GJO–97–1–TAR
GJO–HAN–8

Vadose Zone Characterization Project at the Hanford Tank Farms

U Tank Farm Report

May 1997

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

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U.S. Department of Energy
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Work performed under DOE Contract No. DE–AC13–96GJ87335 for the U.S. Department of Energy.

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Contents

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

Page

Contents (continued)

Tables

Vadose Zone Characterization Project at the Hanford Tank Farms

U 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, to identify contamination sources when possible, and to develop a baseline of the contamination distribution that will permit future data comparisons. This characterization work also allows an initial assessment of the impacts of the vadose zone contamination as required by the Resource Conservation and Recovery Act (RCRA).

This characterization project involves acquiring information regarding vadose zone contamination with borehole geophysical logging methods and documenting that information in a series of reports. This information is presently limited to detection of gamma-emitting radionuclides from both natural and man-made sources. Data from boreholes surrounding each tank are compiled into individual Tank Summary Data Reports. The data from each tank in a tank farm are then compiled and summarized in a Tank Farm Report. This document is the Tank Farm Report for the U Tank Farm.

Logging operations used high-purity germanium detection systems to acquire laboratory-quality assays of the gamma-emitting radionuclides in the sediments around and below the tanks. These assays were acquired in 59 boreholes that surround the U Tank Farm tanks. Logging of all boreholes was completed in December 1995, and the last Tank Summary Data Report for the U Tank Farm was issued in September 1996.

Log data were analyzed by identifying man-made radionuclides in the sediments and by determining equivalent concentrations (i.e., concentrations calculated under the assumption that radionuclides are uniformly distributed in the medium surrounding the borehole). Vertical profile plots or logs of the radionuclide concentrations as a function of depth were prepared for each borehole and provided in the appendix of corresponding Tank Summary Data Reports. The borehole logs and the Tank Summary Data Reports constitute the baseline database. The Tank Summary Data Reports also provide a review of the tank history and status, present summaries of other tank monitoring data, and place the information gained from the logging operation in the context of what is known about the tank.

The U Tank Farm Report is the final document of this characterization project that discusses the vadose zone contamination in the entire U Tank Farm. This report describes the vadose zone contamination with empirical three-dimensional models of the contamination developed from the log data and places the information into the appropriate geotechnical context.

A brief review of characteristics of some important radionuclides is presented in this report. The U Tank Farm geology and hydrology give the reader an understanding of the potential implications that the presence of the contamination has on the environment. The geologic and

hydrologic information were obtained from data in previously published Hanford contractor documents.

Background information regarding U Tank Farm construction, history of operations, tank contents, and tank monitoring is provided. Some of the information presented in this document is not included in the individual Tank Summary Data Reports. A description of waste sites adjacent to the U Tank Farm is also presented.

The spectral-gamma logging operations are described with references made to all pertinent documentation related to data acquisition, data analysis and log preparation, data management, and quality assurance. Particular emphasis is placed on descriptions of the technical aspects of the measurements, including instrumentation calibration and data reduction.

The spectral gamma log data show ^{137}Cs is the most abundant and highest concentration man-made gamma-emitting radionuclide detected throughout the U Tank Farm. Other gamma-emitting radionuclides detected include ^{235}U, ^{238}U, ^{60}Co, and ^{154}Eu.

Models of the ^{137}Cs, ^{235}U, and ^{238}U contamination plumes were developed and are based on the geostatistical analyses of the data acquired in the monitoring boreholes. The occurrences of ^{60}Co and ^{154}Eu were not abundant enough to correlate those radionuclides among boreholes. The geostatistical structures of the ^{137}Cs, ^{235}U, and ^{238}U models are based on the observed contamination distribution. Visualizations of the computed model show three-dimensional solid-surface representations of the contamination from several view angles. Because those visualizations are interpretations of the actual radionuclide contamination distributions, potential inaccuracies and uncertainties in the model are discussed so that the limitations of the visualizations are recognized.

The estimated assay uncertainty of the log data points calculated from spectral peak data was not included in the calculation of the model. Because the spatial variance is much greater than the assay uncertainty, inclusion of the assay uncertainty in the model calculations is not necessary.

The most significant inaccuracies in the models result from potential situations where the contamination is actually only within the borehole and not distributed in the formation. Interpretations suggest the occurrence of such conditions in several boreholes where it is suspected that contamination has fallen down and settled at the bottom of boreholes, creating false, deep, low-concentration plumes, as shown on the visualizations. Other inaccuracies result from cases where contamination may have moved down a borehole during drilling or later as a result of an unsealed borehole. These inaccuracies result from a situation where the log data may not actually represent a homogeneously distributed source as assumed by the calibration condition.

Visualizations were prepared showing the contamination around each tank, usually from more than one viewpoint. In almost all cases, the visualizations show the sources of the contamination confirm the current listed integrity-status of the tanks.

The highest concentrations of ^{137}Cs contamination in the U Tank Farm boreholes were detected on the north side of tank U-112, providing confirmation that this tank has leaked. ^{137}Cs contamination was detected in borehole 60-12-01 in a large zone, part of which was not quantified because of high detector dead time caused by high ^{137}Cs concentrations. ^{137}Cs contamination most likely related to leakage from tank U-110 was detected in borehole 60-10-07 at a depth near the base of this tank. Other high ^{137}Cs concentrations were detected in the U Tank Farm boreholes; however, this contamination was associated with near-surface contamination resulting from surface spills, piping leaks, or proximity of the boreholes to piping containing contamination. ^{137}Cs contamination was detected throughout the lengths of several boreholes, but the concentrations were usually 1 pCi/g or less.

Uranium contamination containing the identified uranium isotopes ^{235}U and ^{238}U was detected in several boreholes in the U Tank Farm.

Because the monitoring boreholes in the U Tank Farm only extend to a depth of about 155 ft, the maximum depth extent of the contamination plumes in this farm is not known. The depth to groundwater in the vicinity of the U Tank Farm is about 200 ft; therefore, any impacts of the vadose zone contamination on the groundwater cannot be directly and positively determined.

It is recommended that additional records and information available at Hanford be collected, catalogued, assessed, and analyzed to make the information available for the SST vadose zone characterization project. Historical records reviewed during the preparation of this report proved to be valuable when interpreting the spectral gamma-ray data and assessing the distribution of some of the contamination in the vadose zone. As discussed in Section 10.0, "Discussion of Results," the historical records proved to be valuable in assessing the sources of some of the contamination plumes. Although several comprehensive documents have been prepared regarding historical tank farm information, data are lacking for large periods of tank farm operations.

Additional logging characterizations are recommended, including measurements that can determine formation moisture content and bulk density. Moisture data may produce lithologic information that will enable better correlation of log data among boreholes. The ^{40}K concentration plots were the main focus for applying correlation of lithology among the boreholes, and distinct lithologic features were identified in the sediments beneath the U Tank Farm. Some of these features appeared to control the distributions of contamination. Moisture information may assist correlation of the minor plumes because moisture is the driving force for contaminant migration.

Concentrations of nongamma-emitting radionuclides, particularly the higher health-risk nuclides such as plutonium and technetium, should be identified and evaluated. It is also important to obtain samples that are analyzed for the presence of RCRA constituents in the vadose zone sediments.

The results presented in this report provide a basis from which more comprehensive models of the contamination distribution can be developed to better determine the nature and extent of the contamination.

Finally, it is recommended that a vadose zone monitoring program be implemented to detect changes in the contaminant concentrations and distributions, to permit tracking the movement of the contaminants, and to help identify or verify leaks from the tanks.

1.0 Introduction

The U Tank Farm is located in the southwest portion of the 200 West Area of the Hanford Site (Figure 15-1) and consists of twelve 530,000 gallon (gal) and four 55,000 gal single-shell tanks (SSTs). These tanks currently store high-level nuclear waste that was generated primarily from the chemical processing of irradiated uranium fuel reactor materials. Four of the 530,000-gal tanks are listed in Hanlon (1996) as "assumed leakers" and have been estimated to have leaked a total of more than 100,000 gal of high-level radioactive liquid into the vadose zone sediments.

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 gamma-emitting contamination in the vadose zone at all the Hanford Site SST farms by performing spectral gamma-ray logging of boreholes that surround the tanks. The U Tank Farm geophysical logging was completed, and the results of this baseline characterization are presented in this report.

This characterization project was undertaken to help establish the nature and extent of the distribution of gamma-emitting contamination in the vadose zone around the SSTs. Existing monitoring boreholes in the U 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 sediment surrounding the boreholes. These data were then used to develop a three-dimensional model of the distribution of these radionuclides in contamination plumes in the vadose zone around the U Tank Farm tanks.

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 may be utilized to develop a more comprehensive vadose zone characterization project that can be used to establish a tank monitoring program and to determine the implications or impacts of the contamination.

Radionuclide concentration logs for individual boreholes were compiled and presented in 12 individual Tank Summary Data Reports (DOE 1996h, 1996i, 1996j, 1996k, 1996l, 1996m, 1996n, 1996o, 1996p, 1996q, 1996r, 1996s).

Section 15.0, "Figures for the U Tank Farm," in this report contains figures in the order they are presented in the report text.

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 in the vadose zone and to determine the nature and extent of the contamination.

Because only passive gamma logging methods are used, only gamma-emitting radionuclides are assayed. The gamma-ray signatures of the radionuclides in the waste that may have leaked from the tanks can be detected through existing steel-cased boreholes that surround the tanks.

An integral objective of this project is to identify or confirm the sources of the contamination, when possible. In a few instances, an individual tank or other source is identified, on the basis of the log data, in the Tank Summary Data Reports.

It is also a purpose of this project to produce a baseline measurement of the contamination concentration around the individual boreholes and a baseline of the contamination distribution within the U Tank Farm in general. That baseline consists of the individual borehole logs or the log database and the contamination distribution model. These data can be used for future comparisons of radionuclide migration studies and to provide a baseline that can be used for identifying and quantifying new tank leaks.

An additional 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 moisture and contaminant migration. These KUT data are correlated in this report with similar data from nearby groundwater monitoring wells.

2.2 Scope of the Project

The primary scope of this project involves spectral gamma logging of existing vadose zone monitoring boreholes. No boreholes were drilled in the U Tank Farm during the course of this project; therefore, the assessments of the vadose zone contamination are based on the limited distribution of existing boreholes. These boreholes extend 100 to 155 feet (ft) down into the vadose zone, while the groundwater is approximately 200 ft below the ground surface. Because none of the boreholes were deepened, these assessments are limited to the depth of existing boreholes. This limitation is based strictly on economics. It is prudent to log the existing boreholes, develop a contamination model based on those data, and determine the model uncertainty before conducting a more rigorous and expensive characterization.

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. Much of this information has not been comprehensively compiled, reviewed, and analyzed to understand its significance in relation to the U Tank Farm vadose zone contamination. The historical information helps to identify potential sources of contamination and to explain the nature and extent of the contamination identified by the new 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 the project also includes preparation of reports that provide the results to current and future Hanford Site personnel and identification of the quality of the data in terms of precision and accuracy as well as quality assurance. Documentation on procedures, instrument calibration, quality assurance, and data analysis methods has been prepared (DOE 1994a, 1994b, 1995e, 1995f, 1995g, 1995h, 1995i, 1995j, 1995k, 1996c, 1996d, 1996e, 1996f, 1996g). All reports and the log data are available from Hanford databases. By making these data available and quantifying the uncertainty associated with the data, decision makers can make use of these data 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 treatment, storage, and/or disposal (TSD) units, they are a 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, including DOE orders and interim status requirements of RCRA. By developing a baseline characterization, future monitoring activities will be more effective.

2.4 Purpose of Report

This report presents a compilation of the results of the spectral gamma logging characterization at the U Tank Farm that were originally reported in individual Tank Summary Data Reports and provides models of the ^{137}Cs, ^{235}U, and ^{238}U contamination distributions. The models of the contaminant distributions correlate the individual borehole logs in three dimensions and help to identify contamination plumes, to develop relationships between the plumes, and to determine the sources of the contamination. Section 9.0 documents model development, identifies assumptions and model parameters, and explains the uncertainty associated with the model.

This report provides brief introductory information regarding the U Tank Farm, including background information, a history of the tank farm, geologic and hydrologic reviews, and descriptions of the waste sites and facilities that are adjacent to the U Tank Farm.

This report also identifies some potential environmental impacts from the contamination identified in the baseline characterization so that those impacts can be evaluated in a quantitative manner in either the EIS or the SST closure plan as more definitive data become available.

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 reviews the general the risk levels associated with each radionuclide.

Many radionuclides in the original tank wastes that had short half-lives have since decayed away and are no longer detectable. Some of the radionuclides of interest are identified in the following sections. These radionuclides include those that are detectable with the SGLS, those whose occurrences can be inferred from the SGLS data, and radionuclides that are related to those detected with the SGLS.

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 that 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 (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 long half-life and relatively high concentration in the tank waste, ^{137}Cs is the most abundant radionuclide in the vadose zone around the SSTs. This contaminant is easy to detect and quantify with passive gamma logging and was detected in every borehole in the U Tank Farm. ^{137}Cs is reported to have a high sorptive capacity in sediment. However, in the presence

of competing positive ions such as from 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 groundwater 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 1480 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 is 99.8 and 99.9 percent, 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 this radionuclide emits both beta particles and gamma rays during decay that are relatively high-energy 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 over 4 orders of magnitude and is strongly dependent on the type of sediment in which it was measured or calculated (Adams 1995).

^{60}Co is usually present as a divalent cation in the subsurface sediments and is strongly adsorbed onto sediment, particularly to the surface of clay minerals. However, dilute acid or chelating compounds such as ethylenediaminetetraacetic acid (EDTA) interfere with this adsorption. At the other extreme, the noncationic form of ^{60}Co is not adsorbed by the sandy soils that are prevalent at Hanford.

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 cesium. 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 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. The presence of ^{60}Co in the subsurface provides an indication of the location and extent of a contamination plume; monitoring for changes in ^{60}Co concentrations may indicate changing conditions of a plume that are due to remobilization from precipitation infiltration or new tank releases or to changes merely reflecting the decay rate of ^{60}Co.

3.3 Europium-152 (^{152}Eu) and Europium-154 (^{154}Eu)

Europium radionuclides in the tank wastes include the isotopes ^{152}Eu and ^{154}Eu. ^{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. Of these isotopes, only ^{154}Eu was detected in the U Tank Farm. ^{154}Eu was detected near the ground surface of the U Tank Farm in a few thin contamination zones.

^{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).

^{152}Eu, with a half-life of 13.5 years, decays by electron capture and positron emission to samarium-152 (^{152}Sm) and by beta particle emission to gadolinium-152 (^{152}Gd) with the release of a large number of possible gamma rays, the most intense of which include 344 keV (27 percent), 779 keV (13 percent), 964 keV (14.6 percent), 1,112 keV (13.6 percent), and 1,408 keV (21 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. Brodeur et al. (1993) did not consider potential lithologic control over the migration and deposition of europium.

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

^{152}Eu and ^{154}Eu both present short-term exposure risks because of gamma radiation, but these radionuclides are not considered a long-term risk because of their relatively short half-lives. 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, long-lived 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 (15.7 s), 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 radiation or braking radiation can be measured in a borehole with gamma-ray detectors. Bremsstrahlung radiation 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 it is present at about 2,000 pCi/g or greater, it can be positively identified but not readily quantified with spectral gamma-ray detection equipment.

Because of its long half-life, the inventory of ^{90}Sr 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 the second most abundant radionuclide in the tank waste material. ^{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.

^{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 can apparently 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 another fission product, but its yield from slow neutron fission of uranium-235 (^{235}U) or plutonium-239 (^{239}Pu) is only about 0.02 percent (out of 200 percent of the fission atoms) and does not account for a large percentage of the total fission product. The 2.8 year half-life of ^{125}Sb is relatively short; however, its percentage of abundance in the waste products increases as the waste ages because it has a long half-life relative to other more abundant fission and activation products (excluding ^{137}Cs and ^{90}Sr).

^{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 not detected in any of the U Tank Farm monitoring boreholes.

^{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 can be very mobile in the environment. It is an important radionuclide in long-term risk assessments and can generate 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), technetium will precipitate out of solution as a sulfide or hydrated oxide if sufficient reducing conditions exist in the sediment. 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 groundwater is 900 pCi/L. ^{99}Tc is highly mobile in the groundwater at Hanford and has been detected in the groundwater samples obtained in groundwater monitoring boreholes near the U 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. ^{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 with its daughter nuclides, 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, as are remediation processes. 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.

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 groundwater is 20 micrograms per liter (µg/L) or about 13 pCi/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 U Tank Farm, and will not be discussed in this report, but 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 neutron capture by ^{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 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 groundwater 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 DOE (1993).

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 Columbia River Basalt Group

The basement rock 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. They are generally of tholeiitic composition. The thickest flows are more than 100 ft thick, with sedimentary interbeds occurring between some of the lava flows. The character and internal structure of the lava flows differ depending on the thickness and/or composition of the rock and the location within the flow. Thinner flows can be fractured or brecciated with well-developed cooling structures.

The Columbia River Basalt Group is divided into five formations (listed from oldest to youngest): Imnaha Basalt, Picture Gorge Basalt, Grand Ronde Basalt, Wanapum Basalt, and Saddler Mountains Basalt. The Picture Gorge Basalt is absent in the Pasco Basin. The Saddle Mountains Basalt is the uppermost basalt formation throughout most of the Pasco Basin and the Hanford Site. On anticlinal ridges surrounding the Pasco Basin, the Saddle Mountains Basalt is absent, exposing the Wanapum and Grand Ronde Basalts.

4.1.1.2 Ellensburg Formation

The Ellensburg Formation consists of a series of sedimentary units that are interbedded with and overlie many of the basalt flows of the Columbia River Basalt Group. The Ellensburg Formation includes two types of sedimentary rocks: epiclastic and volcaniclastic. Epiclastics consist of reworked clastics, plutonic, and metamorphic materials deposited by the ancestral Clearwater and Columbia Rivers (Fecht et al. 1987). Most of the volcaniclastics consist of materials produced during volcanic events in the Cascade Range, such as debris flows and pyroclastic air-fall deposits. At the Hanford Site, the uppermost units of the Ellensburg Formation are the Levey interbed, the Rattlesnake Ridge interbed, and the Selah interbed.

4.1.1.3 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 separates the Ringold Formation and the Hanford formation.

4.1.1.4 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.

Recent 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 outcrop dominates this association. Intercalated strata consist of lenticular silty sands and clays as much as 3 meters (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 flood plain 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 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). The relationships between these units are shown on Figure 15-4. The lowermost of the fine-grained sequences that overlie the Ringold Formation unit A is designated the lower mud sequence. Unit E, which is the uppermost gravel sequence, grades upward into interbedded fluvial sand and overbank fine-grained sediments. These fine-grained sediments are overlain by lacustrine fine-grained sediments.

Fluvial gravels designated Ringold Formation units A and E correspond to the basal and middle Ringold units respectively, as defined in DOE (1988). Gravel units B, C, and D do not correlate to any previously defined units of the Ringold Formation. The lower mud sequence correlates to

the upper basal and lower units defined by DOE (1988). The upper basal and lower units are not differentiated.

4.1.1.5 Plio-Pleistocene Unit

The laterally discontinuous Plio-Pleistocene unit unconformably overlies the Ringold Formation in the western Cold Creek syncline in the vicinity of the 200 West Area (see Figure 15-2). 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 the 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.

4.1.1.6 Early Palouse Soil

The Early Palouse soil overlies the Plio-Pleistocene unit in the western Cold Creek syncline in the vicinity of the 200 West Area. This unit is as much as 65 ft thick and consists of compact loess-like silt and fine-grained sand. This unit is differentiated from the overlying fine-grained sediments of the Hanford formation by its greater calcium-carbonate content. DOE (1988) indicates that the Early Palouse soils may be difficult to differentiate from the underlying Plio-Pleistocene unit without careful analyses of calcium-carbonate content and gross-gamma logs. The upper contact of this unit may be poorly defined and may grade up-section into the fine-grained interval of the Hanford formation (Baker et al. 1991).

4.1.1.7 Pre-Missoula Gravels

Gravels underlying the Hanford formation in the east-central Cold Creek syncline and at the east end of Gable Mountain anticline east and south of the 200 East Area are designated the pre-Missoula gravels. This unit is as much as 80 ft thick and contains less basalt than the overlying Hanford formation sediments and the underlying Ringold Formation gravels. It is unclear as to the nature of the contact of the pre-Missoula gravels with the Hanford formation and whether or not the pre-Missoula gravels overlie or interfinger with the Early Palouse soil and Plio-Pleistocene unit sediments.

4.1.1.8 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 multiple drainages 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, plane 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, which is present in the 200 Areas, is transitional between the gravel-dominated facies to the north and the rhythmite facies to the south. The laminated-sand facies was deposited adjacent to the main flood channelway as it spilled out of the main channel or was 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 (Myers et al. 1979; 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, distinctive patterned ground is observed.

4.1.1.9 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.

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, 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.

Distinctive features of the Yakima Fold Belt are 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 accumulation 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 degrees. 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 West Area

4.2.1 General Geologic Background

The 200 West Area is situated on a generally southward-dipping north limb of the Cold Creek syncline about 0.6 to 3.0 mi north of the synclinal axis (Lindsey et al. 1992). The gently sloping surface on which the 200 West Area is situated resulted from 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 the deposition of sand and gravel in the waters that were 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 West Areas are located (Figure 15-5). 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 West Area consists of basalt flows and associated sedimentary interbeds that constitute the Columbia River Basalt Group and Ellensburg Formations. The Columbia Basin basalts are overlain by younger sedimentary units consisting of the Ringold Formation, the Plio-Pleistocene unit, the Early Palouse soil, the Hanford formation, and Holocene surficial deposits.

4.2.1.1 Ringold Formation

The Ringold Formation in the vicinity of the 200 West Area is as much as 600 ft thick and consists of fluvial gravels of unit A, paleosol and lacustrine mud of the lower mud sequence, the fluvial gravels of unit E, and the sands and gravels of the Ringold Formation upper unit (DOE 1993). Ringold Formation units B, C, and D are not present in the 200 West Area.

In the western and southern portions of the 200 West Area, Ringold Formation unit A gravels, intercalated lenticular sand, and silt are most common. In the Ringold Formation unit E gravels, intercalated lenticular sand and silt occur throughout the 200 West Area. The upper unit of the Ringold Formation in the 200 West Area tends to be dominated by sand.

Beneath the 200 West Area, the fluvial gravels of the Ringold unit A and the Ringold Formation lower mud sequence tend to thicken and dip to the south-southwest, towards the axis of the Cold Creek syncline. The maximum thickness of unit A sediments occurs in the southern portion of the 200 West Area, and the unit pinches out north of the 200 West Area northern boundary.

The Ringold Formation lower mud sequence dips to the south-southwest beneath the 200 West Area. The lowermost sequence pinches out in the northeastern corner of the 200 West Area. A maximum thickness of the unit of about 110 ft occurs in the west central portion of the 200 West Area.

The gravels of the Ringold Formation unit E generally thin from the north-northwest to the east-southeast. Thicknesses for the unit E sediments range from 350 ft in the north to less than 179 ft in the southwest portion of the 200 West Area.

The Ringold Formation upper unit is present in only the western, northern, and central portions of the 200 West Area. Where it is present, it generally dips to the south-southwest. The Ringold Formation upper unit reaches a maximum thickness of 45 ft or more in the central and northwest portions of the 200 West Area.

4.2.1.2 Plio-Pleistocene Unit

The Plio-Pleistocene unit sediments unconformably overlie the Ringold Formation in the 200 West Area. This unit is laterally discontinuous and pinches out in the northern, eastern, and southern boundaries of the 200 West Area. The sediments consist of locally derived basaltic alluvium and pedogenic calcium-carbonate-rich material; both of these facies may be present at some locations. The basaltic material consists of weathered and unweathered locally derived basaltic gravel containing varying amounts of sand and silt. The carbonate-rich sediments consist of calcium-carbonate cemented silt, sand, and gravel interfingering with carbonate-poor sediments. The Plio-Pleistocene unit generally dips to the south-southwest.

The thickness of the Plio-Pleistocene unit varies; it is thickest in the southwest, southeast, and north-central portions of the 200 West Area. These sediments may be as much as 82 ft thick.

The Plio-Pleistocene unit may be completely eroded in areas where it thins; however, this has not been documented. The carbonates may be fractured, and interbedding with carbonate-poor facies is found at many locations. All these features may impact the integrity of the Plio-Pleistocene unit as a barrier between downwardly migrating contamination and groundwater beneath the 200 West Area.

4.2.1.3 Early Palouse Soil

The Early Palouse soil is largely restricted to the vicinity of the 200 West Area. This unit pinches out in the west-central portion of the 200 West Area and near the southern, eastern, and northern boundaries. Limited lithological data acquired in boreholes west of the 200 West Area suggest the Early Palouse soil may extend to the west. The Early Palouse soil consists of loess-like sediments of silt and fine-grained sand. The upper contact of the Early Palouse soil is difficult to define and may grade up-section into the lower portion of the Hanford formation.

The Early Palouse soil is thickest in the southwest and southeast portions of the 200 West Area, where it reaches a maximum thickness of 65 ft.

4.2.1.4 Pre-Missoula Gravels

The pre-Missoula gravels have not been identified in the 200 West Area.

4.2.1.5 Hanford Formation

The cataclysmic flooding that eroded the Ringold Formation sediments also deposited unconsolidated sand, gravels, and silt informally identified as the Hanford formation. On the basis of lithology, the Hanford formation is divided into two major sequences: the lower fine-grained unit and the upper coarse-grained unit. Neither of these sequences are continuous across the 200 West Area, and both display significant changes in thickness and continuity and are very heterogenous (DOE 1993).

In the vicinity of the 200 West Area, the lower fine-grained unit is thick but locally discontinuous. This unit is about 105 ft thick and consists mainly of silt, silty sand, and sand typical of the silt-dominated facies imbedded with sands like those constituting the sand-dominated facies. This unit is cross-cut by vertical clastic dikes in places. The distribution of facies within the lower fine-grained unit of the Hanford formation is variable; however, the unit generally fines to the south, where the silt-dominated facies is prevalent. The lower unit is not present in the northern portion of the 200 West Area and generally thickens to the south. Areas of erosion within the lower fine-grained unit have been identified; these areas are elongated in a north-south orientation.

The interstratified gravel, sand, and minor silt of the upper coarse-grained unit of the Hanford formation are as much as 150 ft thick beneath the 200 West Area. The upper coarse-grained unit is laterally discontinuous and is present in the northern, east central, and eastern portions of the

200 West Area. The thickness and distribution of the facies within the upper coarse-grained unit are highly variable.

The base of the upper coarse-grained unit is cut into sediments of the underlying fine-grained unit of the Hanford formation. Where the lower fine-grained unit sediments are absent, sediments of the upper coarse-grained unit fill erosional scoured areas. The contact between the gravels of the upper coarse-grained unit and the underlying fine-grained sediments of the lower unit, the Early Palouse soil, or Plio-Pleistocene sediments, is generally sharp.

4.2.1.6 Holocene Surficial Deposits

Holocene surficial deposits in the 200 West Area consist of a thin veneer of eolian sands.

4.2.2 Geologic Background of the U Tank Farm

Price and Fecht (1976) provided the initial lithological information about the U Tank Farm geology on the basis of data collected during the construction of the first monitoring boreholes surrounding the tanks. A majority of these boreholes were drilled between 1973 and 1975. Approximately 1,300 samples were collected during the drilling of 40 tank monitoring boreholes and two groundwater monitoring wells. Cross sections were prepared on the basis of analytical results obtained from these samples and from information documented on the driller's log (on which drilled materials were recorded at 5-ft intervals). Caggiano (1992), Lindsey and Law (1993), and Lindsey et al. (1994) present detailed descriptions and interpretations of the geologic formations in the vicinity of the U Tank Farm. This information is considered very valuable because the importance of drilling information was recognized and site geologists obtained and analyzed lithological samples and logged lithological features in detail.

The most current and highest quality geologic information specific to the U Tank Farm is obtained from the most recently drilled groundwater monitoring wells. Wells 299-W18-25, 299-W19-31, and 299-W19-32 were drilled in 1990, and wells 299-W18-30 and 299-W18-31 were drilled in 1991. Figure 15-6 shows the locations of these and other groundwater monitoring wells in relation to the U Tank Farm and other adjacent facilities. The RCRA standard monitoring wells are distinguished from the non-RCRA standard monitoring wells in this figure. All these wells were completed during the drilling programs for installation of RCRA standard monitoring wells for SSTs in calendar year (CY) 1990 and CY 1991. Well 299-W19-1 was constructed in 1957 and is not a RCRA standard monitoring well.

Appendix A contains lithology information for those wells, including copies of the interpreted lithologic logs, results of laboratory sample analysis of calcium-carbonate content and moisture content, and diagrams of well construction configuration. Gross gamma-ray log data for all the wells are included in one of two forms: copies of the original log plot acquired in the field and/or computer plots of the log data. Copies of the original log plots for wells 299-W18-25, 299-W19-1, 299-W19-31, and 299-W19-32, and computer generated plots for wells 299-W18-30 and 299-W18-31 are provided in Appendix A.

A set of ^{40}K, ^{238}U, and ^{232}Th radionuclide concentration plots for well 299-W19-32 are also provided in Appendix A. This information (with the exception of the spectral gamma-ray data) is also provided in Caggiano (1992 and 1993) and is available in digital form on the Hanford Environmental Information System (HEIS) database. The spectral gamma-ray geophysical data are available from the Rust Federal Services Northwest Operations Geophysics Group (formerly the Westinghouse Hanford Company [WHC] Geophysics Group).

The lithologic information is the result of field analysis of sediment retrieved during well drilling operations. This information is the most detailed information obtained to date because greater emphasis was placed on obtaining good lithologic information and because well-qualified geologists examined and documented descriptions of drill cuttings. All the wells were drilled with a cable tool drill rig, and drilled sediments were retrieved from the drive barrel generally over a depth interval the length of the drive barrel (less than 3 ft). Lithologic descriptions were recorded as cuttings were removed from the drive barrel. At a minimum, samples were collected every 5 ft and at lithologic changes. Samples were also collected at the discretion of the site geologist.

The gross gamma-ray logs were obtained by logging the wells with a logging system operated by Pacific Northwest Laboratory (PNL).* These logs show some variations in gross activity as a result of variations in the concentration of ^{40}K in the formation. Because the logs were obtained with a system that had a low-efficiency detector, the log responses were not usually good and the utility of these logs is limited.

The spectral gamma-ray data acquired in well 299-W19-32 were collected with a spectral gamma-ray logging system designated the Radionuclide Logging System; this system was placed into service in January 1991 and was operated by the WHC Geophysics Group. No documentation describing the system or specifications for the analysis software was prepared; therefore, the reported concentrations of the radionuclides are not quality assured. The well was logged after it was completed in the final casing configuration (4-in.-diameter stainless-steel casing) for the RCRA standard monitoring wells. Grout added into the annulus between the formation and 4-in. casing (the well was drilled with 8-in. and 10-in. casings [see well data in Appendix A]) attenuated gamma rays emanating from the formation and limited the usefulness of the data acquired in this well. Under these conditions, no man-made radionuclides were detected in well 299-W19-32.

4.2.3 U Tank Farm Geology Description

The surface of the basalt beneath the U Tank Farm is the eroded surface of the Elephant Mountain Member of the Saddle Mountains Basalt. The basalt lies at a depth of about 540 ft and dips gradually to the south-southwest.

*PNL was formally renamed Pacific Northwest National Laboratories (PNNL) in 1996.

Overlying the basalt are about 390 ft of Ringold Formation sediments consisting of gravels of Ringold unit A, fine-grained sediments of the Ringold lower mud sequence, and sediments consisting of uncemented gravels of the Ringold unit E. The unconfined aquifer beneath the U Tank Farm is contained in the Ringold unit E gravels. On the basis of data collected during RCRA borehole construction, the top of the Ringold Formation unit E in the vicinity of the U Tank Farm is about 145 ft below the ground surface.

The Early Palouse and Plio-Pleistocene sediments overlie the Ringold Formation unit E gravels beneath the U Tank Farm and range in thickness from about 10 to 20 ft. A calcium-rich caliche zone in the Plio-Pleistocene unit is correlatable among wells surrounding the U Tank Farm, and the most recent data acquired from sample analyses indicate that the Plio-Pleistocene unit is slightly deeper on the west side of the U Tank Farm than it is on the east side. The Plio-Pleistocene sediments have significant increases in calcium-carbonate content (weight percent) ranging from 6 to 17 percent. The Early Palouse and Plio-Pleistocene sediments provide barriers for downwardly migrating fluids, and the Plio-Pleistocene has been shown to confine carbon tetrachloride beneath it. Vapor from this organic compound was identified as the caliche was penetrated during drilling. The calcium-carbonate data for the RCRA standard monitoring wells drilled around the U Tank Farm are presented in Appendix A.

The abundance of silt-rich strata in the Early Palouse and Plio-Pleistocene unit also provides potential for perched water conditions within the unit, and increased moisture content was observed in the data analyzed from samples collected within the unit. Appendix A contains the moisture data for the RCRA standard wells drilled around the U Tank Farm.

Overlying the Early Palouse and Plio-Pleistocene unit is 75 to 100 ft of sediments of the Hanford formation fine-grained sequence consisting of stratified, lenticular bedded sands of the sand-dominated facies and intercalated occurrences of the silt-dominated facies (Lindsey and Law 1993). The frequency of silty strata increases downward, increasing the potential for zones of perched water lower in the fine-grained sequence. The irregular depositional surface between the Hanford fine-grained sequence and underlying Early Palouse and Plio-Pleistocene unit may contain depressions that may have potential for localized perched water conditions (Lindsey and Law 1993). At some locations, well data provide insufficient evidence to positively distinguish the Hanford fine-sequence sediments from those of the underlying Early Palouse and Plio-Pleistocene units; therefore, in some documentation regarding stratigraphy at the Hanford Site, the Early Palouse and Plio-Pleistocene units are combined and referred to as an "undifferentiated Hanford formation to Plio-Pleistocene unit" (Caggiano and Goodwin 1991).

The contact of the Hanford formation fine-grained unit with the overlying Hanford formation upper coarse-grained unit occurs at depths from about 20 to 25 ft on the western side of the U Tank Farm; this contact occurs at a depth of about 45 ft on the eastern side of the U Tank Farm. The Hanford upper coarse-grained unit consists of sediments typical of the gravel-dominated facies with few if any fine-grained strata that would create zones of perched water. The excavation for the U Tank Farm tanks was constructed entirely in Hanford formation sediments; on the east side of the tank farm the bottom of the excavation was in gravelly sediments, while on the west side of the tank farm the sediments were fine grained. The backfill

placed around the completed tanks was the excavated materials that were stockpiled next to the tank farm during tank construction.

The gross gamma-ray logs can be used for identification of gross features. The contact between the Hanford upper coarse-grained unit and Hanford fine-grained unit is shown on the log plots by an increase in count rate in the fine-grained unit. The clays and silts of the Early Palouse unit are also identifiable as peaks of increased gamma-ray activity. The caliche of the Plio-Pleistocene is shown on the gross gamma-ray plots by decreased gamma-ray activity. The fine-grained sediments containing the natural gamma-emitting radionuclides have been replaced with nongamma-emitting calcium-carbonate cement. This log plot feature enables positive correlation of the caliche zone among boreholes.

4.3 Hanford Site Hydrology

4.3.1 Surface Hydrology

The following discussion regarding the Hanford Site hydrology is summarized from Lindsey and Law (1993) and from DOE (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 Priest Rapids Dam and the headwaters of Lake Wallula near the 300 Area. The closest position of the Columbia River to the U Tank Farm is about 8.5 mi north-northwest of the U Tank Farm.

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. 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 groundwater beneath the Hanford Site occurs under confined, semiconfined, and unconfined conditions.

The basalt aquifers are generally confined and are located in the sedimentary interbeds of the Ellensburg Formation, flow-top breccias, and in permeable interflow zones that occur between basalt flows. The shallow basalt flows are generally located in the Saddle Mountains and upper Wanapum Basalts. Recharge to these shallow basalt aquifers occurs through infiltration of precipitation and runoff along the margins of the Pasco Basin. Groundwater from the shallow basalt aquifers most likely discharges to the overlying sediments and to the Columbia River.

Dense regions within the interior of the basalt flows of the Columbia River Basalt Group separate the flow tops and interflow zones and act as aquitards in the confined system.

The deep basalt aquifers are located in the Grand Ronde and lower Wanapum Basalts. Recharge to these aquifers is inferred to be from interbasin groundwater movement from northeast and northwest portions of the Hanford Site, where the basalts outcrop extensively (DOE 1988). Discharge of the deep basalt aquifers is uncertain; however, direction of groundwater movement is to the southwest, and discharge is speculated to be south of the Hanford Site (DOE 1988). Intercommunication between the basalt aquifer system and suprabasalt sediments occurs through erosional windows through the basalt flows at the top of the basalt aquifer system (Graham et al. 1981).

The unconfined aquifer system is contained within the fluvial/lacustine sediments of the Ringold Formation and glaciofluvial sand and gravel sediments of the Hanford formation. The top of the unconfined aquifer ranges from 1 ft in depth near West Lake and the Columbia and Yakima Rivers to more than 350 ft in depth in the center of the Hanford Site (Lindsey and Law 1993). The base of the aquifer system is the surface of the uppermost basalt flow. In the western portion of the Hanford Site, the aquifer is generally in gravels of the Ringold Formation (unit E). Overbank and lacustrine deposits of the Ringold Formation form locally confining layers above underlying Ringold Formation fluvial gravel and sand, creating semiconfined aquifer conditions. In the northern and eastern portions of the Hanford Site, the aquifer is generally within the Hanford formation. 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.

Natural recharge of the uppermost aquifer is through rainfall and runoff from the hills bordering the Hanford Site, infiltration from small ephemeral streams, water infiltration through faults and fractures in the underlying basalts, and 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, where the sediments are layered and vary in texture, and that all moisture penetrating the soil is lost through evapotranspiration.

Artificial recharge of the uppermost aquifer occurs from the disposal of wastewater at the Hanford Site and from large-scale agricultural irrigation that surrounds the Site.

Unsaturated (vadose) conditions across the Hanford Site show variations similar to those observed in the uppermost aquifer system. Sediments in the vadose zone range 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 and 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 U Tank Farm Hydrology

The unconfined aquifer is the uppermost aquifer in the area of the U Tank Farm and is the focus of groundwater monitoring. At the U Tank Farm, the upper portion of the uppermost aquifer is contained in the Ringold Formation unit E, which consists of fluvial/lacustrine gravelly sediments. The lower portion of the uppermost aquifer is within Ringold Formation unit A fluvial gravels. This portion of the aquifer is semiconfined to confined by overlying fine-grained sediments of the Ringold Formation lower mud sequence. The thickness of the Ringold unit A confined aquifer ranges in thickness from more than 125 ft thick in the southeastern portion of the 200 West Area to zero in the northern and northeastern portions of the 200 West Area, where the confining Ringold lower mud sequence sediments pinch out. The confining lower mud sequence is about 100 ft thick in the south central portion of the 200 West Area; it pinches out in the north-northeast portion of the area. In the vicinity of the U Tank Farm, the top of the saturated zone is about 200 ft below the ground surface, and the base, which is the top surface of the uppermost basalt flow (the Elephant Mountain Member of the Columbia River Basalt Group), is about 540 ft below the ground surface.

The elevation of the groundwater beneath the 200 West Area has varied significantly since the 1940s, when artificial recharge of the aquifers occurred through liquid discharges to several sites in the 200 West Area. The most significant of these sites in terms of volumes discharged to the subsurface is the 216-U-10 Pond, which is about 1,600 ft southwest of the U Tank Farm; this site covered about 30 acres at its maximum extent. In the first decade of Hanford operations (1945 to 1955), the elevation of the groundwater mound below the 216-U-10 Pond increased 75 ft. The apex of the groundwater mound below the 216-U-10 Pond shifted as additional liquid waste discharge sites around the 200 West Area became active. The 216-U-10 Pond was deactivated in 1984, and the during the last half of the 1980s, the elevation of the groundwater mound below the pond decreased more than 10 ft. At the present time, the surface of the groundwater is about 200 ft below the surface of the U Tank Farm. A water-table map of the 200 West Area compiled from 1996 data is presented in Figure 15-7. The water table contours are in meters (m), and the contours are dashed when inferred. Solid dots represent the location of monitoring wells where water-level measurements were acquired, and the numbers represent the measurements at the well locations.

The direction of groundwater flow before Hanford Site operations is postulated to have been from west to east. As the groundwater mound developed under the 216-U-10 Pond, a radial flow pattern developed that disrupted the natural west-to-east flow. As the mound diminished, the flow pattern was directed to a more easterly direction, and as the groundwater elevations decreased, the flow pattern was expected to return to pre-Hanford conditions in about 20 years (DOE 1993). For several years, the groundwater flow was easterly in the southern portion of the 200 West Area and north and northeast (through Gable Gap) in the northern portion of the 200 West Area. In 1994, groundwater-level measurements confirmed that the direction of groundwater flow had changed from an easterly direction to north and west directions in the vicinity of the U Tank Farm (DOE 1995a).

The lateral extent and lithological properties of the Early Palouse soil and Plio-Pleistocene units in the 200 West Area provide conditions for the development of perched water zones. These zones form when moisture that is migrating through the unsaturated or vadose zone sediments encounters an impervious strata that inhibits continued downward migration of the moisture. If sufficient moisture is trapped in the pore spaces of the sediments overlying the impervious strata, saturated conditions may develop. The loess-like silt and fine-grained sand of the early Pliocene soil and calcium-carbonate cemented gravel, sand, and silt of the Plio-Pleistocene unit can form zones of perched water. The large volume of liquids discharged to the vadose zone in the 200 West Area during Hanford operations provided the moisture to create these zones.

The 216-U-14 Ditch is located along the eastern and south-eastern sides of the U Tank Farm (see Figure 15-6). This facility was removed from service in stages, and the last active portion was located about 400 ft south-southeast of the U Tank Farm. Three vadose zone boreholes adjacent to the 216-U-14 Ditch (299-W19-91, 299-W19-92, and 299-W19-93) intersected saturated sediments at a depth of 110 ft, about 10 ft above the top of the Early Palouse soil. This is indicative of a zone of a perched water, because the depth to groundwater in that area is about 200 ft. The areal extent of this zone is unknown. It is unknown whether leakage from the 207-U Retention Basin may have contributed to the perched water zone because no leaks from the basin were recorded. The 207-U Retention Basin is located immediately east of the U Tank Farm, and discharges from the basin were made to the 216-U-14 Ditch.

The geologist's logs from wells 299-W18-25, 299-W19-31, and 299-W19-32 were reviewed to determine the north-northwestern extent of the perched water resulting from the 216-U-14 Ditch and to identify any perched water zone(s) that may have resulted from leakage from the 207-U Retention Basin. The logs from wells 299-W19-31 and 299-W19-32 describe moist to very moist sediments at depths of 135 and 145 ft, respectively. These sediments were located immediately above the calcium-carbonate cemented sediments of the Plio-Pleistocene unit. No elevated moisture zones were encountered in wells 299-W18-25. This moisture may have resulted from either or both of these facilities or from leakage from U Tank Farm tanks.

Perched water conditions were also identified at the 216-U-1 and 216-U-2 Cribs, which are located about 1,500 ft east of the U Tank Farm. Large volumes of liquids discharged to the cribs created a perched water zone 80 to 90 ft thick. It is unknown if this perched zone may have affected contamination distribution or redistribution in the vadose zone at the U Tank Farm.

Hydraulic properties for the Ringold unit E unconfined and unit A confined have been determined from aquifer testing that was conducted in a number of wells in the 200 West Area. The transmissivity and hydraulic conductivity were determined by analyzing the results of the aquifer tests, the details of which are provided in DOE (1993). Data were acquired in wells 299-W18-25, 299-W18-30, 299-W18-31, 299-W19-30, and 299-W19-31, which surround the U Tank Farm on the northern, eastern, and western sides (see Figure 15-6). These data indicate the hydraulic conductivity ranges between 0.2 and 61 feet per day (ft/day) for the Ringold Formation unit E aquifer and between 1.7 and 4 ft/day for the Ringold Formation unit A aquifer. Transmissivities were determined only for the Ringold unit E aquifer; these transmissivities ranged between 20 and 51,000 square feet per day (ft^2/day). The results of the aquifer tests and

shortcomings of the results are discussed in detail in DOE (1993) and Connelly et al. (1992). Figure 15-8 presents a hydraulic conductivity map of the 200 West Area (from Connelly et al. 1992).

Vadose or unsaturated zone hydraulic properties are an important factor in understanding the effects of transport of aqueous contaminants and the infiltration and potential recharge of the vadose zone through precipitation. Determination of the moisture content of a soil and its hydraulic properties are significant factors in assessing the potential of a soil to transport aqueous contaminants; however, these are difficult and expensive properties to acquire. Measurements of hydraulic conductivity for several samples of the unsaturated sediments were determined in the laboratory using measured water-retention data. These measurements used theoretical methods to determine the hydraulic conductivity, and various methods produced differing results. Laboratory results indicated a high degree of variability in the moisture retention data where data were available; there was a sparsity of data for some of the lithologic units encountered in the vadose zone beneath the 200 West Area. The reader is advised to reference DOE (1993) and Connelly et al. (1992) for details regarding these analyses, as well as for the results of the analyses performed on samples of the vadose zone sediments from the Hanford formation, the Early Palouse soil, the Plio-Pleistocene unit, and the Ringold Formation.

4.5 Groundwater Contamination in the U Tank Farm Area

The 200 West Area of the Hanford Site was used to chemically process irradiated nuclear fuel, to separate and purify plutonium, and through several processes, to manufacture plutonium metal. Facilities associated with these operations include processing plants, manufacturing plants, and waste disposal facilities, including tank farms, landfills, injection wells, impoundments, cribs, ponds, and ditches. Figure 15-6 shows the location of the U Tank Farm relative to some of the adjacent waste handling and discharge facilities.

Groundwater beneath several facilities in the 200 West Area is monitored under a RCRA groundwater monitoring program administered by PNNL. Included in the monitoring program, which was initiated in 1990, is Waste Management Area (WMA) U, an area in the 200 West Area that includes the U Tank Farm. Data are acquired from monitoring wells 299-W18-25, 299-W18-30, 299-W18-31, 299-W19-1, 299-W19-30, and 299-W19-31; these data are analyzed and interpreted and the results are reported in quarterly and annual reports. The *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1 Through September 30, 1995* (DOE 1996a) and the *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1994* (DOE 1995a) were reviewed during the preparation of this report.

Groundwater is sampled semiannually in the WMA-U monitoring wells. These samples are analyzed for drinking water standards, general contamination indicators, and water quality parameters. Samples were also analyzed for ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{60}Co, and tritium because these radionuclides were most prevalent in the wastes discharged to the SSTs. Iodine-129 is analyzed semiannually as part of another monitoring program, and the data are included for the SSTs (DOE 1995a). Plutonium and uranium are also monitored.

Some of the background data collected from the WMA-U wells were reevaluated because the change in direction of the groundwater flow beneath the U Tank Farm resulted in downgradient wells becoming upgradient wells (relative to their position around the U Tank Farm). Details regarding these reevaluations are described in DOE (1995a). Appendix B provides a detailed evaluation of the groundwater dynamics beneath the U Tank Farm.

The data reported in DOE (1995a) indicate that elevated gross beta activities were identified in groundwater samples acquired in monitoring wells 299-W19-31 and 299-W19-32 during 1992 and 1993. These elevated activities are due to the presence of ^{99}Tc. In well 299-W19-31, the gross beta activity was slightly above the drinking water and Washington water-quality standards of 50 pCi/L. The gross beta activities in well 299-W19-32 were slightly more than twice the standard for samples acquired during the same collection period. The ^{99}Tc concentrations in wells 299-W19-31 and 299-W19-32 were less than 200 and 500 pCi/L, respectively. No other constituents that exceeded regulatory limits were detected in any of the monitoring wells surrounding the U Tank Farm.

The ^{99}Tc detected in wells 299-W19-31 and 299-W19-32 defines the western extent of a very large ^{99}Tc plume that extends east of these boreholes beyond U Plant (see Figure 15-9). Near U Plant, this plume is the result of discharges of large volumes of liquid waste to the 216-U-1 and 216-U-2 Cribs. ^{99}Tc has some chemical properties that are similar to uranium and follows uranium contamination plumes; however, ^{99}Tc is more mobile than uranium and the extents of ^{99}Tc plumes are often greater than associated uranium plumes. The associated uranium plume is shown on Figure 15-10. The east-west elongation of both the plumes reflects the eastward directional flow of the groundwater in this area. The extension of the ^{99}Tc plume west of the 216-U-1 and 216-U-2 Cribs to the two monitoring wells (with no other waste sites between) may be indicative of ^{99}Tc contamination originating from tank U-104 leakage that migrated downward into groundwater below the U Tank Farm. Discussions regarding groundwater chemistry presented in Appendix B describe some possible scenarios for plume detection in these monitoring wells relative to influences from waste discharges to facilities adjacent to the U Tank Farm. Regardless of the dynamics resulting from shifts in the hydraulic gradient, there is a ^{99}Tc plume adjacent to the U Tank Farm. Waste leakage from U Tank Farm tanks cannot be positively confirmed or denied as a source of this ^{99}Tc contamination plume.

The monitoring data and contaminant concentration data reported in the RCRA groundwater monitoring reports are also compiled with other groundwater monitoring data from adjacent facilities and are used to prepare groundwater elevation and contamination maps for Hanford publications. These publications report the chemical as well as radiological contaminants in the groundwater. Groundwater contamination plume data in Dresel et al. (1995) and DOE (1995a) were reviewed as part of this baseline characterization project. The reader is advised to refer to Dresel et al. (1995) and DOE (1995a) for further details regarding contaminant distributions, for discussions regarding methods and quality assurance of sample analyses, and for interpretations of the results.

5.0 U Tank Farm Background

5.1 Construction

The U Tank Farm tanks were constructed between 1943 and 1944 and are located in the south-central portion of the 200 West Area (Figure 15-1). The 16 tanks in the U Tank Farm are SSTs of two design types. The four Type I tanks are 20 ft in diameter, have a 3-ft radius knuckle at the junction of the tank's bottom and side walls, and have a 0.5-ft dished bottom (the sides of the tank bottom are 0.5 ft above the center of the tank bottom). At the maximum waste capacity of 55,000 gal per tank, the level of the waste in the tank is 18.75 ft above the bottom of the tank base. The twelve Type II tanks are 75 ft in diameter, have a 38-in. radius knuckle at the junction of the tank's bottom and side walls, and have a 1-ft dished bottom. At the maximum waste capacity of 530,000 gal per tank, the level of the waste in these tanks is 18.75 ft above the tank bottoms. The domed tops of both types of tanks are about 7 ft below the finished grade of the tank farm surface; the bases of the tanks are at a depth of about 42 ft below the ground surface. The U Tank Farm is one of the original tank farm designs along with the B, C, and T Tank Farms. Figure 15-11 presents a plan view of the U Tank Farm showing the 16 waste tank locations. This figure also shows the locations of the monitoring boreholes around the large Type II tanks. The actual locations of the monitoring boreholes are in the center of the borehole designations (e.g., in the center of the "01" in the borehole designation 60-01-10).

Details regarding the construction of the Type II tanks were derived from construction details outlined in *Specifications for Construction of Composite Storage Tanks Bldg. No. 241* (DOE 1944). The following discussion of tank construction is based on this information.

One large rectangular excavation about 42 ft deep was made for the construction of all the U Tank Farm tanks. The excavation was developed as close to the final grade as possible (within 3 in.) with earth-moving equipment, then completed by hand with shovel to final grade. The bottom grade for the tanks was established and the material was compacted before the concrete bases of the tanks were poured. Depressions below final grade were not backfilled with earth materials but were filled with concrete. Concurrent with tank construction, as the sides were being built, the original excavated material was uniformly backfilled around the tanks in 0.5- to 2-ft-thick layers and compacted. The concrete was allowed sufficient time for curing before placement of the backfill materials. The backfill was uniformly distributed to prevent excessive unbalanced loading against the completed tank structures. The tanks were covered with about 7 ft of backfill material (Brevick et al. 1994b).

The base of each tank consists of a steel-reinforced concrete circular pad with a concave upper surface. The concrete was worked in place around the reinforcement with a mechanical vibrator and formed to specific dimensions and curvature by a revolving screed. Following curing of the concrete, the top of the concave surface of the tank bases was covered with a 3-ply asphalt impregnated fabric that was also coated with asphalt. After the asphalt membrane was installed on the tank base foundation, a 2-in.-thick gunite layer was placed over the membrane for protective purposes.

Tank liner construction consists of a steel-reinforced concrete shell approximately 1 ft thick and a carbon-steel inner liner that covers the bottom and sides of the shell. The thickness of the bottom section of liner plating and both wall sections of plating are 1/4 in. The steel tank sides are joined to the steel liner of the tank bottom by rounded knuckle sections of 3/8-in.-thick steel plating formed to a 38-in. radius. The knuckle sections allowed for expansion of the base liner. Six steel angle stiffeners are welded horizontally around the interior of the tank walls. The specifications for liner plating and protective membrane composition are outlined in Drawing W-71387, which is available from the Lockheed Martin Services, Inc., Microfiche Library, Richland, Washington.

All interior surfaces of the steel liner were sandblasted and coated with primer. The exteriors of the walls were covered with a 3-ply asphaltic membrane followed with a protective layer of reinforced gunite 3/4 in. thick. The steel tank shells formed the inner form for the concrete tank shell.

The walls of the tank are reinforced concrete about 1 ft thick and were poured as a continuous operation. Wooden forms were used to hold the wet concrete on the outside wall. Before pouring the concrete shell walls, the tanks were filled with preheated water that simulated the conditions under which the tanks would operate; the hydrostatic pressure of the water also provided support for the steel liner during concrete placement.

The domes of the tanks were constructed with reinforced concrete approximately 1 ft thick. The inside surface of the dome above the steel liner was coated with several applications of Lapidolith, which is a concrete hardening agent. All dome risers and encasements were treated with applications of coal-tar primer and enamel and finish coated with water-resistant whitewash. Upon completion of the dome construction, the interior of the tank steel liner was given a second application of primer.

Several inches of gravel was placed on top of the backfilled sediments to provide protection and retard establishment of vegetation that could bring subsurface contamination up to the ground surface. The ground layer also helped prevent or reduce exposure to personnel from contaminated near-surface sediment and pipelines. Unfortunately, the lack of vegetation inhibits evapotranspiration of precipitation and may promote infiltration of precipitation into the subsurface at the farm. The infiltration of precipitation could promote movement of contaminants through the vadose zone.

The U tanks are sited at slightly different elevations, creating a gradient that allows liquids to flow from one tank to another as they are filled. The tanks are arranged in four cascades, each consisting of a three-tank cascade series with the receiving tank 1 ft lower than the feed tank. For example, one three-tank cascade series consists of tanks U-101, -102, and -103, where U-101 cascades into U-102 and tank U-102 cascades into U-103. The height of the cascade line outlets from the tank bottoms establishes the maximum capacity of the tanks. The cascade inlet and overflow connections are sleeved and welded to the tank steel liners about 2 ft below the top of the liner, which is about 21 ft below the ground surface. The cascade lines are set on reinforced

concrete beams that bridge the distance between the tanks. The beams are set on concrete pilasters built into sides of the concrete walls of the tanks beneath the inlet or outlet ports.

Each tank is equipped with four spare 3-in.-diameter inlet nozzles. These nozzles are located at an azimuth of about 135 degrees at the same height as the cascade line connections to the tanks. It is unknown if these nozzles are capped or connected to piping.

The domes of the tanks are penetrated by several risers that allow access to the tank interiors. Tanks U-102, -103, -105, -106, -107, -108, -109, and -111 have liquid observation wells (LOWs) that penetrate the wastes in these tanks. The LOWs are used to monitor the interstitial water levels in the waste solids by logging with neutron-neutron and gamma probes. A cross section of a typical SST with associated risers and access ports is shown on Figure 15-12; Brevick et al. (1994b) provides information specific to each U Tank Farm tank.

As will be discussed in Section 5.2, "History and Tank Contents," some of the tank wastes have potential for explosion because of their chemical composition; therefore, the waste temperatures are monitored. All tanks with the exception of tank U-104 contain thermocouple trees that are used to monitor the temperatures of the wastes. Several thermocouples are installed on a single tree to allow the waste to be more effectively monitored at several specific depth locations. The data are automatically transmitted from the thermocouple trees to the tank farm operations via the Tank Monitor and Control System (TMAC).

Several of the U Tank Farm tanks contain a 12-in.-diameter salt well that penetrates the tank waste and allows pumping of interstitial liquids. These wells have a section of screened casing that allows access to the interstitial water within the waste. A submersible pump is installed in the salt well to remove liquid wastes.

Transfer lines connect the tanks to each other as well as to other facilities at the Hanford Site. Most of the lines are constructed of 3-in.-diameter steel piping with welded joints. These lines are generally below the ground surface and some are contained within reinforced concrete encasements that allow capture and diversion of leaked waste liquid to appropriate catchment tanks. Diversion boxes contain the switching mechanisms that allow transfers from one transfer line to another. The diversion boxes are constructed of concrete and are buried below the ground surface to a depth of about 12 ft; like the transfer-line encasements, the diversion boxes are drained to catchment tanks. Several diversions boxes are located within the U Tank Farm; these diversion boxes drain into the 241-U-301 Catch Tank at the south end of the U Tank Farm. This tank is 20 ft in diameter and 18 ft high; the base of the tank is about 29 ft below the ground surface. Other receiver tanks and vaults associated with U Tank Farm operations are described in detail in DOE (1992). These facilities are identified and discussed because of their potential to contribute to shallow vadose zone contamination at the U Tank Farm.

The U Tank Farm also includes four auxiliary tanks that are located in the southwest portion of the tank farm. These tanks are single walled, about 20 ft in diameter and 26 ft high, and have capacities of 55,000 gal. The bases of these tanks are about 37 ft below the ground surface.

Limited construction information was located for these tanks, although DOE (1994) indicates that the construction of the Type I tanks was similar to that of the Type II tanks.

The four auxiliary tanks are designated sound. Each of these tanks contain approximately 3,000 to 5,000 gal of sludge with about 1,000 gal of drainable liquid (Hanlon 1996). A manual ruled tape is the method for leak detection because there are no monitoring boreholes surrounding these tanks.

5.2 History and Tank Contents

High-level radioactive waste generated at Hanford from 1945 to 1989 was derived predominantly from the chemical dissolution and extraction of plutonium and uranium from irradiated reactor fuel elements. The extractions during these years evolved through three basic processes: the bismuth phosphate process ($BiPO_4$), the reduction-oxidation process (REDOX), and the plutonium uranium extraction process (PUREX). These processes were used for the extraction of plutonium. A fourth process, the tributyl phosphate (TBP) process, was designed for the recovery of uranium. The wastes from these processes were neutralized and discharged to the underground waste-storage tanks.

Anderson (1990) provides general information about the contents of the U Tank Farm tanks. More information specific to this farm and each tank is provided in a recent compilation of historical monitoring information assembled in several volumes of reports by ICF Kaiser Hanford Company, Los Alamos National Laboratory, and WHC. Volumes prepared by Brevick et al. (1994a and 1994b) specifically address the U Tank Farm; these documents present historical waste inventories for each of the U Tank Farm tanks.

In the Brevick et al. documents, the authors have compiled most of the available monitoring information on the tanks, and they have provided detailed summaries of tank construction and configuration, tank photographs, and other data. Much of the information provided in this section of this report is from those two documents.

General tank content quantities (liquid and solid levels) data and some tank monitoring data are summarized quarterly in the *Waste Tank Summary Report.* Hanlon (1996) is an example of one of those reports. Table 5-1 shows current tank waste quantities, current monitoring methods, and some historical information.

The wastes in the U Tank Farm consist mainly of sludge, salt cake, and liquid. Sludge is composed of solid (hydrous metal oxides) precipitate that results from the neutralization of acid waste. The wastes were neutralized before being transferred to the waste tanks. Salt cake is composed of salts formed by the evaporation of water from the waste. Sludge and salt cake form the "solids" component of the tank waste. Liquids are present as supernatant and interstitial liquids. Supernatant is found on the top of the solid waste surface, and 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.

Table 5-1. General U Tank Information

Tank	Total Waste Volume (1,000 gal)[a]	Drainable Liquid (1,000 gal)[a]	Current Leak Detection Method	Tank Monitoring Methods[a]	Leaker (Y/N)[a]	Original Leak Indication
U-101	25	0	Manual tape	Manual tape	Y	Unknown
U-102	374	126	LOW[b]	Neutron and/or gamma probe(s)	N	
U-103	468	176	ENRAF[c]	ENRAF and LOW	N	
U-104	122	7	None	Manual tape	Y	Borehole gamma Soundings through tank risers
U-105	418	142	ENRAF	ENRAF and LOW	N	
U-106	226	68	ENRAF	ENRAF and LOW	N	
U-107	406	147	ENRAF	ENRAF and LOW	N	
U-108	468	172	LOW	LOW	N	
U-109	463	163	ENRAF	ENRAF and LOW	N	
U-110	186	15	None	ENRAF	Y	Waste-level decrease Borehole gamma
U-111	329	122	LOW	ENRAF and LOW	N	
U-112	49	0	None	Manual tape	Y	Waste-level decrease
U-201	5	1	None	Manual tape	N	
U-202	5	1	None	Manual tape	N	
U-203	2	1	None	Manual tape	N	
U-204	2	1	None	Manual tape	N	

[a] Information taken from Hanlon (1996)
[b] LOW = liquid observation well
[c] ENRAF = device is described on page 38

The U Tank Farm was placed into service in 1946. The tanks in the U Tank Farm contained several types of wastes, including metal waste, REDOX waste, coating waste, decontamination waste, and evaporator feed and bottoms waste. Metal waste consisted of waste from the extraction of plutonium and contained all of the uranium, 90 percent of the original fission product activity, and approximately 1 percent of the product (plutonium). Coating waste was salt waste resulting from the process of dissolving metal coatings of the reactor fuels. REDOX waste contained the high-level component of the process waste from the REDOX Plant.

Decontamination waste resulted from the bismuth phosphate process used to remove plutonium from irradiated fuel at the T and B Plants. Evaporator waste was contained in the U Tank Farm tanks in two basic forms: evaporator feed staging waste and evaporator bottoms waste.

Decontamination waste resulted from the bismuth phosphate process used to remove plutonium from irradiated fuel at the T and B Plants. Evaporator waste was contained in the U Tank Farm tanks in two basic forms: evaporator feed staging waste and evaporator bottoms waste. Evaporator feed staging waste was the evaporator input material to be concentrated by evaporation, and evaporator bottoms waste was the resultant solid material remaining after evaporation. Some of the principle radionuclides in the U Tank Farm tank waste include ^{137}Cs, ^{134}Cs, ^{60}Co, $^{89\text{-}90}Sr$, ^{125}Sb, ^{106}Ru, ^{144}Ce, ^{95}Zr, and ^{154}Eu (Brevick et al. 1994b).

