the Pasco Basin

The stratigraphic columns of the Hanford Site 200 East and West Areas are shown on Figures 15-3 and 15-4. Figure 15-4 provides detail showing the differentiation of the stratigraphic units within the Ringold Formation.

4.1.1.1 Basement Rocks

The basement rocks at the Hanford Site consists of a series of basalt flows that are a part of the Columbia River Basalt Group. These flows are continental flood basalts of Miocene Age that extend from north-central Washington, south into Oregon, and east into Idaho, covering an area of more than 63,000 square miles. Approximately 50 basalt flows are present beneath the Hanford Site with a combined thickness of more than 3,000 meters (m) (DOE 1988). Interbedded with and overlying many of the basalt flow are sedimentary units that constitute the Ellensburg Formation. Sediments of the Ellensburg Formation consist of fluvial and lacustrine muds, sands, and gravels that were deposited between volcanic eruptions.

4.1.1.2 Suprabasalt Sediments

The suprabasalt sediments are dominated by laterally extensive deposits of the late Miocene to middle Pliocene Age Ringold Formation and the Pleistocene Age Hanford formation. Locally occurring strata of the Plio-Pleistocene unit separate the Ringold Formation and the Hanford formation.

4.1.1.3 Ringold Formation

The Ringold Formation is the most extensive suprabasalt sedimentary unit at the Hanford Site. This formation is as much as 600 ft thick south of the 200 West Area. It is absent in the north and northeastern portions of the 200 East Area and adjacent areas to the north, and it pinches out against structural highs in the uppermost basalt flows.

Studies of the Ringold Formation (Lindsey and Gaylord 1989; Lindsey 1991) indicate that this formation is best described and divided on the basis of sediment facies associations and their distribution. Facies associations in the Ringold Formation (defined by lithology, petrology, stratification, and pedogenic alteration) include fluvial gravel, fluvial sand, overbank deposits, lacustrine deposits, and alluvial fan. The facies associations are as follows:

Fluvial gravel. Clast-to-matrix-supported granule-to-cobble gravel with a sandy matrix dominates the fluvial gravel facies association. Lithologic features observed in outcrop include low angle to planar stratification, massive bedding, wide shallow channels, and large-scale cross-bedding. Sediments of this association were deposited in a gravelly fluvial braid plain characterized by wide, shallow, shifting channels.

Fluvial sand. Quartzo-feldspathic sand that displays cross-bedding and cross-lamination in outcrops dominates this association. Intercalated strata consist of lenticular silty sands and clays as much as 3 m thick and thin (less than 0.5 m) gravels. Fining upwards sequences less than 1 m to several meters are common. Sediments of this association were deposited in wide, shallow channels.

Overbank deposits. This association consists predominantly of laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic calcium carbonate. Sediments of this association were deposited in proximal levee to more distal floodplain conditions.

Lacustrine deposits. Sediments consisting of well-stratified silt and silty sand that display some soft-sediment deformation characterize this association. These sediments were deposited in lakes under standing water to deltaic conditions.

Alluvial fan. Massive to crudely stratified, weathered to unweathered, basaltic detritus dominates this association. These deposits are generally present around the periphery of the Pasco Basin, and record debris flow in an alluvial fan environment and sidestream drainage into the basin.

The upper portion of the Ringold Formation, as desribed by Lindsey (1991, 1995), is composed of interbedded fluvial sand and overbank facies that are overlain by mud-dominated lacustrine facies. The lower half of the Ringold Formation contains five separate stratigraphic intervals dominated by fluvial gravels. These gravels, which are designated units A, B, C, D, and E, are

separated by basin-wide intervals containing deposits typical of the overbank and lacustrine facies associations (Lindsey 1991).

Lindsey performed a detailed investigation into the stratigraphy of the Ringold Formation and published his findings in Lindsey (1995). During the preparation of that report, surface outcrops of Ringold Formation sediments were investigated and mapped, lithologic logs of cores acquired in several Hanford Site boreholes were analyzed, and geologic logs (based on drill cuttings) and cutting samples for several hundred boreholes within and surrounding the Hanford Site were reviewed. On the basis of these data, Lindsey divided the Ringold Formation stratigraphy into five facies based on sediment facies: fluvial gravel, fluvial sand, overbank-paleosol, lacustrine, and basaltic alluvium. These facies are divided into three informal members: Wooded Island (lowermost), Taylor Flats, and Savage Island. The lower Ringold Formation Wooded Island member is divided into the five stratigraphic units designated A, B, C, D, and E.

4.1.1.4 Post-Ringold and Pre-Hanford Sediments

In the vicinity of the 200 West Area, the laterally discontinuous Plio-Pleistocene unit unconformably overlies the Ringold Formation. This unit is as much as 82 ft thick and is divided into two facies: basaltic detritus and pedogenic calcrete. Depending on the location, one or both of these facies may be present. The detritus facies consists of weathered and unweathered basaltic gravels deposited as slopewash, colluvium, and sidestream alluvium. The calcrete facies generally consists of interfingering carbonate-cemented silt, sand, and gravel and carbonate-poor silt and sand. The Plio-Pleistocene unit is not present in the 200 East Area of the Hanford Site.

4.1.1.5 Hanford Formation

The Hanford formation consists of pebble-to-boulder gravel, fine- to coarse-grained sand, and silt. The gravel deposits range from well sorted to poorly sorted. These deposits are divided into three facies: gravel-dominated, sand-dominated, and silt-dominated. These facies are referred to as the coarse-grained deposits, the plane-laminated sand facies, and the rhythmite facies, respectively (Baker et al. 1991). The Hanford formation is thickest in the 200 East and 200 West Areas, where it is as much as 350 ft thick, and it is absent on ridges more than 1,160 ft above sea level. These sediments were deposited during several episodes of cataclysmic flooding that resulted from drainage of glacial lake Missoula in the Pleistocene Age (Baker et al. 1991).

The gravel-dominated facies generally consists of coarse-grained basaltic sand and granule-to-boulder gravel. In outcrop, these sediments display massive bedding, planar to low-angle bedding, and large-scale planar cross-bedding. Gravels dominate the Hanford formation in the 100 Areas north of Gable Mountain, the northern portion of the 200 East Area, and the eastern portion of the Hanford Site. The gravel-dominated facies was deposited by high-energy flood waters in or immediately adjacent to the main flood channel.

The sand-dominated facies consists of fine- to coarse-grained sand and granule gravel. In outcrop, these sediments display plane lamination and bedding, and, less commonly, plane bedding and channel-fill sequences. These sands may contain small pebbles or pebble-gravel

interbeds less than 8 inches (in.) thick. The silt content of the sands is variable, but where it is low, open framework texture occurs. The sands are typically basaltic, displaying a salt-and-pepper appearance. The sand-dominated facies is transitional between the gravel-dominated facies to the north and the rhythmite facies to the south, and it is present in the 200 Areas. The laminated-sand facies was deposited adjacent to the main flood channelway as it spilled out of the main channel, or it may have been deposited during the diminishing stages of flooding.

The rhythmite facies sediments were deposited under slack water conditions and in back-flooded areas remote from the main flood channelway. These sediments consist of thinly bedded, plane-laminated and ripple cross-laminated silt and fine- to coarse-grained sand and commonly display normally graded rhythmites a few centimeters to several tens of centimeters thick (Baker et al. 1991; DOE 1988). This facies dominates the Hanford formation occurrence along the western, southern, and northern margins of the Pasco Basin, within and south of the 200 Areas.

Clastic dikes are present in the Hanford formation as well as in other sedimentary units in the Pasco Basin (Black 1980). Locally, these dikes normally cross-cut bedding, although they do parallel bedding. They usually consist of thin alternating vertical to subvertical layers of silt, sand, and granules. Clastic dikes are more common in the finer-grained facies and rare in the open-framework gravels (Connelly et al. 1992). Where the dikes intersect the ground surface, distinct patterned ground is observed.

4.1.1.6 Holocene Surficial Sediments

Holocene surficial deposits consist of silt, sand, and gravel that form a thin layer across much of the Hanford Site. These sediments were deposited by a combination of aeolian and alluvial processes. These sediments are absent in the area of the AX Tank Farm; the tank farm surface now consists of a gravel cover that was placed to prevent establishment of vegetation for both operation purposes and radiological controls.

4.1.2 Geologic Structure of the Pasco Basin

The Columbia Plateau is a part of the North American continental plate and lies in a back-area setting east of the Cascade Range. It is bordered on the east by the Rocky Mountains and Idaho Batholith, on the north by the Okanogan Highlands, and on the south by the High Lava and Snake River Plains. The Columbia Plateau is divided into three informal structural subprovinces: the Blue Mountains, the Palouse Slope, and the Yakima Fold Belt (Tolan and Reidel 1989). The Hanford Site lies within the Pasco Basin, one of the largest structural basins in the Columbia Plateau, near the junction of the Yakima Fold Belt and the Palouse subprovinces. Figure 15-2 shows the Hanford Site 200 East and West Areas relative to the major structural features in a portion of the Pasco Basin.

A distinctive feature of the Yakima Fold Belt is a series of segmented, narrow, asymmetrical anticlines that are generally east-west trending. The northern limbs generally dip steeply to the north and are vertical or overturned. The southern limbs generally dip to the south at shallow angles. The anticlines have wavelengths between 3 and 19 miles (mi) and amplitudes less than

0.6 mi (Reidel et al. 1989). The anticlinal ridges are separated by broad synclines or basins that may contain thick accumulations of sediments. The Umtanum-Gable Mountain anticline divides the Pasco Basin into the Wahluke and Cold Creek synclines. The Cold Creek syncline is asymmetrical and is a relatively flat-bottomed structure. The Hanford Site 200 Areas are located on the northern limb of the Cold Creek syncline, where the bedrock dips to the south at an angle of approximately 5°. Anticlines to the north and south create topographic high areas with outcropping basalt flows of Gable Mountain and Rattlesnake Mountain, respectively (Reidel et al. 1989).

4.2 Geology of the 200 East Area

4.2.1 General Geologic Background

The 200 East Area is situated on a gently sloping low-relief surface that resulted from two geomorphological processes: Pleistocene cataclysmic flooding and Holocene eolian activity. Flooding resulted when glacially created dams failed and drainage from the dammed lakes flowed across the Columbia Plateau. These floods led to deposition of sand and gravel in the waters that were hydraulically impounded (with the formation of Lake Lewis) behind Wallula Gap. Deposition of sand and gravel created Cold Creek bar, a prominent feature on which the 200 East Area is located (Figure 15-5). The northern boundary of the Cold Creek bar is an east-southeast trending erosional channel that formed during waning stages of flooding as floodwaters drained from the basin (Bjornstad et al. 1987).

Since the Pleistocene, winds have locally reworked the surface of the glacio-fluvial sediments, depositing a thin veneer of eolian sand in places.

The general stratigraphy of the 200 East Area consists of basalt flows and sedimentary interbeds that constitute the Columbia River Basalt Group and Ellensburg Formations, respectively. Above the Columbia Basin basalts lie sediments that consist of fluvial-to-lacustrine deposits of the Ringold Formation. The Ringold Formation is subdivided into four stratigraphic units; however, not all the units are present in the 200 East Area. Erosion by the ancestral Columbia River and later cataclysmic flooding has removed some or all of the Ringold sediments in some areas of the Hanford Site (DOE 1988; Tallman et al. 1979). The thickness of the Ringold sediments decreases with proximity to the main flood channel, and limited occurrences of Ringold sediments are present in the northeastern portion of the 200 East Area (Last et al. 1989; Tallman et al. 1979).

The cataclysmic flooding that eroded the Ringold Formation sediments also deposited unconsolidated sand, gravels, and silt that are informally identified as the Hanford formation. In the northern portion of the 200 East Area, the sediments of the Hanford formation consist of gravel (Pasco Gravel facies) that grades to sand southward. These sediments were deposited close to the flood channels and decrease in grain size with increasing distance from the channel. To the south and west, slack water sediments of sand and silt lie between flood deposits of sand and gravel (Last et al. 1989). The maximum thickness of the Hanford formation is 350 ft east of the 200 East Area (Tallman et al. 1979).

Lindsey et al. (1992) investigated the distribution of the Hanford formation facies and informally divided the Hanford formation into three stratigraphic sequences designated as the lower gravel, sand, and upper gravel sequences. Because of the high variability of the Hanford formation sediments, the contacts between these sequences can be difficult to establish.

The contact between the Ringold Formation and Hanford formation is commonly a transition upward from more indurated deposits containing a variety of lithologies (Ringold Formation) to uncemented or unconsolidated sediments with a higher proportion of basaltic clasts (Hanford formation) (Lindsey et al. 1992). Establishing the contact between the Ringold Formation and Hanford formation in this area can be difficult; not only are textural features similar, but reworked Ringold material may be incorporated into the Hanford formation sediments.

The Plio-Pleistocene unit is not present in or near the 200 East Area.

4.2.2 Geologic Background of the AX Tank Farm

A description of the geology beneath the AX Tank Farm was completed after the drilling of 23 tank monitoring boreholes and four groundwater monitoring wells in the AX Tank Farm. The geology, which was described from sediment samples collected at 1- to 5-ft depth intervals during drilling, is presented in Price and Fecht (1976). A cross section based on these data is shown in Figure 15-6.

Caggiano and Goodwin (1991) present a detailed description of the geology of the AX Tank Farm. For this report, historical data were reviewed along with lithological data that were acquired during the completion of RCRA standard groundwater monitoring wells around the AX Tank Farm. These data are included in Appendix A of this report. The lithologic data acquired during the completion of these wells were more detailed than any previously collected data because the importance of detailed data was realized and experienced geologists were at the drilling sites to collect and document drilling information.

4.2.3 AX Tank Farm Geology Description

The AX Tank Farm is underlain by three major stratigraphic units: unconsolidated sand, gravel, and silt of the Hanford formation (collectively termed glaciofluvial sediments); semiconsolidated sediments of the Ringold Formation; and the basalt of the Columbia River Group that forms the bedrock beneath the AX Tank Farm.

The sediments of the Hanford formation were deposited during several episodes of cataclysmic flooding that resulted from drainage of glacial Lake Missoula in the Pleistocene Age (Baker et al. 1991). These sediments consist of coarse to very coarse gravel, fine- to coarse-grained sand, and silt. These sediments have been defined as the gravel dominant, sand dominant, and silt dominant facies (ordered from top to bottom of the formation) (Lindsey and Law 1993). Other investigators have applied different names to these same facies. Connelly et al. (1992) have referred to these facies as the upper gravel, the sandy unit, and the lower gravel sequences,

respectively. The terminology from Connelly et al. (1992) will be used in the following discussions.

The eroded surface of the uppermost basalt flow of the Columbia River Group lies about 375 ft below the ground surface of the AX Tank Farm. The surface of the basalt dips gently to the south-southeast. Sediments of the Ringold Formation Unit A overlie the basalt to a depth of about 260 ft below the ground surface. These sediments consist of well-rounded gravels and cobbles in a matrix of very coarse to coarse sand and are representative of migrating channel deposits of a major river system. Overlying the Ringold Formation sediments are about 225 ft of undifferentiated sediments of the Hanford formation that consist of sands from the sandy unit and gravels from the lower gravel sequence. These sediments are overlain by 35 ft of gravel sediments of the Hanford formation upper gravel sequence.

4.3 Hanford Site Hydrology

4.3.1 Surface Hydrology

The following discussion regarding the surface hydrology at the Hanford Site is summarized from Lindsey and Law (1993).

The Columbia and Yakima Rivers are the primary surface-water features near the Hanford Site. The free-flowing Columbia River borders the Hanford Site on the north and east between the Priest Rapids Dam and the headwaters of Lake Wallula near the 300 Area. The Columbia River's nearest proximity to the AX Tank Farm is about 8 mi to the northeast.

Approximately one-third of the Hanford Site is drained by the Yakima River system in the southern and southwestern portions of the Site. Cold Creek and its tributary Dry Creek are ephemeral streams within the Yakima River drainage system. Surface flows, which may occur during spring runoff or after heavy precipitation, infiltrate and disappear into the surface sediments.

West Lake, which is about 10 acres in size and less than 3 ft deep, is the only natural lake within the Hanford Site (DOE 1988). It is located at the base of Gable Mountain, a few miles north-northwest of the 200 East Area.

4.3.2 Subsurface Hydrology

The Hanford Site is underlain by a multiaquifer system consisting of four hydrologic units that correspond to the three uppermost formations of the Columbia River Basalt Group and the suprabasalt sediments (DOE 1988; Delaney et al. 1991). The aquifer in the suprabasalt sediments is of most interest because it has been most affected by operations at the Hanford Site.

The suprabasalt sediment aquifer system (the unconfined aquifer) is contained within the Ringold Formation and the Hanford formation. The top of the aquifer ranges in depth from ground surface at West Lake and the Columbia and Yakima Rivers to more than 350 ft in the center of

the Hanford Site (Lindsey and Law 1993). The base of the unconfined aquifer system is the surface of the uppermost basalt flow. In the western portion of the Hanford Site, the unconfined aquifer is generally in gravels of the Ringold Formation (unit E). In the northern and eastern portions of the Hanford Site, the unconfined aquifer is generally within the Hanford formation.

Overbank and lacustrine deposits of the Ringold Formation form confining layers above the Ringold fluvial sands and gravels, creating a semiconfined aquifer condition. The unconfined aquifer is bounded laterally by anticlinal ridges of basalt. North of the 200 East Area, erosion has removed a portion of the uppermost basalt; the uppermost aquifer includes the Rattlesnake Ridge interbed.

At the Hanford Site, natural recharge of the uppermost aquifer is by rainfall and runoff from the hills bordering the Site, by infiltration from small ephemeral streams, by water infiltration through faults and fractures in the underlying basalts, and by infiltration from the Columbia and Yakima Rivers. Moisture movement through the unsaturated (vadose) zone has been studied at various locations at the Hanford Site. Gee (1987) and Routson and Johnson (1990) concluded that no downward percolation of precipitation occurs in the 200 Areas (except where surface conditions have been altered), where the sediments are layered and vary in texture, and that all moisture penetrating the soil is lost through evapotranspiration.

However, Gee (1987) and Routson and Johnson (1990) suggest that where the natural surface conditions have been altered, the potential exists for a significant amount of precipitation to infiltrate to the uppermost aquifer. Recharge from precipitation has been estimated to range from near zero to greater than 4 in., depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). Recharge is highest in coarse-grained sediments with little or no vegetative cover, which are typical tank farm surface conditions.

Artificial recharge of the uppermost aquifer occurs from the disposal of waste water at the Hanford Site and from large-scale agricultural irrigation that surrounds the Site. At the present time, large-scale waste-water disposal on the Hanford Site occurs only at the Treated Effluent Disposal Facility, which is located southeast of the 200 East Area, and at the Effluent Treatment Facility State Approved Land Disposal System, which is located north of the 200 West Area.

Vadose zone conditions across the Hanford Site show variations similar to those observed in the uppermost aquifer system. Sediments in the vadose zone vary from open-framework gravels of the gravel-dominated facies and interbedded sand and silt of the silt-dominated facies of the Hanford formation to calcium-carbonate-rich deposits of the Plio-Pleistocene unit to cemented gravels of the Ringold Formation. These sediments are characterized by numerous lateral discontinuities, such as pinchouts and erosion truncations, and flow patterns are irregular. If clastic dikes are present, they may enhance vertical flow patterns.

4.4 AX Tank Farm Hydrology

The unconfined aquifer beneath the AX Tank Farm, which is in the Hanford and Ringold Formations, is about 95 ft thick. These sandy gravel and gravelly sands lie directly on the

Columbia River Basalt Group basalt. The depth to the top of the unconfined aquifer is about 280 ft below the ground surface.

Groundwater flow beneath the tank farm is generally in a westerly direction (DOE 1997a) and is controlled mainly by westward flow from the B Pond groundwater mound located east of the 200 East Area. The hydraulic gradient is steep west of the B Pond groundwater mound, then flattens and is very low across the region of the AX Tank Farm (DOE 1997a), as well as the entire 200 East Area (Caggiano and Goodwin 1991). The high transmissivities of the aquifers in the 200 East Area contribute to the low hydraulic gradients. A groundwater elevation map for the 200 East Area is presented in Appendix B.

4.5 Groundwater Contamination in the Area of the AX Tank Farm

The 149 SSTs at the Hanford Site have been grouped into seven Waste Management Areas (WMAs); the A and AX Tank Farms form WMA-A-AX. WMA-A-AX is monitored with a network of groundwater monitoring wells that surround the unit; the locations of these wells are shown on Figure 15-7. Groundwater flow in the vicinity of the WMA-A-AX is to the west; therefore, monitoring wells 299-E25-2, 299-E25-40, and 299-E25-41 are upgradient wells relative to WMA-A-AX, and wells 299-E24-19, 299-E24-20, and 299-E25-46 are downgradient monitoring wells for WMA-A-AX. These monitoring wells were all constructed to monitor the top (approximately 20 ft) of the unconfined aquifer.

Groundwater-level measurements are acquired in all the WMA-A-AX groundwater monitoring wells quarterly, and groundwater samples for chemical and radiological analyses are acquired in the RCRA standard groundwater monitoring wells semiannually. The results of the analyses of the data are presented annually in a report prepared by Pacific Northwest National Laboratory (PNNL); *Hanford Site Groundwater Monitoring for Fiscal Year 1996* (DOE 1997a) is an example of the most recent presentation of the monitoring data. That report summarizes the results of groundwater and vadose zone monitoring activities that were conducted at the Hanford Site during fiscal year (FY) 1996. The following discussions are based on results and interpretations presented in that report.

^{129}I concentrations above the 1.0-pCi/L drinking water standard have been measured in the groundwater from all the WMA-A-AX monitoring wells. The area of the AX Tank Farm is centered within a small plume of ^{129}I contamination with concentrations greater than 5 pCi/L, which is shown on the map of the FY 1996 average ^{129}I concentrations for the 200 East Area that is provided in Appendix B. This small ^{129}I plume is part of the large ^{129}I plume that is present beneath much of the 200 East Area.

Tritium concentrations in upgradient monitoring well 299-E25-41 increased during the 1996 monitoring period, while the tritium concentrations decreased or remained essentially unchanged in the other upgradient well and in the three downgradient wells. Historically, the tritium concentrations in this well have been high, and these elevated values have been attributed to past discharges of PUREX generated waste to the 216-A-8 and 216-A-24 Cribs that are located about 900 to 1,000 ft east-northeast and northeast of the AX Tank Farm, respectively. A map of the

FY 1996 average tritium concentrations in the 200 East Area is provided in Appendix B. A lobe of the large tritium plume beneath the 200 East Area is shown beneath the 216-A-8 and 216-A-24 Cribs, and it extends in a southwest direction downgradient from the cribs.

Chromium and nickel concentrations in downgradient monitoring well 299-E24-19 showed decreased values during the monitoring period; however, the concentrations were well above the chromium and nickel concentrations observed in the other WMA-A-AX network wells (both upgradient and downgradient). This suggests a localized source (near the monitoring well) for these elements.

With the exception of monitoring well 299-E25-46, ^{99}Tc concentrations in the upgradient and downgradient WMA-A-AX network wells decreased during the 1996 monitoring period. The average ^{99}Tc concentrations ranged from 5.5 to 51 pCi/L, well below the 900-pCi/L drinking water standard concentration. During the 1996 monitoring period, the average ^{99}Tc concentrations in well 299-E25-46 increased from 70.5 to 120 pCi/L. The decline in ^{99}Tc in other WMA-A-AX network wells suggests a localized source for this ^{99}Tc contamination that is near monitoring well 299-E25-46. This well is downgradient of the 242-A Evaporator.

5.0 Review of Tank Farm History

5.1 Tank Construction

The tanks in the AX Tank Farm were constructed to store high-level radioactive waste generated during the chemical processing of irradiated uranium fuel materials. The AX Tank Farm, which was constructed in 1963 and 1964, is located in the eastern portion of the 200 East Area, north-northeast of the PUREX facility. The AX Tank Farm was designed to receive and store PUREX high-level wastes. The plan view of the AX Tank Farm shown in Figure 15-8 shows the position of the tanks and the monitoring boreholes surrounding them.

The AX Tank Farm consists of four 1,000,000-gal SSTs that were constructed in a 55-ft-deep excavation. The tanks are 75 ft in diameter and about 47 ft in height (from the bottom of the base to the top of the dome) and are comprised of a steel-reinforced concrete shell that encompasses a 3/8-in.-thick steel plate liner. The concrete shell is 15 in. thick along the upper and domed portions of the tanks and 24 in. thick below the maximum waste capacity level (30.25 ft above the tank bottom). The steel liner is located within the storage or lower portion of the tank, which includes the tank bottom and cylindrical tank sides. The liner extends to a height of 32.5 ft above the flat tank bottom. The tank sides are joined to the bottom with rolled and mitered sections of steel plating. At the maximum operating waste level, the top of the liner was 2.25 ft above the waste level. Approximately 7 ft of backfill materials covers the tank domed top. A cut-away view of typical SST construction is shown in Figure 15-9. The AX Tank Farm tanks, which were designed specifically for operation with boiling waste, were not equipped to overflow via cascade connections as other SSTs at the Hanford Site.

Each tank in the AX Tank Farm has a system of drain channels that are located in the concrete tank base immediately beneath the steel liner of the tank bottom. The channels drain into 60-ft deep, 24-in.-diameter leak-detection pits, which are sump-type systems from which tank leakage can be pumped. The leak-detection pits are located about 15 ft from the sides of the tanks, outside the rings of tank monitoring boreholes. The leak-detection pits are located on the southwest sides of tanks AX-101 and AX-103, and on the northwest sides of tanks AX-102 and AX-104. Each leak-detection pit is equipped with a 6-in.-diameter casing (adjacent to the 24-in. casing) that permits access for radiation detecting instrumentation. Additional details regarding the AX Tank Farm leak-detection system are presented in Harvey (1970).

Additional details regarding the construction of the AX Tank Farm tanks are presented in Brevick et al. (1994a).

5.2 Tank Waste Constituents

The wastes in the AX Tank Farm tanks consist mainly of sludge, salt cake, and liquids (depicted in Figure 15-9). Sludge is composed of solid (hydrous metal oxides) precipitate that results from the neutralization of acidic wastes. The nitric acid solutions of metals that result from dissolution of the irradiated fuel elements during processing at PUREX were neutralized with sodium hydroxide before they were transferred to the tanks. Salt cake is composed of salt formed by evaporation of water from the aqueous waste. Sludge and salt cake form the solids component of the tank waste.

Liquids are present as supernatant and interstitial liquid. Supernatant liquid rests on top of the tank solids, while interstitial liquid fills the interstitial spaces within the waste solids. Interstitial liquid may be drainable if it is not held in the void spaces by capillary forces. Tank content quantities of sludge, salt cake, and liquids are summarized monthly in the *Waste Tank Summary Report.* Hanlon (1997) is an example of one of these reports.

The chemical composition of the waste is complex: anions are predominantly carbonates and nitrates with minor phosphate, sulfate, and hydroxyl. Cations include Na^{+}, K^{+}, AL^{+3}, Fe^{+3}, Cr^{+3}, Sr^{+2}, Ni^{+2}, Pb^{+2}, Bi^{+3}, Ca^{+2}, Zr^{+2}, La^{+3}, and other metals including uranium, plutonium, and americium. Radionuclides contained in the waste include the isotopes ^{90}Sr, ^{137}Cs, ^{235}U, ^{238}U, ^{239}Pu, ^{60}Co, ^{152}Eu, and ^{154}Eu. These elements were introduced into the tanks in solution, and through evaporation and in-tank reactions, resulted in precipitate as sludge and salt cake.

Detailed descriptions of the waste compositions, the processes that generated the wastes, and a comprehensive inventory of the tank contents are provided in Agnew (1997). Brevick et al. (1994a) provide a summary of the waste stream for each of the tanks in the AX Tank Farm.

5.3 Operational History

The tanks in the AX Tank Farm were designed to receive and store boiling wastes from the PUREX facility. The tanks were placed into service in 1963 and began receiving waste in 1965. Following the steam explosion and bulging of the bottom liner of tank A-105, it was decided that

concentrations of ^{137}Cs and ^{90}Sr in the PUREX wastes (with resulting high waste temperatures) were too high for storage in the SSTs. PUREX wastes were sent to B Plant, where the ^{137}Cs and ^{90}Sr were separated from the PUREX acid waste and encapsulated. The waste remaining after this process was transferred from B Plant to the AX Tank Farm tanks. The PUREX waste that had previously been placed in AX Tank Farm tanks was sluiced in the early 1970s and was also reprocessed at B Plant.

The AX Tank Farm tanks also received organic wash waste, high-level supernatant liquids, and other self-boiling or self-concentrating wastes. Brevick et al. (1994a) provide detailed summaries of the waste transactional history for each of the AX Tank Farm tanks; Agnew (1997) provides details regarding the waste content of the tanks.

The four AX Tank Farm tanks were removed from service by 1980. Tank AX-104 was removed from service and declared an assumed leaker in 1977. Tank AX-102 was deactivated in 1980 and declared an assumed leaker in 1988. Tanks AX-101 and AX-103 were deactivated in 1980 and are categorized sound. The assumed leakers are indicated on Figure 15-7. Additional historical operational information for each tank is presented in Section 10.0, "Discussion of Results."

5.4 Current Status

The total volume of waste currently contained in the AX Tank Farm tanks is 906,000 gal. This waste consists of 884,000 gal of salt cake, 19,000 gal of sludge, and 3,000 gal of supernatant; the solids component of the waste contains 370,000 gal of interstitial liquid (Hanlon 1997). Hanlon (1997) presents definitions and volume calculations for each waste type.

Tanks AX-101 and AX-103 were added to the Hydrogen Watch List in 1991. The wastes in these two tanks are suspected to have a potential to generate hydrogen/flammable gas that would develop an explosive environment within the tanks. There are Unreviewed Safety Questions (USQ) associated with these tanks because of the potential for release of radiological contaminants following an explosive event. Tank AX-102 was added to the Organics Watch List in 1994. The USQ for this tank is associated with a small potential for organic nitrate reaction within the tank. The temperatures in all three of these tanks are monitored on a weekly basis (Hanlon 1997).

The waste surfaces in tanks AX-101 and AX-103 are monitored with ENRAF gauges (manufactured by ENRAF, Incorporated) that determine the waste levels by detecting variations in the weight of a displacer that is suspended in the wastes. The waste levels in tanks AX-102 and AX-104 are monitored with FIC devices (manufactured by Food Instrument Company [FIC]) that consist of conductivity probes that are suspended from calibrated steel measuring tapes; some of the spooling reels for the FICs are designed to automatically raise and lower the FIC devices. In addition, tank AX-101 is equipped with a liquid observation well (LOW) that allows the interstitial liquid level of the waste in this tank to be measured with gamma or neutron sondes. Additional details regarding these devices are provided in Hanlon (1997).

5.5 Unplanned Releases

Two documented unplanned releases have occurred within the perimeter fence of the AX Tank Farm that may have created the contamination detected at the ground surface of the AX Tank Farm. However, neither unplanned release appears to have involved a large quantity of material. The locations of these releases are shown on Figure 15-10.

5.5.1 UPR-200-E-115

This unplanned release occurred in February 1974 and was associated with the AX-103 Pump Pit. During operations, an undocumented volume of contaminated liquid was released during bleeding of a pipeline. Two employees and the ground surface adjacent to the pump pit were contaminated. All the contamination was limited to the area of the AX Tank Farm. The disposition of the contaminated soil is not known.

5.5.2 UPR-200-E-119

This unplanned release occurred in December 1969 and was associated with tank AX-104. A contaminated electrode was removed from the tank and set on the ground. A small area of ground near tank AX-104 and an employee's gloves were contaminated. The disposition of the contaminated soil is not known.

5.6 Leak-Detection Monitoring

The SSTs have been monitored for leak-detection purposes throughout the years using either liquid-level measurements, solid-level measurements, or direct detection of contamination in the vadose zone with gross gamma logging. Section 5.8, "Gross Gamma-Ray Logging," presents a discussion of previous gross gamma logging programs used to detect contamination in the vadose zone.

Solid- and liquid-level measurements continue to be made by direct access to the surface of the waste inside the tanks through surface riser ports built into the domed tops of the tanks. Instruments lowered down to the waste surface to determine the level include simple instruments like weighted hand-held measuring tapes, sparker probes, electronic tapes, and, more recently, manual automated ENRAF gauges. The precision of the measurements or potential problems likely to be encountered are described in Welty (1988), Scott (1993), and Catlin (1980).

Sealed fiberglass or TEFZEL reinforced epoxy-polyester resin (TEFZEL is a trademark of E.I. du Pont de Nemours & Company) casings were also inserted into the waste solids (sludge and salt cake) in a majority of the tanks to allow access for borehole monitoring tools. These sealed casings are called liquid observation wells (LOWs) at the Hanford Site. The monitoring tools used in the LOWs include very low-efficiency gamma-ray detection probes (Geiger-Mueller detectors) to measure the variations in gamma flux and neutron-neutron probes to measure variations in the hydrogen content profile. These tools are intended to detect changes in the

solid-to-liquid interface level, and, thus, changes in the liquid level. They are particularly important for detecting leaks because the wastes in most of the tanks now have a surface of relatively solid sludge and salt cake components and the liquid is only found in the interstices or pores of the solid material. For example, the waste in tank AX-101 contains 320,000 gal of interstitial liquid in 748,000 gal of salt cake and sludge. Therefore, surface-level measurements will not detect changes in the interstitial liquid level. Scott (1993), Isaacson (1982), and Catlin (1980) describe the instrumentation used to measure interstitial liquid levels in the tanks.

New LOW liquid-level measurement instrumentation has been recently procured at Hanford and will reportedly soon be used to monitor the interstitial liquid level.

The in-tank solid- and liquid-level measurements currently provide the primary method of detecting leaks from the tanks. Work is in progress to install liquid-level-measuring ENRAF gauges and to perform LOW liquid-level measurements on a regular basis for all the tanks (Hanlon 1997).

Determining the liquid level is not an easy task. In addition to uncertainties or error of the instrumentation, physical changes can occur in the waste that create changes in the measured solid or liquid level. Scott (1993) provides some understanding of the precision of the liquid-level measurement instrumentation, but that understanding has not yet been applied to assessing tank-leak volumes or to determining the uncertainty of the tank leak-volume estimates.

5.7 Vadose Zone Monitoring Boreholes

All the SST farms, including the AX Tank Farm, have monitoring boreholes installed around the tanks. The 32 boreholes in the AX Tank Farm were installed in late 1974 and early 1975; these boreholes were used as a part of a tank-leak detection monitoring program where gamma-ray detectors were lowered into the boreholes to detect the presence of gamma-ray-emitting radionuclides in the sediments surrounding the tanks. The majority of the boreholes in the AX Tank Farm are 100 ft deep; a few are about 125 ft deep. The locations and identifications of the boreholes surrounding the tanks in the AX Tank Farm are shown on Figure 15-8.

The construction of most boreholes is documented in the form of driller's logs. Most of the drilling logs provide some level of detail and description regarding the drilling operations, geologic descriptions of sediments penetrated by the drilling, and explanation of the construction configurations of the "as-built" boreholes. Although in most instances the information provided in the driller's logs is limited in scope, the drilling logs provide information on when and how the boreholes were drilled and usually document the occurrences of radiological contamination encountered during drilling. All the drilling logs are available in borehole archive files maintained by Waste Management Federal Services Northwest Operations.

All the vadose zone monitoring boreholes were drilled with a cable-tool drill rig. This type of drill rig uses a slip-jointed drill stem suspended from a cable to drive an open-ended drive barrel into the sediments. The filled drive barrel is removed from the borehole and struck to remove the sediments. When sediments are encountered that do not remain in the drive barrel as the drive

barrel is removed from the borehole, water is added to the borehole to wet the drilled sediments and to improve cohesion within the drive barrel.

As the drive barrel is driven downward and the drill cuttings are removed to create the borehole, the borehole is open along the drilling interval, which can be from about 4 to 10 ft, depending on the competency of the sediments being drilled. A carbon-steel casing is then driven down into the slightly undersized, open portion of the borehole, and the drilling process then proceeds over another drilling interval. The first sediments drilled after casing advancement are those materials sheared off the formation wall into the borehole as the casing was advanced.

During cable tool drilling, there is a possibility that the borehole wall will collapse along the "open hole" portion of the borehole, before the steel casing is driven into place. If formation material sloughs from the borehole wall into the borehole, the sloughed material will be removed with the drive barrel; however, a void is created in the borehole. Once the casing is driven into place, the void may remain behind the borehole casing.

Voids behind the casing or a highly rugose borehole can create a pathway for migration of contaminants down the outside of the borehole casing. Minor contamination movement could occur as sloughed material sifted downward within the gap between the outside of the casing and formation. The pounding action of the cable tool drilling process would significantly amplify the sifting action along the casing.

Small concrete collars were installed at the ground surface at the completion of the construction of the boreholes. These collars may have been designed to prevent water from migrating down the interface of the outside of the casing and the sediments if this interface was exposed at ground surface. However, these collars would be insignificant barriers if considerable water was present at the ground surface. Ponding resulting from natural meteorological or operational events may have created conditions of standing water at the ground surface of the AX Tank Farm. Ponded water could drain along the borehole casing, pick up contaminants at some intermediate level, and carry them further downward.

In addition, when a borehole is drilled through a zone of contamination with a cable tool rig, contamination could be carried down at least to the maximum extent of the drilling interval (4 to 10 ft) if sloughing were to occur in the open portion of the borehole as it is being drilled. However, because most of the sediment is removed from the hole by the drive barrel after the casing is driven into place, only a relatively small amount of contaminated sediment would be left at the bottom of a drilled interval around the outside of the casing.

The potential for contamination either being carried down during the drilling process or being driven down by ponded water from the ground surface has been considered for each borehole in the Tank Summary Data Reports and in this report.

All the borehole casings were cut off at the top of the surface collars; the casings are at most only a few inches above the surface grade of the tank farm. Plugs or caps were put into the boreholes to keep dust, contaminants, and water out of the boreholes, but the caps are not watertight and

were meant merely to keep objects from inadvertently falling into the boreholes. If ponding occurs at the surface, there is potential for water and contaminated sediments to enter and migrate down the inside of the borehole casings even though the cap is on the top of the casing. If a borehole cap is removed for a significant amount of time, contaminated sand or silt can be blown into the borehole and settle at the bottom of the hole. When low-level contamination is present at the bottom of a borehole with contamination-free regions above it, it is relatively conclusive that the contamination is on the inside of the borehole casing and not deposited in the vadose zone sediments.

Casing may have been contaminated by wind-driven contamination as it was stored on the ground at the drill site. Contamination deposited on the rust scale of metal is difficult to remove and may have remained both on the inside and outside of the casing as the borehole was drilled.

Log Data Reports accompany the log plots in the Tank Summary Data Reports. The borehole data presented in the Log Data Reports contain information regarding borehole drilling details, geological information, well construction configuration, and other pertinent information found in the documentation on file.

5.8 Gross Gamma-Ray Logging

A gross gamma logging program provided a primary means of detecting leaks from the SSTs for many years. This program has recently been discontinued in favor of upgraded in-tank measurements, and reliance on the gross gamma logging was eliminated for all but a small number of SSTs.

Gross gamma logs were acquired for all the AX Tank Farm boreholes according to a schedule specified in Walker and Stalos (1987), Welty and Vermeulen (1989), and Welty (1988). In the past, logging was performed more frequently because it was often the only leak-detection method available.

Gross gamma logging of some fashion began at Hanford in the 1960s by making station measurements with Geiger-Mueller detectors that were lowered by hand into the boreholes. Almost no documentation is available about this work, other than references to the monitoring in some daily operations logs of the health physics technicians.

In the mid-1970s, the gross gamma logging program was upgraded to more automated systems installed in vans that are documented in Isaacson (1982). These logging systems were used to create a large monitoring database. The systems used three different downhole gamma-ray detector probes that sent shaped pulses up a cable to a rate meter. The rate meter tallied the pulses and output a total count value to a computer every second. The downhole probes were withdrawn from the hole at a set rate, thereby summing the counts throughout an interval in the borehole.

The three downhole probes consisted of a 1-in.-diameter by 1-in.-long sodium iodide detector, a lower efficiency probe containing three Geiger-Mueller tubes, and a low-efficiency probe

containing a small, shielded Geiger-Mueller tube. The intent of the three probes was to be able to cover a large gamma-ray flux range without saturating the instrumentation. These systems were effective at covering the high range of activity but were not effective at detecting lower radionuclide concentrations (less than 10 pCi/g equivalent ^{137}Cs). At the time, the intent of the logging program was to detect a leak front that was thought to produce high concentrations of radionuclides.

Boreholes were logged at a set rate of 45 feet per minute (ft/min). With a counting time of 1 second (s) and a delay required to save the data, the resulting data acquisition interval was 1 ft. These logging systems recorded the total number of gamma-ray photons detected throughout the 1-ft intervals and recorded the top depth of the data acquisition interval.

Data were presented as plots of the gross count rate in counts per second (cps) as a function of depth. Spatial count-rate activity peaks were compared visually with previous data to determine, in a qualitative manner, if changes had occurred. No additional processing or analysis were completed on the data. If a change was suspected, the borehole was relogged or the monitoring frequency was increased. Eventually, an increasing count-rate activity trend in the data was used to identify a leak.

The criteria for identifying that a leak had occurred or was occurring (Isaacson 1982) that were used throughout the years in one form or another are no longer considered to be appropriate for the task (GAO 1992). Because the logging instrumentation was not calibrated to a radionuclide concentration response, calculations of contaminant migration were made on the basis of changes in instrument response instead of on radionuclide concentrations. However, there is an empirical nature to the calculations, and the relative changes in detected count rate were related in time to leaks from some tanks.

Review and visual comparison of gross gamma log profiles over time have been useful to determine if contamination has migrated downward or changed in intensity. However, because of the poor spatial resolution of the data (1 ft), tabulation of the maximum spatial peak count rates and comparison of those count rates over time are not recommended. Small changes in the position of the borehole probe between log runs cause large variations in the spatial peak count rates. Only by qualitatively reviewing changing trends in the temporal data is it possible to identify actual changes in the formation contamination concentration.

When evaluating any gross gamma log data, the low sensitivity of the instruments to the presence of ^{137}Cs must be considered. Comparison of the Tank Farms gross gamma log data to the ^{137}Cs concentration plots has shown that a positive gross gamma response can only be expected when ^{137}Cs is present at 10 pCi/g or more. ^{60}Co and other lower specific-activity nuclides each have higher detection thresholds with the gross gamma logging system.

Despite problems inherent with the gross gamma log data, the gross gamma logging database is the best historical record of the vadose zone contamination around the SSTs. This instrumentation was designed to respond in a consistent manner throughout the years, making it possible to compare spatial and temporal differences in relative peak count-rate spatial integrals.

Because the boreholes were consistently logged, an extensive and fairly comprehensive library of gross gamma activity is available for many of the boreholes. Once the limitations of these data are well understood, the data library can be useful for assessing some of the history of the vadose zone contamination.

At the present time, no gross gamma-ray logging is being conducted in the monitoring boreholes surrounding the tanks in the AX Tank Farm. Leak detection is conducted through acquisition of in-tank measurements within LOWs and/or by manual ENRAF measurements of waste surfaces (Hanlon 1997). The most recent procedures for leak detection are outlined in the *Operating Specifications for Tank Farm Leak Detection* (WHC 1994).

6.0 Adjacent Waste Site Information

Several facilities into which millions of gallons of liquid waste and wastewater were discharged to the soil column, and several underground storage tanks containing high-level radiological waste are located adjacent to the AX Tank Farm. These facilities are discussed in the following sections, and a plan view map showing their locations relative to the AX Tank Farm is presented in Figure 15-10.

Geophysical logging was conducted in monitoring wells and boreholes within and around these facilities as early as 1958, and subsequent evaluations were performed that report the interpretation of the log data. An evaluation of gross gamma-ray log data acquired in boreholes at the 216-B-3 Pond was presented in the *B Plant Source Aggregate Area Management Study Report* (DOE 1993a), while evaluations of data collected at other facilities (pertinent to AX Tank Farm) are presented in the *PUREX Source Aggregate Area Management Study Report* (DOE 1993b). Along with summaries of these gross gamma-ray log evaluations, both of these reports provide detailed descriptions of the methodology of the gross gamma logging and details of the log data interpretations.

Brodeur (1988) presents the results of spectral gamma-ray logging that was conducted in selected boreholes at waste disposal facilities located throughout the 200 East and 200 West Areas. Results and interpretations of these data that are pertinent to the waste disposal facilities adjacent to the AX Tank Farm are included in the following discussions.

Details regarding the construction configurations, operational histories, and waste components that are presented in the following sections were derived from DOE (1993a, 1993b). The reader is advised to reference those documents for additional information.

Radiological waste constituents presented in the following sections are derived from waste inventories presented in DOE (1993b). The following radionuclides are included in the inventory listings: ^{60}Co, ^{90}Sr, ^{137}Cs, promethium-147 (^{147}Pm), plutonium, ^{106}Ru, tin-113 (^{113}Sn), uranium, ^{129}I, ^{241}Am, and tritium. Alpha and total beta activities are also included in the inventories.

6.1 216-B-3 Pond System

The 216-B-3 Pond System is located about 3,500 ft east of the 200 East Area east perimeter boundary. It covers an area of roughly 35 acres and ranges in depth from 2 to 20 ft. Historical documentation indicates that throughout its service life, the areal extent of the pond ranged between 19 and 46 acres (DOE 1993a). Increasing discharge flow rates resulted in the expansion of the original 216-B-3 Pond, and the 216-B-3A, 216-B-3B, and 216-B-3C lobes were added to handle the required discharges. Wastes from PUREX and associated facilities were transferred to the 216-B-3 Pond System via the 216-A-29 Ditch and the PUREX Cooling Water Line. There was also a connection to B Plant operations through the 216-B-3 Ditch.

The 216-B-3 Pond system received an estimated 63.4 billion gal of liquid waste between 1945 and 1991 (DOE 1993a). The wastes that reached the pond(s) consisted of steam condensate and cooling water with little potential for chemical or radiological contamination; these wastes constituted the bulk of river water used in the 200 East Area (DOE 1993b). Releases of contamination occurred, but these releases represent a small fraction of the volume of waste discharged to the 216-B-3 Pond System (DOE 1993a).

The B Pond System is monitored with several groundwater monitoring wells. None of the data acquired in these wells have indicated the presence of radiological contamination.

The discharges to the 216-B-3 Pond System significantly recharged the uppermost aquifer and created a large groundwater mound beneath the pond. The groundwater flows in a radial pattern from the mound; consequently, the groundwater flow was redirected from pre-Hanford operation conditions. During maximum wastewater discharge to the B Pond System, the height of the groundwater mound was about 43 ft above pre-operational conditions (DOE 1997a). As the effluent rate of discharge decreased, water levels in groundwater monitoring wells within the influence of the mound decreased. The reader is advised to consult DOE (1997a) for details regarding groundwater monitoring at the 216-B-3 Pond System.

6.2 216-A-1 Crib

The 216-A-1 Crib is located approximately 350 ft south-southeast of the AX Tank Farm (see Figure 15-10). This facility is 30 ft by 30 ft by 15 ft deep, and consists of an H-shaped 6-in.-diameter perforated piping arrangement surrounded by gravel backfill.

The 216-A-1 Crib was in service during November and December of 1955. During this period it received approximately 26,000 gal of depleted uranium waste from the 202-A Building, which was a chemical separations facility. The major radionuclides in this waste are ^{137}Cs, ^{90}Sr, uranium, and plutonium (DOE 1993b).

The 216-A-1 Crib is monitored with well 299-E25-2. Data from this borehole were evaluated by Fecht et al. (1977), and it was determined during this study that elevated levels of gamma-ray activity within a 5-ft-thick zone were declining and that there was no measurable migration of the

contamination. The bottom of the contamination zone was at a depth of 30 ft beneath the ground surface, or 15 ft below the base of the crib. The contamination had not reached groundwater.

6.3 216-A-7 Crib

The 216-A-7 Crib is located approximately 450 ft south-southeast of the AX Tank Farm (see Figure 15-10). This facility is 10 ft by 10 ft by 15 ft deep, and consists of cross-patterned 6-in.-diameter perforated piping surrounded by gravel backfill.

The 216-A-7 Crib was in service from November 1955 to November 1966. During its service life it received 82,129 gal of liquid waste consisting of effluent from the 241-A-302B Catch Tank (PUREX facility), drainage from the 241-A-152 Diversion Box (A Tank Farm), and TBP-kerosene organic waste from the 202-A Building. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, and plutonium (DOE 1993b).

This crib is monitored with borehole 299-E25-54. Chamness (1986) eveluated the gamma-ray data acquired in this borehole and concluded that the zones of elevated activity were decreasing in intensity. Two contamination zones are present at this borehole. An upper zone occurs from the ground surface to a depth of about 10 ft, and a lower zone occurs beneath the crib at a depth of 30 ft. The lower zone is 5 ft thick. There is no indication that the contamination reached groundwater.

6.4 216-A-8 Crib

The 216-A-8 Crib is located approximately 550 ft east of the AX Tank Farm, outside the east perimeter fence of the 200 East Area (see Figure 15-10). This facility consists of an excavation that is 850 ft by 20 ft by 14 ft deep, which contains a perforated 24-in.-diameter distribution pipe surrounded by gravel backfill. An overflow line from the 216-A-8 Crib led to a 200-ft by 200-ft pond that was located between the 216-A-8 and 216-A-24 Cribs.