Tanks U-101 through U-109 received metal waste from T Plant; the waste was subsequently removed from these tanks by sluicing to recover the uranium in the waste. During sluicing, water under high pressure was injected into the solid waste, dissolving and/or dispersing the solid waste into suspension. The dissolved or suspended waste was then pumped from the tank and transferred to U Plant for reprocessing. Sluicing was conducted in these tanks during 1956 and 1957. Tanks U-110 through U-112 received first-cycle decontamination waste; these three tanks were also used to store REDOX and evaporator feed wastes. The four auxiliary tanks, U-201 through U-204, were in service from 1954 through 1978. These four tanks received and stored REDOX waste, coating waste, and evaporator feed wastes.

Approximately 60 tons of diatomaceous earth was added to tank U-104 in 1972 (Anderson 1990) to stabilize the waste by binding the available liquid waste. This tank was designated a leaker in 1961.

Several tanks in the U Tank Farm are designated "watch list" tanks and are monitored for hydrogen and/or organic salts. The wastes in these tanks have been determined to have safety-related issues regarding the potential of the contents of these tanks to react explosively. Tanks U-103, -105, -107, -108, and -109 are listed on the Hydrogen/Flammable Gas Watch List (Hanlon 1996), and tanks U-103, -105, -106, -107, -108, and -109 are listed on the Organic Salts Watch List. Auxiliary tanks U-203 and U-204 are listed on the Organic Salts Watch List. The temperatures of the wastes within these tanks are automatically monitored by thermocouples that are installed within these tanks and connected to the tank farm operations TMACS. Detailed discussions regarding the chemical stability of the wastes in the SSTs are presented in Borsheim and Simpson (1991).

Table 5-2 provides estimates from Anderson (1990) of the major chemical constituents of the waste at the time it was placed in the U Tank Farm tanks.

Specific information about the contents of each tank is available in Anderson (1990), Brevick et al. (1994a and 1994b) and Agnew (1995 and 1996). When data were compiled for those publications, historical information such as tank operations logs was still classified and had not been reviewed.

A relatively large program is currently devoted to determining the physical and chemical properties of the wastes in the tanks by analyzing core samples of the tank wastes. That work combined with a revision of the tank contents history information in Brevick et al. (1994a and

Table 5-2. General Chemical Composition of U Tank Waste Feed (from Anderson 1990)

Waste Type	Constituent	Concentration
Alkaline coating	$NaAlO_2$	1.2 M[a]
	NaOH	1.0 M
	$NaNO_3$	0.6 M
	$NaNO_2$	0.9 M
	Na_2SiO_3	0.02 M
	SpG	1.19
	Pu	0.4 %
	U	0.4 %
Metal	U	0.5 lb/gal[b]
	OH	0.71 M
	CO_3	2.4 M
	NO_3	2.7 M
	PO_4	1.4 M
	SpG	1.86
	Na	4.8 M
	Pu	1 %
REDOX	$NaAlO_2$	1.2 M
	NaOH	0.69 M
	$NaNO_3$	4.83 M
	Na_2CrO_7	0.066 M
	$Cr(OH)_3$	0.045 M
	$Na_2(SO_4)$	0.031 M
	$Fe(OH)_3$	0.016 M
	SpG	1.29
	U	0.05 %
	Pu	0.04 %
First-cycle	$CePO_4$	<0.01 M
	$Zn_3(PO_4)_2$	<0.01 M
	$NaNO_3$	0.85 M
	$Fe_2(SO_4)_3$	0.07 M
	$NaPO_4$	0.75 M
	$Cs(NO_3)_3$	<0.01 M
	$NH_4(SO_4)$	0.04 M
	$NH_4(SiFe)$	0.07 M
	NH_4NO_3	0.06 M
	Pu	1 %

[a] M = molar = moles per liter
[b] lb/gal = pound per gallon.

1994b) and Agnew (1995) will be available in the future. The best information so far on tank radionuclide content and chemistry is probably found in the current version of the Brevick documents. Work on determining the chemical and radiological content of the tanks is ongoing.

Four of the twelve U Tank Farm tanks are currently listed as assumed leakers (Hanlon 1996). Assumed leakers are designated on Figure 15-11. The reasons the tanks were declared assumed leakers vary, and the details or assumptions leading to this designation are discussed in the Tank Summary Data Reports for these tanks.

Hanlon (1996) provides estimates of the volumes of liquid that leaked from the tanks. A variety of methods were used to calculate these estimates. A few estimates were calculated directly from measurements of decreases in the liquid levels in the tanks and are probably relatively accurate, although the precision of past liquid-level measurements has not been established. However, many leak-volume estimates for U Tank Farm tanks may have been nothing more than best guesses. Therefore, some leak-volume estimates have little validity and could be inaccurate by orders of magnitude. Leak volumes that are documented as being calculated directly from a decrease in liquid level were used in the assessment of the vadose zone contamination data during preparation of the individual Tank Summary Data Reports and during the preparation of this report.

Review of the historical tank waste-level measurement documentation revealed that increases in tank waste-level measurements were observed in several tanks in the U Tank Farm. These increases were documented as having resulted from crustal growth of the waste, intrusion from drainage of valve pits and other such ancillary facilities that were drained into the tanks, and errors with the measurements themselves. When waste levels increased, the affected tank was surveyed for evidence of direct discharge into the tank. Intrusions were often unexplained.

5.3 Unplanned Releases

Eight unplanned releases within or adjacent to the U Tank Farm are documented. Table 5-3 provides a synopsis of these releases, and Figure 15-6 shows the locations of the unplanned releases within the U Tank Farm and at adjacent areas. This information was obtained from the *U Plant Source Aggregate Area Management Study Report* (DOE 1992). The referenced sources of this information are the Hanford Site Waste Information Data System (WIDS) database, the recently created Hanford Environmental Sites Database (ESD), and DOE (1992). The descriptions of the individual sites were derived from DOE (1992). None of the sources for the unplanned releases contain documentation of all unplanned releases associated with operations at the U Tank Farm. Several undocumented spills or leaks were identified at the ground surface within the U Tank Farm from the SGLS data.

Four of the listed unplanned releases were actual tank leaks; the other releases were related to tank farm operations and tank ancillary equipment or facilities.

The entire ground surface within the U Tank Farm is radiologically contaminated to some degree (see Section 10.1); however, no documentation was identified describing the source(s) of the widespread surface contamination within the U Tank Farm.

Table 5-3. Documented Unplanned Releases Near or Within the U Tank Farm

Unplanned Release Number	Location	Date	Coordinates E Washington State Plane	Coordinates N Washington State Plane	Description	Reference(s)
UN-200-W-6	East of the U Tank Farm at Diversion Boxes 241-U-151 and 241-U-152	1950	566017	134991	Unknown beta/gamma contamination with a dose rate of 20 mr/hr at ground surface. Area was covered with clean soil.	ESD DOE (1992)
UN-200-W-71	241-U Tank Farm, Tank U-102	1974	Many locations	Many locations	Contamination resulting from a heel jet that was removed from tank U-102 was spread to several locations along the route from the tank to the 200 West Burial Ground	ESD DOE (1992)
UPR-200-W-24	241-U-Tank Farm, 244-UR Vault	1953	566775	135272	Contamination resulted from a violent chemical reaction at the 244-UR Vault. The nature and extent of resulting contamination are unknown; however, the affected area was covered with clean backfill and stabilized.	ESD DOE (1992)
UPR-200-W-128	241-U Tank Farm, Tank U-103	1971	566781	135104	Worker cut through a waste line in tank U-103. Extent and type of contamination resulting from the line rupture are not known.	ESD DOE (1992)
UPR-200-W-154	241-U Tank Farm, Tank U-101	1959	566842	135104	Leakage of approximately 113,500 liters (L) of waste from tank U-101.	ESD DOE (1992)
UPR-200-W-155	241-U Tank Farm, Tank U-104	1956	566842	135074	Leakage of approximately 208,175 L of waste from tank U-104.	ESD DOE (1992)
UPR-200-W-156	241-U Tank Farm, Tank U-110	1975	566842	135013	Leakage of approximately 30,659 L of waste from tank U-110. Increasing radiation was observed in monitoring boreholes.	ESD DOE (1992)
UPR-200-W-157	241-U Tank Farm, Tank U-112	1969	566781	135012	Leakage of approximately 1,892 L of waste from tank U-112. A more substantial leak volume of 32,000 L was suspected.	ESD DOE (1992)

5.4 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 5.6, "Gross Gamma 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 tank's domed tops. 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 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 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 most tanks now have a relatively solid sludge and salt cake waste component and the liquid is only found in the interstices or pores of the solid material. Therefore, a surface-level measurement 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 reportedly will soon be used to monitor the interstitial liquid level. .

Currently, the in-tank solid- and liquid-level measurements 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 1996).

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.

5.5 Vadose Zone Monitoring Boreholes

All the SST farms, including the U Tank Farm, have monitoring boreholes installed around the tanks. These boreholes were installed and 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 locations and identification of the boreholes surrounding tanks in the U Tank Farm are shown on Figure 15-11.

The majority of the boreholes in the U Tank Farm are 125 ft deep, well above the groundwater. A few boreholes around the perimeter of the tank farm extend to depths of about 150 ft. Most of the vadose zone monitoring boreholes surrounding the tanks were drilled in the early to mid-1970s. There were no monitoring boreholes installed around the four auxiliary waste tanks.

The construction of most boreholes is documented in the form of driller's logs. Most of the drilling logs provide varying degrees 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 document the occurrences of radiological contamination when it was encountered during drilling. All the drilling logs are available in borehole archive files maintained by Rust Federal Services, Inc., 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 the ground surface. However, these collars would be insignificant barriers if considerable water was present at the ground surface. Flooding that created standing water at the surface of the U Tank

Farm was identified as the cause of increased liquid levels (intrusions) in some of the tanks. A volume of surface water that would produce a measurable rise in the tank level in a tank could most likely drive contamination down the outside of the casing. Flood 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 flood 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 flooding occurred at the ground 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 is 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 include information regarding borehole drilling details, geological information, well construction configuration, and other pertinent information found in the documentation on file.

5.6 Gross Gamma Logging

A gross gamma logging program provided a primary means of detecting leaks from the SSTs for many years. More recently, this program has 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 U 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 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 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 was 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 properly 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. Therefore, there is no way to relate an instrument count rate or even a gamma-ray flux in a borehole to a leak from a tank. 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. Regardless of the calculational mechanism, the count-rate response has at least been measured and applied to create some empirical leak-detection criteria.

The gross gamma logging program was implemented strictly as a tank leak-detection monitoring program (Isaacson 1982). It was not designed to determine the nature and distribution of contamination, nor was it intended to be used to monitor the movement of the contamination through the vadose zone. As a result, these data do not provide a good historical record of the vadose zone contamination, nor do they adequately identify migration of the contamination. However, these data are useful for some migration assessment purposes. In fact, leaks have been identified in many instances from the gross gamma log data, and changing conditions have been identified in several instances. The ^{235}U and ^{238}U contamination that resulted from tank U-104 leakage was identified through comparison of gross gamma-ray log data.

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.

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 over 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 U Tank Farm. Leak detection is conducted through acquisition of in-tank measurements within LOWs and/or by manual tape measurements of waste surfaces. 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 are located in the vicinity of the U Tank Farm, and descriptions of these facilities are provided in the following sections. Figure 15-6 shows the locations of these waste sites. Only sites that could have affected the groundwater or vadose zone contamination at the U Tank Farm are considered. Groundwater monitoring wells adjacent to these sites are monitored under sitewide monitoring programs and reported in quarterly and annual reports, such as DOE (1996a) and Dresel et al. (1995). Groundwater monitoring is not performed at these sites under the RCRA groundwater monitoring program because these facilities are inactive. No vadose zone monitoring or characterization has been conducted at these facilities, other than some previous limited gross gamma logging.

Radionuclide inventories presented in the following site descriptions are included in the Hanford ESD and its predecessor, the WIDS database; the radionuclide inventories are those presented in the WIDS database with the activities calculated (decayed) through December 31, 1989.

6.1 216-U-3 French Drain

The 216-U-3 French Drain is located about 200 ft south of the U Tank Farm.

This facility consists of a 12-ft-deep rock-filled excavation that is 6 ft in diameter at the bottom; the sides of the excavation slope at a ratio of 3:1. A 4-in.-diameter black iron pipe runs down the center of the excavation to a depth of 7 ft. A heavy-gauge screen was installed at the bottom of the pipe. This type of waste disposal facility is also known as an underground injection well.

The 216-U-3 French Drain was in operation during 1954 and 1955 and received approximately 791,000 liters (L) of condensed vapor from the condenser on tank U-110 in the U Tank Farm. The major radionuclides in the condensate waste were ^{137}Cs and ^{90}Sr; chemically, the waste was neutral to basic.

6.2 216-U-13 Trench

The 216-U-13 Trench is located immediately west of the U Tank Farm.

This facility consists of two trenches that were 200 ft long, 25 ft deep, and 18 ft wide at the bottom. This facility was used to decontaminate vehicles and is also known as the 241-UR Steam Cleaning Pit.

The 216-U-13 Trench was in operation from 1952 to 1956, and during this period generated approximately 11,400 L of waste that was deposited in the sediments at the bottom of the trenches. The major radionuclides in the waste were ^{137}Cs and ^{90}Sr.

When this facility was decommissioned, 640 m^3 of contaminated soil material was removed and taken to the 200 West Burial Ground. The trenches were then backfilled with clean soil material.

A comprehensive radiation survey of the reclaimed 216-U-13 Trench area was conducted in 1981, and the site was subsequently released as a radiation area. There are presently no restrictions for access to this area.

6.3 216-U-14 Ditch

The 216-U-14 Ditch was an open ditch approximately 1 mi long and 8 ft deep at the bottom that ran from northeast to southwest across the 200 West Area. The 216-U-14 Ditch originated 1,100 ft east and 3,300 ft north of the U Tank Farm and terminated 1,400 ft southwest of the U Tank Farm at the 216-U-10 Pond. The 216-U-14 Ditch was also known as the "laundry ditch" because it received wastewater from the 2724-W Laundry Building that was located near the head origin of the ditch.

The 216-U-14 Ditch was put into service in 1944 and received laundry wastewater, wastewater from the 200 West Area Powerhouse, chemical sewer waste and cooling water waste from 221-U and 224-U, and condenser and evaporator waste. A volume of 4,900 m^3 of soil materials was contaminated from wastes discharged in the 216-U-14 Ditch. The radionuclide inventory of the waste discharged through the ditch is included with the 216-U-10 Pond inventory.

Decommissioning and stabilization of the 216-U-14 Ditch was performed in stages, with some portions of the ditch being used as late as 1995. The last open and in-use segment of the 216-U-14 Ditch was located about 600 ft southeast of the U Tank Farm. Stabilization included removal of vegetation along the ditch and backfilling with 2 to 4 ft of spoil material. The contaminated sediments were left in the bottom of the ditch.

Surface maintenance includes weed prevention and upkeep of posting requirements. The surface of the reclaimed ditch area is presently designated an "Underground Radioactive Materials" area, and access to this area is controlled.

6.4 216-Z-1D Ditch

The 216-Z-1D Ditch was located about 500 ft west of the U Tank Farm.

The ditch was more than 4,000 ft long, 4 ft wide, and 2 ft deep, and it originated near Z Plant and terminated at the 216-U-10 Pond. The 216-Z-1D Ditch is also known as the 216-Z-1 Ditch, the 216-Z-19 Ditch, and the Z Plant Ditch.

Operation of the 216-Z-1D Ditch commenced in 1944 and continued until 1959. During its service life, this ditch received approximately 1,000,000 L of low-level process cooling water, steam condensate, and other wastewaters from the 231-Z, 234-5Z, and 291-Z Buildings. It was deactivated in 1959 when it was replaced by the 216-Z-11 Ditch.

The site of the 216-Z-1D Ditch was decommissioned and backfilled to grade in stages. Some of the course of the 216-Z-1D Ditch was common with the 216-Z-11 and 216-Z-19 Ditches and was not reclaimed. Some of the significant radionuclides contained in the ditch bottom sediments are ^{137}Cs, ^{239}Pu, and ^{240}Pu. The 216-Z-1D Ditch is classified as a TRU-Contaminated Soil Site.

6.5 216-Z-11 Ditch

The 216-Z-11 Ditch was a replacement ditch for the 216-Z-1D Ditch; it paralleled the early ditch along most of its course. It was located about 500 ft west of the U Tank Farm.

This ditch was slightly more than 2,600 ft long, 4 ft wide, and 2 ft deep; it originated near Z Plant and terminated at the 216-U-10 Pond. The 216-Z-11 Ditch was also known as the 216-Z-1D Ditch and the Z Ditch.

The 216-Z-11 Ditch was in service from March 1959 to May 1971. It received process cooling water, steam condensate, and laboratory wastewater from various facilities supporting Z Plant operations. The total volume of liquid discharged to this ditch is unknown.

In 1971, the 216-Z-11 Ditch was deactivated and replaced with the 216-Z-19 Ditch. The 216-Z-11 Ditch site was backfilled with clean soil to grade when it was retired. Significant radionuclides contained in the ditch bottom sediments are ^{137}Cs, ^{239}Pu, and ^{240}Pu. The 216-Z-11 Ditch is classified as a TRU-Contaminated Soil Site.

6.6 216-Z-19 Ditch

The 216-Z-19 Ditch, which replaced the 216-Z-11 Ditch, for the most part paralleled the courses of the 216-Z-1D Ditch and earlier 216-Z-11 Ditch. The 216-Z-19 Ditch was located about 500 ft west of the U Tank Farm.

This ditch was slightly more than 2,700 ft in length, 4 ft deep, and 4 ft wide at the bottom, and it originated near Z Plant and terminated at the 216-U-10 Pond. The 216-Z-19 Ditch was also known as the Z Plant Ditch and the 216-U-10 Ditch.

The 216-Z-19 Ditch was in service from May 1971 to September 1981. During its service life it received process cooling waste and steam condensate from Z Plant operations; the volume of the waste discharged to the 216-Z-19 Ditch is unknown.

The 216-Z-19 Ditch was deactivated and liquid wastes were diverted to the newly constructed 216-Z-20 Crib. The 216-Z-19 Ditch was reclaimed in stages, and final backfilling of the Z Ditch complex (216-Z-1D, 216-Z-11, and 216-Z-19 Ditches) was completed in 1981. The head end (origin) of the ditch is grossly contaminated with ^{241}Am, ^{239}Pu, and ^{240}Pu. The Z Ditch complex area is posted as an "Underground Radioactive Material" zone, with a "cave-in potential" at the head of the ditch.

6.7 216-U-10 Pond

The 216-U-10 Pond was constructed in 1944 to receive low-level radiological liquid effluent from processing facilities. It is located in the southwest portion of the 200 West Area about 1,600 ft southwest of the U Tank Farm. At its maximum extent, the 216-U-10 Pond covered an area of about 30 acres.

The 216-U-10 Pond was deactivated in 1985 and no longer contains water.

During its service life, the 216-U-10 Pond received approximately 1.65×10^{11} L of contaminated liquid consisting of 200 West Powerhouse process cooling water, steam condensate from Z Plant operations, wastewater from the 2724-W Laundry, chemical sewer waste and cooling water from U Plant facilities, Z Plant laboratory waste, condenser water from tank U-110 in the U Tank Farm, and evaporator steam condensate from the 242-S Evaporator. The high volume of liquid waste discharged to the 216-U-10 Pond during the 1950s and 1960s resulted in significant mounding of groundwater beneath the pond. Since the deactivation of the facility in 1985, the depth of the groundwater mound has been decreasing at a rate of about 1 ft per year (ft/yr) (DOE 1993).

Estimates of the radionuclide inventory of the U Pond system, which consists of the 216-U-10 Pond and the 216-Z-1D, 216-Z-11, 216-Z-19, and 216-U-14 Ditches, include 8.2 kilograms (kg) plutonium, 1,500 kg uranium, 15.3 Ci ^{137}Cs, and 22.6 Ci ^{90}Sr. The diversity of discharge sources and duration of the discharges make it difficult to assign inventories to individual components of the U Pond system.

During reclamation of the 216-U-10 Pond site, soil at peripheral areas of the pond was removed and replaced with clean soil material. The contaminated soil materials were placed in the center of the pond site. Peripheral areas were covered with 2 ft of clean soil material while a 4-ft thickness of clean soil was placed in the central portions of the 216-U-10 Pond site. The area was seeded with a soil binding vegetation. Subsequent radiological surveys of the site identified localized areas of surface contamination. Additional soil cover was applied over this contamination and the areas were reseeded.

6.8 207-U Retention Basin

The 207-U Retention Basin is located about 300 ft east of the U Tank Farm.

This facility consists of two concrete structures or ponds that are 106 ft long, 106 ft wide, and about 6.5 ft deep; the capacity of each pond is about 500,000 gal. There are sumps, ancillary piping, and inlet and outlet structures for each pond.

The 207-U Retention Basin began operation in 1952; it received steam condensate, cooling water waste, and chemical sewer waste from U Plant facilities. These wastes were discharged from the 207-U Retention Basin to the 216-U-10 Pond through the 216-U-14 Ditch. No estimates of

waste volumes processed or discharged through this facility were identified. There are no documented spills or leaks associated with the 207-U Retention Basin.

This facility was investigated during the preparation of this report because of its proximity to the U Tank Farm and its potential to contribute to vadose zone contamination or to provide moisture to drive or redistribute contamination deposited in the sediments from other sources. Leakage of liquids from the 207-U Retention Basin could have impacted contamination in the U Tank Farm through creation of a perched water zone above the Plio-Pleistocene unit.

7.0 Spectral Gamma Logging Measurements

7.1 Equipment

Logging operations were accomplished with two SGLSs (designated for identification purposes as Gamma 1 and Gamma 2). These systems were manufactured in 1993 by Greenspan, Inc., of Houston, Texas. They are a custom assemblage and adaptation of laboratory-quality spectroscopy instrumentation; the systems were designed specifically 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 probe, a logging cable and delivery system, and surface computer electronics mounted in a cabin on a heavy-duty truck chassis. Figure 15-13 shows one of the SGLSs in a typical logging 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 is practical because of advances in portable electronic systems and because of developments by the manufacturers of the detection systems that made production of higher efficiency detectors more economical.

The detectors, which are housed in downhole cylindrical probes, are mounted in a portion of the housing with a decreased housing wall thickness that reduces the attenuation of the gamma-ray signal. The downhole probes also contain a high-voltage supply, a preamplifier, and a liquid nitrogen dewar and cryostat assembly. The liquid nitrogen dewar system is needed to cool the detector diode to liquid nitrogen temperatures. The dewar holds a quantity of liquid nitrogen that allows 10 hours of logging between refills.

The sonde is delivered downhole on a Kevlar-reinforced, multiconductor cable. The cable transmits the preamplified detector pulses and timing pulses uphole to the truck-mounted instrumentation. Conductors provide low-voltage power to the downhole power supply. The cable also has a vent tube for releasing nitrogen gas as the liquid nitrogen in the dewar vaporizes.

The vent tube allows the downhole probe to be used in water-filled boreholes. Figure 15-14 shows a high-purity germanium detector suspended over a borehole.

Sonde movement within a borehole is governed by a servo-controlled hydraulic winch that receives its control signal from the system computer. The probe position in the borehole is measured with a digital rotary encoder mounted on a sheave wheel hanging from a boom (Figure 15-14). The boom is used to position the detector 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 1995e). 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 was completed in the spring of 1995 and included initial testing and qualification of the logging systems. This calibration was performed using the DOE borehole calibration models at the DOE-GJO as standards. These models are concrete cylinders or monoliths with large homogeneous regions where the concrete is enriched with known concentrations of KUT. Boreholes were cast with pipes when the concrete of the enriched zones was poured so that a logging sonde could be lowered into the zones. When a logging tool 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 direct 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 15-15 presents 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 efficiency function 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 are not system dependent and 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 of 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 1995e). The first biannual calibration (second field calibration), which was performed in October 1995 during the period when the U Tank Farm logging was being conducted, is reported in DOE (1996g). The data acquired during the second field calibration demonstrate that there was no statistically significant change in the performance of the system.

The field calibration models are essentially identical to the national standards in Grand Junction. These 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 shown on Figure 15-15. The dead-time correction is determined 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 probe, 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 performance of the U Tank Farm logging, 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 verify system performance in the field.

The field verification data for the second and third field calibrations have been analyzed and are reported in DOE (1996c) and DOE (1996g), respectively. The data show no trend over time, verifying the stability and the consistent performance of the systems.

7.3 Logging Process and Procedures

Data acquisition or logging work is performed according to a logging procedure (DOE 1995h). 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 engineer 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 are 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 for each borehole 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. 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. These zones are identified on the log plots.

The SGLSs have digital spectrum stabilizers that automatically adjust the gain and maintain the natural ^{40}K peak at 1460 keV within an established spectrum channel range. Occasional fine adjustments of the gain may be required throughout an 8-hour (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 for any reason, such as when a high count-rate region is encountered or operations cease for the day, 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.

Upon completion of the logging of a borehole, 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 1995j). 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 1995h). 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 1995j). 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 accurate concentrations. The radionuclide concentration data are put into a log profile format and then plotted.

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.

Figure 15-16 shows a flow chart of the data analysis process that is also provided in the data analysis manual. The office computer system consists of five 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 procedures and protocol discussed above in Section 7.4, "Data Management" and in the records management plan.

Analysis begins by converting all the raw *.chn spectra files into a format that can be read by the commercial spectrum analysis software written by APTEC Nuclear Inc. and called "PCMA/WIN." 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 specific 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

radionuclide was detected. One file is created for each nuclide or photon peak, and each file contains the data from all depths for the spectra for the particular photon peak.

All environmental corrections are applied to the measured peak count rates to correct for casing thickness, water-filled boreholes, dead time, etc. Next, 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). 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 Jandel Scientific "SigmaPlot" plotting software. SigmaPlot is used to create logs or graphs of the radionuclide concentration versus depth.

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 1995e).

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 it 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.

Preparation of a Log Data Report is the final step of the data analysis process. The Log Data Report documents the analysis 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 the 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 planned for implementation in fiscal year 1998.

8.0 Log Data Results

8.1 Instrumentation Performance

The two logging systems (Gamma 1 and Gamma 2) logged a total of 59 boreholes within the U Tank Farm in about 3 months. 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 the logging engineers recorded the logging information on the Log Data Sheets. The information on the Log Data Sheets was 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 was often obscured by a small concrete pad placed around each borehole; consequently, sometimes the casing thickness recorded in the field 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 were 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.

A maximum radiation flux from ^{137}Cs from which a meaningful spectrum could be recorded corresponded to a concentration of about 5,000 pCi/g. Above this concentration level, large instrument dead times yield distorted spectra and the data cannot be analyzed.

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 ^{235}U and ^{238}U are 1 pCi/g and 10 pCi/g, respectively; the MDL for ^{60}Co is about 0.15 pCi/g; the MDL for ^{154}Eu and ^{152}Eu is about 0.2 pCi/g; and the MDL for ^{125}Sb in the one borehole in which it was detected was less than 1 pCi/g. These values represent the lower limit of detection for the system when it is operated with a 100-s counting time. The detector can be operated at much longer counting times, but more time would be required to log a borehole. The assay capability for these nuclides down to the levels reported is well within any health and safety risk levels.

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 U Tank Farm, the most abundant gamma-emitting radionuclide contaminants in the vadose zone were ^{137}Cs, ^{235}U, and ^{238}U. ^{137}Cs was detected in every borehole, while ^{235}U and ^{238}U were detected in a plume associated with leakage from tank U-104. ^{154}Eu and ^{60}Co were detected in thin zones near the ground surface; the occurrences of these radionuclides resulted from surface spills and/or 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 above 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 log plots showing concentration relative to depth in the boreholes. A set of logs for each borehole consists of a separate log plot of any man-made radionuclides, a log plot of the naturally occurring radionuclide concentrations (KUT), and a combination plot showing logs of the man-made and naturally occurring radionuclides along with the total gamma log and the historical gross gamma-ray log from the Tank Farms 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 a part of 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 (see Section 8.4) for the boreholes surrounding each tank are provided in Appendix C 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 U 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 effect 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 reader is referred to the individual Tank Summary Data Reports listed in Section 15.0 of this report for information on a specific borehole.

9.0 Development of the ^{137}Cs, ^{235}U, and ^{238}U Contamination Models

It was desirable to create visualizations of the major contamination distribution within the three-dimensional space that constitutes the vadose zone in the U Tank Farm and present the 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 U Tank Farm vadose zone are key products of the vadose zone characterization effort.

Creating the visualizations required developing models of the ^{137}Cs, ^{235}U, and ^{238}U contamination distributions, which are the three major contaminants detected in the vadose zone in significant quantities. For this project, the contamination model is considered to be an empirical model, as contrasted with a conceptual model or a model developed from predictive calculations such as contamination transport calculations. The contamination model is considered an empirical model because it is based on data obtained by measuring the contamination concentrations at discrete points in the subsurface. It is not considered a "concept" because it is not based on predictive or assumed data. The only conceptual part of the model 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 errors and inaccuracies. Explanations regarding the known and possible errors and 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 two data points in the three-dimensional space beneath the U 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 contamination concentration at unsampled points in three-dimensional space.

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 contamination could be produced that resulted in a solid surface model of the contamination. That model can be moved, rotated, and viewed from any angle or direction, and color pictorials of the model 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 the model.

The radionuclide concentration data that constitute the spectral gamma-ray log data reported in the Tank Summary Data Reports for the U 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. At the U Tank Farm, the most abundant contaminants were ^{137}Cs, ^{235}U, and ^{238}U. Other nuclides

such as ^{60}Co and ^{154}Eu were detected in the vadose zone sediments but were isolated distributions of contamination. Therefore, the contamination models were based on the ^{137}Cs, ^{235}U, and ^{238}U distributions, and the visualizations consist of only these three contaminants.

9.1 Geostatistical Structural Model

The initial stage in developing an empirical model of the ^{137}Cs, ^{235}U, and ^{238}U contamination was to determine the geostatistical structure of the data by performing a geostatistical structural analysis. A geostatistical structural analysis determines if two data points can be correlated and quantifies the quality of the correlation. These analyses were performed for the ^{137}Cs, ^{235}U, and ^{238}U data spectral gamma-ray log data collected with the SGLS.

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, ^{235}U, and ^{238}U contamination.

The total data domain of the calculations included all vadose zone boreholes within the U Tank Farm. The domain was extended in the north-south and east-west directions to include the maximum and minimum borehole coordinates. 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. Initial variogram calculations were made with a horizontal-to-vertical anisotropy of 10. Through trial and error, the anisotropy value was eventually determined to be 7 (the horizontal continuity is 7 times greater than the vertical continuity). This value produced sill values and horizontal and vertical ranges that appeared to be representative of the contamination distribution.

During the variogram calculations for each model, the program was allowed to let the Z symmetry axis vary from the vertical direction. The principal component axis that resulted was a structural model with a Z axis that had an angle 0.538° from the vertical for the ^{137}Cs contamination model, an angle of 0.452° from the vertical for the ^{235}U model, and an angle of 0.481° for the ^{238}U model. These low principal-component axis angles indicate that there is almost no deviation from the vertical of the principal axis.

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. In real terms, the range is multiplied by 7 (the anisotropy factor) to produce 504 ft, which is the distance at which the correlation of two data points is strictly random. 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 axis of the vertical variogram is actually the principal component axis of the data and has an angle of 0.538° from the vertical, confirming that the assumption of horizontal-to-vertical anisotropy is a good assumption and that the horizontal axes are isotropic.

The calculated variogram for ^{235}U contamination that was used to represent the geostatistical structure in the horizontal direction had a range value of 42.1 ft and a sill value of 0.1. In real terms, the range is multiplied by 7 (the anisotropy factor) to produce 294 ft, which is the distance at which the correlation of two data points is strictly random. The range for the vertical variogram was 35.4 and the sill value was 0.11. This shows the a spatial relationship between two data points to be 35.4 ft in the vertical direction, such that the knowledge of one point will decrease the mean estimation uncertainty of the other. The axis of the vertical variogram is actually the principal component axis of the data and has an angle 0.452° from the vertical, confirming that the assumption of horizontal-to-vertical anisotropy is a good assumption and that the horizontal axes are isotropic.

The calculated variogram for ^{238}U contamination that was used to represent the geostatistical structure in the horizontal direction had a range value of 41.4 ft and a sill value of 0.312. In real

terms, the range is multiplied by 7 (the anisotropy factor) to produce 287 ft, which is the distance at which the correlation of two data points is strictly random. The range for the vertical variogram was also 41.4 and the sill value was 0.297. This shows the spatial relationship between two data points to be 41.4 ft in the vertical direction, such that the knowledge of one point will decrease the mean estimation uncertainty of the other. The axis of the vertical variogram is actually the principal component axis of the data and has an angle 0.481° from the vertical, confirming that the assumption of horizontal-to-vertical anisotropy is a good assumption and that the horizontal axes are isotropic.

The geostatistical structural analysis produced the equations for the variograms that were used to define the ^{137}Cs, ^{235}U, and ^{238}U contamination concentration models.

9.2 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.

The kriging process also calculates the variance of the radionuclide concentration to show the quality of the calculated concentration value. This concentration error estimation shows the utility of geostatistics. The minimum-maximum plume visualizations result from this type of calculation; these visualizations show the smallest and greatest extent of the plume based on the uncertainty of the data.

The kriging process used a maximum reach of 70 ft or a maximum of 20 data points in the calculation of the concentration at every data point. 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 minimized the potential for a misinterpretation when contamination may have migrated down along the inside or outside of a borehole.

For data sample points with less than detectable concentrations of ^{137}Cs, ^{235}U, and ^{238}U, 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 that the concentration is less than 0.1 pCi/g, rather than ignore those data points.

Similarly, in regions where the radionuclide concentration was so high that the detection system became saturated, the value of 5,000 pCi/g was placed in the database for the kriging operation. This setup has minimal effect on the U Tank Farm data because there were very few zones with

concentrations that saturated the detector. The maximum identified ^{137}Cs concentration identified on the visualizations was 5,000 pCi/g; there were only a few occurrences of ^{137}Cs contamination over this value in borehole 60-12-01 (adjacent to tank U-112).

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 sill distance 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 model. 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.

For the discussions presented in Section 10.0, "Discussion of Results," the lowest level of ^{137}Cs, ^{235}U, and ^{238}U contamination visualized (the isolevel) is 0.2 pCi/g. This isolevel for ^{137}Cs contamination is lower than reported in the SX and BY Tank Farm Reports because in those two tank farms there was extensive ^{137}Cs contamination; consequently, using a lower isolevel produced confusing visualizations of the ^{137}Cs plume distribution. The lower concentration and more sparse distribution of ^{137}Cs contamination encountered in the U Tank Farm allowed a lower isolevel to be used.

All visualizations are presented in color and are discussed in Section 10.0. An animation of the contamination would be beneficial by providing a data file showing progressive planar slices of these data. This type of animation provides the best understanding of the contamination distribution. Unfortunately, such animation requires too much media memory space, but this type of visualization may be available on a Hanford database at a later date.

9.3 Potential Model Uncertainty and Inaccuracies

One of the greatest concerns in preparing the contamination models is that the contamination is not actually distributed within the sediments but that it is either on the inside or on the outside of the borehole casing. At the beginning of model development, an assumption was made that all contamination was distributed within the formation and 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 ^{137}Cs, ^{235}U, and ^{238}U concentrations to blocks bound by data point nodes. The software program does not include a mechanism to factor in the uncertainty estimation for the assays at the individual data points. The assay uncertainty-estimation calculation is discussed in the base calibration report (DOE 1995e) 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 uncertainty 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 and/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. The anisotropy factor allows data points in a horizontal direction away from a data point node to influence the kriged value at that data point node 7 (the anisotropy factor for the U Tank Farm ^{137}Cs data) times more than the data points an equal distance away in a vertical direction.

Potential model uncertainties and inaccuracies associated with zones of high ^{137}Cs concentrations are not significant in the U Tank Farm because of the limited occurrences of these zones (boreholes 60-12-01 and 60-10-07 were the only boreholes in which high concentrations were encountered). 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 the 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 good compromise between performing the data acquisition for all the boreholes in the U 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 8.1 "Instrument Performance," of this report.

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 U 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 and 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 sediments or with contamination that migrated down the inside of the borehole casing. As a result, the photons 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 borehole.

A more rigorous geostatistical structural analysis would be desirable. The data samples are 0.5 ft apart in the vertical dimension, creating an ideal database for geostatistical assessment. But 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.

There are cases where the apparent concentration is not an actual representation of the vadose zone contamination and consequently the concentration estimation will not be valid. This possibility was considered by interpreting the plumes with the visualizations and with the spectral gamma-ray logs from the individual boreholes provided in the Tank Summary Data Reports. The interpretation of each plume or group of plumes is discussed in Section 10.0, "Discussion of Results." Potential problems with each plume are also identified and explained in Section 10.0 in an attempt to understand the limitations of the models.

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 of the logging probe is the center of the HPGe detector, and this reference is etched into the detector housing and ensures consistent depth measurements. 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 surface, the reported radionuclide concentrations would be higher than is actually present in the formation.

The other reason the concentrations are not valid is because most 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 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 (predominantly ^{137}Cs) in the sediment. The ^{137}Cs concentration may be higher or lower by an unknown amount. However, for most of the lengths of the boreholes, the models are accurate representations of the distribution and intensity of the contamination in the vadose surrounding the tanks in the U Tank Farm.

Areas of surface ^{137}Cs contamination were observed throughout the U Tank Farm. This contamination was most continuous in the eastern half of the tank farm; the southeastern quarter was almost completely contaminated with ^{137}Cs, as shown in Figure 15-17. This figure is a horizontal slice 10 ft below the ground surface of the U Tank Farm; therefore, there are no inaccuracies associated with these measurements as there are for near-surface measurements (as discussed previously).

For most of the U Tank Farm area, the ^{137}Cs concentrations ranged between 1 and 10 pCi/g. In areas near tanks U-105 and U-110 and between tanks U-109 and U-112, the ^{137}Cs contamination concentrations were as high as 100 pCi/g. Surface and near-surface contamination is indicative of surface spills or leaks from ancillary piping; however, there was no documentation in the ESD recording such events.

DOE (1992) was reviewed to determine if there was an assemblage of facilities in the southeast area of the U Tank Farm that may have been contributing to this surface contamination. Several facilities were identified in that report, including the 241-UR-152, 241-UR-153, and 241-UR-154 Diversion Boxes and the 241-U Receiver. All these facilities supported U Tank Farm operations and were used to transfer high-level wastes to and from the tank farm (DOE 1992). These facilities had networks of piping connected to the U Tank Farm tanks in order to complete waste transfer operations, and all this piping had potential for leakage. The most spatially continuous contamination coincides with these facilities and is indicative of their contribution to the contamination on the east side of the U Tank Farm.

Some of the high gamma-ray count rates detected near the ground surface may be related to contamination from leaks from pipelines that traverse the surface of the U Tank Farm in many locations. Near-surface contamination was detected in boreholes 60-11-03 and 60-11-12 in thin zones ranging in depth from 2 to 5 ft. ^{137}Cs, ^{60}Co, and ^{154}Eu contamination was detected in these zones.

The ^{137}Cs contamination distribution model shows that the surface contamination has, for the most part, migrated downward from 10 to 30 ft below the ground surface and that it has diminished in intensity. This distribution is not as apparent on the visualizations as it is on the borehole correlation plots provided in Appendix C, because the ^{137}Cs concentrations are low and there is not significant color contrast on the visualizations at concentrations of about 5 pCi/g and less.

The most likely scenario(s) for the contamination from the ground surface to a depth of about 30 ft is downward migration of surface contamination from spills or leakage from pipelines and ancillary equipment. In most boreholes, the surface contamination was observed in the first gross gamma-ray log data acquired when the boreholes were completed. Some contaminated sediments at the ground surface were most likely carried downward during borehole drilling as casing was advanced in the borehole. The pounding action of the cable tool drilling method would cause the finer materials to sift downward around the outside of the casing.

A majority of the monitoring boreholes have a small circular concrete pad around the borehole casing at the ground surface. The only exceptions are those boreholes that are located within berms; those boreholes have had casing extensions welded to the original borehole casing at the ground surface. Other than the surface pad, there was no other seal between the casing and formation to prevent migration along the casing and formation interface. In the event of a surface spill of contaminated material or a natural meteorological event that produced flooding at the tank farm surface, surface contamination could have migrated downward or previously deposited contamination may have been driven down the borehole-created pathway within the sediments.

No actively migrating contamination plumes were identified from the gross gamma log data recorded for the past 20 years at Hanford. Contamination that was detected near the ground surface with the gross gamma logging system is shown to be relatively stable and to have not migrated any significant degree. The database extends from the early 1970s to the late 1980s.

Future development of a spectral-shape factor analysis of the gamma-ray spectra may provide additional information for analysis of the distribution of contaminants around the boreholes. The spectral-shape factor parameter called SF1 is the ratio of the counts in the low-energy Compton continuum to the counts in the full energy photon peak, and this parameter is high for uniformly distributed cesium and low for cesium distributed on the outside of the casing. Shape factor analysis may provide a more conclusive identification of regions in a borehole where it is suspected that contamination is not within the formation and has simply migrated down the borehole casing.

10.2 Processed Uranium Contamination

^{235}U and ^{238}U contamination was detected in several U Tank Farm boreholes at concentrations exceeding those of naturally occurring uranium in Hanford Site sediments. The source of these elevated concentrations was determined to be from waste associated with processed uranium fuel materials. During the processing of uranium, the daughter products of ^{238}U, such as the radionuclides ^{214}Bi and radium-226 (^{226}Ra), are removed; therefore, the ^{238}U decay series is interrupted and is no longer in secular equilibrium. Assays of naturally occurring uranium in uncontaminated Hanford Site sediments are based on the 609.3-keV or 1764.5-keV gamma rays of ^{214}Bi. In the intervals where processed ^{235}U and ^{238}U concentrations are identified, the activities for ^{214}Bi (609.3-keV) and ^{226}Ra (185.9-keV) are not elevated, indicating an interruption in the ^{238}U decay series. Processed ^{235}U is identified from the 185.7-keV energy peak, and processed ^{238}U is identified from the 1001-keV energy peak. Spectra from intervals containing processed uranium contamination show enhanced intensities at these energies. Under the current 100-s live time acquisition time for the SGLSs in this characterization project, the 185.7-keV and 1001-keV peaks are not usually identified in spectra of uncontaminated sediments containing naturally occurring uranium concentrations of 1 to 2 pCi/g.

Where ^{235}U and ^{238}U are present as contamination from processed fuel, the 185.7-keV and 1001-keV gamma-ray intensities indicate that the molar $^{235}U/^{238}U$ concentration ratio is close to that for naturally occurring uranium. These isotopes occur together in the sediments because they are chemically identical and they originated from the same source. Plots of the ^{235}U and ^{238}U concentrations are provided in Appendix C.

10.3 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 U Tank Farm boreholes. The visualizations are provided in Section 15.0 in the order in which they are discussed.

Figures 15-18, 15-19, and 15-20 present the data used in the geostatistical models and are included to let the reader compare the individual borehole ^{137}Cs, ^{235}U, and ^{238}U contamination concentration data with the visualizations depicting these radionuclides. The data are presented as hexagons that are colored and sized according to the ^{137}Cs, ^{235}U, and ^{238}U concentration data 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 15-11.

Figures 15-21 and 15-22 present the ^{137}Cs contamination with the ^{235}U contamination and the ^{137}Cs contamination with the ^{238}U contamination, respectively.

Visualizations were prepared that show the ^{137}Cs, ^{235}U, and ^{238}U contamination plumes with concentrations above 0.2 pCi/g. The ^{238}U plume almost completely engulfs the ^{235}U plume; therefore, the ^{238}U contamination plume was made transparent to allow viewing of the

distribution of the ^{235}U plume. Figures 15-23, 15-24, 15-25, and 15-26 present these visualizations from various viewpoints.

Several visualizations were prepared and are discussed in the following sections. The most widely cited visualizations present ^{137}Cs and ^{238}U contamination plumes on the same visualization. The ^{238}U contamination was slightly more extensive than the ^{235}U contamination and was used in these visualizations to represent the maximum extent of the contamination from waste containing processed uranium. The ^{137}Cs contamination plume concentrations are presented logarithmically in a range from 0.1 to as high as 1,000 pCi/g; the ^{238}U contamination plume concentrations are presented logarithmically in a range from 0.1 to 1,000 pCi/g. These visualizations were used in the tank-by-tank discussion in the following sections.

Depth references regarding waste-level measurements that are stated in the following sections are derived from illustrations and measurements provided in Brevick et al. (1994a and 1994b).

10.3.1 Tank U-101

Tank U-101 was placed into service in 1946. Throughout its service life, this tank received and stored metal waste, REDOX waste, and evaporator feed waste. This tank also received six cask loads of experimental fuel-element shroud tubes and samarium "poison" ceramic balls, 1,530 grams (g) of enriched uranium, 6 g of plutonium, a quantity of cobalt slugs containing approximately 180 kilocuries (kCi) of ^{60}Co, and 130 Ci of mixed fission products.

In 1955 and 1956, sluicing was conducted within tank U-101 to recover uranium from the tank waste.

Tank U-101 was designated a leaker in 1959 and was removed from service (Hanlon 1996). A leak volume of 30,000 gal was estimated; however, the details regarding the discovery of the leak and the method used to establish the leak volume are unknown.

The current inventory of tank U-101 is 25,000 gal of waste consisting of 3,000 gal of supernatant and 22,000 gal of sludge (Hanlon 1996); the supernatant is considered to be pumpable liquid. The waste level is about 1.5 ft above the tank's dished bottom (Brevick et al. 1994).

Tank U-101 is monitored with four monitoring boreholes (see Figure 15-11) that are located on the east, south, and west sides of the tank. There are no monitoring boreholes on the north side of the tank. The concentration plots for the contaminants detected in these boreholes are presented in Appendix C.

Figures 15-27 and 15-28 show the contamination distribution in the vadose zone sediments surrounding tank U-101. These views are from the southeast and northwest, respectively; both views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-101-to-U-103 and U-104-to-U-106 rows of tanks. The north face of these visualizations is the northern extent of the U Tank Farm data domain.

A plume of ^{137}Cs contamination on the south and west sides of tank U-101 is defined by data collected from boreholes 60-01-08 and 60-04-12. This plume is related to surface or near-surface spills and/or leaks that migrated downward and decreased in intensity. This contamination may have been in the sediments before the boreholes were drilled and been carried downward as the boreholes were drilled.

Scattered plumes of low ^{137}Cs concentrations are based on the occurrences of ^{137}Cs at the bottoms of three of the four boreholes (as shown on the borehole correlation plots in Appendix C). This ^{137}Cs contamination most likely entered the inside of the boreholes and migrated downward to the bottoms of the boreholes. These are false contamination plumes.

The log data acquired in the four boreholes surrounding tank U-101 do not indicate that this tank leaked. However, a leak may have occurred on the north side of the tank, where there are no monitoring boreholes. It is possible that this tank did not leak because no basis was found for designating this tank as a leaker.

Details regarding the data acquired in the boreholes surrounding tank U-101 are provided in the Tank Summary Data Report for tank U-101 (DOE 1996h).

10.3.2 Tank U-102

Tank U-102 was placed into service in 1946. Throughout its service life, this tank received and stored metal waste, REDOX waste, and evaporator bottoms waste. Tank U-102 also received a category of waste designated "Hanford defense residual liquor" (Brevick et al. 1994b); a definition of this type of waste was not found in historical information. Tank U-102 was sluiced in 1955 and 1956 for recovery of uranium from the tank waste.

Tank U-102 was removed from service and declared inactive in 1976. It is presently designated sound.

The current inventory of tank U-102 consists of 18,000 gal of supernatant, 43,000 gal of sludge, and 313,000 gal of salt cake and salt slurry (Hanlon 1996). The solids component of these wastes contains 126,000 gal of interstitial liquid, which when combined with volume of the supernatant totals 144,000 gal of drainable liquids. The liquid waste level is 12 ft above the tank's dished bottom; the level of the waste solids is 11.5 ft above the dished bottom.

Tank U-102 is monitored with eight monitoring boreholes (see Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-27, 15-28, and 15-29 show the contamination distribution in the vadose zone sediments surrounding tank U-102. These views are from the southeast, northwest, and southwest, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data

domain between the U-101-to-U-103 and U-104-to-U-106 rows of tanks. The north face of these visualizations is the northern extent of the U Tank Farm data domain.

Surface ^{137}Cs contamination was detected in all the boreholes surrounding tank U-102, and a ^{137}Cs plume is defined by these data. The plume is thickest on the eastern and southwestern sides of the tank, where the data from boreholes 60-02-01 and 60-01-08 are most predominant. This plume resulted from contamination from a surface or near-surface spill or leak that decreased in intensity as it migrated downward. This contamination may have been in the sediments before the boreholes were drilled and been carried down as the boreholes were drilled.
Borehole 60-02-01 may be near a subsurface pipeline that produced a distinct peak of ^{137}Cs contamination from 7 to 11 ft. The ^{137}Cs concentrations within this peak were more than 1,000 pCi/g.

The low ^{137}Cs concentrations at the bottoms of six of the eight boreholes define a tabular ^{137}Cs plume near the base of the visualization. This is a false contamination plume defined from ^{137}Cs contamination that migrated down the inside of the casing and settled at the bottoms of the boreholes.

Details regarding the data acquired in the boreholes surrounding tank U-102 are provided in the Tank Summary Data Report for tank U-102 (DOE 1996i).

10.3.3 Tank U-103

Tank U-103 was placed into service in 1947. Throughout its service life, this tank received and stored metals waste, REDOX waste, and evaporator feed and bottoms waste. Tank U-103 was sluiced in 1956 to recover uranium from the waste.

Tank U-103 was removed from service and declared inactive in 1978.

The current waste inventory of tank U-103 consists of 13,000 gal supernatant, 32,000 gal of sludge, and 423,000 gal of salt cake and salt slurry (Hanlon 1996). The solids component of this waste contains 189,000 gal of drainable liquids that includes the supernatant volume. The level of the liquid waste is 15 ft above the tank's dished bottom; the solids level is 14.5 ft above the dished bottom (Brevick et al. 1994b).

Tank U-103 is monitored with six monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-28, 15-29, and 15-30 show the contamination distribution in the vadose zone sediments surrounding tank U-103. These views are from the northwest, southwest, and northeast, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-101-to-U-103 and U-104-to-U-106 rows of tanks. The north face of these visualizations is the northern extent of the U Tank Farm data domain.

^{137}Cs contamination was detected at the ground surface in all the boreholes. This contamination resulted from surface spills or leaks and decreased in intensity with depth. These data are reflected in the visualizations by the contamination plume that is present near the ground surface and around tank U-103. A well-defined peak of ^{137}Cs contamination in borehole 60-03-08 at depths between 4 and 6 ft may be indicative of a nearby pipeline containing ^{137}Cs contamination.

Low concentrations of ^{137}Cs contamination were detected at the bottoms of four of the six monitoring boreholes. This contamination migrated down the inside of the casing and settled at the bottoms of the boreholes, defining a false tabular ^{137}Cs plume near the bases of the visualizations.

Details regarding the data acquired in the boreholes surrounding tank U-103 are provided in the Tank Summary Data Report for tank U-103 (DOE 1996j).

10.3.4 Tank U-104

Tank U-104 was placed into service in 1947. Throughout its service life, this tank received and stored metal waste. Sluicing operations to recover uranium from the tank waste were conducted as early as 1953. During a sluicing operation in 1956, a bulge in the tank's interior steel liner was discovered when a recovery pump could not be installed deep enough to reach the tank bottom. Subsequent investigation revealed that the tank bottom liner in the northeast quadrant of the tank (near the center of the tank) had bulged upward about 5 ft. Sluicing operations were discontinued, the interior of the tank was inspected, and a tear in the liner was observed. At the time sluicing was discontinued, the tank waste contained about 60 tons of uranium (Clukey 1956). Water had been added to the tank during both the sluicing operations and the leak test following the discovery of the bulge. Tank leakage was confirmed with soundings through tank risers. The volume of the leak was estimated at 55,000 gal (Hanlon 1996); however, the basis of this estimate is unknown.

Increased activity was identified in borehole 60-04-08 at a depth of 53 ft. The intensity of the activity increased to a maximum in 1978; it then decreased and stabilized in 1979. This activity is related to the uranium contamination identified with the SGLS.

Tank U-104 is presently designated a leaker (Hanlon 1996). The current waste inventory consists of 122,000 gal of sludge containing 7,000 gal of drainable interstitial liquid (Hanlon 1996). The waste level is about 4.5 ft above the tank's dished bottom (Brevick et al. 1994b).

Tank U-104 is monitored with six monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-31, 15-32, 15-33, and 15-34 show the contamination distribution in the vadose zone sediments surrounding tank U-104. Figures 15-31 and 15-32 show views of tanks U-104 to U-106 from the northeast and southwest, respectively; these views are from below the tanks. The south face of the visualizations was created with an east-west-oriented cut face that was inserted

in the U Tank Farm data domain between the U-103-to-U-106 and U-107-to-U-109 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-101-to-U-103 and the U-104-to-U-106 rows of tanks. Figures 15-33 and 15-34 show only tank U-104 and are views from the southwest and southeast, respectively; both views are from above the tank. A north-south-oriented cut face was inserted in the U-104-to-U-106 row of tanks between tanks U-104 to U-105. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was detected in all the boreholes from the ground surface to various depths, at a maximum depth of slightly more than 30 ft. This contamination resulted from surface spills or leaks that migrated downward or from contaminated sediments that were in the vadose zone sediments before the boreholes were drilled and carried downward during drilling. This contamination is shown in the visualizations as a continuous plume from the ground surface to below the top of the tank, completely engulfing the top portion of the tank.

^{235}U and ^{238}U contamination was detected in almost coincident zones in four of the six boreholes. This contamination is related to leakage from tank U-104 and is associated with elevated gross gamma-ray count rates encountered in borehole 60-04-08 in 1978. Figures 15-33 and 15-34 are visualizations of only tank U-104; these figures show views from below the tank from the southeast and southwest, respectively. Figure 15-33 shows the thickness and breadth of the distribution of the ^{238}U plume in both the north-south and east-west directions. The visualizations show that the uranium plume migrated slightly downward as well as laterally, and the contamination does not occur right at the base of the tank, but is slightly below it.

The tabular ^{137}Cs contamination plume near the bottom of the visualization is defined by low ^{137}Cs concentrations that were detected in four of the six monitoring boreholes that surround tank U-104. This contamination most likely migrated down the inside of the casing and settled at the bottoms of the boreholes and is not in the formation sediments.

Details regarding the data acquired in the boreholes surrounding tank U-104 are provided in the Tank Summary Data Report for tank U-104 (DOE 1996k).

10.3.5 Tank U-105

Tank U-105 was placed into service in 1947. Throughout its service life, this tank received and stored metal waste, REDOX waste, coating waste, and evaporator feed and bottoms waste. These wastes consisted of both complexed (containing organics) and noncomplexed wastes. Tank U-105 was sluiced in 1956 to reprocess the waste for uranium recovery.

Several occurrence reports were issued in the mid-1970s addressing liquid-level increases and decreases within tank U-105; the Tank Summary Data Report for tank U-105 (DOE 1996l) provides a detailed description of the issues described in the occurrence reports. None of the liquid-level variations were attributed to leakage from the tank.

Tank U-105 is presently designated a sound tank. The present waste inventory consists of 37,000 gal of supernatant, 32,000 gal of sludge, and 349,000 gal of salt cake and salt slurry; this waste contains 179,000 gal of drainable liquid (Hanlon 1996). The liquid waste level is 13 ft above the tank's dished bottom, and the solids level is 12 ft above the dished bottom (Brevick et al. 1994b).

Tank U-105 is monitored with five monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-31, 15-32, and 15-35 show the contamination distribution in the vadose zone sediments surrounding tank U-105. These views are from the northeast, southwest, and northwest, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-103-to-U-106 and U-107-to-U-109 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-101-to-U-103 and the U-104-to-U-106 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified in all five of the boreholes from the ground surface to a depth of at least 10 ft. This contamination occurred to a depth of 20 ft in borehole 60-05-04 and to a depth of almost 50 ft in borehole 60-05-05; these two boreholes are located on the southeast side of the tank. This ^{137}Cs contamination most likely resulted from surface or near-surface leaks or spills that migrated to various depths. This contamination distribution may reflect redistribution of contaminated sediments during drilling. This ^{137}Cs contamination is shown on the visualizations as a plume that, in places, is above the top of the tank, and on the southeast side of the tank extends deeper, reflecting the ^{137}Cs contamination in boreholes 60-05-04 and 60-05-05.

The deeper ^{137}Cs plume is defined by data from boreholes 60-05-05 and 60-05-07; ^{137}Cs contamination extends continuously from a depth of 107 ft to total depth (TD) in borehole 60-05-05 and intermittently from a depth of 102 ft to TD in borehole 60-05-07. The source of this contamination is unknown. The absence of ^{137}Cs contamination above this plume and laterally around these boreholes suggests that this is an isolated occurrence that is probably the result of contamination inside the borehole casing or some other borehole-related condition.

Boreholes 60-05-04 and 60-05-05 have zones of ^{235}U and ^{238}U contamination at depths from 50 to 72 ft and 52 to 75 ft, respectively. Historical tank farm gross gamma-ray logs indicate that this contamination was present in the sediments around borehole 60-05-05 as early as 1974 when the borehole was first logged; subsequent log data indicated that the contamination had stabilized. Uranium contamination was also detected in borehole 60-05-04 when the borehole was first logged in 1978; the contamination appeared to increase in intensity then stabilize in 1981. This contamination is most likely from leakage from tank U-104 that migrated in a southwesterly direction. This pathway may be indicative of the presence of a geologic horizon that promotes lateral migration of the ^{235}U and ^{238}U radionuclides. During sluicing and subsequent leak studies at tank U-104, significant quantities of water may have been discharged to the vadose zone

around tank U-104, providing the driving mechanism to spread the uranium contamination. There is no positive indication in the data acquired for this initial characterization that tank U-105 leaked.

Details regarding the data acquired in the boreholes surrounding tank U-105 are provided in the Tank Summary Data Report for tank U-105 (DOE 1996l).

10.3.6 Tank U-106

Tank U-106 was placed into service in 1948. Throughout its service life, this tank received and stored metal waste, REDOX waste, B-Plant waste, PUREX waste, and evaporator feed and bottoms waste. These wastes consisted of both complexed (containing organics compounds) and noncomplexed wastes. Tank U-106 was not sluiced.

A 1.7-in. liquid-level decrease was observed during a 31-hr period in 1977. Because the measurements showed no signs of stabilizing, the waste in tank U-106 was transferred to tank SY-103 in the SY Tank Farm. Photographs of the tank's interior following the waste transfer revealed the presence of "tar spots" on the interior walls of the tank. At the time, the origin of the tar spots was unknown; however, tar rings were observed on the interior walls of several SSTs. The tar rings were hypothesized to have resulted from entry of tar coating material from outside the steel liner to the interior of the tank through either the lead shield at the top of the liner or through corrosion of the liner itself. Discovery of the tar rings raised a question about the integrity of the liner, and waste levels in the tanks with tar rings were maintained below the level of the tar rings. As a result of the liquid-level decreases, tank U-106 was removed from service and declared of "questionable integrity." After further review, the tank was designated sound in 1981 and was removed from service.

Tank U-106 is presently designated a sound tank. The present waste inventory consists of 15,000 gal of supernatant, 26,000 gal of sludge, and 185,000 gal of salt cake; this waste contains 68,000 gal of drainable liquid (Hanlon 1996). The liquid waste level is 7.5 ft above the tank's dished bottom, and the solids level is 7.0 ft above the dished bottom (Brevick et al. 1994b).

Tank U-106 is monitored with five monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-31, 15-32, and 15-35 show the contamination distribution in the vadose zone sediments surrounding tank U-106. These views are from the northeast, southwest, and northwest, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-103-to-U-106 and U-107-to-U-109 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-101-to-U-103 and U-104-to-U-106 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified at the ground surface in all five boreholes; this contamination did not migrate deeper than 10 ft except for a few isolated occurrences. This contamination resulted from surface spills or leaks. The resulting ^{137}Cs plume is limited to the near surface. Minimal low ^{137}Cs concentrations that were detected at the bottoms of four of the five boreholes defined a thin tabular plume. These low ^{137}Cs concentrations resulted from migration of contaminated materials down the inside of the borehole casing; therefore, this is a false plume. There is no evidence from the spectral data that tank U-106 leaked.

Details regarding the data acquired in the boreholes surrounding tank U-106 are provided in the Tank Summary Data Report for tank U-106 (DOE 1996m).

10.3.7 Tank U-107

Tank U-107 was placed into service in 1948. Throughout its service life, this tank received and stored metal waste, coating waste, and evaporator feed and bottoms waste. These wastes consisted of both complexed (containing organics compounds) and noncomplexed wastes. Tank U-107 was sluiced in 1957 to reprocess the waste for uranium recovery. The tank was removed from service and declared inactive in 1980.

Several discrepancies in liquid-level measurements (both increases and decreases in liquid waste levels) encountered at tank U-107 were documented in occurrence reports. The reader is advised to consult the Tank Summary Data Report for tank U-107 for details regarding those occurrence reports. Large increases in liquid levels were observed and documented in 1982. In two events, liquid-level increases beyond the 3-in. liquid-level increase criterion were measured; the increases were attributed to intrusions from drainage. Each inch of waste level in the U Tank Farm tanks equates to 2,750 gal of waste. These measurements suggest significant surface runoff that will provide the driving force that may remobilize in-place contamination.

Tank U-107 is presently designated a sound tank. The present waste inventory consists of 31,000 gal of supernatant, 15,000 gal of sludge, and 360,000 gal of salt cake; this waste contains 147,000 gal of drainable liquid (Hanlon 1996). The liquid waste level is 13 ft above the tank's dished bottom, and the solids level is 12 ft above the dished bottom (Brevick et al. 1994b).

Tank U-107 is monitored with seven monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-36, 15-37, and 15-38 show the contamination distribution in the vadose zone sediments surrounding tank U-107. These views are from the southeast, northwest, and southwest, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-107-to-U-109 and U-110-to-U-112 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-104-to-U-106 and the U-107-to-U-109 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified in all seven boreholes at the ground surface; this contamination decreased in intensity with increasing depth. This ^{137}Cs contamination most likely resulted from downward migration of contamination from surface and near-surface spills or leaks and redistribution of contaminated sediments during borehole drilling. The visualizations for this contamination show a ^{137}Cs plume that engulfs the top portion of the tank.