The 216-A-8 Crib was in service from November 1955 to September 1991. During its service life, this facility received 304 million gal of waste consisting mainly of cooling water and condensate from several sources including the A, AX, and AY Tank Farms (DOE 1993b). The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, uranium, and plutonium (DOE 1993b).

Groundwater monitoring wells 299-E25-4, 299-E25-5, 299-E25-6, 299-E25-7, 299-E25-8, 299-E25-9, 299-E25-14, and vadose monitoring borehole 299-E25-169 are used to monitor the 216-A-8 Crib. Gross gamma log data were acquired in these boreholes as early as 1958, and subsequent logging during the period that this crib was in operation indicates that significant vertical migration of gamma-emitting radionuclides occurred. Elevated activities were detected near groundwater when this crib was in service.

Spectral gamma log data were acquired in wells 299-E25-4, 299-E25-5, and 299-E25-7 by the Westinghouse Hanford Company (WHC) Geophysics Group; these data are provided in Appendix C. The only man-made radionuclide detected was ^{137}Cs. These data indicate that a

majority of the contamination at the 216-A-8 Crib is contained near the surface within the crib structure and slightly below it to depths of 50 ft. However, there is indication that ^{137}Cs migrated down to groundwater, as shown in the concentration plots for wells 299-E25-4 and 299-E25-7 (Appendix C).

6.5 216-A-9 Crib

The 216-A-9 Crib is located approximately 800 ft southwest of the AX Tank Farm (see Figure 15-10). This facility is 420 ft by 20 ft by 13 ft deep, and consists of a horizontal 4-in.-diameter perforated pipe surrounded by gravel backfill.

The 216-A-9 Crib was in service from March 1956 to August 1969. During its service life, it received 259 million gal of liquid waste consisting of condensate and condenser cooling water from the 202-A Building and N-Reactor decontamination waste. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, plutonium, and tritium (DOE 1993b).

The 216-A-9 Crib is monitored with wells 299-E24-3, 299-E24-4, 299-E24-5, and vadose monitoring borehole 299-E24-63. Fecht et al. (1977) reported that a region of elevated activity located about 25 ft below the crib distribution line detected in 1963 had declined to background levels of activity. Chamness (1986) noted that the gamma-ray profile of data acquired in borehole 299-E24-63 in 1986 did not change from the profile of the 1976 data. Also, there was no indication in any of the monitoring data that the contamination had reached groundwater.

6.6 216-A-16 and 216-A-17 French Drains

The 216-A-16 and 216-A-17 French Drains are located approximately 400 ft south of the AX Tank Farm (see Figure 15-10). These facilities are 3.5 ft in diameter and 17 ft deep and consist of 6-ft-long bell-ended concrete pipes placed vertically over gravel backfill. The bottoms of the pipes are 11 ft below the ground surface, and the pipes are gravel filled. They are connected to each other via a pipeline.

The 216-A-16 and 216-A-17 French Drains were in service from January 1956 to March 1969. During their service lives, the 216-A-16 and 216-A-17 French Drains received liquid wastes consisting of floor drainage and stack drainage from the 241-A-431 Building. The 216-A-16 French Drain received 32,000 gal of waste that was estimated to contain less than 10 Ci total beta activity. The 216-A-17 French Drain received 16,000 gal of waste that was estimated to contain less than 1 Ci total beta activity.

There are no monitoring well(s) for either of these facilities.

6.7 216-A-18 Trench

The 216-A-18 Trench is located approximately 300 ft east-northeast of the AX Tank Farm (see Figure 15-10). This facility was an open excavation 80 ft by 80 ft by 15 ft deep; it was backfilled after it was taken out of service.

The 216-A-18 Trench, which was in service from November 1955 to January 1956, received depleted uranium waste from the 202-A Building. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, plutonium, and uranium (DOE 1993b).

The 216-A-18 Trench is monitored with well 299-E25-10. Gamma-ray log data acquired in this well in 1958 and 1976 indicated no elevated gamma-ray activity.

6.8 216-A-19 Trench

The 216-A-19 Trench is located approximately 550 ft east-northeast of the AX Tank Farm (see Figure 15-10). This facility was an open excavation 25 ft by 25 ft by 15 ft deep; it was backfilled after its service.

The 216-A-19 Trench, which was in service from November 1955 to January 1956, received depleted uranium waste from the 202-A Building. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, plutonium, and uranium (DOE 1993b).

The 216-A-19 Trench is monitored with well 299-E25-10. Gamma-ray log data acquired in this well in 1958 and 1976 indicated no elevated gamma-ray activity.

6.9 216-A-20 Trench

The 216-A-20 Trench is located approximately 700 ft east-northeast of the AX Tank Farm (see Figure 15-10). This facility was an open excavation 25 ft by 25 ft by 15 ft deep; it was backfilled after its service.

The 216-A-20 Trench, which was in service from November 1955 until January 1956, received depleted uranium waste from the 202-A Building. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, plutonium, and uranium (DOE 1993b).

The 216-A-20 Trench is monitored with well 299-E25-10. Gamma-ray log data acquired in this well in 1958 and 1976 indicated no elevated gamma-ray activity.

6.10 216-A-23A and 216-A-23B French Drains

The 216-A-23A and 216-A-23B French Drains are located approximately 400 ft south of the AX Tank Farm (see Figure 15-10). These facilities, which are identical in construction,

consisted of 7-ft-long sections of 3.5-ft-diameter bell-ended concrete pipe placed on end into the ground to a depth of 6.5 ft. The concrete pipes were filled with gravel.

Both the 216-A-23A and 216-A-23B French Drains were in service from September 1957 to March 1969. During their service lives, they each received 1,600 gal of condensate and back-flush water from the 241-A-431 Building. Neither of these facilities contain any of the major radionuclides listed in the DOE (1993b) waste inventory summaries.

There are no monitoring well(s) associated with either of these facilities.

6.11 216-A-24 Crib

The 216-A-24 Crib is located approximately 550 ft northeast of the AX Tank Farm, outside the east perimeter fence of the 200 East Area (see Figure 15-10). This facility consists of an excavation 1,600 ft by 20 ft by 15 ft deep that contains a horizontal 15-in.-diameter corrugated pipe overlying a 4-ft-thick layer of gravel that was placed into the bottom of the excavation; the bottom half of the pipe is perforated. The 216-A-24 Crib is divided into four 350-ft segments; the segments were created by dividing the main excavation with 50-ft-wide earth barriers. The segments were designed to cascade from one to another through 15-in. pipes that penetrate the barriers. The 216-A-24 Crib contains a diversion box, risers, and several gauge wells.

The 216-A-24 Crib was in service between May 1958 to January 1966. During its service life, this crib received 200 million gal of waste that consisted of condensate from waste storage tanks in the A and AX Tank Farms. The major radionuclides in these wastes are ^{137}Cs, ^{90}Sr, plutonium, and tritium (DOE 1993b).

Wells 299-E26-2, 299-E26-3, 299-E26-4, and 299-E26-5 are the primary wells that are used to monitor the 216-A-24 Crib. Gross gamma log data acquired in most of these wells as early as 1958 indicate that extensive vertical migration of gamma-emitting radionuclides occurred during the service life of the 216-A-24 Crib. Data acquired in 1963 in wells 299-E26-2 and 299-E26-3 indicated that contamination was present from the ground surface to groundwater.

Wells 299-E26-3 and 299-E26-5 were logged with the WHC Geophysics Team's spectral gamma system; these data are provided in Appendix C. ^{137}Cs was the only man-made radionuclide detected, and it was detected in both boreholes in limited occurrences. In well 299-E26-3, ^{137}Cs contamination occurred in low concentrations at a depth of 4 ft; at the time of logging, this well did not reach groundwater. In borehole 299-E26-5, most of the ^{137}Cs contamination occurred above a depth of 50 ft; no ^{137}Cs contamination was detected deep in the vadose zone near groundwater.

6.12 216-A-29 Ditch

The 216-A-29 Ditch begins about at a location about 1,000 ft southeast of the AX Tank Farm, trends to the northeast, and ends at the 216-B-3 Pond (see Figure 15-10). This facility was an

open excavation approximately 6,500 ft long and 6 ft wide. A portion of the 216-A-29 Ditch is shown in Figure 15-10. The 216-A-29 Ditch was backfilled after its removal from service.

The 216-A-29 Ditch was in service from November 1955 until July 1991. During its service life it received chemical sewer effluent, cooling water, condensate waste, and process cooling water from the 202-A Building. The volume of waste discharged to the 216-A-29 Ditch is included in the 216-B-3 Pond waste estimate.

The 216-A-29 Ditch is monitored with well 299-E25-28. The 1988 gamma-ray log data acquired in this borehole indicated no elevated gamma-ray activity.

6.13 216-A-34 Ditch

The 216-A-34 Ditch is located approximately 550 ft east-northeast of the AX Tank Farm (see Figure 15-10). This facility was an open excavation that was 280 ft long, 30 ft wide at the east end, and 10 ft wide at the west end. It was backfilled after its removal from service.

The 216-A-34 Ditch was in service from November 1955 until December 1957. During its service life it received 241-A-431 Building cooling water and condensate waste that was enroute to the 216-A-19 and 216-A-20 Trenches. The volume of waste discharged to the 216-A-34 Ditch is not reported in DOE (1993b), and may be included in the estimates for the 216-A-19 and 216-A-20 Trenches.

There are no monitoring wells for the 216-A-34 Ditch.

6.14 216-A-39 Crib

The 216-A-39 Crib is located directly north of the AX Tank Farm (see Figure 15-10). The center of this crib is approximately 150 ft north of the northernmost monitoring boreholes in the AX Tank Farm. This facility was constructed to receive approximately 5 gal of high-level waste spilled during operational activities at the 241-AX-801-B Building.

The 216-A-39 Crib was only active during June 1966. During that time it received an unknown volume of liquid in addition to the 5 gal of waste. The major radionuclide in this waste is ^{137}Cs (DOE 1993b).

There are no monitoring well(s) for this facility.

6.15 216-A-40 Trench

The 216-A-40 Trench is located approximately 450 ft west of the AX Tank Farm (see Figure 15-10). This facility is 400 ft by 20 ft by 16 ft deep. The 216-A-40 Trench, which was designed to store effluents, is lined and compartmented into sections.

The 216-A-40 Trench was in service from January 1968 until May 1979. During its service life it received 250,000 gal of cooling water and steam condensate from the 244-AR Vault. This facility does not contain any of the major radionuclides listed in the DOE (1993b) waste inventory summaries.

The 216-A-40 Trench is monitored with borehole 299-E27-3. Currently, there is no indication of contamination below the 216-A-40 Trench.

6.16 216-A-41 Crib

The 216-A-41 Crib is located is located approximately 450 ft west of the AX Tank Farm (see Figure 15-10). This facility is 10 ft by 10 ft by 6 ft deep and consists of a structure of concrete blocks and gravel backfill.

The 216-A-41 Crib was in service from January 1968 to 1974. During its service life it received 2,600 gal of liquid waste consisting of stack drainage from the 244-AR Vault. The waste was estimated to have contained less than 1 Ci total beta activity.

There are no monitoring well(s) for this facility.

6.17 Adjacent Tank Farms

The AX Tank Farm is bounded on the south by the A Tank Farm, which contains SSTs, and on the north and west by the AN, AY, and AZ Tank Farms, which contain double-shell tanks (see Figure 15-10).

Three of the six tanks in the A Tank Farm are assumed leakers. Leak-volume estimates presented in Hanlon (1997) indicate that a total volume of between 16,000 to 280,000 gal of waste leaked from these three tanks. Tank A-105 was the main contributor to this leak volume.

The A Tank Farm tanks are monitored with 50 boreholes and wells that were routinely monitored with gross gamma-ray logging equipment. DOE (1993b) provides several cross sections of the gamma-ray profiles through the A Tank Farm. These cross sections reveal several areas of extensive vadose zone contamination in the A Tank Farm.

Initial characterization of the A Tank Farm vadose zone utilizing spectral gamma log data acquired in the monitoring boreholes has been initiated. The logging portion of this characterization has been completed, and the analyses and publication of the results will be completed in FY 1998.

There have been no leaks associated with the AN, AY, or AZ double-shell tank farms.

7.0 Spectral Gamma-Ray Log Measurements

7.1 Equipment

Logging operations in the AX Tank Farm were conducted with two SGLSs that were manufactured in 1993 by Greenspan, Inc., of Houston, Texas. These systems are a custom assemblage and adaptation of laboratory-quality spectroscopy instrumentation that were specifically designed to perform laboratory-quality assays in boreholes. Complete documentation, including plans, system schematics, software documentation, and specific component manuals, is available in the DOE-GJO archive files.

Both logging units are completely self-contained systems composed of a downhole sonde, a logging cable and delivery system, and surface computer electronics mounted in a cabin on a heavy-duty truck chassis. Figure 15-11 shows a SGLS in a typical setup over a borehole.

These systems use HPGe gamma-ray detectors with efficiencies of 35 percent relative to a 3-in. by 3-in. cylindrical sodium-iodide detector standard. Germanium detectors are used because they provide a high-energy resolution that allows unique identification of the radioisotope source. Use of germanium detectors for both laboratory and field work has become practical because of technological advancements in designs of portable electronic systems and developments in detector manufacturing that have resulted in more economical high-efficiency detectors.

The detectors are housed in downhole cylindrical sondes and are mounted in a portion of the housing with a thinner housing wall thickness that reduces the attenuation of the gamma-ray signal by the housing material. The downhole sonde also contains a high-voltage supply, a preamplifier, and a liquid nitrogen dewar and cryostat assembly. The liquid nitrogen dewar system is required to cool the detector diode to liquid nitrogen temperatures. The dewar holds a quantity of liquid nitrogen that allows about 10 hours of logging time between refills. Figure 15-12 shows a sonde equipped with a high-purity germanium detector suspended over a borehole.

The sonde is delivered downhole by a Kevlar-reinforced, multiconductor cable. Conductors provide low-voltage power to the downhole power supply. The cable transmits the preamplified detector pulses and timing pulses uphole to the truck-mounted instrumentation. A tube is located in the center of the cable for venting nitrogen gas as the liquid nitrogen in the dewar vaporizes. The vent tube allows the downhole probe to be used in water-filled boreholes.

Sonde movement within a borehole is governed by a servo-controlled hydraulic winch that receives its control signal from the system computer. The sonde position in the borehole is measured with a digital rotary encoder mounted on a sheave wheel that is suspended from a boom (Figure 15-11). The boom is used to position the sonde over the borehole.

The surface instrumentation, which is mounted in standard instrument racks inside the rear cabins of the logging trucks, consists of a high-count-rate nuclear spectroscopy amplifier

interfaced to a computer-controlled multichannel analyzer. Spectral log data are recorded by the computers on hard disks.

All instrumentation control, winch control, tool positioning, safety interlocks, and other functions are under computer control using a data acquisition and control program written by the manufacturer of the system and known as "LOG." The extensive computer control and automation of the system allow it to operate much faster than a nonautomated system, making the characterization operation cost effective.

7.2 Calibrations

The calibration of the SGLSs is specified in a calibration plan (DOE 1994a) and reported in a calibration report (DOE 1995c). Koizumi et al. (1991), Brodeur et al. (1991), and Koizumi et al. (1994) provide more general information on calibration methods and procedures for germanium logging systems.

The logging systems are calibrated by several processes that include a base calibration, biannual field calibrations, and daily field verifications.

The base calibration, which was completed in the spring of 1995, included initial testing and qualification of the logging systems. This calibration was performed using the DOE borehole calibration model standards at the DOE-GJO. These models are concrete cylinders or monoliths with large homogeneous regions where the concrete is enriched with known KUT concentrations. The models contain boreholes (through the enriched zones) that allow a logging sonde to pass through the zones and acquire measurements. When a logging sonde is placed in the middle of the zone of enriched concrete, the measurement geometry is such that a homogeneous, isotropic medium of known radionuclide concentration is simulated. The response of the detector to the medium of the calibration zone is recorded, and the mathematical relationships between radionuclide concentration and count rate response are computed. The mathematical relationships constitute the system calibration factors.

During the base calibration, calibration factors were calculated to enable direct conversion of specific photon peak count rate responses to KUT concentration in picocuries per gram. In addition, the efficiency versus energy curve was calculated. This so-called efficiency curve allows calculation of the efficiency of the system at a specified photon energy, thus allowing determination of the concentration of man-made radionuclides that are not present in the calibration models, such as ^{137}Cs or ^{60}Co. Figure 15-13 shows an example of an efficiency calibration function.

The base calibration also determined the environmental corrections that are used to correct for logging in a nonstandard borehole environment. For instance, steel casing installed in a borehole attenuates the gamma-ray signal from the formation to the detector. As a result, the detected count rate is lower than it would have been in an open (uncased) borehole measurement. An environmental correction is applied to the spectral peak intensities to correct for casing attenuation.

Environmental corrections were determined in the base calibration for a large range of casing thicknesses, for the effect of water in the borehole, and for a shield that is used to intentionally lower the gamma-ray flux at the detector. Because the environmental corrections do not change with changes in the detection system, they need to be determined only once.

The base calibration also determined the response of the system to high gamma-ray flux. This test enabled determination of a count-rate correction equation, sometimes called a dead-time correction, that is applied to all the spectra data during data analysis.

Field calibrations are performed biannually at the DOE borehole calibration models at the Hanford Site. These calibrations provide periodic confirmation of proper system performance, and also "close the loop" by ensuring that every borehole measurement is bracketed in time by system calibrations. The field calibrations are designed to quantify the system efficiency and the dead-time correction, because these performance factors are subject to small changes over time and could be appreciably affected in the event of a logging-system malfunction.

Biannual field calibrations are used to quantify any small changes in the performance of the logging systems over time. The first field calibration was completed immediately after the base calibration was completed, before any logging operations began. This first field calibration is documented in the base calibration report (DOE 1995c). The second and third field calibrations were performed in October 1995 and April 1996, respectively, prior to logging at the AX Tank Farm. The field verification data for the first and second biannual field calibrations are reported in DOE (1996c) and DOE (1996g). Calibration data reviewed to the present show no trend over time, verifying the stability and consistent performance of the systems.

The field calibration models at the Hanford Site are essentially identical to the national standards in Grand Junction, Colorado. The field calibration models were constructed at the GJO and eventually moved to the Hanford Site in the late 1980s for use in Hanford environmental logging work. Koizumi (1993) presents descriptions of these calibration models.

The efficiency of the logging systems is checked in the field calibrations by recalculating the direct conversion factors for KUT and by recalculating the energy versus efficiency functions, as shown in Figure 15-13. The dead-time correction is reconfirmed at each field calibration by measuring the system response in calibration zones that have successively increasing radionuclide concentrations. Calibration uncertainties are calculated and incorporated in the analysis of borehole log data.

In addition to the base and field calibrations, the performance of each logging system is verified daily in the field, before and after acquiring log data. These field verifications are performed by recording the system response when the detector, housed in the downhole sonde, is surrounded by a cylindrical-shaped gamma-ray source. By placing the detectors in a consistent geometrical relationship with a large, cylindrical field verification photon source, it is possible to verify the efficiency of the system, as well as other performance factors, such as the energy resolution and system gain.

During the logging of the AX Tank Farm, an extensive database tracking the response of the SGLSs to the field verification sources was developed, and system performance guidelines were established on the basis of these data. These criteria are now being used as a quality-assurance measure that verifies system performance in the field.

7.3 Logging Process and Procedures

Data acquisition or logging work is performed according to a logging procedure (DOE 1995f). Adherence to this procedure ensures consistent and documented operation of the logging systems. This procedure does not specify actual data acquisition parameters, because those parameters may vary in the field according to the borehole environment encountered during the logging process. Parameters such as data acquisition interval, logging mode, logging speed, or counting time may be varied by the logging engineers in an effort to extract as much information from the borehole as possible. Requirements specify that all data acquisition parameters are recorded on Log Data Sheets so that the borehole-specific data acquisition parameters are documented and available for data processing, analysis, and interpretation. Log Data Sheets are completed as the borehole is being logged and transferred from the field site to the office upon completion of logging. Log Data Reports are created from data on the Log Data Sheets, and the Log Data Reports are provided with the log plots in the Tank Summary Data Reports for each tank.

Logging proceeds after an initial instrumentation warm-up time period and after completion of the pre-survey field verification. Under normal conditions with moderate to low man-made radionuclide concentrations, data acquisition is initiated with 100-s detector live time at 0.5-ft depth intervals along the borehole. An acquisition time of 100 s was used for all the logging in the AX Tank Farm. This spatial resolution is adequate to properly define thin zones of contamination, yet it is not overly time consuming or costly.

If high contamination is encountered and the detector dead time increases to a level greater than about 80 percent, the logging engineer will generally change to a real-time (clock time) logging mode. A real-time logging mode was used through zones of high radionuclide concentrations, but even then the system sometimes became saturated and unable to record data. Above a ^{137}Cs concentration of about 10,000 pCi/g, the SGLS becomes saturated and log data cannot be obtained using the current high-efficiency detectors. A thin zone of high concentration ^{137}Cs contamination was detected near the ground surface in borehole 11-02-12, and the logging mode was changed from live time to real time to log this interval.

The SGLSs have digital spectrum stabilizers that automatically adjust the gain and maintain the 1460-keV energy peak from natural ^{40}K within an established spectrum channel range. Occasional fine adjustments of the gain may be required throughout an 8-hr logging period to keep the 1460-keV peak in the established range. However, this adjustment does not affect the system's efficiency or the calculated radionuclide concentration.

Each time the computer is set with specified data acquisition parameters and an automated data acquisition process is executed, it is defined as a separate log run. If the process is interrupted,

such as when a high count-rate region is encountered or operations are interrupted, a new log run is established. The logging parameters for each log run are recorded on Log Data Sheets.

The spectra recorded at each depth in the borehole are automatically transferred by the LOG program to nonvolatile memory on the computer hard disk as each spectrum recording is completed. At the end of the day, another field verification spectrum is recorded.

When the logging of a borehole is complete, the spectra recorded on hard disk are transferred to an optical disk. These optical disks are then transported into the field office, and the data are transferred to the main computer database maintained in the office according to the records management plan (DOE 1995h). Log Data Sheets are completed as the borehole is being logged and also transferred from the field to the office. The data on the Log Data Sheets are entered into the vadose zone characterization database that was created with Corel Corporation's Paradox database program; the Log Data Sheets are then copied and filed.

Qualified logging engineers perform all data acquisition operations and have been trained for their jobs as specified in a training integration plan (DOE 1994b) and in the logging procedures (DOE 1995f). All data acquisition operations are governed by the project-specific quality assurance plan (DOE 1996f). The reader is referred to those manuals and other referenced material for more specific information about this characterization project.

7.4 Data Management

All data and records are managed as specified in the records management plan (DOE 1995h). The objectives of this plan are to maximize the usefulness and to protect and preserve important project information, while minimizing the record-keeping burden and reducing costs.

The records management plan provides guidance and governs the management of the project records from creation to final disposition. This guidance ensures that project records are

- Created, identified, and inventoried.
- Indexed and incorporated into the Vadose Zone Characterization Project Document Log, according to the Vadose Zone Characterization Project File Index specified in the document.
- Controlled to protect against loss, damage, or unauthorized access.
- Retrieved efficiently.
- Disposed of, archived, or transferred according to applicable requirements, procedures, and DOE orders.

The records management plan specifies management requirements for all data, reports, memoranda, and miscellaneous information and governs recording and retention of data and records, copying the data to the computer database, and management and retention of the

database. The records management plan also assigns responsibilities and provides assurance that this work is accomplished.

7.5 Data Analysis

Data analysis can begin after logging of a borehole is completed and the log data are transferred to the office computer. Data analysis is the process of reducing the spectra data to individual peak count rates and converting those raw count rates into concentrations. The radionuclide concentration data are put into a log profile format and then plotted. Figure 15-14 shows a flow chart of the data analysis process.

The data analysis work is accomplished with Pentium microprocessor-equipped personal computers and a combination of commercial and custom software. The data analysis process, instructions, software, and procedures are documented in the data analysis manual (DOE 1996d). All computer programs that are not commercial programs are verified and validated according to DOE standards.

The office computer system consists of nine data analysis work stations interfaced with a central server system that contains several gigabytes of nonvolatile memory. Data are copied from field optical disks to hard disk memory on the server according to documented procedures and protocol.

Analysis begins with conversion of all raw *.chn spectra files into a format that can be read by the commercial spectrum analysis software called "PCMA/WIN" that is written by APTEC Nuclear, Inc. Spectrum analysis then proceeds in batch mode with standard analysis configuration settings identified in the data analysis manual.

Once the analyst is satisfied with the results of the spectrum analysis, all the individual spectra output files are parsed to extract data on particular peaks specified by the analyst. The parsed data are put into individual peak files showing the count rate at each 0.5-ft assay interval that the particular peak was detected. One file is created for each nuclide or photon peak, and each file contains the data from all depths for the particular photon peak.

A custom data analysis software package called "LogAnal" takes the individual peak data files and converts the count rate data to equivalent concentration by applying the basic efficiency calibration functions documented in the calibration plan (DOE 1994a). All environmental corrections are applied to the data to correct for casing, water-filled boreholes, dead time, etc. The output files are saved as *.rlg files, which contain depths, radionuclide concentrations, uncertainties, and the MDL of a particular radionuclide at each depth location.

The *.rlg data files are then imported into a spreadsheet provided with the SPSS "SigmaPlot" plotting software. SigmaPlot is used to create logs or graphs of the radionuclide concentration versus depth using somewhat consistent plot formats.

Statistical uncertainties derived from the logging and calibration data by standard uncertainty propagation methods are also converted in the LogAnal software to equivalent concentrations to produce an estimation of the uncertainty of the concentration determination. The estimated uncertainties provide a measure of the quality of the data and are shown on the log plots as error bars at the concentration data points. Discussion of the uncertainty estimation calculation method is provided in detail in the base calibration report (DOE 1995c).

The MDL is also plotted with the concentration values. Calculation of the MDL is described in the data analysis manual (DOE 1996d). The MDL represents the minimum concentration at which the radionuclide would have to be present for its gamma-ray peak to be identified as a statistically significant peak in the spectrum. It also represents the lowest radionuclide concentration that could be detected using the data acquisition parameters used to acquire the spectra.

A Log Data Report is the final step of the data analysis process. The Log Data Report documents the analysis and processing of the borehole log data and is created using data from the vadose zone characterization database.

The Log Data Report provides information about the borehole construction and casing configuration and how the borehole was logged (log run information). It also includes information regarding data analyses and provides a description of the accompanying log plots. The Log Data Report is provided with the log plots so that others may independently interpret the results.

When data analysis is complete, the original spectra data, the analyzed spectra data, the individual nuclide concentration versus depth data, and the log plots are archived in permanent data storage as specified in the data analysis manual.

This brief synopsis of the data analysis process describes the complexities of the data analyses. The data analysis process is documented in greater detail in the data analysis manual.

Additional work related to analysis of spectrum shapes is currently underway. Theoretical calculations have shown that, in many cases, analysis of the spectral shape can reveal that a ^{137}Cs source is not uniformly distributed in the formation. In some cases it will be possible to infer the spatial distribution of the ^{137}Cs from the spectral shape. As a result, a spectrum shape-factor analysis will allow the analyst to differentiate between ^{137}Cs contamination inside of the borehole casing, ^{137}Cs contamination on the outside of the borehole casing, and ^{137}Cs contamination distributed evenly throughout the formation. Shape-factor analysis is presently being implemented into routine analyses.

8.0 Log Data Results

8.1 Instrumentation Performance

The two logging systems (Gamma 1 and Gamma 2) logged a total of 32 boreholes within the AX Tank Farm in 1 month. An optimum production rate of one 100-ft borehole per day was logged, generally using a counting time of 100 s at 0.5-ft depth intervals.

Field verification spectra were recorded before and after each day's work. The verification data were analyzed before the commencement of logging. All data were recorded on the computer as spectra, and logging information was recorded by the logging engineers on the Log Data Sheets. The entries on the Log Data Sheets were later entered into the vadose zone characterization database and used in the analysis of the spectra.

Some assumptions regarding the borehole casing thicknesses were used in data analysis. The surface of the casings were often obscured by a small concrete pad placed around each borehole; consequently, the casing thickness recorded in the field sometimes appeared to be incorrect. When the casing thickness could not be measured directly, the thickness was assumed to be the standard thickness for casing with the observed inner diameter. The casing thicknesses used to correct the data are recorded on the individual Log Data Reports (provided with the logs in Appendix A of the Tank Summary Data Reports). The original spectral data are saved in the data archive; therefore, the conversion from count rate to concentration can be recalculated for any borehole if the true casing thickness is determined to be different from the value assumed for data analysis.

The maximum radiation flux from ^{137}Cs from which a meaningful spectrum could be recorded is about 8,000 pCi/g. Above this concentration, the acquired spectra are either distorted or they contain no data because of the high detector dead time. In the AX Tank Farm, this situation was encountered only in borehole 11-02-12, where a 1.5 ft-thick zone of high ^{137}Cs concentration was encountered at a depth of 11.5 ft. The highest ^{137}Cs concentration measured before the detector became saturated was 417 pCi/g at a depth of 13 ft; therefore, an extremely high concentration of ^{137}Cs within the thin zone caused the detector to saturate in the adjacent 0.5 depth interval (e.g. 12.5 ft).

For a counting time of 100 s, the MDL for ^{137}Cs is consistently between 0.1 and 0.2 pCi/g. The MDL differs slightly for each spectrum depending on the concentrations of other radionuclides at the individual spectrum depth region, including the naturally occurring nuclides. In regions of higher man-made radionuclide concentrations, the Compton background continuum becomes elevated, increasing the MDL value.

The MDLs for other man-made radionuclides detected in the AX Tank Farm at a counting time of 100 s are as follows: ^{60}Co, between 0.1 and 0.2 pCi/g; ^{154}Eu, 0.4 pCi/g; and ^{125}Sb, 0.3 pCi/g. The MDLs for all the radionuclides are plotted on the radionuclide concentration plots that are provided in the Tank Summary Data Reports for each AX Tank Farm tank.

8.2 Radionuclides Detected

Detection of a nuclide is considered positive when the peak identification routine of the spectrum analysis software detects a peak associated with a gamma ray known to be emitted by the radionuclide and the intensity of the peak is statistically above the MDL. Radionuclides that emit multiple photons are confirmed by detection of two or more peaks associated with the characteristic gamma rays. When a peak is detected and the source radionuclide is identified, the peak count rate is automatically converted to an equivalent concentration in picocuries per gram.

In the AX Tank Farm, the most abundant gamma-emitting radionuclide contaminant in the vadose zone was ^{137}Cs. ^{60}Co, ^{154}Eu, and ^{125}Sb were detected in thin zones near the ground surface. The occurrences of these radionuclides resulted from surface spills, leaks, or the proximity of the boreholes to pipelines.

In many instances, a small photon peak was measured or suspected, but because the peak did not satisfy the detection criteria established for this project, it was not reported. Man-made radionuclides can be present only at extremely low concentrations to be undetected and unreported.

8.3 Log Plots

Log data results are presented in the Tank Summary Data Reports as plots showing concentration relative to depth in the boreholes. A set of plots for each borehole consists of a separate log of any man-made radionuclides, a log of the KUT concentrations, and a combination plot showing logs of the man-made and naturally occurring radionuclides along with the total gamma log and historical gross gamma-ray logs acquired with the gross gamma logging system.

Each set of logs also includes a Log Data Report. The Log Data Reports provide all the information required to analyze and interpret the log data, including explanations of any anomalies or peculiarities in the data or the analysis process. The logs themselves do not provide enough information with which to assess the data; consequently, anyone looking at the data must also read the Log Data Reports. The Log Data Reports are retained with the log plots as required by the project quality assurance program.

The log plots for the boreholes surrounding each of the tanks are provided in the appendix of the Tank Summary Data Reports for the individual tanks. The man-made correlation plots that were used for correlation purposes in the Tank Summary Data Reports for the boreholes surrounding each tank are provided in Appendix D of this report. These plots contain the logs for the man-made contamination detected in the boreholes surrounding each tank.

The log plots and the nuclide-specific data files for each borehole are maintained in the vadose zone characterization computer database. These data will eventually be transferred to other Hanford databases to make the information more readily available.

8.4 Tank Summary Data Reports

A Tank Summary Data Report was prepared for each tank in the AX Tank Farm. Each report provides a mechanism for reporting the results of the spectral gamma logging and allows the analyst to place the data into the context of the documented tank history. The purpose of the Tank Summary Data Report is to provide nontechnical personnel an understanding of the effects that the various tanks had on the vadose zone sediment.

In addition to the log plots for the boreholes surrounding the tank, a Tank Summary Data Report provides a discussion of each borehole and the spectral gamma data analysis and interpretation for each borehole.

The Tank Summary Data Reports provide a correlation and discussion of the contamination around a tank and identify any geologic correlations. A correlation plot provided in the Tank Summary Data Reports shows the contamination concentration plots from each borehole around the tank in a single figure to aid in the cross-borehole correlation. The analysts also make conclusions, where appropriate, about the sources of the contamination in the vadose zone. If the analysis indicates that a particular tank is the source of contamination, this is stated in the Tank Summary Data Report.

In general, the Tank Summary Data Reports provide a summary of the logging data, an assessment of the conditions of the vadose zone, and an analysis of the relationship between the vadose zone contamination and the tank. The Tank Summary Data Reports for the AX Tank Farm tanks are listed in the reference section of this report.

9.0 Development of the Visualizations

9.1 Introduction

An objective of this characterization project is to create visualizations of the major contamination distribution within the three-dimensional space that constitutes the vadose zone in the AX Tank Farm and present those visualizations in this report. These visualizations can be used for many aspects of tank farm operations and management, as well as for the tank remediation programs. Visualizations of the distribution of the contamination in the AX Tank Farm vadose zone are key products of the vadose zone characterization effort. The ^{40}K data were also analyzed and presented in visualizations to determine if there are gross geological features in the AX Tank Farm vadose zone sediments that may be correlatable with contaminant distribution.

Creating the visualizations required developing geostatistical structural models of the ^{137}Cs contamination and ^{40}K distributions. ^{137}Cs is the major gamma-ray-emitting radionuclide detected in the vadose zone at the AX Tank Farm. For this project, the contamination models are considered to be empirical models, as contrasted with conceptual models or models developed from predictive calculations such as contamination transport calculations. The ^{137}Cs and ^{40}K

models are considered empirical models because they are based on data obtained by measuring the ^{137}Cs and ^{40}K concentrations at discrete points in the subsurface. They are not considered "concepts" because they are not based on predictive or assumed data. The only conceptual part of the models is the interborehole relationship, which in turn is based strictly on the observed geostatistical relationship.

However, even a visualization of an empirical model has both known and unknown inaccuracies. Explanations regarding these inaccuracies with the contamination models allow the users of the models to determine the significance of the models for their particular applications.

The development of an empirical model requires a determination of the mathematical relationship or correlation between discrete data points. It is necessary to determine if two data points can be correlated. A visualization is only as good or as accurate as the relationship defining the correlation between multiple pairs of data points in the three-dimensional space beneath the AX Tank Farm.

The best way to correlate discrete data points is to use the process provided by geostatistics. Geostatistics is simply an analysis and application of the spatial variability of data. It is an empirical analysis of the data and application of the results to the determination of the contaminant concentration at unsampled points in three-dimensional space.

The geostatistical models were developed only for the purpose of creating the visualizations of the ^{137}Cs and ^{40}K distributions in the AX Tank Farm. These empirical models are not intended to be used for quantitative calculations because the geostatistical structures are not well understood. They are adequate to visually represent the ^{137}Cs and ^{40}K distributions. A more rigorous geostatistical structural analysis would be desirable. The existing data samples are 0.5 ft apart in the vertical dimension, creating an ideal database for a geostatistical assessment. However, in the horizontal dimension, an ideal structural analysis would require drilling (and logging) several lines of closely spaced boreholes and constructing variograms that are based only on those data. Future assessments may help to refine and validate the variograms that are the basis of the geostatistical structure of the data.

For each radionuclide (^{137}Cs and ^{40}K) a geostatistical structural model was developed and used in a process called "kriging" to estimate the grade or contaminant concentration at points on a defined three-dimensional grid. Once this concentration grid was developed, visualizations of the estimated concentration of each radionuclide could be produced that resulted in a solid surface model of the contamination. That visualization can be moved, rotated, and viewed from any angle or direction, and color pictorials of the visualization can be produced.

The software package from C Tech Development Corporation called "Environmental Visualization Systems" (EVS) was used to perform the geostatistical analysis and to create the visualizations. Journal and Huijbregts (1978) and David (1977) explain the theory and application of geostatistics as applied to the development of a geostatistical structural model.

The radionuclide concentration data that constitute the spectral gamma-ray log data reported in the Tank Summary Data Reports for the AX Tank Farm were placed in data files that defined the position in space of each data sample point and the nuclide-specific concentration for that point. As mentioned previously, the most abundant contaminant was ^{137}Cs. Other radionuclides such as ^{60}Co, ^{154}Eu, and ^{125}Sb were detected in the vadose zone sediments but were isolated distributions of contamination. Therefore, the contamination model was based on the ^{137}Cs distributions, and the visualizations show only this contaminant.

9.2 Geostatistical Structural Model

The initial stage in developing empirical models of the ^{137}Cs contamination and ^{40}K was to determine the geostatistical structures of the data by performing geostatistical structural analyses. A geostatistical structural analysis determines if two data points can be correlated and quantifies the quality of the correlation.

The EVS software performs the geostatistical structural analysis by calculating three-dimensional variograms that are plots of the variance of the data relative to the distance between data points. The EVS software is an "expert" system that automatically determines optimum parameter settings for the geostatistical structural model and for the kriging operation. These optimum settings were used as a starting point for refinement of the structural model. Parameters were initially calculated by the software and then refined to create the most representative geostatistical structures for the ^{137}Cs contamination and ^{40}K.

The total data domain of the calculations included all vadose zone boreholes within the AX Tank Farm. The domain was extended in the north-south and east-west directions to include the maximum and minimum borehole coordinate values. Borehole depths were converted to elevations, and the vertical parameter of the domain was set to include the highest and lowest sample points.

A structural analysis produces a variogram that is a plot of the variance between data points relative to the distance between data point pairs. Once the variances were calculated, the EVS program fit the data to a spherical model with a least-squares fitting algorithm. The spherical model defines the geostatistical structure. The general equation for a spherical variogram model is

$$\gamma(r) = \left[\frac{3r}{2a} - \frac{1r^3}{2a^3}\right] C \qquad \text{for } r \leq a$$

$$\gamma(r) = C \qquad \text{for } r > a$$

where $\gamma(r)$ = *variance*
r = *calculation distance variable*
a = *spherical model range*
C = *spatial variance*

C = *sill value when* $r = a$

The spherical model assumes zero nugget effect (i.e., the data samples have no intrinsic variance or uncertainty with a spatial distance of 0). This zero nugget effect is an acceptable assumption, because the error of the concentration measurements as reported on the logs is negligible compared to the calculated sill values. The sill value is the maximum average variance observed between points that are a common distance apart. The sill value is equal to the calculated average variance between all points and represents what the variance in the data would be if it were modeled with classical statistics. Separate variograms were produced for the horizontal and vertical directions.

The calculated variogram for ^{137}Cs contamination that was used to represent the geostatistical structure in the horizontal direction had a range value of 72 ft and a sill value of 0.88. The range for the vertical variogram was also calculated to be 72 ft, but it had a lower sill value of 0.7. This range shows a spatial relationship between two data points to be 72 ft in the vertical direction, such that the knowledge of one point will decrease the mean estimation uncertainty of the other.

The calculated variogram for ^{40}K that was used to represent the geostatistical structure in the horizontal direction had a range value of 107 ft and a sill value of 0.538. The range for the vertical variogram was also calculated to be 107 ft, but it had a lower sill value of 0.356. This range shows a spatial relationship between two data point to be 107 ft in the vertical direction, such that the knowledge of one point will decrease the mean estimation uncertainty of the other.

During the variogram calculations for the ^{137}Cs model, the program was allowed to let the Z symmetry axis vary from the vertical direction, and the principal component axis of the structural model that resulted had a Z axis with an angle 0.538° from the vertical. This low principal-component axis angle indicates there is almost no deviation from the vertical of the principal axis. The variogram calculations for the ^{40}K model resulted in an angle of 0.481° from the vertical for the Z axis.

The geostatistical structural analysis component of the modeling program produced the equations for the variograms that were used to define the ^{137}Cs contamination and ^{40}K concentration models.

9.3 Three-Dimensional Plume Calculation and Visualization

The kriging process calculates mean grade, or, in this case, radionuclide concentrations of a volume of sediment by using the information from nearby sample points. The influence of each sample point or the weighting of the point in the calculation is determined by the geostatistical structure or the variogram model and is dependent on the proximity of the data sample point to the volume being investigated. Each sample point is combined in such a way that the kriging operation minimizes the error of the radionuclide concentration for the volume being investigated.

A maximum reach of 100 ft or a maximum of 20 data points, which was determined through trial and error, was input into the kriging program parameters and used in the calculation of the ^{137}Cs and ^{40}K concentrations at every data point.

The anisotropy value applies biased weighting on data points in horizontal and vertical directions. The program default is 10, which results in data points a given distance in a horizontal direction from a data point node to influence the data node 10 times more than data points the same distance away in a vertical direction. Through trial and error analyses, an anisotropy value of 7 yielded results that best represented the measured ^{137}Cs and ^{40}K distributions in the AX Tank Farm. Higher anisotropy values extended some plumes horizontally, and lower values had only a minor effect on the plume distributions. Conservative plume distributions were more desirable; therefore, the anisotropy value of 7 was chosen. The horizontal-to-vertical anisotropy ratio of 7 placed 7 times the emphasis on points within the horizontal plane of a grid point. In that manner, the influence of data points from other boreholes was 7 times greater than data points from within the same borehole as the calculation point. This emphasis helped decrease reliance on data from the same borehole and also minimized the potential for a misinterpretation when ^{137}Cs contamination may have moved down along the inside or outside of a borehole.

For data sample points with less than detectable concentrations of ^{137}Cs, values of 0.1 pCi/g were put into the data files, and the kriging process was set to clip 0.1 pCi/g from the calculations. With this setup, the software calculates the radionuclide concentration on the basis of the knowledge that the data samples show the concentration is less than 0.1 pCi/g, rather than ignore those data points. The lowest ^{137}Cs concentration that is visualized and presented in Section 10.0, "Discussion of Results," is 0.5 pCi/g. The concentration cutoff used in the presentation of the ^{40}K visualizations is 13.5 pCi/g; the rationale for using this value is presented in Section 10.3, "Geologic Correlations," where the ^{40}K visualizations are discussed.

In borehole 11-02-12, where the ^{137}Cs concentrations within a 1.5-ft-thick zone were so high that the detection system became saturated, a concentration value of 1,500 pCi/g was placed in the database for the kriging operation. This value was chosen from interpolating the intersection of the slopes of the ^{137}Cs concentration plot above and below the high dead time zone. This produced a conservative estimation of ^{137}Cs concentration and had minimal effect on the AX Tank Farm ^{137}Cs contamination visualizations since this was the only zone in the AX Tank Farm boreholes where high concentrations caused the detector to saturate.

The kriging process calculated the radionuclide concentration for each block bound by grid nodes. Each block was assigned a concentration, a concentration uncertainty, and minimum and maximum concentrations that were based on the uncertainty. These data were input into the visualization component of the program.

The visualizations were constructed to include the highest and lowest node values in three-dimensional space. Because nodes were set up at all data sampling points, the horizontal extent of the model and the visualizations are governed by the positions of the boreholes. The model does not extrapolate beyond the extent of either the range value or the kriging extent. As a result, both the model and the visualizations can extend only to the maximum depth of the boreholes and the extent of the geostatistical range unless other deeper boreholes are nearby.

In the visualization process, solid surfaces were created by connecting the three-dimensional points in space that had equal concentrations. Depending on the view angle and the isolevel, the outermost solid surface of a plume is viewed. To view an inner surface, a cut section is inserted through the solid surface plume. If the isolevel is increased, progressively higher radionuclide concentration surfaces can be visualized. Where a low concentration medium exists surrounding a higher concentration medium, a cut in the three-dimensional plume is necessary to visualize the high-concentration zone.

Tanks were visualized by creating solid three-dimensional surfaces at the location of the tank centers. In regions between the tanks, the model does not insert a contamination barrier; therefore, a borehole directly across a tank can have some influence on a node point concentration calculation. Because a geostatistical model is used in the concentration estimation calculation, the closest boreholes will have the most influence and the model will be close to the actual distribution, except for areas where there are few boreholes.

9.4 Potential Uncertainties and Inaccuracies

One of the greatest concerns in preparing the contamination visualizations is that the contamination may not be actually distributed within the sediments, but that it is either on the inside or outside of the borehole casing. At the beginning of the model development, an assumption was made that all contamination was distributed within the formation and that the EVS software simply processes the data as if the apparent concentration was actually the formation concentration.

The visualizations presented in this report are based on assignments of estimated ^{137}Cs and ^{40}K concentrations to blocks bound by data point nodes. The software program does not include a mechanism to factor in the uncertainty estimation associated with each data point used in the model development (as depicted in the individual borehole concentration plots). The assay uncertainty-estimation calculation is discussed in the base calibration report (DOE 1995c) and is calculated by combining the uncertainties of the calibration efficiency determination, the calibration-model grade assignments, and the individual spectrum photon-peak counting statistics from the field measurements. The spherical variogram model does not allow input of uncertainties associated with the estimations of the individual assays into the structural model. However, that error is relatively small compared with the sill values and the rate of rise in the variogram curve with distance from the source. It would be advantageous to include this error in the variogram model and reflect that particular error in the concentration estimation uncertainty.

Migration of ^{137}Cs contamination down the inside or outside of the borehole casing is suspected to have affected the distribution of some of the contamination detected in the boreholes. Much of the bias of the borehole log data that is due to borehole migration effects will be removed from the plume visualizations because of the high horizontal-to-vertical anisotropy emphasis applied by the software in the modeling process, as discussed previously.

Potential model uncertainties and inaccuracies associated with zones of high ^{137}Cs concentrations are not significant in the AX Tank Farm because of the limited occurrence of these zones. The

method utilized when these zones are encountered was described previously. Interpolated values are entered into the concentration database for all 0.5-ft intervals within the high count-rate zone. The problem with this method is that it puts a bias in the variogram because the variance between two data points in a borehole suddenly becomes zero. The result is a variogram (particularly the variogram in the vertical direction) that may not properly represent the spatial structure of the data.

At the other extreme, there may be low-intensity radionuclides that were not detected by the current logging methods and equipment. The 35-percent-efficiency detectors used in the SGLSs are considered to be a compromise between performing the data acquisition for all the boreholes in the AX Tank Farm in a cost-effective manner and detecting contamination at low concentrations while still doing a reasonable job of characterizing the high-contamination zones. The current contamination distribution models do not include gamma-emitting radionuclides that are less than the detection levels realized with the data acquisition configuration explained in Section 7.3, "Logging Process and Procedures."

The calibration of the logging system assumes a homogeneous medium of contamination that is effectively infinite in extent, with respect to gamma-ray transport, in horizontal and vertical extents. If the contamination is not on the inside or on the outside of the borehole casing, as discussed previously, this assumption is valid for all situations except at the very top and the bottom of the boreholes or where the concentration changes rapidly with depth. The data acquisition interval used to log the AX Tank Farm boreholes (0.5 ft) provides adequate spatial resolution to characterize the situations where the contamination is not homogeneous in the vertical dimension. Contamination-zone edge effects can be removed if desired by spatial deconvolution methods described by Conaway and Killeen (1978).

Near the ground surface, the source distribution is no longer an infinite medium; the inaccuracies associated with that distribution are discussed in Section 10.1, "Surface and Near-Surface Contamination."

Most of the boreholes are open at the bottom and in direct contact with the sediment or with contamination that migrated down the inside of the borehole casing. As a result, the gamma rays produced within the borehole bottom sediments are not attenuated by a casing, but a casing attenuation factor is applied to these data. Therefore, the reported apparent concentrations are most likely slightly high at the bottom of the boreholes.

The plumes presented in the visualizations were evaluated by comparing the visualizations with the spectral gamma-ray log data from the individual monitoring boreholes surrounding the tanks. The interpretation of each plume or group of plumes is discussed in the tank-by-tank discussion section of this summary. Potential problems with each plume are also identified and explained in these discussions.

10.0 Discussion of Results

10.1 Surface and Near-Surface Contamination

The logging operations measured gamma-emitting radionuclide concentrations at the ground surface when the detector was centered at the 0-ft depth location in the boreholes. The zero depth reference, which is etched into the detector housing and ensures consistent depth measurements of the logging probe, is the center of the HPGe detector. Radionuclide concentration values measured at the ground surface are not accurate for two reasons. The calibration of the logging systems makes the assumption of a homogeneous infinite medium; however, this is not the case when the detector is located at the ground surface. Instead, there is only an infinite geometrical half space with gamma rays originating from the sediments in only the lower half space. From the upper surface, gamma rays can originate from surface contamination far from the borehole because they are not attenuated by the sediments or borehole casing materials. If there is an appreciable amount of contamination on the ground surface, the reported radionuclide concentrations would be higher than the concentrations that are actually present in the formation.

The other reason the concentrations are not valid is because most of the boreholes were constructed with a small concrete collar around them. This collar, which is about 6 in. deep and 12 in. in diameter, surrounds the borehole, effectively attenuating the gamma rays. This collar attenuation will cause the reported concentrations to be lower than what is actually present in the formation.