Low ^{137}Cs concentrations were detected at the bottoms of six of the seven boreholes. This contamination most likely resulted from downward migration of contaminated material inside the borehole casing. This contamination defined a tabular ^{137}Cs plume near the bottom of the visualizations.

Uranium contamination was detected in four of the monitoring boreholes. This contamination is located on the northern and western sides of the tank; the maximum thickness was detected in borehole 60-07-11, in which the contamination ranged in depth from 53 to 93 ft. Historical tank farm gross gamma-ray logging data (as early as 1974) indicate that this contamination was in the sediments when the boreholes were first logged and that the intensities have remained stable. The uranium contamination most likely resulted from leakage from tank U-104. This contamination may have been mobilized by enhanced moisture that was added during the leak test of tank U-104 or by runoff that has reportedly been in sufficient enough quantities to raise the liquid level in tank U-107 several inches.

Details regarding the data acquired in the boreholes surrounding tank U-107 are provided in the Tank Summary Data Report for Tank U-107 (DOE 1996n).

10.3.8 Tank U-108

Tank U-108 was placed into service in 1949. Throughout its service life, this tank received and stored metal waste, coating waste, REDOX waste, and evaporator bottoms waste. Tank U-108 was sluiced in 1956 to reprocess the waste for uranium recovery. The tank was removed from service and was declared inactive in 1978.

Liquid-level increases measured in tank U-108 in 1976 and 1977 were documented in occurrence reports. The Tank Summary Data Report for tank U-108 provides further details regarding those occurrence reports (DOE 1996o). The liquid-level increases were attributed to exhauster condensate drainage into the tank.

Tank U-108 is presently designated a sound tank. The present waste inventory consists of 24,000 gal of supernatant, 29,000 gal of sludge, and 415,000 gal of salt cake and salt slurry; this waste contains 172,000 gal of drainable liquid (Hanlon 1996). The liquid waste level is 15 ft above the tank's dished bottom and the solids level is 14 ft above the dished bottom (Brevick et al. 1994b).

Tank U-108 is monitored with seven monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-36, 15-37, and 15-38 show the contamination distribution in the vadose zone sediments surrounding tank U-108. These views are from the southeast, northwest, and southwest, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-107-to-U-109 and U-110-to-U-112 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-104-to-U-106 and the U-107-to-U-109 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified in all seven boreholes at the ground surface; this contamination migrated as deep as 48 ft. In all boreholes the intensity decreased with increasing depth. This ^{137}Cs contamination most likely resulted from downward migration of contamination from surface and near-surface spills or leaks and redistribution of contaminated sediments during borehole drilling. The visualizations for this contamination show a ^{137}Cs plume that engulfs the top portion of the tank.

A zone of ^{137}Cs contamination in borehole 60-08-10 at depths ranging from 45 to 70 ft and intermittently to TD is most likely the result of perforations that were cut into the casing from a depth of about 48 ft to TD. Contamination on fine-grained sediments may have entered the inside of the casing through the perforations as they were installed, or at a later time. If significant amounts of moisture are added to the vadose zone sediments from runoff, moisture may be redistributing the sediments through the perforations. This contamination is shown on the visualizations as an isolated ^{137}Cs contamination plume.

Low ^{137}Cs concentrations were detected at the bottoms of six of the seven boreholes surrounding tank U-108. This contamination most likely resulted from downward migration of contaminated material inside the borehole casing. This contamination defined a tabular ^{137}Cs plume near the bottom of the visualizations that extended the plume below tank U-107.

Uranium contamination was detected in boreholes 60-05-05, 60-08-04, and 60-11-12 in thin zones as much as 2 ft thick; these zones are about 52 to 53 ft deep. These boreholes are located around the eastern side of tank U-108. As shown on the visualizations, these occurrences appear to be an extension of the uranium plume originating below tank U-104.

^{137}Cs, ^{60}Co, and ^{154}Eu concentrations were identified in distinct peaks near the ground surface in boreholes 60-08-04 and 60-11-12. This contamination is most likely from a nearby pipeline that was covered with earth materials for shielding purposes. The measured contamination is within the pipeline.

Details regarding the data acquired in the boreholes surrounding tank U-108 are provided in the Tank Summary Data Report for tank U-108 (DOE 1996o).

10.3.9 Tank U-109

Tank U-109 was placed into service in 1949. Throughout its service life, this tank received and stored metal waste, coating waste, REDOX waste, and evaporator bottoms waste. Tank U-109 was sluiced in 1956 to reprocess the waste for uranium recovery. The tank was removed from service and was declared inactive in 1980.

Several liquid-level increases measured in tank U-109 in 1976 and 1977 were documented in occurrence reports. The Tank Summary Data Report for tank U-109 provides details regarding those occurrence reports (DOE 1996p). The liquid-level increases were attributed to crustal growth and problems with the contact surface of the measuring plummet with the waste surface. No evidence of liquid intrusion into the tank from outside sources was discovered; therefore, no corrective actions were taken.

Tank U-109 is presently designated a sound tank. The present waste inventory consists of 19,000 gal of supernatant, 48,000 gal of sludge, and 396,000 gal of salt cake and salt slurry; this waste contains 163,000 gal of drainable liquid (Hanlon 1996). The liquid waste level is 15 ft above the tank's dished bottom, and the solids level is 14 ft above the dished bottom (Brevick et al. 1994).

Tank U-109 is monitored with eight monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-37, 15-38, and 15-39 show the contamination distribution in the vadose zone sediments surrounding tank U-109. These views are from the northwest, southwest, and northeast, respectively; all views are from below the tank. The south face of the visualizations was created with an east-west-oriented cut face that was inserted in the U Tank Farm data domain between the U-107-to-U-109 and U-110-to-U-112 rows of tanks. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-104-to-U-106 and the U-107-to-U-109 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified at the ground surface in all eight boreholes. In seven of the boreholes, this contamination decreased in intensity at a depth that is the typical concentration profile for contamination that is related to surface spills or leaks or for contamination that may have been driven downward during drilling. This ^{137}Cs contamination defines a plume that covers the top of tank U-109.

A ^{137}Cs plume on the south side of tank U-109 defined by data acquired in borehole 60-12-01 is related to events at tank U-112 that will be discussed in Section 10.2.12.

A plume of ^{137}Cs contamination on the west side of tank U-109 is defined by data acquired in borehole 60-09-10, in which ^{137}Cs concentrations were detected at depths ranging from 85 to

125 ft; the concentrations were generally 1 pCi/g or less. This ^{137}Cs contamination may be associated with leakage from one or more of the auxiliary tanks, the nearest of which is located about 30 ft west of borehole 60-09-10. All the auxiliary tanks are designated sound. This borehole may intersect contamination resulting from leakage from tank U-112; however, the contamination would most likely have been detected in boreholes 60-09-07 and 60-09-08, which are located between tank U-112 and borehole 60-09-10.

Details regarding the data acquired in the boreholes surrounding tank U-109 are provided in the Tank Summary Data Report for tank U-109 (DOE 1996p).

10.3.10 Tank U-110

Tank U-110 was placed into service in 1946. Throughout its service life, this tank received and stored metal waste, $BiPO_4$ waste, REDOX waste, and evaporator feed waste. Tank U-110 was sluiced in 1969 to reprocess the waste for uranium recovery.

In 1975, it was determined that tank U-110 was leaking and the tank was removed from service. Concurrent with decreasing liquid levels within the tank were increasing activities in borehole 60-10-07, which is located on the south side of the tank. The volume of the leak was estimated at 5,000 to 8,000 gal (Hanlon 1996). The details regarding the discovery of the leak and method of determining the leak volume are described in Occurrence Report 75-67 (Jensen 1975) and in the Tank Summary Data Report for tank U-110 (DOE 1996q).

Tank U-110 is presently designated as a leaker (Hanlon 1996). The present waste inventory consists of 186,000 gal of sludge that contains 15,000 gal of drainable interstitial liquid (Hanlon 1996). The waste level is 6 ft above the tank's dished bottom (Brevick et al. 1994).

Tank U-110 is monitored with seven monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-40, 15-41, and 15-42 show the contamination distribution in the vadose zone sediments surrounding tank U-110. These views are from the southeast, northeast, and northwest, respectively; all views are from below the tank. The south face of the visualizations is the southern extent of the U Tank Farm data domain. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-107-to-U-109 and the U-110-to-U-112 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination was identified at the ground surface in all seven boreholes. Except for borehole 60-10-07, this contamination extends as deep as 30 ft. This ^{137}Cs contamination resulted from surface spills or leaks that migrated to varying depths. The ^{137}Cs contamination plume totally engulfs the top of the tank.

Borehole 60-10-07 defines a large ^{137}Cs contamination plume on the southern side of tank U-110. This borehole intersects significant ^{137}Cs contamination from the ground surface to a depth of 65 ft and probably represents more than one event. The contamination from a depth of 5 to 30 ft appears to have resulted from a significant surface spill or leak that migrated downward and decreased in intensity as it migrated. The ^{137}Cs contamination at a depth of about 30 ft may result from redistribution of preexisting ^{137}Cs contamination caused by the infiltration of runoff from the tank's domed top. Significant ponding of runoff from rain or snow occurred at the ground surface in the U Tank Farm and has been attributed to several tank intrusions. The ^{137}Cs contamination from 50 to 60 ft is related to leakage from tank U-110.

Figure 15-43 shows plots of the historical gross gamma-ray log data for borehole 60-10-07. The left plot consists of January log events for several successive years and shows a significant increase in count rate between the January 1975 and January 1976 logging events. The right plot shows the data acquired during selected monthly logging events and shows that the contamination reached borehole 60-10-07 in July to August 1975. Liquid-level decreases in tank U-110 were observed as early as May 1975. The plot of the annual logging events presented in Figure 15-43 shows that in subsequent years following detection, the contamination interval doubled in thickness. This contamination occurs at the interface between the backfill materials and the undisturbed sediments at the bottom of the tank farm excavation and may represent a buildup of contamination above the finer-grained undisturbed sediments, or may reflect lateral migration of the contamination plume.

A plume of ^{137}Cs contamination is shown on the visualizations on the eastern side of tank U-110. This plume is defined by data from borehole 60-00-05, in which a zone of ^{137}Cs contamination was detected at depths from 50 to 65 ft and intermittently to TD. This borehole has been perforated from a depth of 46 ft to the bottom of the borehole. As observed in other perforated boreholes, contamination zones often start where perforations begin. Contaminated materials may be entering the borehole casing through the perforations and migrating down the inside of the casing. The contaminated materials may have entered the borehole when the perforations were installed and been carried down the borehole with the perforation tool. Therefore, the data acquired in these boreholes are questionable (as are the plumes defined by these data) because the contamination is on the inside of the casing,

A ^{137}Cs contamination plume at the bases of the visualization is defined by low ^{137}Cs concentrations detected in several of the boreholes surrounding tank U-110. This contamination migrated down the inside of the casing and settled at the bottom of the borehole.

Details regarding the data acquired in the boreholes surrounding tank U-110 are provided in the Tank Summary Data Report for tank U-110 (DOE 1996q).

10.3.11 Tank U-111

Tank U-111 was placed into service in 1947. Throughout its service life, this tank received and stored $BiPO_4$ waste, REDOX waste, and evaporator feed and bottoms waste. This tank also

received PNL waste, N-Reactor waste, laboratory waste, and Hanford defense waste residual liquor. Tank U-111 was not sluiced, and it was removed from service in 1980.

Tank U-111 is presently designated sound. The present waste inventory consists of 36,000 gal of sludge and 303,000 gal of salt cake and salt slurry; this waste contains 122,000 gal of drainable interstitial liquid (Hanlon 1996). The waste level is 10.5 ft above the tank's dished bottom (Brevick et al. 1994b).

Tank U-111 is monitored with seven monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-41, 15-42, and 15-44 show the contamination distribution in the vadose zone sediments surrounding tank U-111. These views are from the northeast, northwest, and southwest, respectively; all views are from below the tank. The south face of the visualizations is the southern extent of the U Tank Farm data domain. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-107-to-U-109 and the U-110-to-U-112 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination resulting from surface spills or leaks was identified in all seven boreholes. This contamination extended as deep as 25 ft; some of the vertical extent of the migration of this contamination may have been enhanced during the drilling of the boreholes. This contamination is shown on the visualizations as covering the top of tank U-111.

In boreholes 60-11-03 and 60-11-12, distinct peaks of contamination containing ^{137}Cs, ^{60}Co, and ^{154}Eu were detected slightly below the ground surface. These zones were less than 5 ft thick and most likely reflected the proximity of these two boreholes to buried pipelines.

The large, vertically extensive plume on the southeast side of tank U-111 is defined by the data acquired in borehole 60-11-05 and the data from adjacent borehole 60-10-07. The lower portion of the ^{137}Cs contamination detected in borehole 60-10-07 is attributed to leakage from tank U-110. It is unknown whether the ^{137}Cs contamination in borehole 60-11-05 is related to that leakage. Although the concentrations of this contamination are low (less than 1 pCi/g), the contamination is continuous throughout a 60-ft interval. However, in borehole 60-10-07, which is nearer to the source, the contamination is higher concentration (greater than 1,000 pCi/g) but only 10 ft thick. A lithologic feature may be enhancing greater vertical migration near borehole 60-11-05.

Uranium was detected on both sides of tank U-111. In borehole 60-11-07, ^{235}U and ^{238}U concentrations were detected in a 1-ft interval at a depth of 63 ft, and in borehole 60-11-12 ^{235}U and ^{238}U concentrations were detected at a depth of 53 ft. The source of this contamination cannot be positively identified. From an aerial perspective, these two uranium occurrences appear to be the maximum extent of the contamination plume from leakage from tank U-104 and are at about the same elevation as the top of the plume beneath tank U-104. The distribution of

the plume within the sediments may reflect contaminant migration pathways that are regulated by distinct lithological features in the sediments. Although tank U-111 is adjacent to leaking tanks U-110 and U-112, there is no indication that the uranium contamination detected in boreholes 60-11-07 and 60-11-12 is from these tanks.

A ^{137}Cs contamination plume at the bases of the visualizations is defined by low ^{137}Cs concentrations that were detected in several of the boreholes surrounding tank U-110. This contamination migrated down the inside of the casing and settled at the bottom of the borehole.

Details regarding the data acquired in the boreholes surrounding tank U-111 are provided in the Tank Summary Data Report for tank U-111 (DOE 1996r).

10.3.12 Tank U-112

Tank U-112 was placed into service in 1947. Throughout its service life, this tank received and stored $BiPO_4$ waste and REDOX waste. Tank U-112 was not sluiced, and it was removed from service in 1975.

Tank U-112 was declared an assumed leaker in 1980, with a liquid loss estimated to be 8,500 gal (Hanlon 1996). The details regarding both the estimation of the leak volume and the conclusions leading to the designation of the tank as a leaker are unknown. The present waste inventory of tank U-112 consists of 4,000 gal of supernatant and 45,000 gal of sludge; all of the supernatant is considered drainable liquid (Hanlon 1996). The present waste level is 2 ft above the tank's dished bottom.

Tank U-112 is monitored with five monitoring boreholes (Figure 15-11), all of which were logged with the SGLS. The concentration plots for the contaminants detected in these boreholes are provided in Appendix C.

Figures 15-40, 15-44, and 15-45 show the contamination distribution in the vadose zone sediments surrounding tank U-112. Figures 15-40 and 15-44 are views from the southeast and southwest, respectively; all views are from below the tank. Figure 15-45 is a view from the northwest from above the tank. The south face of the visualizations is the southern extent of the U Tank Farm data domain. The north face of these visualizations was created with an east-west-oriented cut face inserted between the U-107-to-U-109 and the U-110-to-U-112 rows of tanks. The ^{238}U contamination plume is shown to represent the greatest extent of the uranium contamination.

^{137}Cs contamination resulting from surface spills or leaks was identified in all five boreholes. The greatest extent of ^{137}Cs contamination related to surface events such as spills or pipeline leaks occurred in borehole 60-12-01 at depths from 2 to 12 ft. The ^{137}Cs concentrations ranged from 100 to 1,000 pCi/g. A large spill or leak deposited ^{137}Cs contamination in the sediments near this borehole, resulting in a plume as depicted on the south side of the tanks in the visualizations.

A large plume of ^{137}Cs contamination on the northwest side of the tanks is shown in the visualizations. This plume is defined from the data acquired in borehole 60-00-08. Low and almost uniform continuous ^{137}Cs contamination was detected in this borehole from the ground surface to a depth of almost 75 ft. This borehole has been perforated from 48 ft to TD. The data from this borehole are questionable because of the possibility of contamination entering the inside of the borehole through the perforations. This has been observed in other perforated boreholes. Because of the proximity of this borehole to auxiliary tank U-203, the data in this borehole may be indicating leakage from this tank or its associated piping system. It clearly is not indicative of leakage from tank U-112.

The major ^{137}Cs contamination plume related to leakage from tank U-112 is shown on the north side of the tank and is defined by data acquired in borehole 60-12-01. This plume resulted from leakage from tank U-112. ^{137}Cs contamination was detected throughout borehole 60-12-01 except for the interval where high dead time was encountered. As was discussed in Section 9.2, "Three-Dimensional Plume Calculation and Visualization," a ^{137}Cs concentration of 5,000 pCi/g was used in the development of the visualizations in the regions where high dead time was encountered. This value was estimated from the concentration values of the log data approaching the high dead time zone, and these concentrations may be actually lower than those present in the zone.

Intermittent low ^{137}Cs concentrations were detected throughout boreholes 60-12-05, 60-12-07, and 60-12-10, and these data define a plume surrounding and lying beneath tank U-112. These occurrences may be related to contamination within the borehole casing; therefore, these plumes are false representations of ^{137}Cs contamination in the vadose zone sediments.

Details regarding the data acquired in the boreholes surrounding tank U-112 are provided in the Tank Summary Data Report for tank U-112 (DOE 1996s).

10.3.13 Auxiliary Tanks

Tanks U-201, U-202, and U-203 were placed into service in 1956, and tank U-204 was placed into service in 1954. These auxiliary tanks received similar waste types that included REDOX waste, coating waste, and evaporator feed waste. Tanks U-201 and U-203 were removed from service in 1977, and tanks U-202 and U-204 were removed from service in 1978.

All the auxiliary tanks are designated sound. The present inventories of these tanks consist of 1,000 gal of supernatant in each tank, 4,000 gal of sludge in tanks U-201 and U-202, and 2,000 gal of sludge in tanks U-203 and U-204 (Hanlon 1996).

Borehole 60-00-08 is the only borehole in the vicinity of the auxiliary tanks that would be considered a monitoring borehole for these tanks. Uniform ^{137}Cs concentrations (about 0.3 pCi/g) were detected in this borehole from the ground surface to a depth of about 75 ft; these data defined a large ^{137}Cs contamination plume on the west side of tank U-112. Because of the proximity of this borehole to tank U-203 (about 15 ft), leakage of this tank or its piping is suspected to be the cause of the ^{137}Cs contamination detected in this borehole. However, this

^{137}Cs contamination is questionable because the inside of the casing may have been contaminated through perforations that were cut in the casing.

Data acquired in borehole 60-09-10 also indicate leakage from auxiliary tanks. In this borehole, ^{137}Cs contamination was detected at depths from 85 to 125 ft, the TD of the borehole. These data define a plume that may have resulted from leakage from tank U-201, which is the closest tank to borehole 60-09-10.

10.4 Major Subsurface Contamination Zones

10.4.1 ^{137}Cs Contamination

The major subsurface ^{137}Cs contamination plumes that occur in the U Tank Farm are located beneath tanks U-110 and U-112 and are associated with leaks from these tanks. Figure 15-46 presents an overhead view of a horizontal slice of the ^{137}Cs contamination 65 ft below the bases of the U Tank Farm tanks. This figure shows the extent of the ^{137}Cs contamination associated with the tank U-112 leakage. Higher ^{137}Cs concentrations were detected at shallower depths; however, no data were collected in these regions because of high dead time. The plume resulting from leakage from tank U-110 is not shown on this figure because it is above the level of the slice.

Figure 15-46 shows a plume on the west side of tank U-109. This ^{137}Cs contamination plume, which may be related to the auxiliary tanks, is defined by data from the bottom of borehole 60-09-10. This 40-ft-thick zone of ^{137}Cs contamination ranges in concentration from 0.3 to slightly more than 1 pCi/g. Because there is no contamination above this zone in this borehole, it is highly unlikely that this contamination migrated downward from above.

Figure 15-47 presents an overhead view of a horizontal slice 10 ft below the bases of the U Tank Farm tanks. This figure shows portions of the plumes around and beneath tank U-110. The plume on the east side of this tank is based on data acquired in borehole 60-00-05, which is perforated and may possibly be contaminated throughout the perforated interval.

Contamination that is transported down the outside of the borehole casing usually has a pattern of decreasing contamination concentration with depth. The distribution of contamination spread downward during borehole drilling would be similar. This pattern is seen in almost all of the boreholes in the U Tank Farm. The results of these distributions produced contamination plumes that covered the tops of most tanks and the sides of many tanks to varying depths.

^{137}Cs concentrations detected in almost all the boreholes defined tabular ^{137}Cs contamination plumes in several areas of the U Tank Farm. The occurrences of these plumes resulted from low-level contamination that migrated down the inside or outside of the casing. If flooding occurred at the tank farm surface, this contamination may have been carried downward with water as it entered the unsealed boreholes. Historical documentation revealed that significant ponding occurred on one occasion in the vicinity of tank U-110; it is highly likely that ponding or

flooding occurred at other times during the service life of the U Tank Farm, and it is also likely that flooding occurred at other locations within the farm.

10.4.2 ^{235}U and ^{238}U Contamination

The only ^{235}U and ^{238}U contamination plume is associated with leakage from tank U-104. This plume is situated between tanks U-104, -105, -107, and -108, and the extent of this plume is shown on Figure 15-48. The ^{238}U plume is shown on this figure as a horizontal slice that is located 15 ft below the tank bases. This slice intersects the ^{238}U contamination plume in the region of highest concentrations.

^{235}U and ^{238}U contamination that may be related to the tank U-104 leak was detected around tank U-111 on the north and south sides of this tank. The uranium contamination moved predominantly laterally between tanks U-104 and U-111; the top of the plume is at a depth of 52 ft near tank U-104 and at a depth of 53 ft near tank U-111. The plume is 41 ft thick near tank U-104 and 2 ft thick near tank U-111. The mechanism(s) that drove this contamination to the locations around tank U-111 (located about 150 ft southwest of the primary plume) may be related to lithological features within the sediments beneath the tanks and to enhanced moisture conditions in the sediments that resulted from sluicing and leak testing of tank U-104.

10.5 Geologic Correlations

Plots of naturally occurring KUT radionuclide concentrations were generated from data acquired with the SGLS to determine if there were any correlatable lithologic features in the upper vadose zone at the U Tank Farm. These plots were included in the Tank Summary Data Reports for each tank in the U Tank Farm.

The KUT concentrations for Hanford Site sediments determined from the SGLS data range 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 for time efficiency 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 often useful for lithologic correlation among boreholes and often correlate well with historical geologic data that were acquired in the boreholes. The ^{40}K concentrations often reflect the fine-grained content in sediments; therefore, increased ^{40}K concentrations indicate increases in silt or clay sediments.

In the vicinity of the U Tank Farm, several lithologic horizons are present that show pronounced responses on the ^{40}K log plots. The uppermost major contact in the U Tank Farm is between the Hanford formation upper coarse-grained unit and the Hanford formation fine-grained unit. However, this contact is not identifiable in the data from any U Tank Farm boreholes because the contact occurs within what is now the backfilled materials of the tank farm. The contact of the backfill sediments and undisturbed Hanford formation fine-grained unit sediments at a depth of about 50 ft marks the bottom of the tank farm excavation, and is indicated in most of the ^{40}K concentration plots by distinct increases in the ^{40}K concentrations. Deeper in the U Tank Farm, the silts of the Palouse soils often produce peaks of increased ^{40}K concentrations that vary both in

depth location and peak intensity between boreholes. The ^{40}K concentration plot response to calcium-carbonate cemented sediments of the Plio-Pleistocene unit is distinct decreased ^{40}K concentrations. Calcium-carbonate is present in the pore spaces of the sediments instead of silts or clays containing ^{40}K. The Plio-Pleistocene unit is 142 ft deep in the vicinity of the U Tank Farm, and few boreholes were deep enough to intercept it. When they did intercept it, however, the contact was distinct.

The ^{40}K concentration data were modeled using the geostatistical modeling software that is described in detail in Section 9.0 of this report. The resultant ^{40}K data were reviewed and several visualizations at different concentration cutoffs were created and reviewed to identify any features within the data. Visualizations of the ^{40}K concentrations above 18 pCi/g were prepared and are presented in Figures 15-49, 15-50, 15-51, and 15-52. Figures 15-49 and 15-50 are views from the southwest from below the tanks and from the northwest from above the tanks, respectively. Figures 15-51 and 15-52 are eye-level views from the east and from the west, respectively.

These visualizations show large areas as void space where the ^{40}K concentrations are less than 18 pCi/g and where decreased ^{40}K concentrations suggest decreased content of fine-grained sediments. Where the fine-grained sediments are absent from the interstitial spaces in the sediments, fluid migration may be enhanced. When the ^{40}K data are combined with the ^{137}Cs contamination data that were generated using the same modeling software, the distributions of some of the ^{137}Cs plumes appear to be related to the more coarse-grained regions in the ^{40}K data that are depicted by voids (see Figure 15-53).

In borehole 60-12-01, the borehole in which the thickest accumulation and highest concentrations of ^{137}Cs were detected, the ^{137}Cs contamination migrated to a depth of 125 ft, the maximum depth of the borehole. This thick zone of ^{137}Cs contamination is coincident with a void in the ^{40}K visualization, suggesting higher content of coarse-grained sediments. The relationship between the ^{40}K data and the ^{137}Cs contamination plume on the northern side of tank U-112 is shown in Figure 15-53.

The distribution of the ^{235}U and ^{238}U plumes suggests that the plumes originated from leakage from tank U-104 and that the contaminants migrated in a southwesterly direction. The contaminants migrated essentially laterally from tanks U-104 to U-111; there was minimal depth difference in the top of the uranium plumes between tanks U-104 and U-111. The occurrences of these radionuclides at tank U-111 are minimal. The distribution of this contamination is most likely controlled by the lithology; however, it is not as obvious as with the ^{137}Cs contamination at tank U-112. Slices of the ^{40}K data alone and the ^{40}K data with the ^{137}Cs and uranium contamination are shown on Figures 15-54 and 15-55, respectively. These figures were created with east-west-oriented slices that were inserted between the U-104-to-U-106 and U-107-to-U-109 rows of tanks; both figures are views from the north. The U-104-to-U-106 row of tanks was superimposed on the slices to show the distribution of the data relative to the positions of the tanks. Figure 15-55 shows that a majority of the ^{238}U contamination plume is contained within the finer-grained sediments.

The Hanford and Ringold Formation sediments were deposited in fluvial environment. The distributions of fine- and coarse-grained sediments as suggested by the ^{40}K data may be reflective of several fluvial environmental features such as channels, cut-and-fill structures, clastic dikes, and ripple features. It is not uncommon to have several of these features present over short lateral and vertical distances in a fluvial environment.

10.6 Potential Effect of Adjacent Waste Facilities

Waste facilities adjacent to the U Tank Farm include several ditches that fed the 216-U-10 Pond System (see Figure 15-16). The 216-U-14, 216-Z-1D, 216-Z-11, and 216-Z-19 Ditches fed low-level liquid wastes into the 216-U-10 Pond, which discharged the liquids to the soil column. None of these facilities were close enough to the U Tank Farm to have affected or contributed to the deposition of the contaminants detected in the tank farm vadose sediments. However, the effect that the perched water beneath the 216-U-14 Ditch may have had on driving U Tank Farm contamination deeper into the vadose zone, and possibly to groundwater, is unknown.

The 216-U-13 Cribs, which are located immediately west of the U Tank Farm, were constructed to steam-clean vehicles. The waste discharge to the soil was minimal.

The 216-U-3 French Drain, which is located about 200 ft south of the U Tank Farm, discharged a large volume of condensate to the ground during its service life from 1954 to 1955. The discharges to this facility have had no influence on U Tank Farm contaminant distribution.

11.0 Impacts and Implications of the Vadose Zone Contamination

11.1 Nature of Contamination

The primary gamma-emitting contaminants detected in the vadose zone beneath the U Tank Farm were ^{137}Cs, ^{235}U, and ^{238}U. Only minor quantities of ^{60}Co and ^{154}Eu were detected, mostly near the ground surface in isolated occurrences that could not be correlated among boreholes. Other gamma-emitting radionuclides may have been present at the time the tanks leaked, but they have since decayed to such low levels that they can no longer be detected using current logging methods.

Radionuclides are present in the vadose zone beneath the U Tank Farm that do not emit detectable gamma rays. On the basis of a comparison with the tank T-106 leak, it is reasonable to expect ^{99}Tc, ^{90}Sr, isotopes of plutonium, ^{3}H, and other more mobile radionuclides deeper in the vadose zone than the ^{137}Cs contamination. Only a more comprehensive characterization effort using other data collection and analysis methods will help to define the distribution of the nongamma-emitting radionuclides and RCRA constituents.

11.2 Extent of Migration

Historical Tank Farms gross gamma-ray log data that were reviewed during the preparation of the Tank Summary Data Reports for the U Tank Farm tanks indicated changes in the gross gamma-ray data for intervals of elevated count rate; these changes occurred with both activity intensity and depth of occurrence of the contamination zones. Most of the activity increases were related to intersections of contamination plumes with boreholes as a plume front intersected and passed the boreholes. Active plume movement was observed with both ^{137}Cs and processed uranium contamination plumes; these contamination plumes were identified as originating from tank leaks. The gross gamma-ray log data indicate that the activities eventually stabilized in all boreholes where dynamic activities were detected.

The Tank Farm gross gamma-ray log data identified the uranium contamination plume when the plume first intersected the boreholes. The activities eventually stabilized, and because of the long half-lives of the ^{235}U and ^{238}U isotopes, no decreases are observed as a result of the decay of the nuclides. Because of the insensitivity of the gross gamma-ray system, detection and tracking of subtle migration of the plume with the gross gamma-ray system is not possible. Subsequent borehole measurements with the SGLS and comparison of these data with the baseline established in this characterization are needed to evaluate the stability of the uranium contamination plumes.

In most cases, the historical Tank Farm gross gamma log data collected in intervals of ^{137}Cs contamination indicate minor changes in intensity from the first detection, which for most of the boreholes was 1974, to the most recently acquired data. Although ^{137}Cs is not suspected to be very mobile in the subsurface, it has migrated deep in the vadose zone beneath tank U-112. Further evaluation of the mobility of this radionuclide can be assessed through detailed monitoring with the sensitive HPGe detectors.

11.3 Stability of Contamination Distribution

No data are available at this time to quantify or determine the long-term stability of the contamination in the vadose zone beneath the U Tank Farm. In the past, contaminant movement was identified with the gross gamma-ray system. This activity was related to movement of the uranium contamination through the vadose zone. The only data baseline available is from the gross gamma logging. Because of the low sensitivity of those systems and the poor spatial control, small changes in the contamination distribution cannot be quantified.

Future review of all gross gamma logs for all boreholes may provide some conclusive evidence that movement has occurred. Until that evidence is produced, the possibility of contamination moving down the outside of borehole casings will remain speculative.

The stability of radionuclides that do not emit gamma rays cannot be addressed in this report because they were not assessed in this project. Nongamma-emitting radionuclides and other non-radioactive waste constituents must be studied by alternative sampling methods.

11.4 Impacts to Groundwater

The characterization of the ^{137}Cs, ^{235}U, and ^{238}U contamination distributions in the vadose zone at the U Tank Farm has not provided evidence that the U Tank Farm contamination has impacted the groundwater, because the monitoring boreholes do not extend through the greatest depth extent of the contamination and the deeper vadose zone was not characterized. The lateral extent of the perched water above the Plio-Pleistocene is not known. The effects that this water may have had on redistributing the contamination below the U Tank Farm by driving it deeper into the vadose zone (possibly to groundwater) are also not known.

The presence of uranium and ^{99}Tc in groundwater monitoring boreholes adjacent to the U Tank Farm has been identified and suggests that leakage from U Tank Farm tanks may be the source of these radionuclides. However, the groundwater data from these boreholes indicate instability in the hydrological gradient in the area caused by the changing recharge sources that resulted in several changes in groundwater flow direction. Therefore, it cannot be positively determined at this time that leakage from U Tank Farm reached and contaminated the groundwater.

12.0 Use of Data/Interfaces

12.1 Operations

The vadose zone characterization of the U Tank Farm was completed to establish a baseline that defines the contamination in the vadose zone. This baseline will be used to compare with future monitoring data to determine if changes have occurred and to assess the potential causes of the changes.

Most SSTs with any appreciable amount of liquid in them are presently monitored with in-tank leak detection equipment. In-tank leak detection is the best method to detect leaks from the tanks because it provides the highest leak-detection precision. However, if a leak occurs, it is useful to confirm the leak with other monitoring methods such as by detecting the contamination in the vadose zone sediment. Now that a baseline of the vadose zone contamination is established, new tank leaks can be detected or verified.

Color visualizations of ^{137}Cs and uranium contamination models are published in this report to illustrate the contamination around the tanks (see Section 15.0, "Figures for the U Tank Farm"). In addition, the ^{137}Cs and uranium contamination models are available with the visualization software so that a visualization of any area of the U 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. This knowledge may also be useful for locating excavations and future characterization boreholes.

12.2 Tank Remediation and Waste Retrieval

This baseline characterization of the U Tank Farm vadose zone contamination provides data needed to understand the scope of the vadose zone cleanup issues. Data provided in this document 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.

Some amount of contamination is expected to leak from the tanks during waste retrieval operations. Previous studies of the impacts of any waste retrieval operations have assumed that no tank leaks have impacted groundwater. On the basis of the groundwater monitoring data, the apparent extent of migration of ^{137}Cs beneath tank U-112, and the possibility that lithologic features exist beneath the U Tank Farm tanks that promote vertical migration of contaminants, this assumption will need to be reevaluated. The current baseline of the vadose zone ^{137}Cs and uranium contamination characterization will provide a basis to determine those impacts.

12.3 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 U Tank Farm has resulted in an understanding of the potential for the SSTs to be a near-term groundwater contamination source. These data can be used in the next revision of the groundwater protection and groundwater remediation strategies at Hanford. The vadose zone characterization data at the U Tank Farm will provide some of the basic data used to build strategies to protect and remediate the groundwater.

The *Hanford Site Groundwater Protection Management Plan* (GPMP) (DOE 1995c) 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.

Developing a groundwater remediation strategy requires characterizing the nature and extent of contamination plumes and developing a conceptual model, which includes determining the contamination source(s) and predicting future migration. The *Hanford Sitewide Groundwater Remediation Strategy* (DOE 1995d) assumed that no groundwater contamination originated from vadose zone contamination from the SSTs. The vadose zone characterization data presented in this report can be used to revise the conceptual model of the groundwater.

12.4 Environmental Monitoring Reports

Since early 1943, radionuclide contamination was released at Hanford into the air, surface water, groundwater, surface sediment, and the vadose zone sediment. The risks associated with those releases vary considerably, depending on pathways to receptors and the potential for exposure. Environmental monitoring programs at Hanford are generally designed to monitor all media, including surface water, groundwater, and surface and subsurface sediments. For economic reasons, environmental monitoring programs justifiably place more emphasis on monitoring environmental media that determining pathways most likely to cause an exposure in the near term or those that have a higher exposure risk.

If the total radioactivity of the releases, the radionuclide mass content, or the total volume of releases is considered, most of the contamination that was released into the environment at Hanford was released into the vadose zone sediments. However, limited characterization and monitoring of that contamination has been conducted because the near-term risk presented by the contamination is low.

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 U Tank Farm. Therefore, it is necessary 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 the *Operational Environmental Monitoring Report* (Schmidt et al. 1995). Schmidt et al. (1995) is an annual publication that provides a review of the monitoring of all environmental media that was performed for the different operational facilities at Hanford. The operational environmental monitoring program for the Hanford Site is specified in the Hanford Site *Environmental Monitoring Plan* (DOE 1995b). The Hanford Site environmental monitoring plan does not currently include references to, or requirements for, vadose zone monitoring. The next revision of that plan may include vadose zone monitoring.

13.0 Conclusions

Fifty-nine vadose zone boreholes in the U Tank Farm were logged with the SGLSs, and gamma-emitting radionuclide concentration data were generated at 0.5-ft intervals. The product of these logging activities was used to create a large baseline database for this tank farm. Log plots were prepared and published in individual Tank Summary Data Reports for each tank. The Tank Summary Data Reports provide a history of each tank and provide the SGLS log data in a format that can be used for future tank farm operations and remediation.

Empirical ^{137}Cs, ^{235}U, and ^{238}U contamination distribution models were created with the geostatistical tools available in a commercial software package. These models were used to create visualizations of the contamination distribution that were reviewed and interpreted in this report.

The geostatistical software and the visualizations are powerful tools for use in the assessment and interpretation of borehole contamination data. Those tools made it possible to identify ^{137}Cs and uranium contamination zones, to segregate false plumes from actual vadose zone contamination, identify contamination sources, and to relate the contamination to historical events for the various tanks. The information on the contamination distribution beneath the U Tank Farm can now be used by operations, various monitoring programs, and personnel responsible for tank closure.

Interpretation of the logging data was not always conclusive, and questions remain about the true nature and extent of the ^{137}Cs and uranium contamination. However, a high-quality database has been established for the distribution of these contaminants within the U Tank Farm. Future monitoring can be conducted to determine if the contamination is migrating, where the contamination is going, and if additional contamination sources are present. In addition, the data provided in this characterization may be used to determine if future characterizations are required, what type of data are required, and how these characterizations may be conducted. The database will be made available to other Hanford programs in the near future.

14.0 Recommendations

14.1 Tank and 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. Brevick et al. (1994a

and 1994b) theorized that significant surface spills and flooding occurred at the surface of the U Tank Farm. Records may exist that prove and evaluate the significance of this theory to the subsurface contamination recorded in the spectral gamma-ray log data. 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

Development of a spectral-shape factor analysis system has been initiated and field trials of the software are presently being conducted. Selective intervals in six U Tank Farm boreholes should be analyzed with this technique to attempt to confirm the distribution of the ^{137}Cs contamination detected in these boreholes. These boreholes are: 60-05-05, 60-09-10, 60-10-07, 60-11-05, 60-11-12, and 60-12-01. The objective of the analysis is to distinguish contamination distributed in the formation from contamination adhering to the inside or outside of the borehole casing.

14.3 Additional Logging Characterizations

Although borehole geophysical methods do not provide all the required characterization data, they are emphasized 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, it is recommended that a project 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 will help identify stratigraphy and permit future determinations of horizon 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. As a result, a formation bulk-density logging

It is also recommended that a carbon/oxygen log 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. This sonde 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 of 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 vadose zone at the U 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.

The eastern extent of the uranium plume must be defined further. This may initially be accomplished by logging the two non-RCRA standard boreholes 299-W19-1 and 299-W19-12 with a SGLS. These boreholes are located on the southeast and east sides of the U Tank Farm (see Figure 15-6). These boreholes do not have grout in the annulus between the casing and formation sediments as do the RCRA standard boreholes, and they are constructed with a single casing configuration. Therefore, the gamma-ray attenuation resulting from borehole conditions is significantly reduced in these boreholes, which may allow lower concentrations of certain radionuclides (i.e., the uranium isotopes ^{235}U and ^{238}U) to be detected and identified. Drilling new characterization boreholes may be required to define the extent of the uranium plume.

The effectiveness of the Plio-Pleistocene to conduct fluid flow in the vicinity of the U Tank Farm should be evaluated. Perched water conditions are present above the Plio-Pleistocene unit below the 216-U-14 Ditch; however, the lateral extent of the perched water is unknown. Available data from monitoring boreholes should be reviewed to evaluate and characterize the Plio-Pleistocene unit in the vicinity of the U Tank Farm. In addition, the potential effects that perched water may have had on redistribution of contamination below the U Tank Farm tanks to deeper in the vadose zone (and perhaps to groundwater), should be investigated.

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 and the 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.

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.

Distributions of some of the contaminants in the U Tank Farm were determined to be related to lithologic features in the sediments beneath the tank farm. These features were defined on the nuclear properties of the sediment materials, particularly ^{40}K concentrations. Comparison of the ^{40}K concentration data with the actual lithologic samples acquired when the boreholes were drilled may provide insight into the lithology of the vadose zone beneath the U Tank Farm and explain some of the contaminant distributions in the vadose sediments.

Characterization of the upper vadose zone should also conclusively determine the extent of contaminant migration down the outside of the borehole casings. It is impossible to determine if, and to what extent, contaminants have migrated down the borehole casings in the U Tank Farm. This contamination defined a significant amount of the plume development above and surrounding the tanks in the U Tank Farm.

Characterization of the deeper vadose zone can be accomplished by deepening some of the existing monitoring boreholes to define the deepest extent of the ^{137}Cs contamination below tank U-112.

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. As the tanks become older their integrity diminishes and the possibility of leaks increases. DOE is required to monitor the nature and extent of the contamination that leaks from the tanks as well as to determine the extent of the 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 to confirm a leak and evaluate the extent of the contamination.

Tank U-101

Tank U-101 is designated as a leaker. Additional research should be directed towards determining that this tank leaked and confirming the leak volume. If data indicate that a leak has occurred, an effort should be undertaken to identify the location of the contamination plume. This may necessitate the installation of a borehole on the north side of the tank, where there are presently no monitoring boreholes.

Tank U-102

Tank U-102 is designated as a sound tank. This tank still contains 126,000 gal of liquids that have a potential to leak if the integrity of the tank liner is breached. Because of the age of the tank and the large volume of stored liquids, the boreholes surrounding tank U-102 should be monitored to verify the stability of the contamination.

Tank U-103

Tank U-103 is designated as a sound tank. This tank still contains 176,000 gal of liquids that may have a potential to leak if the tank's steel liner fails. Because of the age of the tank and the large volume of liquid waste stored in the tank, the boreholes surrounding tank U-103 should be monitored to verify the stability of the contamination.

Tank U-104

Tank U-104 is designated as a leaker. This tank contains a minimal volume of liquids (7,000 gal).

Boreholes 60-07-01, 60-07-11, 60-04-08, and 60-04-10 should be relogged in selected intervals to confirm the stability of the ^{235}U and ^{238}U contamination plumes around this tank. No other monitoring is required.

Tank U-105

Tank U-105 is designated as a sound tank. This tank still contains 142,000 gal of liquids that could leak to the vadose zone sediments if the tank liner failed. Because of the age of the tank and the volume of liquids stored in the tank, the boreholes surrounding tank U-105 should be monitored to verify the stability of the contamination.

^{235}U and ^{238}U contamination plumes were identified in boreholes 60-05-04 and 60-05-05. These boreholes should be selectively relogged to acquire data to quantifiably determine the stability of the uranium plumes. In addition, the ^{137}Cs contamination near the bottoms of boreholes 60-05-05 and 60-05-07 should be re-examined to determine changes in intensity and/or depth location of this ^{137}Cs contamination.

Tank U-106

Tank U-106 is designated as a sound tank. This tank presently contains 68,000 gal of liquids. Because of the age of the tank and the potential for leakage resulting from the failure of the steel liner, the boreholes surrounding tank U-106 should be monitored to verify the stability of the contamination.

Borehole 60-00-10, which is perforated from 48 to 148 ft, should be abandoned under the current well abandonment specifications. The quality of data acquired in this borehole may be

questionable because ^{137}Cs contamination appears to have entered the inside of the borehole through the perforations.

Tank U-107

Tank U-107 is designated sound. This tank presently contains 147,000 gal of liquids that could leak into the vadose zone sediments if the tank liner failed. Because of the age of this tank and the large volume of liquids stored in the tank, the boreholes surrounding tank U-107 should be monitored to verify the stability of the contamination.

Boreholes 60-07-01, 60-07-10, and 60-07-11 should be relogged in selective intervals to determine the stability of the ^{235}U and ^{238}U contamination plumes that were detected in these boreholes.

Tank U-108

Tank U-108 is designated as a sound tank. This tank presently contains 172,000 gal of liquids. These wastes have a potential to leak into the vadose zone sediments if the tank liner fails. Because of the age of the tank and large volume of liquids stored, the boreholes surrounding tank U-108 should be monitored to verify the stability of the contamination.

Data collected from boreholes 60-05-05, 60-08-04, and 60-11-12 define ^{235}U and ^{238}U contamination plumes. These boreholes should be relogged in selected intervals to determine the stability of the uranium plumes. The deeper ^{137}Cs contamination zones in boreholes 60-05-05 and 60-11-12 should be re-examined to determine any changes in the intensity and depth of this contamination.

Borehole 60-08-10, which is perforated from 48 to 148 ft, should be abandoned according to the current borehole abandonment specifications. The quality of the data acquired in this borehole are questionable because ^{137}Cs contamination may have entered the inside of the borehole through the casing perforations.

Tank U-109

Tank U-109 is designated as a sound tank containing 163,000 gal of liquids that have potential for leakage into the vadose zone sediments if the tank liner failed. Because of the age of the tank and the large volume of stored waste, the boreholes surrounding tank U-109 should be monitored to verify the stability of the contamination.

The ^{137}Cs contamination at the bottom of borehole 60-09-10 should be re-examined to determine the stability of this contamination in terms of intensity and depth location.

Tank U-110

Tank U-110 is designated as a leaker and contains 15,000 gal of liquids. Leakage from this tank was confirmed by ^{137}Cs concentration data acquired in borehole 60-10-07 from 50 to 60 ft. This borehole should be relogged in selected depth intervals to determine the stability of the ^{137}Cs contamination plume. Because the tank contains minimal liquids, the other boreholes surrounding tank U-110 do not require periodic monitoring.

Borehole 60-00-05, which is perforated from 46 to 148 ft, should be abandoned according to the current borehole abandonment specifications. The usefulness of this borehole is questionable because it appears that contamination may have entered the inside of the borehole through the casing perforations.

Tank U-111

Tank U-111 is designated as a sound tank. This tank presently contains 122,000 gal of liquid waste that has a potential to leak into the vadose zone sediments if the tank liner failed. Because of the age of the tank and large volume of liquids stored in the tank, the boreholes surrounding tank U-111 should be monitored to verify the stability of the contamination.

Data collected from boreholes 60-11-07 and 60-11-12 define very limited occurrences of ^{235}U and ^{238}U contamination. These boreholes should be relogged in selective intervals to determine the stability of this contamination. The low ^{137}Cs concentrations in borehole 60-11-12 should be monitored to determine the stability of the contamination in terms of intensity and depth location.

Borehole 60-00-06, which is perforated from 48 to 148 ft, should be abandoned according to the current borehole abandonment specifications. The quality of the data collected in this borehole is questionable because ^{137}Cs contamination may have entered the inside of the borehole through the perforations.

Tank U-112

Tank U-112 is designated as a leaker and does not contain any drainable liquids.

The high count-rate zone in borehole 60-12-01 should be relogged with a less sensitive detector. This would more precisely define the boundaries of the high concentration interval against which future logging can be compared to determine the stability of the ^{137}Cs contamination plume.

The vertical extent of the ^{137}Cs contamination detected in borehole 60-12-01 should be determined by either deepening the existing borehole or drilling a new borehole. Lithologic information suggests enhanced vertical migration in the sediments surrounding this borehole, and the ^{137}Cs contamination may have migrated much deeper than expected.

15.0 Figures for the U Tank Farm

The following section presents the figures cited in this report in the order in which they were presented.

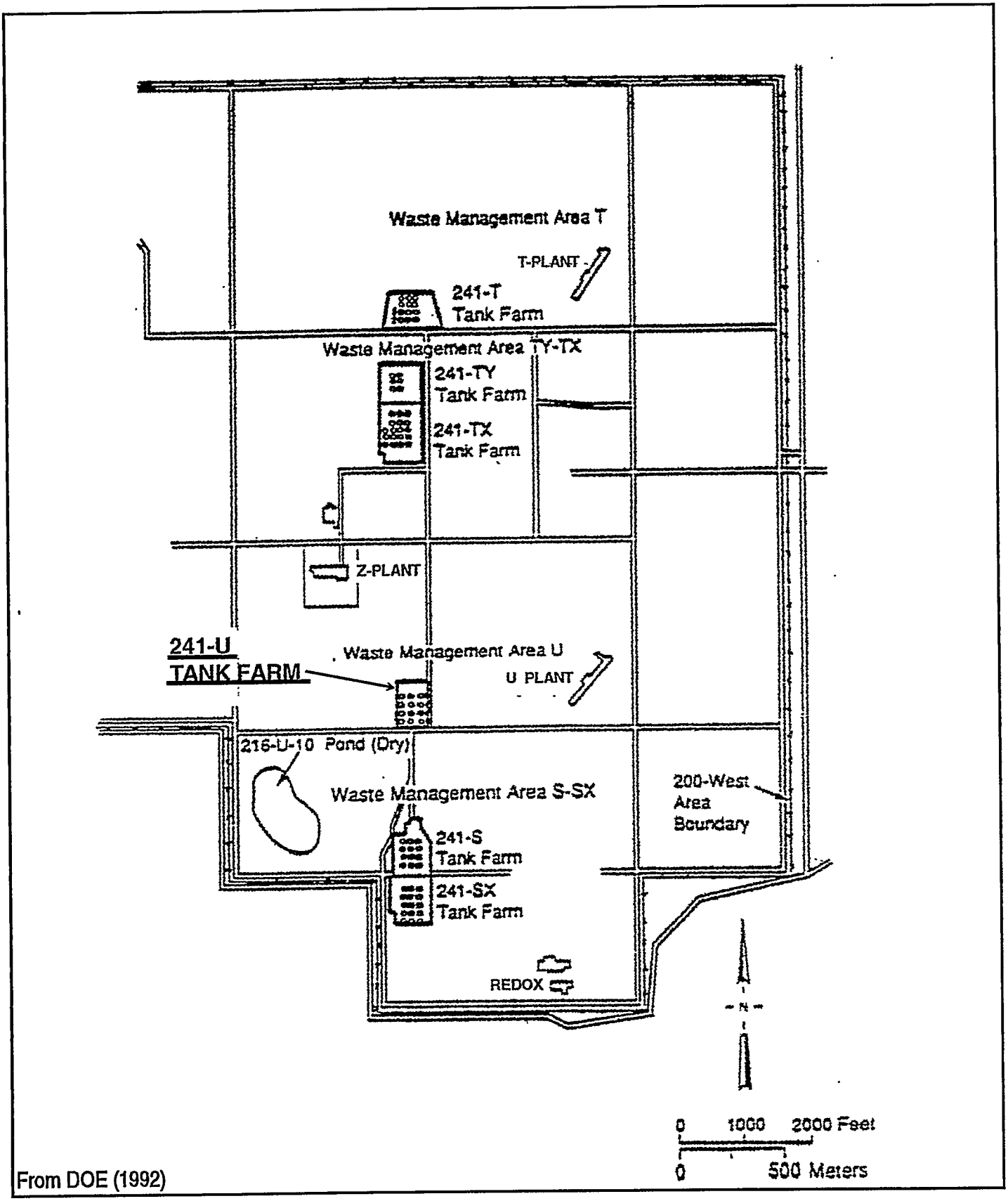
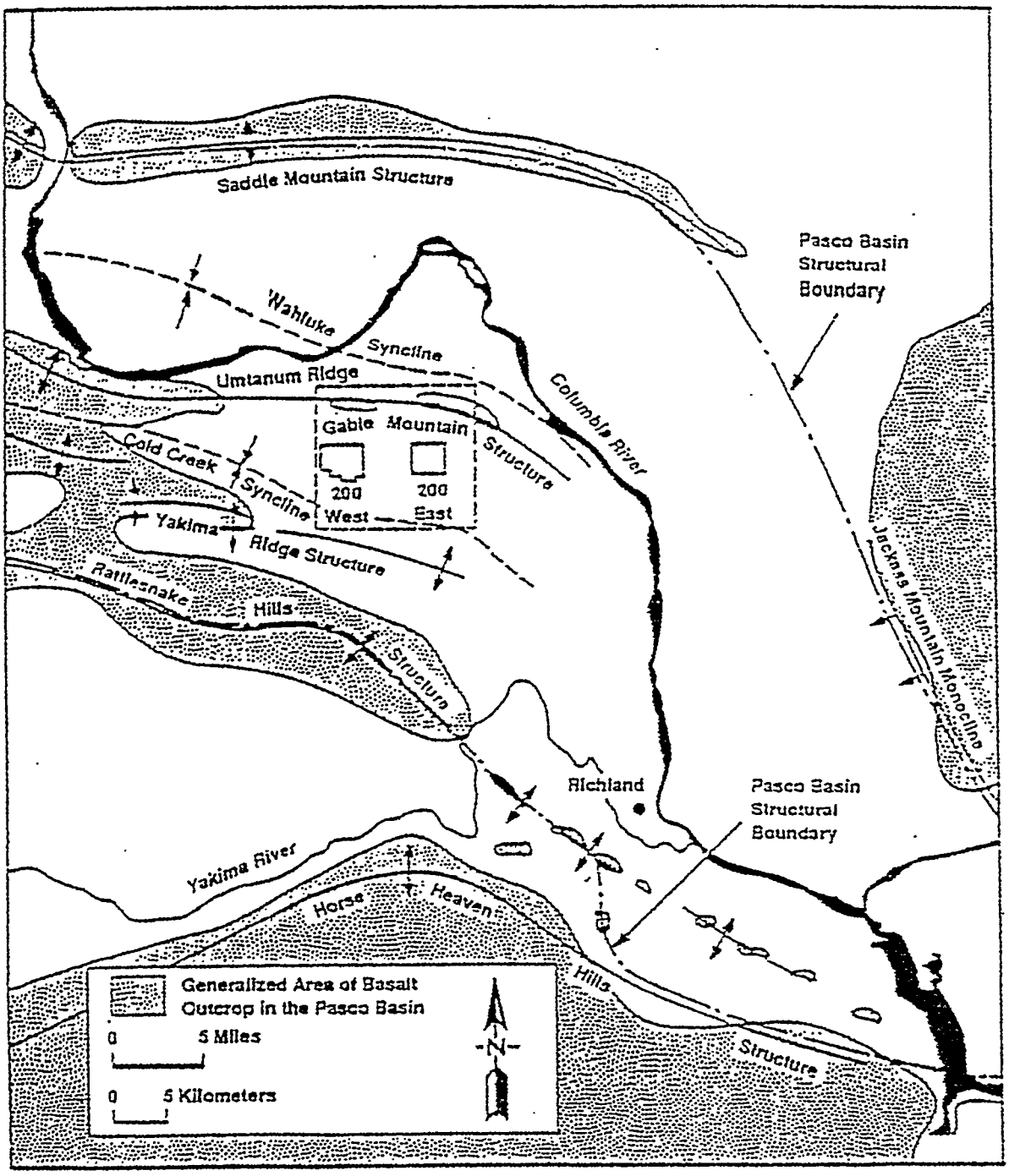


Figure 15-1. Map of the Central Portion of the Hanford Site 200 West Area Showing the Location of the U Tank Farm



From Caggiano and Goodwin (1991)

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

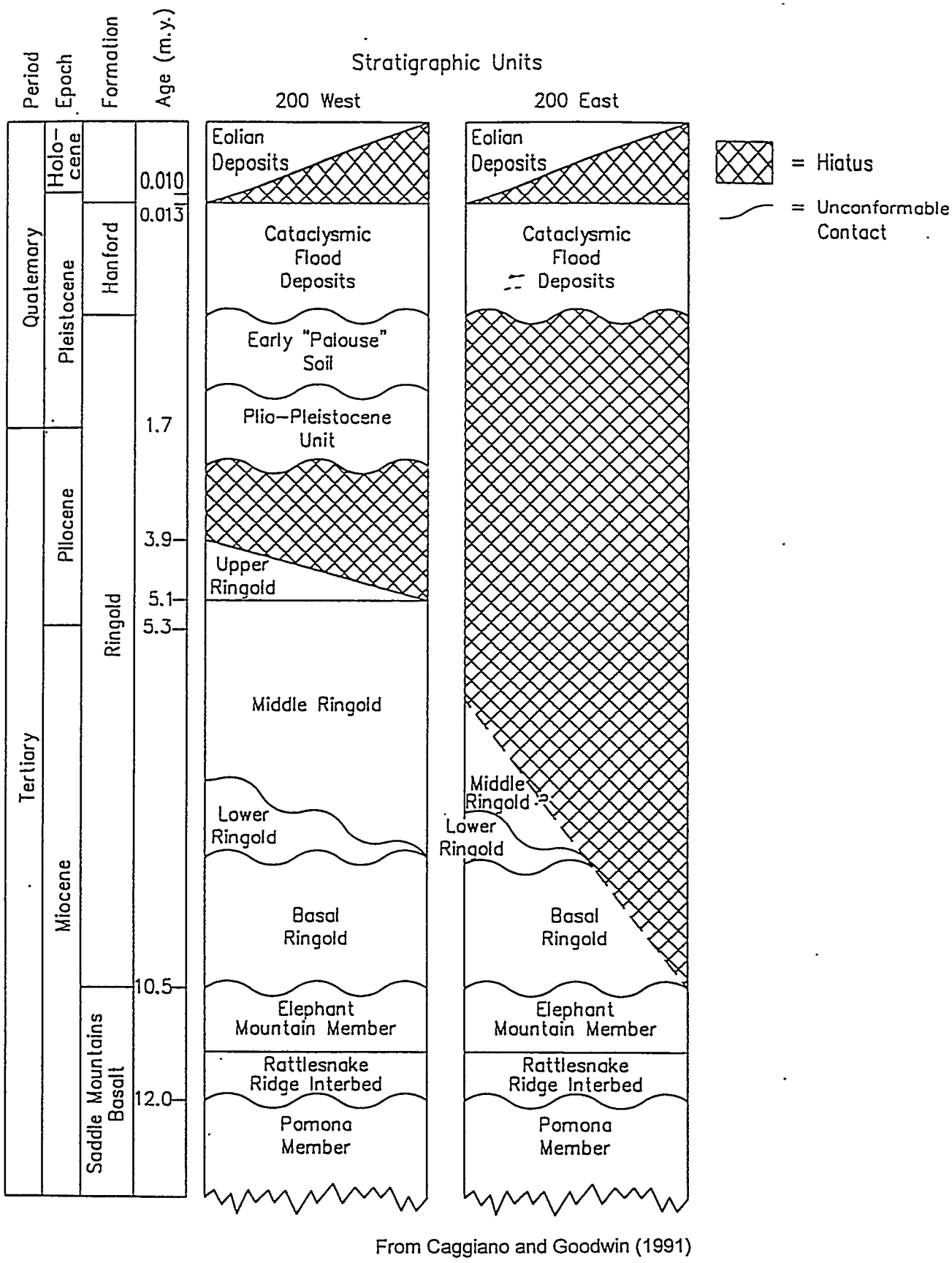
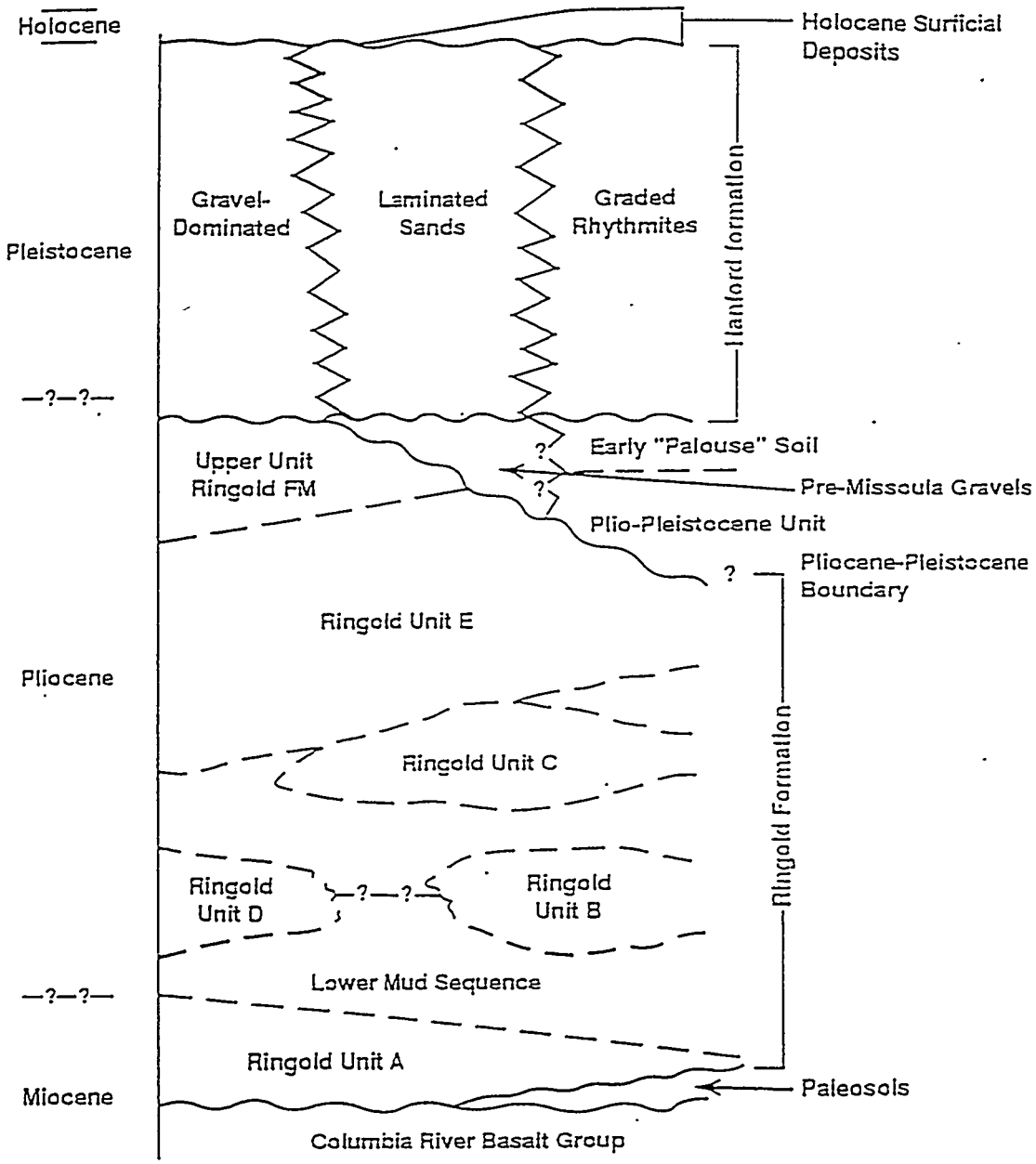


Figure 15-3. Stratigraphic Columns of the 200 East and 200 West Areas of the Hanford Site