Because the contamination model was developed without attempting to correct for this attenuation, the visualization of the surface contamination is not correct in terms of the actual concentration of the contaminant in the sediment (predominantly ^{137}Cs). The ^{137}Cs concentration may be higher or lower by an unknown amount. For most of the lengths of the boreholes, however, the models are accurate representations of the distribution and intensity of the contamination in the vadose zone surrounding the tanks in the AX Tank Farm.

Figure 15-15 shows the ^{137}Cs contamination in the AX Tank Farm viewed from above. The ^{137}Cs contamination in this figure is representative of a horizontal planar slice at a depth of 10 ft below the ground surface of the AX Tank Farm. ^{137}Cs contamination is present almost everywhere at the ground surface in the tank farm. Figure 15-16 shows a horizontal planar slice at a depth of 21 ft below the ground surface. The highest ^{137}Cs concentrations shown in both of these figures is in an area between tanks AX-101 and AX-103 on the north sides of these tanks and in an area west of tank AX-104. This contamination resulted from surface spills or piping leaks. The *PUREX Aggregate Area Management Study Report* (DOE 1993b) was reviewed to determine if any unplanned releases occurred in these areas that could explain the presence of this surface contamination. Two unplanned releases discussed earlier in this report, UPR-200-E-115 and UPR-200-E-119, were identified in proximity to tanks AX-103 and AX-104; however, the Hanford Environmental Sites Database (ESD) does not include details regarding these events that would explain the extent of contamination observed in the visualization, especially the ^{137}Cs contamination on the north side of the tank farm.

The contamination plumes depicted in Figures 15-15 and 15-16 pass through to the interiors of the tanks because in the kriging process, contaminant concentrations are calculated for these regions. At the present time, there is no mechanism with which to insert a barrier at the tank boundaries to remove these interior tank regions from the data domain; therefore, kriging operations are performed on all data in the AX Tank Farm.

10.2 Tank-by-Tank Discussion

The following sections are related to the results of the geostatistical modeling that were performed with the data acquired in the AX Tank Farm boreholes. The visualizations are provided in Section 15.0, "Figures for the AX Tank Farm," in the order in which they are discussed.

Figure 15-17 presents the data used in the geostatistical model and is included to allow the reader to compare the individual borehole ^{137}Cs contamination concentration data with the contamination plumes shown in the visualizations. The ^{137}Cs concentration data are presented as hexagons that are colored and sized according to the concentrations and are presented in the spatial position in which the data were collected. The borehole identifications are included to allow correlation with the plan plot presented in Figure 15-8 and the correlation plots presented in Appendix D.

Several visualizations were prepared and are discussed in the following sections. The ^{137}Cs contamination plume concentrations are presented logarithmically in a range from 0.1 to as high as 10,000 pCi/g. The lowest ^{137}Cs concentration presented on the visualizations is 0.5 pCi/g. The highest concentration observed on the visualizations is 1,500 pCi/g. As discussed previously, this value was input into the data for borehole 11-02-12 within the zone of detector saturation.

The background tank information regarding depth references for waste levels that is presented in the following sections was derived from illustrations and measurements provided in Brevick et al. (1994a). Measurements that are reported in these documents, as well as those stated in Hanlon (1997), are relative to the top of the liner at the tank bottom.

10.2.1 Tank AX-101

Tank AX-101 was constructed during 1963 and 1964 and was placed into service in 1965. This tank received PUREX high-level waste, B Plant effluent, organic wash waste, evaporator waste, and double-shell classified slurry feed. Tank AX-101 was sluiced for ^{90}Sr and ^{137}Cs recovery in 1975 and 1976 and was deactivated in November 1980.

During the tank's service life, several reportable liquid-level decreases were documented that were attributed to evaporation, measurement errors, and other factors. These issues are described in Jensen (1977b), Deichman (1977a), and Carter (1980). Increases in radiation levels in the detection pit exceeded the reporting criteria in June 1987 and again in March 1989; these events are documented in Anderson (1987) and Vermeulen (1989), respectively. There were no

explanations for these events, and no further actions were taken to determine the causes for the elevated activities. Tank AX-101 continued to be designated sound.

The present inventory of tank AX-101 consists of 748,000 gal of waste consisting of 745,000 gal of salt cake and 3,000 gal of sludge; these wastes contain 320,000 gal of drainable liquids (Hanlon 1997). The current waste level is about 23 ft above the tank base (Brevick et al. 1994a).

The vadose zone surrounding tank AX-101 is monitored with eight monitoring boreholes (see Figure 15-8), the majority of which were drilled in late 1974 and early 1975; borehole 11-01-10 was drilled in 1978. The man-made contaminant concentration plots for these boreholes are provided in Appendix D.

Figures 15-18, 15-19, 15-20, and 15-21 are visualizations of the ^{137}Cs contamination that surround tank AX-101. Figures 15-18 and 15-19 are visualizations of the ^{137}Cs contamination in the AX Tank Farm viewed from below the tank farm from the northeast and northwest, respectively. Figures 15-20 and 15-21 are visualizations showing tanks AX-101 and AX-103 from below the tank farm from the southeast and southwest, respectively. Figures 15-20 and 15-21 were created with an east-west-oriented cut face inserted between the AX-101-to-AX-103 and AX-102-to-AX-104 rows of tanks.

With the exception of the large high-concentration ^{137}Cs contamination plume on the north-northwest side of tank AX-101, minimal contamination is observed in the vadose zone around and beneath this tank. The large ^{137}Cs contamination plume, which most likely resulted from a surface spill or leak, is primarily defined by the data acquired in boreholes 11-01-10 and 11-03-02. This contamination was present in the initial tank farm gross gamma-ray logging event after the borehole was drilled (1978). Some of the near-surface contamination may have been carried downward during drilling, as indicated by the occurrence of low, intermittent ^{137}Cs concentrations from the bottom of the high concentration zone (at a depth of about 18 ft) to a depth of about 80 ft. The contamination distribution is shown on the ^{137}Cs concentration plots in Appendix D. Therefore, the vertical extent of the ^{137}Cs contamination indicated in the log data may be greater than that actually present in the vadose zone sediments.

Surface ^{137}Cs contamination was detected in all the boreholes surrounding tank AX-101, and this contamination migrated to varying depths. The visualizations reflect this contamination as a ^{137}Cs plume that engulfs the top of the tank.

Very small occurrences of ^{137}Cs contamination were detected at the bottoms of several of the boreholes surrounding tank AX-101. This contamination most likely resulted from particulate matter that fell down the inside of the borehole casing. This is shown on the visualizations by very small isolated ^{137}Cs occurrences.

Details regarding the data acquired in the monitoring boreholes surrounding tank AX-101 are provided in the Tank Summary Data Report for tank AX-101 (DOE 1997c).

10.2.2 Tank AX-102

Tank AX-102 was constructed during 1963 and 1964 and was placed into service in 1965. During its service life, this tank received PUREX high-level waste, B Plant high-level waste, organic wash waste, evaporator feed waste, and residual waste from the 242-Evaporator. Tank AX-102 also received complexant waste or concentrated complexant waste. From the end of 1976 to early 1977, tank AX-102 was sluiced for recovery of ^{137}Cs and ^{90}Sr. Tank AX-102 was removed from service in September 1980. In 1988, tank AX-102 was declared an assumed leaker with an estimated leak volume of 3,000 gal (Hanlon 1997). This tank is still designated an assumed leaker.

During its service life, several occurrence reports (ORs) were issued (beginning in 1975) for events related to tank AX-102. Two ORs were generated for increased gamma-ray activity in borehole 11-02-11 (Jensen 1975a and 1975b); two ORs were issued for liquid-level decreases (Deichman [1977b] and Vermeulen [1988]); and one OR was issued for increases in gamma-ray activity in the leak-detection pit (Jensen 1976). The elevated activities in borehole 11-02-11 prompted investigations into the source(s) of the elevated activity; these investigations included installation of new monitoring borehole 11-02-22, in-situ moisture measurements, and spectral and gross gamma-ray logging. A leaking coupling on an exhaust vapor header leading from tank AX-102 was surmised to be the source of the contamination, and an asphalt seal was installed to stop the leak; however, elevated gross gamma-ray activity continued, indicating that the seal may not have stopped the leak or that the leak source was not a failed coupling.

Liquid-level decreases occurred in tank AX-102 that could not be attributed solely to evaporation; consequently, the tank was declared an assumed leaker on the basis of these unexplained decreases.

Tank AX-102 presently contains 39,000 gal of waste consisting of 29,000 gal of salt cake, 7,000 gal of sludge, and 3,000 gal of supernatant; these wastes contain 14,000 gal of drainable liquid (Hanlon 1997). The waste level is 14 in. above the tank bottom (Brevick et al. 1994a).

The vadose zone surrounding tank AX-102 is monitored with ten monitoring boreholes (see Figure 15-8), the majority of which were drilled in 1975; boreholes 11-02-01 and 11-02-03 were drilled in 1978. The contaminant concentration profile plots for these boreholes are provided in Appendix D.

Figures 15-22, 15-23, 15-24, and 15-25 are visualizations of the ^{137}Cs contamination that surrounds tank AX-102. Figures 15-22 and 15-23 are visualizations of the ^{137}Cs contamination in the AX Tank Farm viewed from below the tank farm from the southeast and southwest, respectively. Figures 15-24 and 15-25 are visualizations showing tanks AX-102 and AX-104 from below the tank farm from the northeast and northwest, respectively. Figures 15-24 and 15-25 were created with an east-west-oriented cut face inserted between the AX-101-to-AX-103 and AX-102-to-AX-104 rows of tanks.

^{137}Cs contamination was detected near the ground surface in all of the tank AX-102 monitoring boreholes, and this contamination migrated to varying depths. The source of this contamination was surface or near-surface spills or leaks that migrated downward through the sediments along the inside or outside of the casing or other undetermined pathways. The plumes defined by these data cover the top of tank AX-102. The thickest accumulation of ^{137}Cs contamination near the ground surface occurred in boreholes 11-02-03 and 11-02-22, and the visualizations show slightly thicker plumes in the areas around these two boreholes.

The highest concentrations of ^{137}Cs contamination were detected in borehole 11-02-12 in a 2-ft-thick zone at a depth of about 12 ft. In this zone, ^{60}Co and ^{154}Eu contamination were detected with the ^{137}Cs contamination. This contamination is related to the questionable coupling on the tank AX-102 exhaust vapor header. Because of the limited occurrences of the ^{60}Co and ^{154}Eu, these radionuclides were not analyzed with the modeling program.

^{137}Cs contamination was detected in boreholes 11-02-01 and 11-02-02 at depths of 50 and 30 ft, respectively; both of these zones are about 20 ft thick. The origin of this contamination is unknown; however, tank AX-102 may be a possible source. The visualizations show these zones as two separate contamination plumes; however, the contamination zone at a depth of 30 ft in borehole 11-02-02 was processed by the modeling program as a deeper extension of the surface ^{137}Cs contamination. These regions of ^{137}Cs contamination are of greatest concern as indicators of leakage from this tank and are considered prime targets for future monitoring.

Details regarding the data acquired in the monitoring boreholes surrounding tank AX-102 are provided in the Tank Summary Data Report for tank AX-102 (DOE 1997d).

10.2.3 Tank AX-103

Tank AX-103 was constructed during 1963 and 1964 and was placed into service in 1965. During its service life, this tank received PUREX high-level waste, B Plant effluent, organic wash waste, and evaporator feed waste. The tank was sluiced during 1976 and 1977 for ^{137}Cs and ^{90}Sr recovery. Waste sent to the tank during its final operations was concentrated complexant waste and noncomplexant and complexant concentrate. Tank AX-103 was deactivated in September 1980 and is presently designated sound.

In 1979, a liquid-level increase observed in the leak-detection pit was reported in an OR (Carter 1979). No significant increase in gamma-ray activity was detected, and the increase of liquid was determined to be from surface runoff. A reportable liquid-level decrease occurred in 1980 that was attributed to erosion of the solid waste surface in the vicinity where the measuring plummet contacted the waste surface (Lindsay 1980).

Tank AX-103 presently contains 112,000 gal of waste. This waste consists of 110,000 gal of salt cake and 2,000 gal of sludge that contains 36,000 gal of drainable liquid (Hanlon 1997). The waste surface is 3.4 ft above the tank bottom (Brevick et al. 1994a).

The vadose zone surrounding tank AX-103 is monitored with seven monitoring boreholes (see Figure 15-8) that were drilled in late 1974 and early 1975. The man-made contaminant concentration profile plots for these boreholes are provided in Appendix D.

Figures 15-18, 15-19, 15-20, and 15-21 are visualizations of the ^{137}Cs contamination that surround tank AX-103. Figures 15-18 and 15-19 are visualizations of the ^{137}Cs contamination in the AX Tank Farm viewed from below the tank farm from the northeast and northwest, respectively. Figures 15-20 and 15-21 are visualizations showing tanks AX-101 and AX-103 and are views from below the tank farm from the southeast and southwest, respectively. These two visualizations were created with an east-west-oriented cut face inserted between the AX-101-to-AX-103 and AX-102-to-AX-104 rows of tanks.

^{137}Cs contamination was detected at the ground surface in all the boreholes surrounding tank AX-103, and this contamination migrated downward through the sediments or by a pathway created by the borehole casing. This contamination resulted from surface or near-surface spills and/or leaks. In boreholes 11-03-02, 11-03-07, and 11-03-12, ^{60}Co, ^{154}Eu, and ^{125}Sb were detected with the ^{137}Cs contamination. A continuous ^{137}Cs contamination plume is shown over the top of tank AX-103 in the visualizations.

Intermittent ^{137}Cs contamination detected in several boreholes is shown on the visualizations as isolated occurrences of contamination.

The most extensive ^{137}Cs contamination in terms of both magnitude of concentrations and vertical distribution was detected in borehole 11-03-02. This contamination is shown on the visualizations as a narrow ^{137}Cs contamination plume that is defined by this borehole and adjacent borehole 11-01-10 (associated with tank AX-101). The ^{137}Cs contamination peak between depths of 33 and 38 ft may have resulted from leakage from tank AX-103; this peak is within the depth region of the tank operating level, or it may have resulted from downwardly migrating contamination that was trapped at this particular depth in backfilled sediments that were compacted during placement during tank construction. This contamination was detected with the tank farm gross gamma-ray logging system following the construction of the borehole; therefore, it was in the sediments before the borehole was drilled and may have been carried downward during drilling.

A plume defined by ^{137}Cs contamination that was detected at the bottoms of the boreholes is most likely a false plume. This plume most likely reflects contamination that resulted from particulate matter that migrated down the inside of the borehole casing.

Details regarding the data acquired in the monitoring boreholes surrounding tank AX-103 are provided in the Tank Summary Data Report for tank AX-103 (DOE 1997e).

10.2.4 Tank AX-104

Tank AX-104 was constructed during 1963 and 1964 and was placed into service in 1966. During its service life, this tank received PUREX high-level waste, organic wash waste, B Plant

waste, and evaporator feed waste. The tank was sluiced for ^{137}Cs and ^{90}Sr recovery in late 1976 and early 1977. In 1977, the tank was declared as having "questionable integrity" and was removed from service. A leak volume of 8,000 gal was estimated (Hanlon 1997); however, the basis for this determination is unknown. Although the tank was removed from service, sluicing continued to remove wastes still contained in the tank.

Four ORs were generated for elevated gamma-ray activities in boreholes 11-04-01, 11-04-08, and 11-04-11. Elevated activity detected in borehole 11-04-08 in 1977 coincided with the end of the final sluicing campaign to empty tank AX-104. Routson (1978) and Stalos (1979) concluded that tank AX-104 was the source of the elevated activities observed in borehole 11-04-01, and Garbrick (1977) concluded that a specific source could not be identified.

A fifth OR was generated for a liquid-level decrease that was attributed to evaporation (Jensen 1977a).

The present waste volume for tank AX-104 is 7,000 gal of sludge with no drainable liquid (Hanlon 1997); the waste level is 2.5 in. above the tank bottom (Brevick et al. 1994a).

The vadose zone surrounding tank AX-104 is monitored with eight monitoring boreholes (see Figure 15-8), most of which were drilled in late 1974 and early 1975; boreholes 11-04-11 and 11-04-19 were drilled in 1978. The contaminant concentration profile plots for these boreholes are provided in Appendix D.

Figures 15-22, 15-23, 15-24, and 15-25 are visualizations of the ^{137}Cs contamination that surround tank AX-104. Figures 15-22 and 15-23 are visualizations of the ^{137}Cs contamination in the AX Tank Farm viewed from below the tank farm from the southeast and southwest, respectively. Figures 15-24 and 15-25 are visualizations showing tanks AX-102 and AX-104 and are views from below the tank farm from the northeast and northwest, respectively. These two visualizations were created with an east-west-oriented cut face inserted between the AX-101-to-AX-103 and AX-102-to-AX-104 rows of tanks.

^{137}Cs contamination was detected in all the boreholes surrounding tank AX-104. This contamination migrated to varying depths and resulted from surface spills and/or leaks that migrated through the sediments down the inside or outside of the borehole casing or by other undetermined pathways. In borehole 11-04-10, ^{60}Co and ^{154}Eu contamination was detected with the ^{137}Cs contamination in a thin zone at a depth of 3 ft. In the visualizations, ^{137}Cs contamination is shown overlying tank AX-104.

Low, intermittent ^{137}Cs concentrations are indicated on the visualizations as isolated occurrences of contamination.

Neither the spectral data nor the resulting plume visualizations are positive indicators of waste leakage from tank AX-104. However, historical data for this tank provide positive indications that this tank leaked, or at least that the integrity of the liner was breached when contamination was detected at the end of the sluicing campaign.

Details regarding the data acquired in the monitoring boreholes surrounding tank AX-104 are provided in the Tank Summary Data Report for tank AX-104 (DOE 1997f).

10.3 Geologic Correlation

Plots of the KUT concentrations were generated from the data acquired with the SGLSs to determine if there were any correlatable lithological features in the vadose zone beneath the backfill in the AX Tank Farm. These plots were provided as appendices in the Tank Summary Data Reports for each of the AX Tank Farm tanks.

The KUT concentrations determined from the SGLS data for Hanford Site sediments are as follows: ^{40}K, 10 to 20 pCi/g; ^{238}U, 0.5 to 1.0 pCi/g; and ^{232}Th, 0.5 to 2.0 pCi/g. When logging at an acquisition rate of 100-s stationary measurement per 0.5-ft depth increment, the ^{238}U and ^{232}Th logs had relatively high uncertainty and showed essentially no correlation. However, the ^{40}K concentration data are useful for lithologic correlation among boreholes and often correlate well with geological data that were acquired in the boreholes. The ^{40}K concentrations reflect the fine-grained component in sediments; therefore, these concentrations are indicators of silt or clay content.

The ^{40}K concentration data were analyzed using the geostatistical modeling software that was described previously. The resultant ^{40}K data were reviewed, and several visualizations at different concentration cutoffs were created and reviewed to identify any features or trends within the data. Visualizations of the ^{40}K concentrations above 13.5 pCi/g are presented in Figures 15-26 and 15-27. These figures are views from above the tank farm from the northeast and the northwest respectively; Figure 15-28 is a view from below the tank farm from the northeast.

Where ^{40}K concentrations exceeded 13.5 pCi/g, there were no trends in the ^{40}K data, and the visualizations were featureless and depicted a three-dimensional block of the entire AX Tank Farm data domain. At a cutoff of 13.5 pCi/g, the visualizations show large areas as void spaces where the ^{40}K concentrations are less than 13.5 pCi/g and where decreased ^{40}K concentrations may indicate decreased potassium-rich fine-grained sediments. Where the fine-grained sediments are absent from the pore spaces in the sediments, fluid migration may be enhanced. An extensive region in the northeast portion of the AX Tank Farm indicates these potential conditions. The most extensive ^{137}Cs contamination was detected in boreholes 11-01-10 and 11-03-02, which are located near this region, and coarse and more permeable sediments may have provided a vertical pathway to enhance this migration. This analysis is strictly qualitative and is not intended to be indicative of hydrological or chemical properties of the sediments.

11.0 Impacts and Implications of the Vadose Zone Contamination

11.1 Nature of the Contamination

The primary gamma-emitting contaminant detected in the vadose zone beneath the AX Tank Farm was ^{137}Cs. Only minor quantities of ^{60}Co, ^{154}Eu, and ^{125}Sb were detected, mostly near the ground surface in isolated occurrences that could not be correlated among boreholes. Other gamma-emitting radionuclides were present at the time the tanks leaked (as indicated by historical gross gamma logging results), but they have since decayed to such low levels that they can no longer be detected using current logging methods.

11.2 Extent and Stability of the Contamination

In most cases, the historical Tank Farm gross gamma log data collected in intervals where ^{137}Cs contamination was identified indicate minor changes in intensity from the first detection (which for most of the boreholes was from 1973 to 1975) to the most recently acquired data. Further evaluation of the mobility of this radionuclide can be assessed through detailed monitoring with the sensitive HPGe detectors.

Historical Tank Farms gross gamma-ray log data that were reviewed during the preparation of the Tank Summary Data Reports for the AX Tank Farm tanks indicated changes in the gross gamma-ray data in depth intervals where the present spectral gamma log data show no contamination, indicating that the gross gamma-ray logging system was detecting short-lived gamma-emitting radionuclides. The sources of the contamination from these detections were assessed as ancillary equipment leaks, even though the elevated gross gamma activities were detected deep in the vadose zone, below the depth of the tank bases (e.g. from 69 to 76 ft in borehole 11-01-05). The gross gamma-ray log data indicate that the activities eventually stabilized in all boreholes where dynamic activities were detected.

11.3 Potential Effects of Adjacent Waste Facilities

Several waste disposal facilities were investigated to determine their potential contribution to the vadose zone contamination detected in the vadose zone at the AX Tank Farm. The AX Tank Farm contamination resulted from operations or incidents within the tank farm boundary and there are no indications of contributions from adjacent waste facilities. However, this initial investigation of the AX Tank Farm vadose zone is limited to the upper 100 ft of the vadose zone sediments.

11.4 Impacts to Groundwater

The characterization of the ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{125}Sb contamination distributions in the vadose zone at the AX Tank Farm has not provided evidence that contamination from leaking AX Tank Farm tanks has impacted the groundwater, because the monitoring boreholes are limited to the upper 100 ft of the vadose zone. Although the presence of contaminants in the groundwater monitoring wells adjacent to the AX Tank Farm has been identified, waste disposal facilities upgradient of the monitoring wells may have been the source of this contamination. It cannot be determined from this initial characterization if waste from AX Tank Farm tanks contaminated the groundwater.

12.0 Conclusions

^{137}Cs was detected at the ground surface throughout the AX Tank Farm; ^{60}Co, ^{154}Eu, and ^{125}Sb were detected in several boreholes with near-surface ^{137}Cs contamination. These occurrences resulted from spills and/or leaks associated with tank ancillary piping and equipment. This contamination migrated to varying depths through the sediments, down the inside and/or outside of the borehole casings, or by undetermined pathways.

The highest ^{137}Cs concentrations and most extensive vertical contamination distributions were detected with the SGLSs on the north side of the AX Tank Farm in boreholes 11-01-10 and 11-03-02, which are adjacent to sound tanks. This contamination most likely resulted from a surface source and migrated to depths of more than 100 ft.

The ^{137}Cs concentration profile in borehole 11-03-02 at depths from 33 to 38 ft indicates that the borehole intersected contamination from a subsurface source, such as a piping or tank leak, or from a surface spill that migrated off the top and down the sides of tank AX-103 to a medium that caused the contamination to spread. The historical gross gamma-ray logs acquired between 1975 and 1990 indicate that the intensity and location of this contamination have remained stable since it was identified in the initial gross gamma-ray logging event.

Within the depth range of the boreholes in the AX Tank Farm, there are no identified lithologic horizons that may impede vertical migration. Liquids leaking from the bottoms of tanks may have migrated downward and never reached the lateral extent necessary to be intersected by the monitoring boreholes. Figure 15-29 shows the very limited ^{137}Cs contamination at the depth of the tank bases, and Figure 15-30 shows the ^{137}Cs contamination at a depth of 53 ft below the tank bases. The contamination plume in both of these figures was defined by boreholes 11-01-10 and 11-03-02 and is related to a surface source.

The visualization developed for the ^{40}K concentrations and depicted in Figures 15-26, 15-27, and 15-28, indicates variances in the ^{40}K concentrations may be correlatable to deep migration of ^{137}Cs contamination north of tanks AX-101 and AX-103.

13.0 Use of Data/Interfaces

13.1 Operations

The vadose zone characterization of the AX Tank Farm was conducted to establish a baseline that defines the contamination from gamma-emitting radionuclides in the vadose zone sediments surrounding the tanks. This baseline will be used to compare to future monitoring data to determine if changes have occurred and to assess the potential causes of the changes.

Color visualizations derived from a ^{137}Cs contamination model are presented in this report to illustrate the contamination around the AX Tank Farm tanks (see Section 15.0, "Figures for the AX Tank Farm") defined by data acquired in the tank monitoring boreholes. In addition, the ^{137}Cs model is available with the visualization software so that a visualization of any area of the AX Tank Farm can be generated.

All log data are maintained in a database. Because the logging instruments are calibrated to an in situ radionuclide concentration, borehole log data are available for comparison with concentration data that will be determined in the future, perhaps with other instrumentation. The data from this characterization project can also be correlated and compared with information other than concentration data, such as temperature and moisture data, and any relationships that are developed may provide insight as to the environment within which the contamination exists.

This characterization provides data that may be used for tank farms operations in situations where knowledge of subsurface contamination are important for personnel exposure determinations. Also, the knowledge of the location of subsurface contamination may also be useful for locating excavations and future characterization boreholes.

13.2 Tank Remediation and Waste Retrieval

This baseline characterization of the AX Tank Farm vadose zone contamination provides data needed to understand the scope of the vadose zone cleanup issues. These data can be used in feasibility studies to evaluate the cost and potential effectiveness of various closure options. Additional data pertaining to the distribution and total depth extent of nongamma-emitting radionuclides as well as RCRA constituents may also be required to satisfy the data needs of the SST farm closure process.

13.3 Groundwater Protection and Remediation

Vadose zone contamination is the most significant source of contamination reaching the groundwater at the Hanford Site. Most of the groundwater contamination at the Hanford Site is the result of releases to the vadose zone at the cribs and other waste sites. This characterization of the vadose zone at the AX Tank Farm has provided some insight as to the potential for this SST farm to be a near-term groundwater contamination source.

The *Hanford Site Groundwater Protection Management Plan* (GPMP) (DOE 1995a) outlines the basic strategy used at Hanford to protect the groundwater from further contamination. This strategy includes identifying and controlling sources of contamination, eliminating discharges, and continued monitoring of the groundwater and vadose zone. In the next revision of the GPMP, the SST vadose zone characterization, monitoring methods, and approach can be included as a part of the total groundwater protection strategy.

13.4 Environmental Monitoring Reports

As work begins on remediation of the Hanford Site and plans are prepared, more information is needed about the vadose zone contamination. Therefore, the availability of consistent and comparable vadose zone characterization and monitoring data is important. This vadose zone characterization report is the first such characterization report for the AX Tank Farm. It is important to summarize and report the results of this work in other Hanford characterization and monitoring reports to make the information available to professionals working on the remediation or monitoring programs.

The primary environmental monitoring report in which to summarize and reference the findings of this study is an annual report published by PNNL; the *Hanford Site Environmental Report for Calender Year 1995* (DOE 1996a) is an example. This publication provides a summary of environmental data and information, describes environmental management performance, and demonstrates the status of compliance with environmental regulations. Discussions of the tank farm vadose zone characterization activities that were conducted in 1996 are included in the draft of the *Hanford Site Environmental Report for Calender Year 1996.*

14.0 Recommendations

14.1 Tank and Tank Farm Characterization Data

It is recommended that additional work be conducted to collect, catalog, assess, and analyze historical documents, publications, and records pertaining to the tanks and tank farms. There is a scarcity of available historical information about the tanks, and access to these data is limited.

Some comprehensive work on collecting historical data was performed and is presented in a multivolume publication (Brevick et al. 1994a and 1994b). Continuation of that work is recommended, as well as expansion to include more information that is not directly tied to tank contents information such as some of the significant operational records. This work should also include assessments of the data that would be valuable to operations and remediation decision makers.

It is recommended that valid leak-volume estimates be determined. For the leak-volume estimates to be valid, they must include estimates of the precision and accuracy of the determinations. An evaluation of tank leaks that assigns a leak volume to a tank as an average

among several tanks that leaked has little validity. A search for records with valid information should be instigated.

14.2 Improvements to Spectral Gamma Logging

It is recommended that a spectral-shape factor analysis method be performed to analyze ^{137}Cs contamination identified in logs from borehole 11-01-10. Shape factor analysis is an analytical technique that helps distinguish between ^{137}Cs contamination located on the borehole casing, ^{137}Cs uniformly distributed in the formation near the borehole, and ^{137}Cs located remotely from from the outside of the borehole. The shape factor analysis does not produce unequivocal results; however, with an understanding of the uncertainties and inaccuracies of the method, the results may help to explain contaminant distributions.

14.3 Additional Logging Characterizations

Although borehole geophysical methods do not provide all the required characterization data, they are favorable for characterization because the methods are cost effective and safe, and because there are numerous existing boreholes that allow access to the subsurface. Other borehole geophysical methods, such as moisture, porosity, and carbonate logging are recommended for development and implementation at the Tank Farms to provide better characterization data.

Because moisture movement provides the most likely driving force for the migration of radionuclides, a project should be implemented to log all the boreholes with an effective moisture-assay logging tool. Like the SGLSs, a moisture logging sonde must be properly characterized, calibrated, and documented before a full-scale logging project begins. Development of a baseline of the moisture conditions in the vadose zone may help identify stratigraphy and permit future determinations of moisture changes.

Porosity or pore volume is another parameter that strongly controls the migration of contaminants through the vadose zone. Porosity can be deduced from measurements of the formation bulk density. Because there is a potential for variations in the bulk density of the material next to the casing as a result of the drilling process, any formation bulk-density sonde must be designed to remove the effect of the near-hole variations in density. To date, no formation bulk-density sonde has been successful in measuring the formation bulk density in the presence of such a near-hole density variation. A formation bulk-density logging sonde should be developed for future use in characterizations of the SST farms.

Carbon/oxygen logging technology should be evaluated for possible deployment in the Hanford Tank Farms. This type of log might show that changes in the calcium-carbonate content are related to changes in the lithology; therefore, this log data would be a useful tool for lithologic correlation. Even though the lithology of the Hanford formation varies significantly over short distances, calcium-carbonate content may provide insight on the nature of the contamination distribution profiles. The calcium carbonate fills pore spaces in sediments, making them more impervious to fluid migration. Implementation of carbon/oxygen logging for vadose zone

characterization at the Hanford Site would require calibrating the logging sondes to borehole-specific conditions encountered in the vadose zone and analyzing and interpreting the results.

14.4 Additional Vadose Zone Characterizations

This report presents an initial characterization of the vadose zone at the AX Tank Farm. Because of the limited scope of this project, additional characterization activities should be accomplished before the baseline characterization can be considered complete or even moderately comprehensive. There is some degree of uncertainty and skepticism, in some cases, about conclusions regarding the actual distribution of contamination around the boreholes. This uncertainty and skepticism must be resolved. Therefore, it is recommended that additional characterization of the vadose zone be performed.

In the upper portion of the vadose zone, emphasis should be placed on determining the concentrations and distributions of radionuclides and contaminants that do not emit gamma radiation, which includes many of the high-risk radionuclides, as well as RCRA constituents. Knowledge of the distribution of these contaminants is a basic data need for determination of long-term risks that are used to evaluate proposed remedial actions, as well as tank waste retrieval alternatives.

Characterization of the upper vadose zone should include a characterization of the sediment chemistry. Knowledge gained with this type of characterization will lead to a better understanding of contaminant transport mechanisms that are required to predict future risks.

Characterization of the upper vadose zone should also conclusively determine the extent of contaminant migration down the outside of the borehole casings. This contamination defined a significant amount of the plume development above and surrounding the tanks in the AX Tank Farm.

14.5 Future Vadose Zone Monitoring

Recommendations regarding future vadose monitoring presented in the Tank Summary Data Reports for each tank resulted from interpretation of the spectral gamma-ray data and review of historical information for the tanks. The following suggestions for future monitoring are based on the recommendations stated in the Tank Summary Data Reports, along with additional information and knowledge that was gained in the preparation of this report.

Several tanks contain sufficient volumes of liquids to contaminate large volumes of vadose zone sediments if the tanks leaked. As the tanks become older, their integrity diminishes, and the potential for leaks increases. DOE is required to monitor the nature and extent of the contamination that leaks from the tanks as well as determine the extent of migration and stability of the contamination. Although the vadose zone monitoring is not a primary leak-detection method (in-tank leak detection methods are far more precise), it may help confirm a leak and evaluate the extent of the contamination.

Tank AX-101

This tank still contains approximately 320,000 gal of drainable liquid waste that would create a significant contamination plume if the tank leaked. The ^{137}Cs contamination in borehole 11-01-10 should be monitored for stability of this contamination, especially at depth intervals appropriate for the level of the waste presently contained in the tank.

Tank AX-102

Boreholes 11-02-01 and 11-02-02 should be monitored from depths of 50 to 72 ft in borehole 11-02-01 and from depths of 30 to 53 ft in borehole 11-02-02. The ^{137}Cs contamination in these boreholes may indicate leakage from tank AX-102, and the stability of this contamination should be verified.

Tank AX-103

This tank contains approximately 36,000 gal of drainable liquid waste. Boreholes 11-03-02, 11-03-09, and 11-03-12 should be monitored to detect changes in the ^{137}Cs concentration profiles at depths between 33 and 45 ft. The contamination detected in these intervals may be related to leakage from tank AX-103.

Tank AX-104

Boreholes 11-04-05, 11-04-19, and 11-04-08 should be monitored for changes in the ^{137}Cs concentration profiles at approximately 55 ft in depth. The ^{137}Cs contamination detected in these boreholes is suspected to have resulted from leakage of tank AX-104.

15.0 Figures for the AX Tank Farm

Many of the AX Tank Farm visualizations are printed and copied in color on one side of the page only. This section contains the figures discussed in the text of the report in the order in which they were presented.

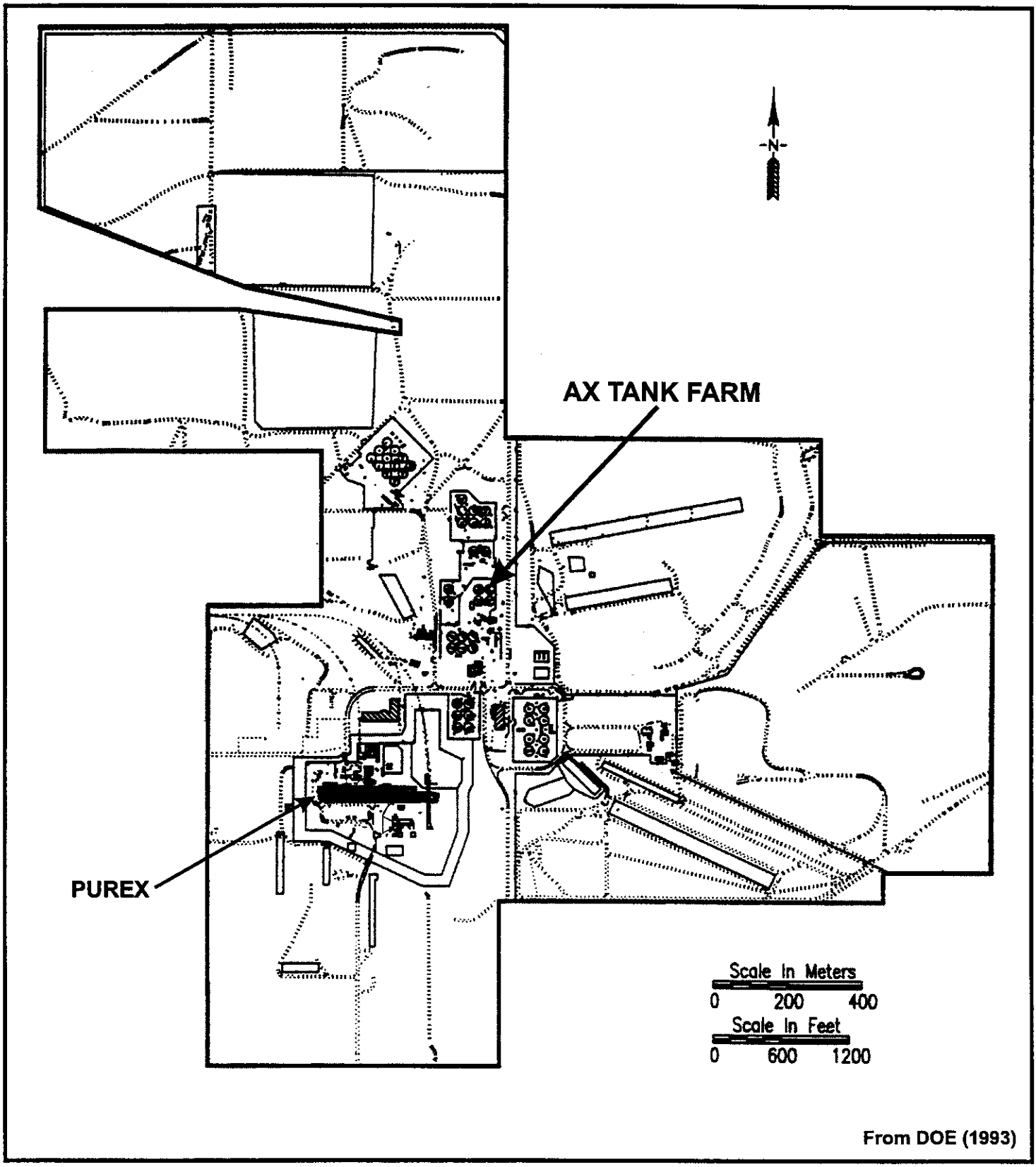
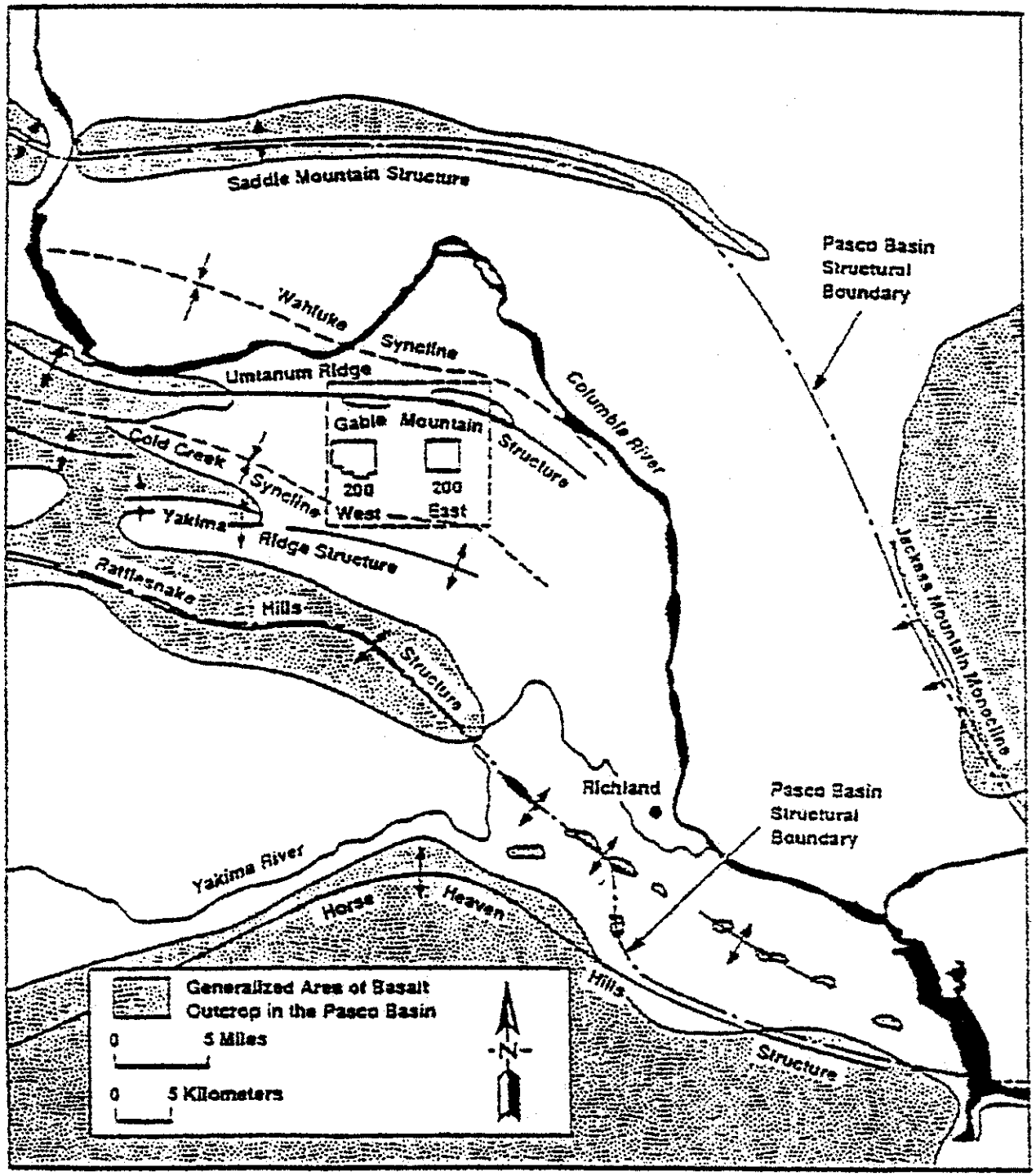


Figure 15-1. Map of the Eastern Portion of the Hanford Site 200 East Area Showing the Location of the AX Tank Farm



From Caggiano and Goodwin (1991)

Figure 15-2. Geologic Structure of the Pasco Basin in the Vicinity of the Hanford Site

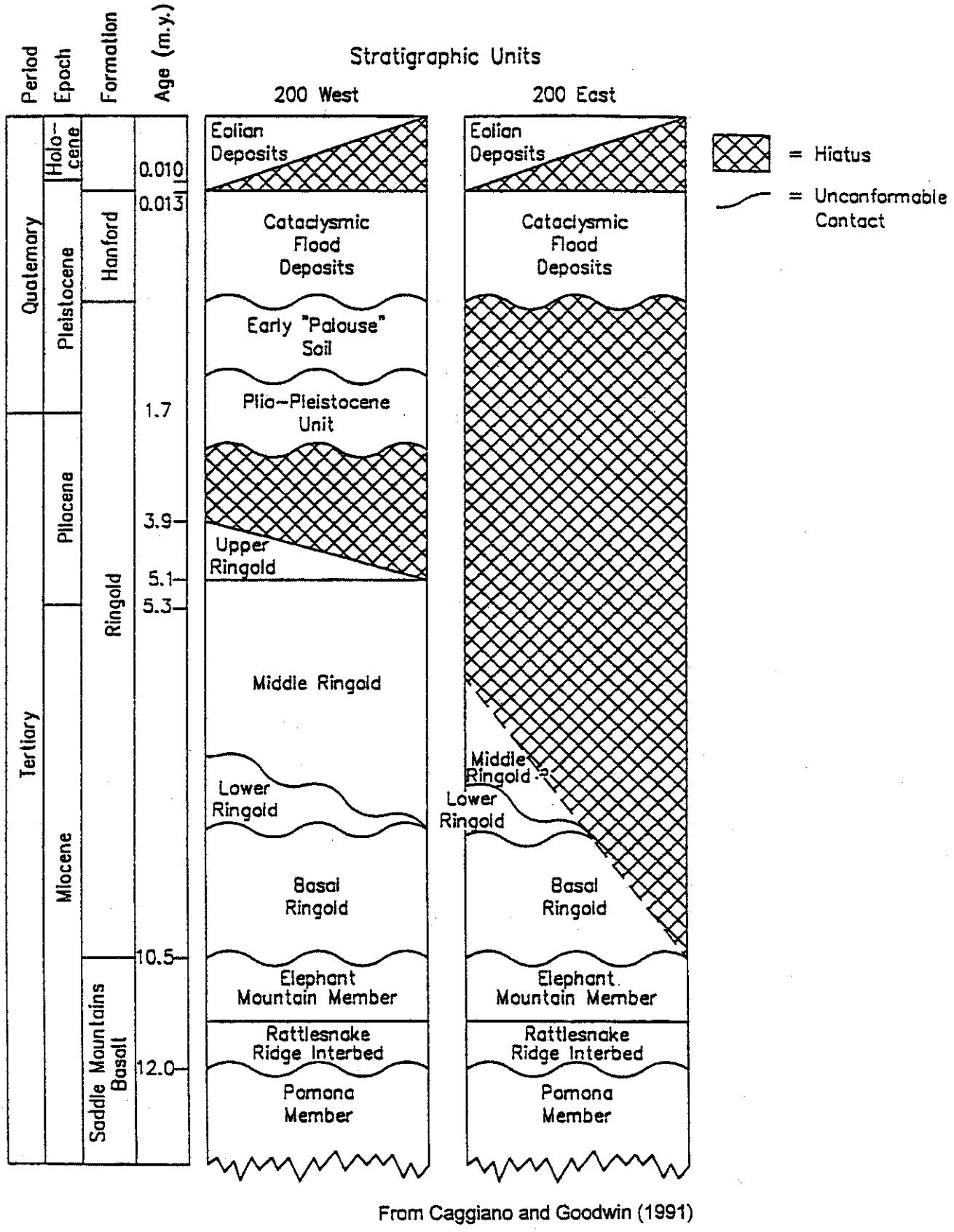


Figure 15-3. Stratigraphic Columns of the 200 East and 200 West Areas of the Hanford Site

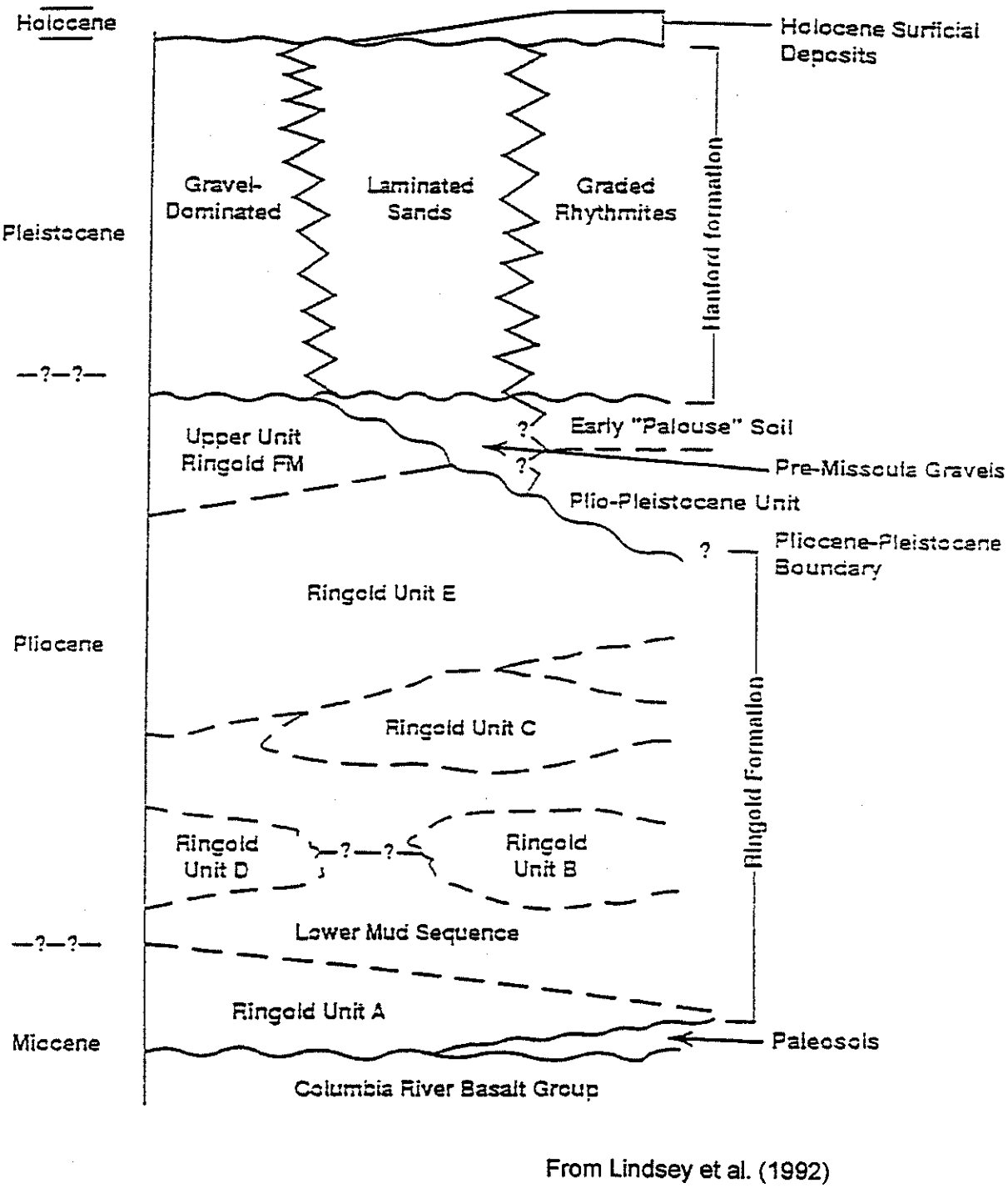


Figure 15-4. Generalized Stratigraphy of the Suprabasalt Sediments at the Hanford Site

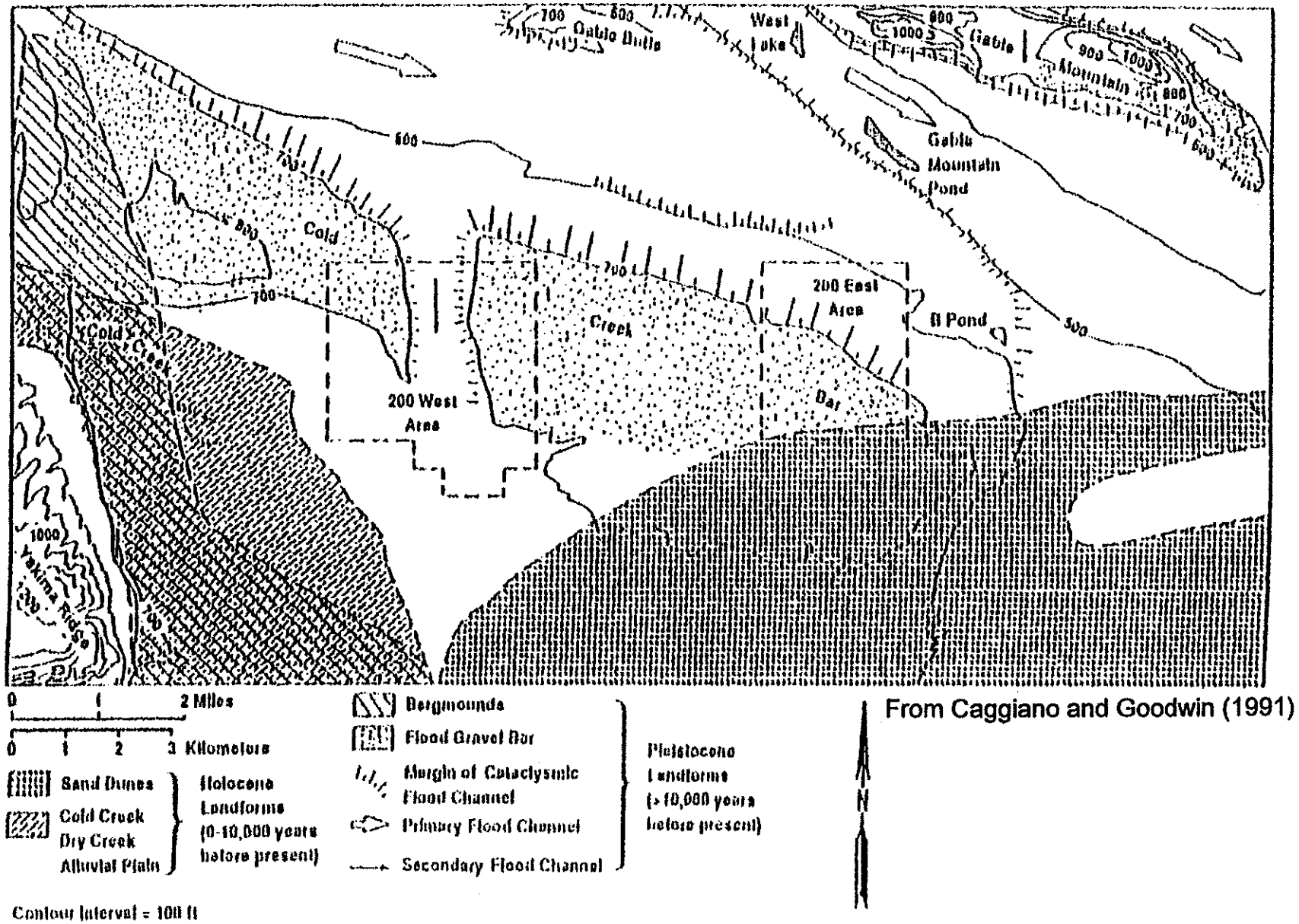


Figure 15-5. Geomorphological Map of the 200 East and 200 West Areas at the Hanford Site

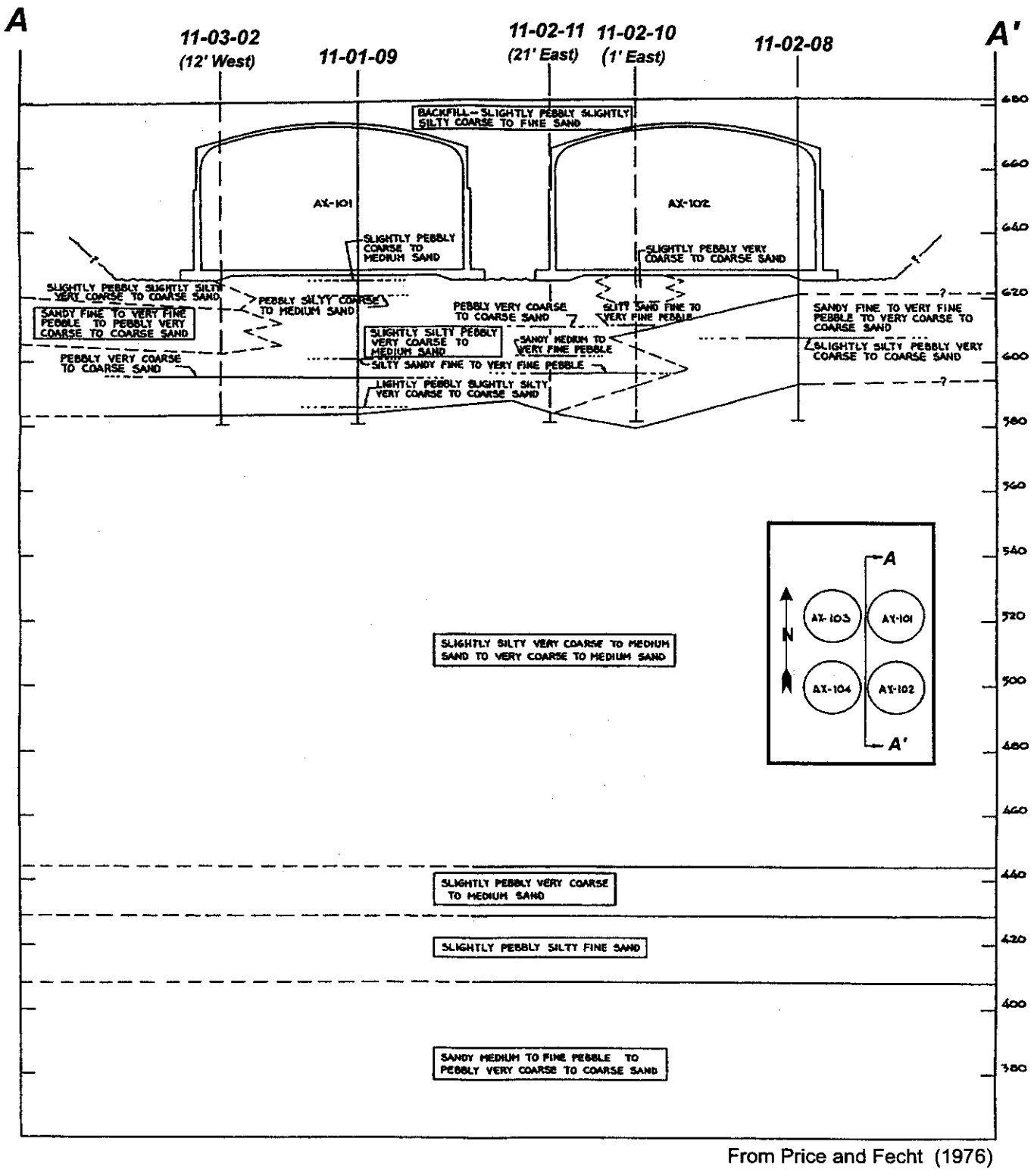


Figure 15-6. Cross Section A-A' Across the AX Tank Farm

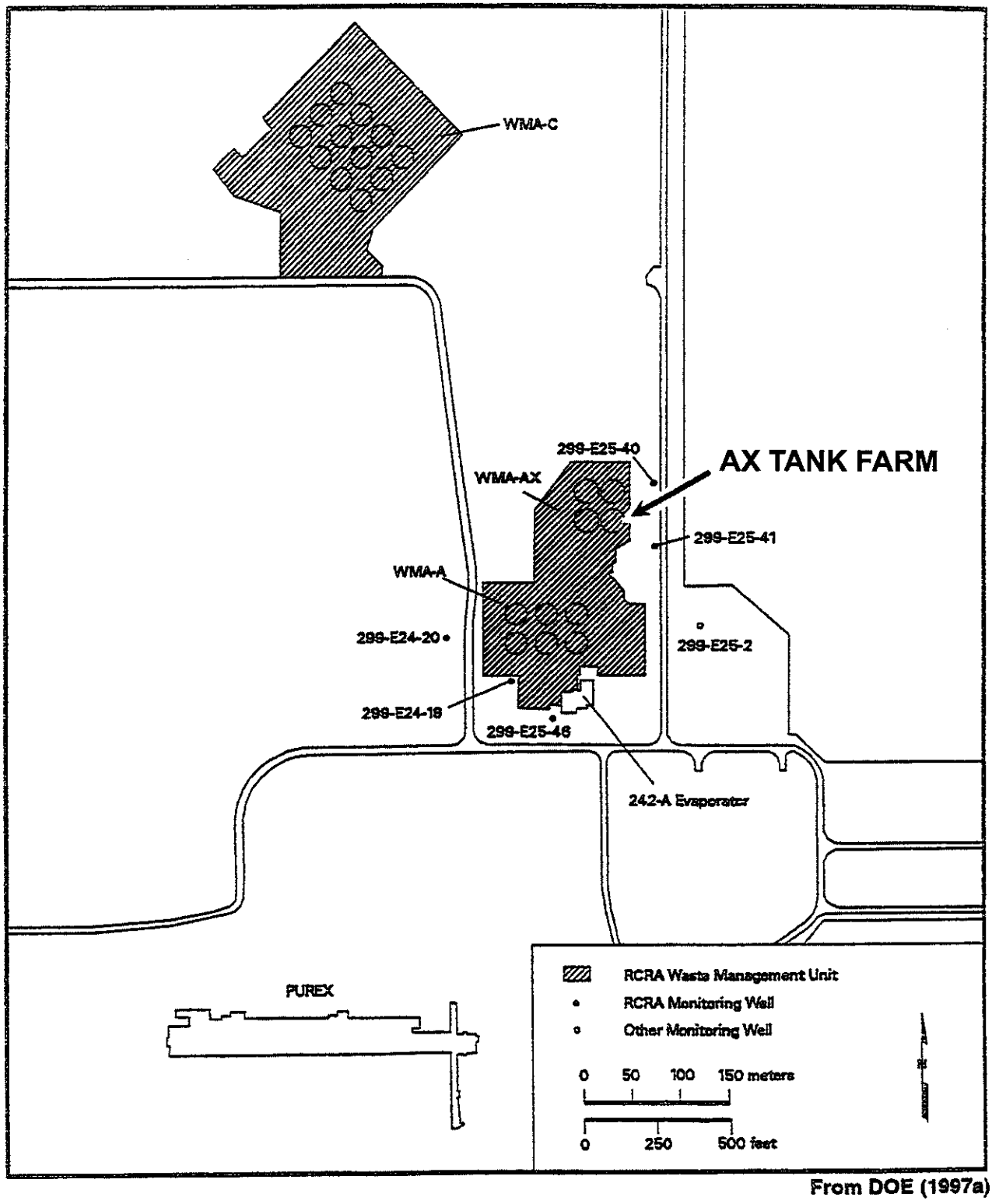


Figure 15-7. Plan Map of the Hanford Site AX Tank Farm Showing Adjacent Groundwater Monitoring Wells

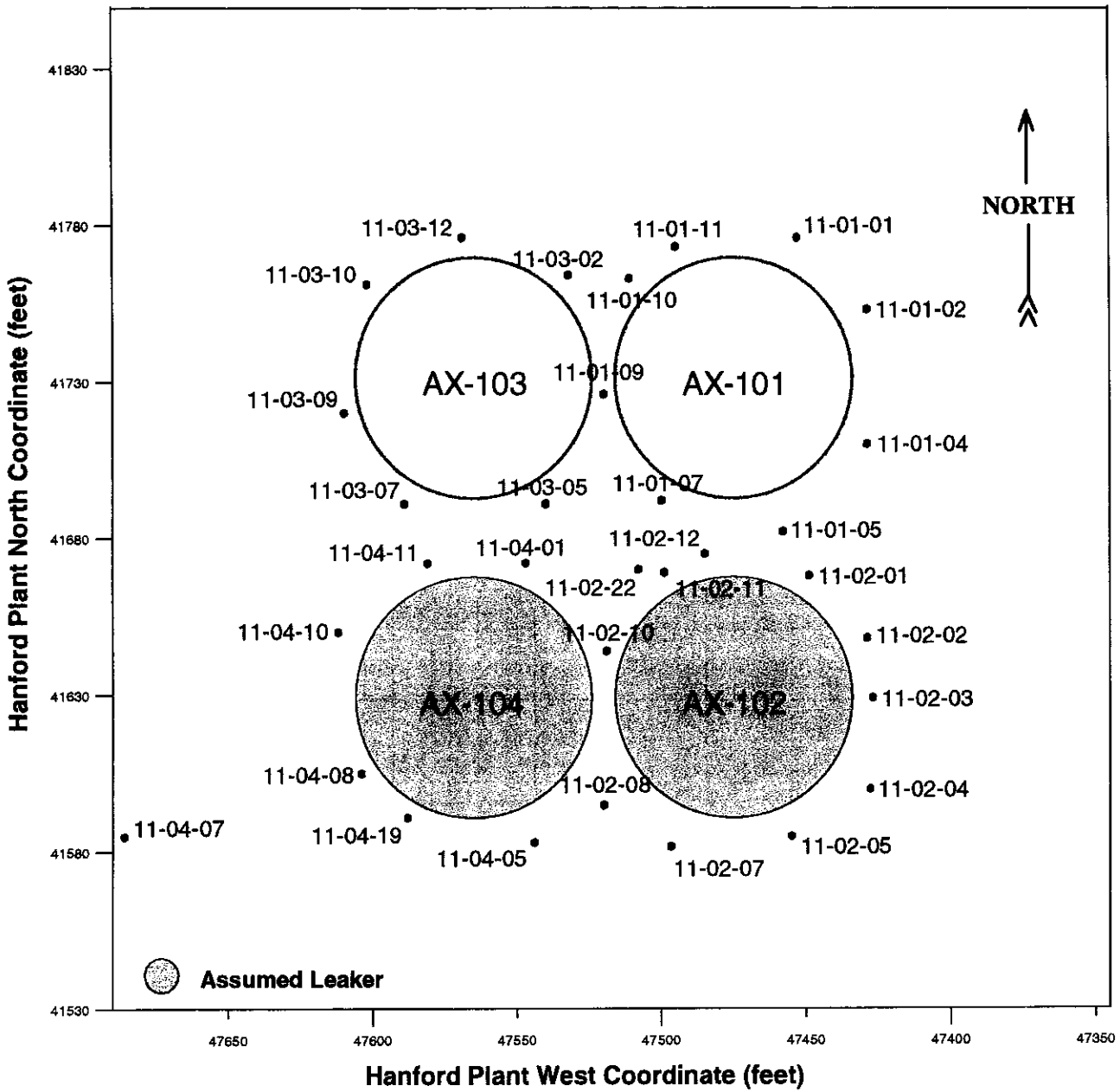
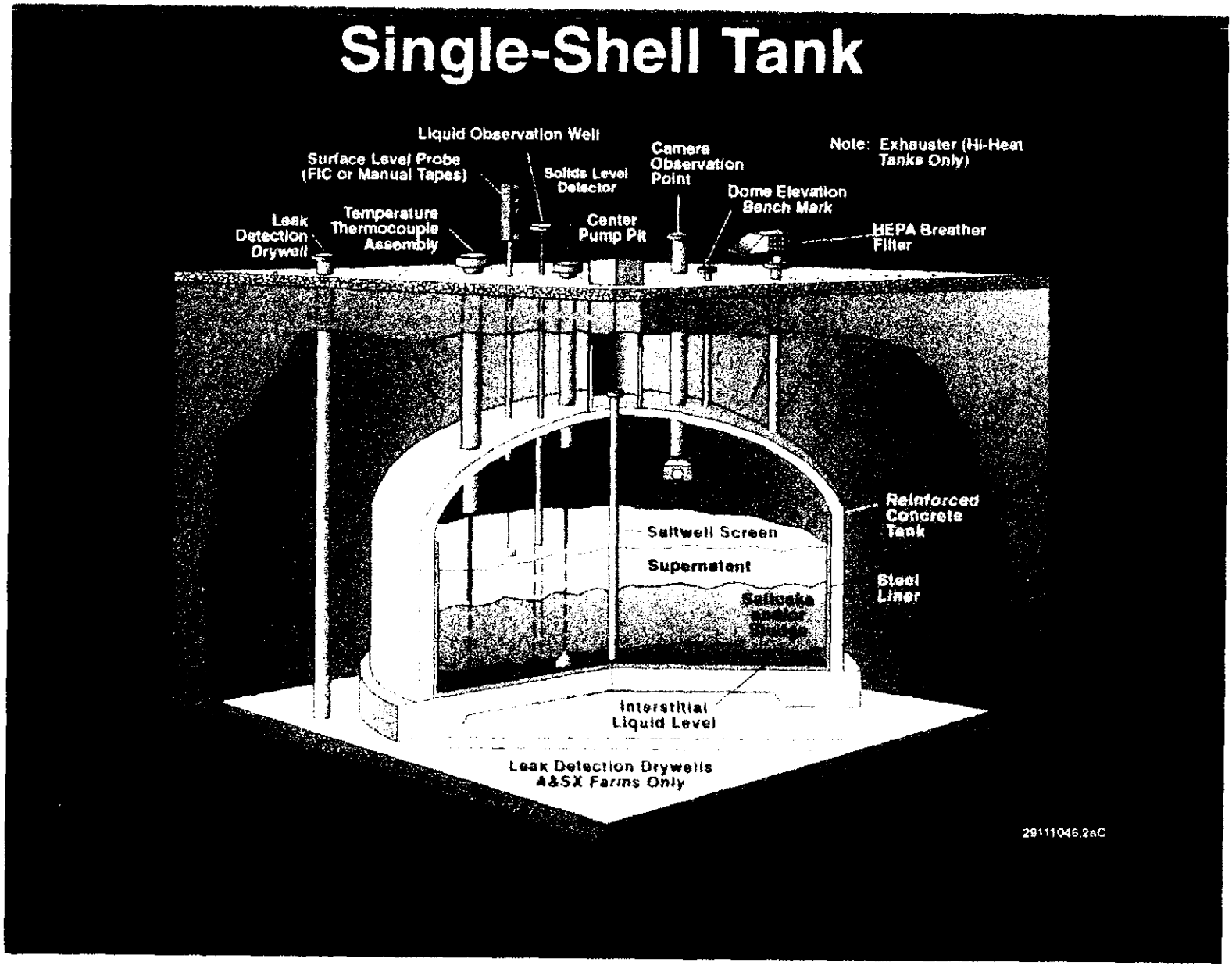


Figure 15-8. Plan Map of the Hanford Site AX Tank Farm Showing the Tank Monitoring Boreholes



From Hanlon (1997)

Figure 15-9. Cutaway View of a Typical Single-Shell Tank With Risers and Instrument Ports

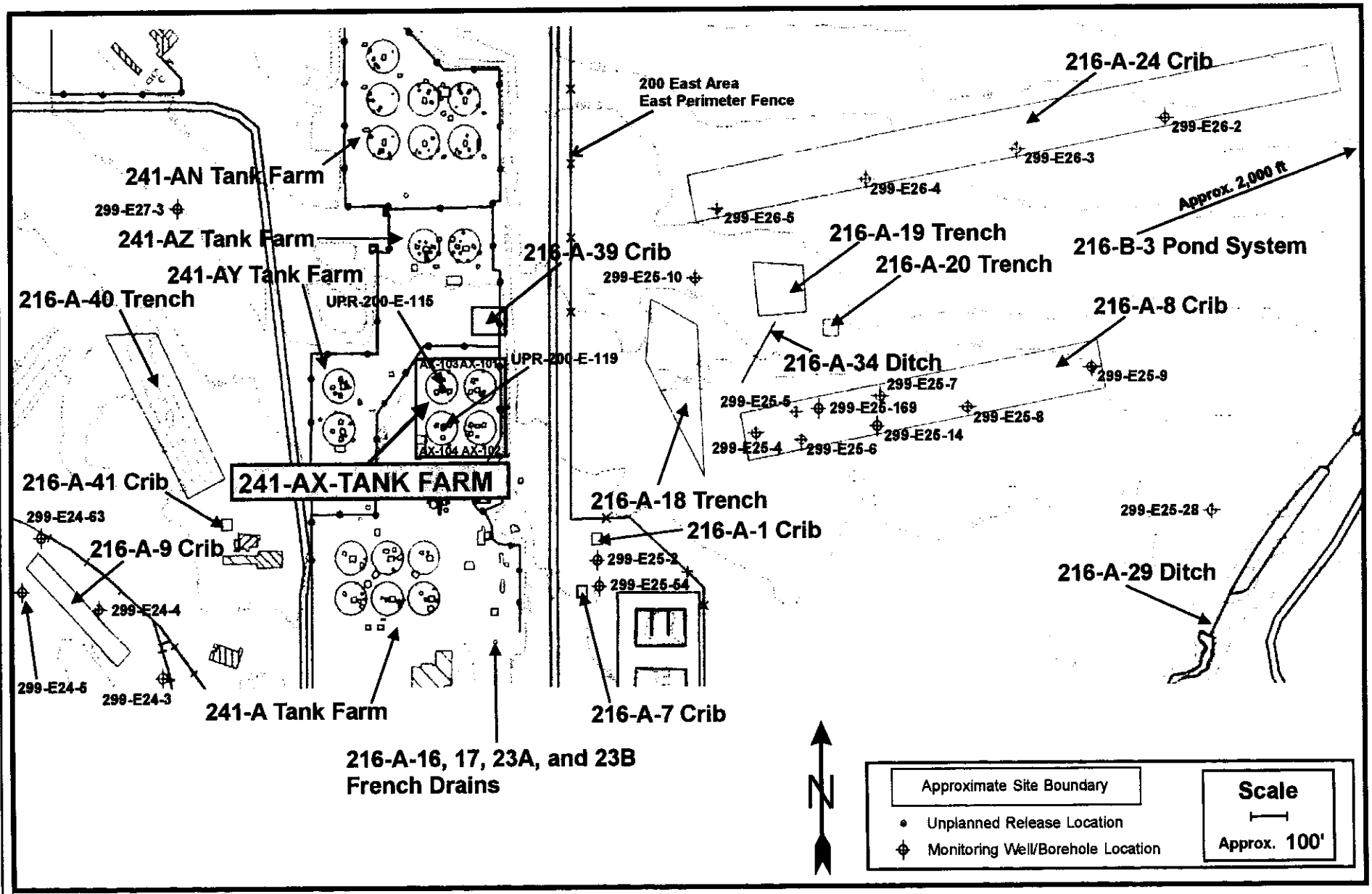


Figure 15-10. Plan Map of the Hanford Site in the Area of the AX Tank Farm Showing Surrounding Facilities and Unplanned Release and Monitoring Locations

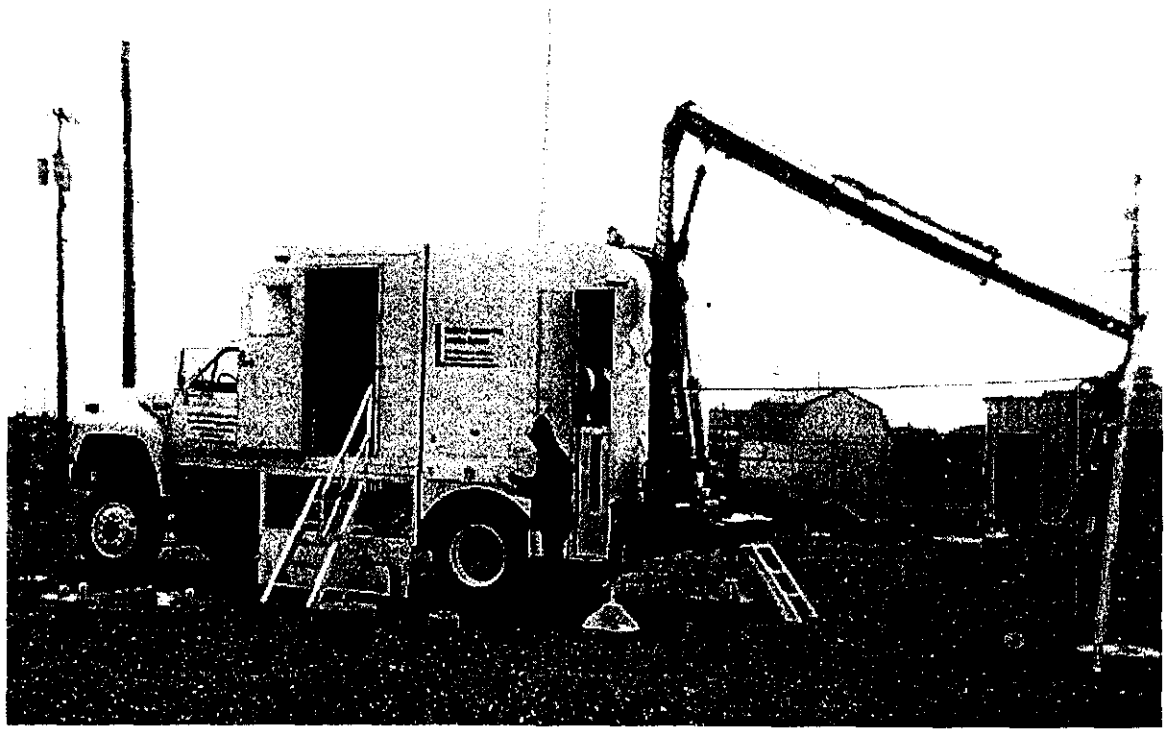


Figure 15-11. View of a Spectral Gamma Logging System Rigged for Logging

Figure 15-12. Sonde With High-Purity Germanium Detector Suspended Over a Borehole

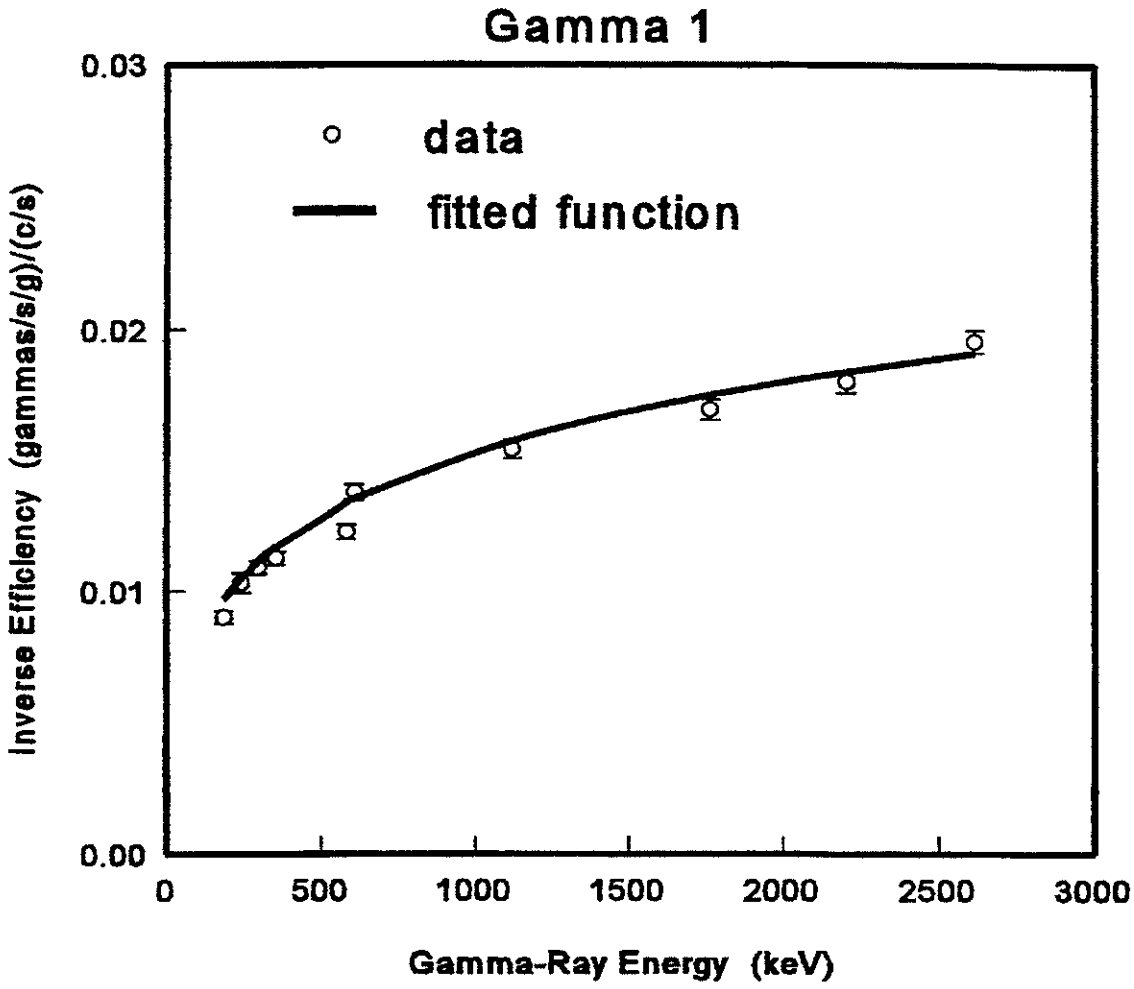


Figure 15-13. SGLS Base Calibration Efficiency Function

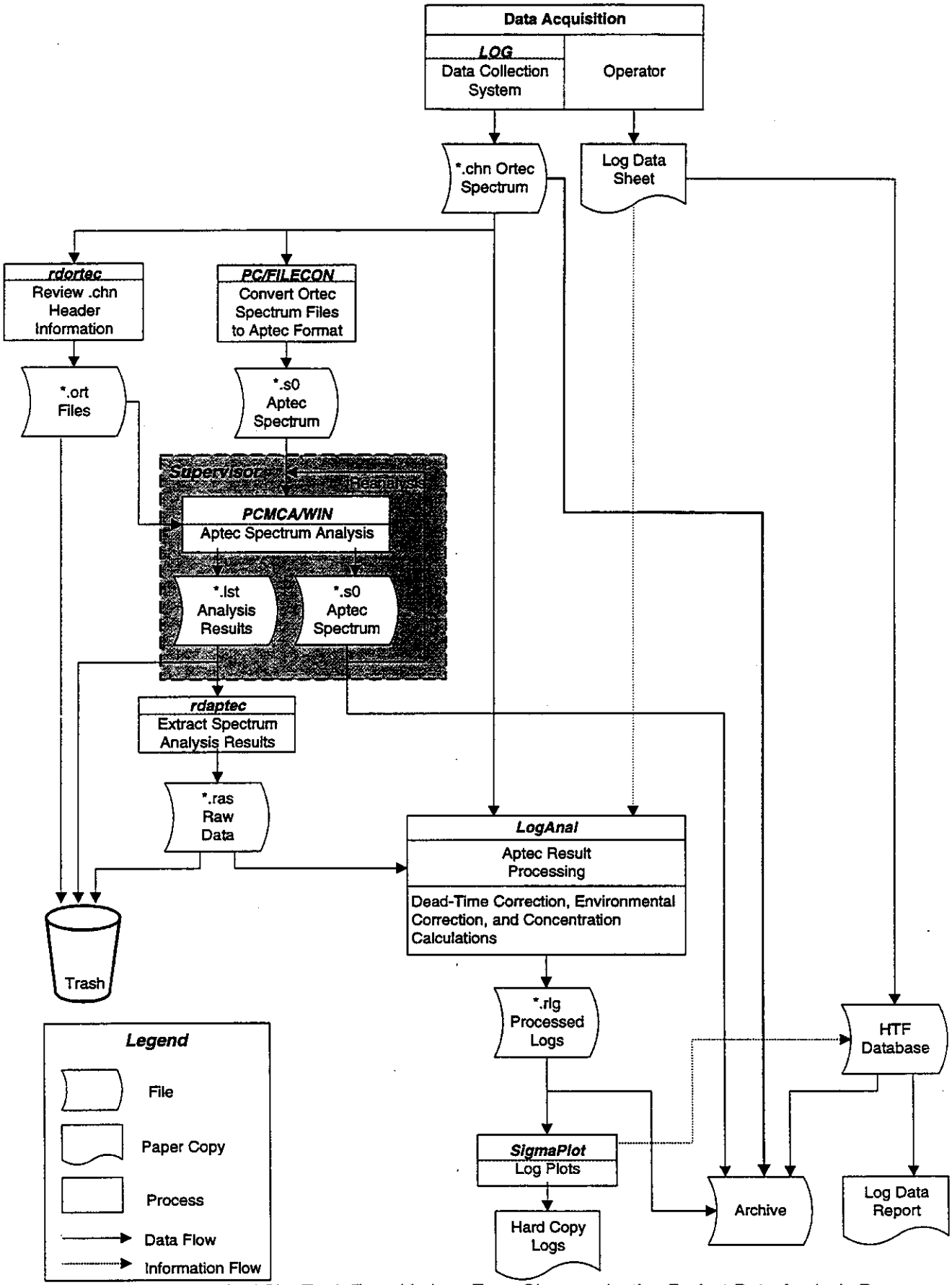


Figure 15-14. Hanford Site Tank Farm Vadose Zone Characterization Project Data Analysis Process

Figure 15-15. Visualization of the ^{137}Cs Contamination at a Depth of 10 Ft in the AX Tank Farm Viewed From Above the Tanks

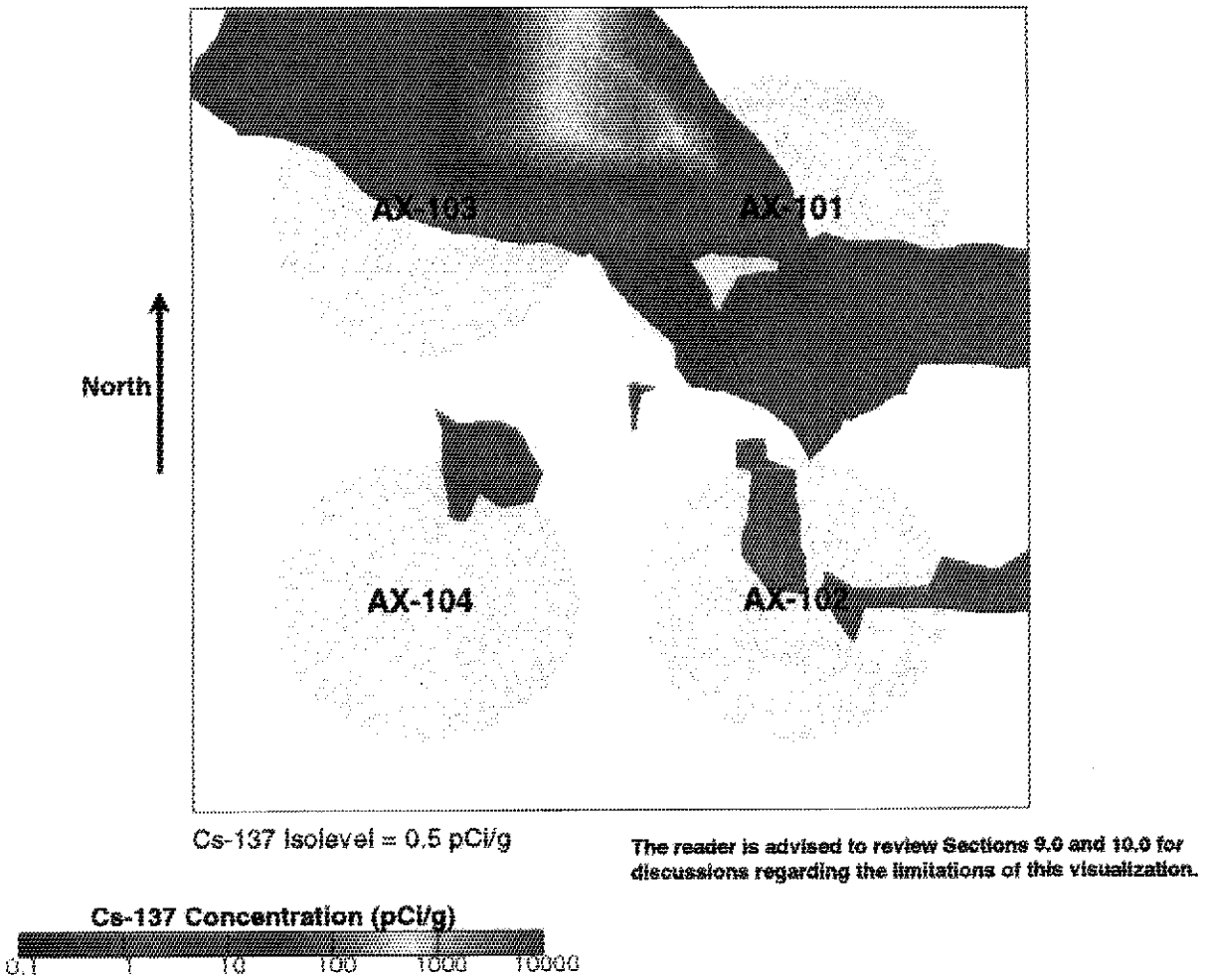


Figure 15-16. Visualization of the ^{137}Cs Contamination at a Depth of 21 Ft in the AX Tank Farm Viewed From Above the Tanks

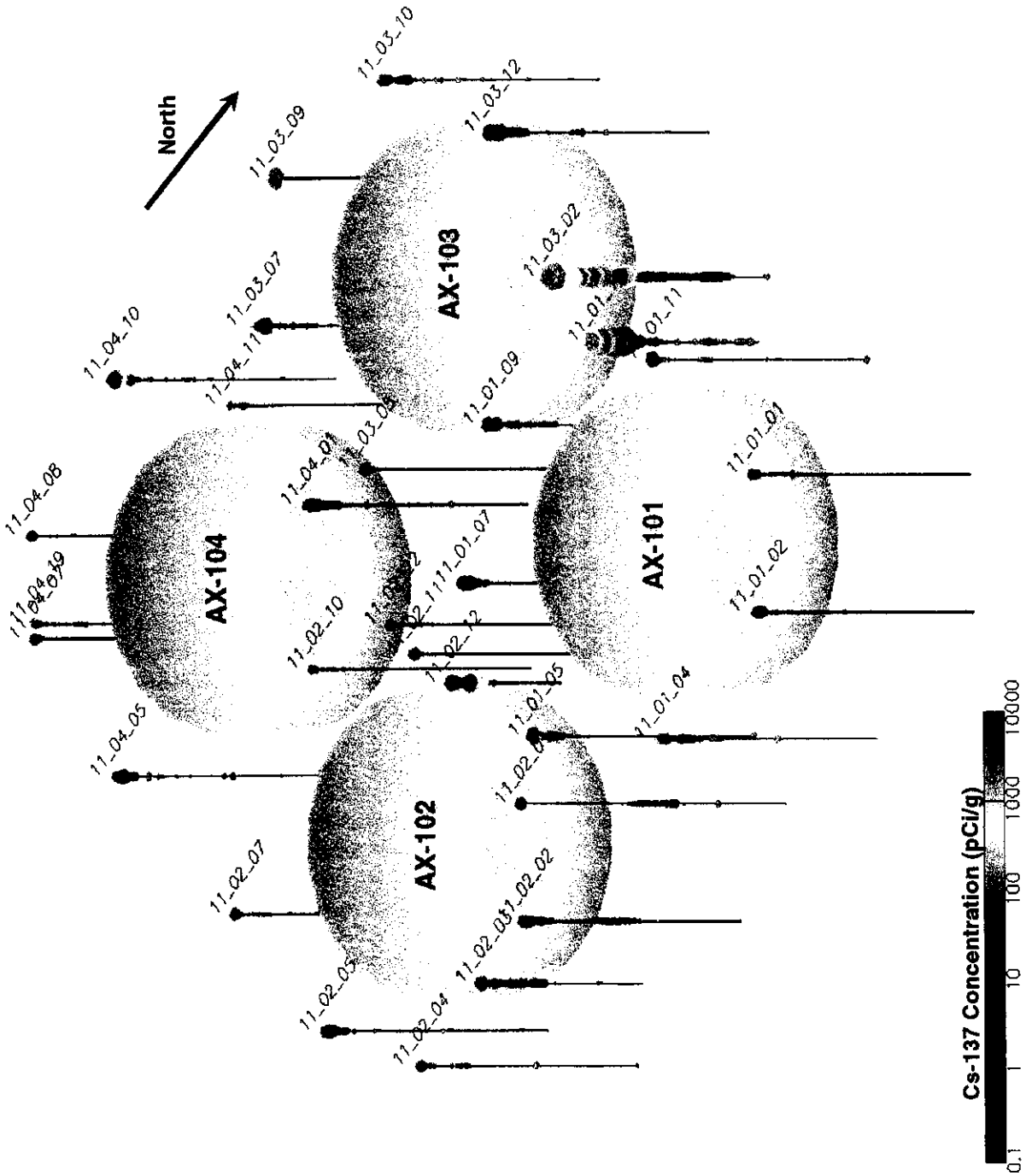


Figure 15-17. Visualization of the ^{137}Cs SGLS Data Acquired at the AX Tank Farm

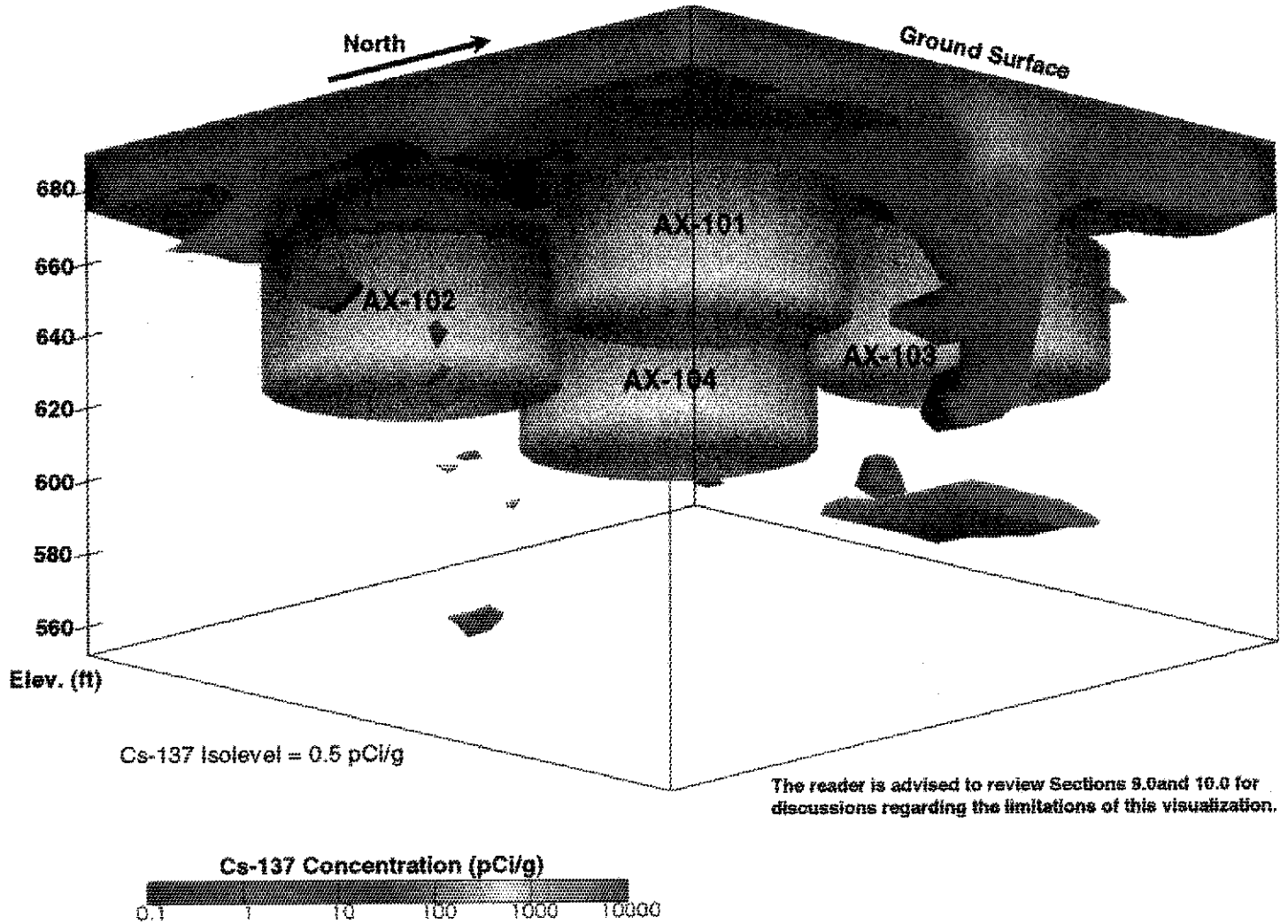


Figure 15-18. Visualization of the ^{137}Cs Contamination in the AX Tank Farm Viewed From Below the Tanks From the Northeast

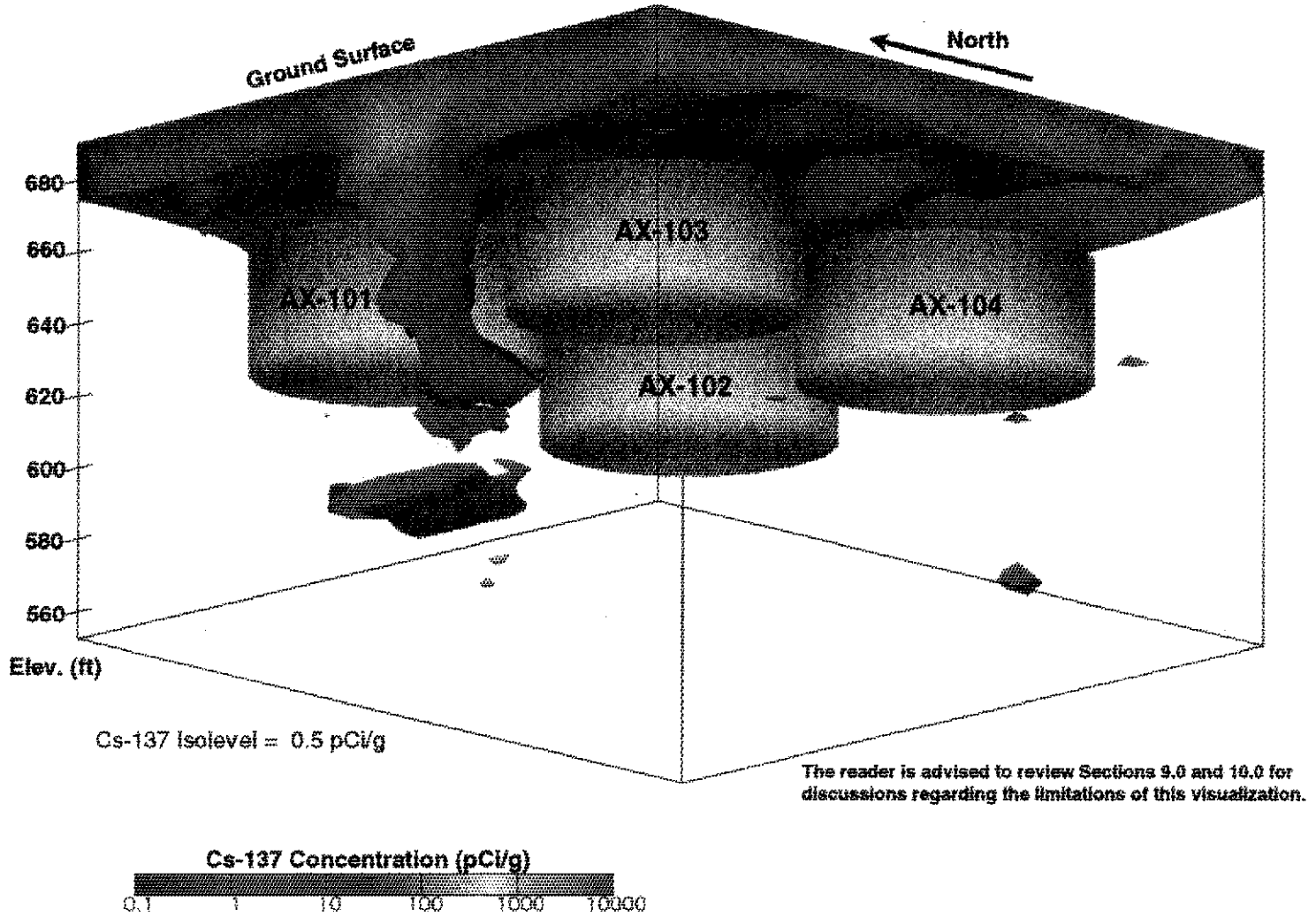


Figure 15-19. Visualization of the ^{137}Cs Contamination in the AX Tank Farm Viewed From Below the Tanks From the Northwest