From Lindsey et al. (1992)

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

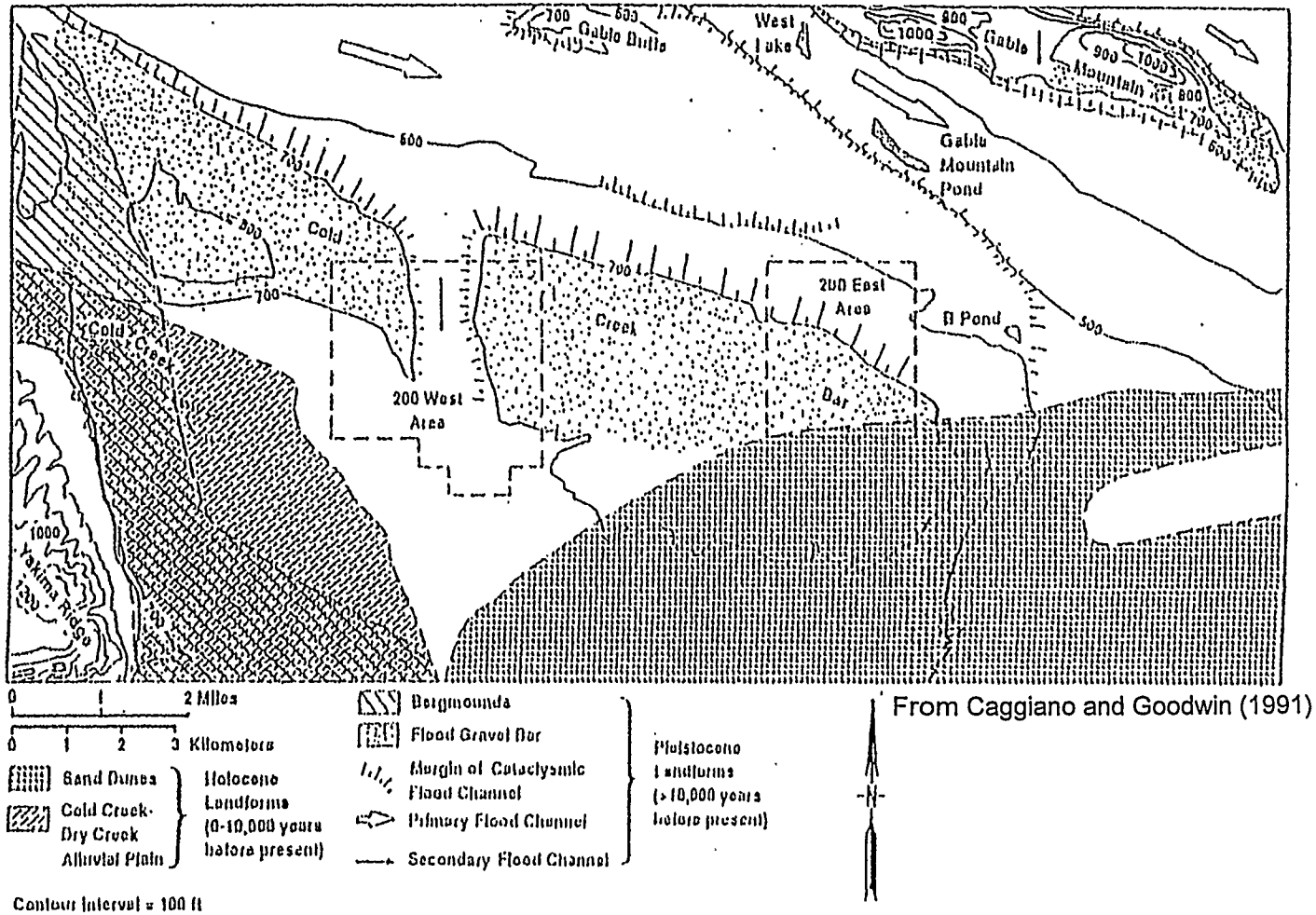


Figure 15-5. Geomorphological Map of the 200 East and 200 West Areas of the Hanford Site

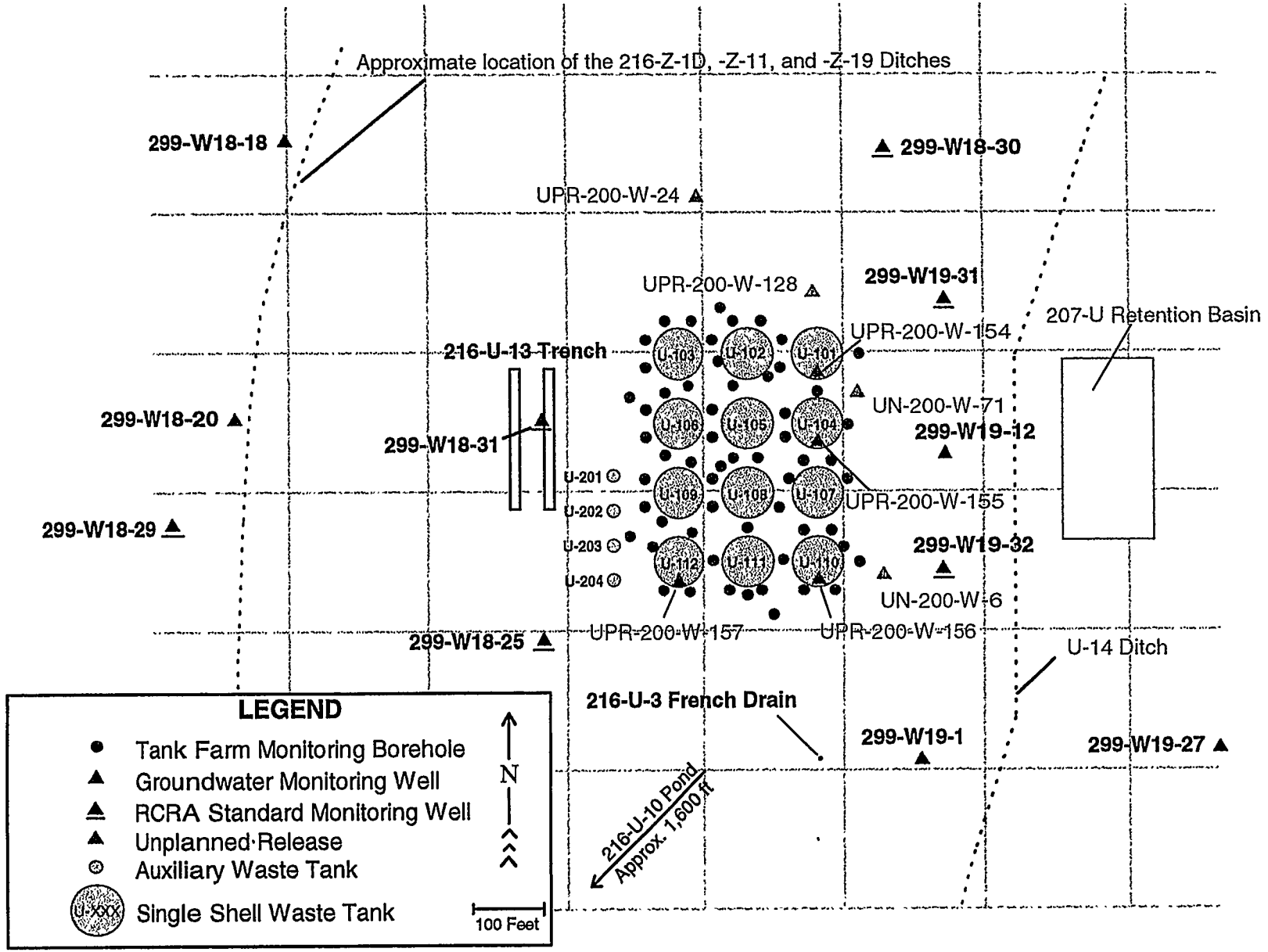


Figure 15-6. Plan Map of the Hanford Site U Tank Farm Showing Adjacent Monitoring Boreholes and Facilities

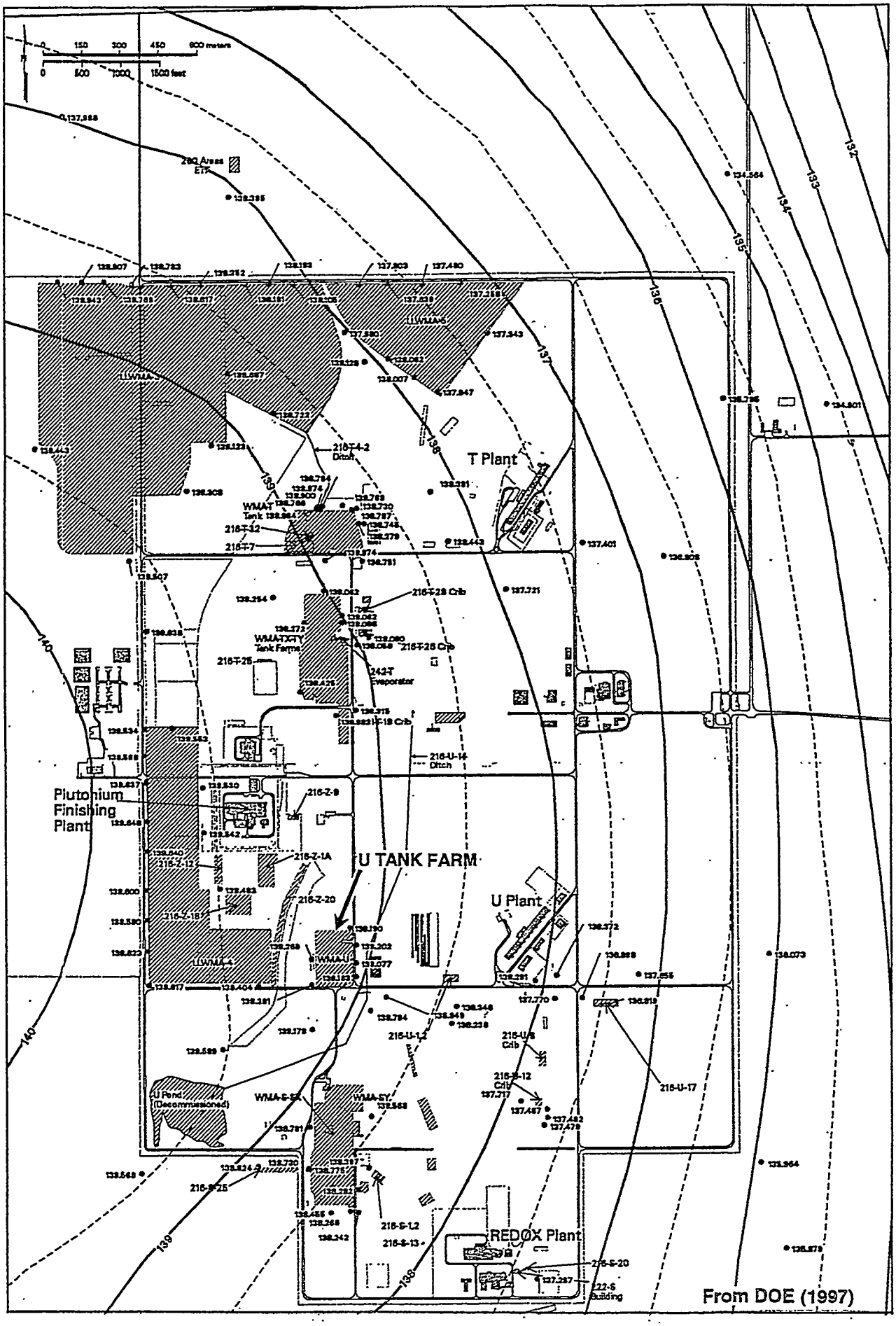
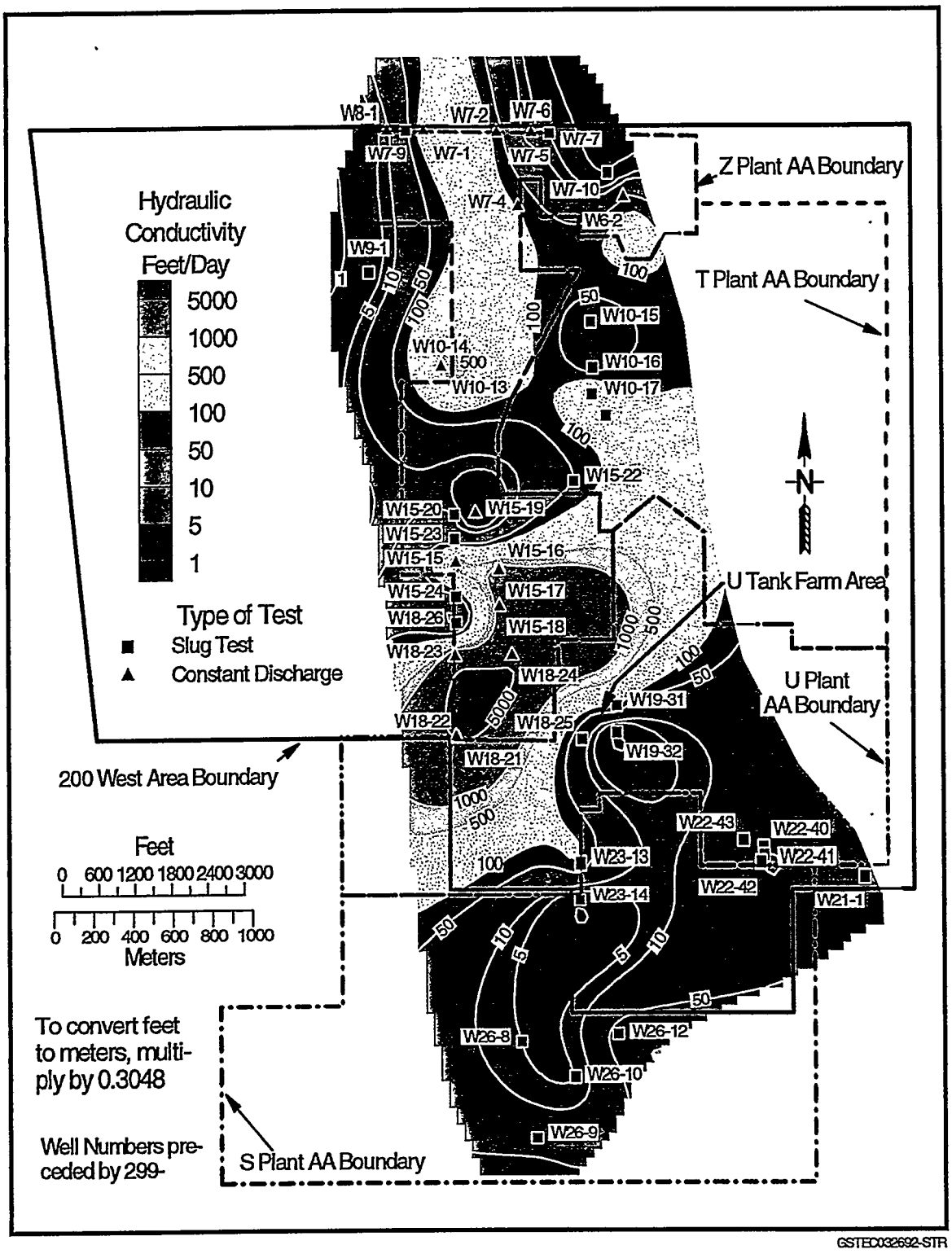
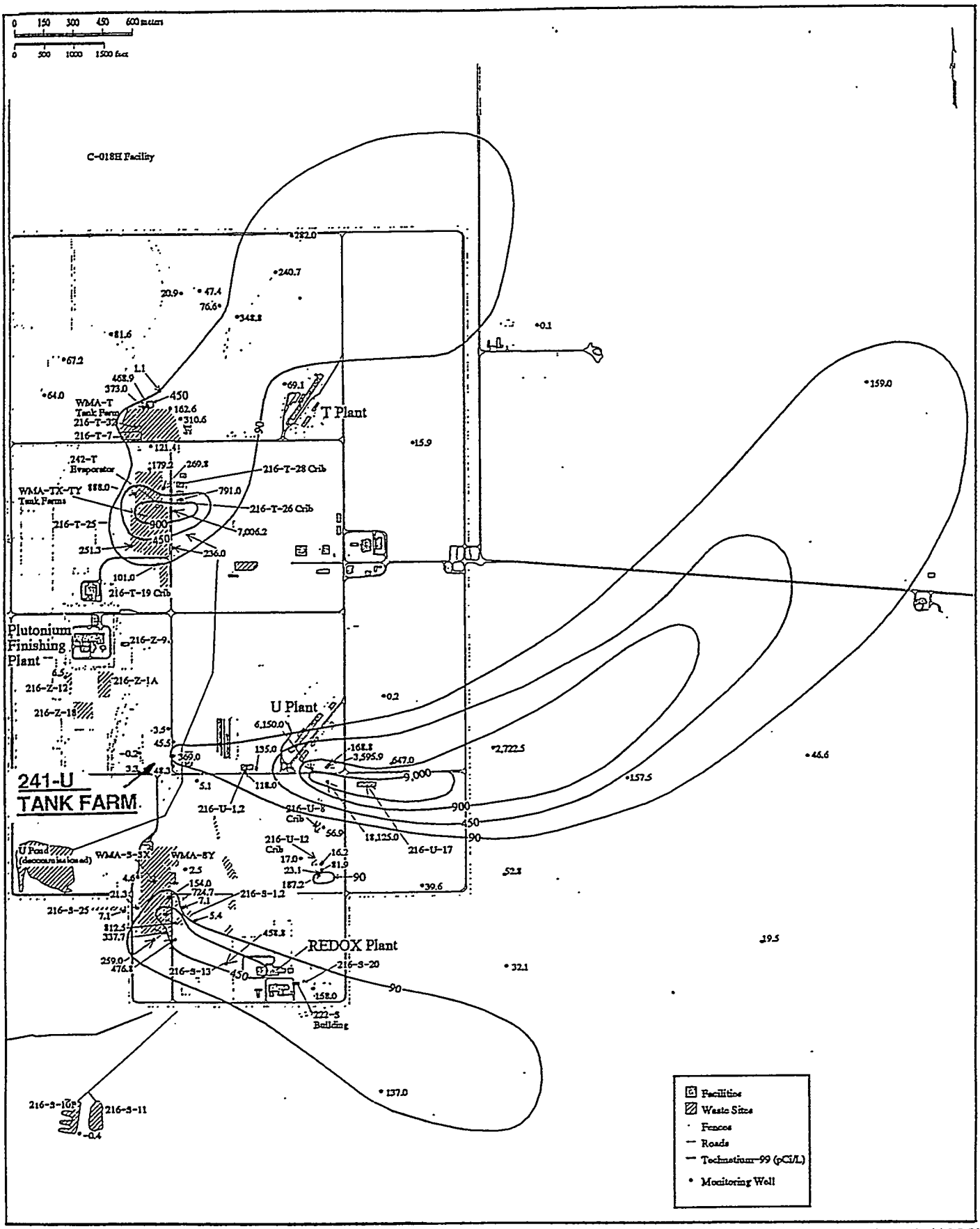


Figure 15-7. June 1996 Water Table Map of the Hanford Site 200 West Area



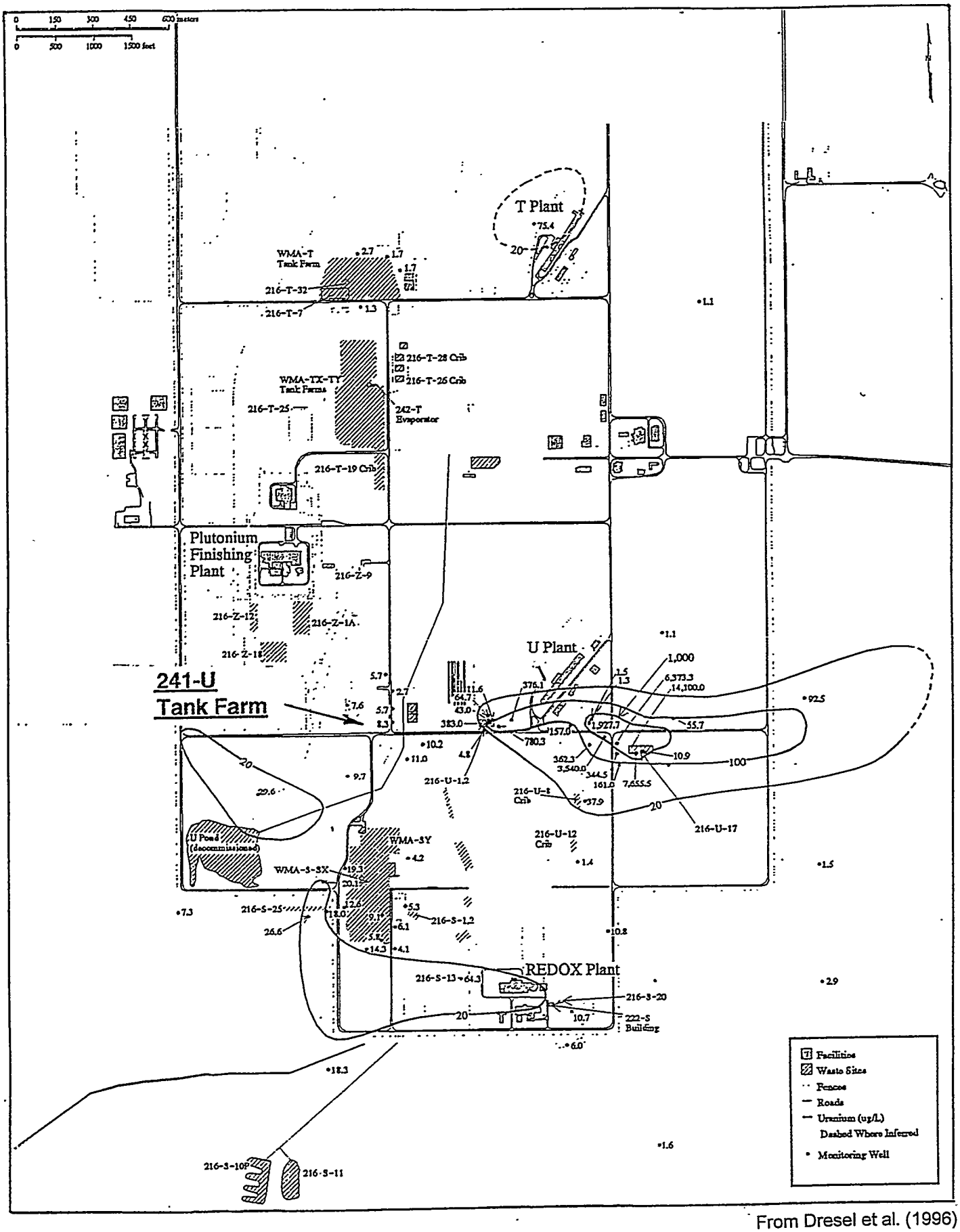
From Connelly et al. (1992)

Figure 15-8. Hydraulic Conductivity Map of the Hanford Site 200 West Area



From Dresel et al. (1996)

Figure 15-9. 1995 Average ^{99}Tc Concentrations in the Hanford Site 200 West Area



From Dresel et al. (1996)

Figure 15-10. 1995 Average Uranium Concentrations in the Hanford Site 200 West Area

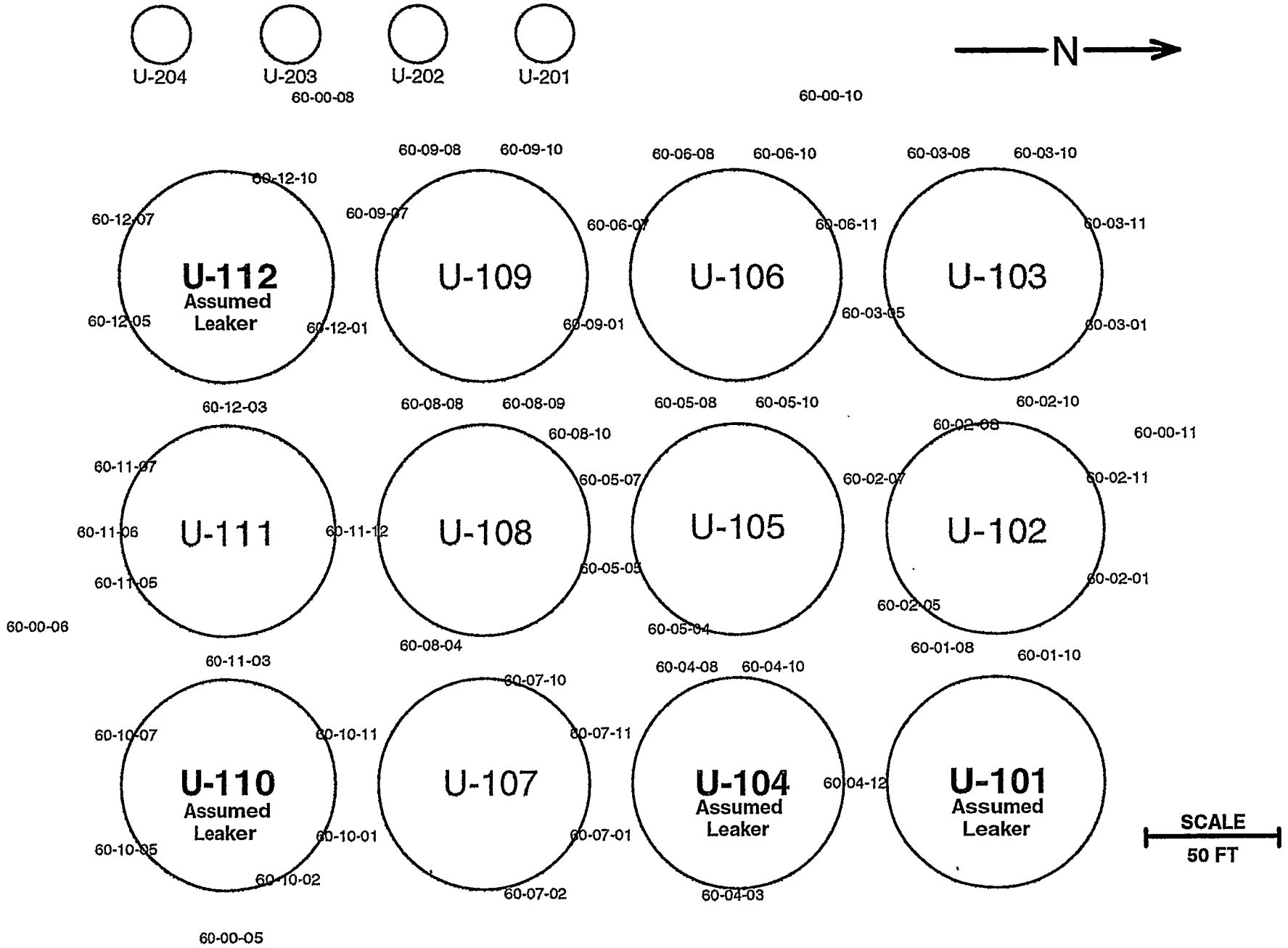
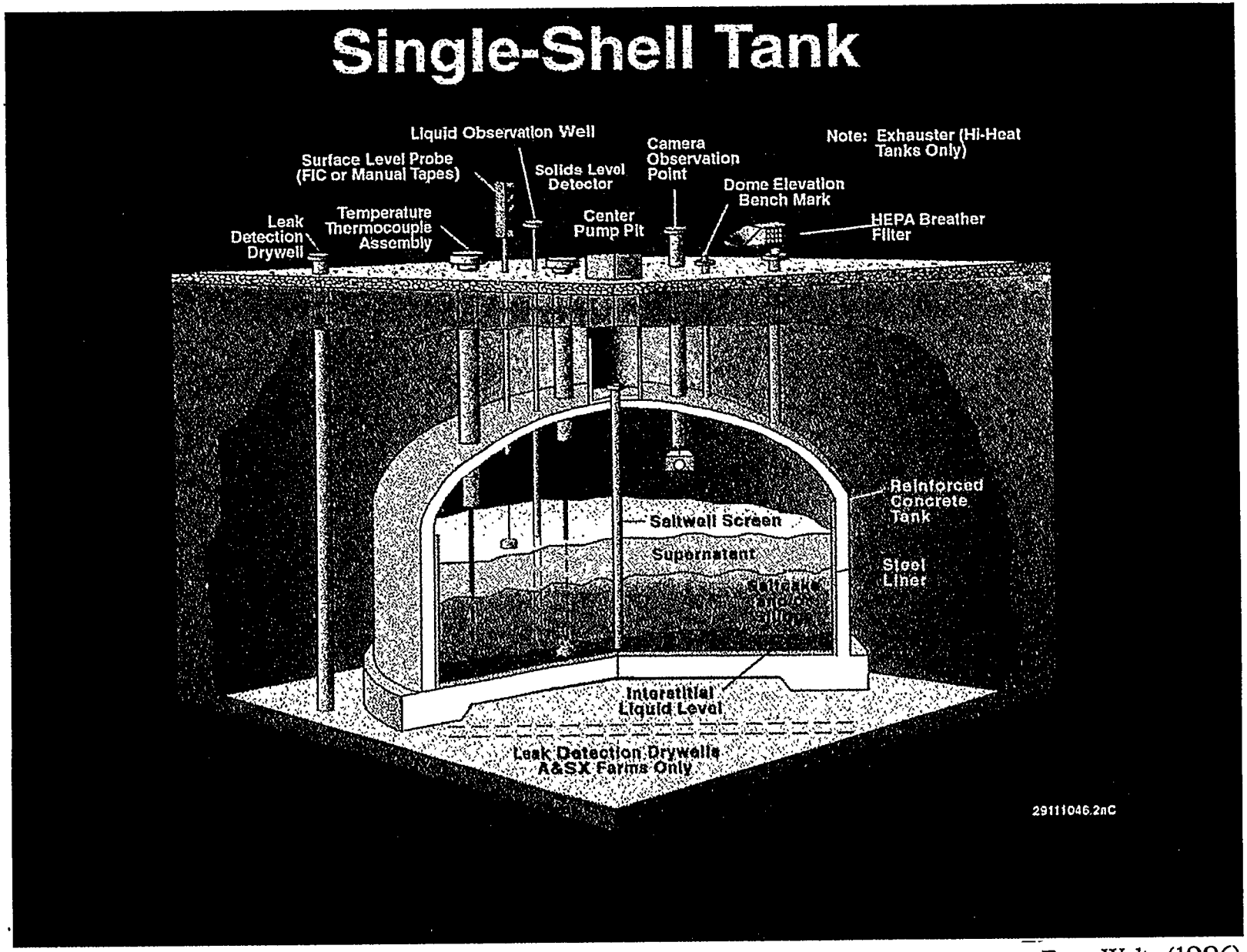


Figure 15-11. Plan Map of the Hanford Site U Tank Farm Area Showing the Monitoring Boreholes



From Welty (1996)

Figure 15-12. Cutaway View of a Typical Single-Shell Tank With Risers and Instrument Ports

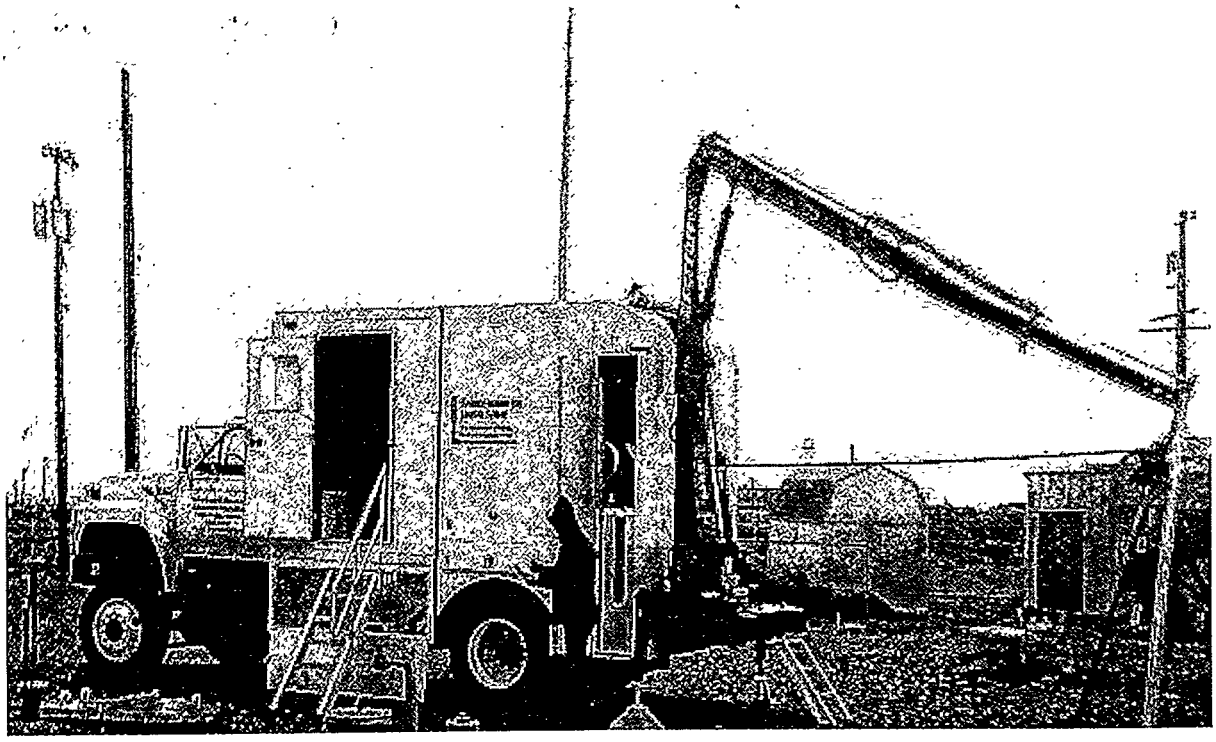


Figure 15-13. View of a Spectral Gamma Logging System Rigged for Logging

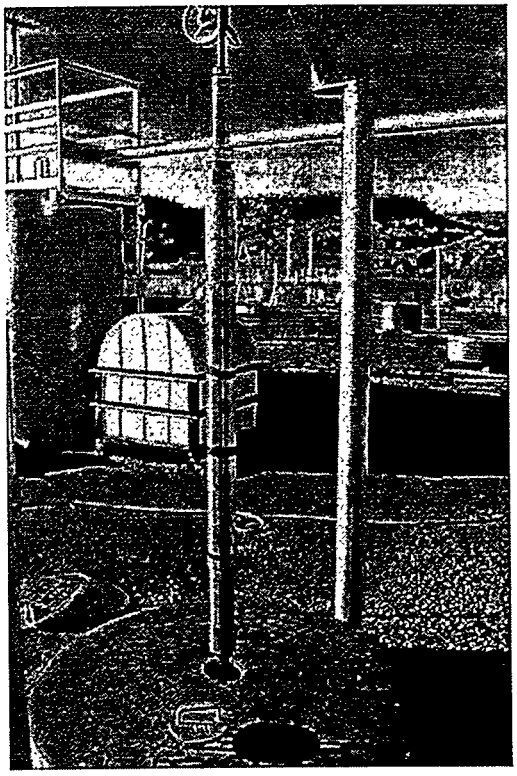


Figure 15-14. Sonde With High-Purity Germanium Detector Suspended Over a Borehole

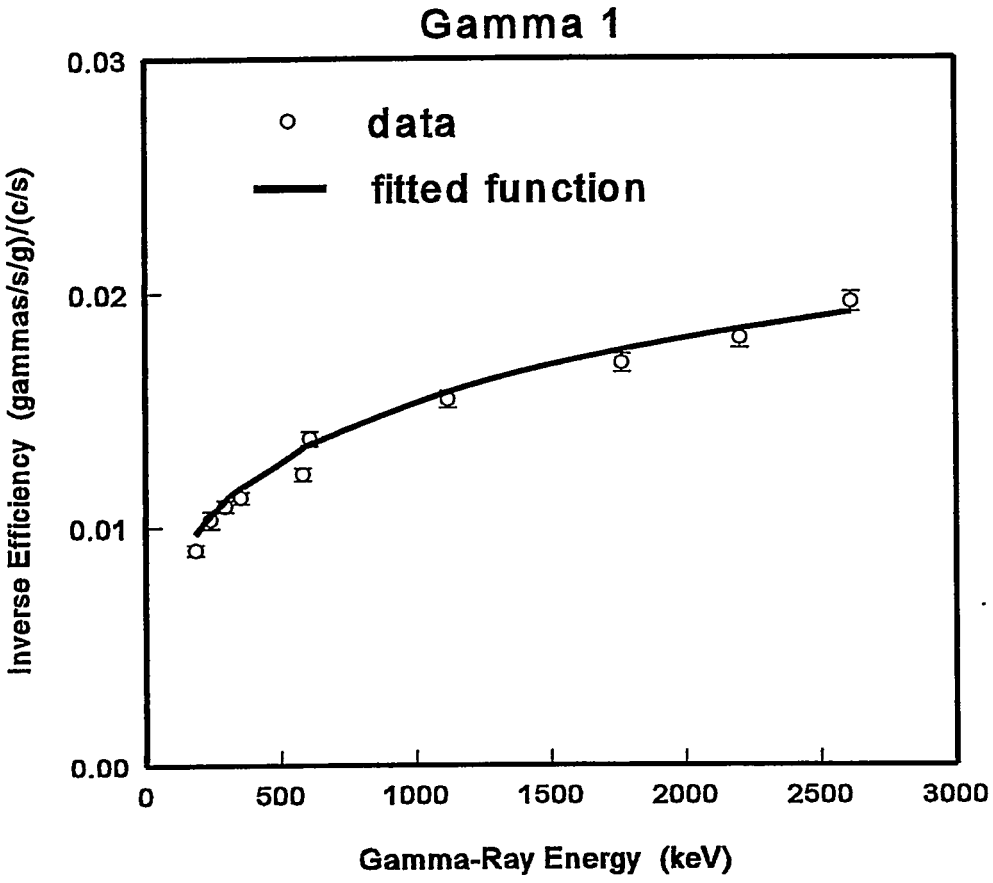


Figure 15-15. SGLS Base Calibration Inverse Efficiency Function

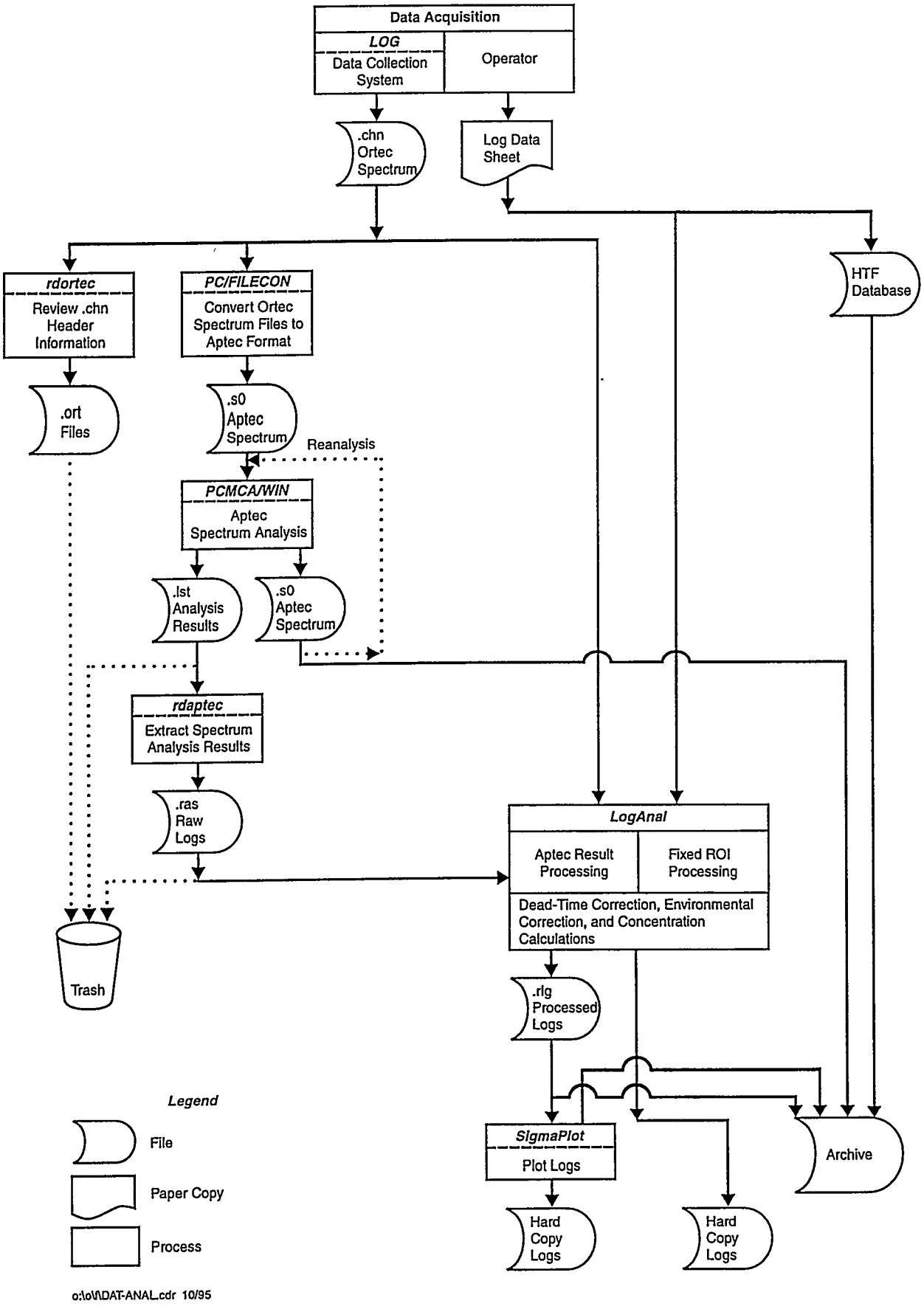


Figure 15-16. Hanford Site Tank Farm Vadose Zone Characterization Project Data Analysis Process

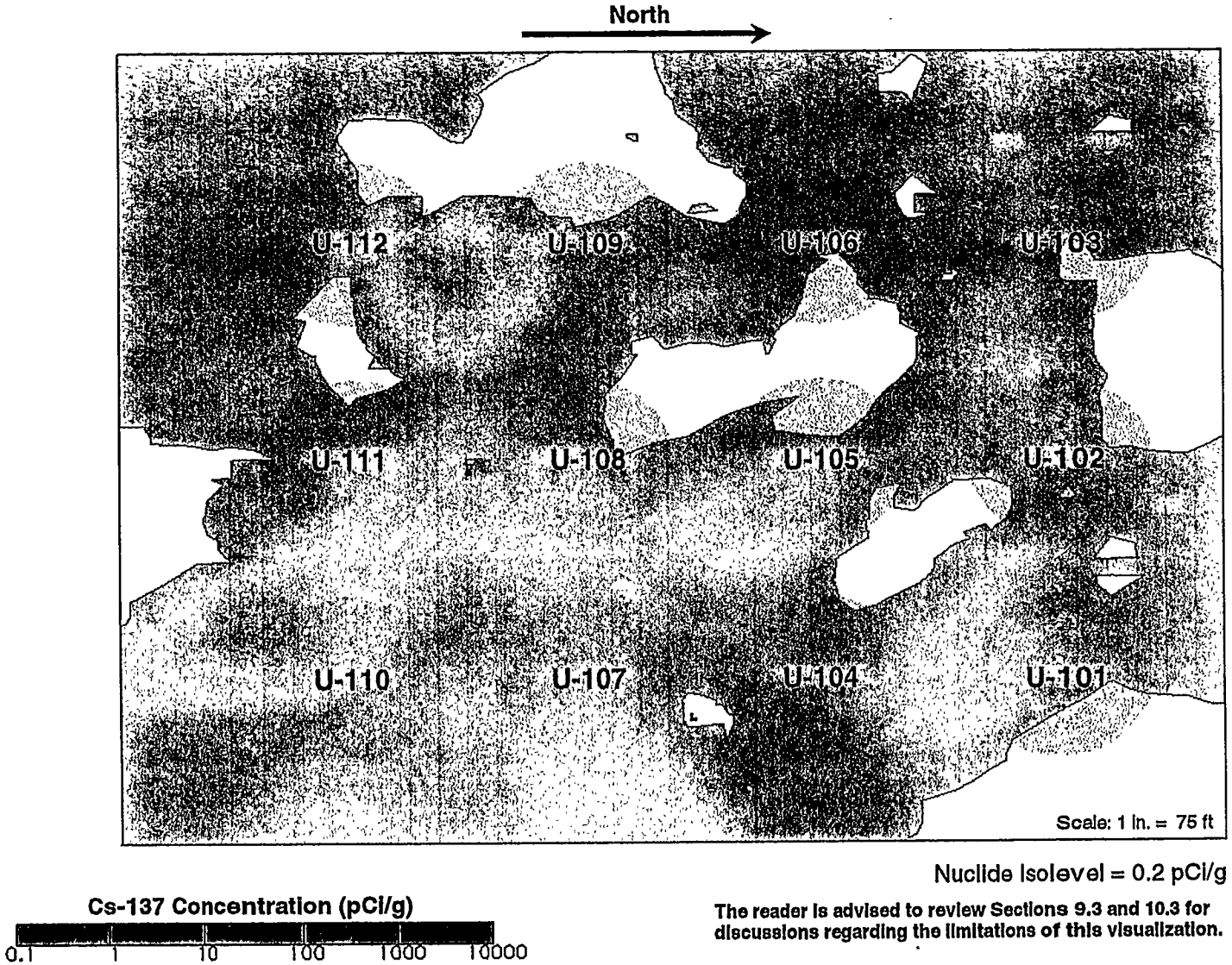


Figure 15-17. ^{137}Cs Contamination at a Depth of 10 Ft Below Ground Surface at the U Tank Farm

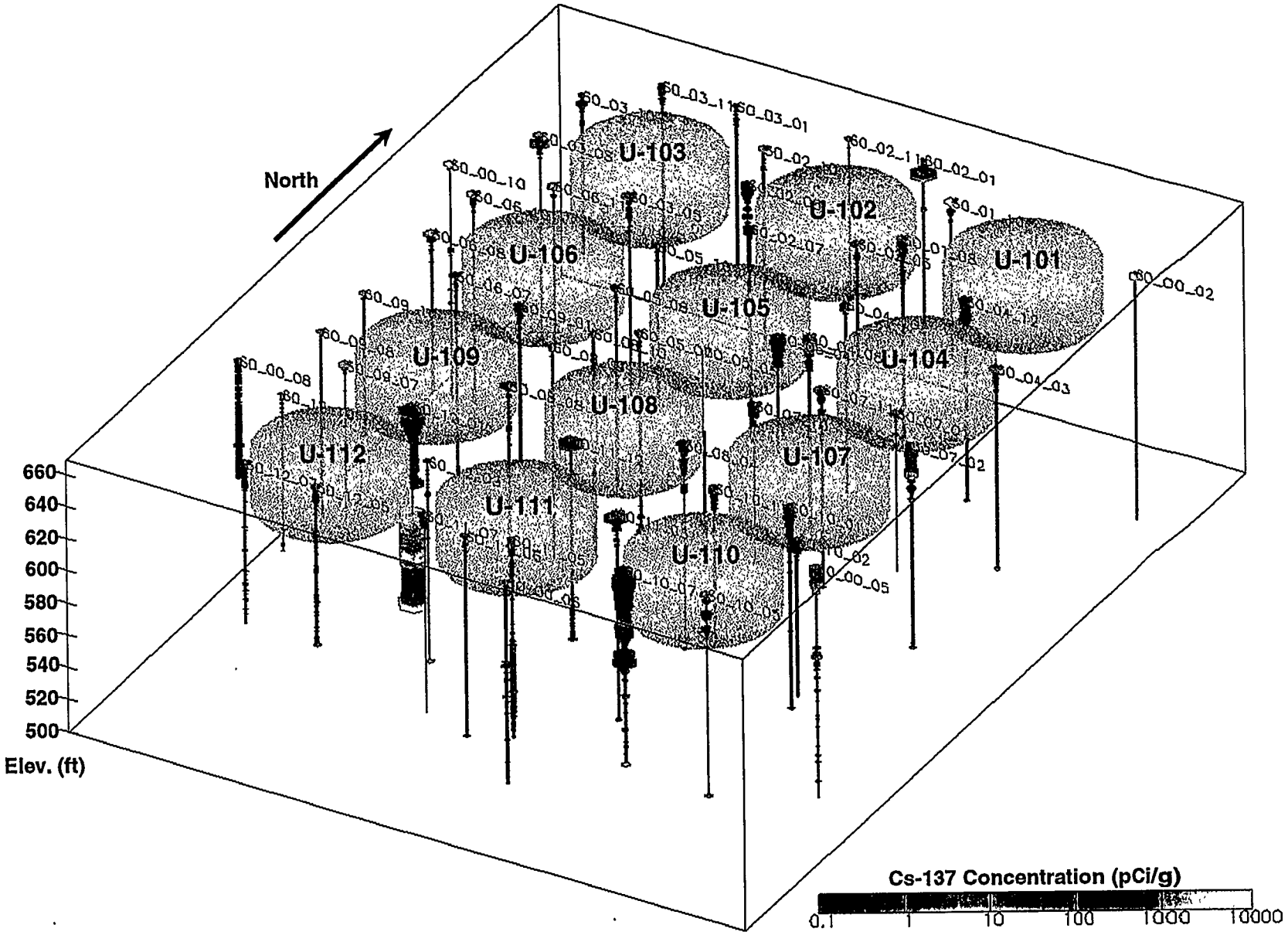


Figure 15-18. Isometric Plot of the ^{137}Cs Data Acquired at the U Tank Farm

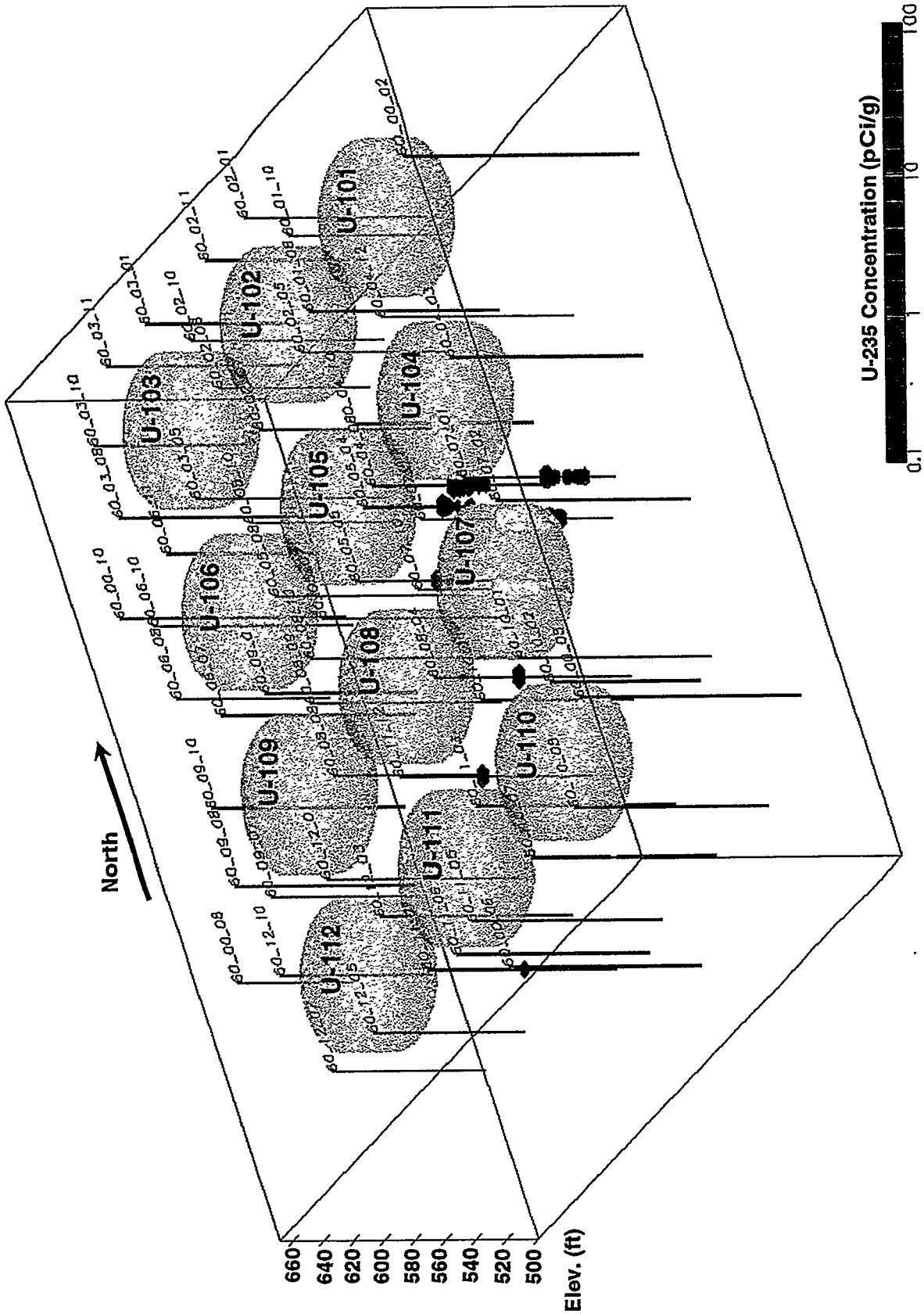


Figure 15-19. Isometric Plot of the ^{235}U Data Acquired at the U Tank Farm

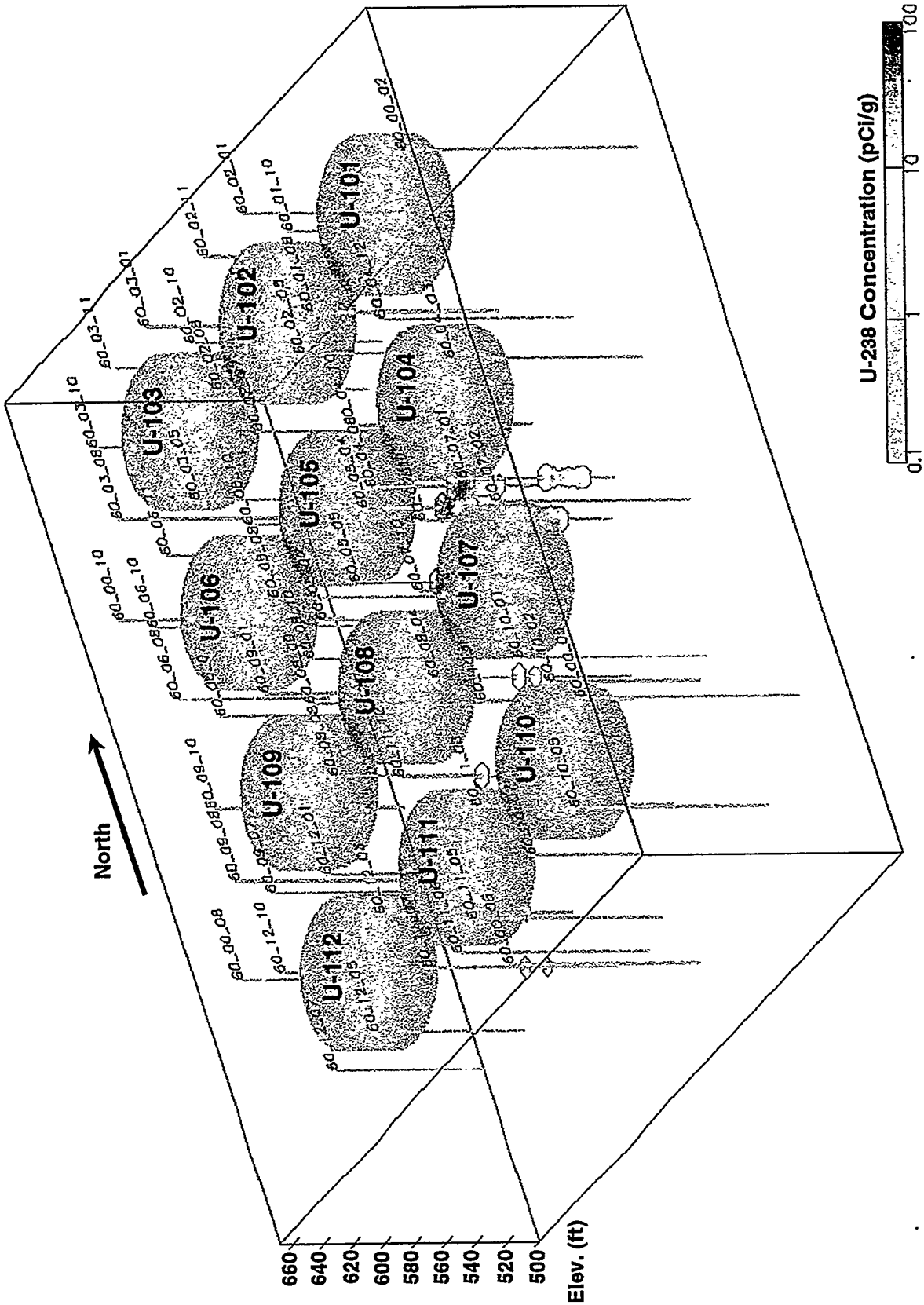


Figure 15-20. Isometric Plot of the ^{238}U Data Acquired at the U Tank Farm

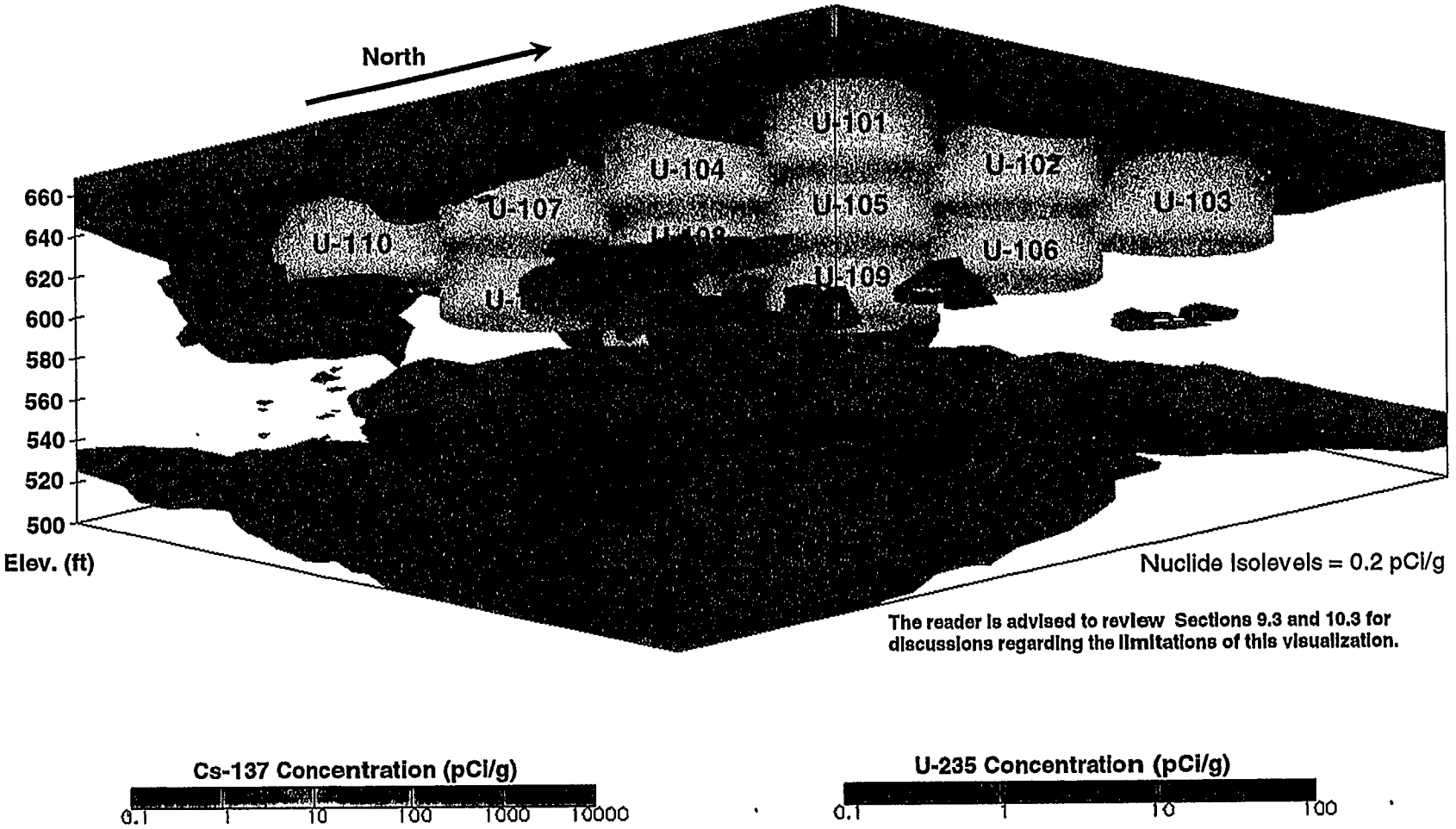


Figure 15-21. Visualization of the ^{137}Cs and ^{235}U Contamination in the U Tank Farm

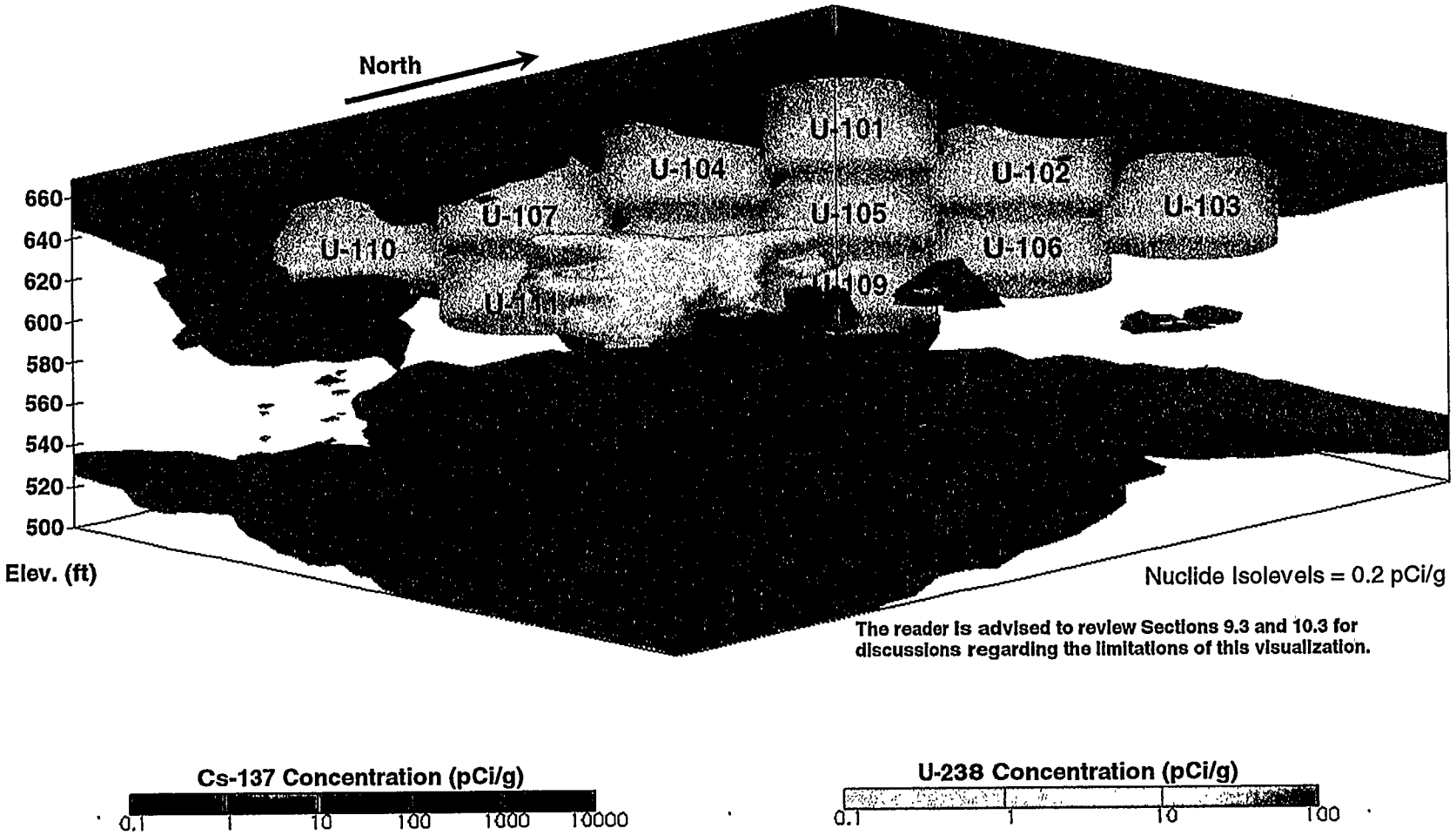


Figure 15-22. Visualization of the ^{137}Cs and ^{238}U Contamination in the U Tank Farm

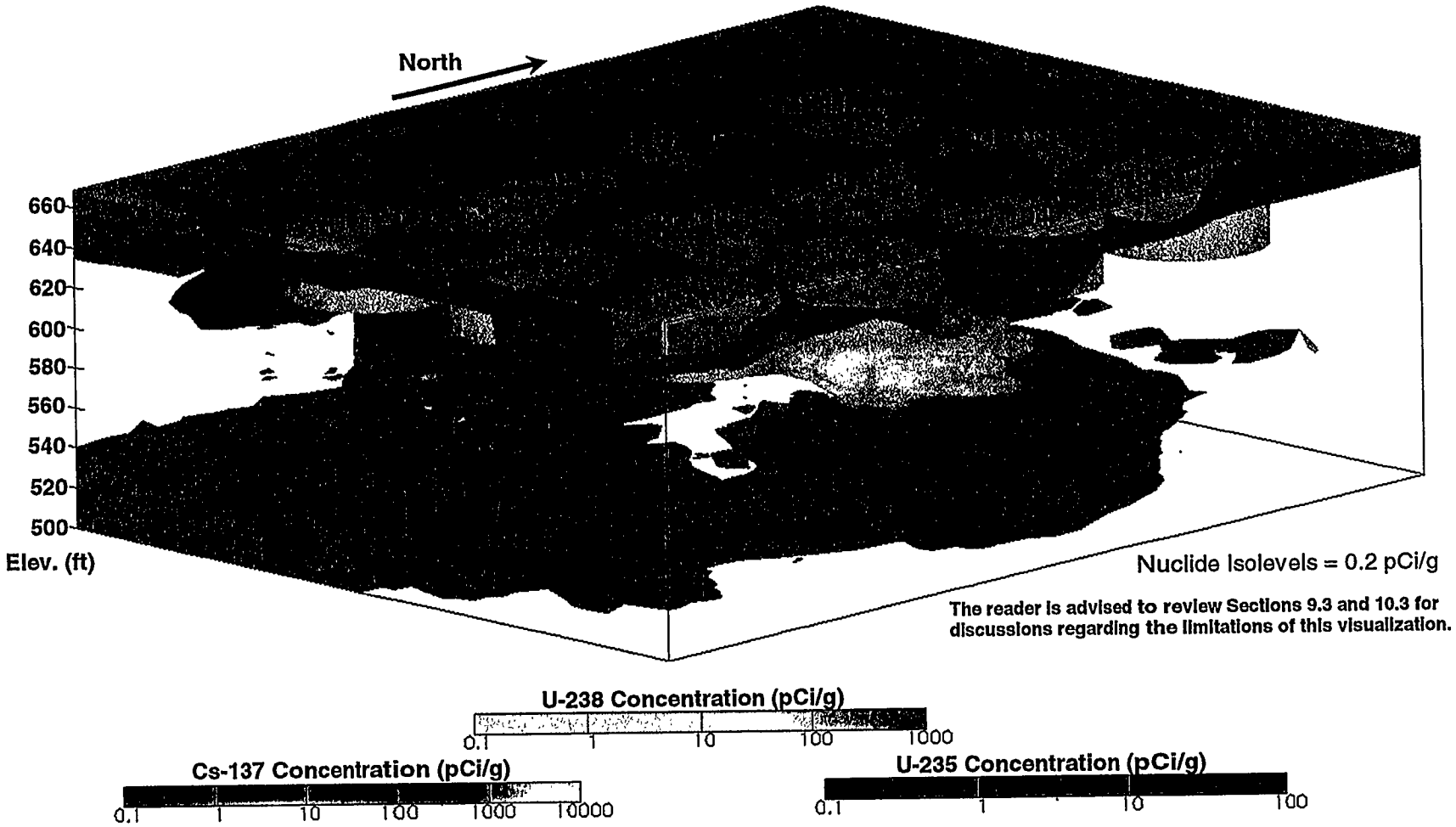


Figure 15-23. Visualization of U Tank Farm Contamination With Transparent ^{238}U Plume From Above the Tanks From the Southeast

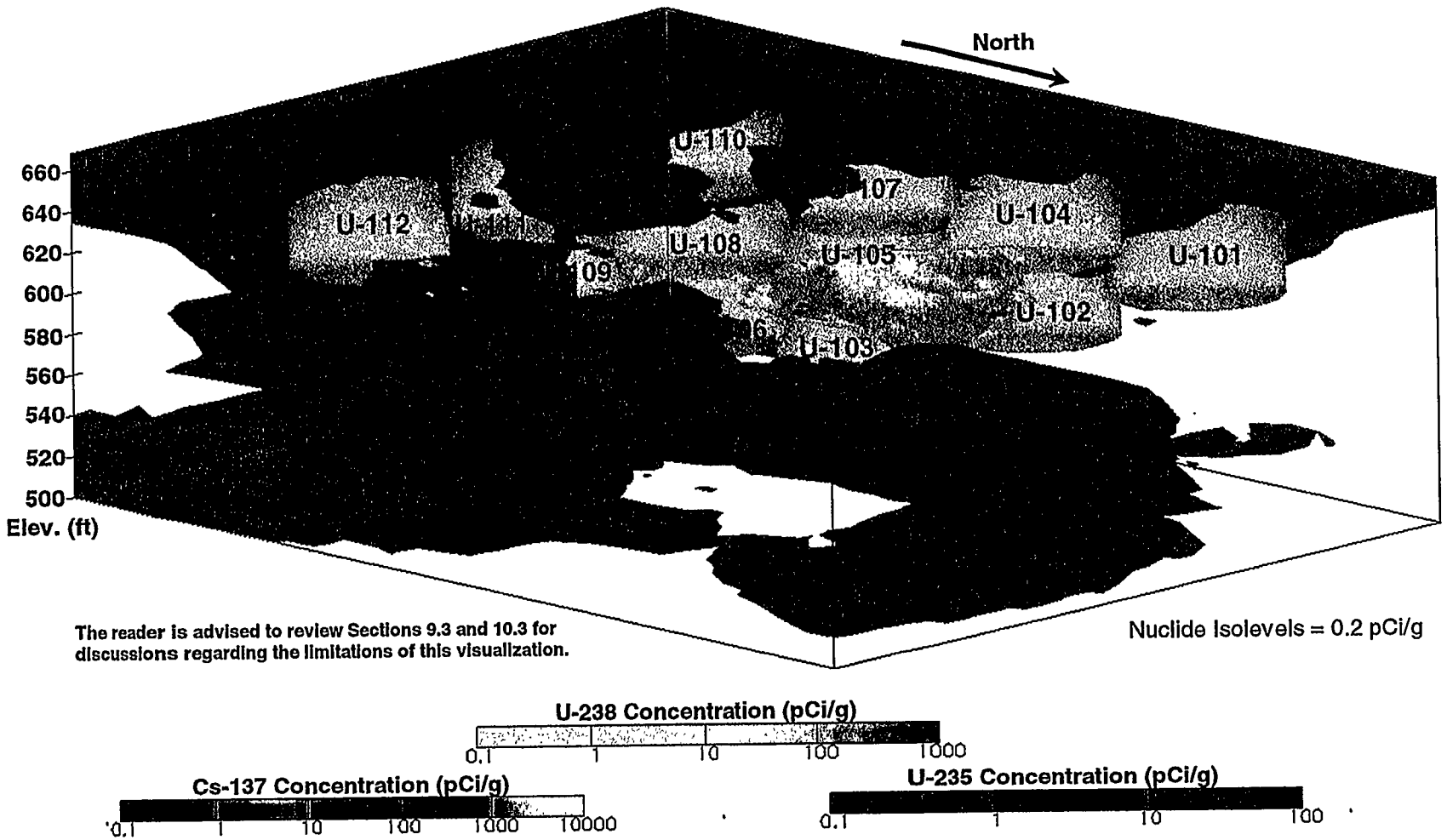


Figure 15-24. Visualization of U Tank Farm Contamination With Transparent ^{238}U Plume Viewed From Below the Tanks From the Southeast

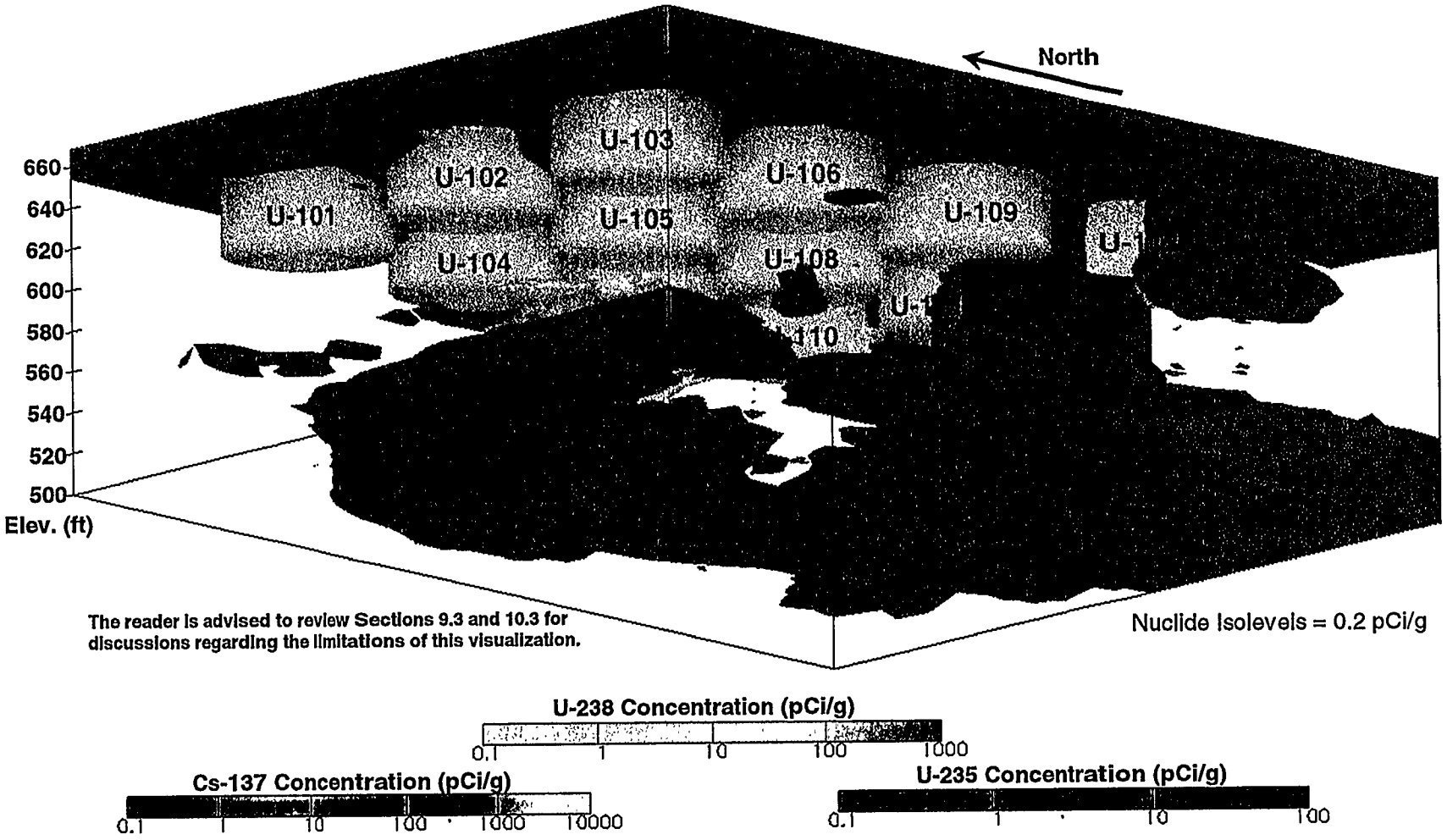


Figure 15-25. Visualization of U Tank Farm Contamination With Transparent ^{238}U Plume Viewed From Below the Tanks From the Northwest

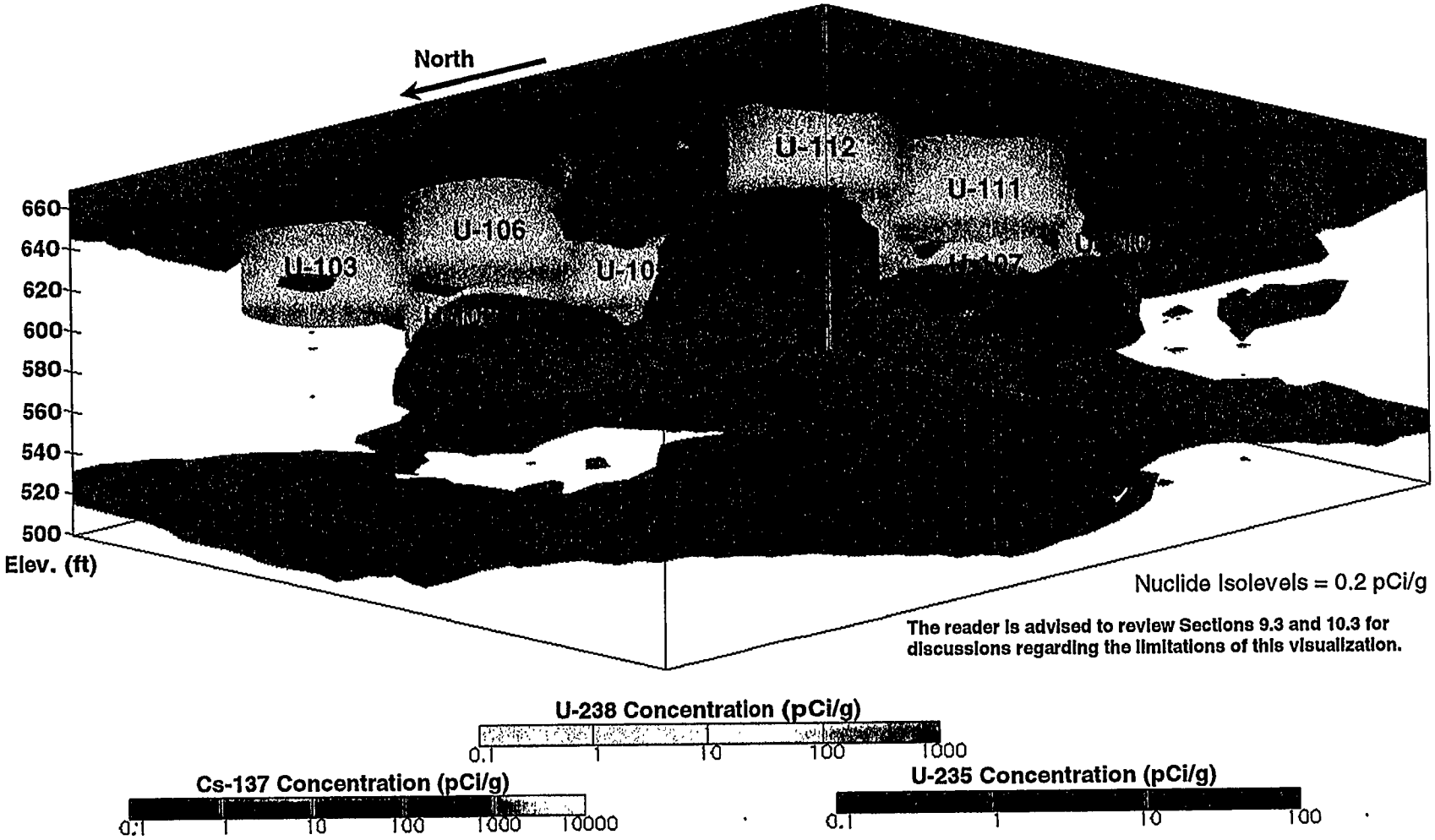


Figure 15-26. Visualization of U Tank Farm Contamination With Transparent ^{238}U Plume From Below the Tanks From the Southwest

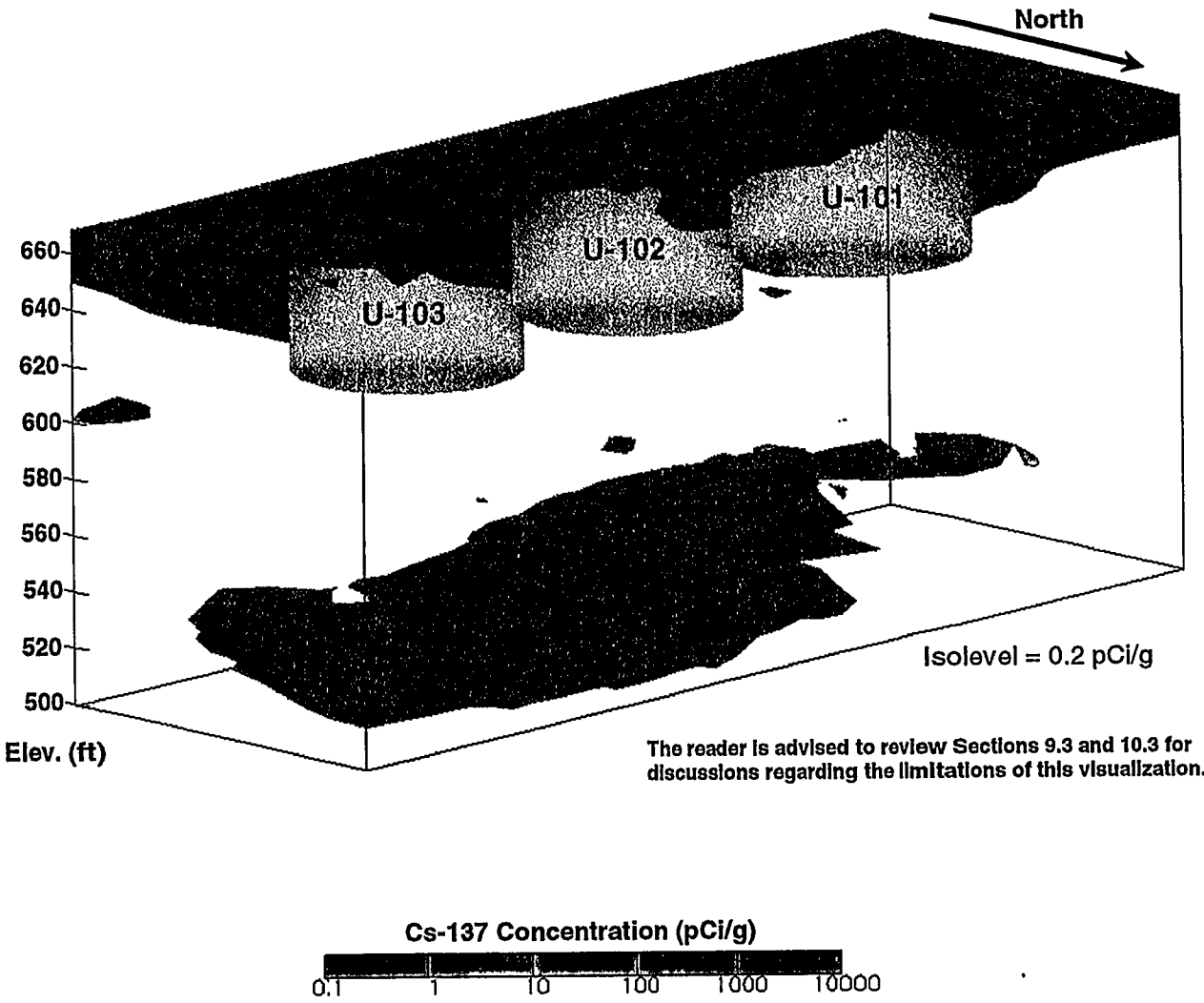


Figure 15-27. Visualization of Tanks U-101, -102, and -103 Viewed From Below the Tanks From the Southeast

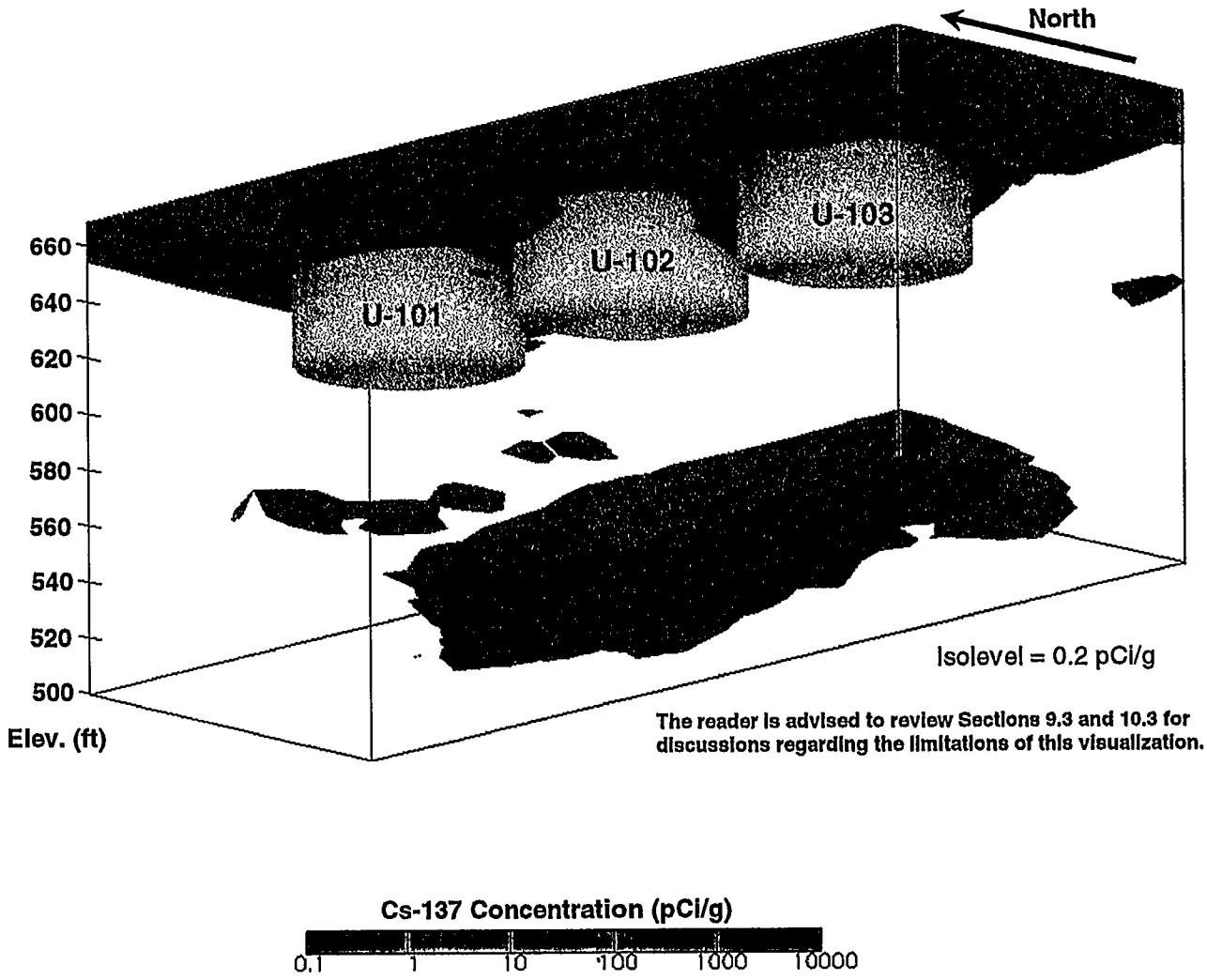


Figure 15-28. Visualization of Tanks U-101, -102, and -103 Viewed From Below the Tanks From the Northwest

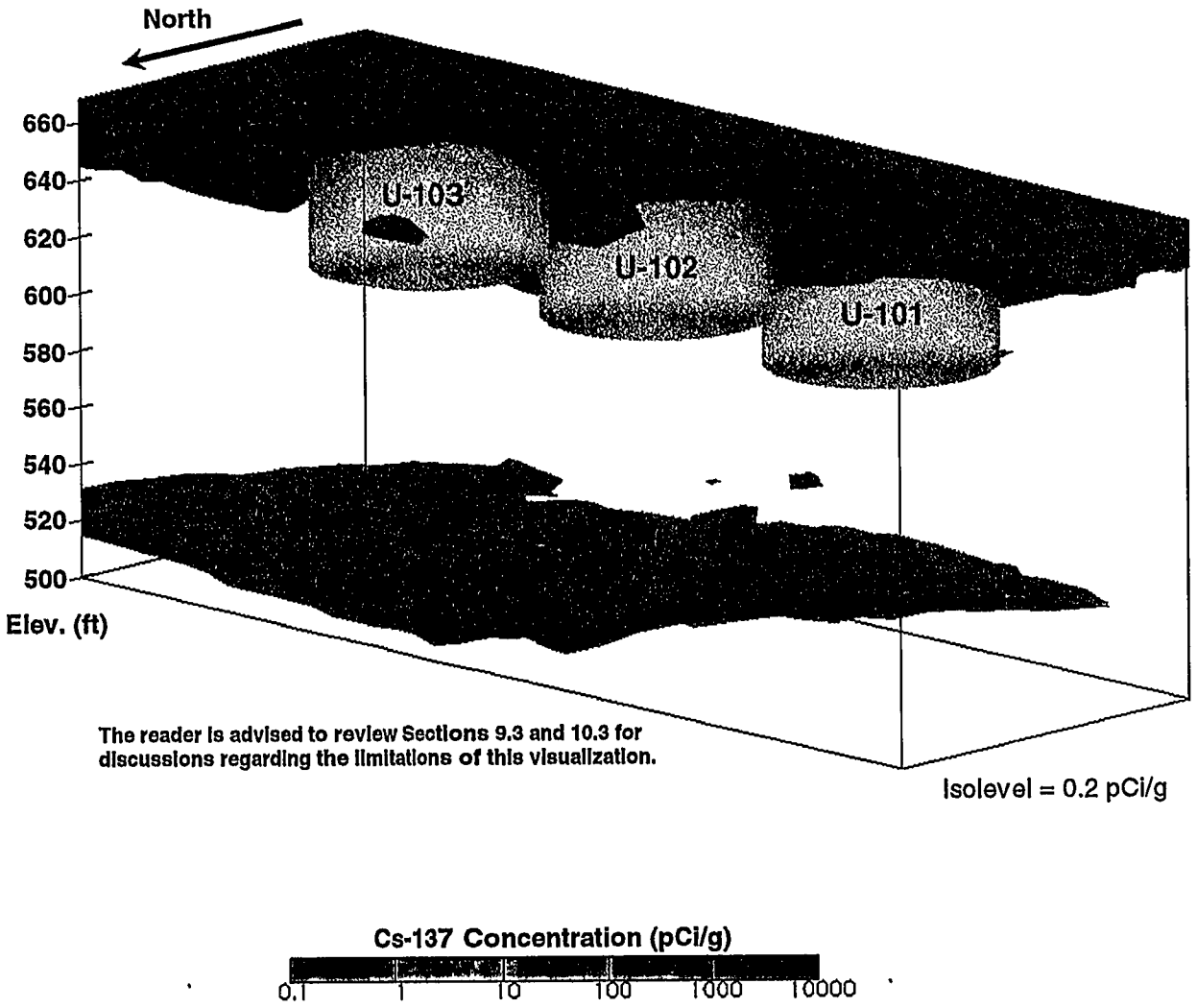


Figure 15-29. Visualization of Tanks U-101, -102, and -103 Viewed From Below the Tanks From the Southwest

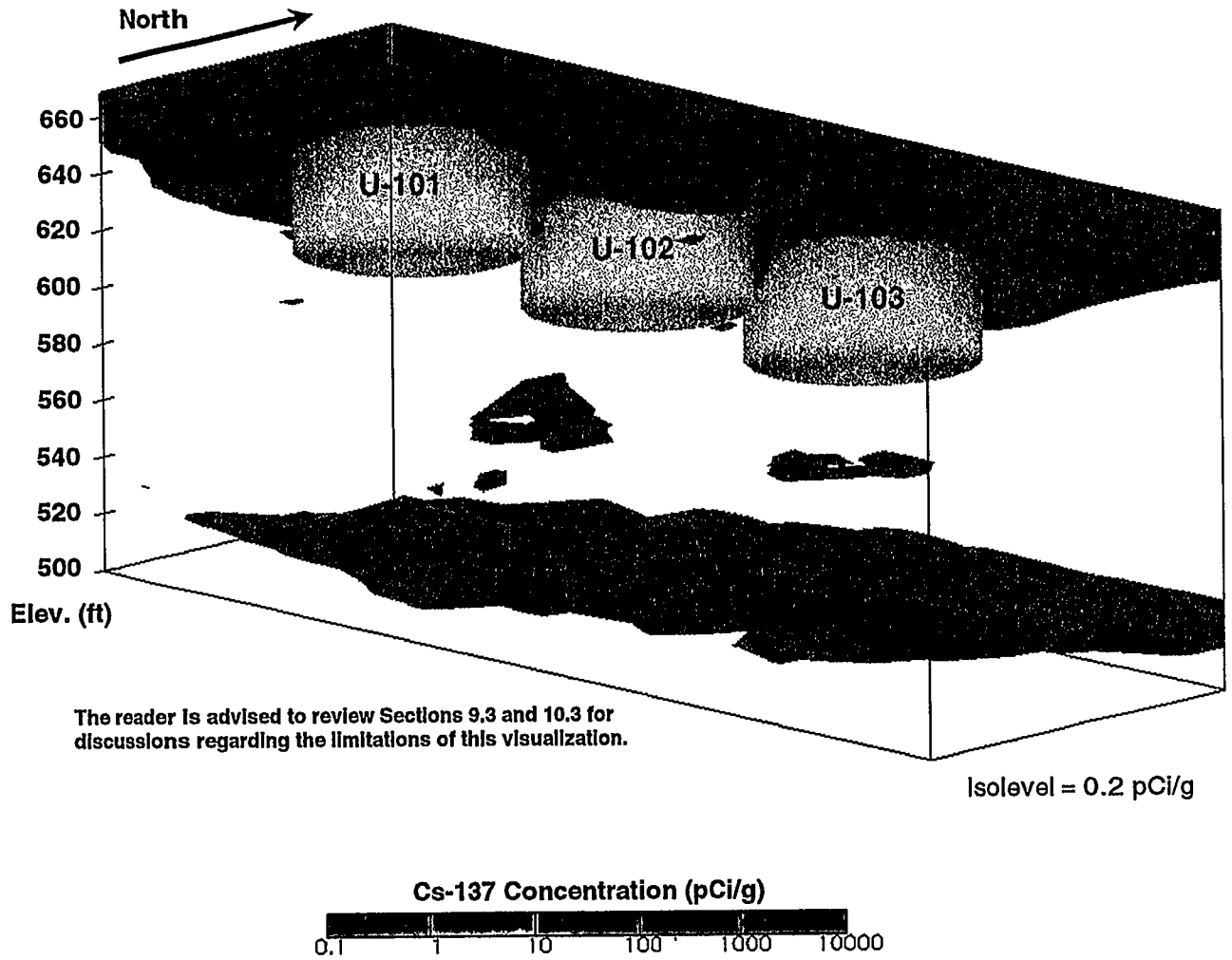
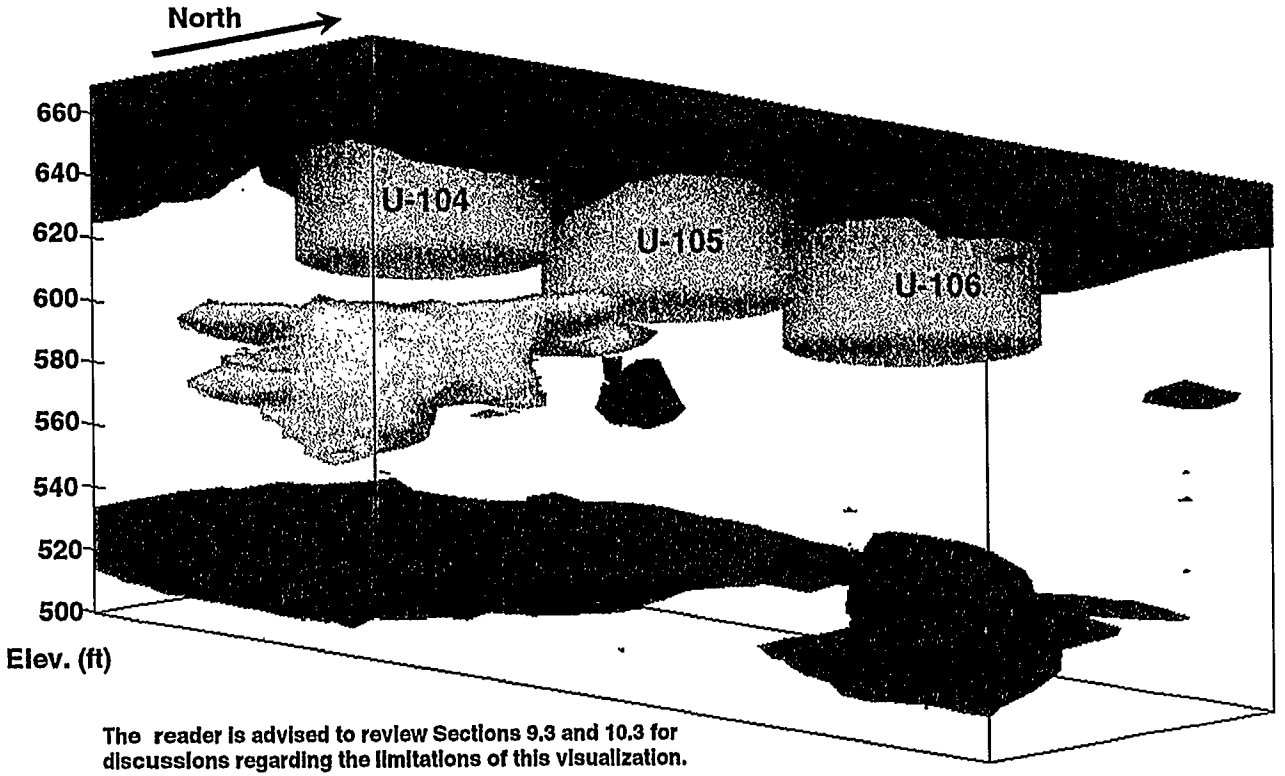


Figure 15-30. Visualization of Tanks U-101, -102, and -103 Viewed From Below the Tanks From the North



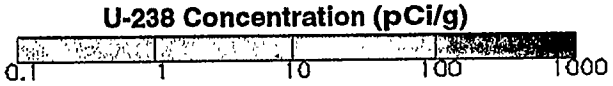


Figure 15-31. Visualization of Tanks U-104, -105, and -106 Viewed From Below the Tanks From the Northeast

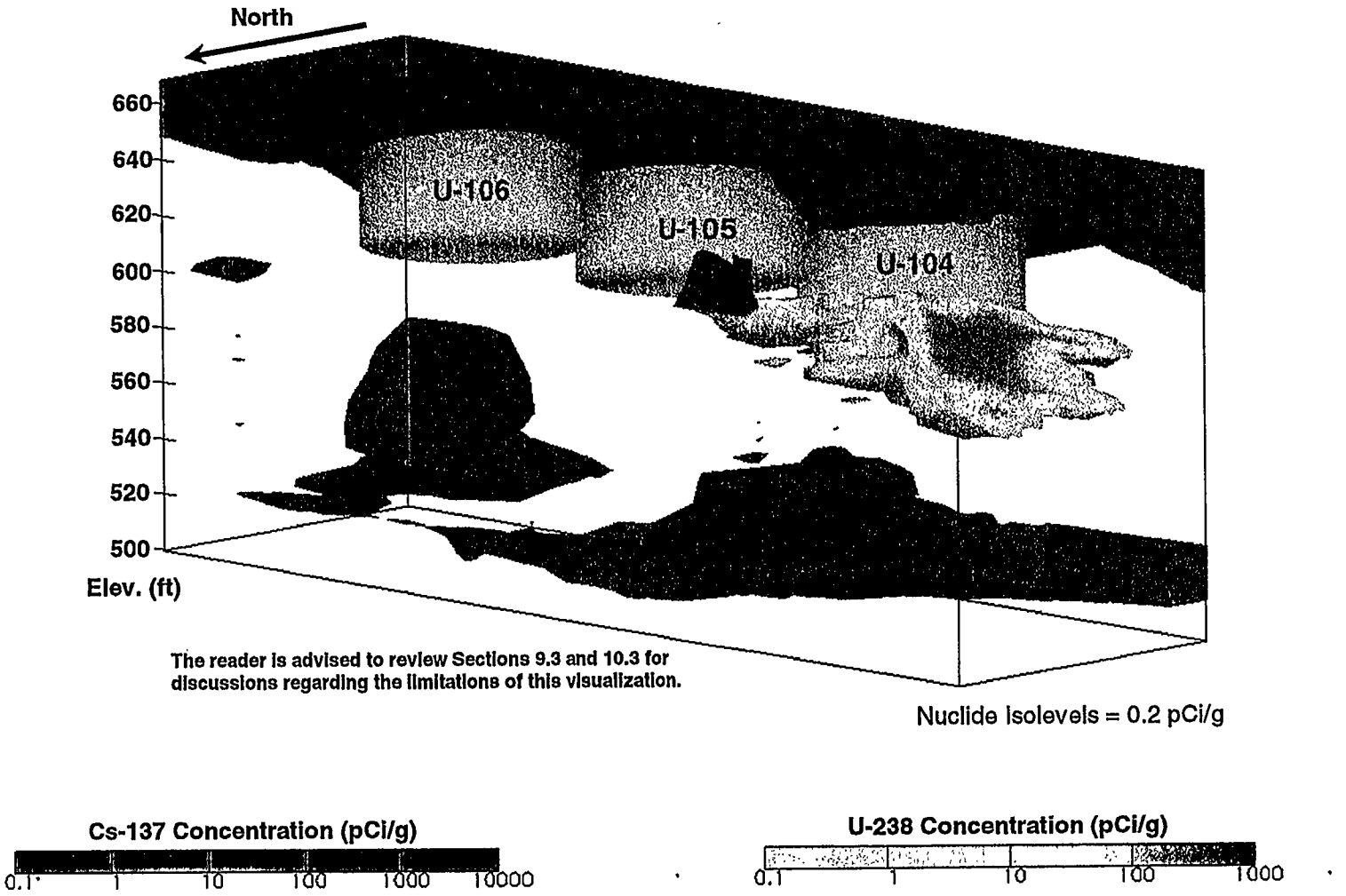


Figure 15-32. Visualization of Tanks U-104, -105, and -106 Viewed From Below the Tanks From the Southwest

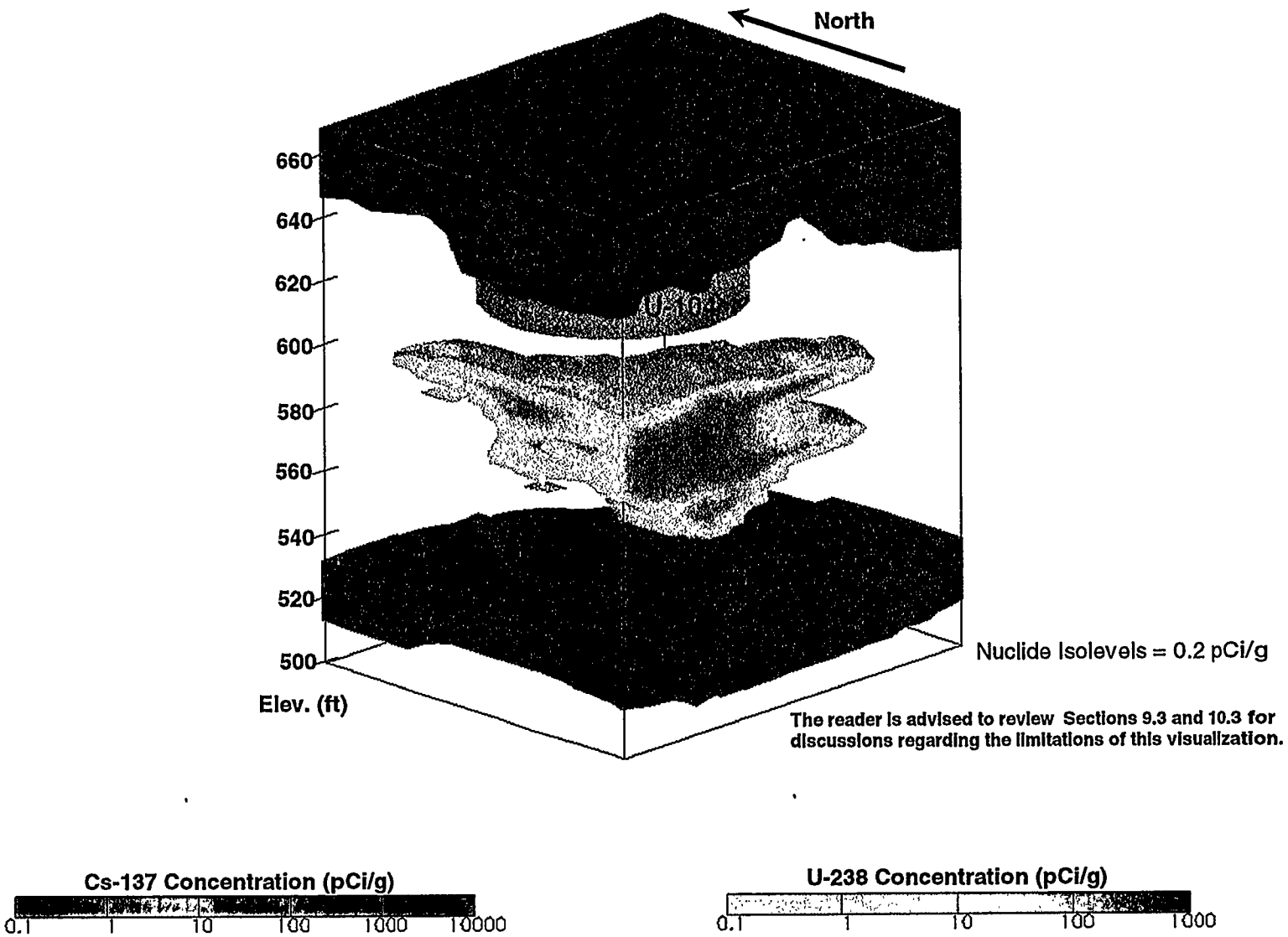


Figure 15-33. Visualization of Tank U-104 Viewed From Above the Tank From the Southwest

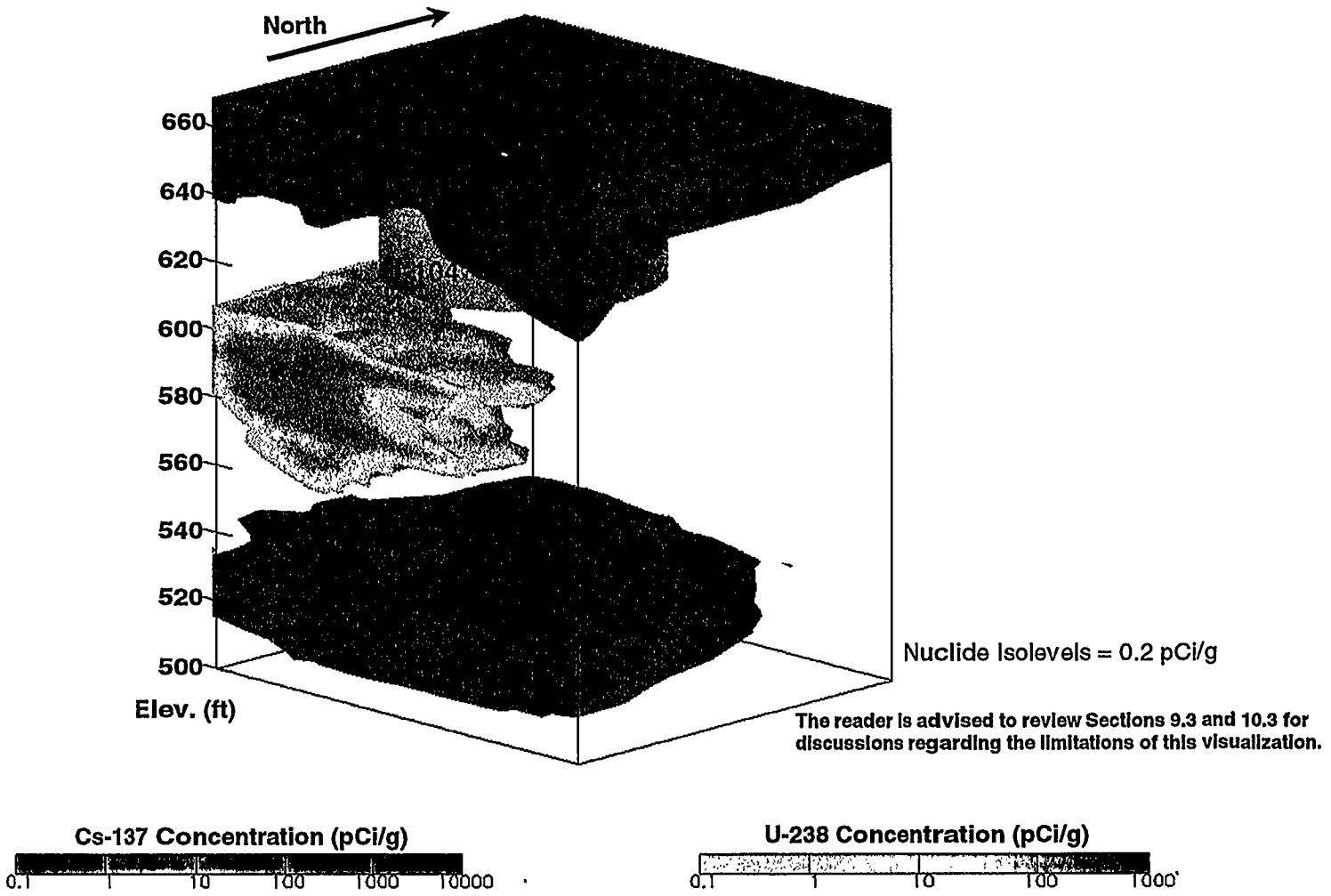


Figure 15-34. Visualization of Tank U-104 Viewed From Above the Tank From the Southeast

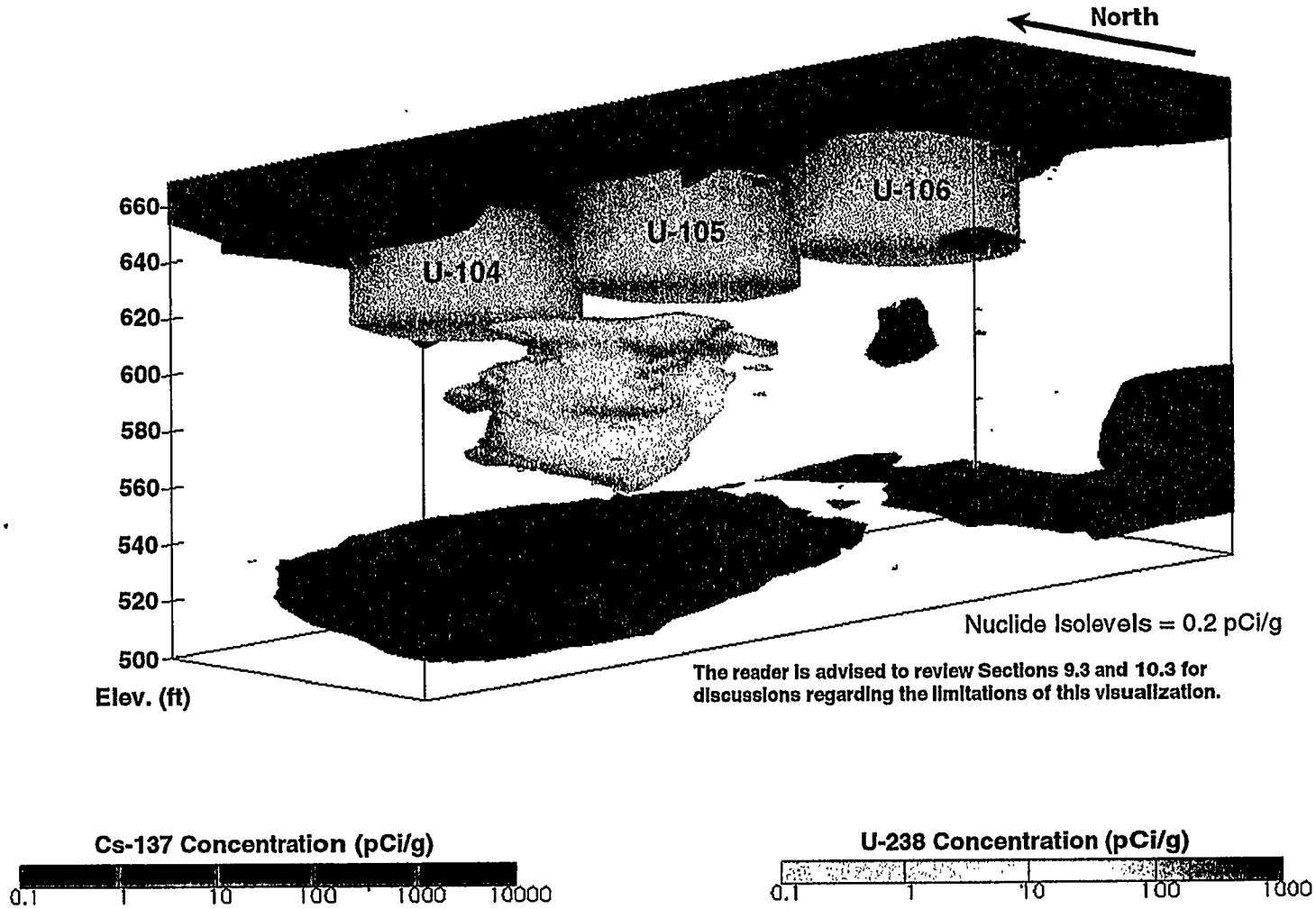


Figure 15-35. Visualization of Tanks U-104, -105, and -106 Viewed From Below the Tanks From the Northwest

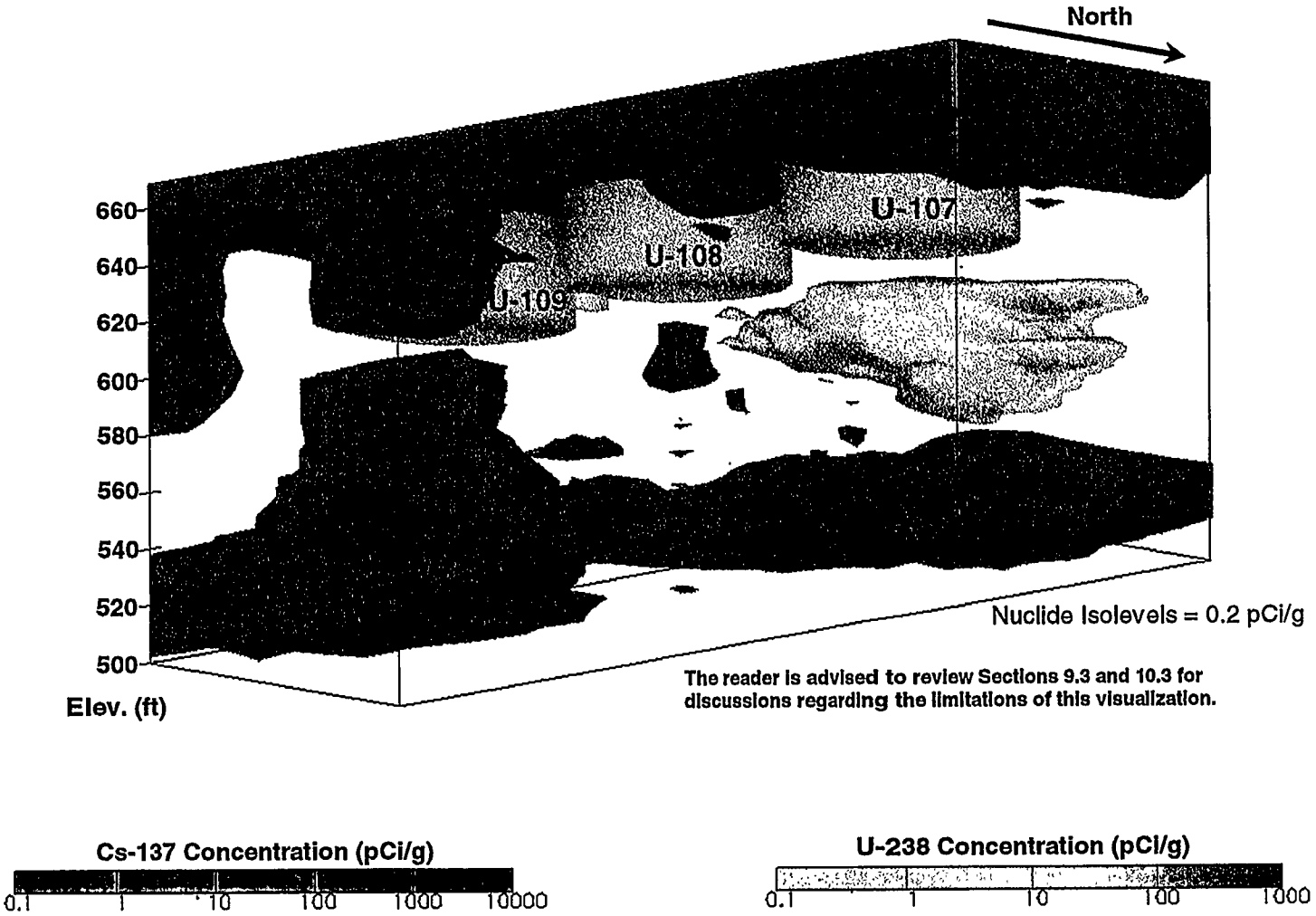


Figure 15-36. Visualization of Tanks U-107, -108, and -109 Viewed From Below the Tanks From the Southeast

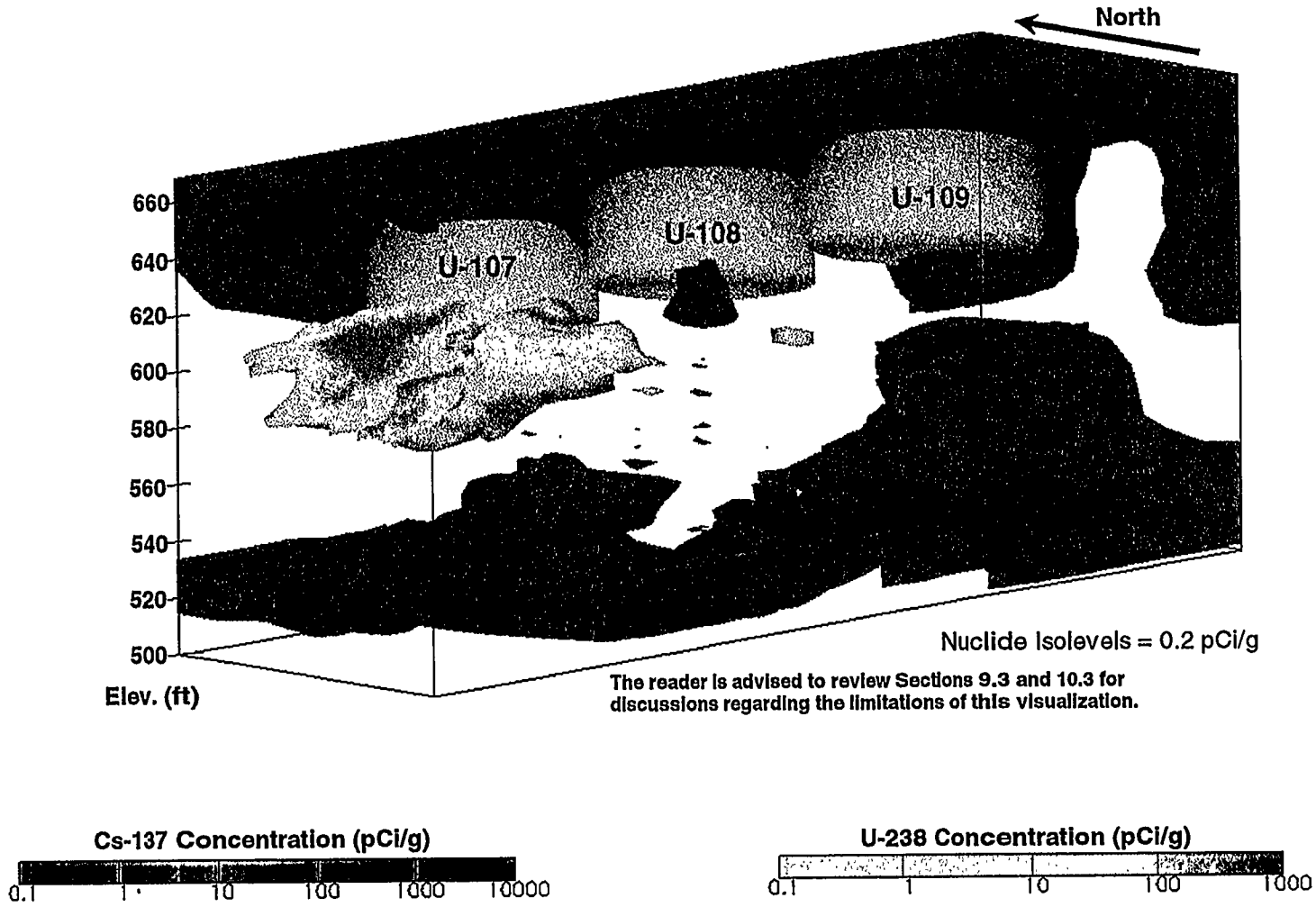


Figure 15-37. Visualization of Tanks U-107, -108, and -109 Viewed From Below the Tanks From the Northwest

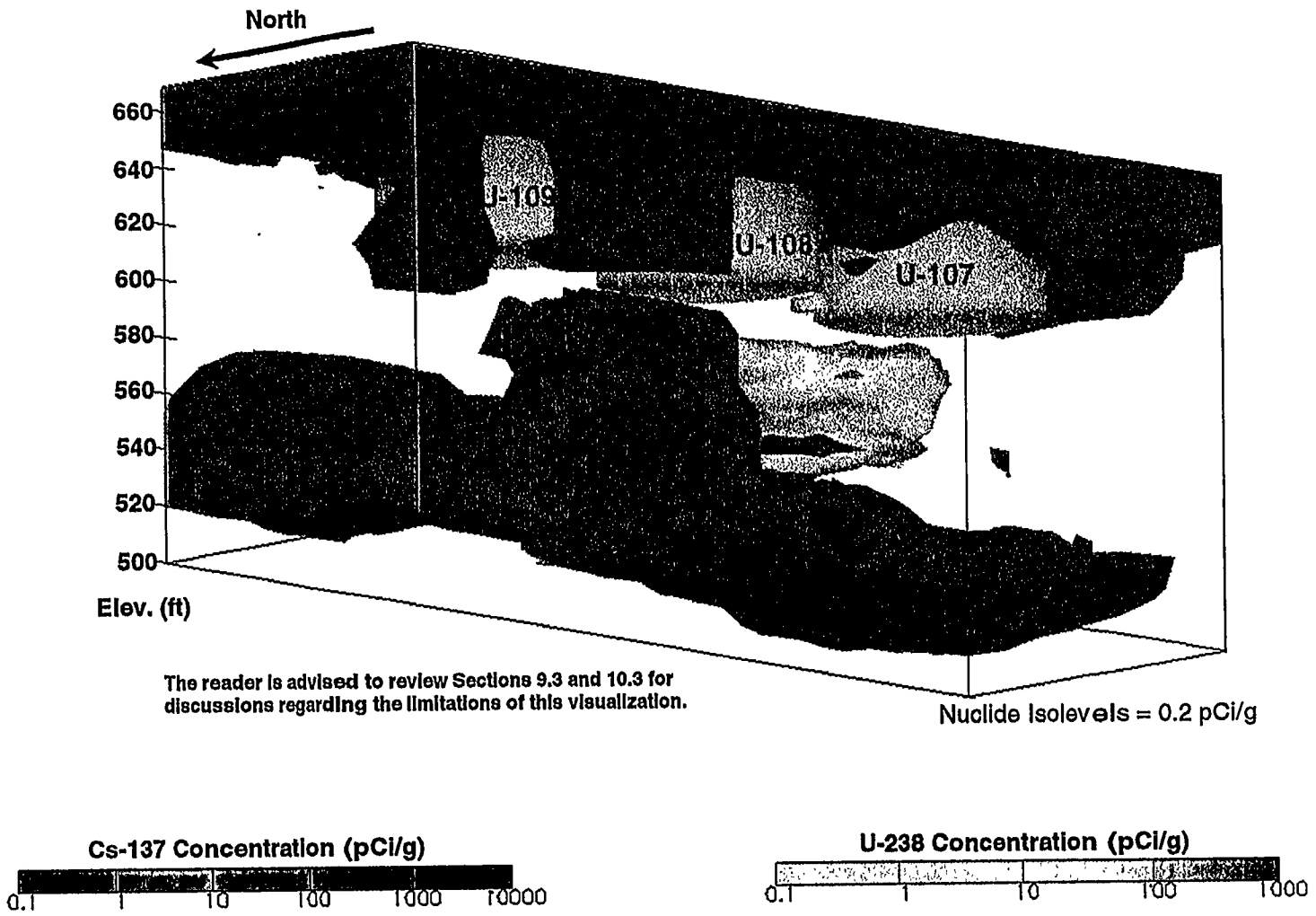


Figure 15-38. Visualization of Tanks U-107, -108, and -109 Viewed From Below the Tanks From the Southwest