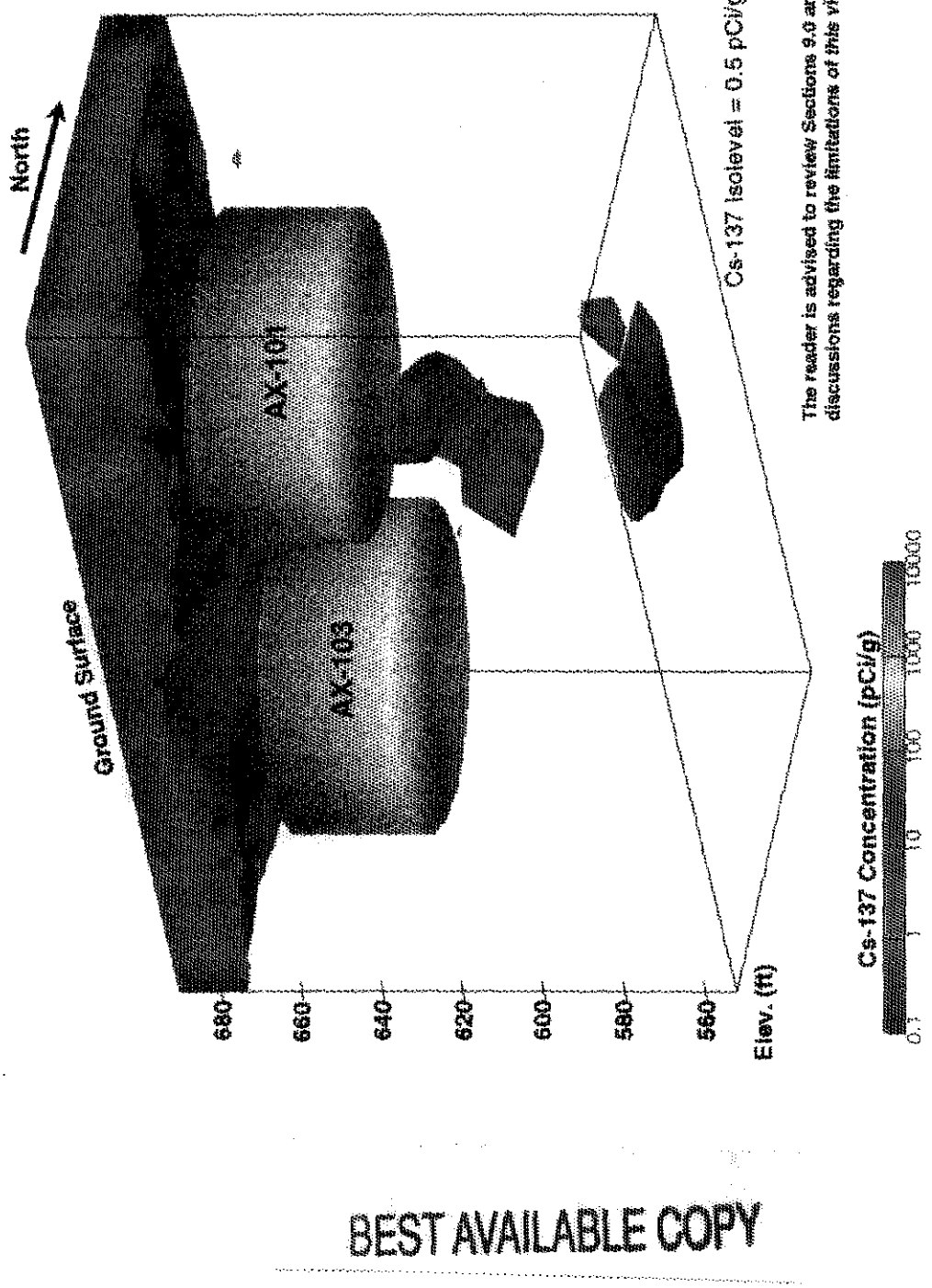


Figure 15-20. Visualization of the ^{137}Cs Contamination Surrounding Tanks AX-101 and AX-103 Viewed From Below the Tanks From the Southeast

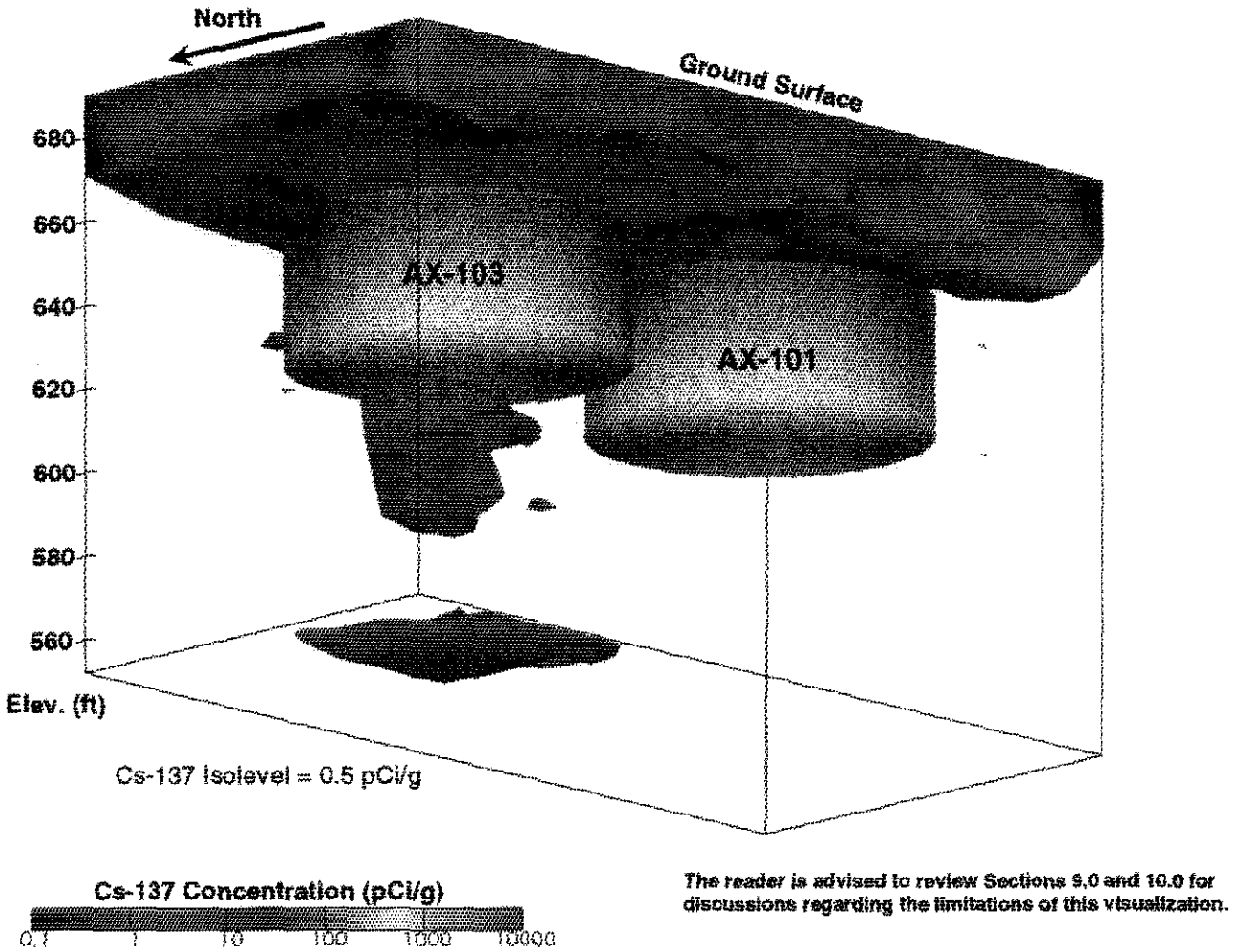


Figure 15-21. Visualization of the ^{137}Cs Contamination Surrounding Tanks AX-101 and AX-103 Viewed From Below the Tanks From the Southwest

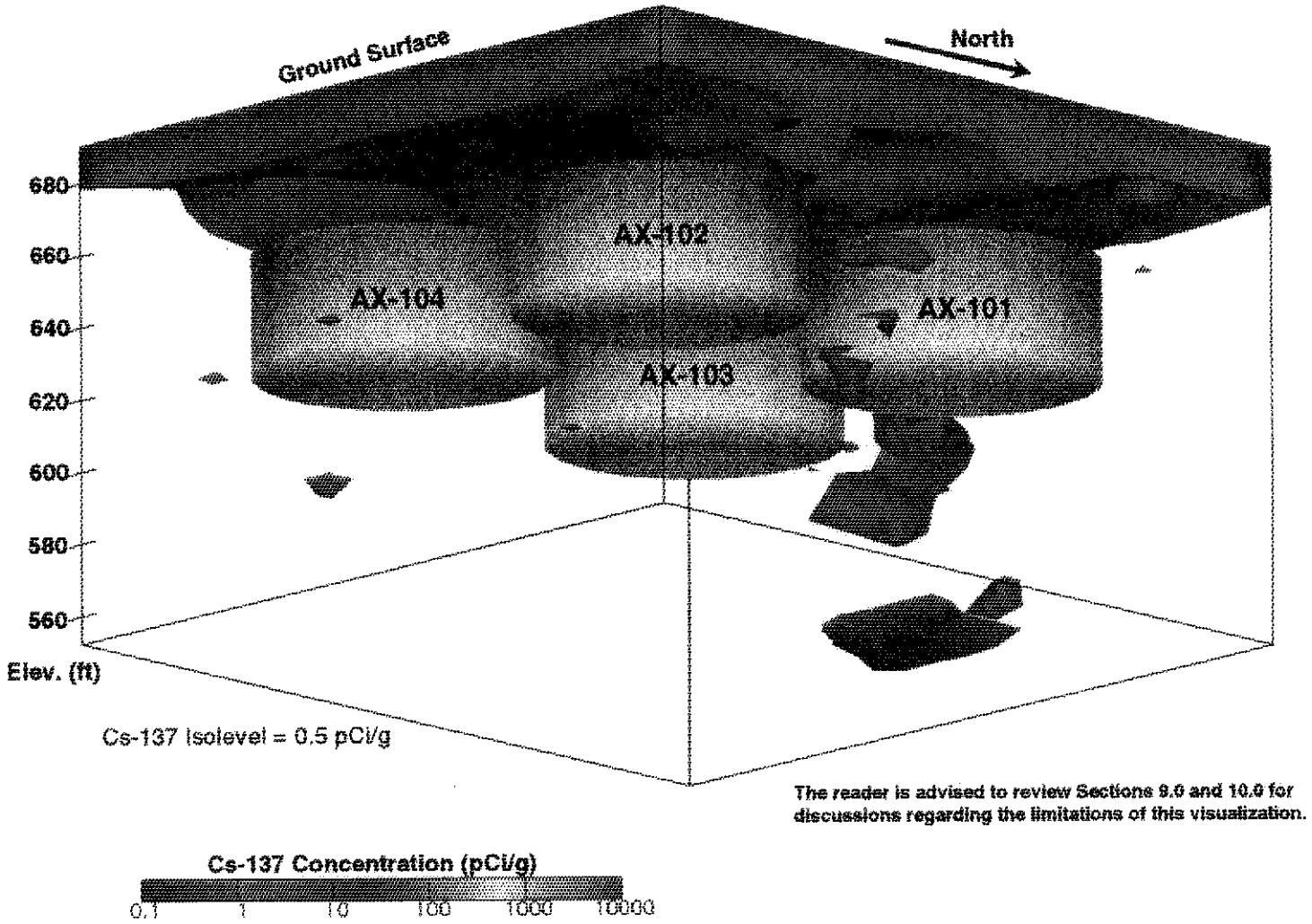


Figure 15-22. Visualization of the ^{137}Cs Contamination in the AX Tank Farm Viewed From Below the Tanks From the Southeast

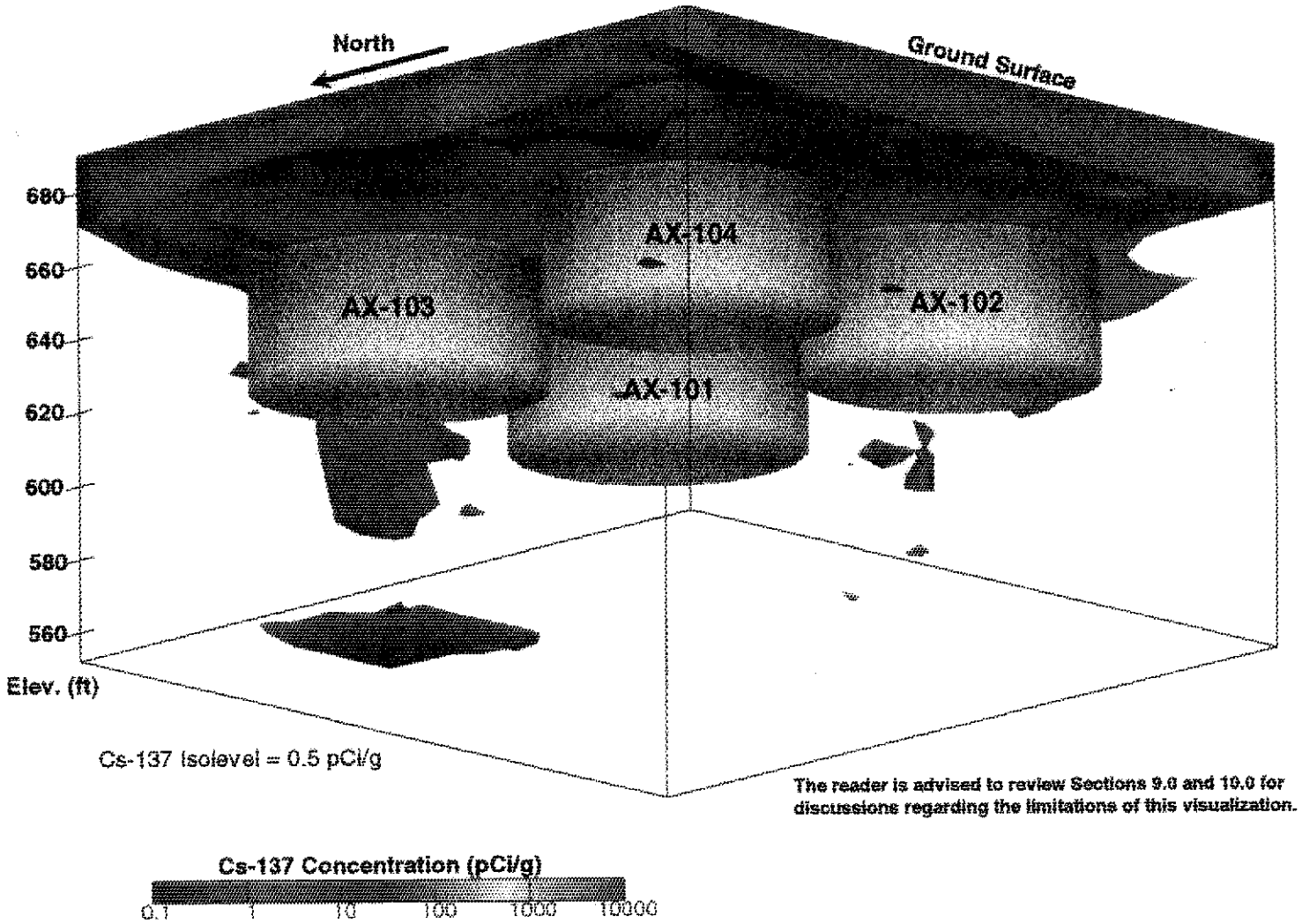


Figure 15-23. Visualization of the ^{137}Cs Contamination in the AX Tank Farm Viewed From Below the Tanks From the Southwest

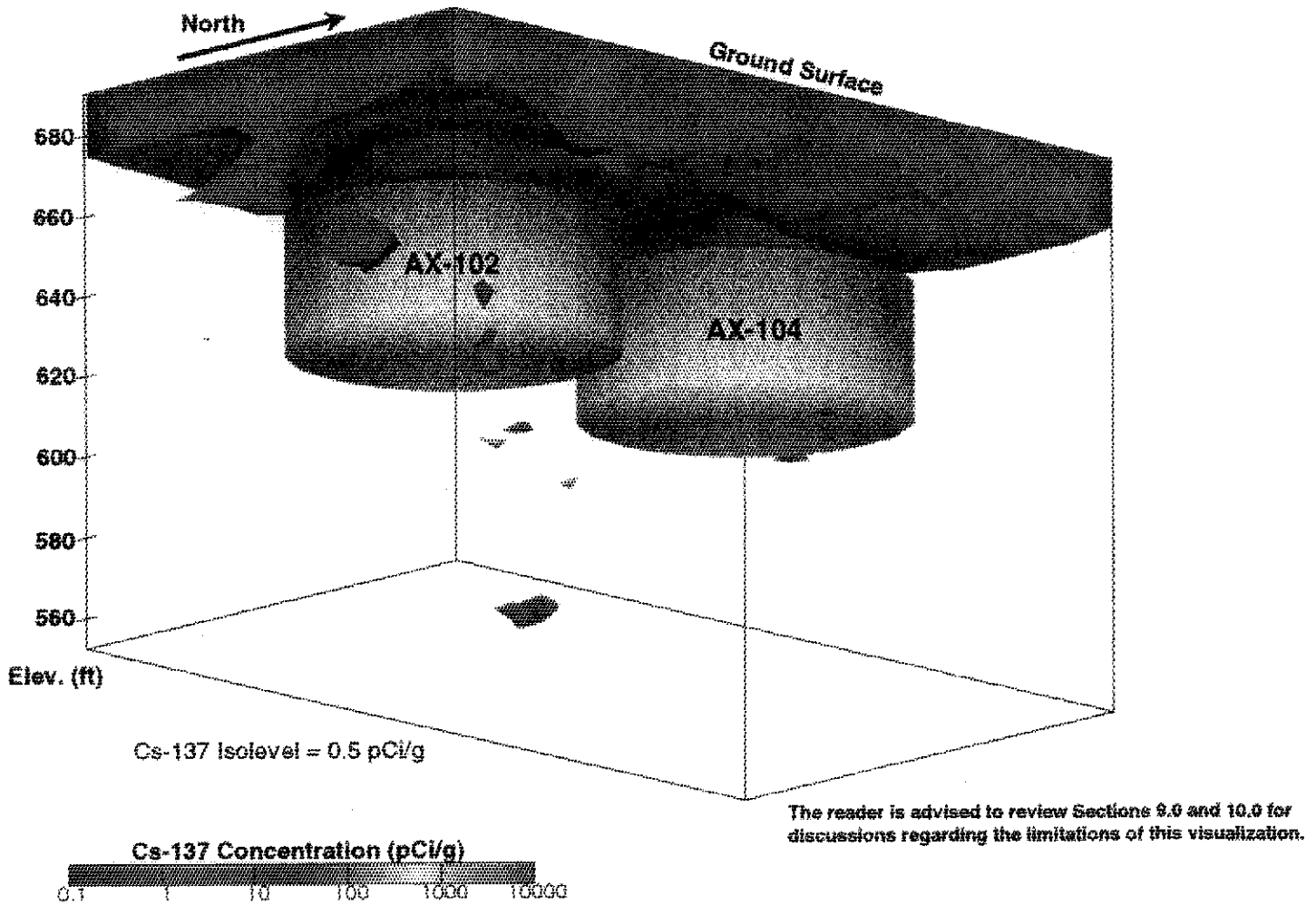


Figure 15-24. Visualization of the ^{137}Cs Contamination Surrounding Tanks AX-102 and AX-104 Viewed From Below the Tanks From the Northeast

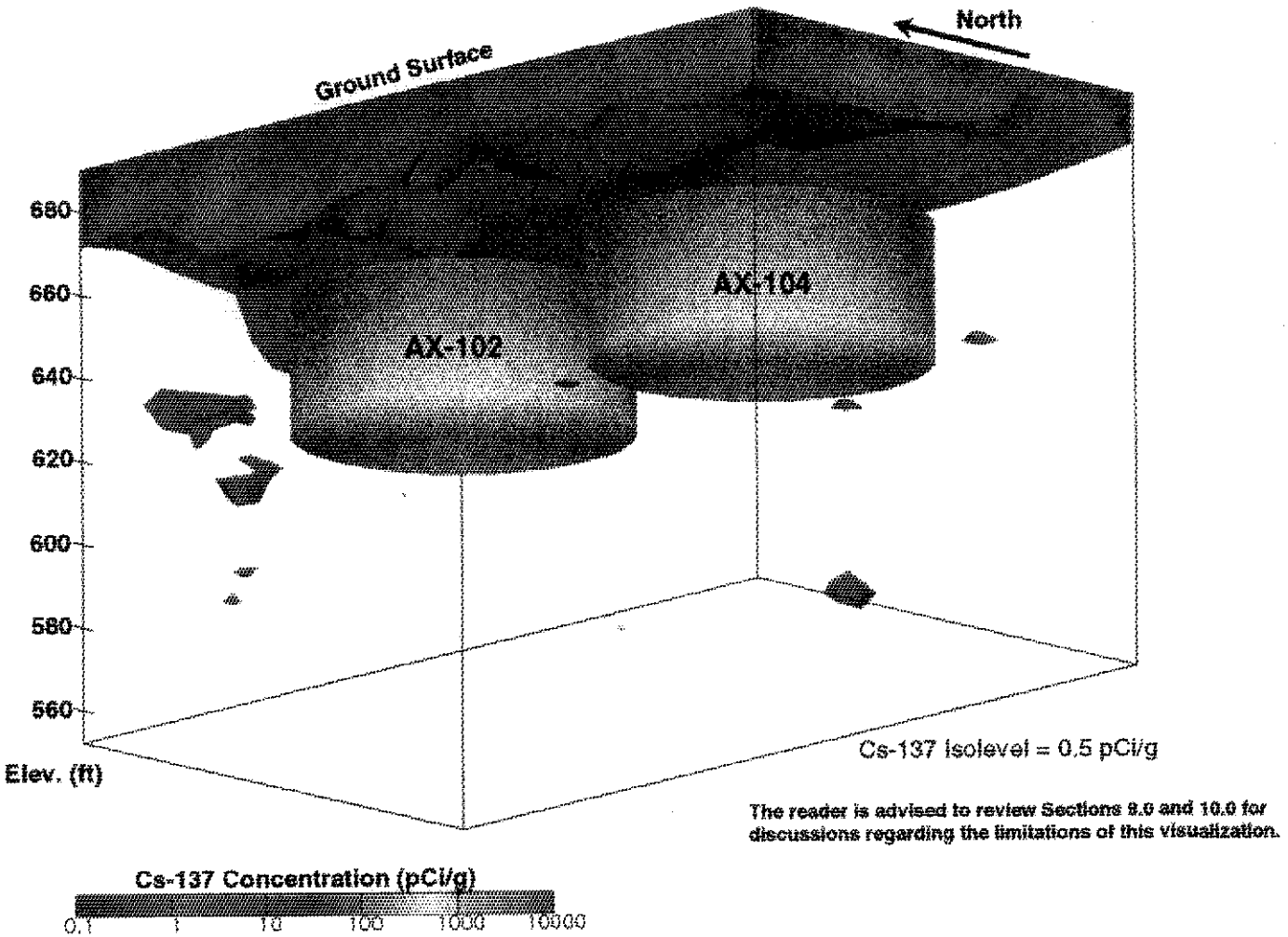


Figure 15-25. Visualization of the ^{137}Cs Contamination Surrounding Tanks AX-102 and AX-104 Viewed From Below the Tanks From the Northwest

Figure 15-26. Visualization of the ^{40}K Concentrations Above 13.5 pCi/g in the AX Tank Farm Viewed From Above the Tanks From the Northeast

Figure 15-27. Visualization of the ^{40}K Concentrations Above 13.5 pCi/g in the AX Tank Farm Viewed From Above the Tanks From the Northwest

Figure 15-26. Visualization of the ^{40}K Concentrations Above 13.5 pCi/g in the AX Tank Farm Viewed From Below the Tanks From the Northeast

Figure 15-29. Visualization of the ^{137}Cs Contamination at the Bases of the AX Tank Farm Tanks Viewed From Above

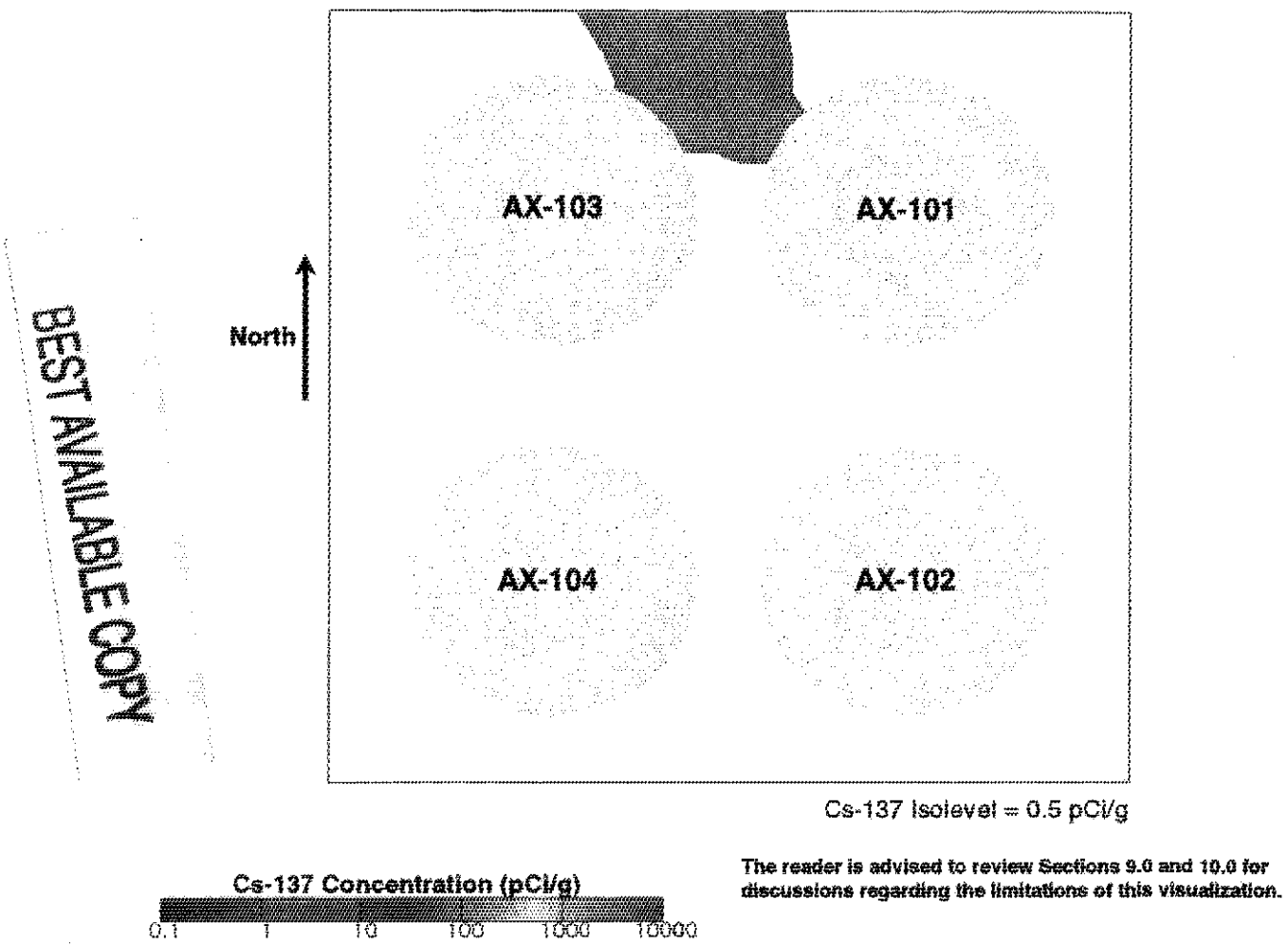


Figure 15-30. Visualization of the ^{137}Cs Contamination 53 Ft Below the Bases of the AX Tank Farm Tanks Viewed From Above

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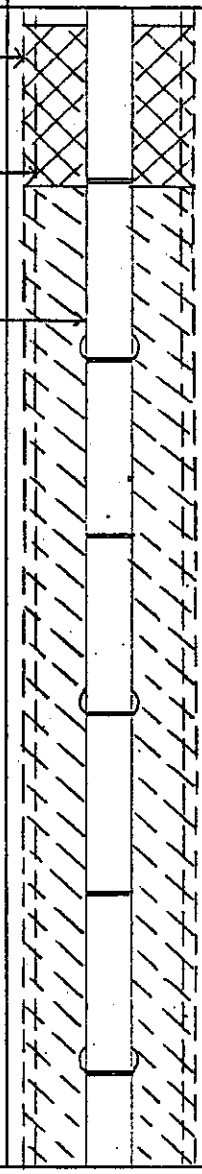
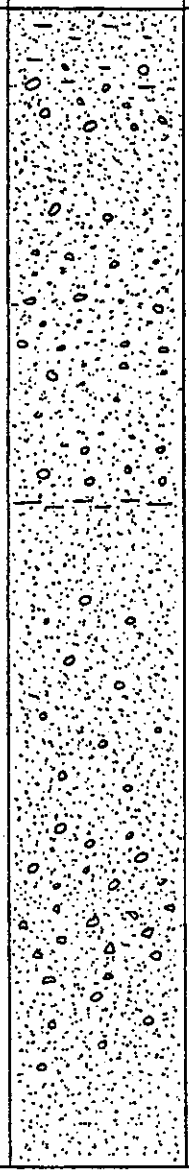
Appendix A
Geology Data for RCRA
Groundwater Monitoring Wells

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E24-19 Geologist GOODWIN, AIRHART, LUBRECHT, KENNEDY Page 1 of 3

Reviewed by V.E. McGlaun Date 12-8-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
151'10" OF 10" CARBON STEEL CASING		5'		MUDDY SAND
		10'		GRAVELLY MUDDY SAND
		15'		GRAVELLY SAND
302'6" OF 8" CARBON STEEL CASING		20'		SAND
		25'		SLIGHTLY GRAVELLY SAND
		30'		SANDY GRAVEL
290.57' OF 4" STAINLESS STEEL CASING		35'		" "
		40'		" "
		45'		GRAVELLY SAND
		50'		SANDY GRAVEL
		55'		" "
		60'		MUDDY SAND @ 56' SAND
		65'		"
		70'		GRAVELLY SAND
		75'		" "
		80'		" "
		85'		" "
		90'		" "
		95'		SANDY GRAVEL
		100'		" "
		105'		" "
		110'		GRAVELLY SAND
		115'		" "
		120'		" "
		125'		SAND
		130'		"

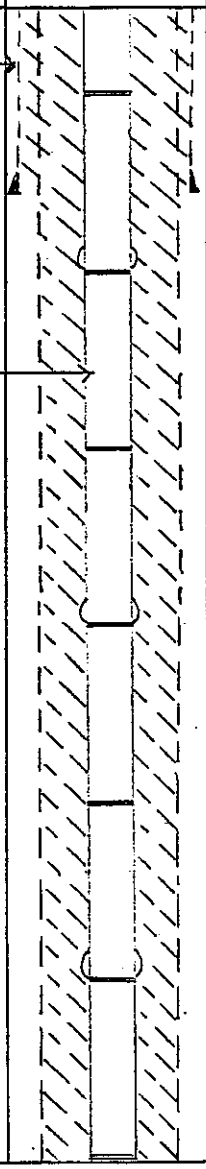
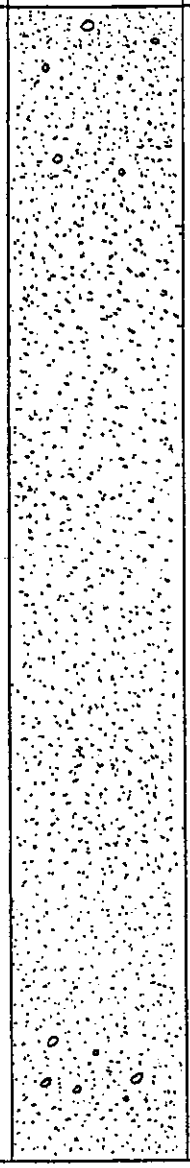
A-1800-186 (3/87)

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E24-19 Geologist GOODWIN, AIRHART, LUBRECHT, KENNEDY Page 2 of 3

Reviewed by W.E. McClain Date 12-8-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
151'10" OF 10" CARBON STEEL CASING WITH DRIVE SHOE		135'		SLIGHTLY GRAVELLY SAND
		140'		" " "
		145'		SAND
		150'		SLIGHTLY GRAVELLY SAND
302'6" OF 8" CARBON STEEL CASING		155'		SAND
		160'		"
		165'		"
280.57' OF 4" STAINLESS STEEL CASING		170'		"
		175'		"
		180'		"
		185'		"
		190'		ENCOUNTERED 350-400 cpm @ 187'
		195'		NO CONTAM. DETECTED 191'-194'
		200'		350-400 cpm @ 195'
		205'		NO CONTAM. DETECTED @ 200' +
		210'		"
		215'		"
		220'		"
		225'		"
		230'		"
		235'		"
		240'		"
		245'		"
		250'		SLIGHTLY GRAVELLY SAND
		255'		GRAVELLY SAND
		260'		SAND

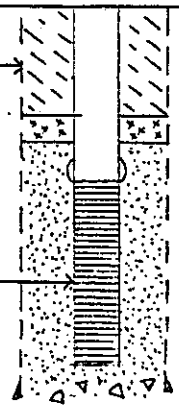
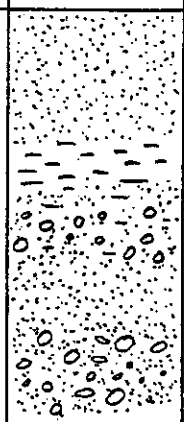
A-1800-186 (3/87)

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E24-19 Geologist GODWIN, AIRHART, LUBRECHT, KENNEDY Page 3 of 3

Reviewed by [signature] Date 12-8-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
302'6" OF 8" CARBON STEEL CASING W/ DRIVE SHOE		265'		SAND
		270'		"
		275'		"
		280'		MUD
		285'		MUDDY SANDY GRAVEL
21.03' OF 4" STAINLESS STEEL CHANNEL-PACK SCREEN		290'		" " "
		295'		SAND
		298'		SANDY GRAVEL
		303'		" "
				T.D. = 303.19'
				COMPLETION DEPTH = 300.68'
COMPLETION SYMBOLS:				
CEMENT GROUT				
BENTONITE CRUMBLES				
BENTONITE PELLETS				
SILICA SAND				
CASING JOINTS				
CASING CENTRALIZER				

A-1800-188 (3/87)

WHC-SD-EN-DP-041, Rev. 0

WELL SUMMARY SHEET

Boring or Well No. 299-E24-20

Sheet 1 of 2

Location 200E/241-A Farm
Elevation 685.85 Brass Cap NGVD'29
Driller K.C. Olson
Prepared By Bryan Walz (Sign/Print Name) Date 1/31/91

Project W-017 / SST
Drilling Contractor Kaiser Engineering Hanford
Drilling Method and Equipment Cable Tool/R.E.-22W
Reviewed By [signature] / DA WILLIAMS (Sign/Print Name) Date 8/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
12" ID Temporary C.S. casing to 20.33' BLS		3.0		Slightly Silty Gravelly SAND
		10		" " " "
				Gravelly SAND
Cement Grout w/aluminum Powder BW 5/25/91		18.3'		Slightly Silty Gravelly SAND
		20		Gravelly SILT
		20.33'		Gravelly SAND
		30		" "
10" ID Temporary C.S. casing to 163.10' BLS				Sandy GRAVEL
		40		" "
				" "
		50		" "
				" "
		60		" "
				" "
8" ID Temporary C.S. casing to 304.02' BLS		70		" "
				" "
		80		" "
				" "
		90		Gravelly SAND
				Slightly Gravelly SAND
		100		SAND
				Sandy GRAVEL
		110		" "
				Gravelly SAND
		120		" "
				Sandy GRAVEL
		130		Gravelly SAND
				SAND
8-20 Mesh Na Bentonite Crumbles		140		Gravelly SAND
				" "
		150		" "
				" "
		160		SAND
		163.10'		"

C-19

A-6000-384 (04/90)

WELL SUMMARY SHEET

Boring or Well No. 299-E24-20

Sheet 2 of 2

Location 200 E/241-A FARM
Elevation 685.85 Brass Cap NGVD 29
Driller K.C. Olson
Prepared By Bryan Walz (Sign/Print Name) Date 3/27/91

Project W-017/SST
Drilling Contractor Kaiser Engineering Hanford
Drilling Method and Equipment Cable Tool - B.E. - 22W
Reviewed By BA Wilkins (Sign/Print Name) Date 8/1/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
8" ID temporary C.S casing to 304.02' BLS		170		SAND
				"
		180		"
				Slightly Gravelly SAND
		190		" " "
				" " "
		200		SAND
				"
		210		Gravelly SAND
				SAND
8-20 mesh bentonite (Na) crumbles to 18.3' BLS		220		Slightly Gravelly SAND
				SAND
		230		Slightly Gravelly SAND
				" " "
		240		Gravelly SAND
				" "
		250		Slightly Gravelly SAND
				Gravelly SAND
¼"-⅜" volclay bentonite pellets to 269.3' BLS		260		" "
	269.3			SAND
		270		"
20-40 CO silica Sand Pack to 274.7' BLS.	274.7'			Gravelly Sandy SILT
		280		Gravelly SAND
.010 Continuous wire wrap SS screen.	281.6 sw/L			" "
		290		Sandy GRAVEL
8-12 CO Silica Sand Pack to 300.5' BLS.	299.6' 300			SAND
	300.5' 303.3' 304.02			Sandy GRAVEL
TD 303.8' BLS sw 5/28/91	303.8' 8 3/15/91			
Final Drive Shoe 2" Depth 304.02' BLS.		C-20		

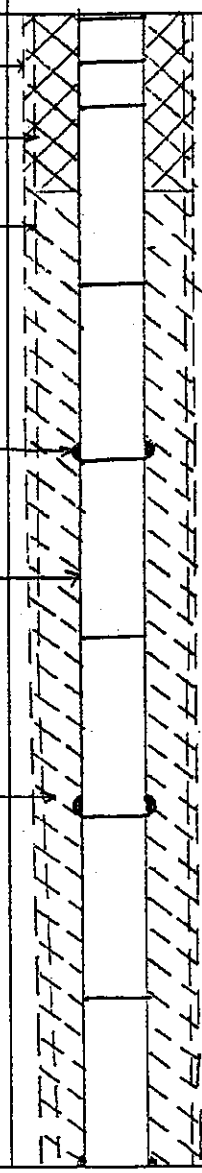
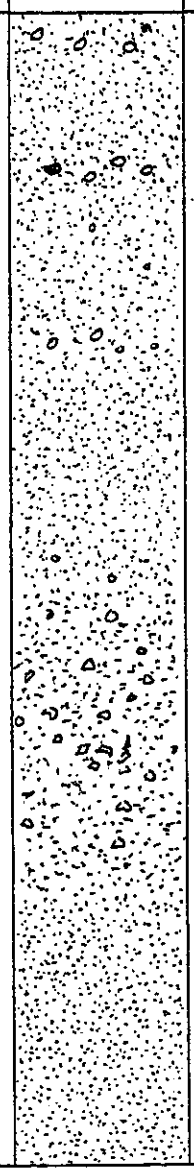
A-6000-384 (04/90)

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E25-40 Geologist M.D. Lubeck Goodwin Page 1 of 3

Reviewed by V. Tom McGhan Date 12-4-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
143.7' OF 10" CARBON STEEL CASING		5		SAND (Tr. Cobbles)
		10		SAND
CEMENT GROUT		15		SAND
		20		SAND (Tr. Cobbles)
273.1' OF 8" CARBON STEEL CASING		25		"
		30		"
		35		"
		40		SANDY GRAVEL
		45		SAND
FACTORY INSTALLED CENTRALIZERS		50		"
		55		"
		60		"
253.25' of 4" DIA. STAINLESS STEEL CASING		65		SLIGHTLY GRAVELLY SAND
		70		Sl. Gravelly SAND
		75		Sandy GRAVEL
		80		Gravelly SAND
		85		Gravelly SAND
8-20 BENTONITE		90		Gravelly SAND
		95		gravelly SAND
		100		SAND
		105		SAND
		110		SAND
		115		SAND
		120		SAND
		125		SAND
		130		SAND

A-1800-186 (3/87)

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Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E25-40 Geologist M.O Lubrecht, GOODWIN Page 2 of 3

Reviewed by V.C. McGhan Date 12-4-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
10" DIA. CARBON STEEL CASING 0' - 143.7'		135		SAND
		140		SAND
		145		SAND
		150		SAND
8" DIA. CARBON STEEL CASING 0' - 273.1'		155		"
		160		"
		165		slightly gravelly SAND
		170		" " "
		175		SAND
		180		"
		185		"
		190		"
		195		Sandy GRAVEL
		200		" "
		205		" "
		210		SLIGHTLY GRAVELLY SAND
		215		" " "
		220		SAND
		225		"
8-20 BENTONITE		230		"
		235		"
		240		"
3/8" VOLCLAY TABLETS		245		"
		250		SLIGHTLY MUDDY SAND
16-30 COL. SILICA SAND		255		MUD
		260	▼ 8-24-89	SLIGHTLY GRAVELLY SAND

A-1800-186 (3/87)

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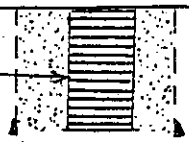
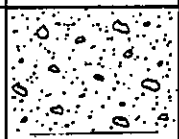
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E25-40 Geologist LUBRECHT, GOODWIN Page 3 of 3

Reviewed by W.T. McKinney Date 12-4-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
10-SLOT, STAINLESS STEEL CHANNEL PACK SCREEN -210'		265 270 275	 T.D. 274'	SANDY GRAVEL " "

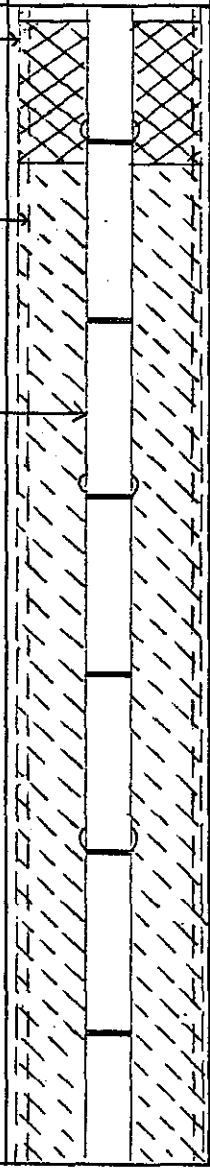
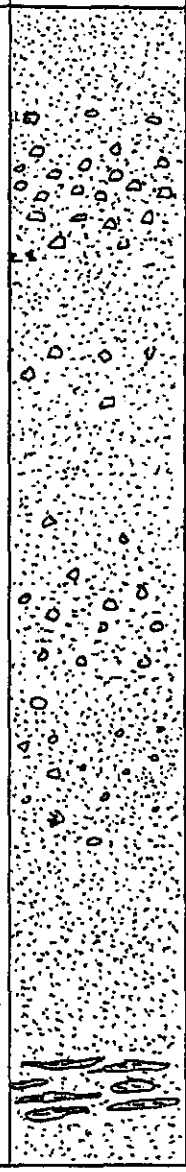
A-1800-186 (3/87)

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E25-41 Geologist M.Lubrecht Page 1 of 3

Reviewed by W.E. McGlynn Date 12-7-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
10" CARBON STEEL CASING 0-138'7 1/2" (TEMPORARY)		5		SAND
		10		SAND
		15		Sl. Muddy SAND
		20		Sandy GRAVEL
280'3" of 8" CARBON STEEL CASING		25		Sandy GRAVEL
		30		SAND
		35		SAND
		40		Muddy Sandy GRAVEL
257.8' of 4" STAINLESS STEEL CASING		45		Sl. Gravelly SAND
		50		SAND
		55		SAND
		60		Sl. Gravelly SAND
		65		Sl. Gravelly SAND
		70		Gravelly SAND
		75		Gravelly SAND
		80		Sl. Gravelly SAND
		85		Gravelly SAND
		90		Gravelly SAND
		95		Gravelly SAND
		100		SAND
		105		SAND
		110		SAND
		115		SAND
		120		Interbedded SAND & muddy f. SAND
		125		Interbedded SAND & muddy f. SAND
		130		SAND

A-1800-188 (3/87)

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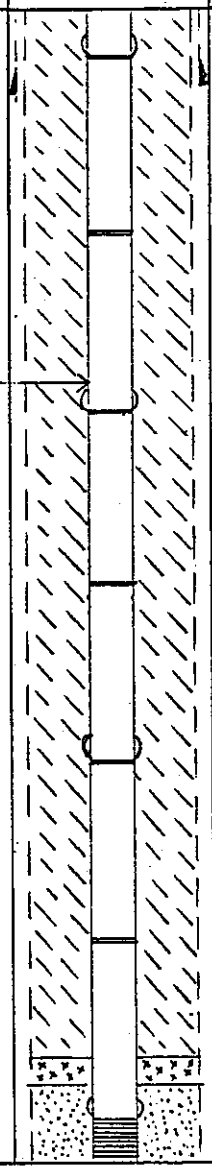
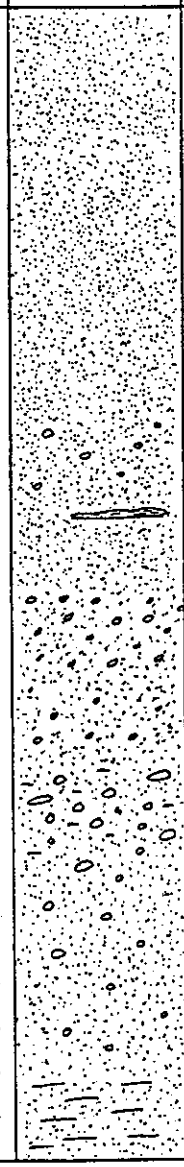
AS-BUILT DIAGRAM

Well Number 299 - E25 - 41 Geologist M. LUBRECHT Page 2 of 3

Reviewed by W. E. McGhan Date 12-7-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description
139' 7 1/2" OF 10" CARBON STEEL CASING		135		SAND
		140		"
		145		"
280' 3" OF 8" CARBON STEEL CASING		150		"
		155		"
		160		"
		165		"
257.43' OF 4" STAINLESS STEEL CASING		170		"
		175		"
		180		slightly gravelly SAND
		185		" " "
		190		SAND
		195		"
		200		sandy GRAVEL
		205		sandy GRAVEL
		210		gravelly SAND
		215		" "
		220		MUDDY SANDY GRAVEL
		225		" " "
		230		GRAVELLY SAND
		235		" "
		240		" "
		245		" "
		250		" "
		255		SANDY MUD
		260		" "

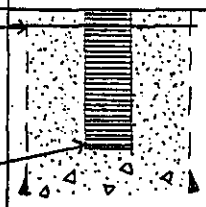
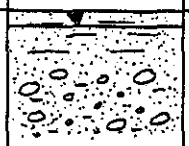
A-1800-186 (3/87)

Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E25-41 Geologist M. LUPPACHT Page 3 of 3

Reviewed by V.L. McGlaun Date 12-7-89

Construction Data		Depth in Feet	Geologic/Hydrologic Data	
Description	Diagram		Diagram Litho.	Lithologic Description D/O @ 262.24 9-22-89
280' 3" of 8" CARBON STEEL CASING		265		SANDY MUD
		270		MUDDY SANDY GRAVEL
		275		SANDY GRAVEL
210' of 4" CHANNEL PACK SCREEN (10 SLOT)				
COMPLETION SYMBOLS:				
CEMENT GROUT				
BENTONITE CRUMBLES				
BENTONITE PELLETS				
SILICA SAND				
CASING JOINT				
CASING CENTRALIZER				

A-1800-186 (3/87)

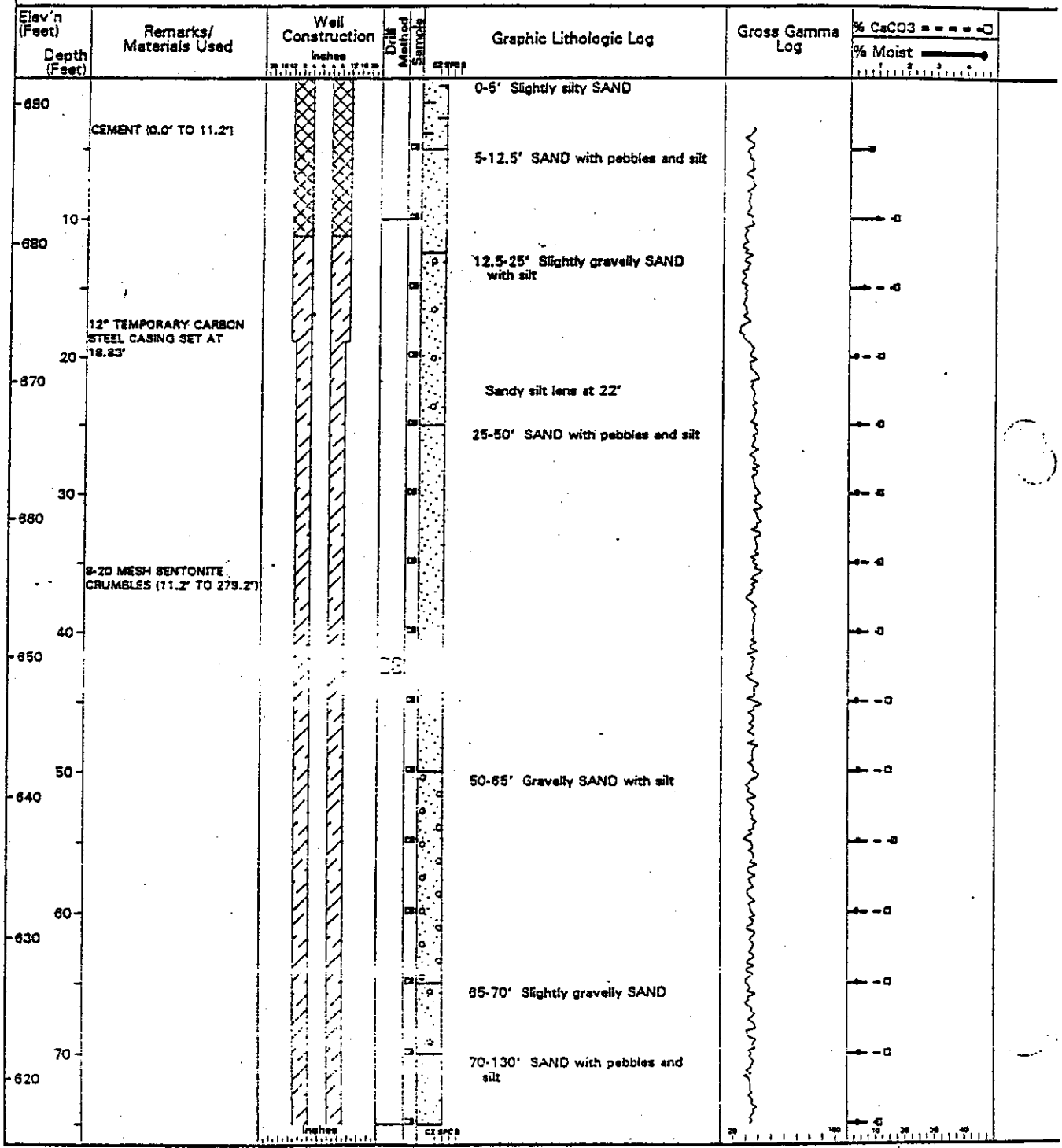
Project:	W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION	**Well No:**	299-E25-46		Page 1 of 4
		Total Depth:	310.31	Static Water Level:	288.4(
Date Started:	7-13-92 Date Completed: 8-10-92	Surface Elevation:	691.79	Casing Elevation:	694.8
Location:	NW OF A-29 EVAPORATOR 200 EAST	Northing:	135963.79	Easting:	5753
Prepared By:	B THOMPSON	Hanford N:	40944.17	Hanford W:	47
Drilling Co:	KEH Driller: L WATKINS/G LYDEN	Drill Meth:	CABLE TOOL	Drill Equip:	

Screen: 20.23' OF 4" DIAMETER 10-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 286.05' TO 306.25

Filter Pack: 20-40 MESH SILICA SAND FROM 282.5' TO 306.7'

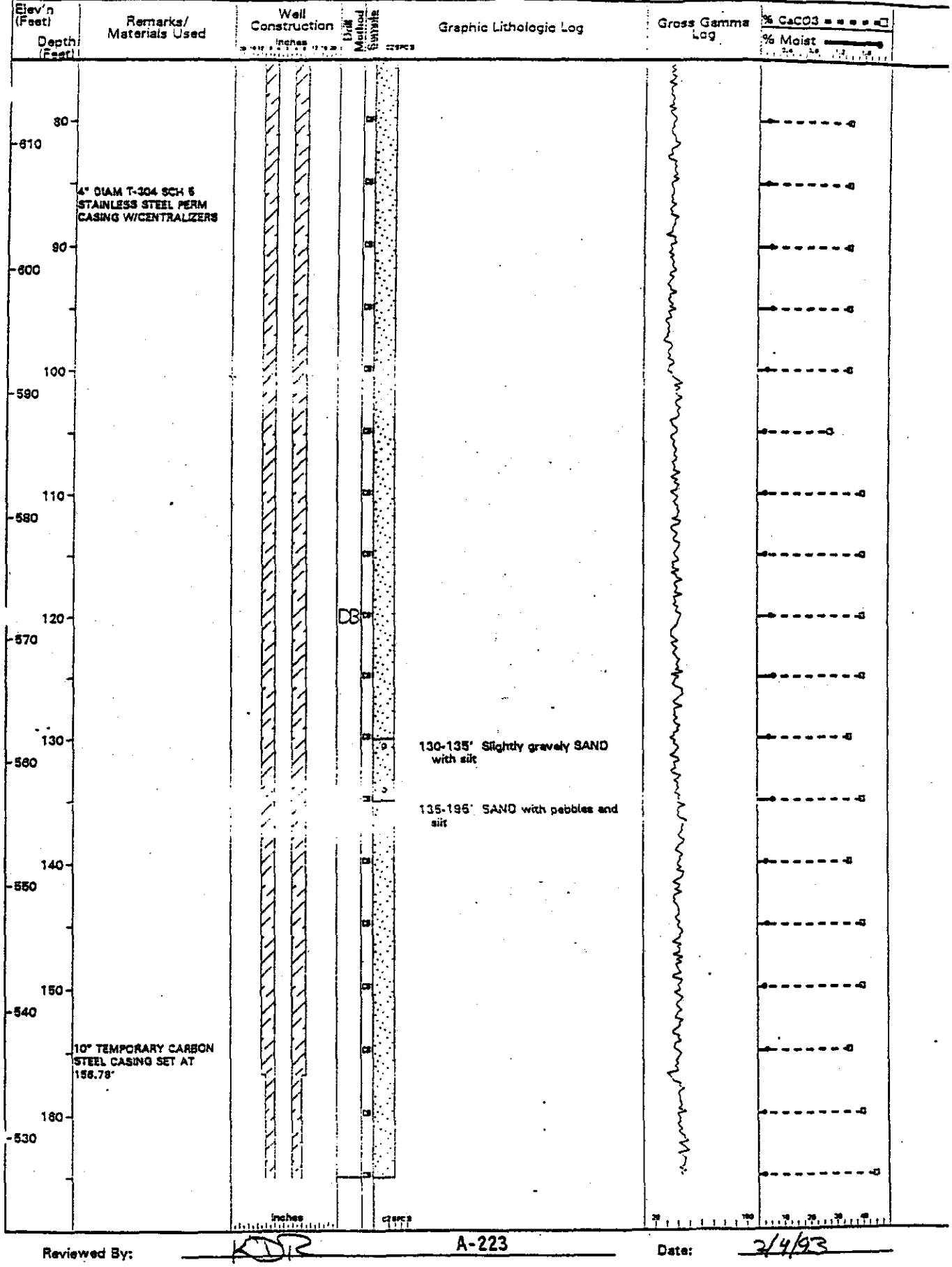
Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 286.05'

Comments: LITHOLOGY RENAMED ACCORDING TO PERCENTAGES LISTED ON BORE HOLE LOG.