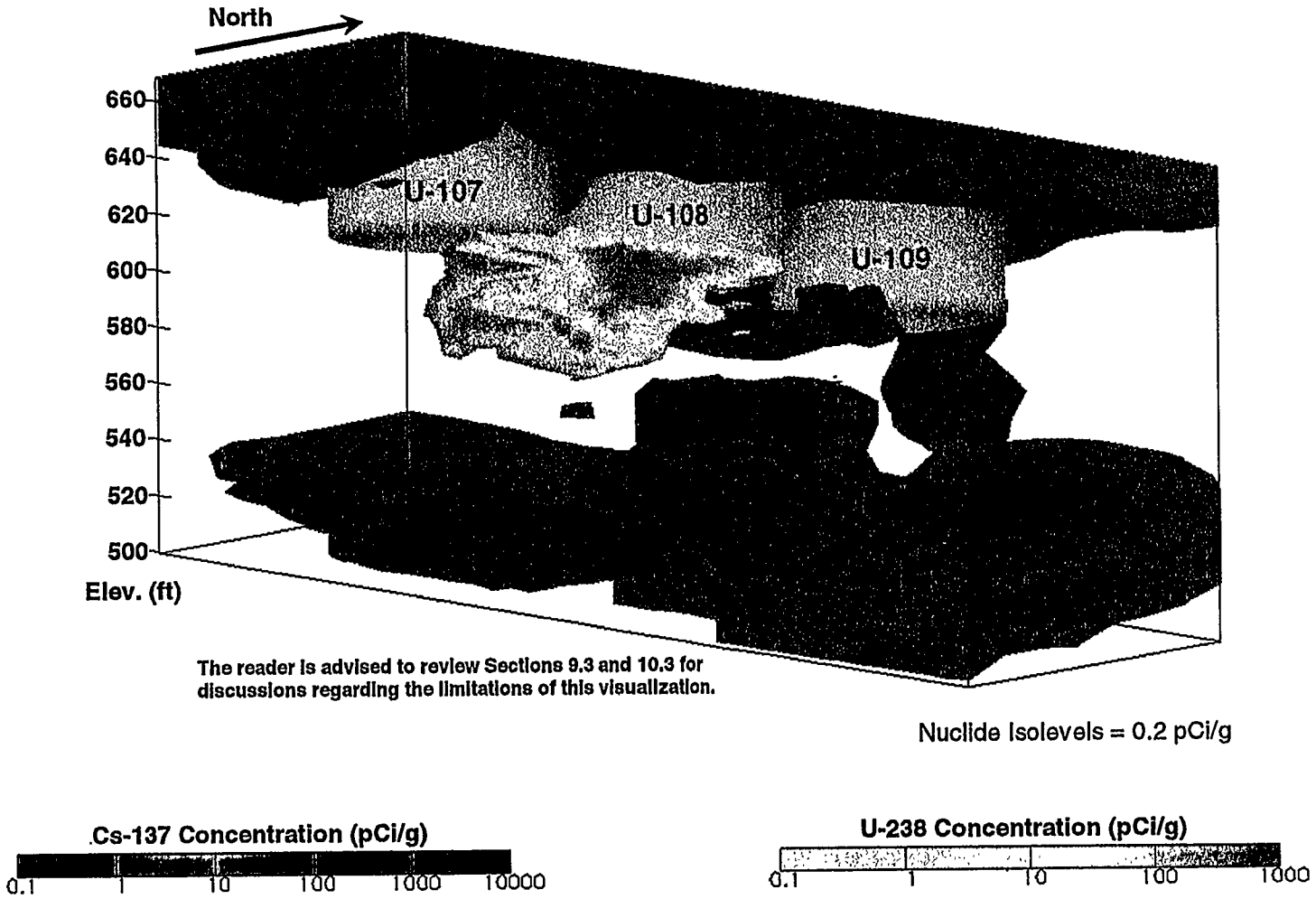
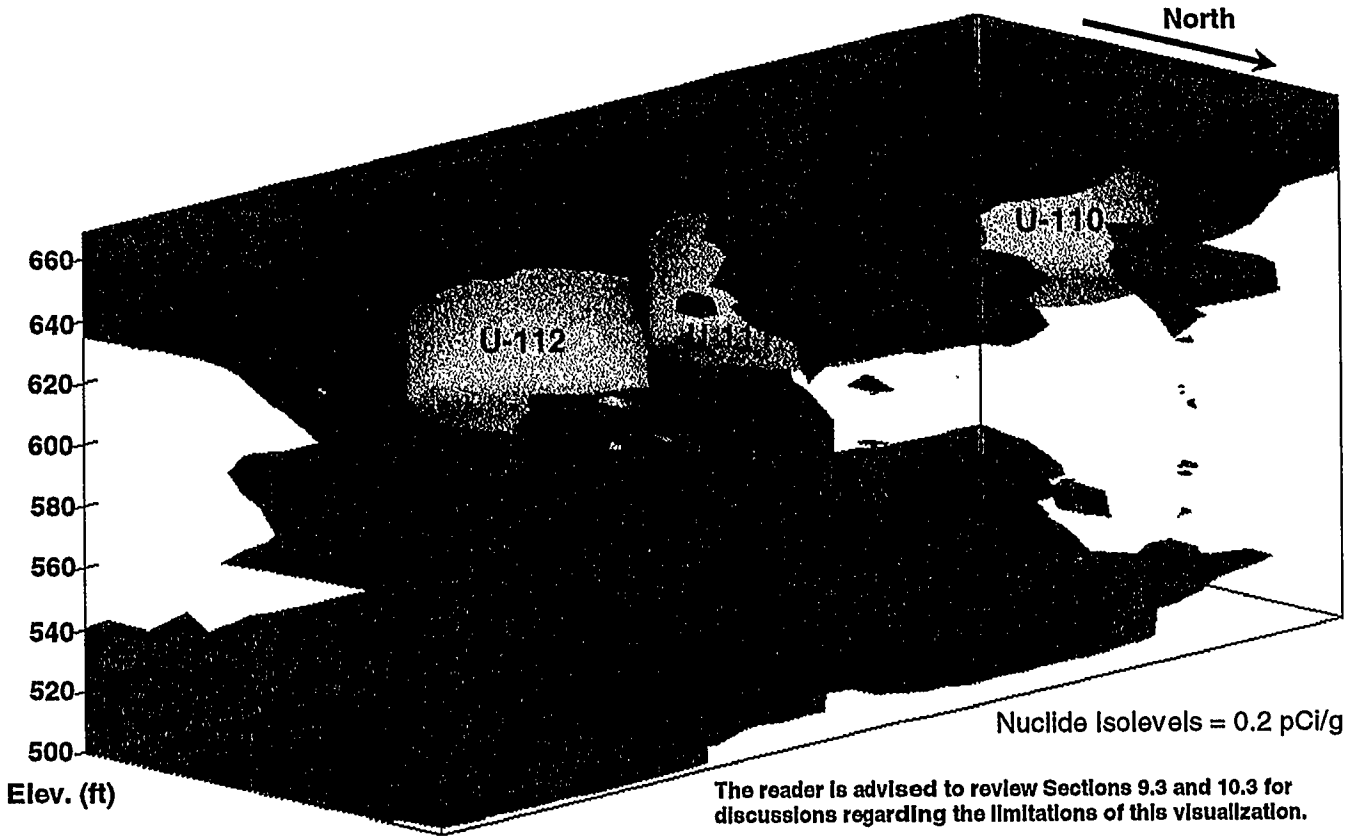


Figure 15-39. Visualization of Tanks U-107, -108, and -109 Viewed From Below the Tanks From the Northeast



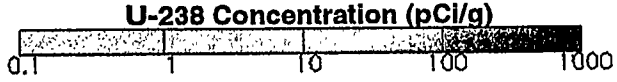


Figure 15-40. Visualization of Tanks U-110, -111, and -112 Viewed From Below the Tanks From the Southeast

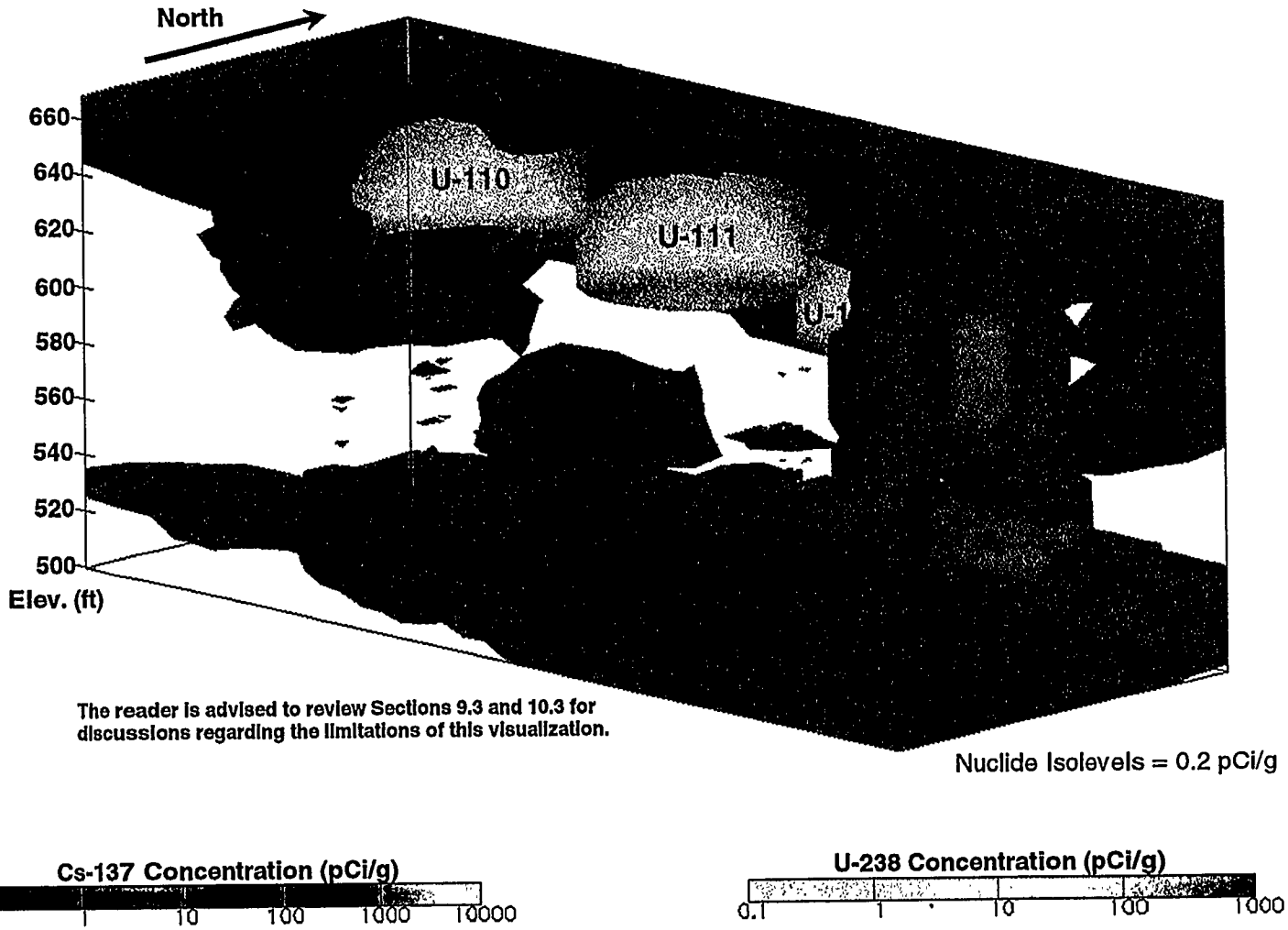


Figure 15-41. Visualization of Tanks U-110, -111, and -112 Viewed From Below the Tanks From the Northeast

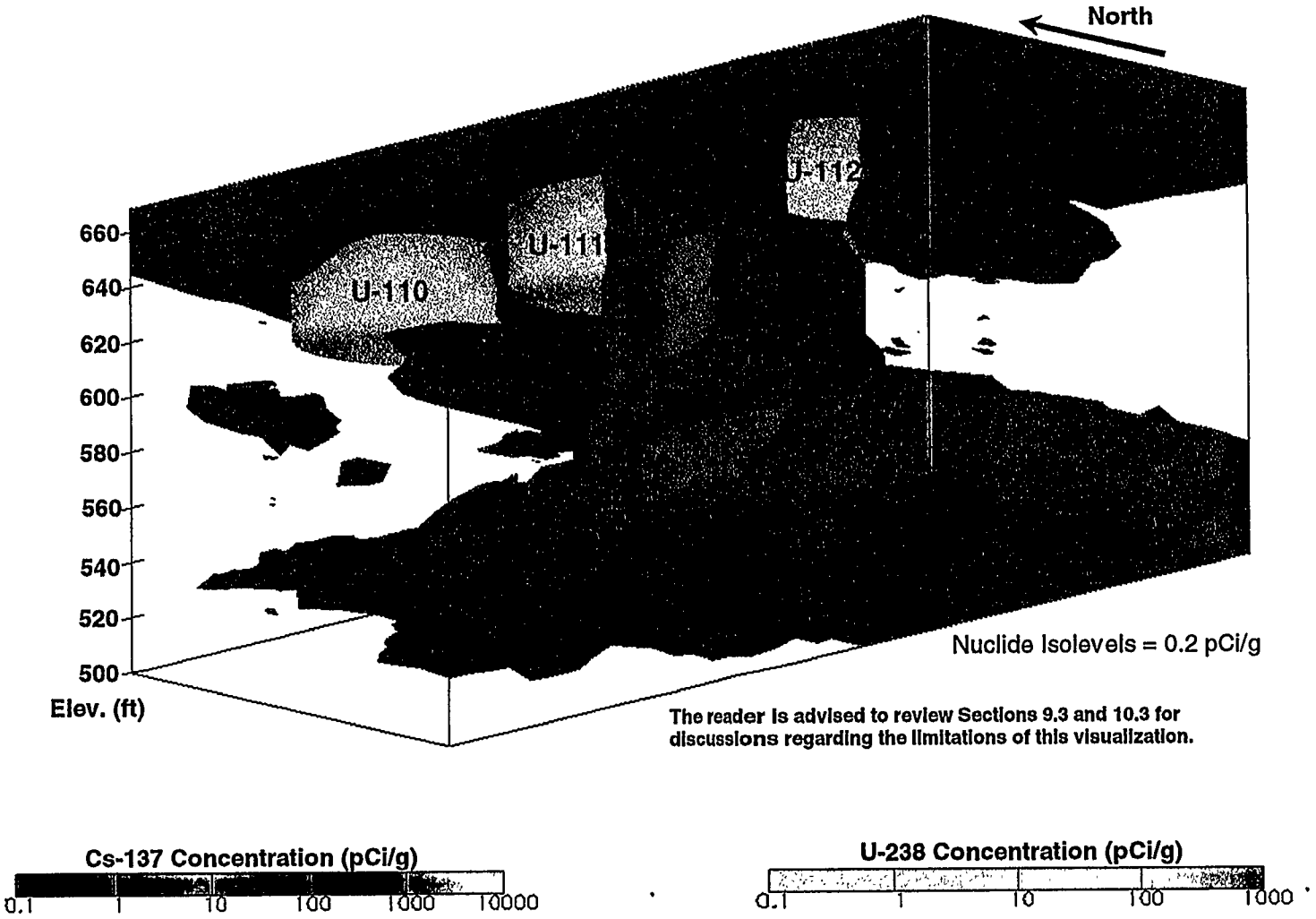


Figure 15-42. Visualization of Tanks U-110, -111, and -112 Viewed From Below the Tanks From the Northwest

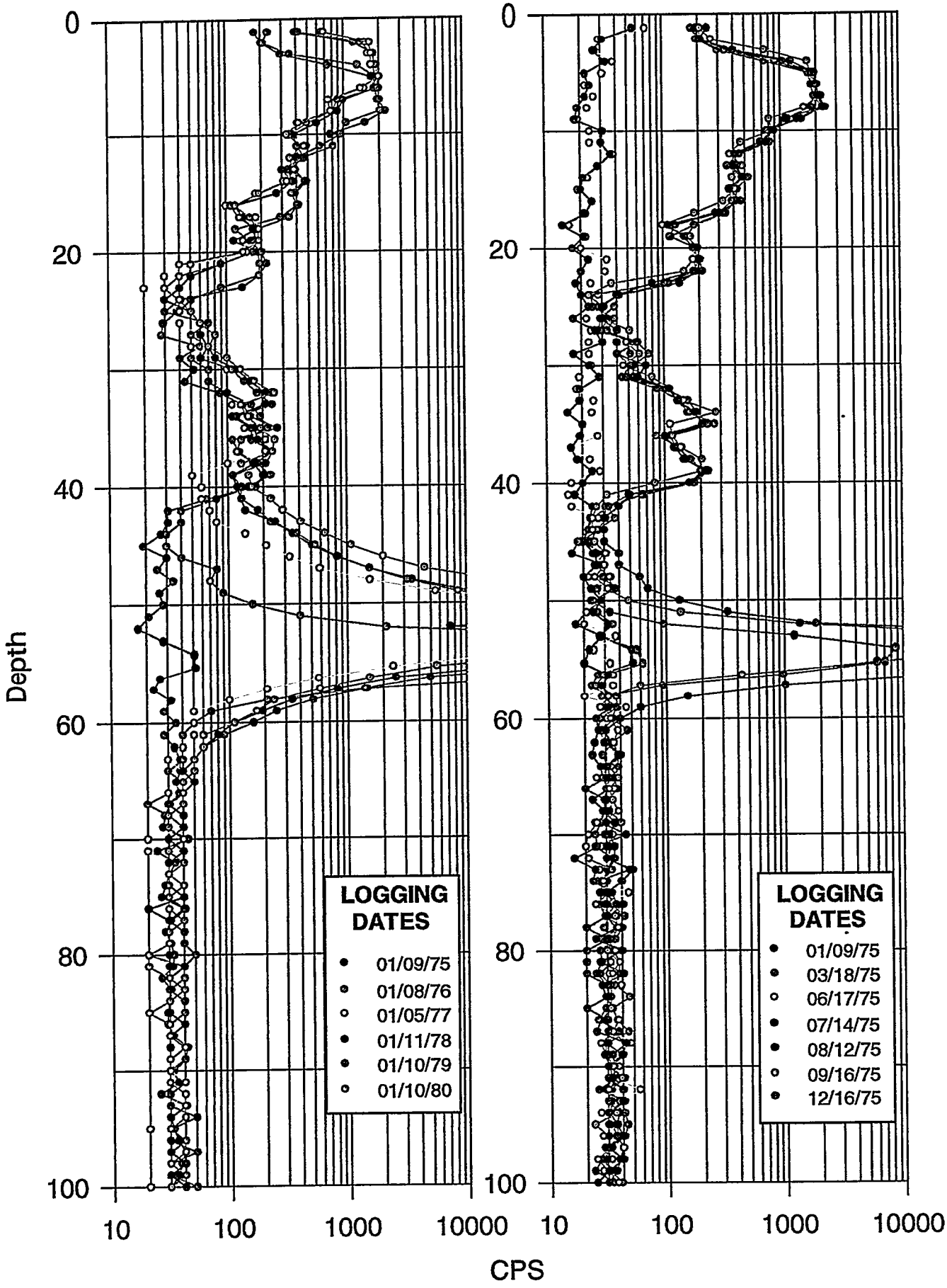


Figure 15-43. Plots of Historical Tank Farm Gross Gamma-Ray Log Data for Borehole 60-10-07

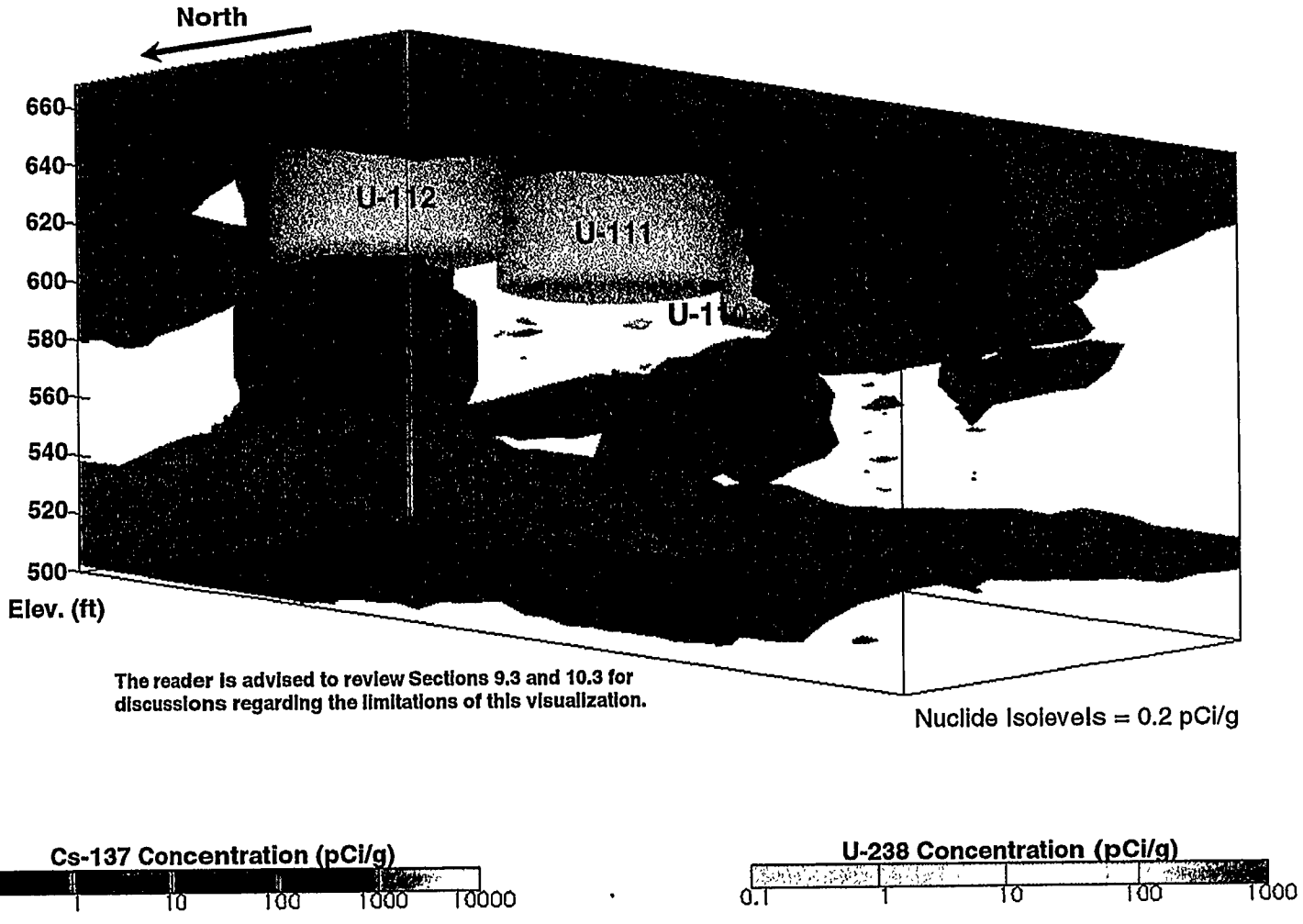


Figure 15-44. Visualization of Tanks U-110, -111, and -112 Viewed From Below the Tanks From the Southwest

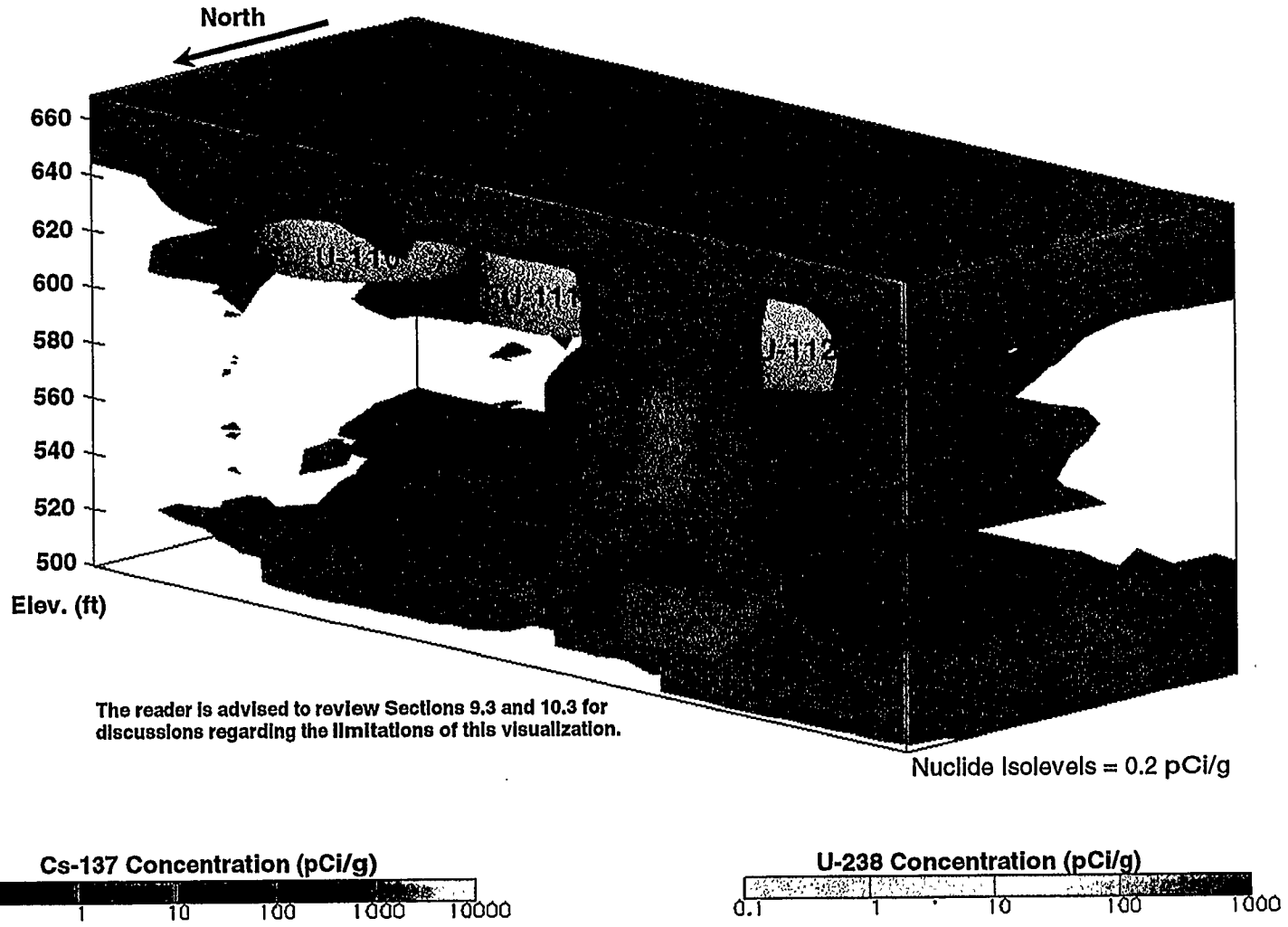


Figure 15-45. Visualization of Tanks U-110, -111, and -112 Viewed From Above the Tanks From the Northwest

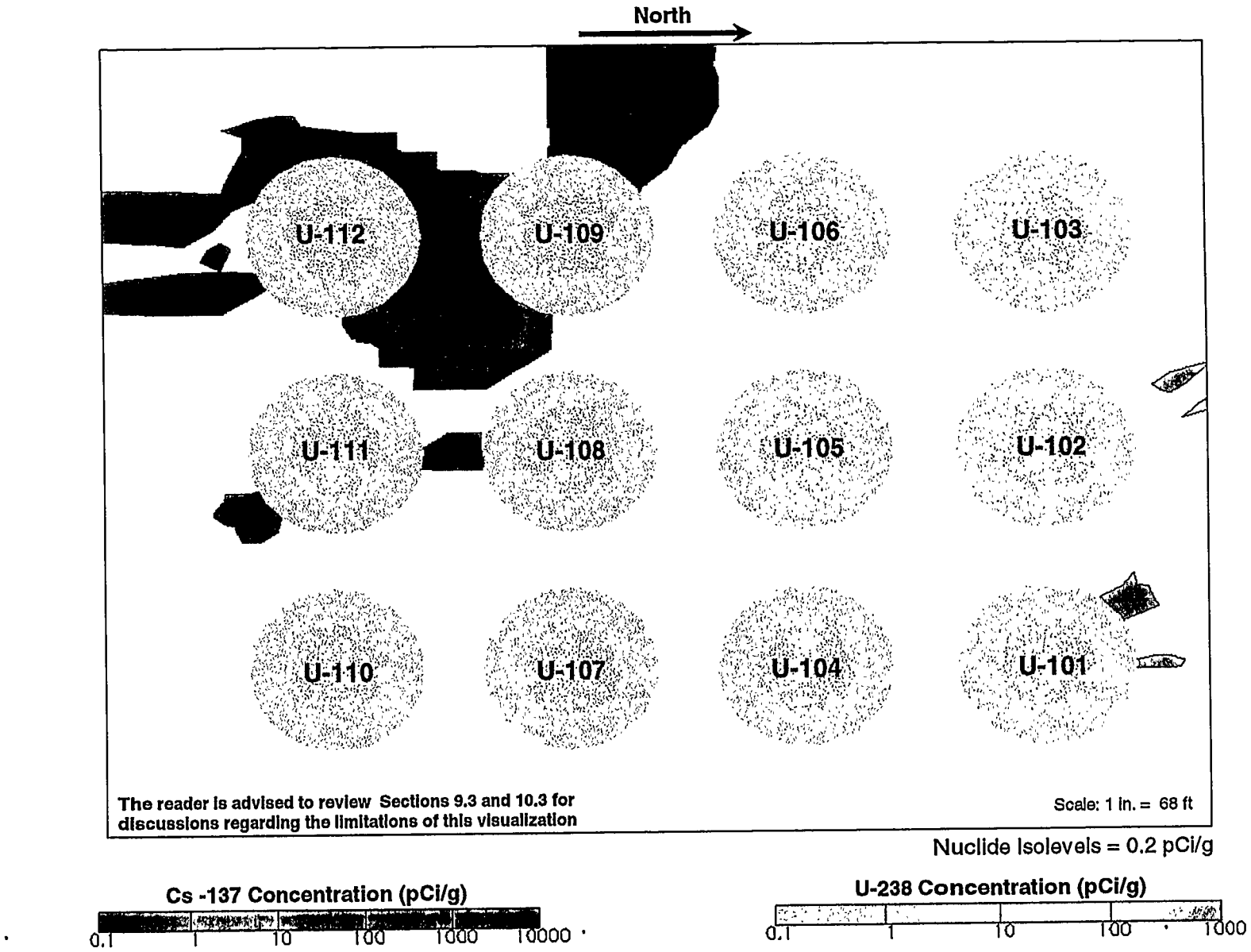


Figure 15-46. Visualization of the ^{137}Cs and ^{238}U Contamination 65 Ft Below the Bases of the U Tank Farm Tanks

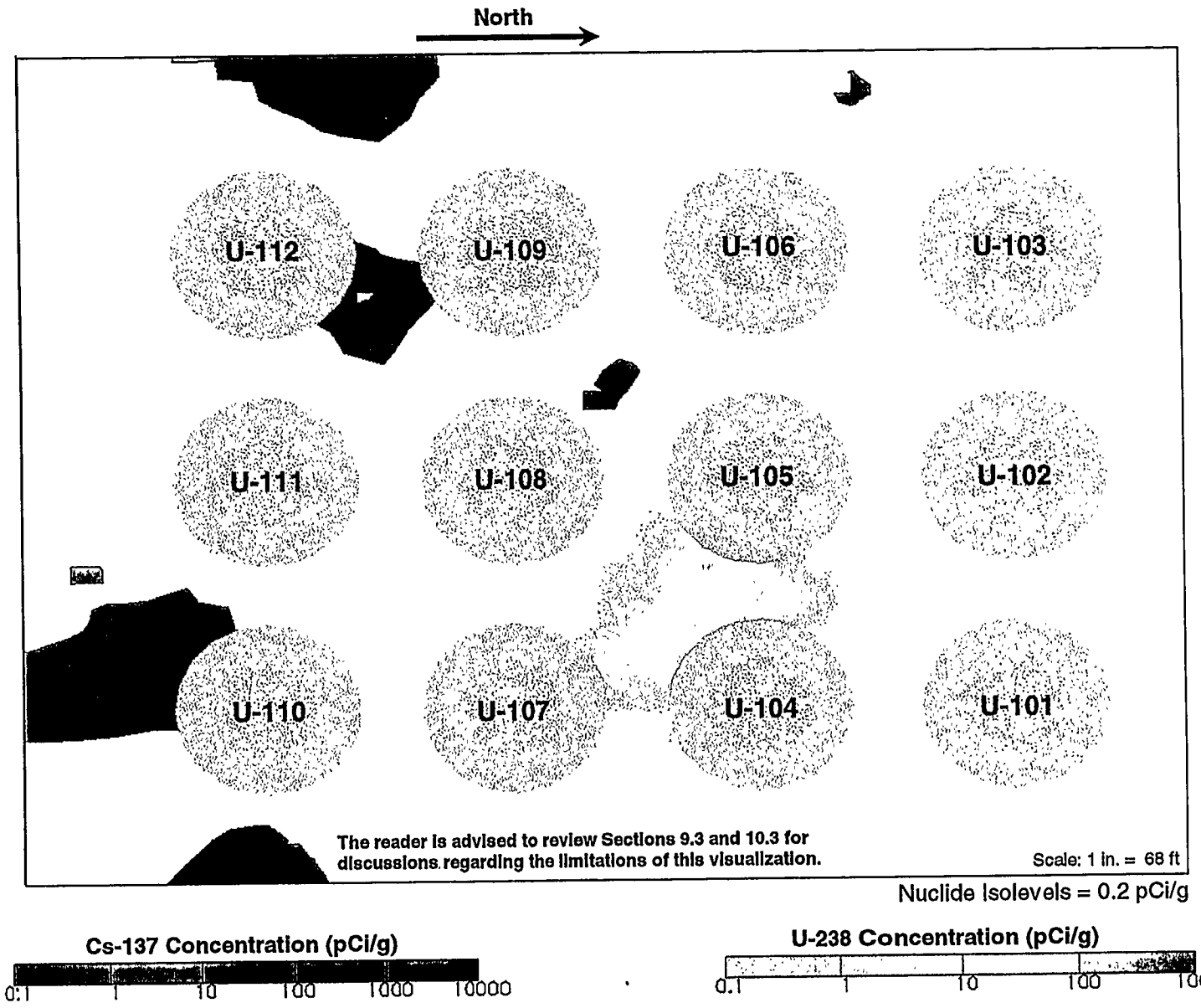


Figure 15-47. Visualization of the ^{137}Cs and ^{238}U Contamination 10 Ft Below the Bases of the U Tank Farm Tanks

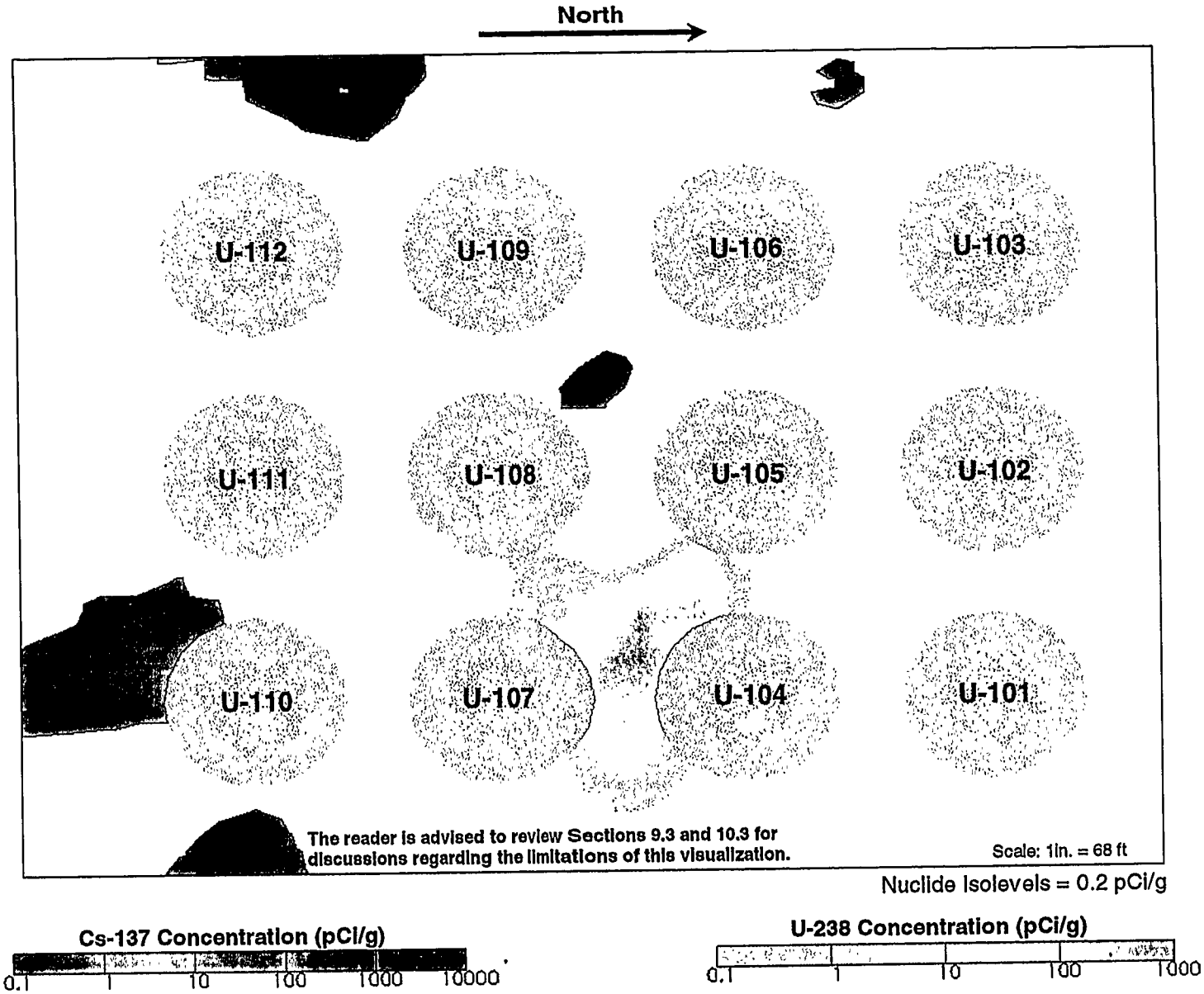


Figure 15-48. Visualization of the ^{137}Cs and ^{238}U Contamination 15 Ft Below the Bases of the U Tank Farm Tanks

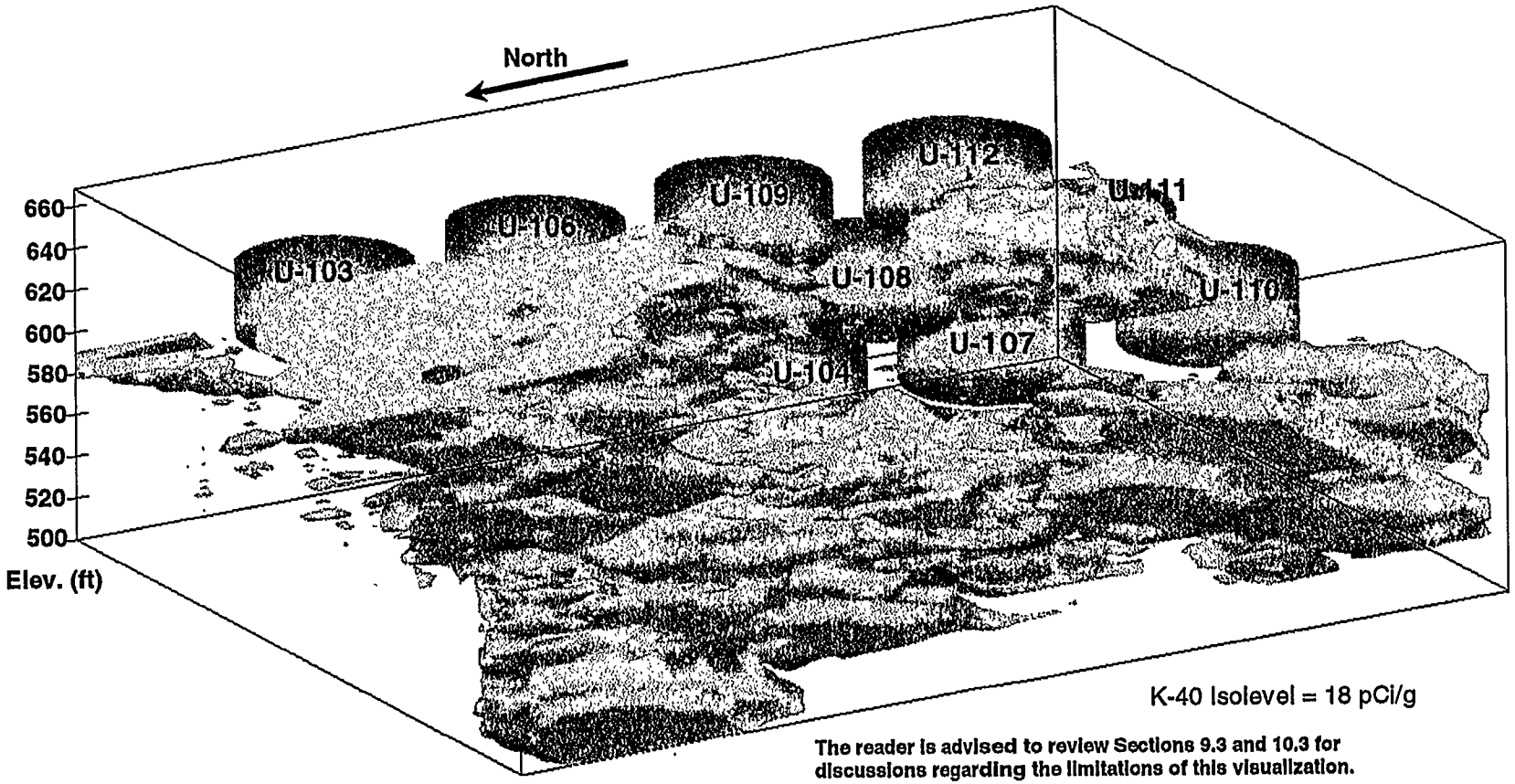


Figure 15-49. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g in the Sediments Surrounding the Tanks in the U Tank Farm Viewed From Below the Tanks From the Southwest

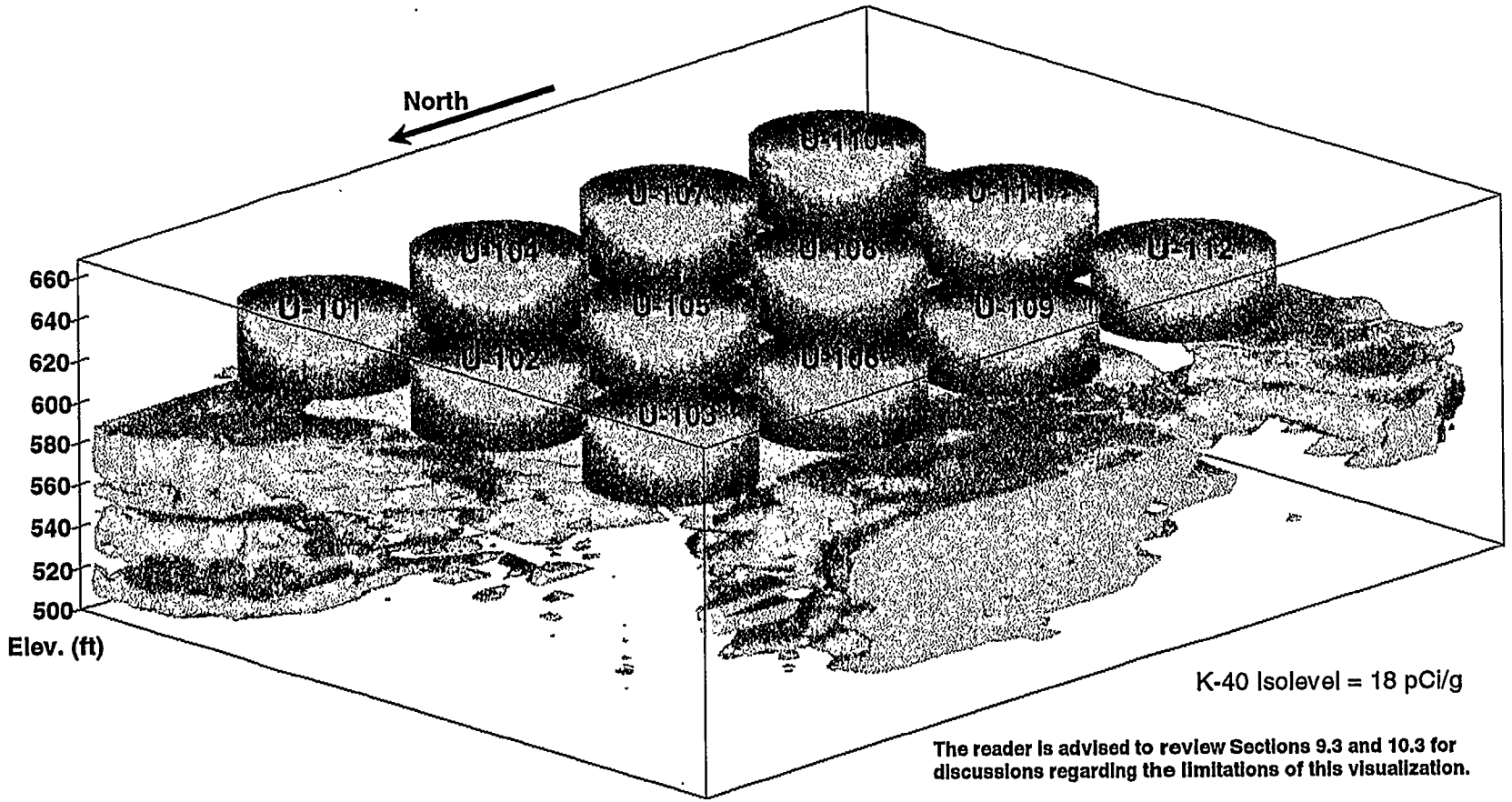


Figure 15-50. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g in the Sediments Surrounding the Tanks in the U Tank Farm Viewed From Above the Tanks From the Northwest

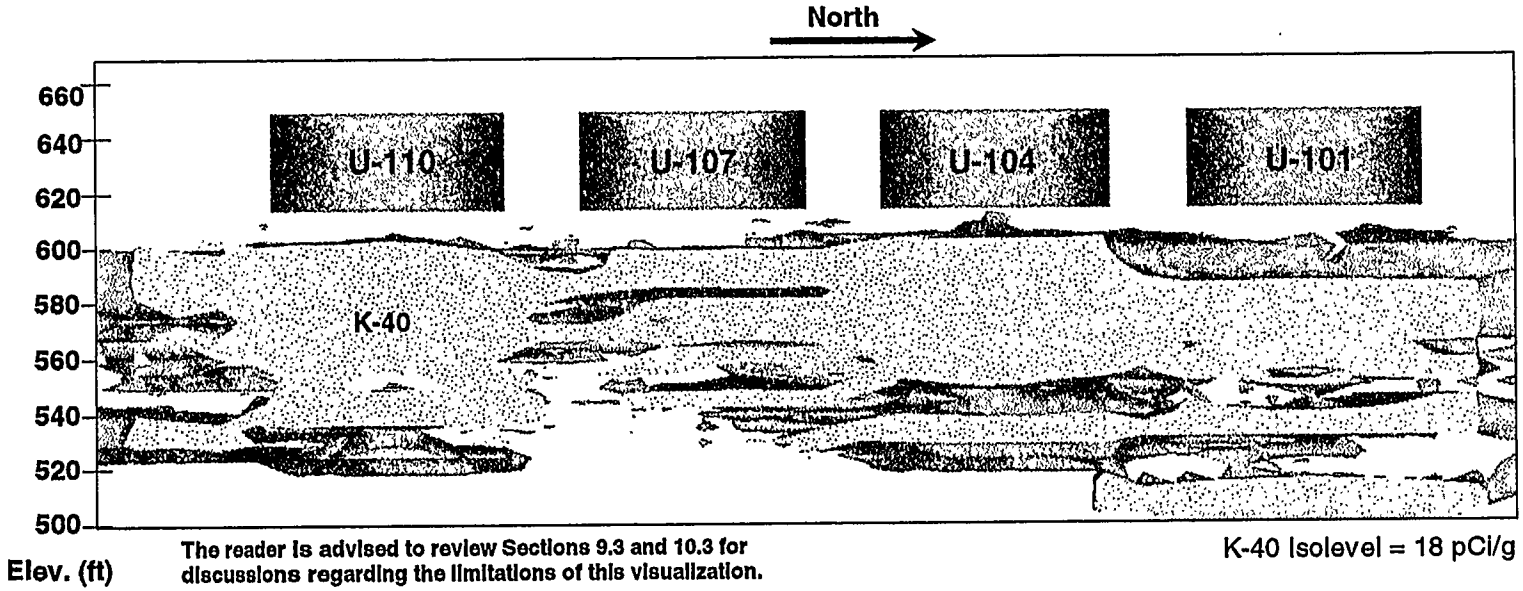


Figure 15-51. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g in the Sediments Surrounding the Tanks in the U Tank Farm Viewed From the East at Eye Level

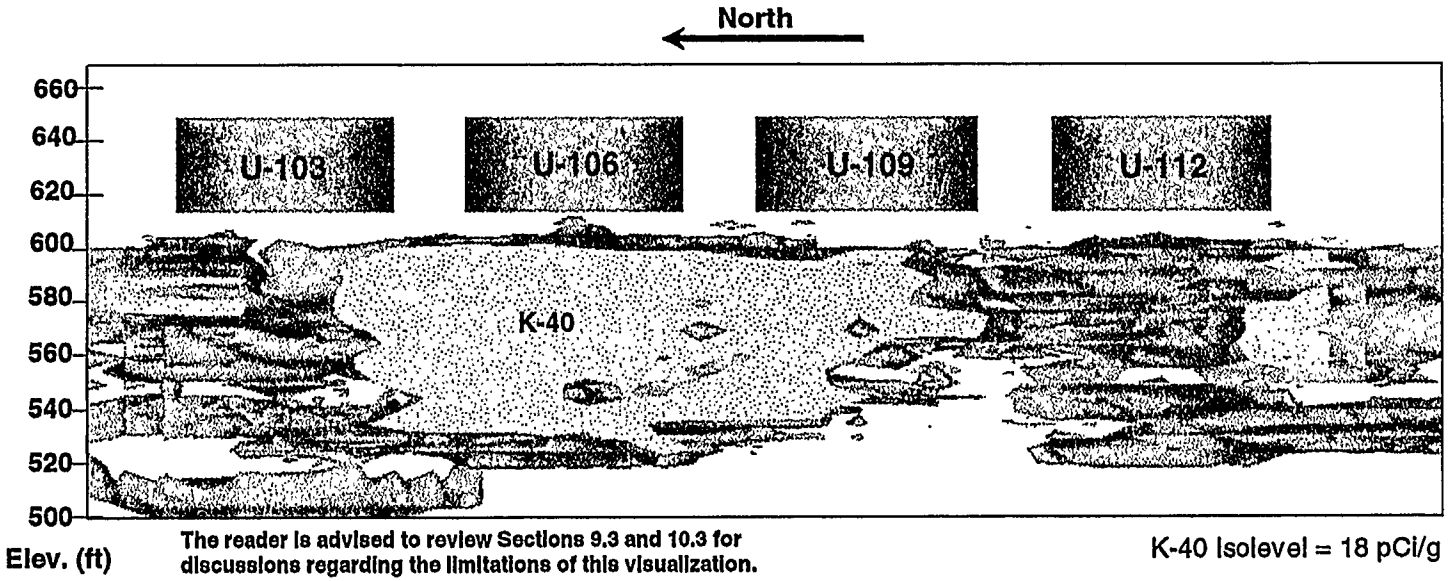


Figure 15-52. Visualization of the ^{40}K Concentrations Greater Than 18 pCi/g in the Sediments Surrounding the Tanks in the U Tank Farm Viewed From the West at Eye Level

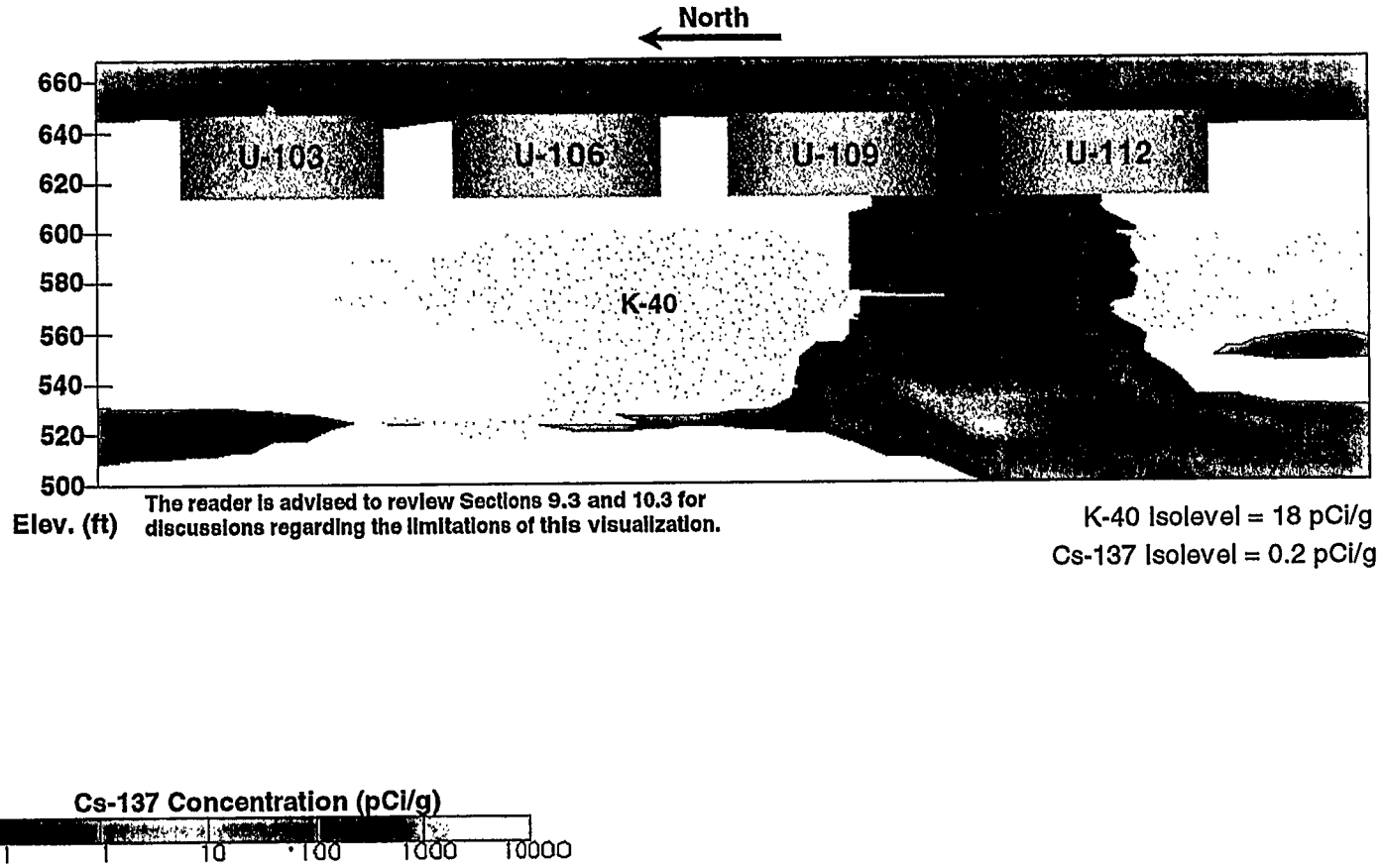


Figure 15-53. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g and ^{137}Cs Contamination Within a North-South-Oriented Slice Through the Centers of Tanks U-103 Through U-112

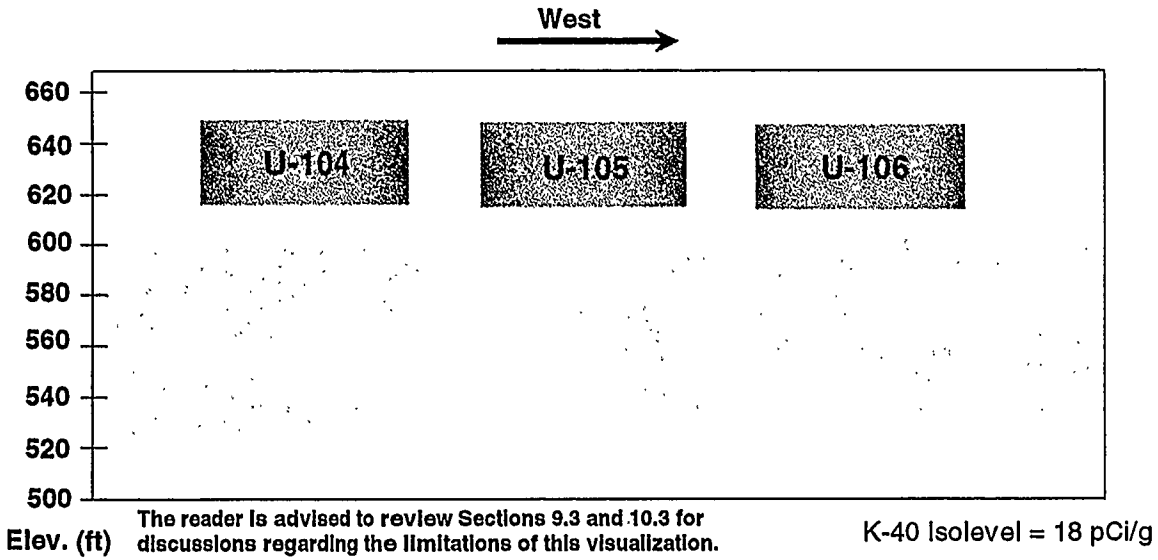


Figure 15-54. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g Within an East-West-Oriented Slice Between the U-104-to-U-106 and the U-107-to-U-109 Rows of Tanks Viewed From the North

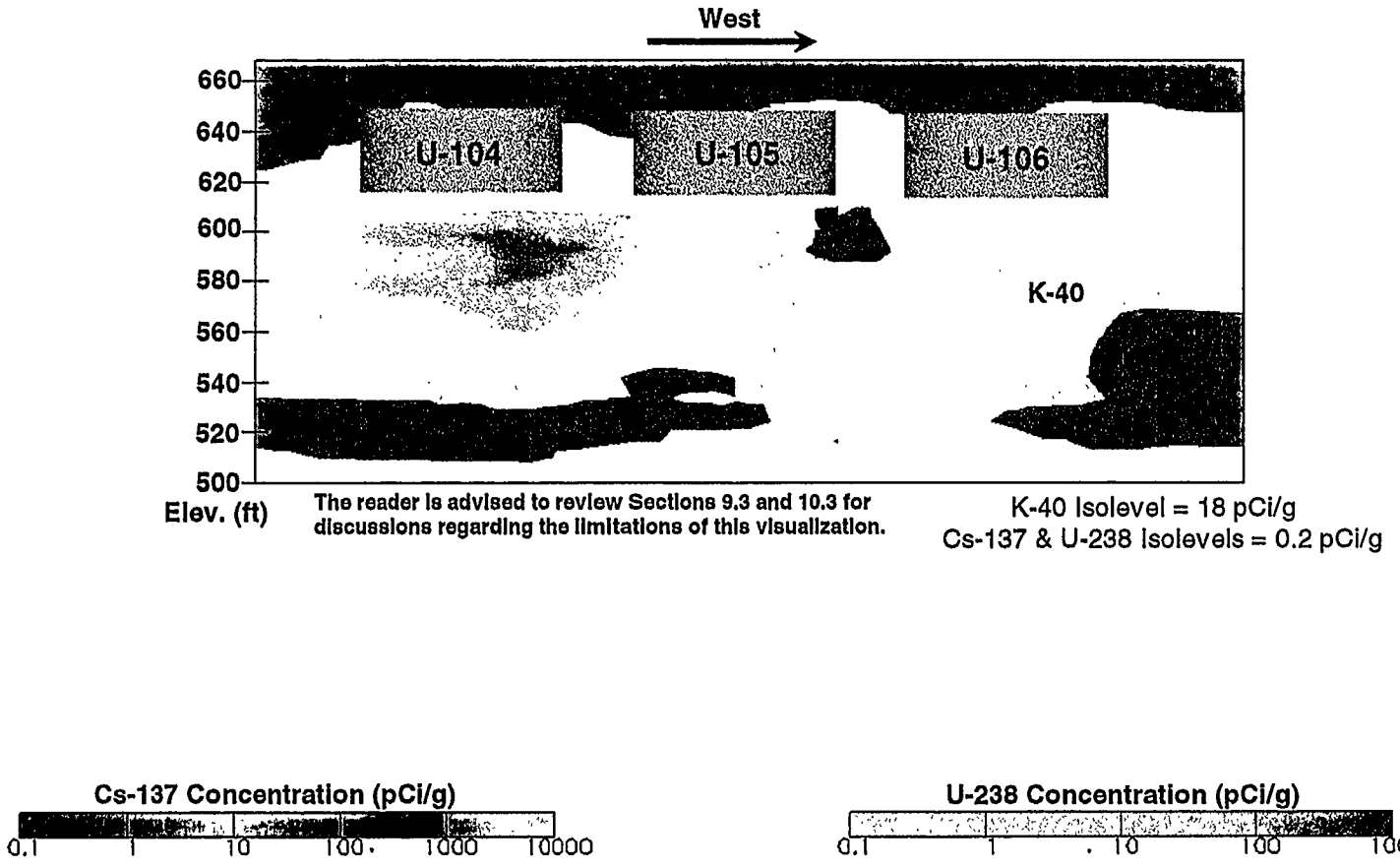


Figure 15-55. Visualization of the ^{40}K Concentrations Greater Than 18 pCi/g and the ^{137}Cs and ^{238}U Contamination Within an East-West-Oriented Slice Between the U-104-to-U-106 and the U-107-to-U-109 Rows of Tanks Viewed From the North

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

WELL SUMMARY SHEET

Boring or Well No. 299-W18-25

Sheet 1 of 2

Location 299-W18-25, U Tank Farm Project W-017 SST

Elevation 663.03 BEHIND CAP (NAVD'29) Drilling Contractor KEH

Driller Gary Lydin, Louis Watkins Drilling Method and Equipment Cable Tool

Prepared By MA Chamness, KO Parton Date 11/16/90 Reviewed By [signature] / [illegible] Date 11/21/90

AW Pearson, CD (Sign/Print Name) (Sign/Print Name)

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
		2.2		
		5		Sand
10" Carbon Steel Casing		10		Sl. Gravelly Sand
136.96' - +1.7' (TEMPORARY)		15		Sandy Gravel
CEMENT GROUT		20		" "
		25		Sand
GRANULAR BENTONITE 16-20 MESH		30		"
		35		Sand
		40		"
		45		"
		50		"
		55		"
4" Ø STAINLESS STEEL CASING		60		"
		65		"
		70		"
		75		"
		80		"
		85		"
		90		"
		95		"
		100		"
		105		"
		110		"
		115		"
		120		SILTY SAND
		125		" "
10"Ø CS CSG		127.9		
		130		SANDY SILT
HOLE PLUG BENTONITE CHUNKS		135		SILT TO SANDY SILT; caliche (?), 136'-
PURE GOLD BENTONITE GROUT		140		SILTY SANDY GRAVEL
8" carbon steel casing		145		" " "
215.01 - +3.0		150		" " "
(TEMPORARY)		155		" " "
		C-7 160		" " "
GRANULAR BENTONITE #8-20 MESH		165		

A-6000-384 (04/90)

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

WELL SUMMARY SHEET

Boring or Well No. 299-W18-25

Sheet 2 of 2

Location West side of U Tank Farm — Project W-017 SST

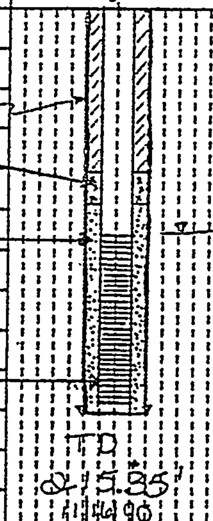
Elevation 663.03 Brass Cap (NGVD '29) — Drilling Contractor KEH

Driller Gary Lydin, Louis Watkins — Drilling Method and Equipment Cable tool

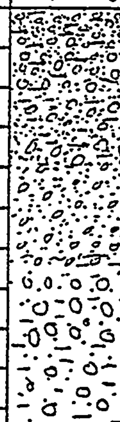
Prepared By NA Channum, KO Burton, AW Pearson, C. [illegible] (Sign/Print Name) — Date 11/16/90 — Reviewed By BA Williams (Sign/Print Name) — Date 11/21/[illegible]

CONSTRUCTION DATA — Description	Depth in Feet	GEOLOGIC/HYDROLOGIC DATA — Lithologic Description
8" Ø temporary (A200) steel casing 219.01' – +3.0' bls	165	
	170	Silty sandy gravel
		" " "
Bentonite pellets 1/4" to 1/2"	175	
	180	Silty sandy gravel
		" " "
8-12 mesh silica sand pack	185	Sandy gravel
	190	" "
	195.99 WL	
	195	
	200	Silty sandy gravel
4" I.D. type 304 stainless steel channel pack screen	205	Silty sandy gravel
	210	
	215	Silty sandy gravel

Diagram:

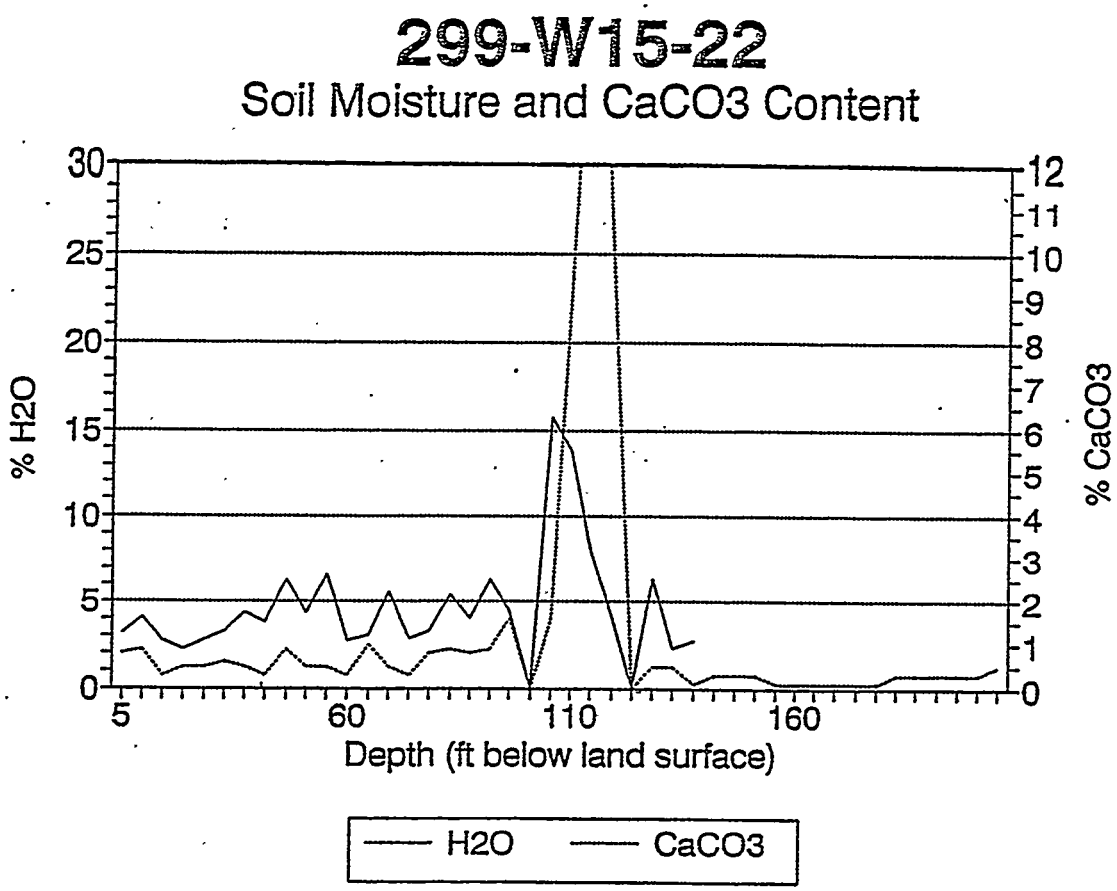


Graphic Log:



C-8

A-6000-384 (04/90)


299-W15-22
Soil Moisture and CaCO3 Content
% H2O
% CaCO3
30
25
20
15
10
5
0
12
11
10
9
8
7
6
5
4
3
2
1
0
5
60
110
160
Depth (ft below land surface)
H2O
CaCO3

B-5

Well 299-W15-22 Soil Moisture, CaCO3, and Radiological Content

DEPTH (ft)	H2O (%)	CaCO3 (%)	ALPHA (pCi/g)	BETA/GAMMA (pCi/g)
5	3.12	0.8	17.1	25.3
10	4.06	0.9	3.3	32.2
15	2.72	0.3	<D	11.3
20	2.24	0.5	2.9	27.8
25	2.78	0.5	<D	20.4
30	3.29	0.6	0.4	30.1
35	4.34	0.5	<D	22.5
40	3.80	0.3	0.3	20.5
45	6.27	0.9	<D	22.6
50	4.23	0.5	0.6	41.6
55	6.57	0.5	<D	41.5
60	2.69	0.3	0.8	47.9
65	3.07	1.0	0.9	40.8
70	5.55	0.5	0.3	46.1
75	2.87	0.3	1.9	38.0
80	3.26	0.8	<D	42.3
85	5.39	0.9	1.0	23.1
90	3.99	0.8	0.5	21.5
95	6.32	0.9	0.5	22.1
100	4.39	1.6	0.4	26.1
103	NA	NA	1.2	26.7
105	15.76	1.6	1.3	31.8
110	13.86	9.5	0.3	10.3
115	7.90	21.0	1.1	17.9
120	3.99	9.4	0.4	19.5
123	NA	NA	0.4	19.1
125	6.32	0.5	0.3	15.9
130	2.29	0.5	0.8	13.2
135	2.68	0.1	<D	14.0
140	NA	0.3	0.3	9.9
145	NA	0.3	0.7	14.0
150	NA	0.3	0.6	12.3
157	NA	0.1	<D	12.0
160	NA	0.1	0.8	16.6
165	NA	0.1	<D	14.3
170	NA	0.1	2.6	13.5
175	NA	0.1	0.7	9.9
180	NA	0.1	<D	15.0
185	NA	0.3	1.2	13.8
190	NA	0.3	1.0	11.3
195	NA	0.3	<D	14.8
200	NA	0.3	<D	11.8
205	NA	0.3	<D	9.2
210	NA	0.5	<D	12.5
215	NA	NA	<D	16.7

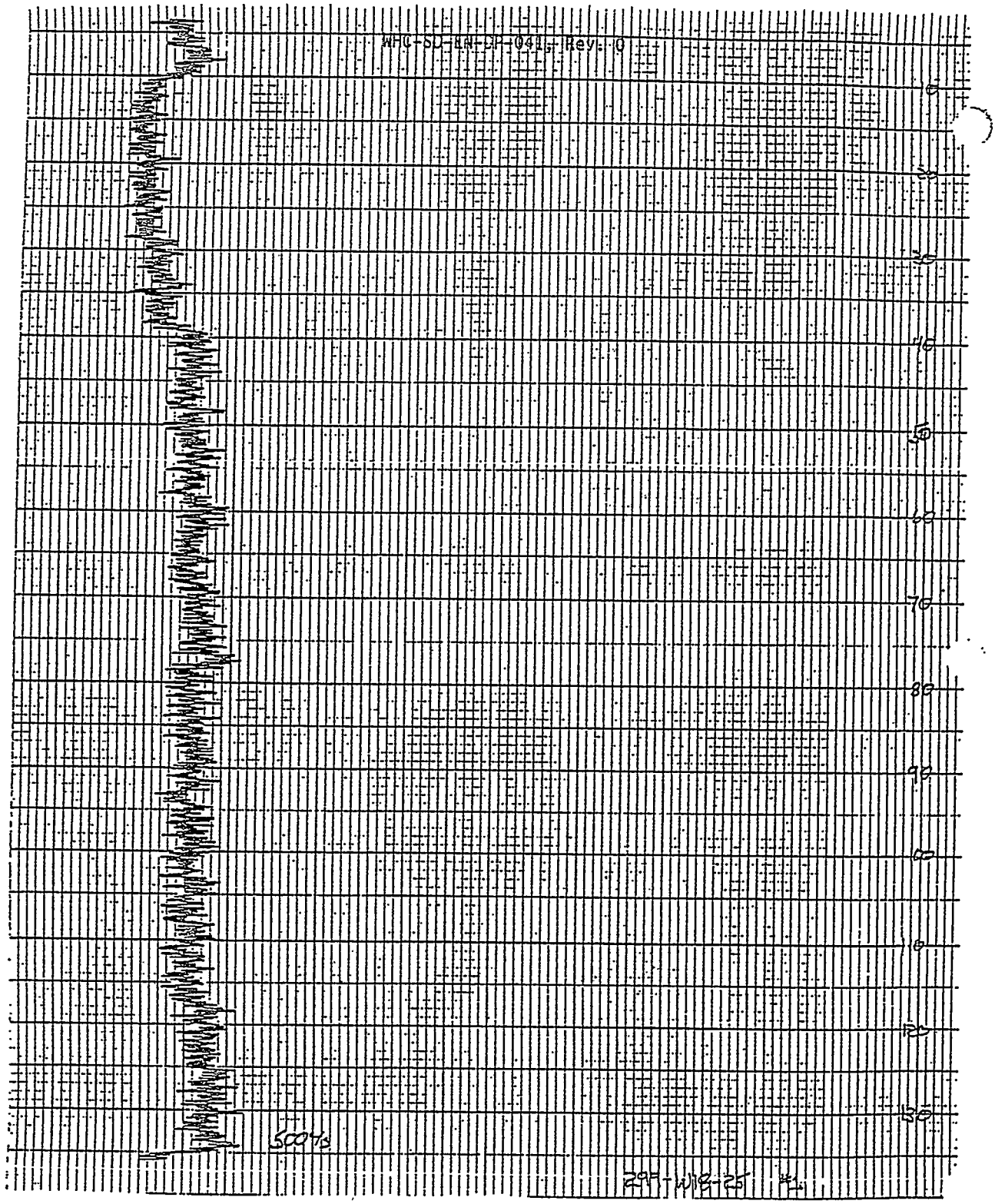
<D - Activity Less Than Background NA - Sample Not Collected or Missing

LOG HEADER	Page 1 of 2
Westinghouse Hanford Company	
Well No. 299-W18-25	Area 200 W Date 12/29/90
Log Run #1	Log Type Gross Gamma
Elevation Datum NGVD-'29	Elevation TOC 640.09
Survey Coordinates N 134,978.22	E 576,721.48
Log Measured From Ground Surface	
Location Description U-Tank Farm	
Ground Surface Elevation BRASS CAP 663.03	
Surface Temperature 9.3°C	Weather Partly Cloudy - Cool

BOREHOLE INFORMATION

Driller Gary Lydin	Bit Type/Diameter 10"/Core Barrel	Depth Logger 136.0	
Drill Rig Type Cable Tool		Liquid Density N/A	
Borehole Diameter(s)/Depth 10"/137.0'		CASING RECORD (up from)	
Depth Driller 137.3'		Liquid Level N/A	Interval 13' 136.9' - 4.7' Stickup
Temperature N/A		Type 10" Carbon Steel Sch. 40	Interval
		Type	Interval
		Type	Interval
		Wall Screen Interval N/A	
		Comments: Return Error: 0.37' high	

LOG HEADER	Page 2 of 2
EQUIPMENT DATA	
Logging Company PNL	
Operator(s) Alan Pearson	
Equipment Brand MLS	Equipment Type Analog
Tool Type Gamma Ray	Serial No. CG27A97
Base Calibration Date 8/90	Calibration Reference PNL-7460 UC-606
Calibration/Probe Factor 787 x 10⁻² cll/API Base Calibration Datum (eU):	Position 1 291.4 cll Position 2 48.5 cll
Dead Time 17.8 μsec	Warm Up Time 15 min
LOGGING INFORMATION	
Log Interval From 136.0'	To 3.4'
Rerun(s) 136.0' to 105.0' ; 135.7' to 3.4' ; 135.6' to 3.4'	
Pre Survey Verification: Position 1 269.2 cll	Position 2 48.0 cll Background 80 cps
Base Calibration Difference: Position 1 -22.2 cll	Position 2 0.5 cll
Logging Speed 5 ft/min	Rerun Scales, CPS/in. 50 cps/in
Start Time 0720	Completion Time 1100
Chart Speed(s), in/in. 10 ft/in	
Chart Recorder Horizontal Scale, CPS/in. 50 cps/in	Time Constant(s) TC=1
Post Survey Verification: Position 1 268.8 cll	Position 2 47.6 cll Background 95 cps
Percent Change: Position 1 0.1%	Position 2 0.8%
Comments Return Error: 0.37' high	
Ran 2 extra repeat sections using a centralizer	
A-13	
Witnessed and Verified by: (sign and print name) Randall Price RANDALL PRICE	Date: 29 Oct 90


WHC-SD-ENV-DP-041, Rev. 0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
500 ft
299-W18-25 #1

A-14

Page 1 of 2

LOG HEADER

Westinghouse Hanford Company

Well No. 299-W18-25 Area 200W Date 11/29/90
Log Run #2 Log Type Gross Gamma
Elevation Datum NGVD-29 Elevation TOC 696.04
Survey Coordinates 134,278.22 N 576,721.48 E
Log Measured From Ground Surface Location Description 3 of 18 Tank Farm
Ground Surface Elevation BRASS CAP 663.0 ft
Surface Temperature 14.0°C Weather Cloudy - Rain

BOREHOLE INFORMATION

Driller Lewis Watkins
Drill Rig Type Cable Tool Bit Type/Diameter 8" Hunt Tool
Borehole Diameter(s)/Depth 10"/136.9' 8"/215.0'
Depth Driller 215.4' Depth Logger 214.6'
Liquid Level 193.4' Liquid Remarks Apparent - Casing
Temperature 16.8°C

CASING RECORD

Type N/A Interval N/A
Type 10" Carbon Steel Sch. 40 Interval 4.5' - 136.96'
Type 8" Carbon Steel Sch. 40 Interval 30' - 215.01'
Type Interval
Well Screen Interval N/A

Comments: Return Error = 0.3' high
Generator overheated during logging. Remarks affected section.

A-6000 (10/91)WHC

Page 2 of 2

LOG HEADER

EQUIPMENT DATA

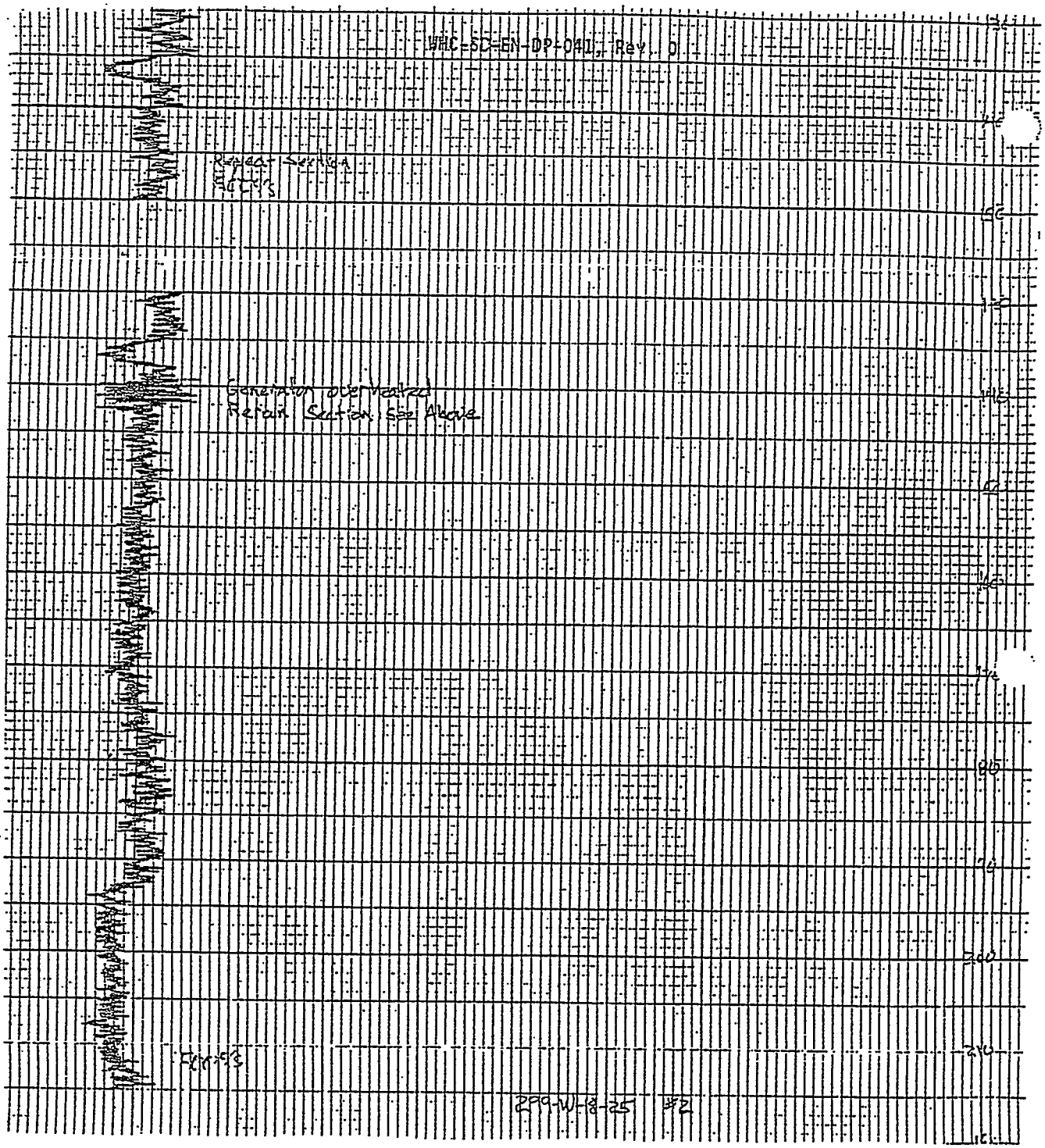
Logging Company PNL
Operator(s) Alan Pearson
Equipment Brand MLS Equipment Type Analog
Tool Type Gamma Ray Serial No. CG27A97
Base Calibration Date 8/90 Calibration Reference PNL-7460 UC-606
Calibration/Probe Factor 1.37E+02 cU Base Calibration Datum (eU): Position 1 291.4 eU Position 2 148.5 eU
Dead Time 17.8 usec Warm Up Time >15 min

LOGGING INFORMATION

Log Interval From 214.6' To ~~25~~ 130.0' DLC 4/23/90
Rerun(s) 214.6' to 130.0' & 150.0' to 130.0'
Pre Survey Verification: Position 1 269.5 eU Position 2 48.4 eU Background 75 c/s
Base Calibration Difference: Position 1 21.9 eU Position 2 0.1 eU
Logging Speed 5 ft/min Rerun Scales, CPS/in. 60 c/s/in
Start Time 1250 Completion Time 1440
Chart Speed(s), f/in. 10 ft/in.
Chart Recorder Horizontal Scale, CPS/in. 50 c/s/in Time Constant(s) TC-1
Post Survey Verification: Position 1 269.5 eU Position 2 48.4 eU Background 75 c/s
Percent Change: Position 1 0.0% Position 2 0.0%
Comments Return Error = 0.3' high

A-15

Witnessed and Verified by: (sign and print name) Steven E. Kos STEVEN E. KOS Date: 11/29/90


WHC-SD-EN-DP-041, Rev. 0
Generation overlapped
Refer. Section 5.2.2 Above
299-W-18-25 #2

A-16

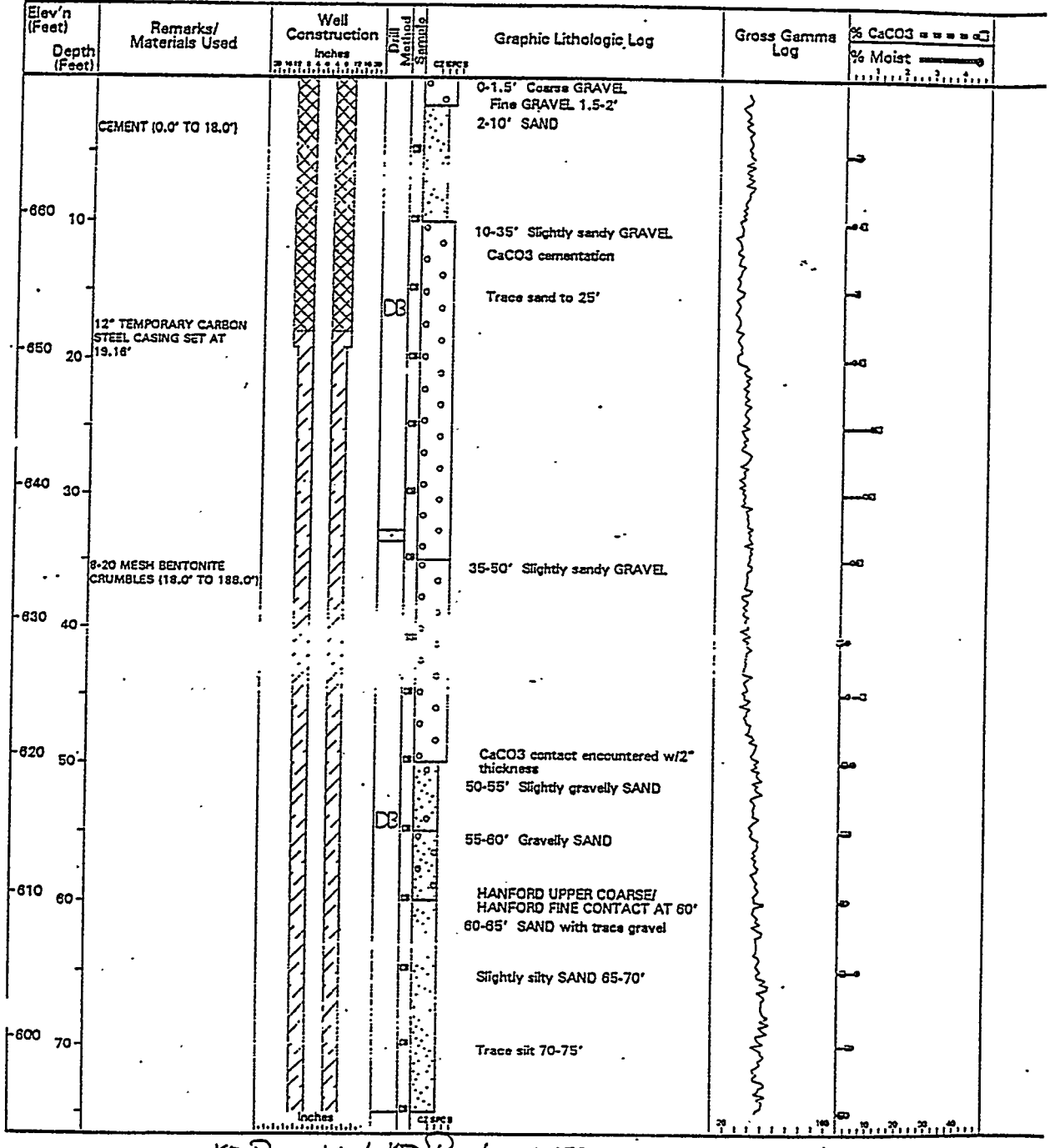
Project:	W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION	**Well No:**	299-W18-30		Page 1 of 3
Total Depth:	235.30	Static Water Level:	201.2		
Date Started:	9-11-91	Date Completed:	12-10-91	Surface Elevation:	669.44
Casing Elevation:	672.3				
Location:	241 U TANK FARM, 200 WEST	Northing:	135193.95	Easting:	566871.0
Prepared By:	DJ ANDERSON	Hanford N:	38492.80	Hanford W:	75541.4
Drilling Co:	KEH	Driller:	D KRUGER	Drill Meth:	CABLE TOOL
Drill Equip:					

Screen: 36.8' OF 4" DIAMETER 20-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 197.5' TO 234.3'

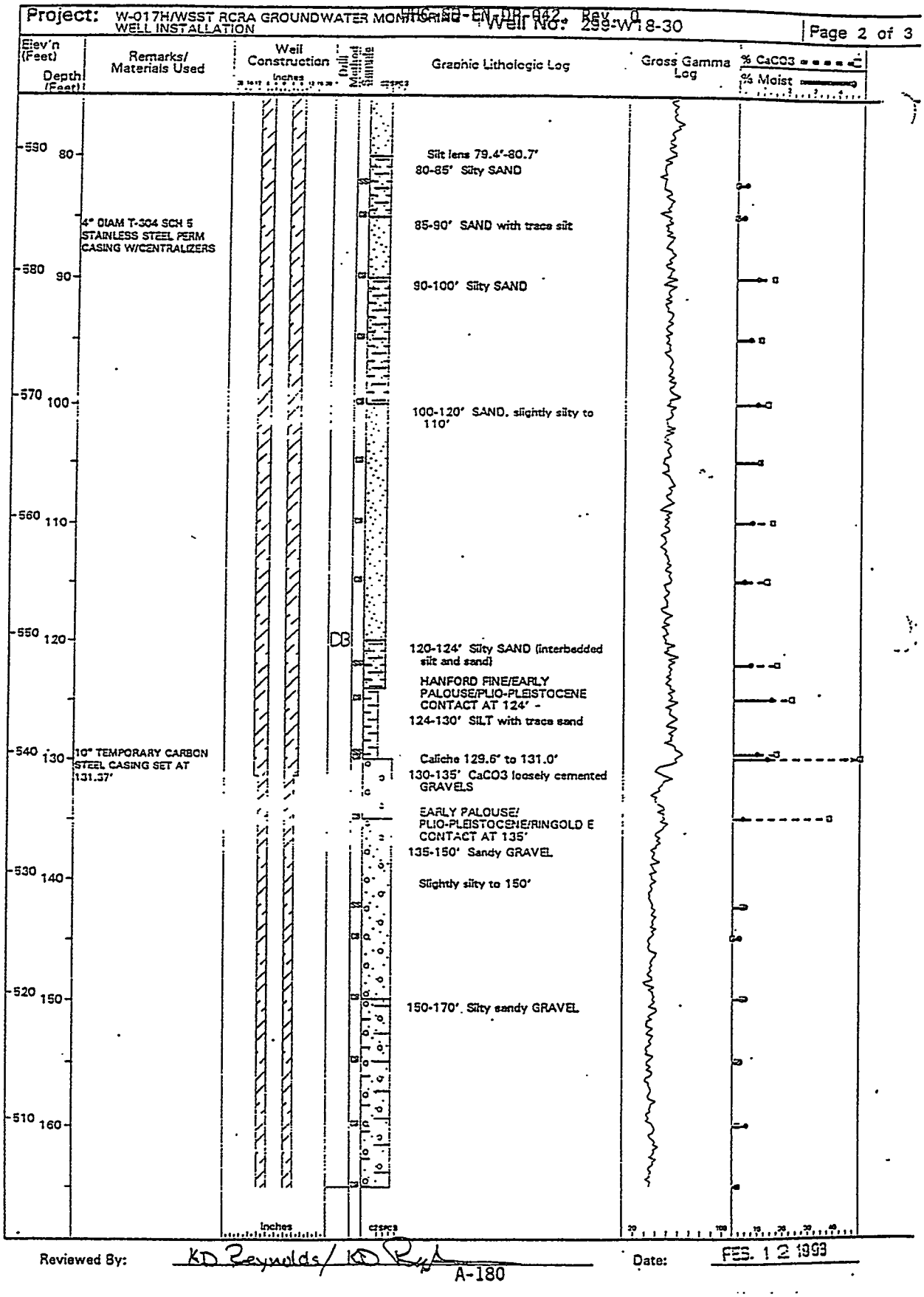
Filter Pack: 10-20 MESH SILICA SAND FROM 193.3' TO 233.7'

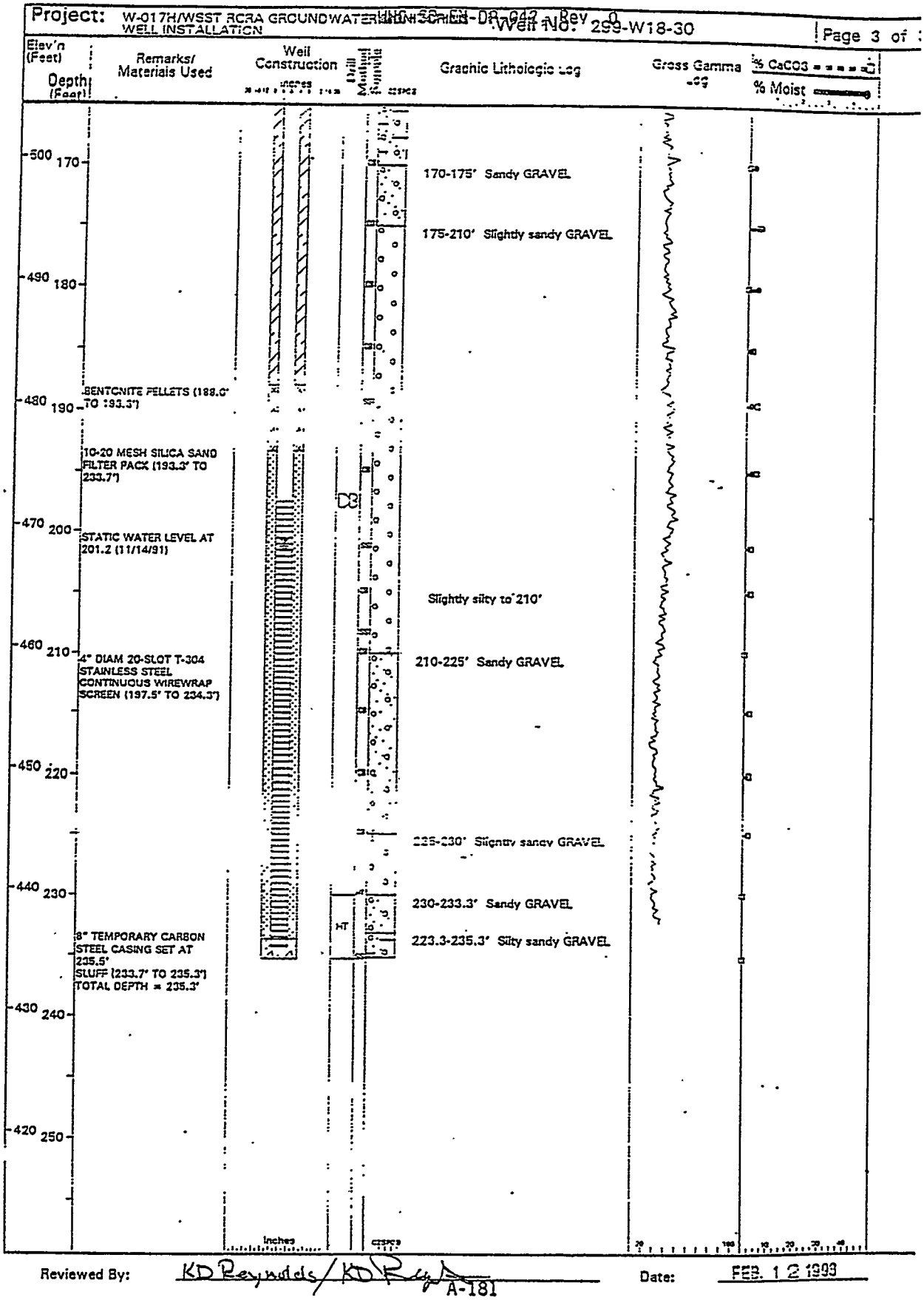
Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 197.5'

Comments:



Reviewed By: KD Reynolds/ KD Rey A-179 Date: FEB 1 2 1993

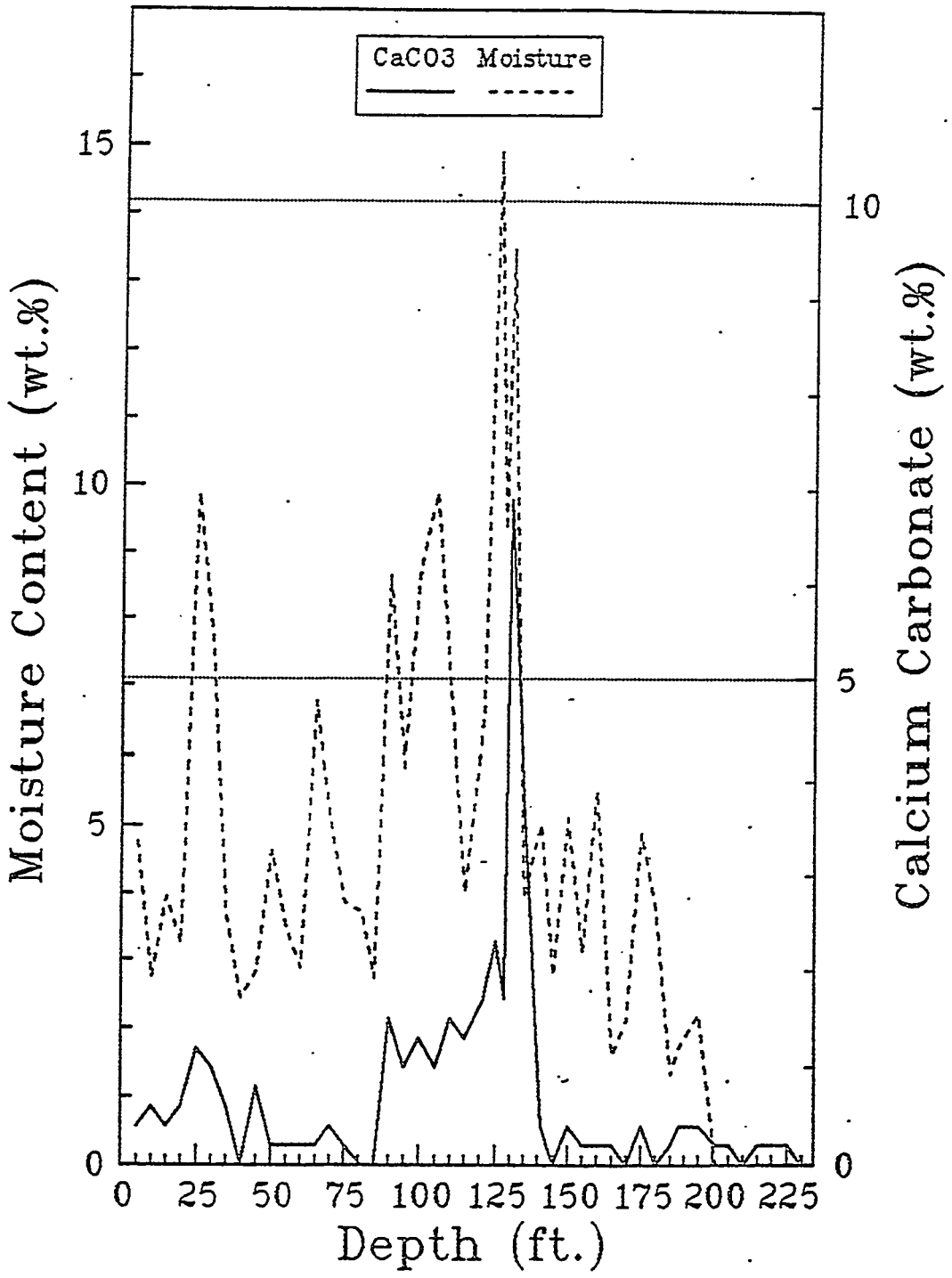

Project: W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION
HNF-SD-EN-DR-042 Rev. 0
Well No: 299-W18-30
Page 2 of 3
Elev'n (Feet)
Depth (Feet)
Remarks/ Materials Used
Well Construction
Inches
Graphic Lithologic Log
Gross Gamma Log
% CaCO3
% Moist
590 80
580 90
570 100
560 110
550 120
540 130
530 140
520 150
510 160
4" DIAM T-304 SCH 5 STAINLESS STEEL PERM CASING W/CENTRALIZERS
10" TEMPORARY CARBON STEEL CASING SET AT 131.37'
DB
Silt lens 79.4'-80.7'
80-85' Silty SAND
85-90' SAND with trace silt
90-100' Silty SAND
100-120' SAND, slightly silty to 110'
120-124' Silty SAND (interbedded silt and sand)
HANFORD FINE/EARLY PALOUSE/PLIO-PLEISTOCENE CONTACT AT 124' -
124-130' SILT with trace sand
Caliche 129.6' to 131.0'
130-135' CaCO3 loosely cemented GRAVELS
EARLY PALOUSE/ PLIO-PLEISTOCENE/RINGOLD E CONTACT AT 135'
135-150' Sandy GRAVEL
Slightly silty to 150'
150-170'. Silty sandy GRAVEL
Inches
Reviewed By: KD Reynolds/ KD Rey
A-180
Date: FEB. 12 1993


Project: W-017H/WSST RCRA GROUNDWATER MONITORING
WELL INSTALLATION
HNF-SD-EN-DR-042, Rev. 0
Well No: 299-W18-30
Page 3 of
Elev'n (Feet)
Depth (Feet)
Remarks/ Materials Used
Well Construction
Drill Method
Graphic Lithologic Log
Gross Gamma
% CaCO3
% Moist
500 170
490 180
480 190
470 200
460 210
450 220
440 230
430 240
420 250
170-175' Sandy GRAVEL
175-210' Slightly sandy GRAVEL
Slightly silty to 210'
210-225' Sandy GRAVEL
225-230' Slightly sandy GRAVEL
230-233.3' Sandy GRAVEL
223.3-235.3' Silty sandy GRAVEL
BENTONITE PELLETS (188.0' TO 193.3')
10-20 MESH SILICA SAND FILTER PACK (193.3' TO 233.7')
STATIC WATER LEVEL AT 201.2 (11/14/91)
4" DIAM 20-SLOT T-304 STAINLESS STEEL CONTINUOUS WIREWRAP SCREEN (197.5' TO 234.3')
8" TEMPORARY CARBON STEEL CASING SET AT 235.5'
SLUFF (233.7' TO 235.3')
TOTAL DEPTH = 235.3'
HT
Inches
Reviewed By: KD Reynolds/KD Reynolds
Date: FEB. 12 1993

A-181

VALIDATED
KDR 3/19/92
SIGNATURE/DATE

WELL 299-W18-30



C-61

	A	B	C
1	WELL 299-W18-30		
2			
3	Depth	CaCO3	Moisture
4	ft.	Wt. %	Wt. %
5			
6	5	0.4	4.76
7	10	0.6	2.73
8	15	0.4	3.94
9	20	0.6	3.24
10	25	1.2	9.87
11	30	1	7.73
12	35	0.6	3.64
13	39-41	0	2.43
14	45	0.8	2.82
15	50	0.2	4.61
16	55	0.2	3.47
17	60	0.2	2.88
18	65	0.2	6.75
19	70	0.4	5.09
20	75	0.2	3.86
21	80-82	0	3.71
22	85	0	2.71
23	90	1.5	8.64
24	95	1	5.88
25	100	1.3	8.77
26	105	1	9.89
27	110	1.5	6.91
28	115	1.3	4.01
29	120-122	1.7	6.59
30	125	2.3	14.90
31	127-129	1.7	9.33
32	130	6.9	13.47
33	135	3.8	3.93
34	140-141	0.4	5.03
35	145	0	2.76
36	150	0.4	5.11
37	155	0.2	3.12
38	160	0.2	5.52
39	165	0.2	1.59
40	170	0	2.11
41	175	0.4	4.88
42	180	0	3.76
43	185	0.2	1.32
44	187-189	0.4	1.71
45	195	0.4	2.20
46	199-201	0.2	
47	205	0.2	

37

	A	B	C
48	210	0	
49	215	0.2	
50	220	0.2	
51	225	0.2	
52	230	0	
53	233-235	0	

* Collected Below Static Water Table.

WHC-SD-EN-DH-042, Rev. 0

Project: W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION

Well No: 299-W18-31 | Page 1 of 3

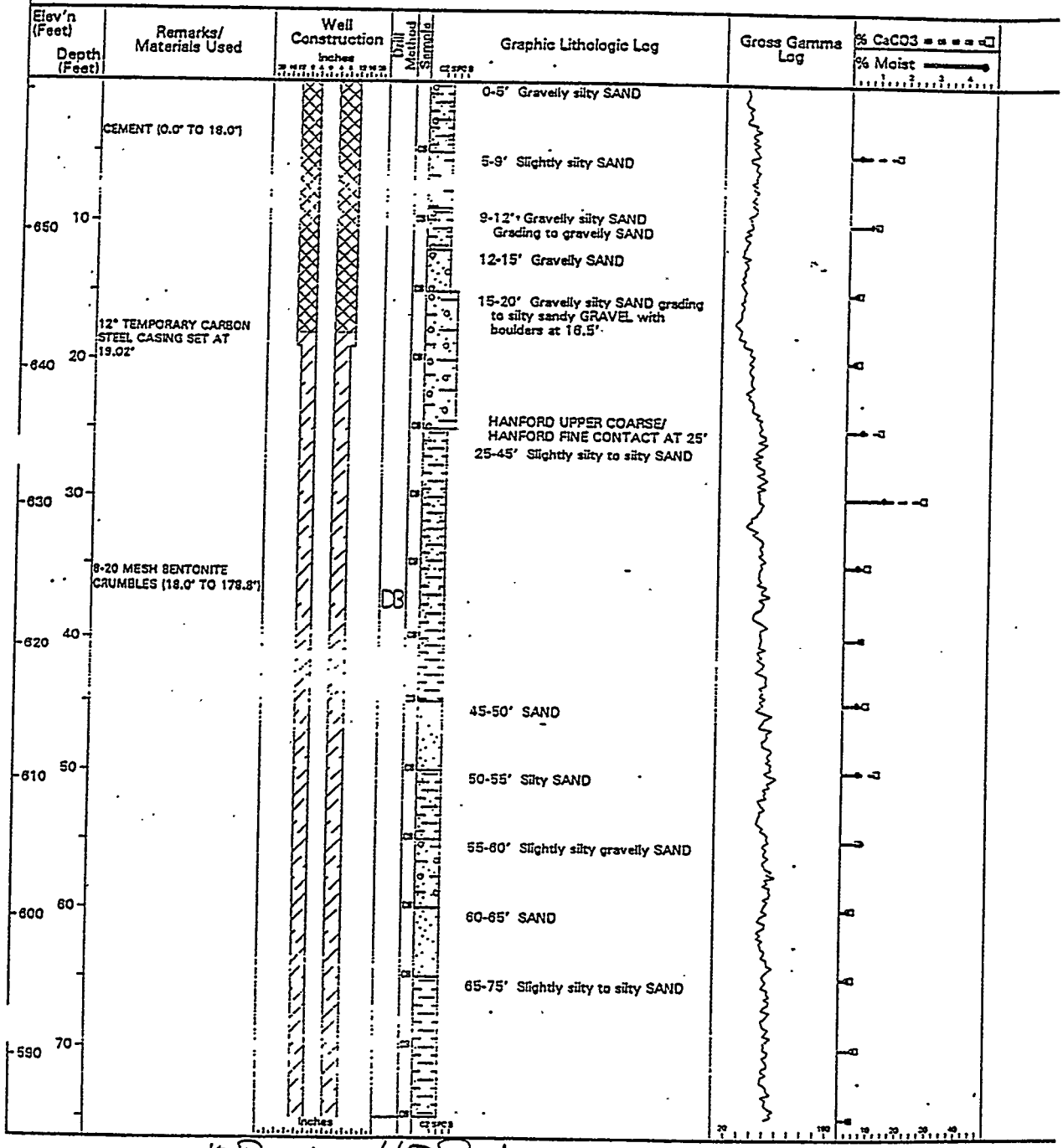
Date Started: 9-5-91	Date Completed: 12-14-91	Total Depth: 227.57	Static Water Level: 191.2
Location: U TANK FARM, 200 WEST		Surface Elevation: 860.73	Casing Elevation: 864.1
Prepared By: R WEINGARZ, et al.		Northing: 135075.47	Easting: 566721.3
Drilling Co: KEH	Driller: H BAKER	Hanford N: 38105.30	Hanford W: 76032.1
		Drill Meth: CABLE TOOL	Drill Equip: BE 60

Screen: 35.00' OF 4" DIAMETER 10-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 187.3' TO 222.3'

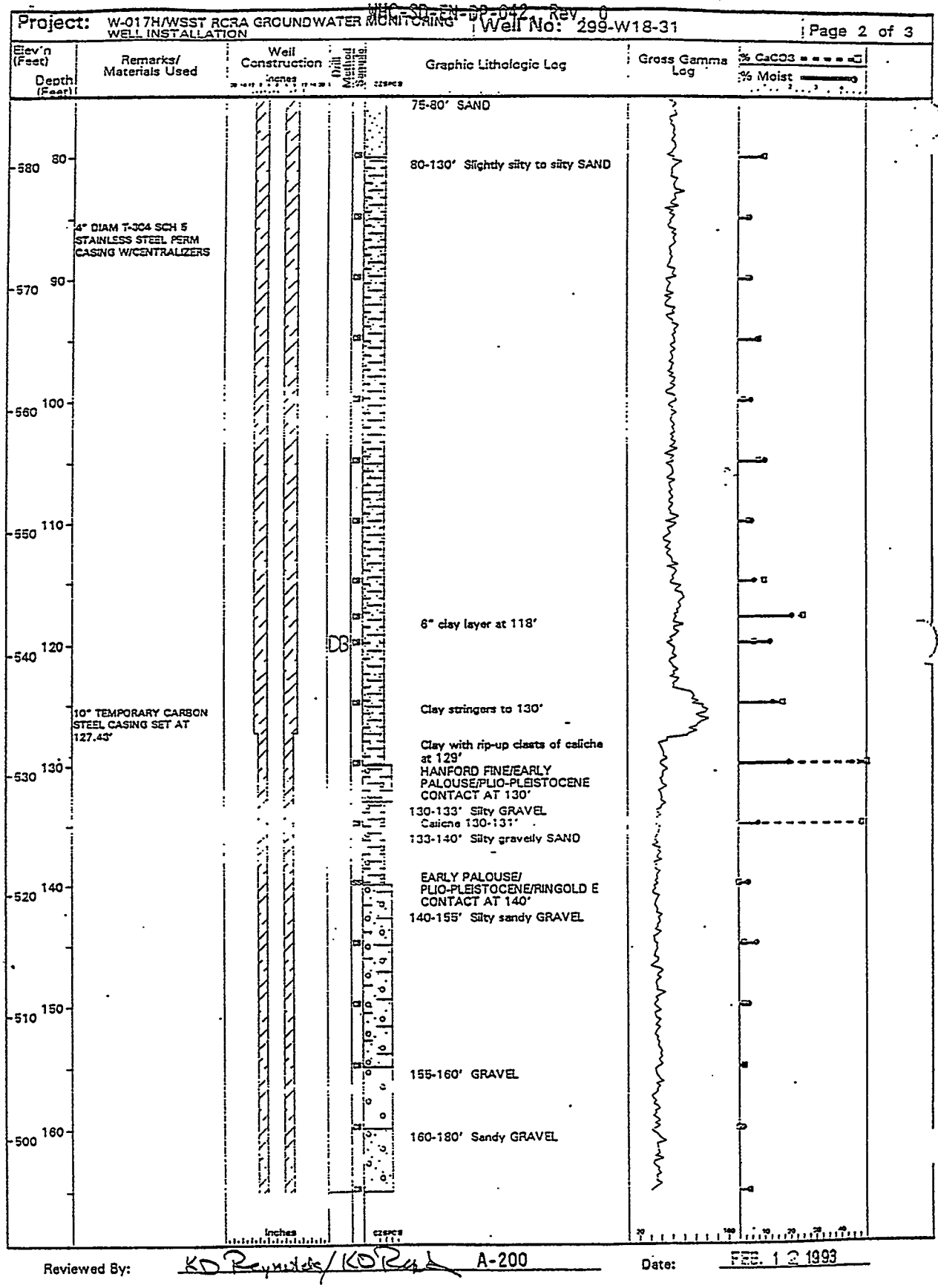
Filter Pack: 20-40 MESH SILICA SAND FROM 181.5' TO 226.0'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 187.3'

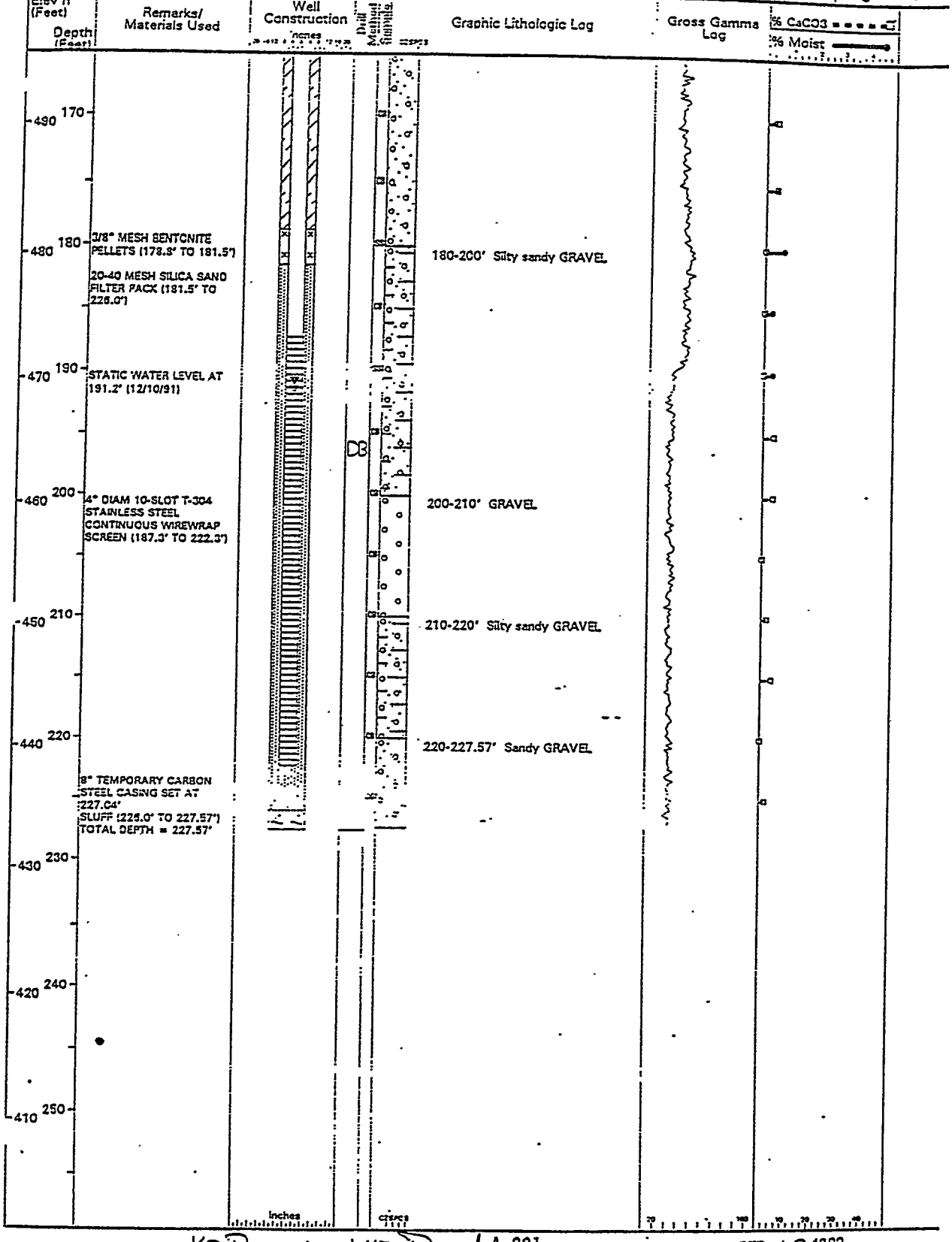
Comments:



Reviewed By: KD Reynolds / KD Ruthe 8-199 Date: FEB. 1 2 1993


Project: W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION
Well No: 299-W18-31
Page 2 of 3
Elev'n (Feet)
Depth (Feet)
Remarks/ Materials Used
Well Construction
Inches
Drill Method
Graphic Lithologic Log
Gross Gamma Log
% CaCO3
% Moist
75-80' SAND
80-130' Slightly silty to silty SAND
4" DIAM T-304 SCH 5 STAINLESS STEEL PERM CASING W/CENTRALIZERS
6" clay layer at 118'
10" TEMPORARY CARBON STEEL CASING SET AT 127.43'
Clay stringers to 130'
Clay with rip-up clasts of caliche at 129'
HANFORD FINE/EARLY PALOUSE/PLIO-PLEISTOCENE CONTACT AT 130'
130-133' Silty GRAVEL
Caliche 130-131'
133-140' Silty gravelly SAND
EARLY PALOUSE/ PLIO-PLEISTOCENE/RINGOLD E CONTACT AT 140'
140-155' Silty sandy GRAVEL
155-160' GRAVEL
160-180' Sandy GRAVEL
580
570
560
550
540
530
520
510
500
80
90
100
110
120
130
140
150
160
DB
Inches
Reviewed By: KD Reynolds/KD Reynolds A-200
Date: FEB. 1 2 1993

Project: W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION | Well No: 299-W18-31 | Page 3 of 3

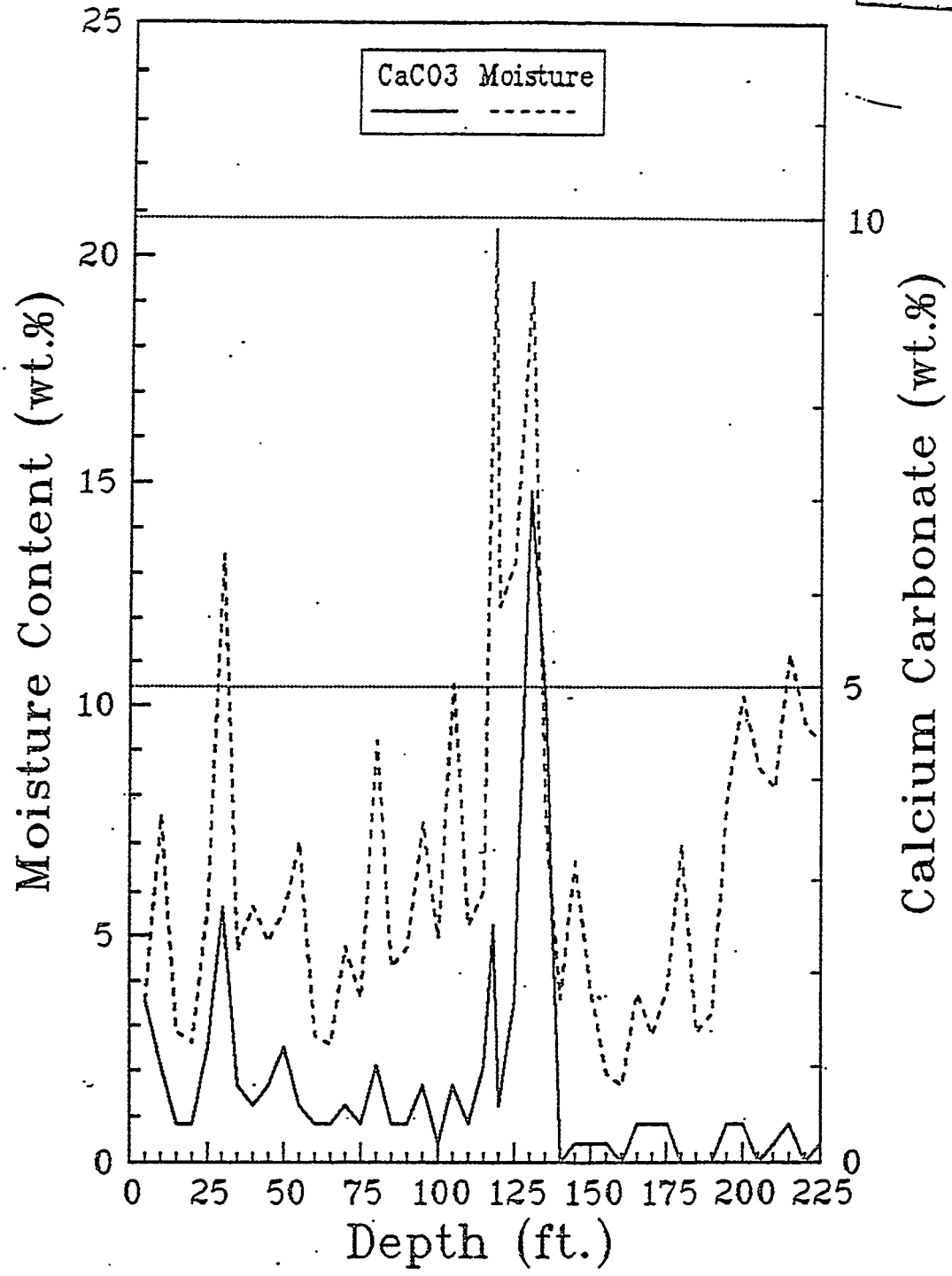


Reviewed By: KD Reynolds / KD Rey LA-201 Date: FEB. 12 1993

193

KDR 3/19/92

WELL 299-W18-31



C-69

293

	A	B	C
1	WELL 299-W18-31		
2			
3	Depth	CaCO3	Moisture
4	ft.	Wt. %	Wt. %
5			
6	5	1.7	3.55
7	10	1	7.58
8	15	0.4	2.85
9	20	0.4	2.61
10	25	1.2	5.58
11	30	2.7	13.40
12	35	0.8	4.65
13	40	0.6	5.66
14	45	0.8	4.84
15	50	1.2	5.53
16	55	0.6	7.04
17	60	0.4	2.76
18	65	0.4	2.56
19	70	0.6	4.74
20	75	0.4	3.59
21	80	1	9.19
22	85	0.4	4.28
23	90	0.4	4.71
24	95	0.8	7.43
25	100	0.2	4.92
26	105	0.8	10.48
27	110	0.4	5.21
28	115	1	6.04
29	118	2.5	20.58
30	120	0.6	12.25
31	125	1.7	13.22
32	130	7.1	19.42
33	135	4.8	7.44
34	140	0	3.58
35	145	0.2	6.64
36	150	0.2	3.75
37	155	0.2	1.92
38	160	0	1.66
39	165	0.4	3.72
40	170	0.4	2.78
41	175	0.4	3.79
42	180	0	6.99
43	185	0	2.83
44	190	0	3.25
45	195	0.4	8.03
46	200	0.4	10.19
47	205	0	8.62

AS-BUILT DIAGRAM

Boring or Well Number 299-W19-1 Sheet 1 of 2

Location Camden Ave. (1/2 E.W. 200W) Project

Logged by Driller: Row-Roberts

Reviewed by Date

Date Well Started 4/15/57

Date Well Completed

Well Construction Data			Depth in Feet	Geologic/Hydrologic Data	
	Drill Bit			Sample Method	Data from Driller's Log
Description	Construction Diagram			Lithologic Diagram	Lithologic Description
301.8' of 8" Carbon Steel Casing (+1.5'-300.3')			5		Top soil-sand-Gravel @ 4'-silt
			10		Gravel and Boulders
			15		" "
			20		" "
			25		Sand-gravel-silt
			30		Gravel, Caves loose water
			35		Pure Gravel " " "
			40		" " - 3' sand and gravels
			45		Gravel. Caves loose water
			50		Gravel-sand " " "
			55		Sand-some silt Caves
			60		" " " "
			65		" " " " Tan
			70		Sandy-some silt-Tan
			75		" " " "
			80		" " " "
			85		" " " "
			90		" " " "
			95		" " " "
			100		Sandy-Tan silt
			105		" " "
			110		" " "
			115		" " "
			120		" " "
			125		" " "
			130		" " "
			135		Heavy silt and sand
			140		" " " "
			145		" " " "
			150		Heavy silt-sand-Caliche-some gravels
			155		Fine sand
			160		" " "
			165		Gravel-Sand Caves loose water