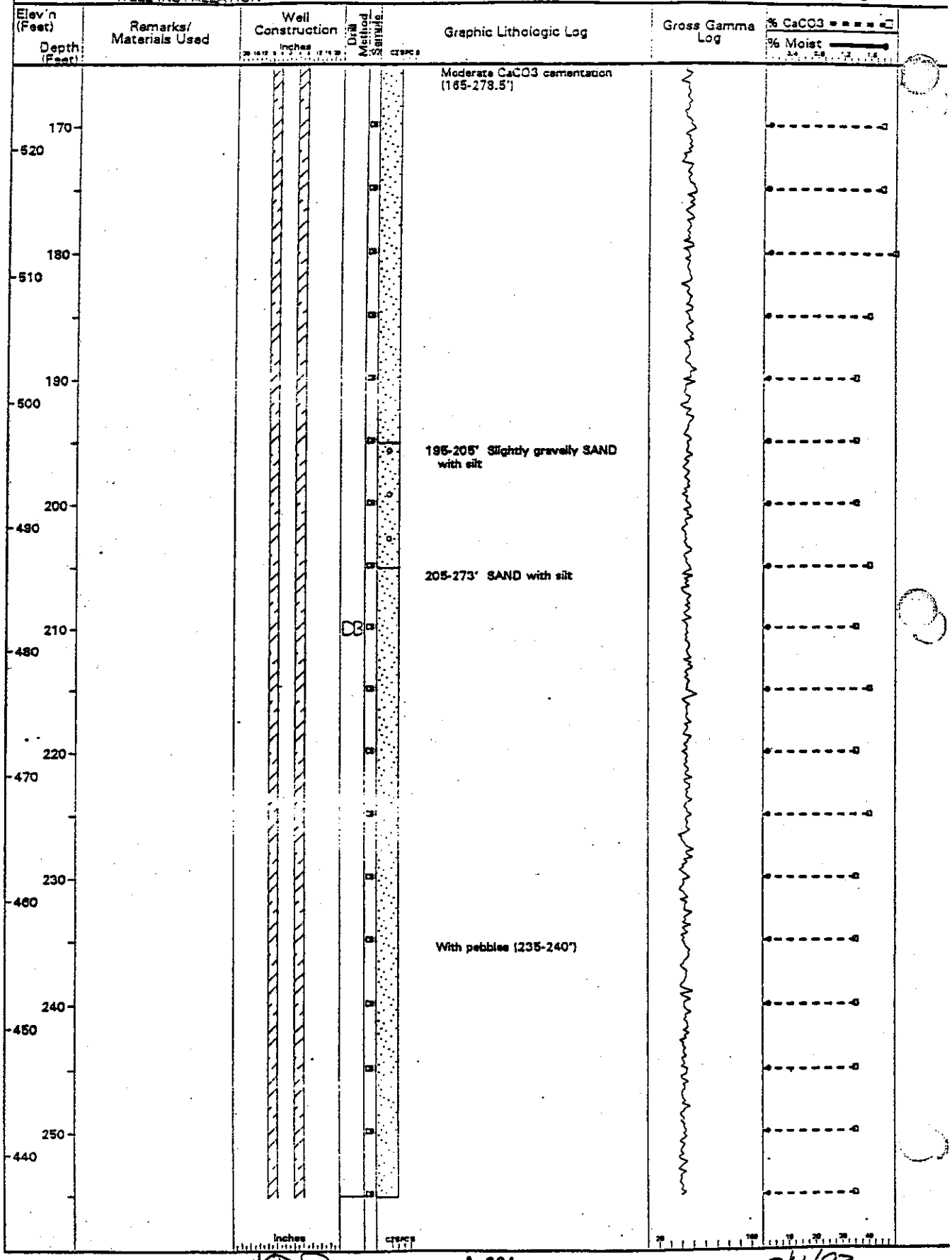
Reviewed By: KDS A-222 Date: 2/4/93

Project: W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION | Well No: 299-E25-46 |

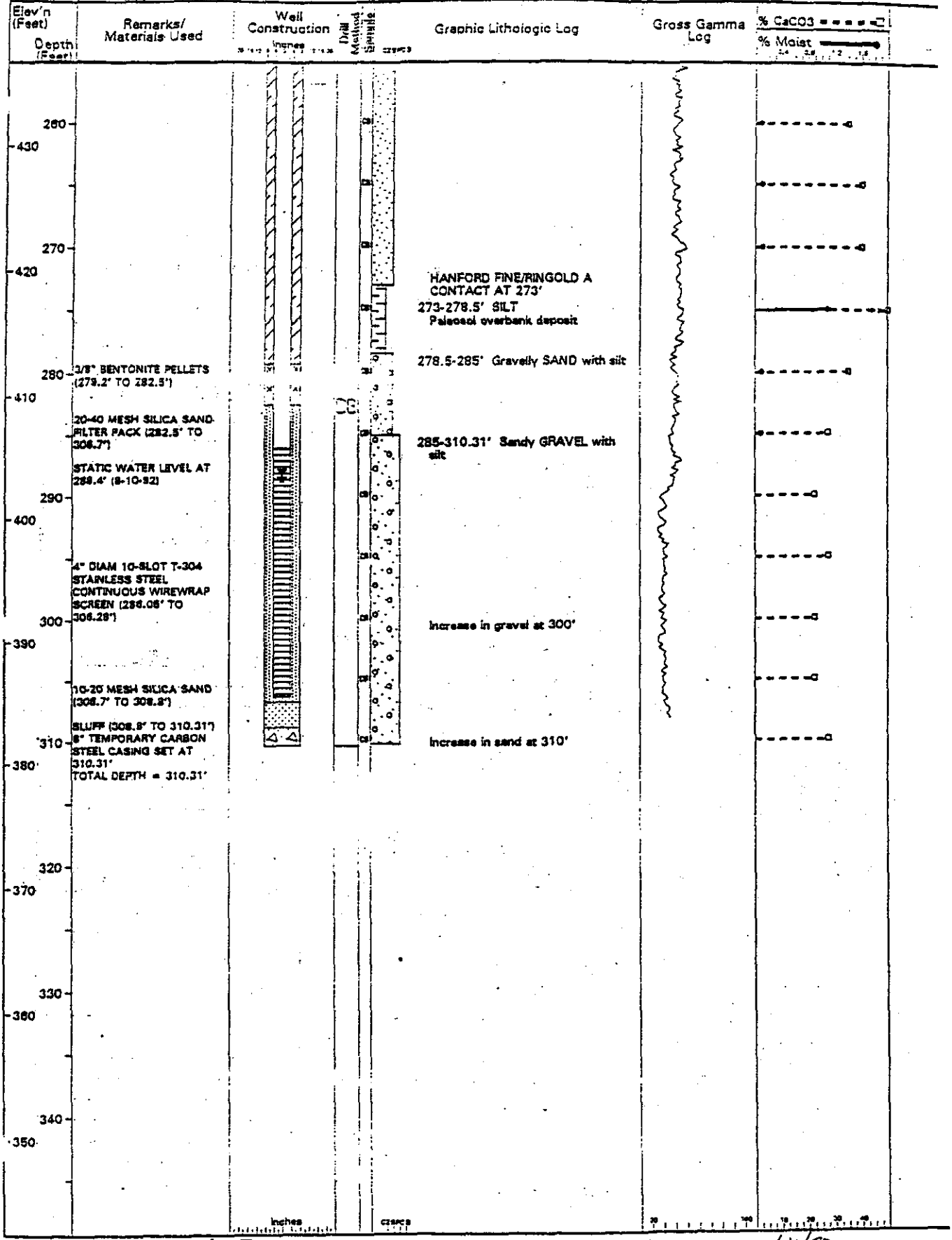


Reviewed By: KDR Date: 2/4/93

Project: W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION | Well No: 299-E25-46 | Page 3 of 4



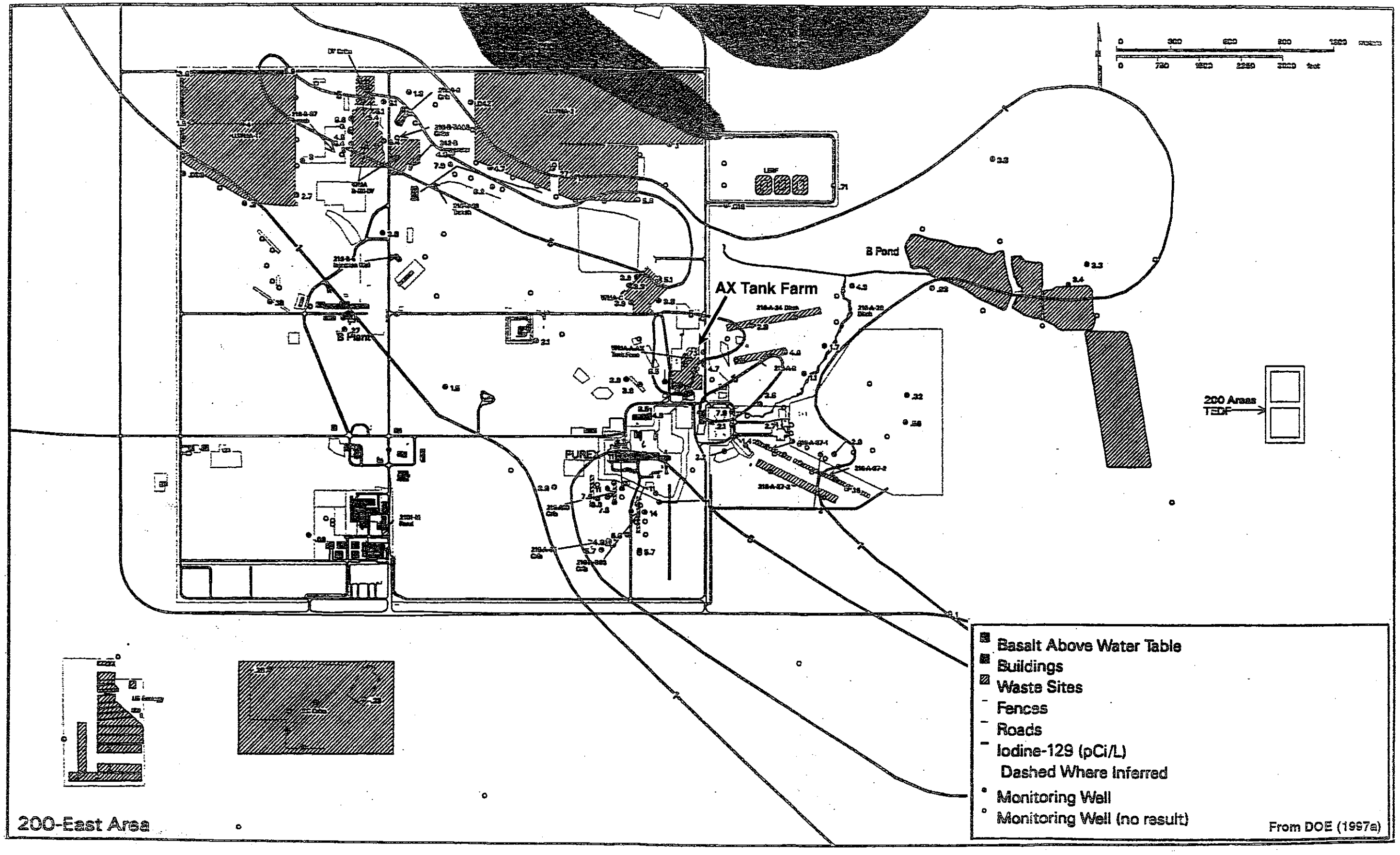
Reviewed By: KDR A-224 Date: 2/4/93



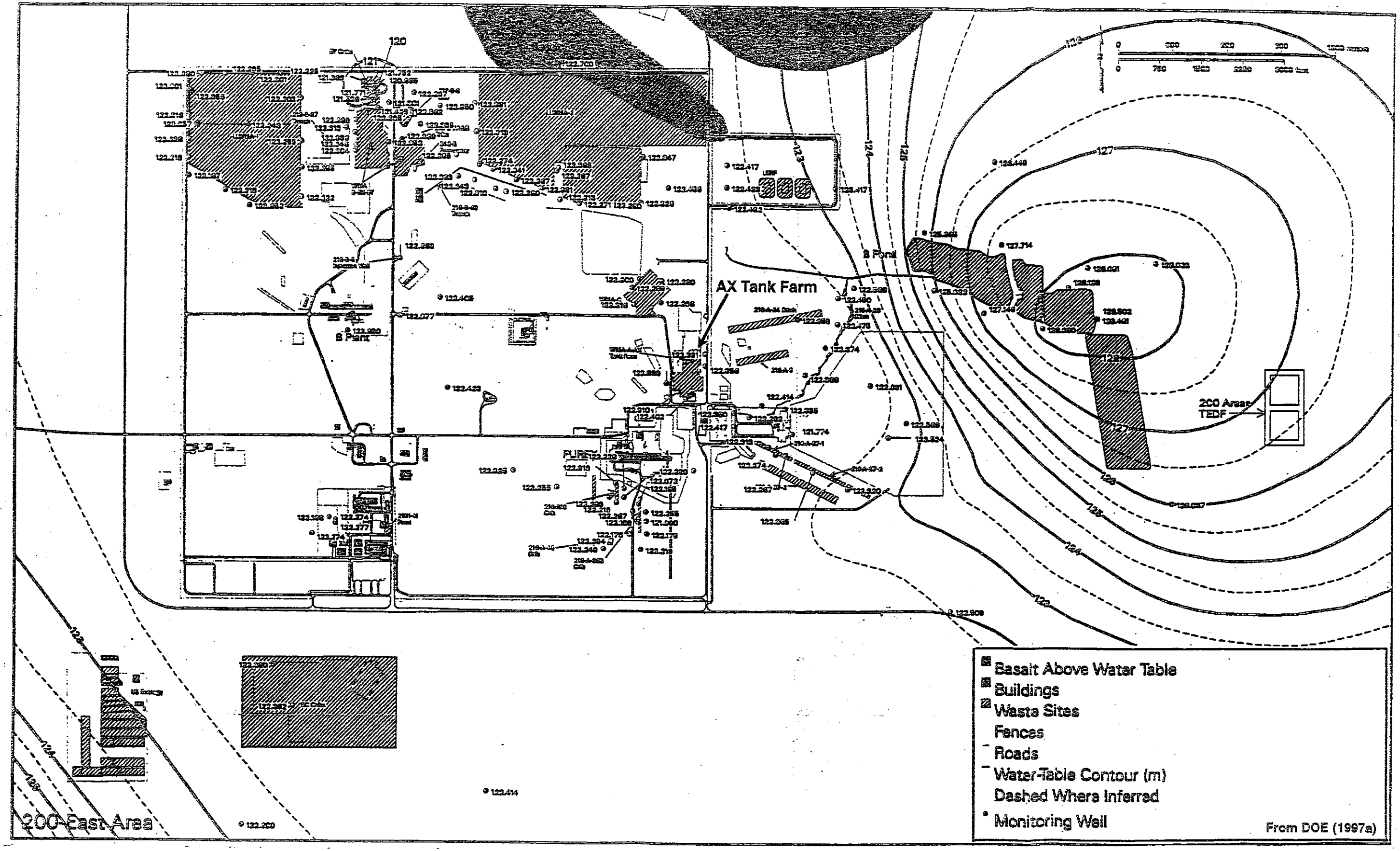
Reviewed By: KDR Date: 2/4/93

A-225

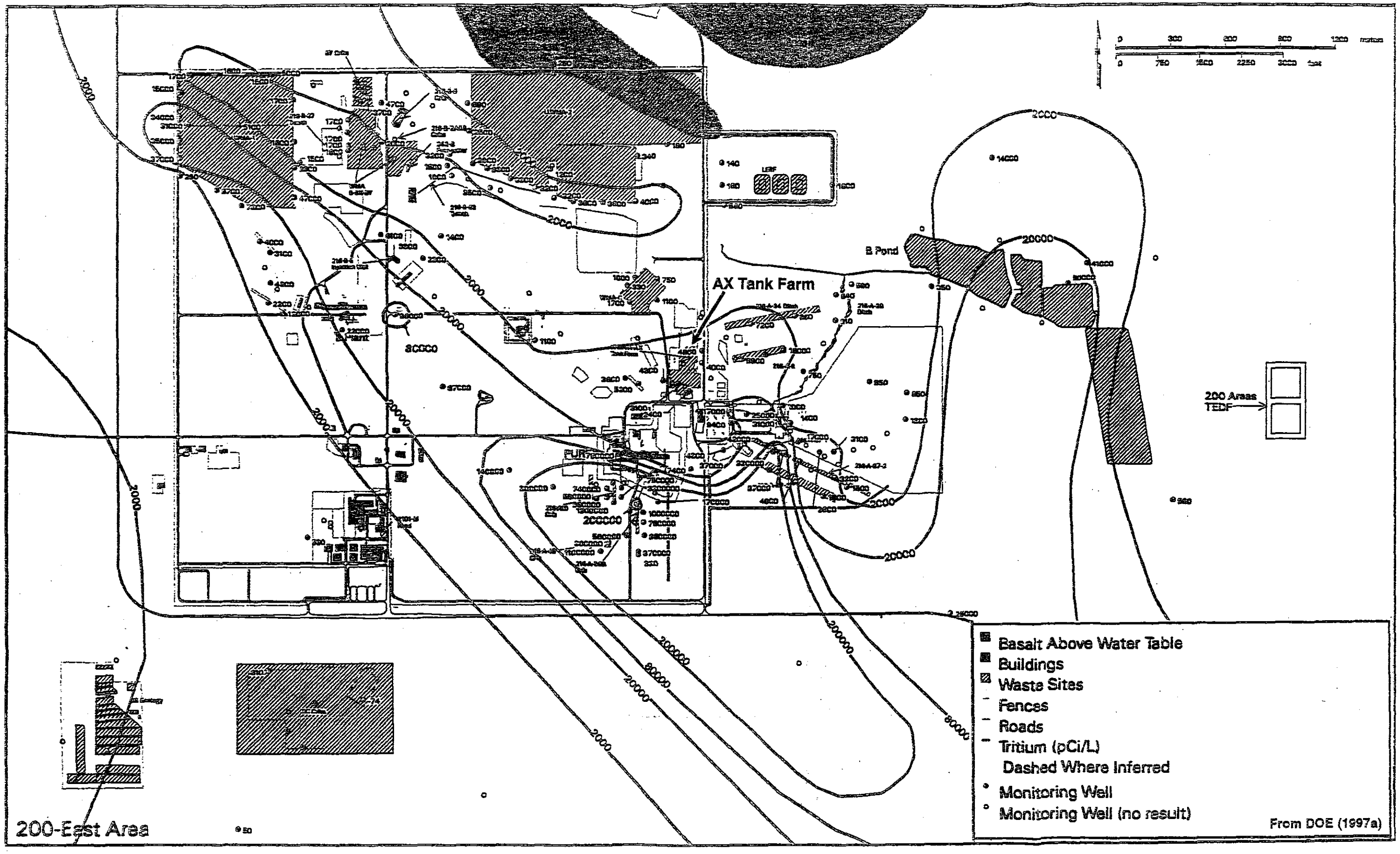
Appendix B
Groundwater Monitoring Data



200 East Area FY 1996 Average Iodine-129 Concentrations



200 East Area Water-Table Map, June 1996



200 East Area FY 1996 Average Tritium Concentrations

Appendix C
Spectral Gamma Data
for Adjacent Waste Sites

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: Vadose Monitoring

Borehole	299-E25-4				
Coordinates	41615	N 46739	W	Feet	(Hanford System)
Elevation	659.39 ft		Top of casing		

Borehole Environment Information

Borehole liquid depth none (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6	0.26	0	289

RLS Passive Spectral Gamma Survey Information

Logging Engineer JR Kunk
Log depth reference at zero (0.0) depth is TOP OF CASING
Logging Instrument RLSG4.2

Log Date	Archive file names	Log mode speed	Depth interval (ft) Top	Base	Incr
30-Oct-95	A670RAW.ZIP A670ANAL.ZIP A670HLAN.ZIP	MSA	2.0	160.0	0.5
31-Oct-95	A671RAW.ZIP A671ANAL.ZIP A671HLAN.ZIP	MSA	155.0	240.0	0.5

MSA: Move Stop Acquire
RT: Real Time

Calibration and Analysis Information

RLS Calibration Date: March 27, 1995
Calibration Report: WHC-SD-EN-TI-292

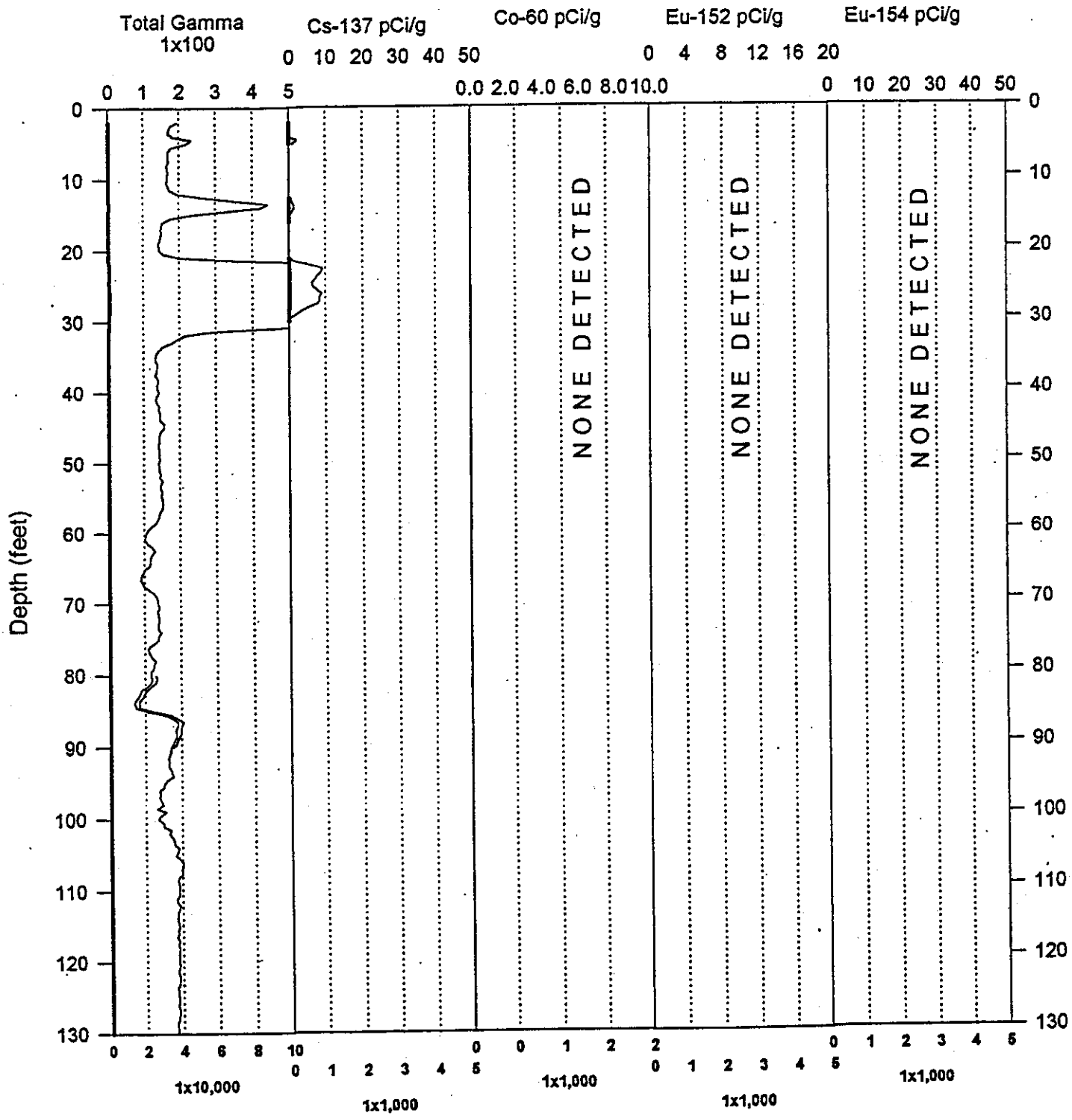
Analyst Name: JR KUNK
Analysis Date: Nov. 15, 1995

Analysis Notes: Previously logged Aug., 1990
Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: Vadose Zone Monitoring
Borehole : 299-E25-04

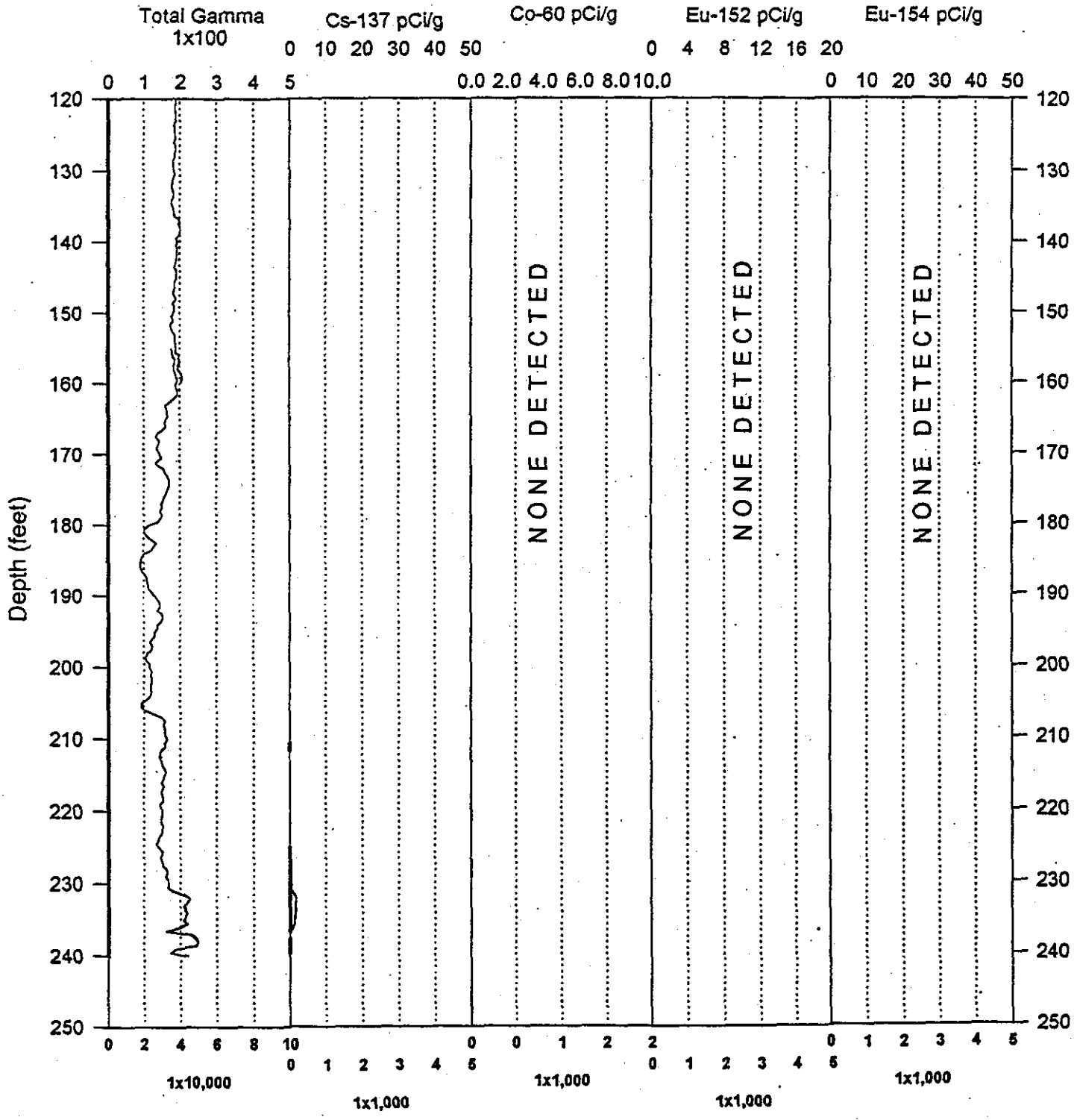
Log Date : Oct. 30&31, 1995
Analysis Date: Nov. 15, 1995



RLS Spectral Gamma-Ray Borehole Survey

Project: Vadose Zone Monitoring
Borehole : 299-E25-04 216-A-8 Crib

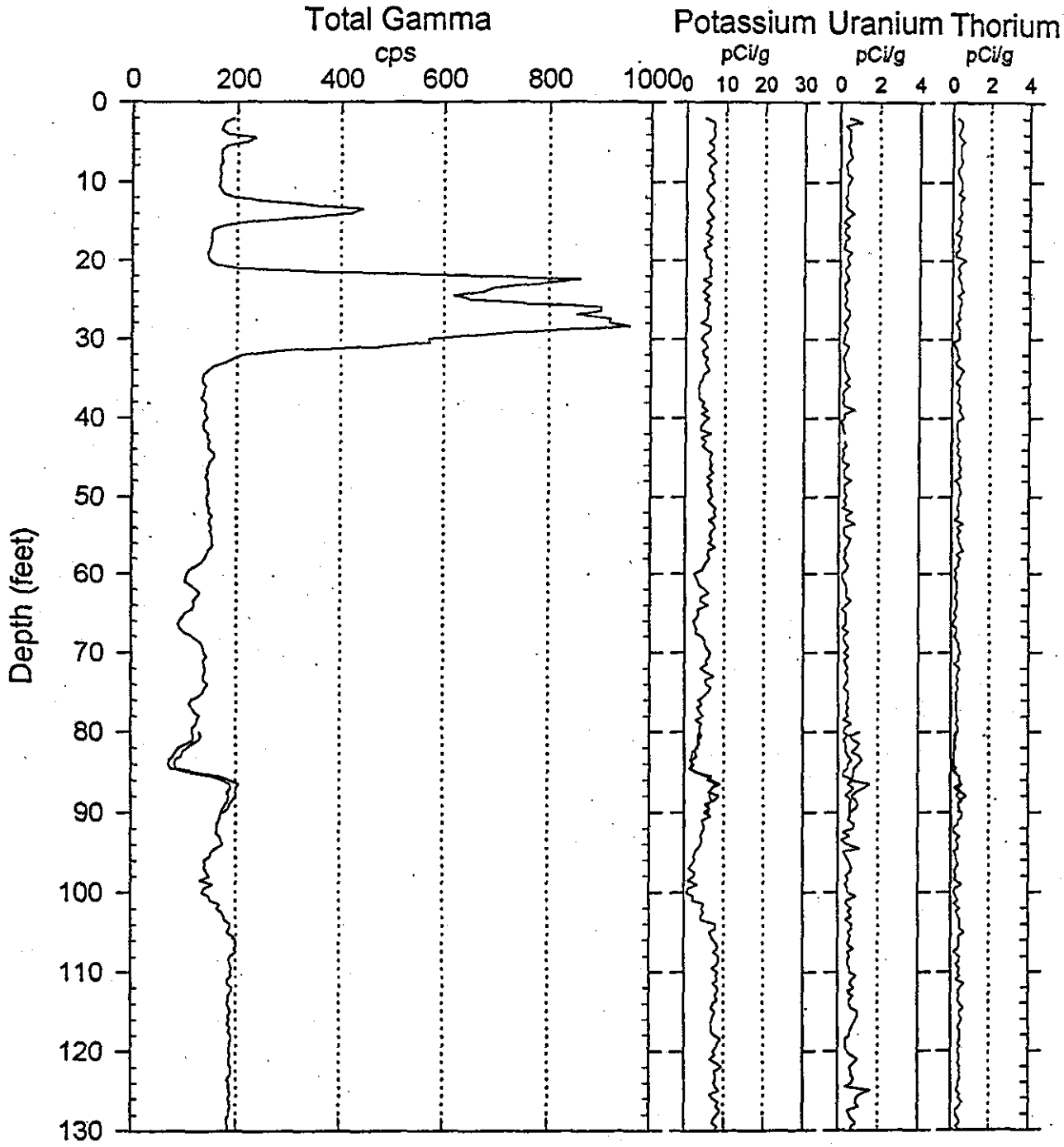
Log Date : Oct. 30&31, 1995
Analysis Date: Nov. 15, 1995



RLS Spectral KUT Processed Data

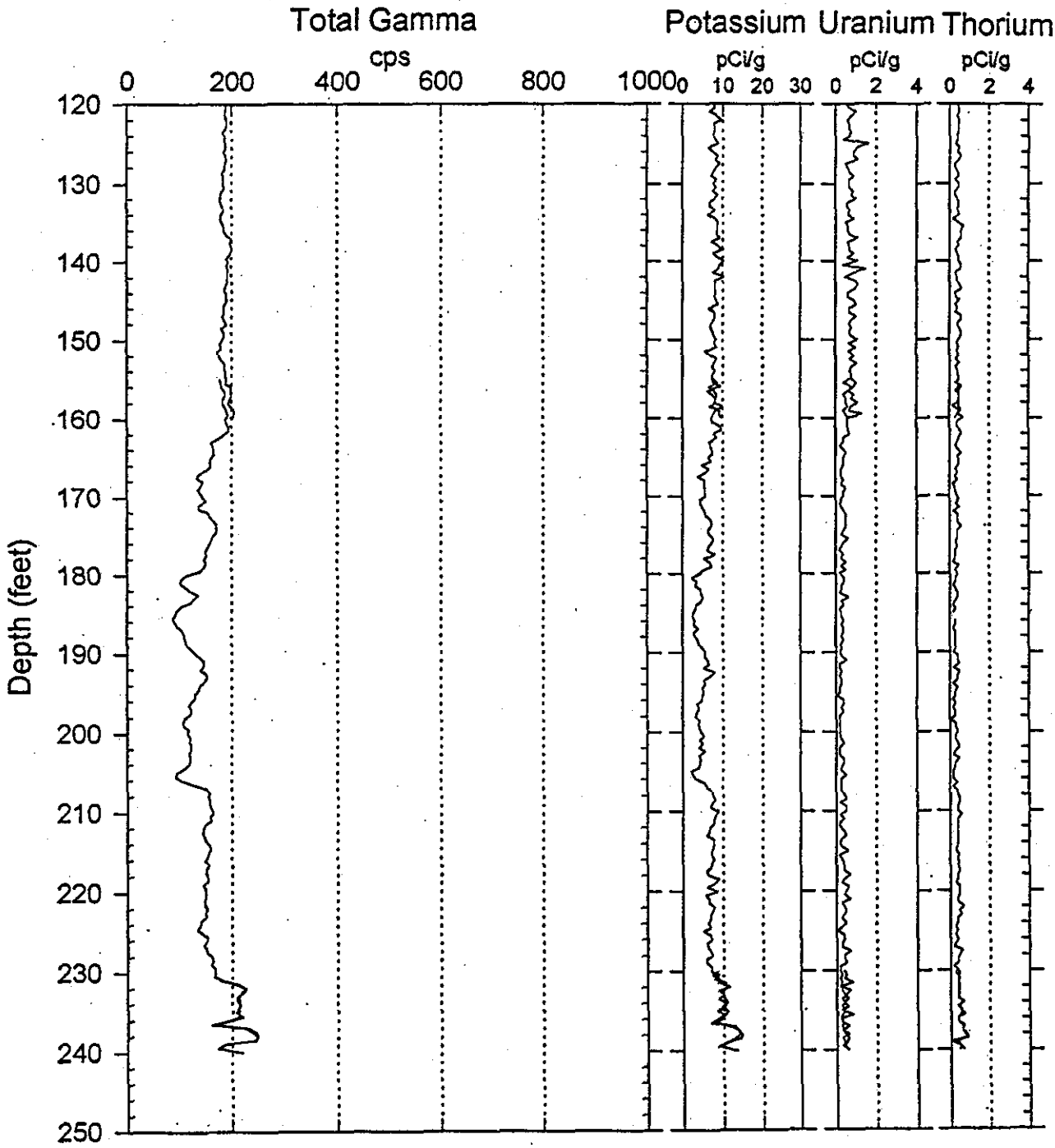
Project: Vadose Zone Monitoring
Borehole: 299-E25-04

Log Date : Oct. 30&31, 1995
Westinghouse Hanford Co.



RLS Spectral KUT Processed Data

Project: Vadose Zone Monitoring Log Date : Oct. 30&31, 1995
Borehole: 299-E25-04 216-A-8 Crib Westinghouse Hanford Co.



RLS Borehole Survey Report

Borehole: 299-E25-4

Casing	Depth: 0.0'- 289'	Size: 6"	Thickness: 0.26"
Water	>250'		
Survey	Depth:2.0'- 160.0'	Date: Oct. 30, 1995	
	155.0 - 240.0	: Oct. 31, 1995	

General Notes:
The well was surveyed from 2.0' to 240' with an acquisition time of 40 sec real time; the sample interval is 0.5'. A repeat sections were conducted from 90' to 80', 155.0' to 160' and 240.0 to 230.0'; these data is included on the plots.

The concentrations of the naturally occurring radionuclides potassium, uranium, and thorium are typical for Hanford sediments.

Man-made Radionuclides
Cesium (Cs-137) was identified along several intervals. It was found from the surface(at 2.0' below the tpo-of-casing) to 5.0', from 12.5' to 16.0', 21.0' to 30.0', 210.5' to 211.5', 225.0' to 236.5' and from 237.5' to 238.5'. The maximum activity of 9.2 pCi/g was occurred 22.5', and a minor deep peak of 1.8 pCi/g occured at a depth of 232.5'.

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: 216-A-8 Crib Restart

Borehole	299-E25-5		
Coordinates	41667 N	46632 W	Feet (Plant 200 Area)
Elevation	657.71 ft		Top of casing (Plant 200 Area)

Borehole Environment Information

Borehole liquid depth 253 (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6	0.33	0	230

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram S. E. Kos
Log depth reference at zero (0.0) depth is ground level

Log Date	Archive file names	Log mode speed	Depth interval (ft) Top	Base	Incr
Aug 21, 1990	H2E2505\A002	MSA 100sec RT	10	26	1.0
Aug 21, 1990	H2E2505\A003	MSA 100sec RT	35	30	1.0
			20	27	1.0
Aug 21, 1990	H2E2505\A004	MSA 100sec RT	30	82	1.0
		MSA 20sec RT	30	29	1.0
Aug 23, 1990	H2E2505\A005	MSA 100sec RT	0	20	1.0
		MSA 5sec RT	21	29	1.0
		MSA 50sec RT	22	33	1.0
		MSA 100sec RT	25	35	1.0
		MSA 100sec RT	75	130	1.0
Aug 24, 1990	H2E2505\A006	MSA 100sec RT	128	249	1.0

MSA: Move-Stop-Acquire
RT: Real time

Calibration and Analysis Information

RLS Calibration Date: Nov. 21, 1991
Calibration Report: WHC-SD-EN-TRP-001

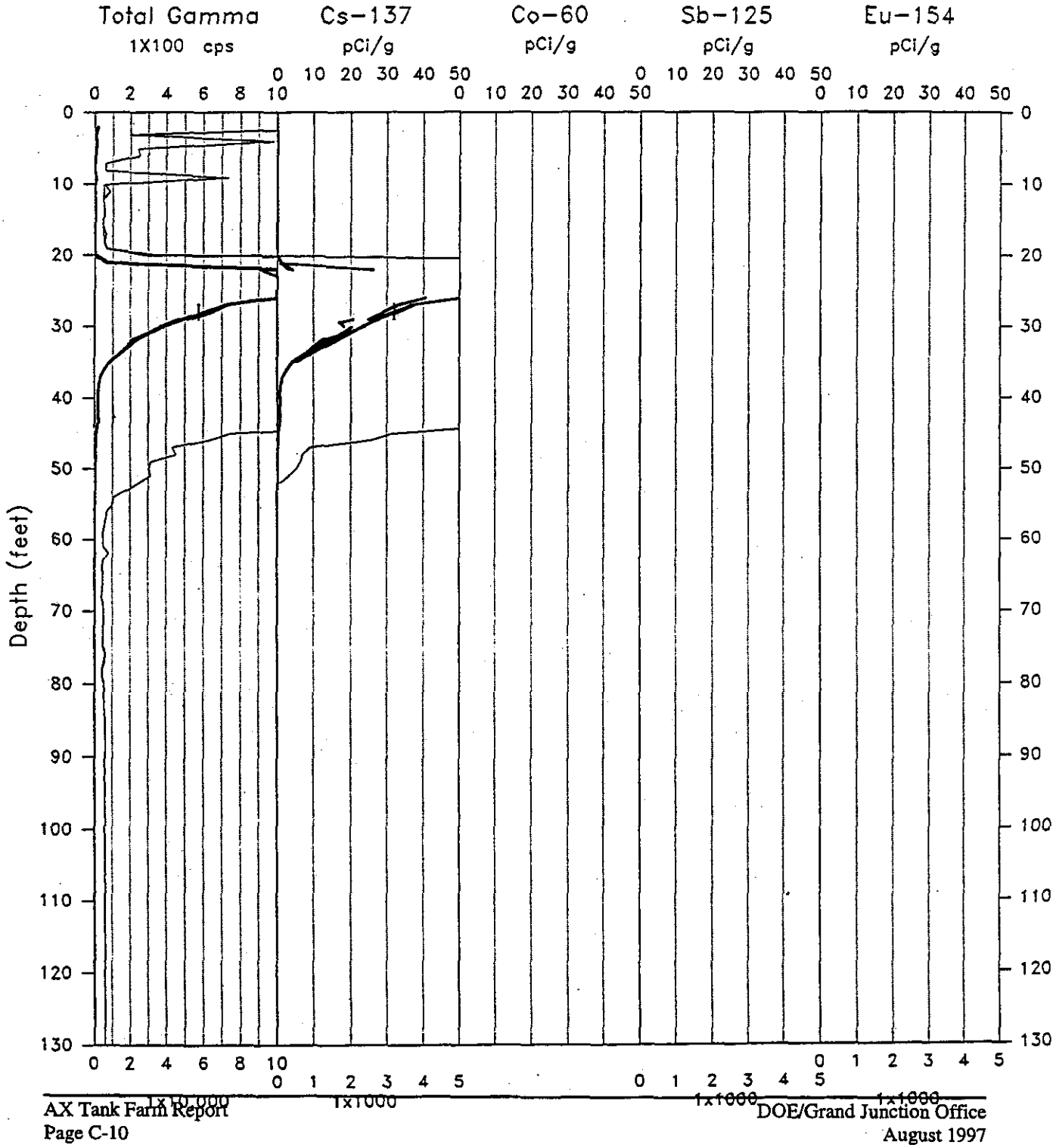
Analyst Names: W. F. Nicaise R. K. Price
Analysis Date: Dec 7, 1992

Analysis Notes: Equipment shake-down test. Several scans thru rad zone.
Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-8 Crib Restart Log Date: Aug 24, 90

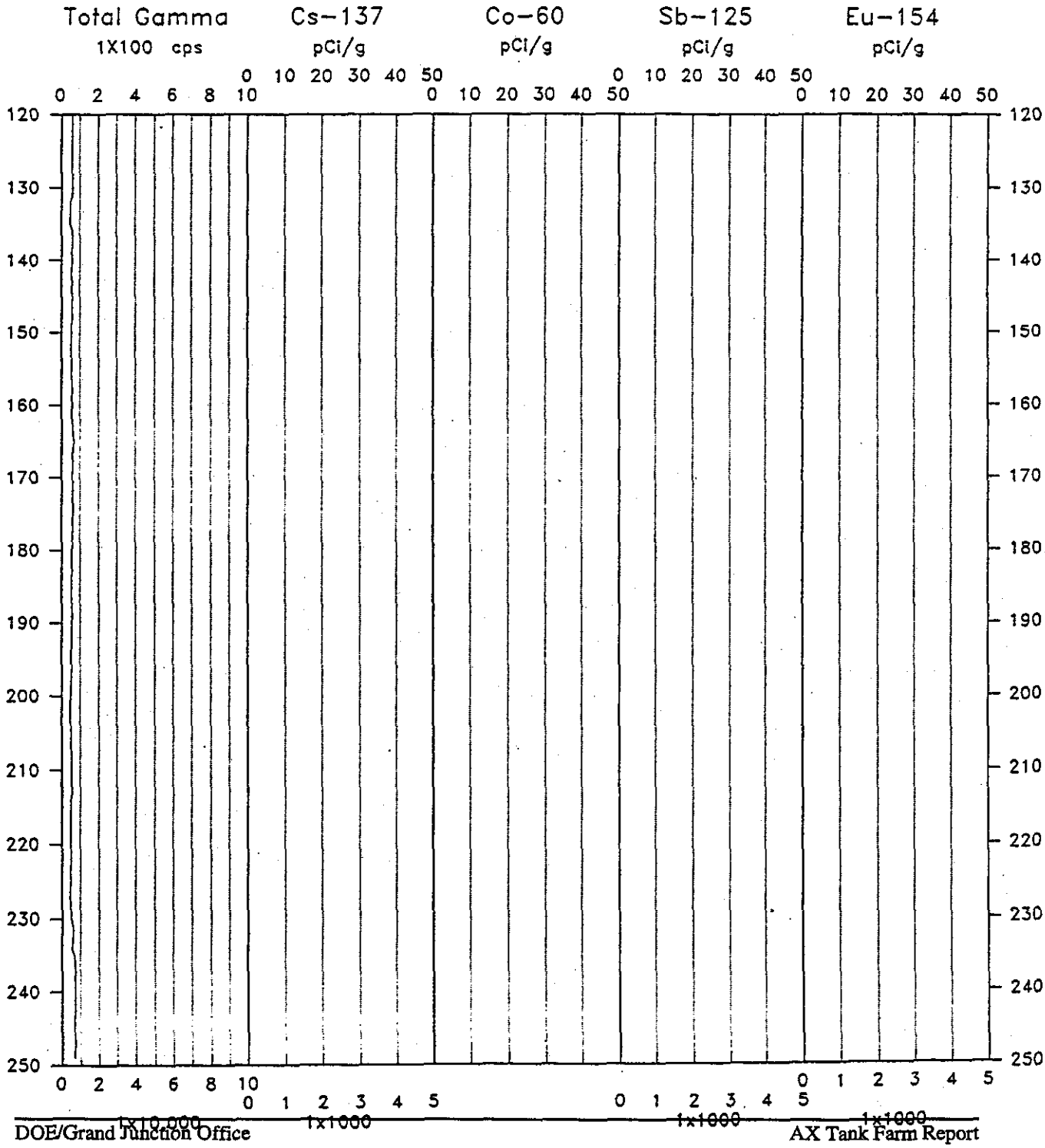
Borehole: 299-E25-5 Anal. Date: Dec 08, 92



RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-8 Crib Restart Log Date: Aug 24, 90

Borehole: 299-E25-5 Anal. Date: Dec 08, 92



RLS Borehole Survey Report

Borehole: 299-E25-5

Casing	Depth:	230′	Size: 6"	Thickness: 0.33"
Water	Depth:	253′		
Survey	Depth:	10 - 82′	Date: 8/21/90	(Multiple scans)
		0 - 35′	8/23/90	(Multiple scans)
		75 - 130′	8/23/90	
		128 - 249′	8/24/90	

General Notes:
The objectives of the borehole survey activities included equipment shake down and identify the radionuclides present in the subsurface for crib assessment.

The equipment performance was compromised by electronic noise on the detector signal wire. The spectra resolution was not considered optimal and the reported activities are considered a lower limit actual subsurface conditions.

Multiple scans from 20 feet to 35 feet were acquired with excellent agreement at indicated on the log plot. The counting system was saturated due to high gamma activity from 23 to 25 feet. Investigation of computer malfunctions prompted other scans from 20 to 35 feet to be repeated.

A stationary measurement acquired at 28 feet is indicated by a vertical bar on the plot.

Excellent agreement for the overlap between surveys is present. The overlap intervals are from 75 to 82 feet and from 128 to 130 feet.

Sporatic electronic noise contributed to the recorded spectra channel counts below 300 keV was observed is some spectra. The computed Total-Gamma activity is elevated in these spectra as indicated from 0 to 10 feet on the plot.

Man-made Radionuclides:
Cesium (Cs-137) was detected from 19 to 52 feet. The cesium decay activity exceeded 200 pCi/g from 21 to 37 feet and exceeded 5000 pCi/g from 23 to 26 feet.

No Cobalt (Co-60) was detected. The template is presented for uniformity of presentration only.

No Antimony (Sb-125) was detected. The template is presented for uniformity of presentration only.

No Europium (Eu-154) was detected. The template is presented for uniformity of presentration only.

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: 216-A-8 Crib Restart

Borehole	299-E25-6		
Coordinates	41598 N	46619 W	Feet (Plant 200 Area)
Elevation	658.31 ft		Top of casing (Plant 200 Area)

Borehole Environment Information

Borehole liquid depth 253 (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6	0.33	0	230

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram S. E. Kos
Log depth reference at zero (0.0) depth is ground level

Log Date	Archive file names	Log mode speed	Depth interval (ft) Top	Base	Incr
Aug 29, 1990	H2E2506\A008	MSA 100sec RT	0	130	1.0

MSA: Move-Stop-Acquire
RT: Real time

Calibration and Analysis Information

RLS Calibration Date: Nov. 21, 1991
Calibration Report: WHC-SD-EN-TRP-001

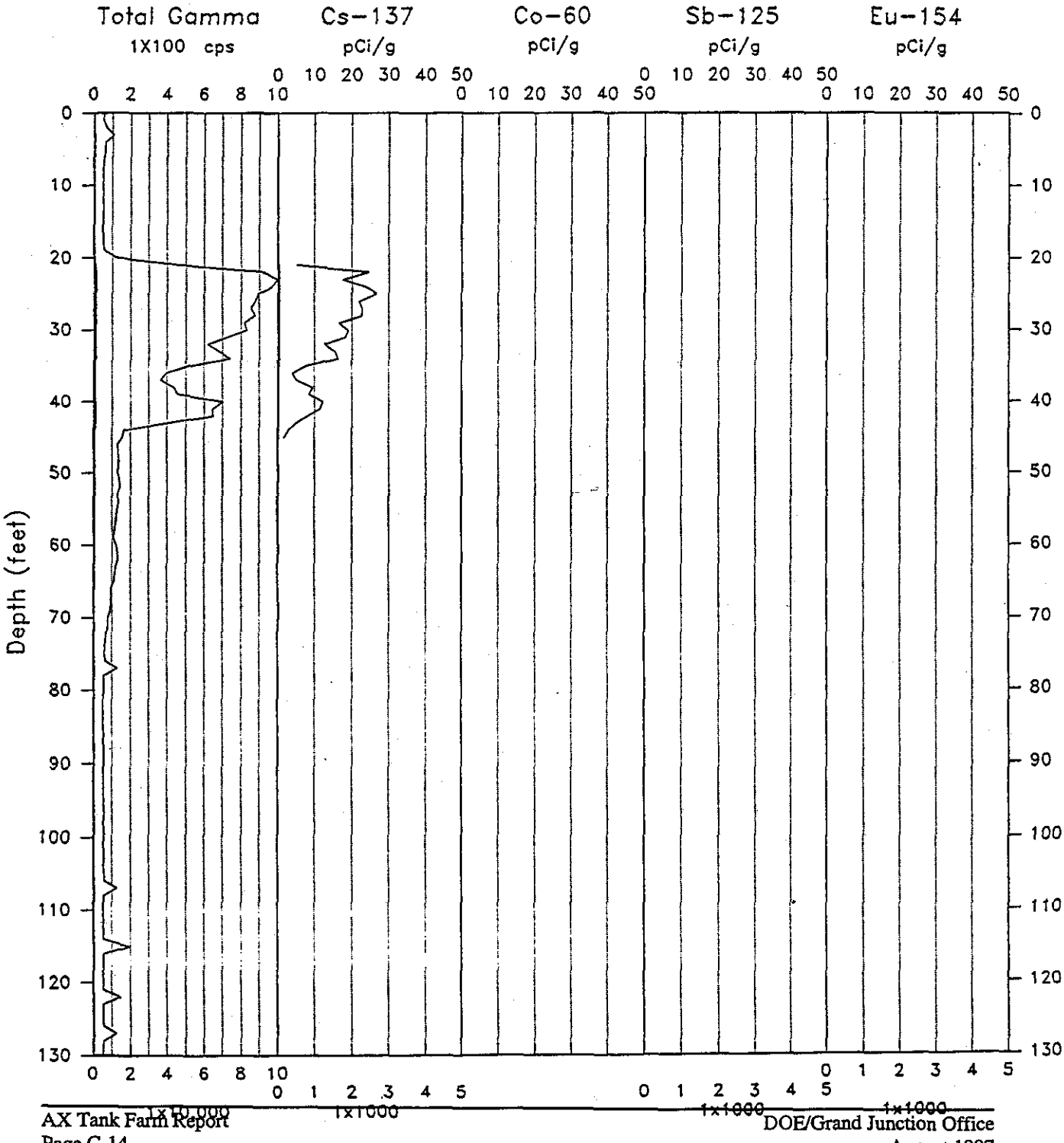
Analyst Names: W. F. Nicaise R. K. Price
Analysis Date: Dec 2, 1992

Analysis Notes: System shake down test; system noise in several spectra.
Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-8 Crib Restart Log Date: Aug 29, 90

Borehole: 299-E25-6 Anal. Date: Dec 02, 92



RLS Borehole Survey Report

Borehole: 299-E25-6

Casing	Depth: 230′	Size: 6"	Thickness: 0.33"
Water	Depth: 253′		
Survey	Depth: 0 - 130′	Date: 8/29/90	

General Notes:
The objectives of the borehole survey activities included equipment shake down and identify the radionuclides present in the subsurface for crib assessment.

The equipment performance was compromised by electronic noise on the detector signal wire. The noise did not impact the evaluation of cesium in the spectra. The spectra resolution was not considered optimal and the reported activities are considered a lower limit of actual subsurface conditions.

Sporatic electronic noise contributed to the recorded spectra channel counts below 350 keV was observed is some spectra. The Total-Gamma activity is elevated as noted on the plot for spectra recorded at the depths: 3, 77, 107, 115, 122, and 127 feet.

Man-made Radionuclides:
Cesium (Cs-137) was detected from 20 to 57 feet. The maximum cesium decay activity detected was 26 pCi/g at 25 feet.

No Cobalt (Co-60) was detected. The template is presented for uniformity of presentration only.

No Antimony (Sb-125) was detected. The template is presented for uniformity of presentration only.

No Europium (Eu-154) was detected. The template is presented for uniformity of presentration only.

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: Vadose Monitoring

Borehole	299-E25-7			
Coordinates	41709	N 46416	W	Feet (Hanford System)
Elevation	657.15 ft : refrence - Top of casing			

Borehole Environment Information

Borehole liquid depth none (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
8	0.30	0	260
6	0.25	0	230

RLS Passive Spectral Gamma Survey Information

Logging Engineer JR Kunk
Log depth reference at zero (0.0) depth is TOP OF CASING
Logging Instrument RLSG4.2

Log Date	Archive file names	Log mode speed	Depth interval (ft) Top	Base	Incr
7-Nov-95	A673RAW.ZIP A673ANAL.ZIP A673HLAN.ZIP	MSA	2.0	140.0	0.5
8-Nov-95	A674RAW.ZIP A674ANAL.ZIP A674HLAN.ZIP	MSA	135.0	264.0	0.5

MSA: Move Stop Acquire
RT: Real Time

Calibration and Analysis Information

RLS Calibration Date: March 27, 1995
Calibration Report: WHC-SD-EN-TI-292

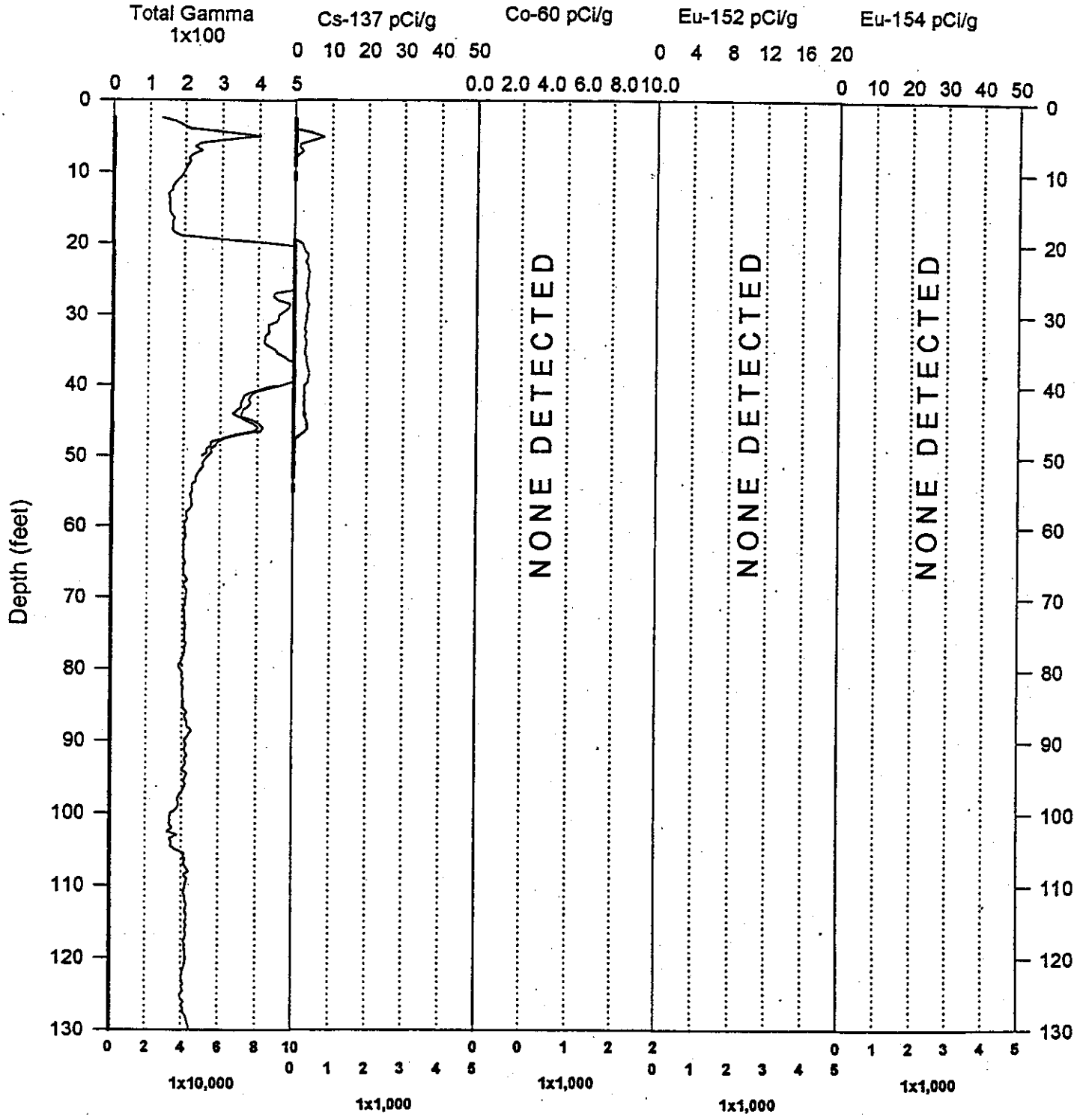
Analyst Name: JR KUNK
Analysis Date: Nov. 22, 1995

Analysis Notes: Previously logged prior to Feb. 1992
Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: Vadose Zone Monitoring
Borehole : 299-E25-07 A-8 Crib

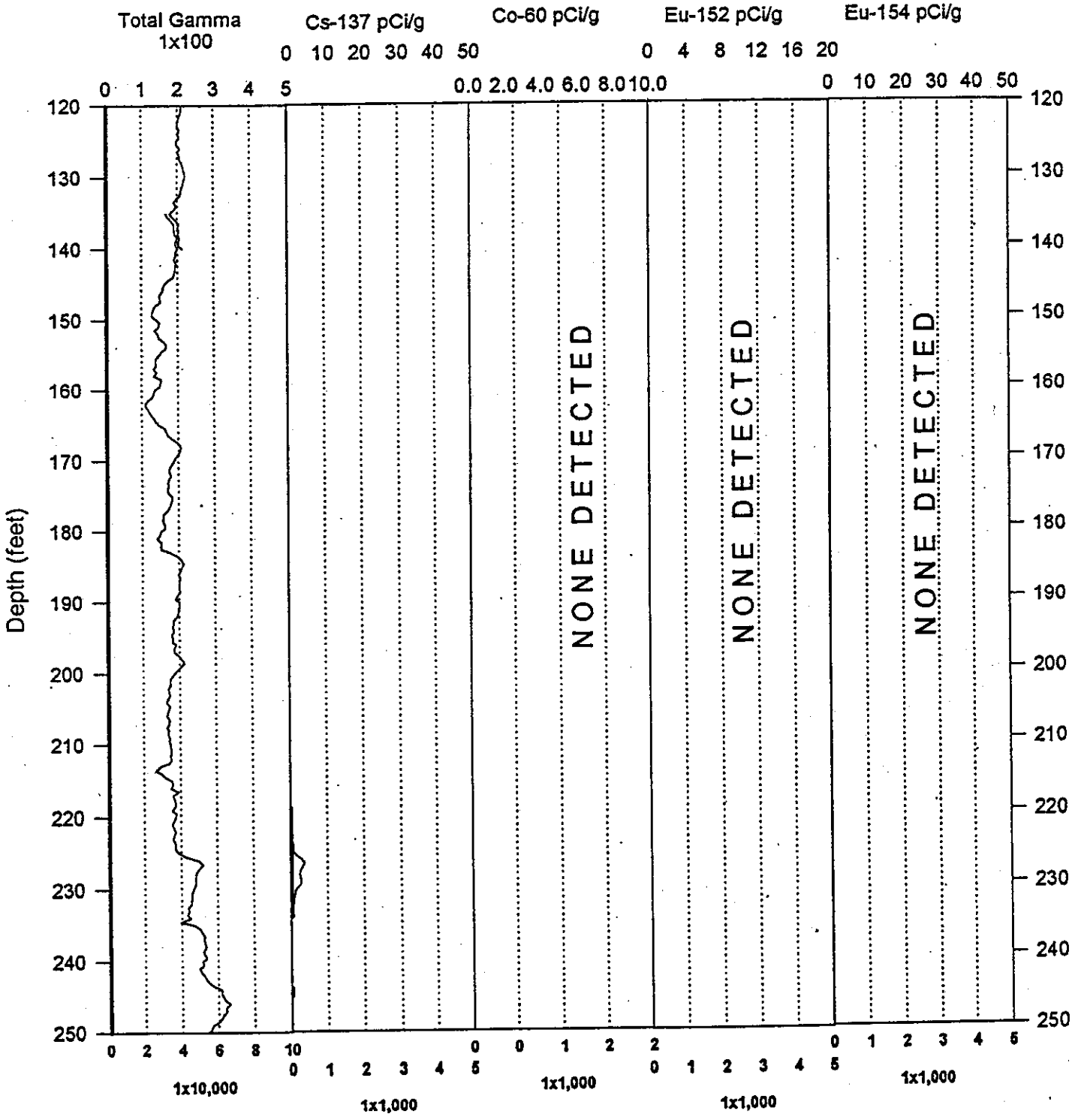
Log Date : Nov 7&8, 1995
Analysis Date: Nov. 22, 1995



RLS Spectral Gamma-Ray Borehole Survey

Project: Vadose Zone Monitoring
Borehole : 299-E25-7 A-8 Crib

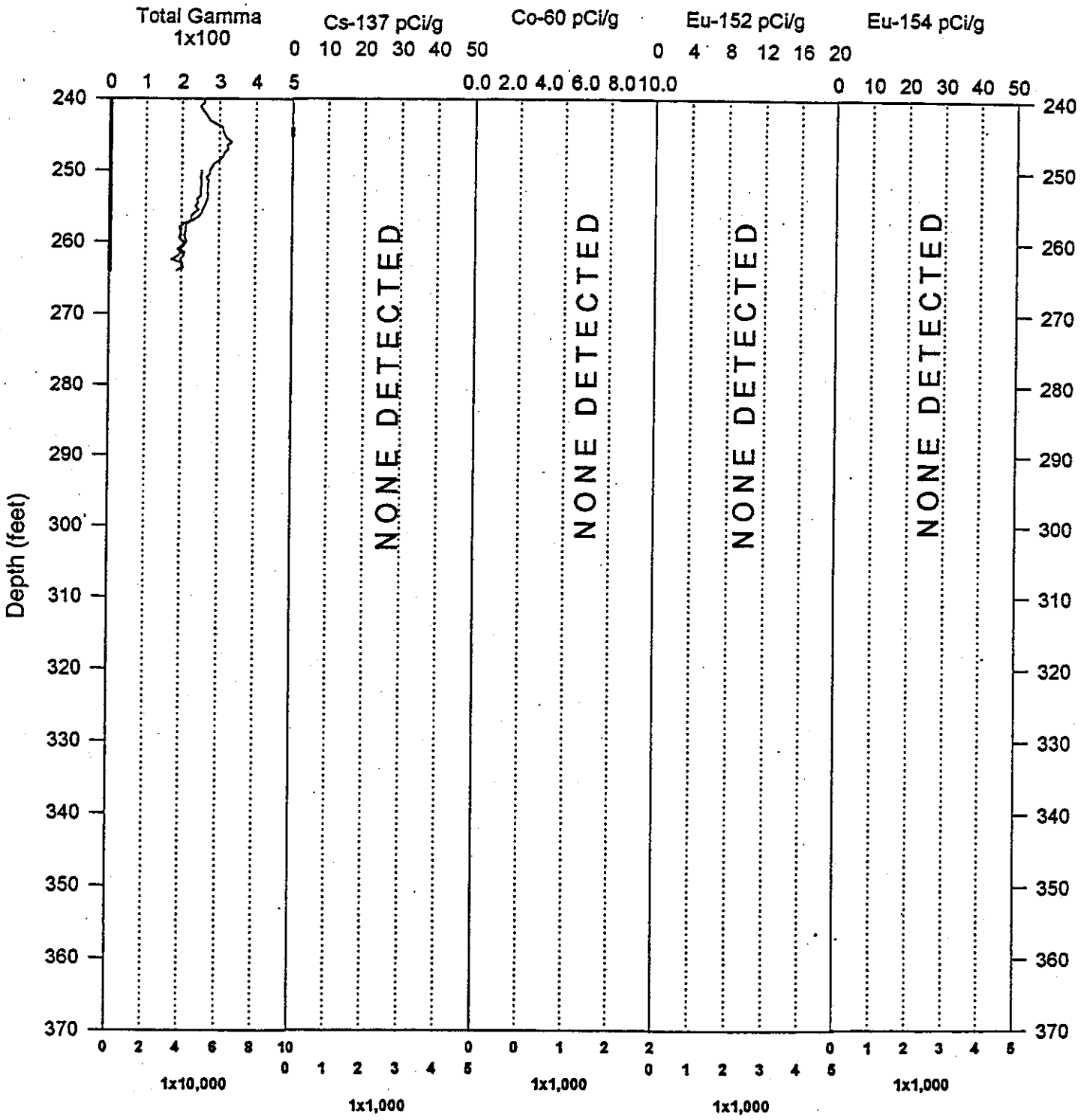
Log Date : Nov. 7&8, 1995
Analysis Date: Nov. 22, 1995



RLS Spectral Gamma-Ray Borehole Survey

Project: Vadose Zone Monitoring
Borehole : 299-E25-7 A-8 Crib

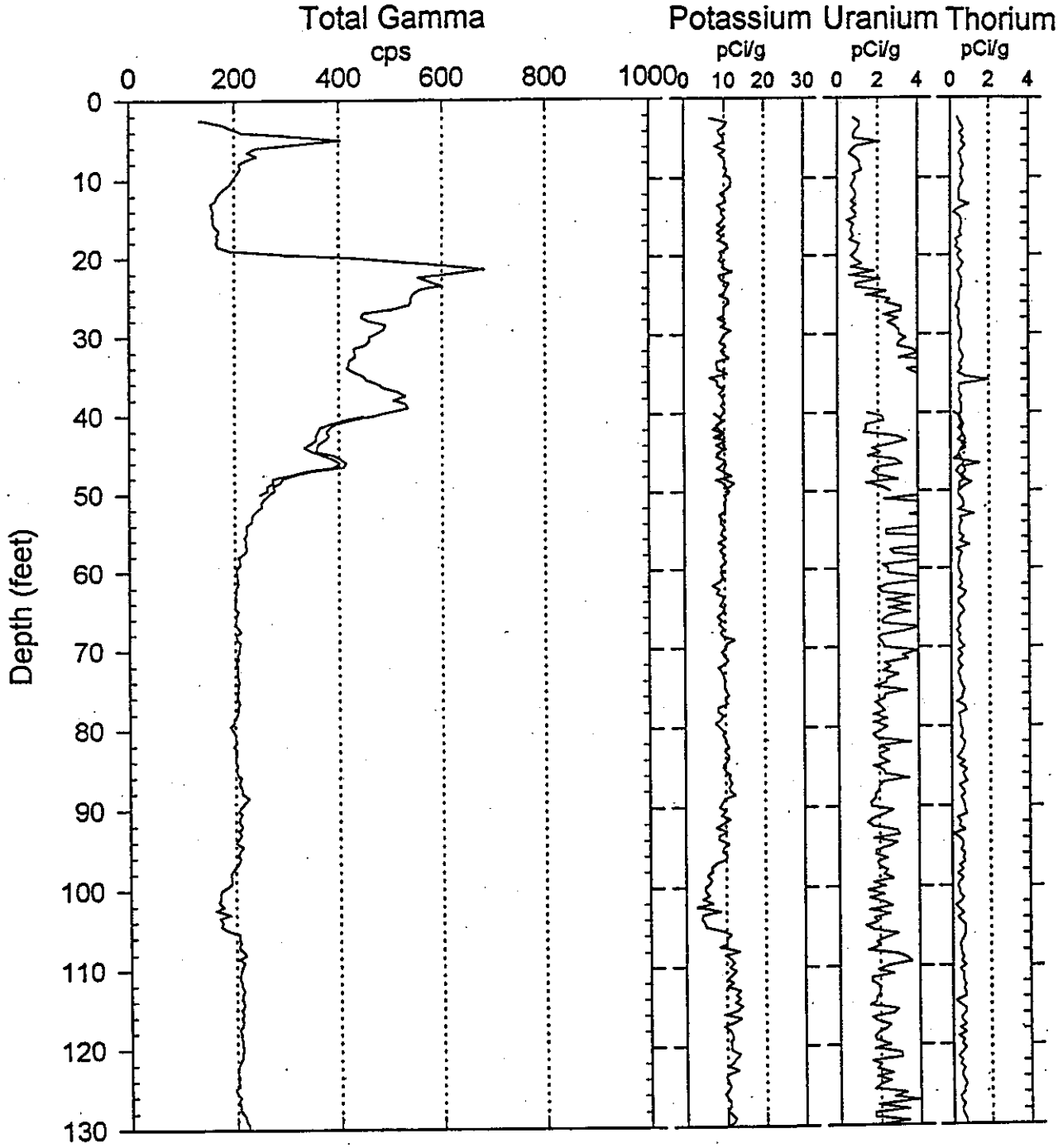
Log Date : Nov. 7&8, 1995
Analysis Date: Nov. 22, 1995



RLS Spectral KUT Processed Data

Project: Vadose Zone Monitoring
Borehole: 299-E25-7 A-8 Crib

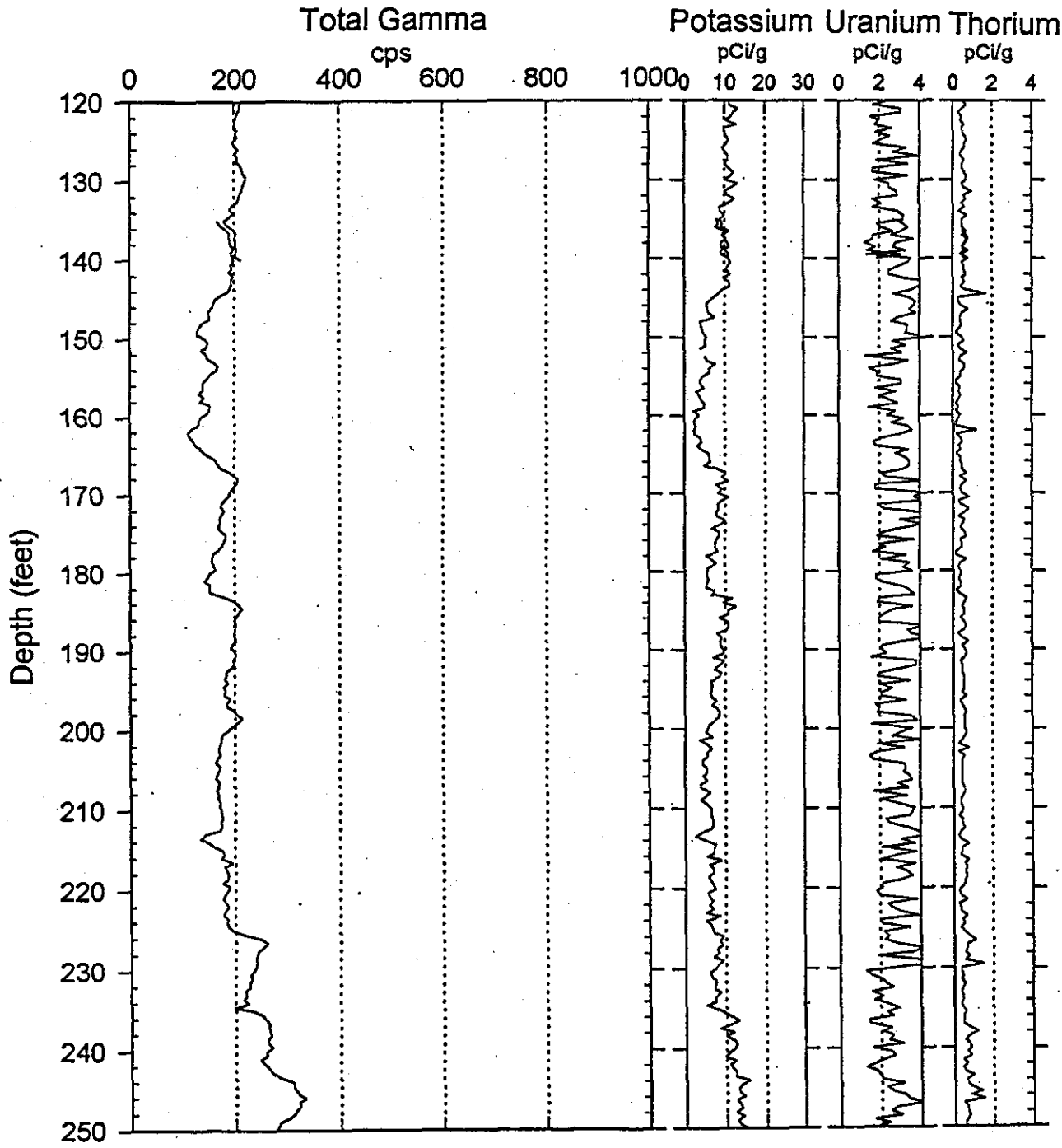
Log Date : Nov. 7&8, 1995
Westinghouse Hanford Co.



RLS Spectral KUT Processed Data

Project: Vadose Zone Monitoring
Borehole: 299-E25-7 A-8 Crib

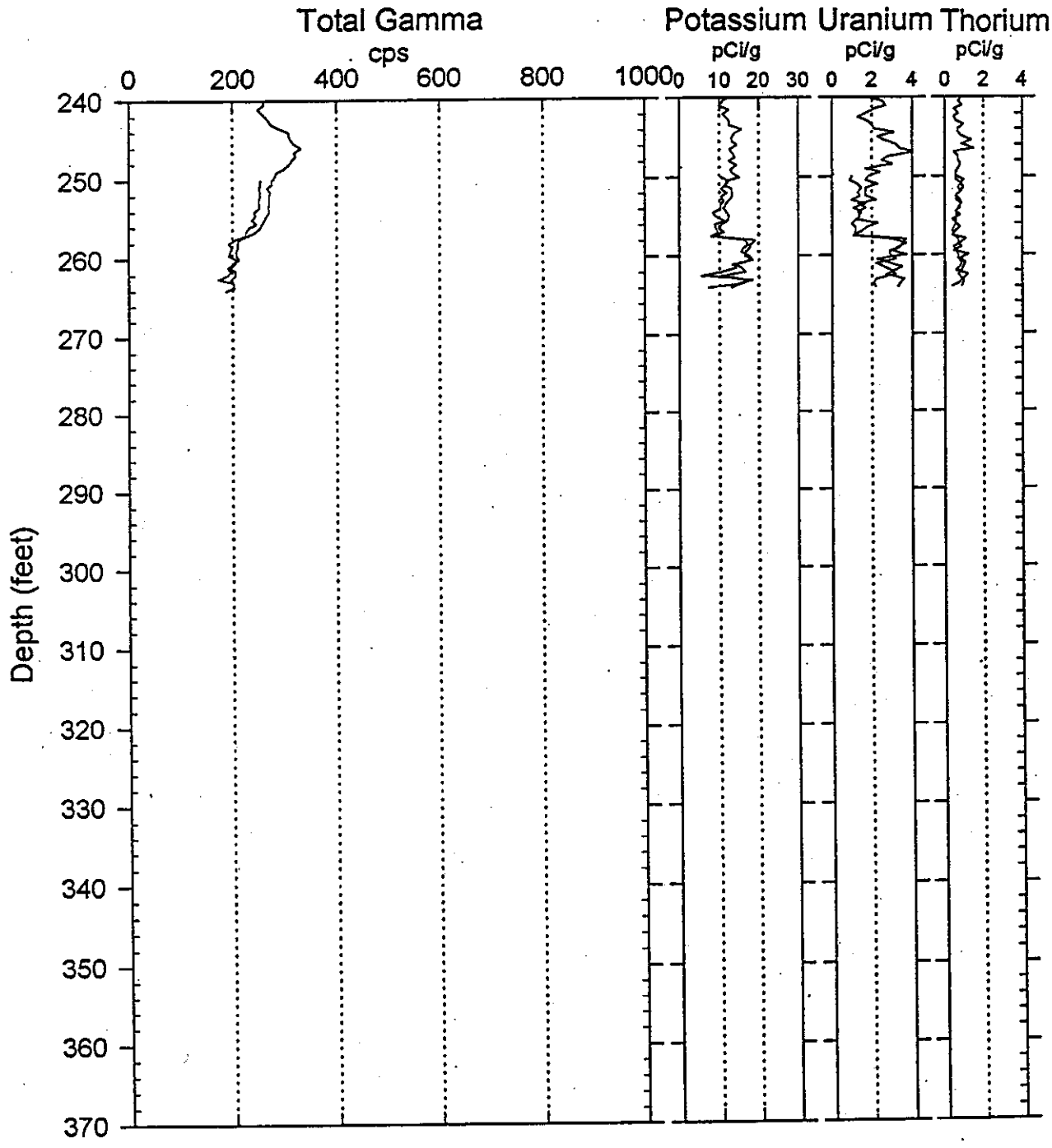
Log Date : Nov. 7&8, 1995
Westinghouse Hanford Co.



RLS Spectral KUT Processed Data

Project: Vadose Zone Monitoring
Borehole: 299-E25-07 A-8 Crib

Log Date : Nov. 7&8, 1995
Westinghouse Hanford Co.



RLS Borehole Survey Report

Borehole: 299-E25-7

Casing	Depth: 0.0' - 260'	Size: 8"	Thickness: 0.30"	
	0.0' - 230'	Size: 6"	Thickness: 0.25	
Water	257.25'			
Survey	Depth: 2.5' - 140.0'		Date: Nov. 7, 1995	
	135.0 - 264.0		: Nov. 8, 1995	

General Notes:
The well was surveyed from 2.5' to 264' with an acquisition time of 40 sec real time; the sample interval is 0.5'. Repeat sections were conducted from 50' to 40', 135.0' to 140' and 264.0 to 250.0'; these data is included on the plots.

The concentrations of the naturally occurring radionuclides potassium, uranium, and thorium are typical for Hanford sediments.

Man-made Radionuclides
Cesium (Cs-137) was identified along 3 major intervals. It was found from the surface(at 2.5' below the tpo-of-casing) to 11.0', from 19.5' to 55.0', and from 219.5' to 234.0'. The maximum activity of 7.6 pCi/g was occurred in the upper interval at 5.0'. The peak activities in the middle interval was at 24.0' and 38.5'each with concentrations of 4.2 pCi/g. The peak in the lower interval was 3.7 pCi/g and occured at 226.5'.

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: Inactive Crib A-24

Borehole	299-E26-3			
Coordinates	NA N	NA W	Feet	(Hanford System)
Elevation	NA ft	Top of casing		

Borehole Environment Information

Borehole liquid depth none (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6	0.25	0.0	201

RLS Passive Spectral Gamma Survey Information

Logging Engineers R.V. Cram J.R. Kunk
Log depth reference at zero (0.0) depth is ground level

Log Date	Archive file names	Log mode speed	Depth interval (ft) Top	Base	Incr
Jun 14, 1994	H2E26003/A574	MSA 80sec RT	0	103	0.5
Jun 15, 1994	H2E26003/A575	MSA 80sec RT	100	201	0.5

MSA: Move Stop Acquire
RT: Real Time

Calibration and Analysis Information

RLS Calibration Date: Nov. 21, 1991
Calibration Report: WHC-SD-EN-TRP-001

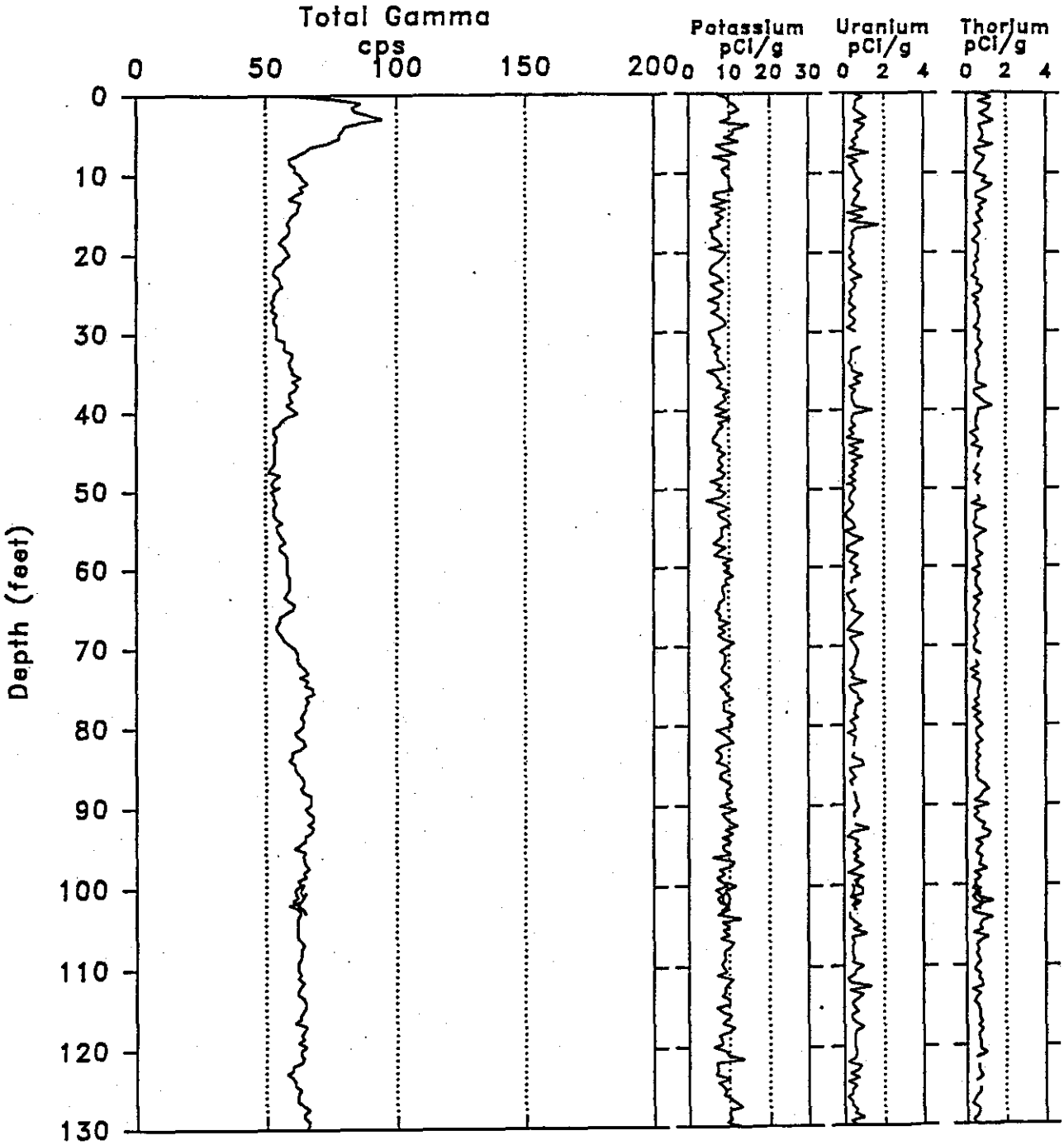
Analyst Names: S.E. Kos J. R. Kunk
Analysis Date: Oct 11, 1944

Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: Inactive Cribs
Borehole: 299-E26-3

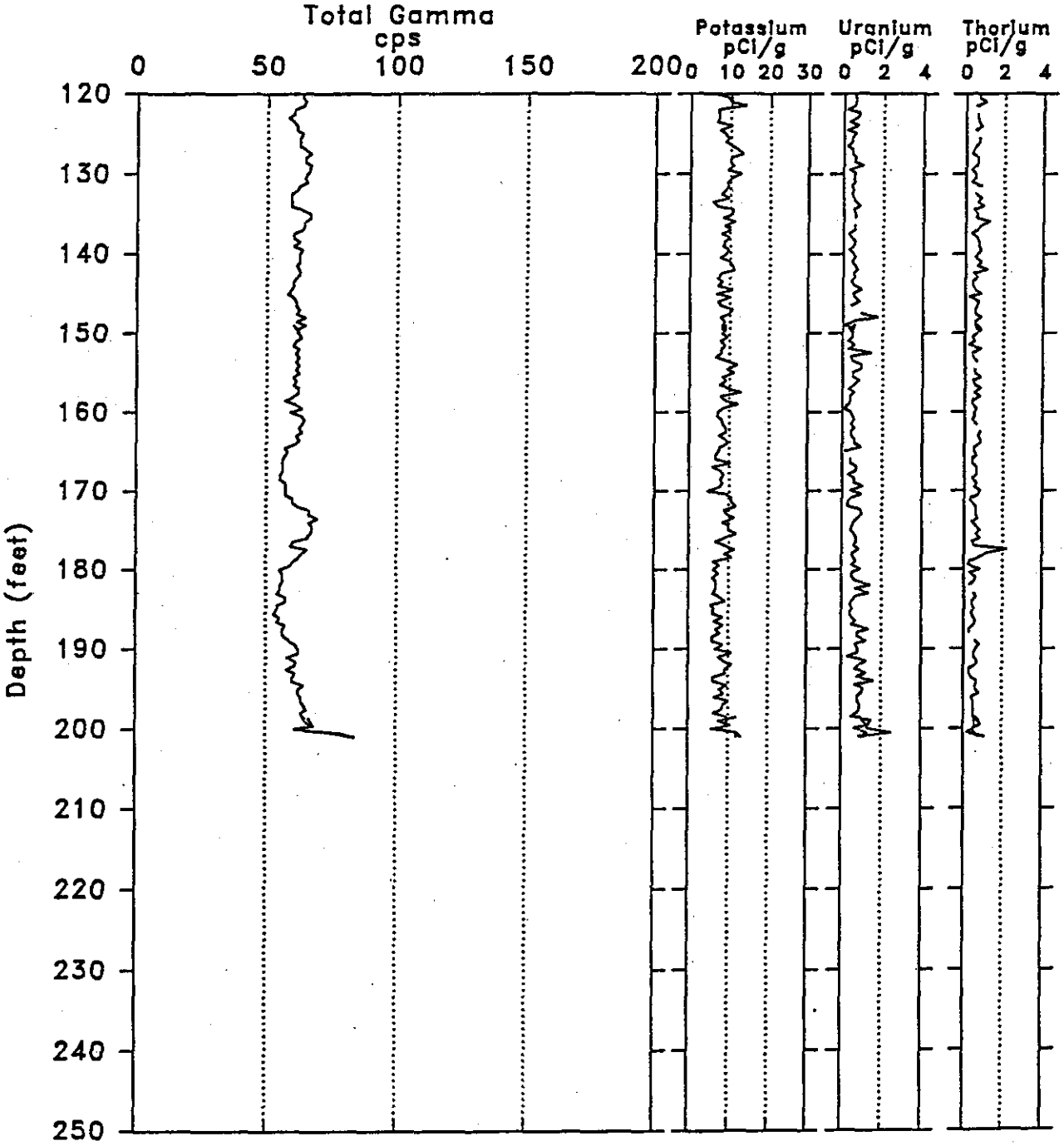
Log Date : Jun 14-15, 1994
Anal Date: Oct 11, 1994



RLS Spectral Gamma-Ray Borehole Survey

Project: Inactive Cribs
Borehole: 299-E26-3

Log Date : jUN 14-15, 1994
Anal Date: Oct 11, 1994



RLS Borehole Survey Report

~~199-K-106A~~

The surveys were conducted in 6-inch-diameter well casing with a wall thickness of .250 inch. The well is located in the A-24 crib, east of the 200 East area.

Repeat surveys were conducted from 100.5 to 103.0 feet, and from 198.5 to 201.0 feet. The repeat data is included on the plots.

The concentrations of the naturally occurring radionuclides potassium, uranium, and thorium are typical for Hanford sediments.

Cs-137 was identified from 3.0 to 4.0 feet, at a concentration of less than 2 pCi/g. Because of the low concentration and thin nature of the interval, the ^{137}Cs data was not plotted.

Westinghouse Hanford Company
RLS Spectral Gamma-Ray Borehole Survey Log Header

Project: Vadose Monitoring

Borehole	299-E26-05
Coordinates	42172W -46842 E
Elevation	651.07

Borehole Environment Information

Borehole liquid depth 250.1 (ft) from zero (0.0) depth reference of log

Casing sizep (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6	0.25	0	200
8	0.375	0	280

RLS Passive Spectral Gamma Survey Information

Logging Engineer(s) J. R. KUNK
Log depth reference at zero (0.0) depth is Top of Casing

Log Date	Archive file names	Log mode	speed	Depth interval (ft) Top	Base	Incr
Feb.27, 1996	H2E2605/B084R AW.ZIP	FIXED FIXED	0.7 fpm 0.7 fpm	3 175	175 165	0.5 0.5
Mar. 4, 1996	H2E2605/B085R AW.ZIP	FIXED	0.7 fpm	170	260	0.5

FIXED: Fixed Velocity of Cable Speed fpm: feet per minute

Calibration and Analysis Information

RLS Calibration Date: Mar 22, 1995
Calibration Report: WHC-SD-EN-TI-292

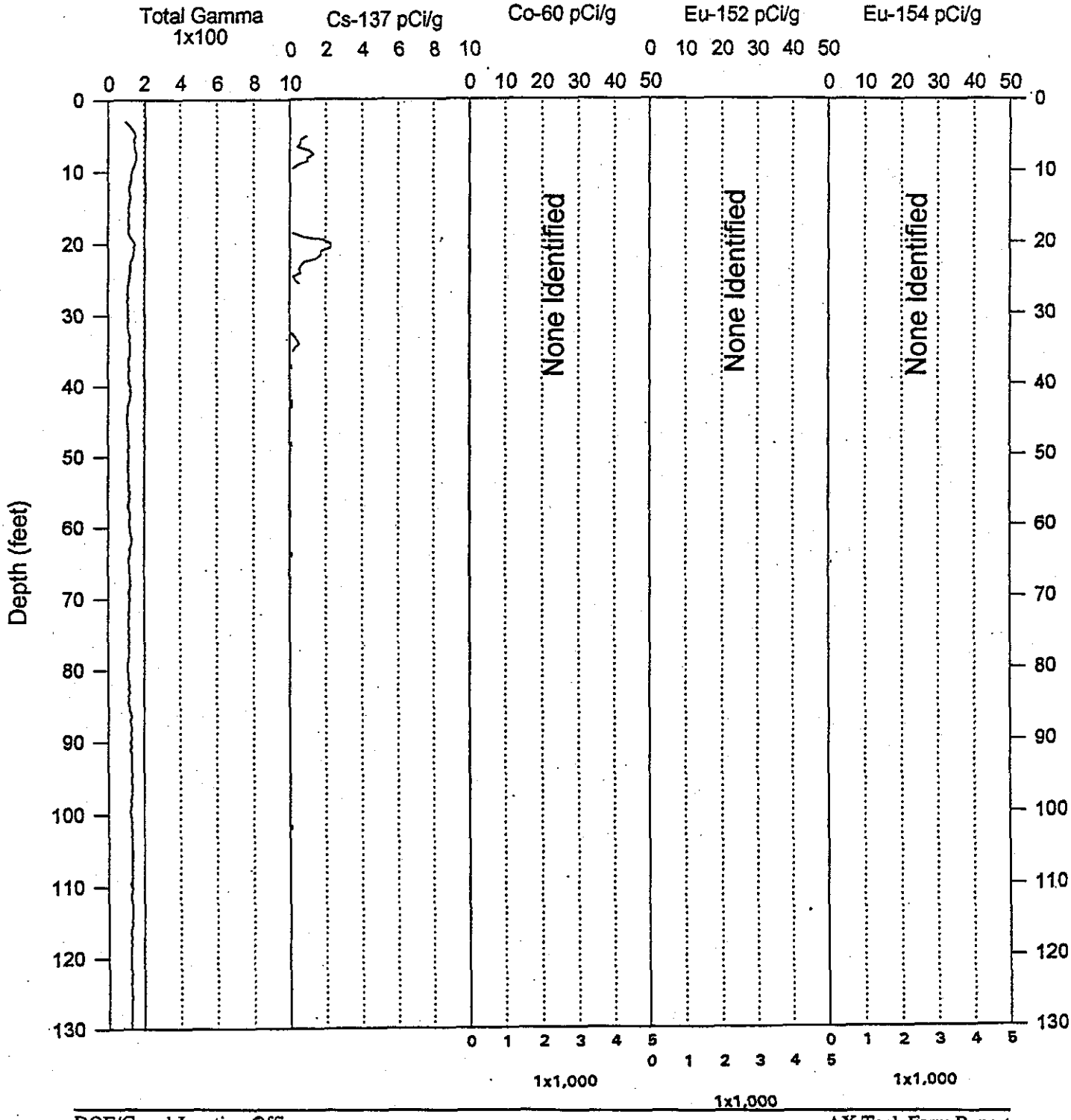
Analyst Name(s): J. R. Kunk
Analysis Date: Mar. 4, 1996

Analysis Notes: Cs-137 located in upper 35 feet.
Radionuclides Identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-24 Crib
Borehole : 299-E26-5

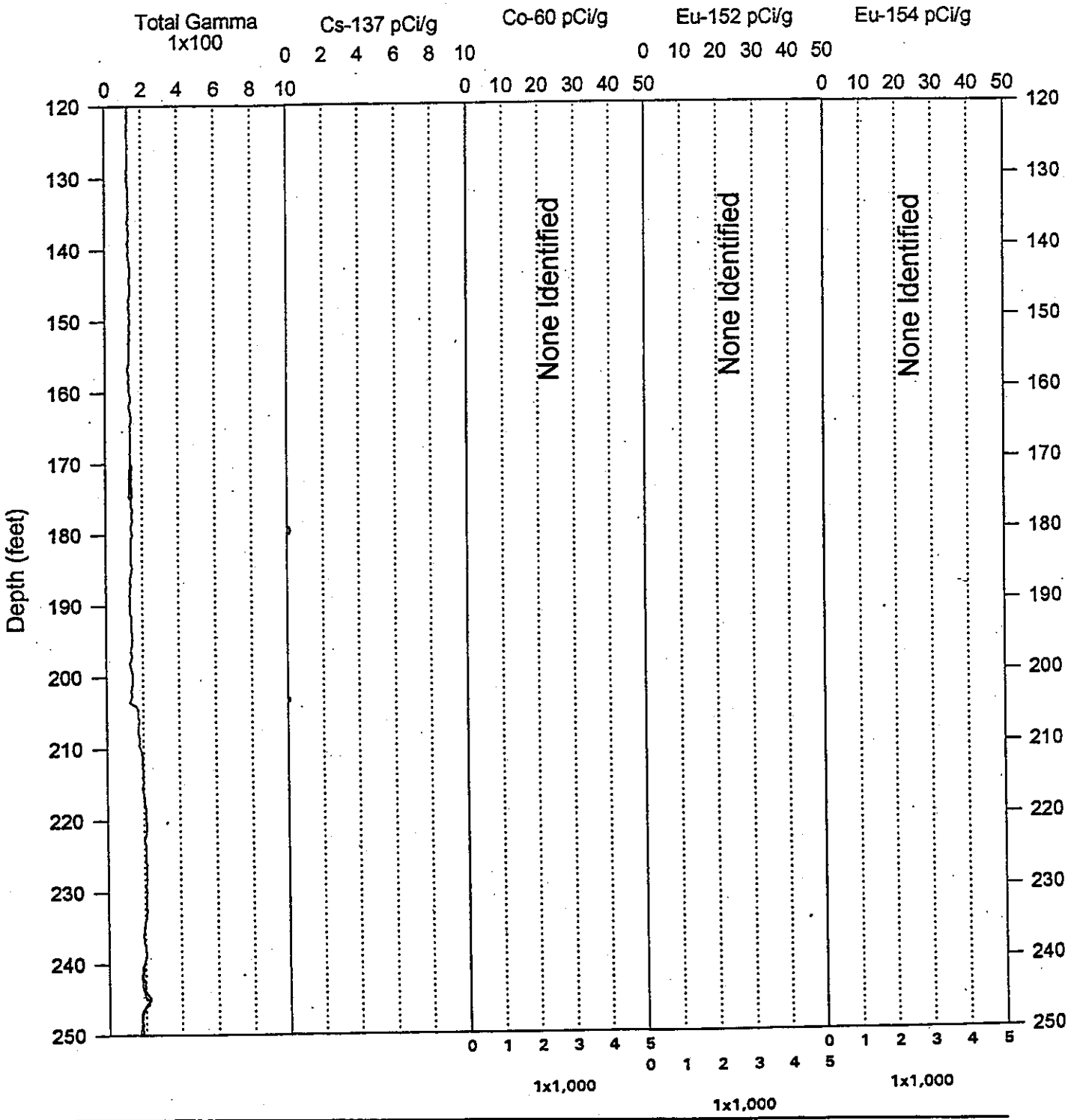
Log Date : Mar. 4, 1996
Analysis Date: Mar. 4, 1996



RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-24 Crib
Borehole : 299-E26-5

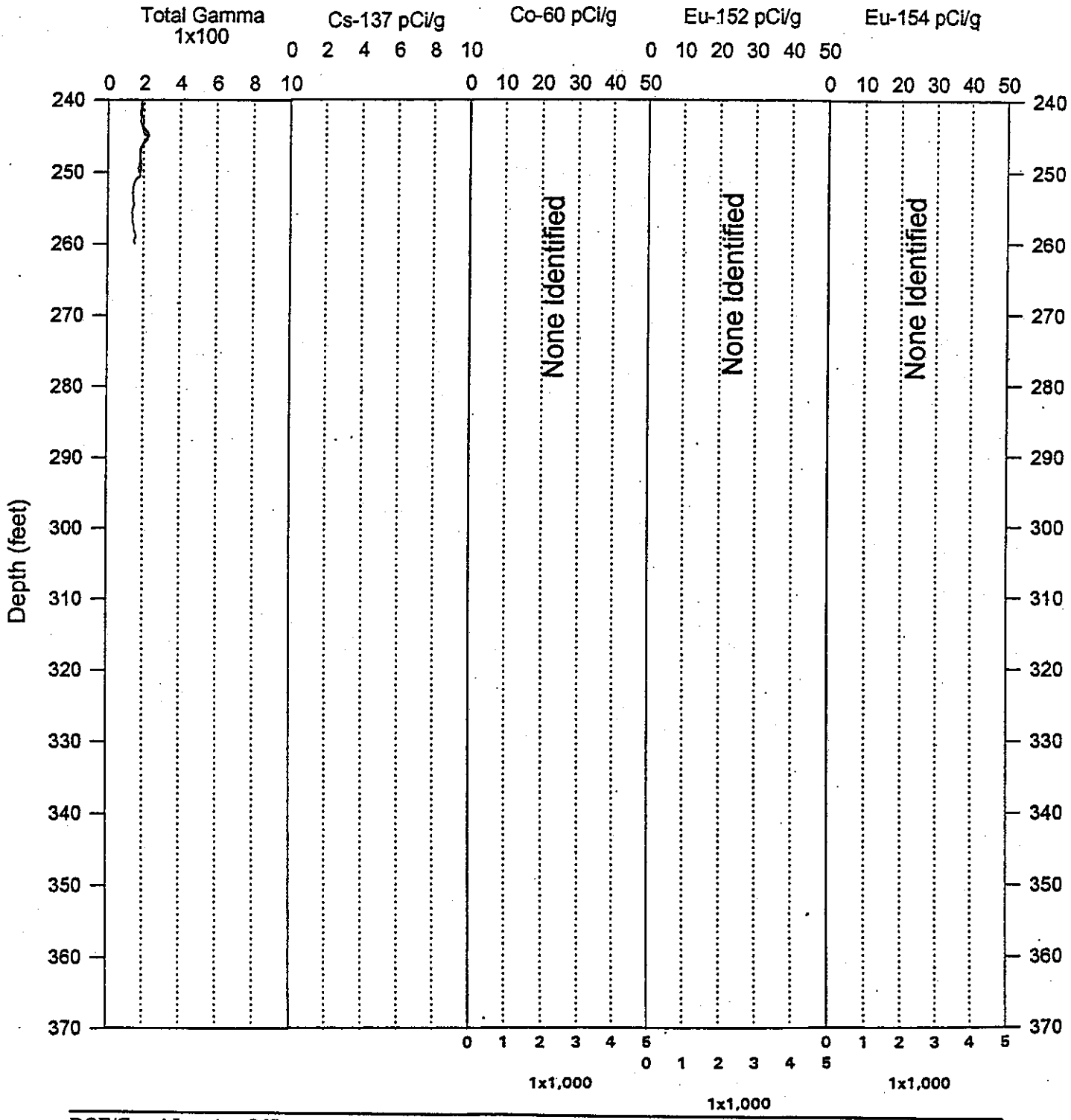
Log Date : Mar. 4, 1996
Analysis Date: Mar. 4, 1996



RLS Spectral Gamma-Ray Borehole Survey

Project: 216-A-24 Crib
Borehole : 299-E26-5

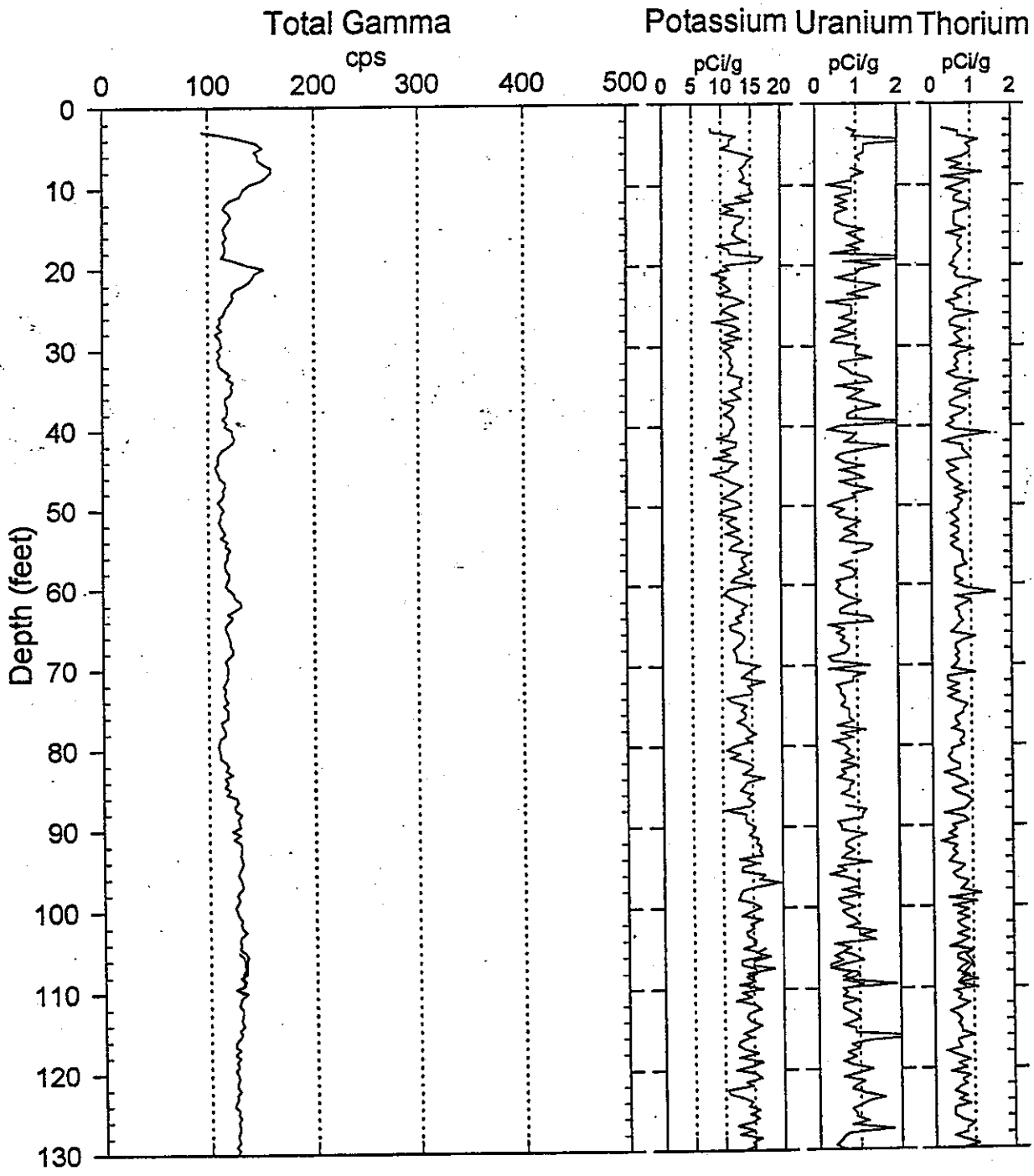
Log Date : Mar. 4, 1996
Analysis Date: Mar. 4, 1996



RLS Spectral KUT Processed Data

Project: 216-A-24 Crib
Borehole: 299-E26-05

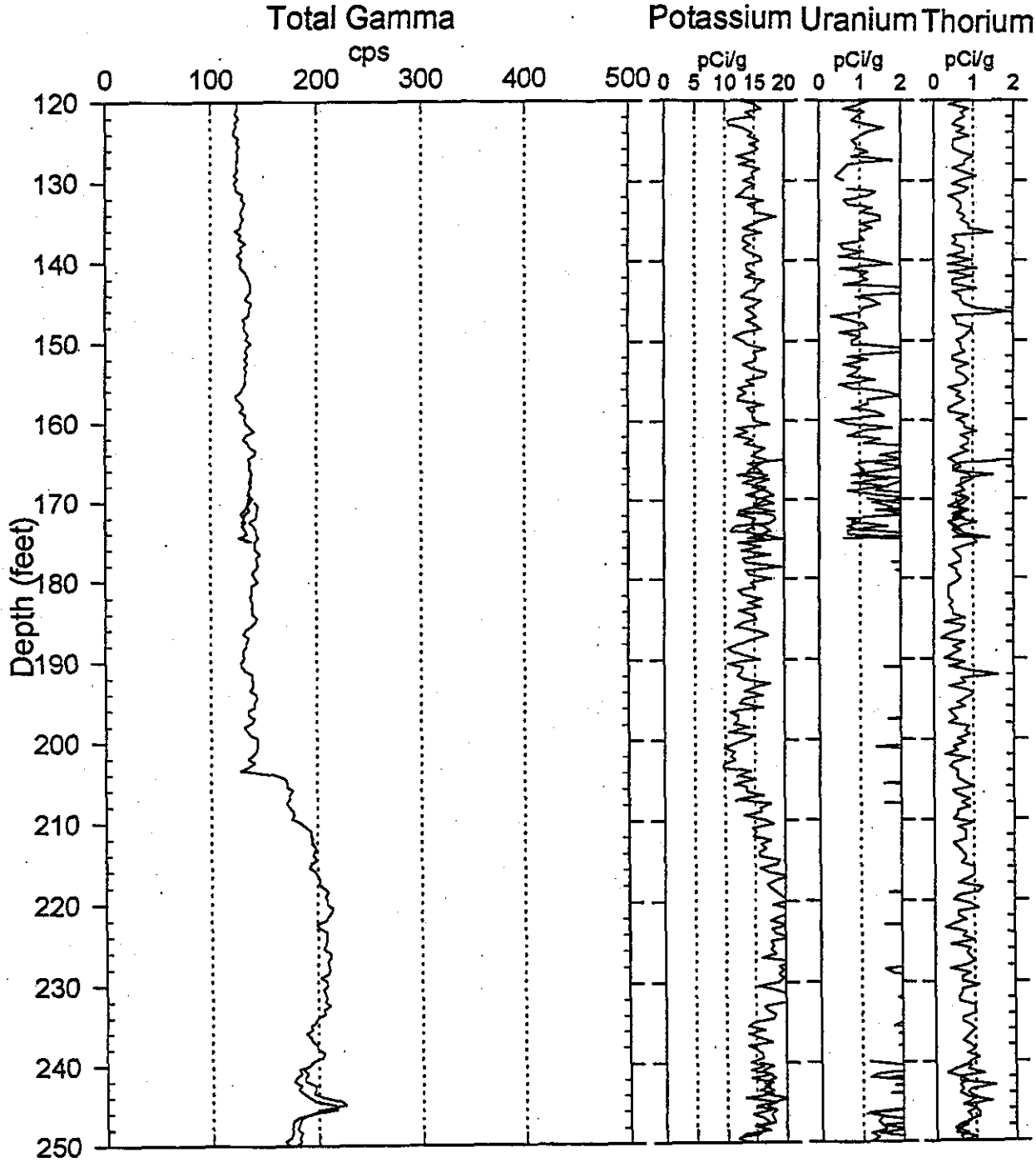
Log Date : Feb 27, 1996
Analysis Date: Feb. 27, 1996



RLS Spectral KUT Processed Data

Project: 216-A-24 Crib
Borehole: 299-E26-5

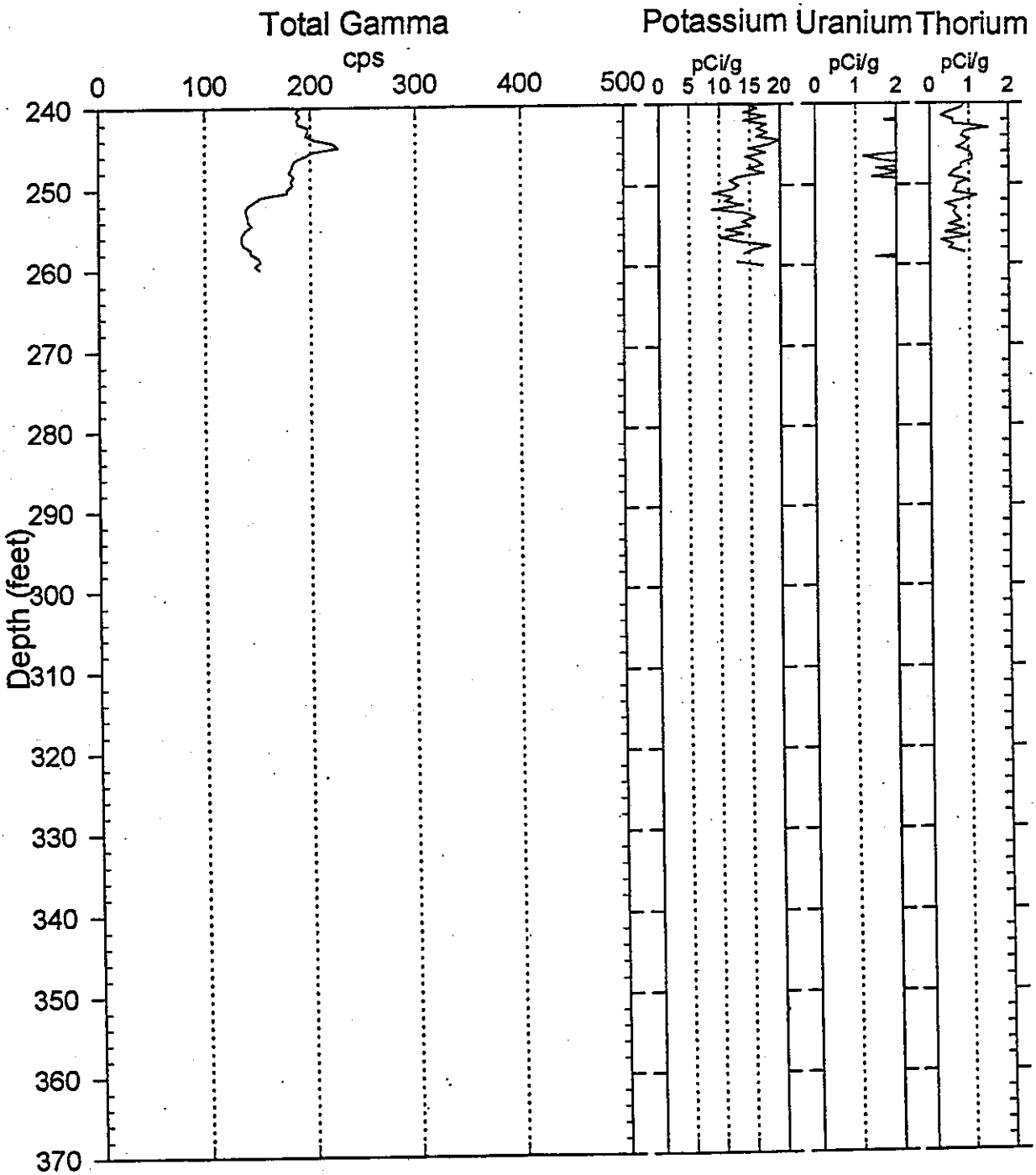
Log Date : Mar. 4, 1996
Analysis Date: Mar. 4, 1996



RLS Spectral KUT Processed Data

Project: 216-A-24 Crib
Borehole: 299-E26-5

Log Date : Mar. 4, 1996
Analysis Date: Mar. 4, 1996



RLS Borehole Survey Report

Borehole: 299-E26-05

Casing	Depth: 0'- 280'	Size: 8"	Thickness: 0.375"
	Depth: 0'- 200	Size: 6"	Thickness: 0.25"
Water	250.1'		
Survey	Depth: 3.0' - 175.0	Depth ref: Top-of-casinig	
	Date: Feb. 27, 1996	Mar. 4, 1996	
	Casing stick-up: 3.1'(8")	0.2'(6")	

General Notes:
The well was surveyed from 3.0' to 175' at fixed cable speed of 0.7 ft/min with a sample interval of 0.5'. A repeat log surveies were acquired from 175' to 165', 170' to 260' and 250' to 240'. The main and repeat survey data are displayed on the plots. The survey depths are measured from top of casing.

The concentrations of the naturally occurring radionuclides potassium, uranium, and thorium are typical for Hanford sediments.

Man-made Radionuclides
Cesium (Cs-137) was identified from 5' to 9.5', 18.5' to 25.5' and 32.5' to 35'. The maximum decay activity was 2.3 pCi/g at 20' and 20.5'.

Cobalt (Co-60) and Europium (Eu-152 and Eu-154) were not identified in the survey spectra. The plot tracks are shown for presentation uniformity.

Appendix D
AX Tank Farm Correlation Plots

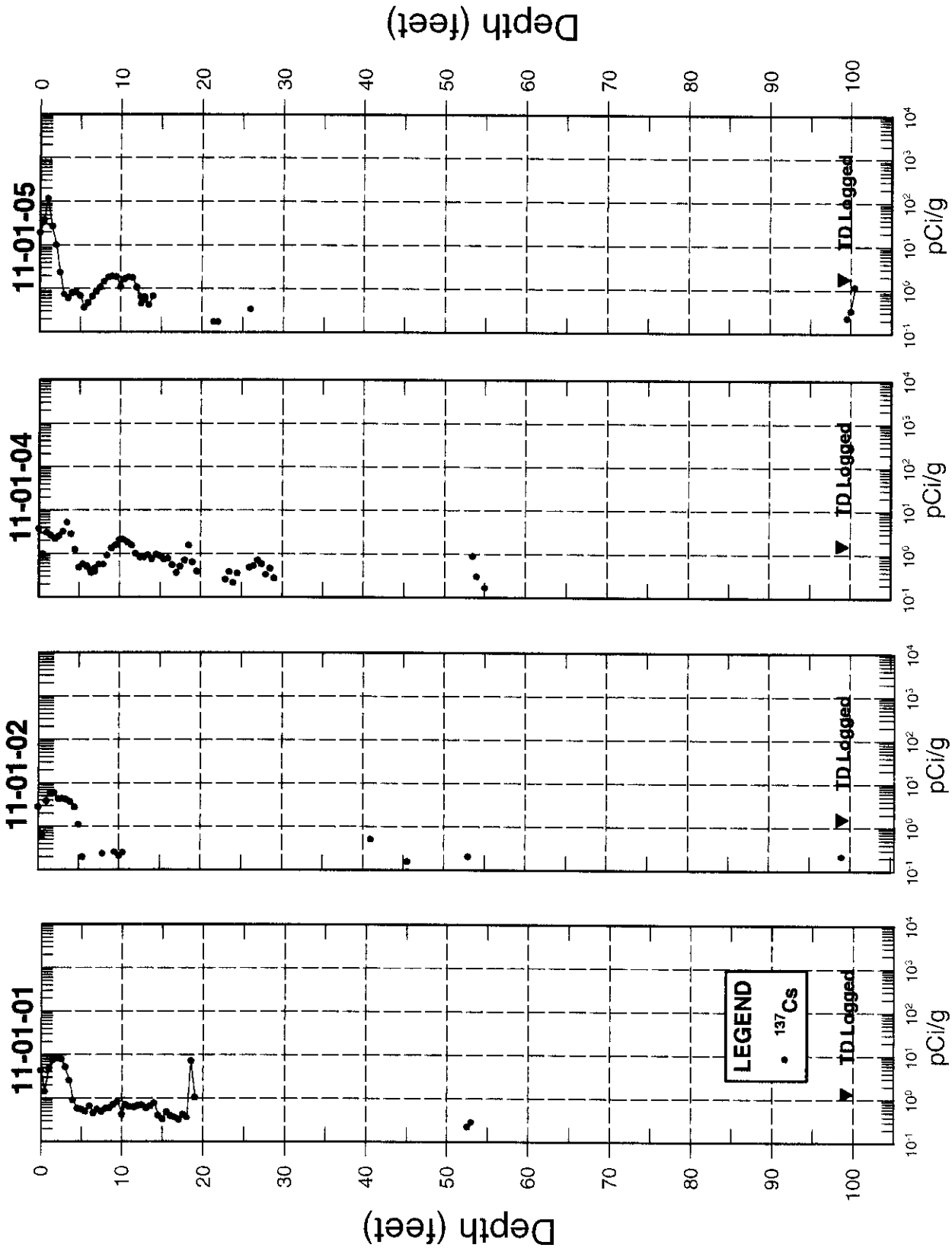


Figure D-1. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-101

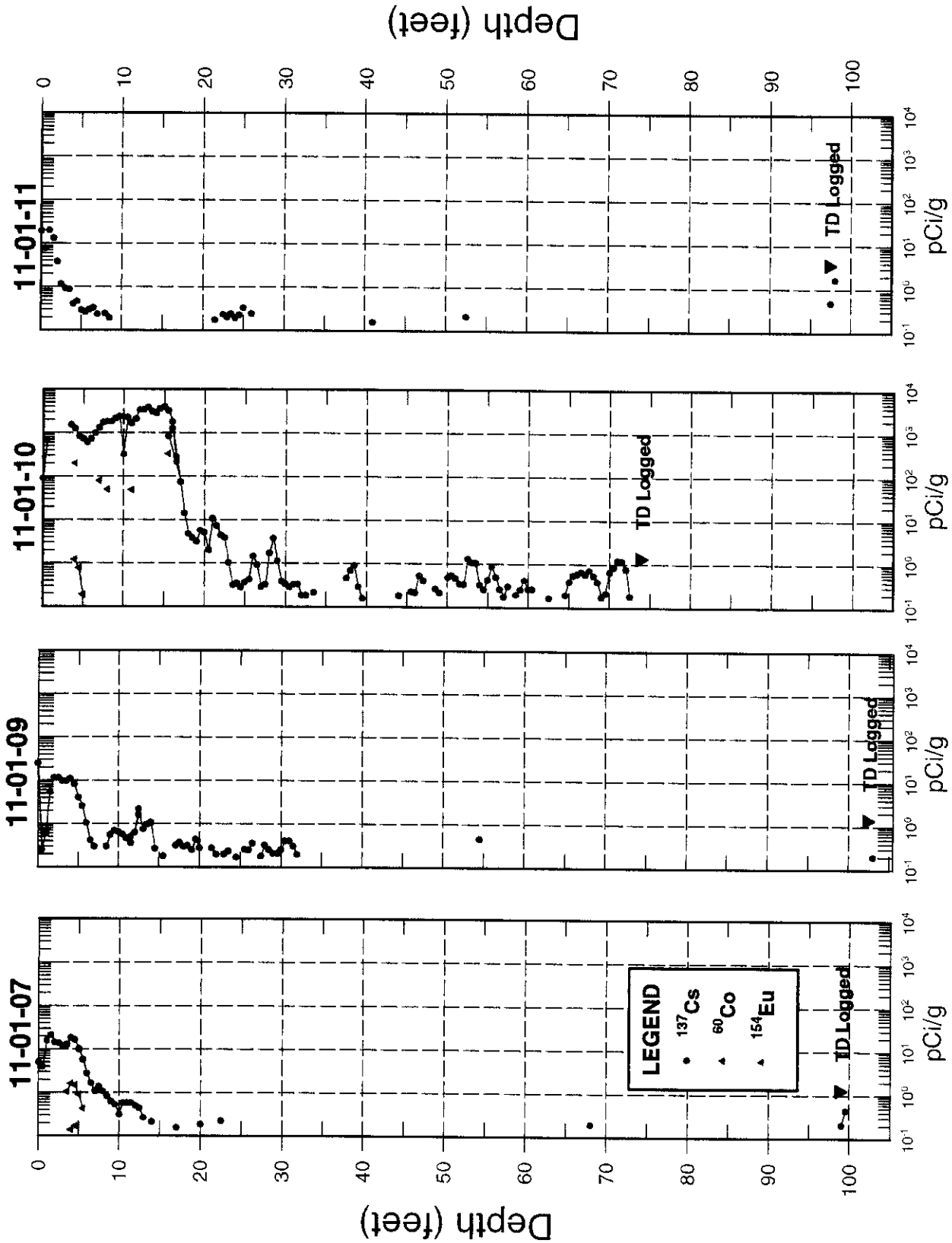


Figure D-1 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-101

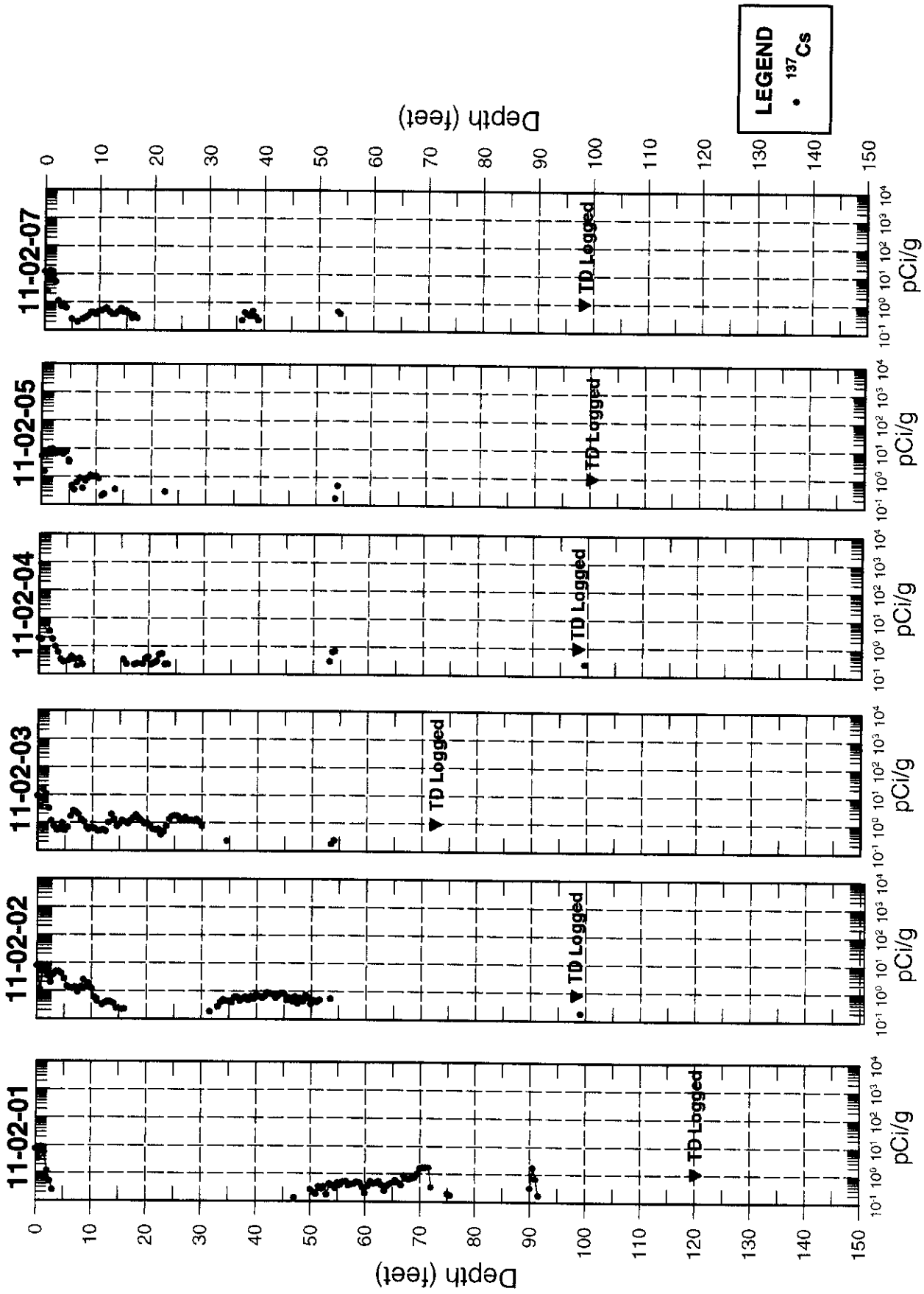


Figure D-2. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-102

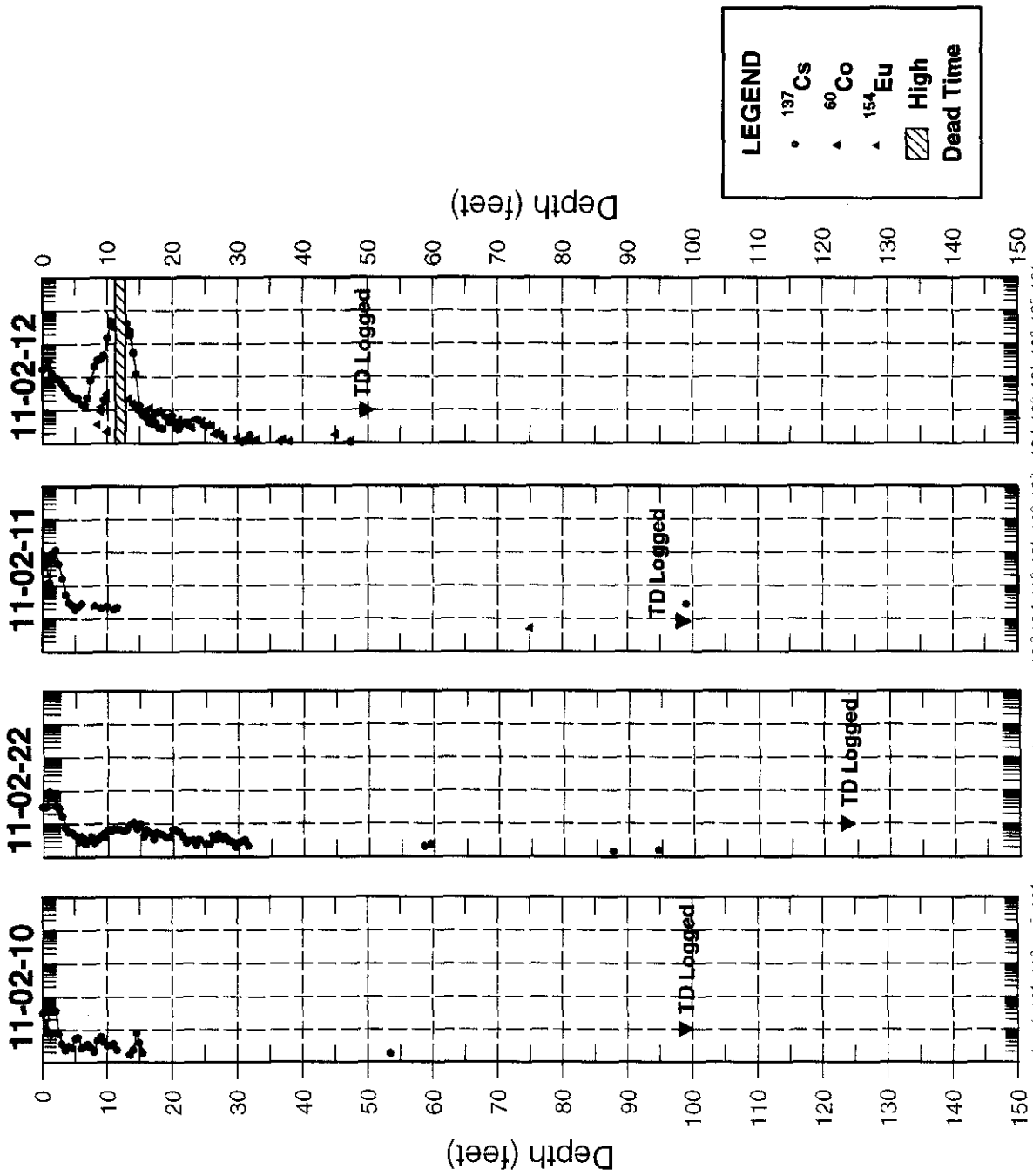


Figure D-2 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-102

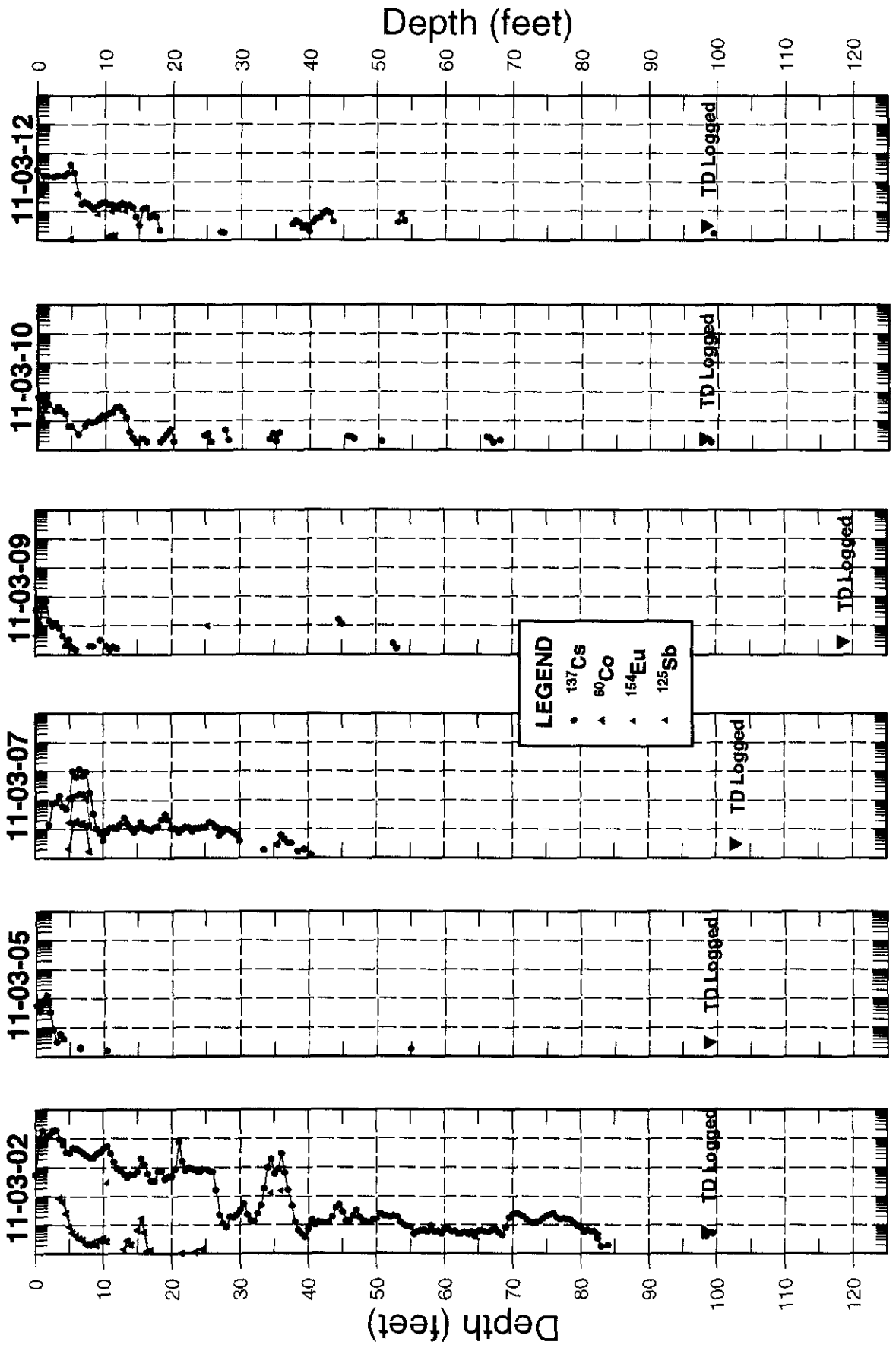


Figure D-3. Correlation Plot of ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{125}Sb Concentrations in Boreholes Surrounding Tank AX-103

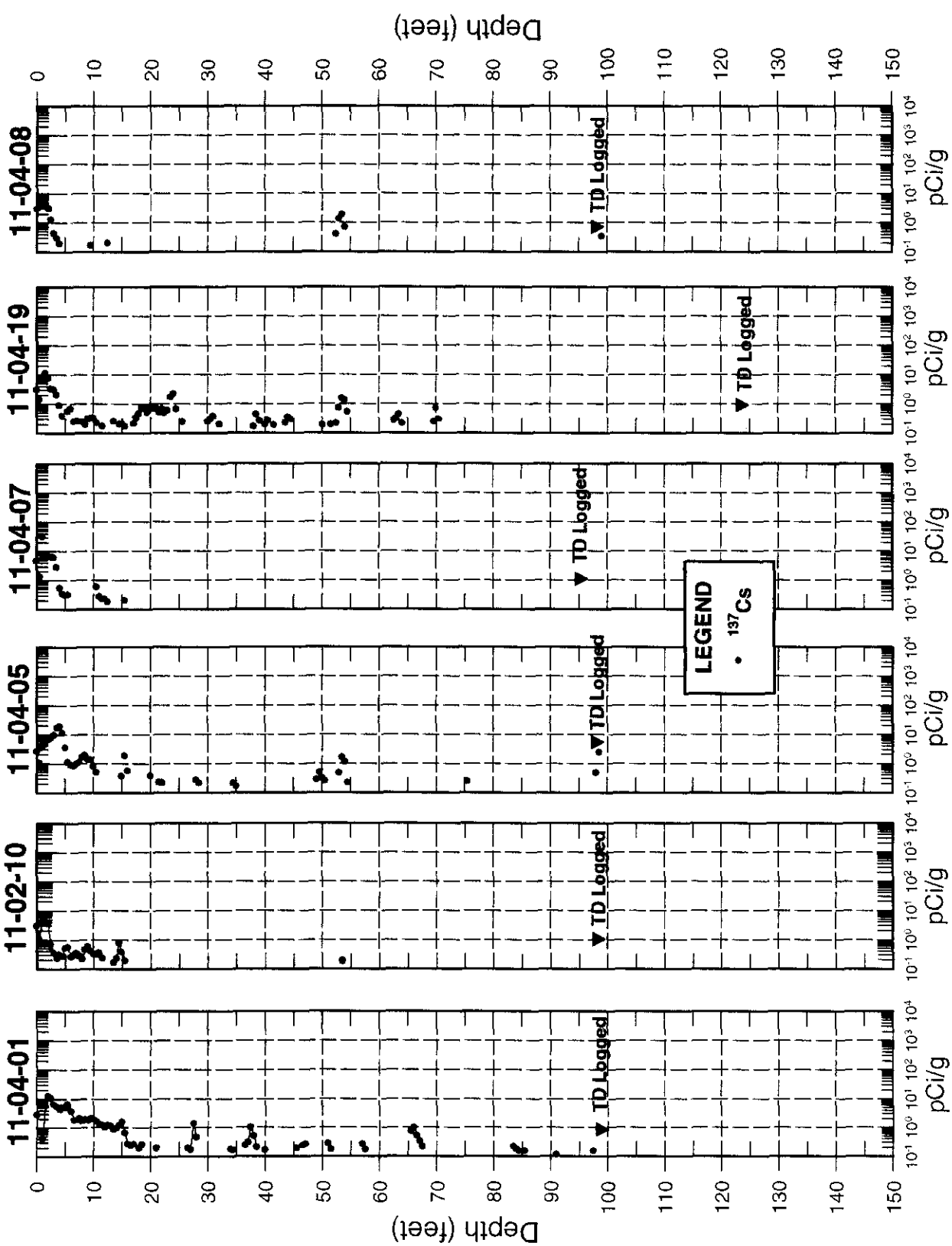


Figure D-4. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-104

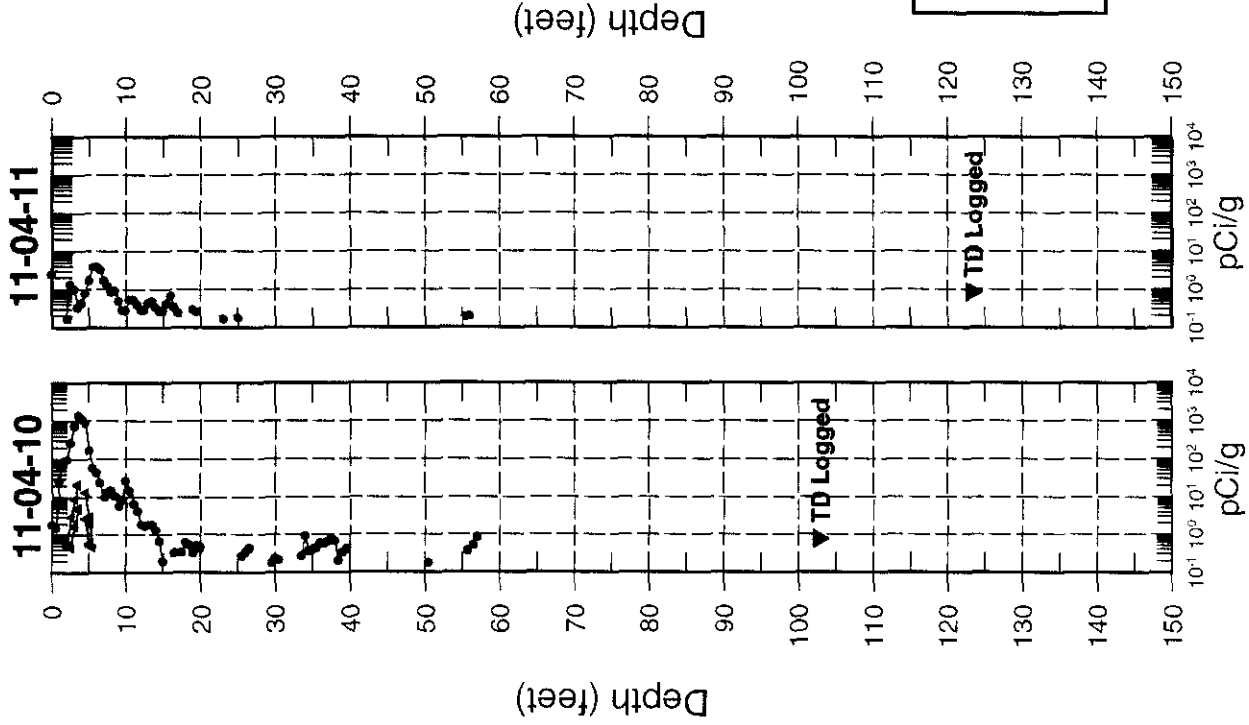


Figure D-4 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank AX-104