Drill Bit/Sample Method Used:
Rotary | Air Rotary | Mud Rotary | Air Percussion | Back Hoe | Auger | Drive Barrel | Hand Tool | Split-Barrel

K-20-5

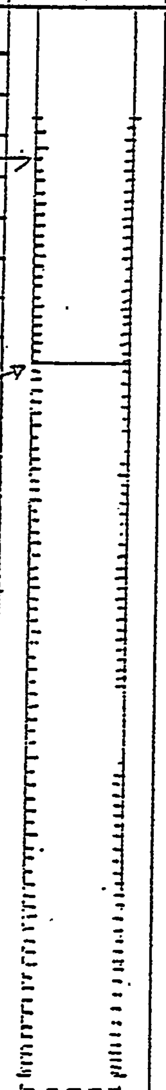
A-1800-186 (05/90)

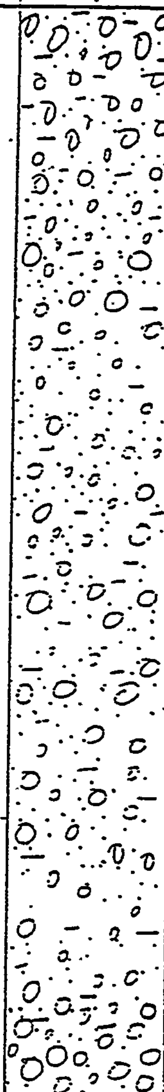
AS-BUILT DIAGRAM

Boring or Well Number 299-W19-1 Sheet 2 of 2
Location Garden-tw... ?5t 200 W Project

Logged by Driller: Roux-Richards
Reviewed by Date
Date Well Started 4/15/53
Date Well Completed

Well Construction Data — Drill Bit
Geologic/Hydrologic Data — Sample Method: Data from Drillers Logs

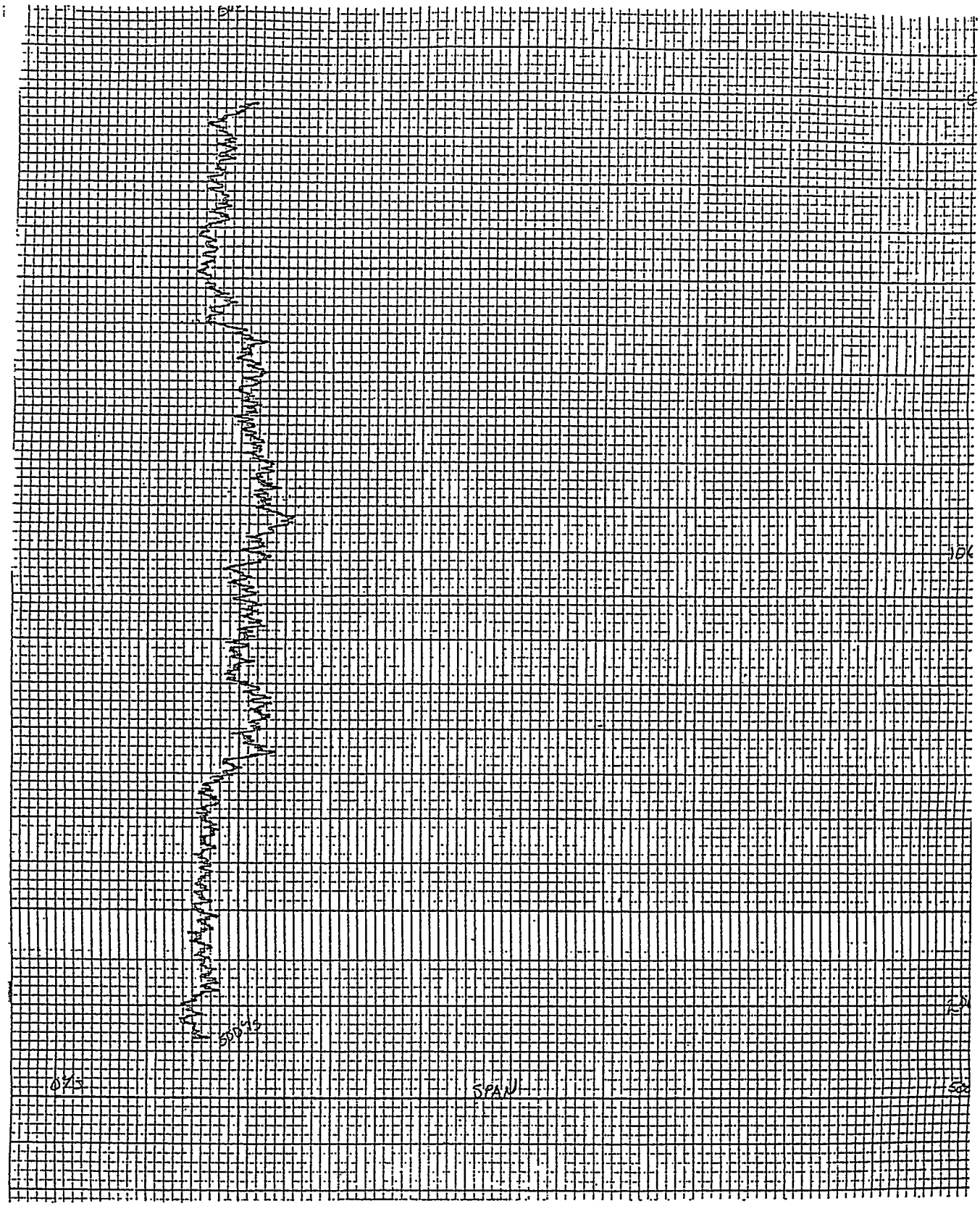




Description	Depth in Feet	Lithologic Description
	170	Gravel-sand, Caves-loose-water
	175	" " " " "
	180	" " " " "
Perforations 1/ft →	185	" " " " "
staggered (178'-299')	190	Sand-gravel " " "
	195	" " " " "
	200	Sand-boulders-gravel " " Grav...
	205	" " " " " "
According to Hanford Well...	210	Sand-gravel
C/Bottom = 2??'	215	Sand-gravel-v. little silt
	220	" " " " " -Caves
2 - 1.5" dia piezometer tubes	225	Sand-gravel-some silt "
installed in 1963 and 1965.	230	Gravel-sand " " "
Screen intervals for these tubes	235	" " silt "
were: (a) 178-192' and (b) ...	240	Boulders-gravel-...
Both of these tubes were later	245	Sand-some silt
re... ... No completion info	250	" " "
is available after tube removal.	255	" " "
	260	Sand-gravel-lots of silt-Caves
	265	" " " " " "
	270	" " " " " "
	275	Muck (heaving)
	280	" "
	285	F Sand-gravel "
	290	" " " "
	295	" " " "
	300	Gravel-sand-some silt
Bottom of 8" Casing = 300.3'	305	
		Final Drilled Depth = 301'

Drill Bit/Sample Method Used: Rotary; Air Rotary; Mud Rotary; Air Percussion; Back Hoe; Auger; Drive Barrel; Hand Tool; Split-Barrel

A-6300-186 (05/90)


SPAN

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

WELL SUMMARY SHEET

Boring or Well No. 299-W19-31

Sheet 1 of 2

Location 200W / SST / 241-U Tank Farm Project W-017

Elevation 671.16 BRASS CAP (NGVD '29) Drilling Contractor KEH

Driller G. Thomas / B. Strode Drilling Method and Equipment Cable Tool

Prepared By R.D. Miller (Sign/Print Name) Date 12/27/96 Reviewed By T.B. Williams (Sign/Print Name) Date 5/21/97

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
10"Ø temporary carbon steel casing to 135.92'bls		21		Gravelly SAND
Cement grout		10		" "
8"Ø temporary carbon steel casing to 224.95'bls		19.9' 20		Sandy GRAVEL
				" "
Granular bentonite #8-20 mesh		30		Slightly Sandy GRAVEL
				" Gravelly SAND
		40		" " "
				" " "
4"Ø stainless steel casing		50		" Silty SAND
				" Gravelly SAND
		60		" " "
				" Silty SAND
		70		SAND
				Slightly Gravelly Slightly Silty SAND
		80		Slightly Silty SAND
				Slightly Gravelly Slightly Silty SAND
		90		Slightly Silty SAND
				" " "
		100		" " "
				" " "
		110		Slightly Gravelly Slightly Silty SAND
				" " SAND
		120		" Silty SAND
				Silty SAND
		130		Sandy SILT
				" "
		135.92' 138		Gravelly SAND - Caliche zone
		140		" "
				" "
		150		" "
		C-9 160		Slightly Silty Gravelly SAND
				" " " "

A-6000-384 (04/90)

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

WELL SUMMARY SHEET

Boring or Well No. 299-W19-31

Sheet 2 of 2

Location 200W / 55T / 241-U Tank farm Project W-017

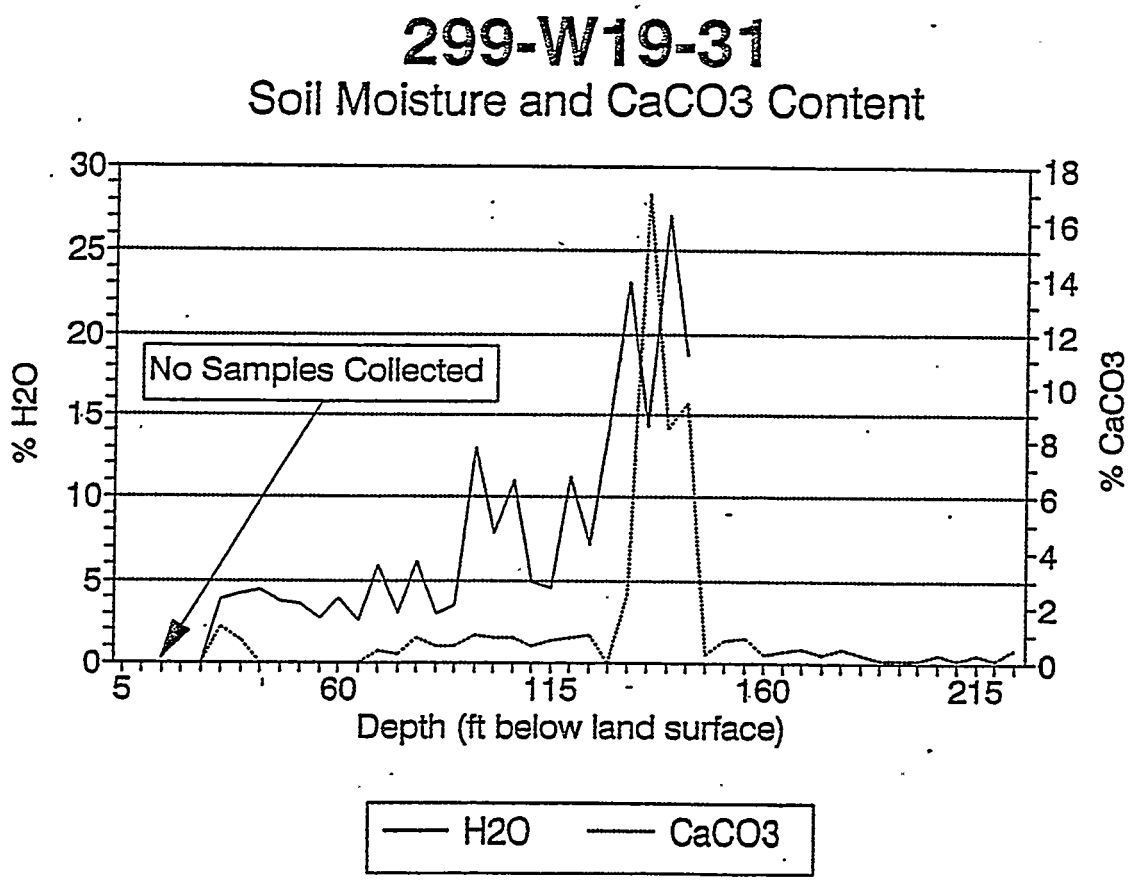
Elevation 671.16 BRASS CAP (NGVD'29) Drilling Contractor KEH

Driller G. Thomas / B. Strode Drilling Method and Equipment Cable Tool

Prepared By R.D. Miller (Sign/Print Name) Date 12/21/90 Reviewed By TA Williams (Sign/Print Name) Date 5/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
8"ø temporary carbon steel casing to 224.95' bls		170		Slightly Silty Sandy GRAVEL
				"
		180		"
				"
Bentonite pellets, 1/4"		190		Sandy GRAVEL
		191.1		SAND
		196.1		Gravelly Silty SAND
WATER LEVEL 202.3		200		Slightly Silty Sandy GRAVEL
		201.3		Sandy GRAVEL
4"ø stainless steel .010 slot (wire wound) screen		210		Slightly Silty Sandy GRAVEL
channel pak (Johnson)				" " " "
		220		" " " "
		222.6		
Sand pack - Silica Sand #20-40		224.9		T.D. 225.3' bls
		230		
		240		
		C-10		

A-6000-384 (04/90)


299-W19-31
Soil Moisture and CaCO3 Content
No Samples Collected
% H2O
% CaCO3
Depth (ft below land surface)
H2O
CaCO3
0
5
10
15
20
25
30
2
4
6
8
12
14
16
18
60
115
160
215

B-7

Well 299-W19-31 Soil Moisture, CaCO3, and Radiological Content

DEPTH (ft)	H2O (%)	CaCO3 (%)	ALPHA (pCi/g)	BETA/GAMMA (pCi/g)
5	NA	NA	1.1	32.4
10	NA	NA	0.6	35.5
15	NA	NA	<D	27.8
20	NA	NA	<D	31.6
25	NA	NA	<D	29.3
30	3.90	1.3	0.3	26.6
35	4.24	0.8	<D	35.1
40	4.47	0.0	<D	27.2
45	3.76	0.0	0.2	22.0
50	3.56	0.0	0.3	37.3
55	2.70	0.0	0.3	35.0
60	3.97	0.0	<D	17.6
65	2.55	0.0	0.7	31.9
70	5.93	0.4	<D	28.1
75	2.98	0.3	0.6	19.4
80	6.20	0.9	1.3	23.6
85	3.00	0.6	1.3	21.2
90	3.52	0.6	3.2	23.8
95	12.94	1.0	1.0	14.4
100	7.80	0.9	<D	17.4
105	10.99	0.9	1.6	18.4
110	4.88	0.6	0.3	17.9
115	4.53	0.8	1.1	12.2
120	11.23	0.9	0.9	18.4
125	7.13	1.0	0.5	14.5
130	14.12	NA	0.7	5.5
135	23.12	2.5	1.1	20.7
135.5	14.24	17.0	1.5	20.9
137.5	27.06	8.5	0.6	15.3
140	18.64	9.4	0.4	16.2
145	NA	0.3	4.8	62.2
150	NA	0.8	2.1	8.5
155	NA	0.9	<D	15.5
160	NA	0.3	0.4	18.5
165	NA	0.4	1.0	13.4
170	NA	0.5	0.6	44.5
175	NA	0.3	0.3	16.4
180	NA	0.5	1.9	19.7
185	NA	0.3	<D	24.2
195	3.99	0.1	<D	21.6
195.5	3.61	0.1	<D	15.0
200	NA	0.1	0.7	13.5
205	NA	0.3	<D	11.4
210	NA	0.1	0.7	18.1
215	NA	0.3	0.9	18.1
220	NA	0.1	<D	16.6
225	NA	0.5	1.1	9.6

<D - Activity Less Than Background NA - Sample Not Collected or Missing

Westinghouse Hanford Company	LOG HEADER	Page 1 of 2

Well No. 299-W19-31 Area 200 West Date 12/22/90
Log Run #1 Log Type Gross Gamma
Elevation Datum NGVD-'29 Elevation TOC 671.19
Survey Coordinates N 135,127.48 E 564,892.00
Log Measured from Ground Surface
Location Description 200 West West of 11-Plant
Ground Surface Elevation BRASS CAP 671.16
Surface Temperature 9.4°C Weather Clear - Cold

BOREHOLE INFORMATION

Driller Gene Thomas
Drill Rig Type Cable Tool Bit Type/Diameter Drive Barrel / 10"
Borehole Diameter(ft)/Depth 10"/136.3' Depth Logger 136.3'
Depth Driller 139' Liquid Density N/A
Liquid Level N/A Temperature N/A

CASING RECORD

Type 10" Carbon Steel Sch.40 Interval 135.92' - +2.0' stickup
Type Interval
Type Interval
Type Interval
Well Screen Interval N/A
Comments: Return Error = 0.3' high

A-6000-120 (05/90)

LOG HEADER	Page 2 of 2

EQUIPMENT DATA

Logging Company PNL
Operator(s) Alan Pearson, Vern McGhan
Equipment Brand MLS Equipment Type Analog
Tool Type Gamma Ray Serial No. CGZ7A97
Base Calibration Date Calibration Reference
Calibration/Probe Factor 7.87×10³ cU/pCi/L Base Calibration Datum (eU): Position 1 791.4 eU Position 2 48.5 eU
Dead Time 17.8 μsec. Warm Up Time >15 min

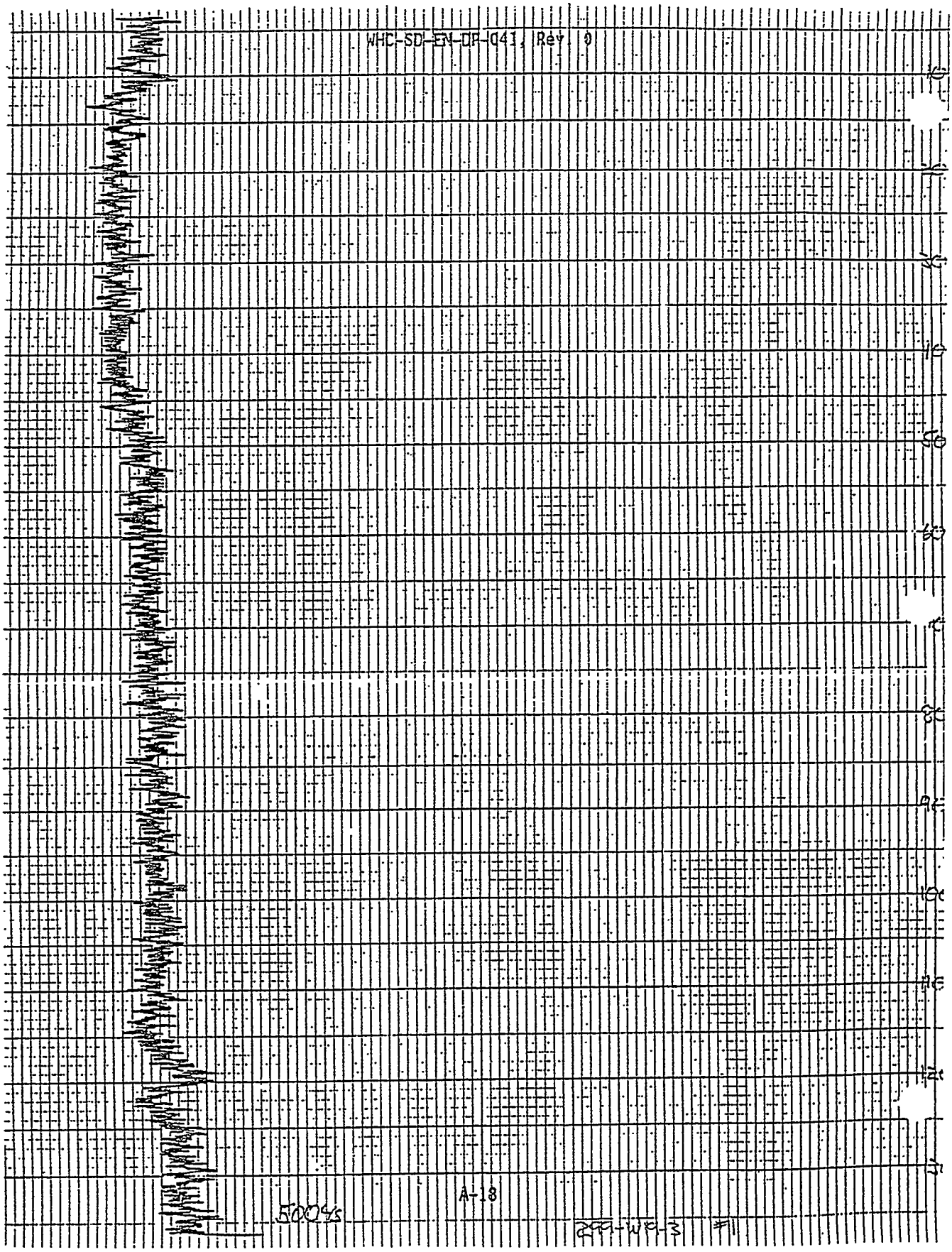
LOGGING INFORMATION

Log Interval From 136.3' To 3.1
Rerun(s) 136.3' to 105.0'
Pre Survey Verification: Position 1 778.6 eU Position 2 48.4 eU Background 385 c/s
Base Calibration Difference: Position 1 12.8 eU Position 2 0.1 eU
Logging Speed 5 ft./min. Rerun Scales, CPS/in. 50 c/s/in.
Start Time 0745 Completion Time 0930
Chart Speed(s), ft/in. 10 ft./in.
Chart Recorder Horizontal Scale, CPS/in. 50 c/s/in. Time Constant(s) TC-1
Post Survey Verification: Position 1 765.2 eU Position 2 ~~44.8 eU~~ 45.6 eU Background 380 c/s
Percent Change: Position 1 4.8% Position 2 5.8%
Comments Return Error = 0.3' high.

A-17

Witnessed and Verified by: (sign and print name) Randall Price Randall Price Date: 22 Oct 90

A-6000-120 (05/90)


WHC-SD-EN-DP-041, Rev. 0
A-13
500 #s
299-W6-3 #1

LOG HEADER	Page 1 of 2
Westinghouse Hanford Company	
Well No. 299-W19-31 #2	Area 200 W Date 12/6/90
Log Run	Log Type Gross Gamma
Elevation Datum NGVD - '29	Elevation TOC 627.19
Survey Coordinates E 135, 127.48	N 5166, 897.00 E
Log Measured from Ground Surface	
Location Description U Tank Farm	
Ground Surface Elevation BRASS CAP 621.16	
Surface Temperature 2.7°C	Weather Clear - Cold

BOREHOLE INFORMATION

Driller Brett Strode	Bit Type/Diameter Hard Tool / 8"	Depth Logger 224.5'	
Drill Rig Type Cable Tool	Borehole Diameter(s)/Depth 10"/139.9' 8"/225.5'	Liquid Level Apparent Muddy	
Depth Driller 225.3'			
Liquid Level 202.4'			
Temperature 15.7°C			

CASING RECORD

Type 10" Carbon Steel Sch 40	Interval +0.6'-135.92'		
Type 8" Carbon Steel Sch 40	Interval 2.1'-224.95'		
Type	Interval		
Type	Interval		

Well Screen Interval N/A

Comments: Return Error = +0.1' high
Centralizer Used

A-6000-130 (05/90)

LOG HEADER	Page 2 of 2

EQUIPMENT DATA

Logging Company PNL	
Operator(s) Alan Pearson	
Equipment Brand MLS	Equipment Type Analog
Tool Type Gamma Ray	Serial No. CG27A97
Base Calibration Date 8/90	Calibration Reference PNL-7460 UC-606
Calibration/Probe Factor 7.87 x10⁻³ eU pR/hr/CPS	Base Calibration Datum (eU): Position 1 291.4 eU Position 2 48.5 eU
Dead Time 17.8 usec.	Warm Up Time >15 min

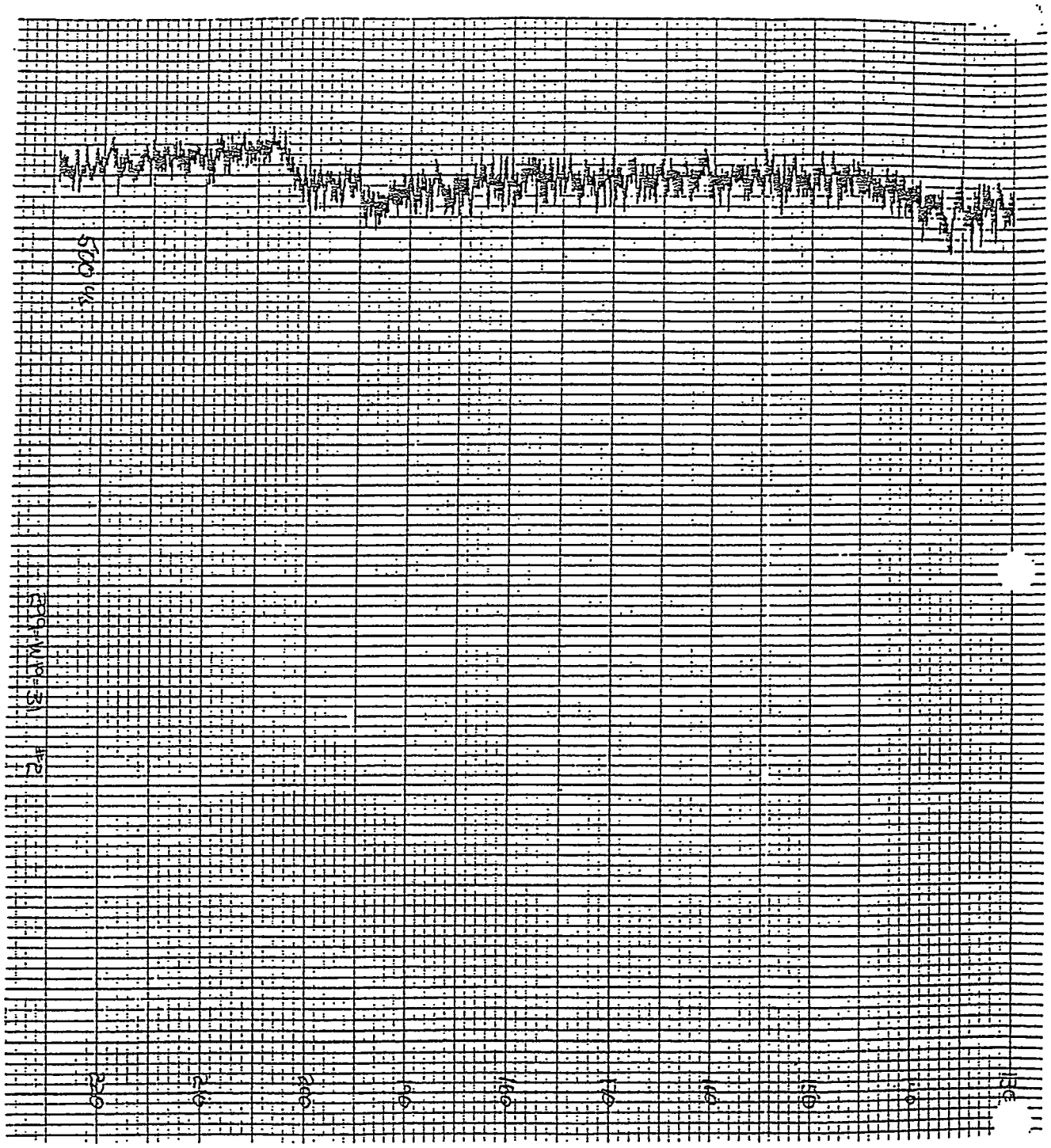
LOGGING INFORMATION

Log Interval From 224.5'	To 130.0'
Rerun(s) 224.5' to 190.0'	
Pre Survey Verification: Position 1 277.4 eU	Position 2 46.4 eU Background 225 c/s
Base Calibration Difference: Position 1 -14 eU	Position 2 2.1 eU
Logging Speed 55ft/min	Rerun Scales, CPS/in. 50 c/s/in
Start Time 1020	Completion Time 1155
Chart Speed(s), ft/in. 10ft/in.	
Chart Recorder Horizontal Scale, CPS/in. 50 c/s/in.	Time Constant(s) TC-1
Post Survey Verification: Position 1 271.9 eU	Position 2 46.4 eU Background 220 c/s
Percent Change: Position 1 2.0%	Position 2 0.0%
Comments Return Error = +0.1' high	
Centralizer used.	

A-19

Witnessed and Verified by: (sign and print name) Kent Reynolds / Kent Reynolds WHC Date: 12/6/90

A-6000-120 (05/90)



A-20

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

WELL SUMMARY SHEET (4 OF 6)

Boring or Well No. 299-W19-32

Sheet 1 of 13 @ 1-6-92

Location 200W/SST/241-U Tank farm Project W-017

Elevation 671.92 Brass Cap NGVD'29 Drilling Contractor KEH

Driller D. Ludtke Drilling Method and Equipment Cable Tool

Prepared By R.D. Miller (Sign/Print Name) Date 12/27/91 Reviewed By T. Jones / B.A. Williams (Sign/Print Name) Date 5/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
10"ø temporary carbon steel casing to 140.3'bls		10		Sandy GRAVEL
Cement grout		20		" "
8"ø temporary carbon steel casing to 223.1'bls		20.5		" "
				Gravelly SAND
Granular bentonite #8-20 mesh		30		Sandy GRAVEL - Silt 22.5-23.0'
		40		" "
4"ø stainless steel casing				Gravelly SAND
		50		Sandy GRAVEL
				" "
		60		Slightly Gravelly SAND
				" " "
		70		" " "
				SAND
		80		"
				"
		90		Slightly Gravelly SAND
				SAND
		100		Slightly Silty SAND
				" Gravelly SAND
		110		" " "
				" " "
		120		SAND
				"
		130		"
				"
		140		Sandy SILT
		140.3		SAND
				Slightly Silty SAND - Caliche 145'
		150		Silty Sandy GRAVEL
		C-11		" " "
		160		" " "
				" " "

A-6000-384 (04/90)

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

WELL SUMMARY SHEET (5 OF 6)

Boring or Well No. 299-W19-32

Sheet 2 of 23 (Rev) 1/1/92

Location 200W/SST/241-U Tank Farm — Project W-017

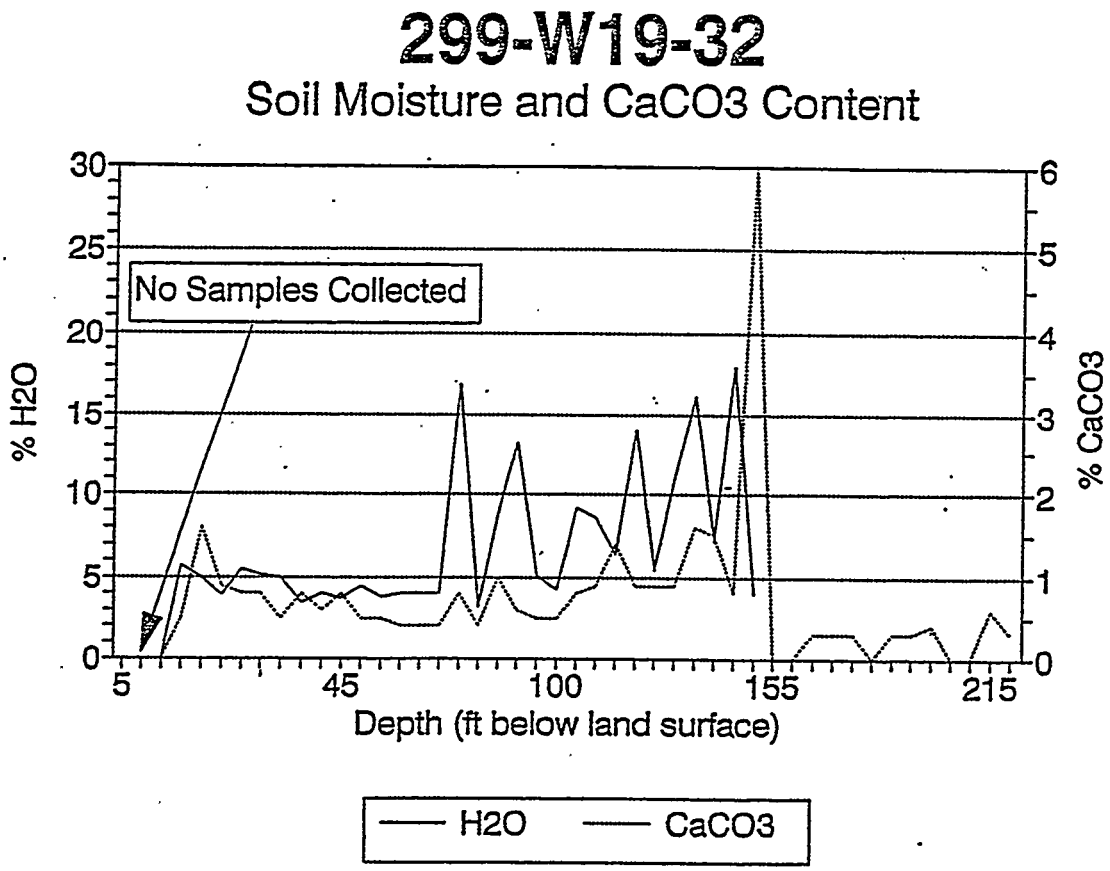
Elevation 671.92 Brass Cap NGVD'29 — Drilling Contractor KEH

Driller D. Ludtke — Drilling Method and Equipment Cable Tool

Prepared By R.D. Miller (Sign/Print Name) — Date 12/27/90 — Reviewed By B.A. Williams (Sign/Print Name) — Date 5/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
8"ø temporary carbon steel casing to 223.1' bls		170		Silty Sandy GRAVEL
		180		" " "
Bentonite pellets 1/4"		190.0		" " "
		195.4		" " "
4"ø stainless steel 202A' 11/15/90		200		" " "
.010 slot (wire wound) screen		201.75		Sandy GRAVEL
		210		Silty Sandy GRAVEL
Sand pack - Silica Sand #20-40		220		" " "
		222.35		" " "
		225.1		
		230		
		C-12		

A-6000-384 (04/90)


299-W19-32
Soil Moisture and CaCO3 Content
No Samples Collected
% H2O
% CaCO3
30
25
20
15
10
5
0
6
5
4
3
2
1
0
5
45
100
155
215
Depth (ft below land surface)
H2O
CaCO3

Well 299-W19-32 Soil Moisture, CaCO3, and Radiological Content

DEPTH (ft)	H2O (%)	CaCO3 (%)	ALPHA (pCi/g)	BETA/GAMMA (pCi/g)
5	NA	NA	NA	NA
10	NA	NA	NA	NA
15	NA	NA	NA	NA
20	5.76	0.5	0.4	23.5
22.5	4.96	1.6	<D	28.3
23	3.85	0.9	<D	32.0
25	5.54	0.8	<D	26.1
30	5.13	0.8	<D	22.4
35	5.00	0.5	0.7	21.8
40	3.41	0.8	1.1	21.6
41	4.05	0.6	0.4	26.9
45	3.76	0.8	1.4	32.8
50	4.49	0.5	<D	10.0
55	3.79	0.5	1.0	15.3
60	4.02	0.4	0.4	40.1
65	4.04	0.4	1.1	46.1
70	4.03	0.4	1.5	40.9
75	16.89	0.8	1.0	20.4
80	3.11	0.4	0.7	15.0
85	8.92	1.0	0.4	29.1
90	13.17	0.6	0.8	19.7
95	5.08	0.5	1.3	30.6
100	4.22	0.5	0.8	15.8
105	9.18	0.8	2.7	33.2
110	8.60	0.9	1.9	23.8
115	6.42	1.4	1.3	20.6
120	14.03	0.9	<D	21.7
125	5.46	0.9	1.6	21.1
130	11.01	0.9	1.2	16.4
135	16.17	1.6	4.3	29.4
140	7.14	1.5	1.6	19.0
145	18.02	0.8	1.2	36.3
150	3.98	6.1	<D	14.0
155	NA	NA	<D	11.6
160	NA	NA	1.2	19.0
170	NA	0.3	0.4	50.9
175	NA	0.3	<D	57.2
180	NA	0.3	1.0	52.0
185	NA	NA	0.9	12.0
190	NA	0.3	0.9	22.8
195	NA	0.3	2.6	42.7
200	NA	0.4	<D	16.0
208	8.04	NA	0.3	10.7
210	7.70	NA	1.4	9.9
215	NA	0.6	0.5	41.5
220	NA	0.3	1.0	14.8

<D - Activity Less Than Background NA - Sample Not Collected or Missing

LOG HEADER	Page 1 of 2
Westinghouse Hanford Company	
Well No. 299-W19-32	Area 200W Date 10/17/90
Log Run #1	Log Type Gross Gamma
Elevation Datum NAVD-27	Elevation TOC 674.90
Survey Coordinates 135,002.22 N	576,896.55 E
Log Measured from Ground Surface	
Location Description 200 West area, West of 12-Plant	
Ground Surface Elevation BRASS CAP 671.93	
Surface Temperature 9.4°C	Weather Cloudy - Cool

BOREHOLE INFORMATION

Driller Darrel Luthe	Bit Type/Diameter 10" / Drive Barrel	Depth Logger 143.1'	
Drill Rig Type Cable Tool	Borehole Diameter(s)/Depth 10"/145.3'	Liquid Density N/A	
Depth Driller 145.3'	Liquid Level N/A	Temperature N/A	

CASING RECORD

Type 10" Carbon Steel Sch 40	Interval +1.34' - 139.4'		
Type	Interval		
Type	Interval		
Type	Interval		

Well Screen Interval N/A

Comments: Return Error = 0.4' High

A-6000-110 (05/90)

LOG HEADER	Page 2 of 2

EQUIPMENT DATA

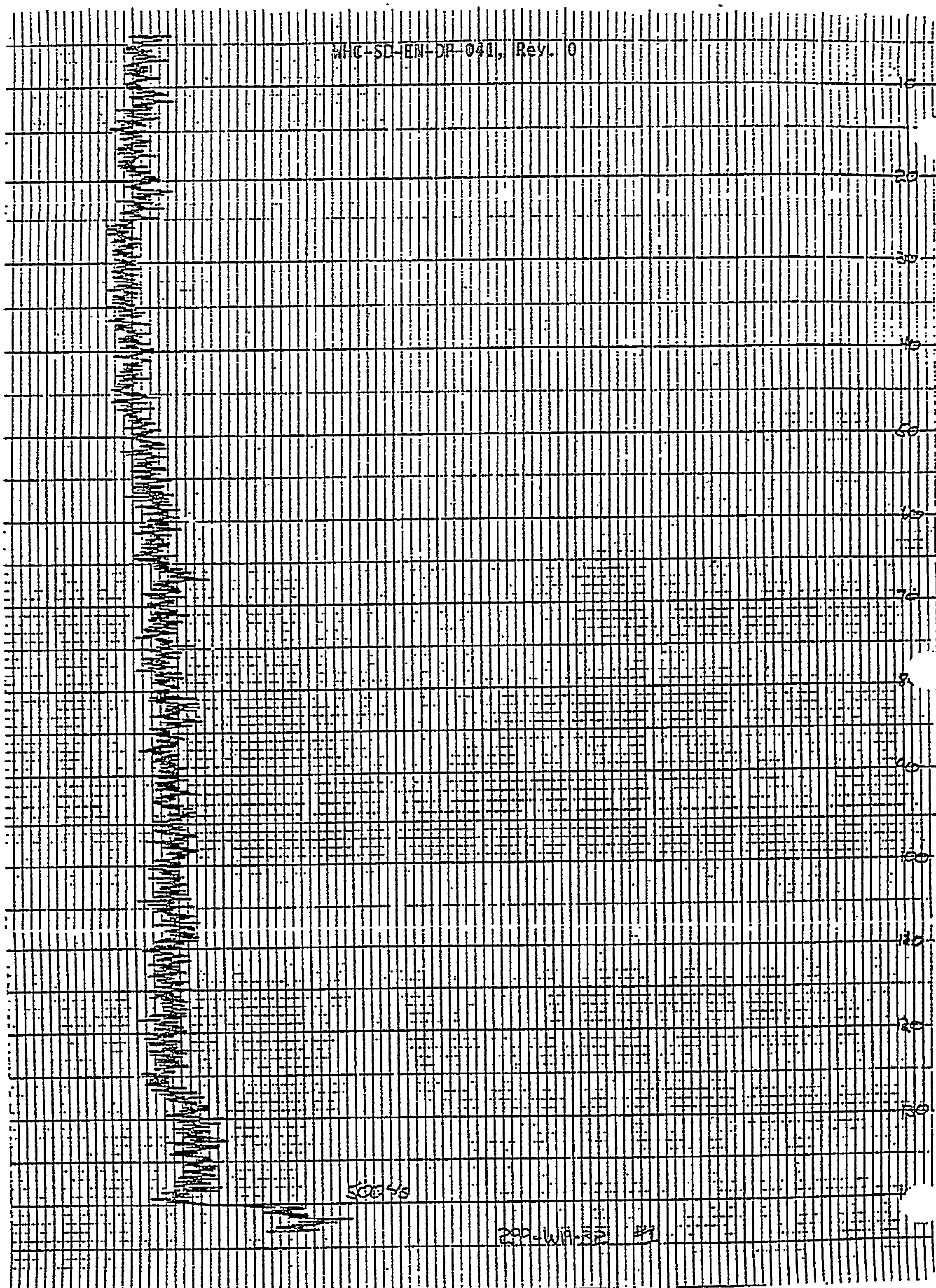
Logging Company PNL	
Operator(s) Alan Pearson	
Equipment Brand MLS	Equipment Type Analog
Tool Type Gamma Ray	Serial No. C627A97
Base Calibration Date	Calibration Reference
Calibration/Probe Factor 7.87×10⁻² dII/nv/cm²	Base Calibration Datum (eU): Position 1 291.4 eU Position 2 49.5 eU
Dead Time 17.8 μsec	Warm Up Time 7/5 min

LOGGING INFORMATION

Log Interval From 143.1'	To 3.8'
Rerun(s) 143.1' to 110.0'	
Pre Survey Verification: Position 1 276.6 eU	Position 2 45.6 eU Background 260 c/s
Base Calibration Difference: Position 1 14.8 eU	Position 2 3.9 eU
Logging Speed 54 ft/min	Rerun Scales, CPS/in. 50 c/s/in
Start Time 0800	Completion Time 0945
Chart Speed(s), I/in. 10 ft/in.	
Chart Recorder Horizontal Scale, CPS/in. 50 c/s/in	Time Constant(s) TC=1
Post Survey Verification: Position 1 276.2 eU	Position 2 46.4 eU Background 265 c/s.
Percent Change: Position 1 0.1 %	Position 2 1.9 %
Comments Return Error = 0.4' high	

A-21

Witnessed and Verified by: (sign and print name) Raymond Price Randall Breed Date: 17/Oct/90



LOG HEADER			Page 1 of 2
Westinghouse Hanford Company	Well No. 299-W19-32	Area 200W	Date 11/13/90
	Log Run #2	Log Type Gross Gamma	
	Elevation Datum NGVD-'29	Elevation TOC 674.90	
	Survey Coordinates 135,009.22 N	39,60,896.55 E	
	Log Measured From Ground Surface	Location Description U-Tank Farm	
	Ground Surface Elevation BRASS CAP 671.92		
	Surface Temperature 14.2°C	Weather Cloudy Cool	

BOREHOLE INFORMATION

Driller Darrel Liddike		Bit Type/Diameter Hard Tool Bit/8"	
Drill Rig Type Cable Tool		Borehole Diameter(s)/Depth 10"/140.3'	8"/219.6'
Depth Driller 220.4'		Depth Logger 216.7'	
Liquid Level 202.4'		Liquid Density Appearance Muddy	
Temperature 17.3°C			

CASING RECORD

Type 10" Carbon Steel Sch. 40	Interval 1403'-'0.5" Stickup	
Type 8" Carbon Steel Sch. 40	Interval 219.6'-'1.40' Stickup	
Type	Interval	
Type	Interval	
Well Screen Interval 4/4		

Comments: Return Error = 0.2' high
Centralizer used

A-6000-310 (05/90)

LOG HEADER	Page 2 of 2

EQUIPMENT DATA

Logging Company PNL			
Operator(s) Alan Pearson			
Equipment Brand MLS	Equipment Type Analog		
Tool Type Gamma Ray	Serial No. CB-27A97		
Base Calibration Date 8/90	Calibration Reference PNL-7460 UC-606		
Calibration/Probe Factor 1.87 x 10² eU/pCi/g	Base Calibration Datum (eU): Position 1 291.4 eU	Position 2 48.5 eU	
Dead Time 17.9 usec	Warm Up Time >15 min.		

LOGGING INFORMATION

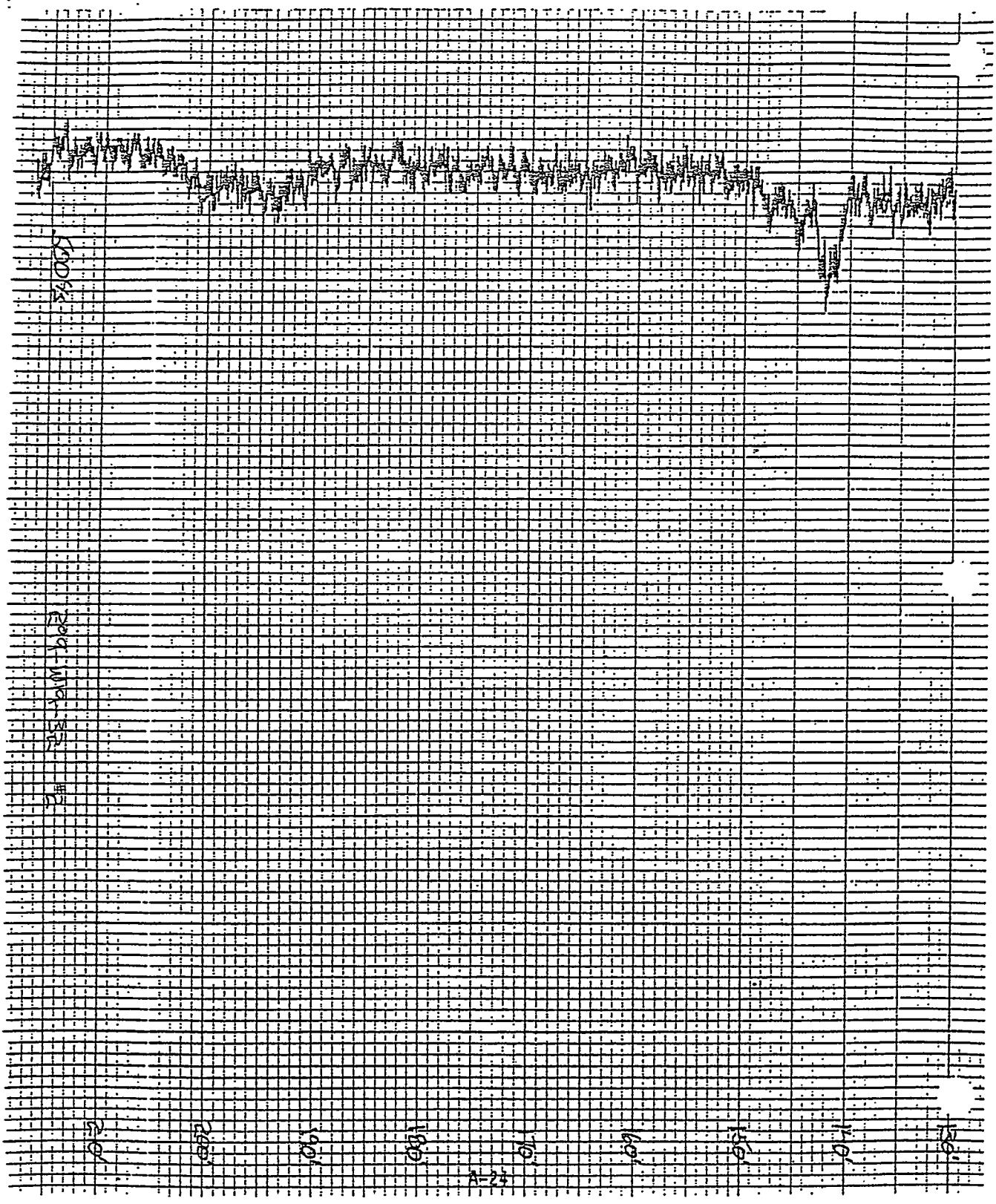
Log Interval From 216.6'	To 130.0'		
Rerun(s) 216.7' to 195.0' &	160.0' to 130.0'		
Pre Survey Verification: Position 1 275.5 eU	Position 2 47.2 eU	Background 150 c/s	
Base Calibration Difference: Position 1 15.9 eU	Position 2 1.3 eU		
Logging Speed 5 ft/min	Rerun Scales, CPS/in. 50 c/s/in.		
Start Time 1100	Completion Time 1300		
Chart Speed(s), f/in. 10 ft/min.			
Chart Recorder Horizontal Scale, CPS/in. 50 c/s/in.	Time Constant(s) TC=1		
Post Survey Verification: Position 1 270.3 eU	Position 2 48.0 eU	Background 140 c/s	
Percent Change: Position 1 1.9%	Position 2 1.7%		

Comments Return Error = 0.2' high
Centralizers used

A-23

Witnessed and Verified by: (sign and print name) Steven E. Kos STEVEN E. KOS Date: 11/13/90

A-6000-320 (05/90)


A-24

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

Project: U-14 Ditch

Borehole	299-W19-32			
Coordinates	37,887 N	75,459 W	Feet	(Hanford System)
Elevation	671.92 ft	Top of casing		

Borehole Environment Information

Borehole liquid depth 206.5 (ft) from zero (0.0) depth reference of log

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
4	0.125	0	201.7
4	0.01	201.7	222.4

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram S. E. Kos J. P. Kiesler
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 18, 1993	H2W1932\A389	MSA 150sec RT	0	50	0.5
Jun 21, 1993	H2W1932\A390	MSA 150sec RT	48.5	116	0.5
Jun 22, 1993	H2W1932\A391	MSA 150sec RT	114.5	183.5	0.5
Jun 23, 1993	H2W1932\A392	MSA 150sec RT	182	220	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

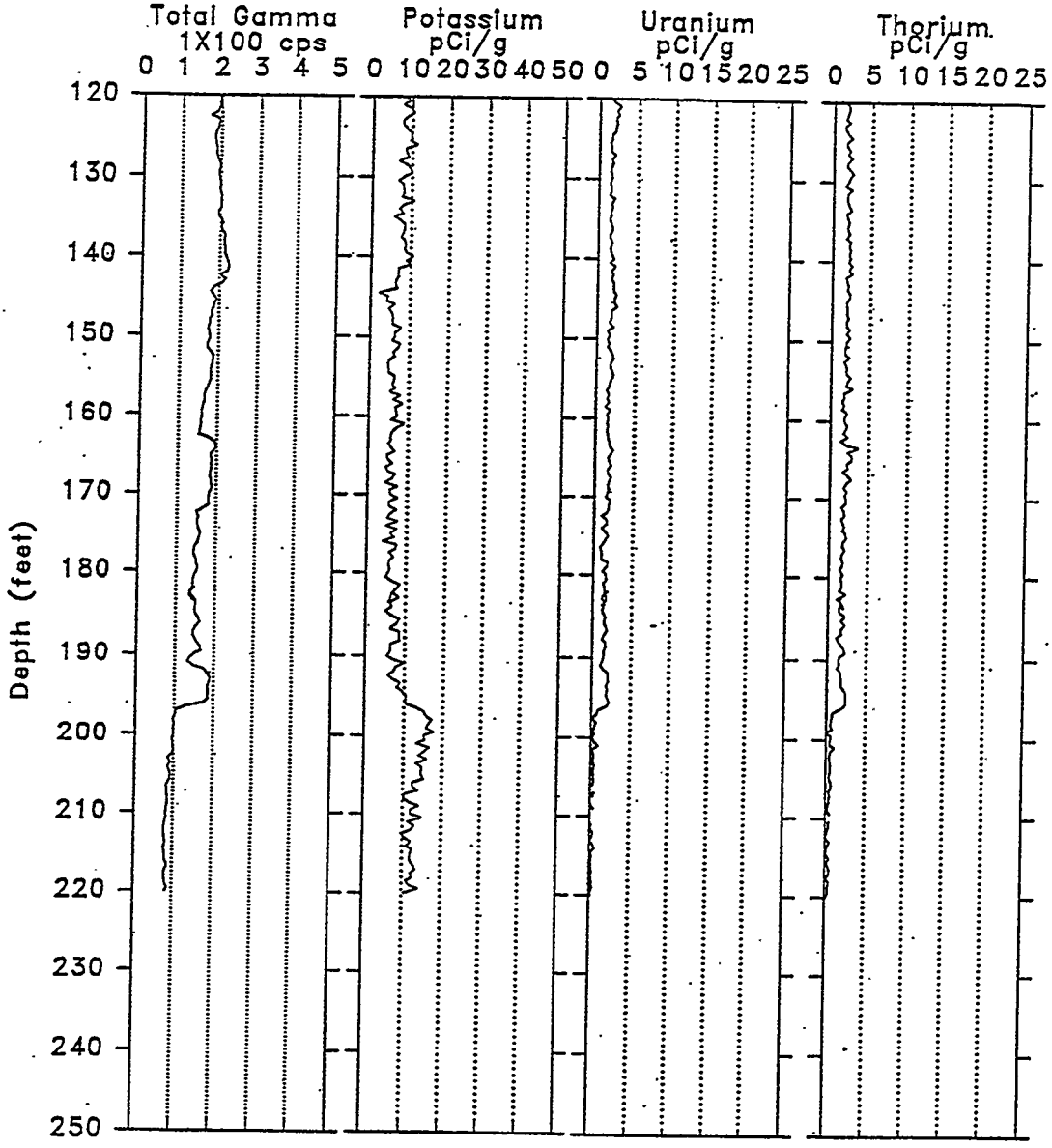
Analyst Names: W. F. Nicaise
Analysis Date: May 18, 1993

Analysis Notes:
Radionuclides Identified: No man-made radionuclides identified.

RLS Spectral Gamma-Ray Borehole Survey

Project: U-14 Ditch
Borehole : 299-W19-32

Log Date : Jun 23, 1993
Anal Date: Aug 02, 1993



RLS Borehole Survey Report

Borehole: 299-W19-32

Casing	Depth: 0'-201.7'	Size: 4"	Thickness: 0.125"	
Casing	Depth: 201.7'-222.4'	Size: 4"	Thickness: 0.01"	
Water	Depth: 206.5'			
Survey	Depth: 0'- 220'	Date: 6/23/93		
	Stations:			

General Notes:
The well was monitored from 0 to 220 feet, in increments of 0.5 feet for real counting periods of 150 seconds. A pre-mix concrete pad extends to 3.1 feet, and a cement grout extends from 3.1 to 20.3 feet below the ground level. From 20.3 to 195.4 feet there is a Bentonite seal. From 195.4 to 223.1 is a sand fill. A four inch stainless steel casing 0.125 inch in thickness extends to 201.7 feet. From there to the well bottom at 222.4 there is a #10-slot stainless steel screen.

There were no man-made radionuclides identified in this well, within the limits of sensitivity of the detection system. The plot tracks for man-made radionuclides are shown for uniformity of presentation only.

The plot tracks for the man-made radionuclides potassium, uranium, and thorium show calculated activities which are typical of Hanford soils. What little variation in these activities with depth are consistent with the known properties of the Bentonite seal materials used in the well.

Man-made Radionuclides:
No man-made radionuclides were observed in the spectral gamma-ray survey.

Appendix B

U Tank Farm Groundwater

U-TANK FARM GROUNDWATER

Floyd. N. Hodges
Pacific Northwest National Laboratory

U-Tank Farm, located in the southwestern portion of the 200 West Area, contains twelve 530,000 gal single shell tanks and four 55,000 gal single shell tanks. The U-Tank Farm began receiving waste in 1946 and during its operational life received waste from a variety of sources, including T-Plant, U-Plant, S-Plant (REDOX), and other tank farms.

The single-shelled tanks stopped receiving waste in 1980; however, they are storing hazardous and radioactive waste and have been designated RCRA facilities. The U-Tank Farm, along with the other single-shelled tank farms, are under interim-status RCRA groundwater monitoring programs (40 CFR 265) and are monitored under a single groundwater monitoring plan (Jensen et al., 1989; Caggiano and Goodwin, 1991). An interim-status groundwater monitoring network was completed at the U-Tank Farm in 1991 and the initial required four quarters of monitoring to establish groundwater background conditions were completed in 1993. The U-Tank Farm has subsequently been in an interim-status detection level monitoring program. The following sections summarize groundwater flow and contaminant dynamics at the site.

Groundwater Dynamics. The strongest influence on groundwater levels and flow directions at the U-Tank Farm has historically been the water table mound beneath U-Pond (216-U-10), and water table elevations in the vicinity of the U-Tank Farms have fallen rapidly since the decommissioning of U-Pond in 1985. Hydrographs for well 299-W19-1, located approximately 50 meters(165 ft) southeast of the U-Tank Farm boundary, indicate a 7.6 meter (25 ft.) drop in the water table between 1984 and 1995. A map of the water table for the vicinity of the U-Tank Farm, based on June 1996 data, is presented in Figure 1.

The shutdown of U-Pond resulted in increased effluent discharge to other sites, particularly the 216-Z-20 Crib northwest of the U-Tank Farm and the 216-U-14 Ditch southeast of the U-Tank Farm. The result of the discharge to the Z-20 Crib was to shift the peak of the declining groundwater mound northward toward the Z-20 Crib, thus changing the groundwater flow direction under the U-Tank Farm from slightly north of east to its present direction of slightly south of east. The result of several large discharges to the U-14 Ditch in 1991 and 1993 (Singleton and Lindsay 1994) was to slow the rate of decrease in the water table, and in the case of the 1993 discharge, to temporarily reverse the direction of groundwater flow beneath the tank farm. This reversal of flow directions was probably

possible because of the greatly reduced discharge to the Z-20 Crib at this time (Johnson 1993).

The effect of discharge to the U-14 Ditch is complicated because of the existence of perched water beneath the ditch. Figure 2 shows hydrographs of two wells (299-W19-91 and 299-W19-92) which monitor the perched water beneath the ditch. The result of the 1993 discharge was a rapid 6 m(20 ft) rise in the level of the perched water table. This effect of the discharge is apparently spread out as water drains downward from the perched water table; however, the gradient reversal resulting from this discharge is illustrated in Figure 3 which shows hydrographs for wells 299-W19-32 and 299-W18-25. The water table elevations in well 299-W19-32 rose above those of 299-W18-25 in Mid-1993, reversing the up- and downgradient relationships within the monitoring network. In late 1995 water levels in 299-W18-25 moved higher, reestablishing the original relationship. Caggiano (1996) recognized the problem with flow directions at the site; however, the reported in-situ flow measurements gave inconsistent results because they were taken as the flow direction was returning to its normal southeastward direction.

Sampling and Analysis Program

The monitoring network at the U-Tank Farm consists of 5 RCRA compliant wells completed between 1990 and 1993, two upgradient (299-W18-25 and 299-W18-31) and three downgradient (299-W19-32, 299-W19-31, and 299-W18-30). All of these wells monitor the top of the unconfined aquifer in Ringold Unit D gravels. In addition to the dedicated monitoring wells, several nearby wells, including 299-W18-33, 299-W19-12, 299-W19-19, and 299-W19-27 are monitored by the Operational and/or Surveillance Programs (Figure 1).

The U-Tank Farm is on a semi-annual sampling schedule, as required by 40 CFR 265. The constituent list for sampling consists of the contamination indicator parameters, the interim primary drinking water parameters, and the groundwater quality parameters. In addition, the list includes tritium and technetium-99 which are site-specific constituents.

Groundwater Chemistry

Two groundwater contaminants are indicated by the RCRA monitoring data at the U-Tank Farms; TOX, which probably has an upgradient source, and technetium-99, which may have a source within the U-Tank Farm. Neither tritium nor uranium are present in significant concentrations.

TOX. There was a general increase in TOX values in the vicinity of the U-Tank Farm during 1996, with well 299-W18-30, the northernmost downgradient well, having the highest values. Concentrations in this well reached 416 µg/L in August 1996, exceeding the critical mean for the site.

The increasing TOX values are, in all probability, a result of carbon tetrachloride. The pattern of TOX concentrations is consistent with increased encroachment by the PFP (234-5Z) carbon tetrachloride plume with the return of groundwater flow directions to a southeasterly direction.

Technetium-99. Technetium-99 and gross beta both showed significant increases in downgradient well 299-W19-31 in 1996, with gross beta (principally a result of Tc-99) reaching 147 pCi/L and Technetium-99 reaching 782 pCi/L in the August 1996 sampling (Figure 4).

The increase in technetium-99 and gross beta in well 299-W19-31 corresponds closely to the change of groundwater flow direction back to a southeasterly direction and probably is related to that change. Historically the highest technetium-99 activities have occurred in well 299-W19-12. Since the start of RCRA monitoring in 1991 the highest activities occurred in downgradient well 299-W19-32 in 1993, coincident with the last major discharge to the U-14 Ditch and the reversal of groundwater flow directions at the site. However, technetium-99 activity in 299-W19-32 declined rapidly in 1994-95 and has remained low. However, technetium-99 activity started to increase in downgradient well 299-W19-12 in late 1994 and in downgradient well 299-W19-31 in late 1995. The increase in well 299-W19-31 was coincident with the return of groundwater flow to a southeasterly direction, and technetium-99 activity in this well reached 782 pCi/L in August 1996.

The relationship between the 1993 increase of technetium-99 activity in well 299-W19-32 and discharge to the U-14 Ditch is problematical. If the two are related there are at least two possibilities. First, the technetium may have been introduced into the groundwater by the effluent discharge, or second, perched water may have moved laterally from the U-14 Ditch and mobilized vadose contaminants resulting from earlier tank or transfer line leaks. Singleton and Lindsay (1994) reported that technetium-99 activities in the perched water beneath U-14 were quite low, indicating that the U-14 effluent is probably not the source. Singleton and Lindsay (1994) also observed that the perched water beneath U-14 is shallow enough that it could potentially mobilize vadose zone contaminants beneath the U-Tank Farm if the perched zone extends as far as the tank farm. A problem with the second possibility is the question of why the

much larger volume from the 1991 discharge to the U-14 Ditch didn't cause technetium-99 increases at the U-Tank Farm. Another possibility is that the coincidence of U-14 Ditch discharge and technetium-99 increase is accidental and the technetium-99 increase is due to contaminant mobilization by enhanced surface water infiltration or some other cause. Whatever the source, the observed contamination pattern is consistent with a localized plume reacting to changing groundwater flow conditions. Contamination at 299-W19-32 would have been pushed to the northwest, beneath the tank farm, when groundwater flow direction reversed and is now present (increasing) in well 299-W19-31 because of the return of groundwater flow to a southeasterly direction.

References.

Caggiano, J. A. 1996. "Single Shell Tanks" in *Annual Report for RCRA Groundwater Monitoring at Hanford Site Facilities for 1995.* DOE/RL-96-01, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A. and S. M. Goodwin. 1991. *Interim Status Groundwater Monitoring Plan for the Single Shell Tanks.* WHC-SD-EN-AP-012, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

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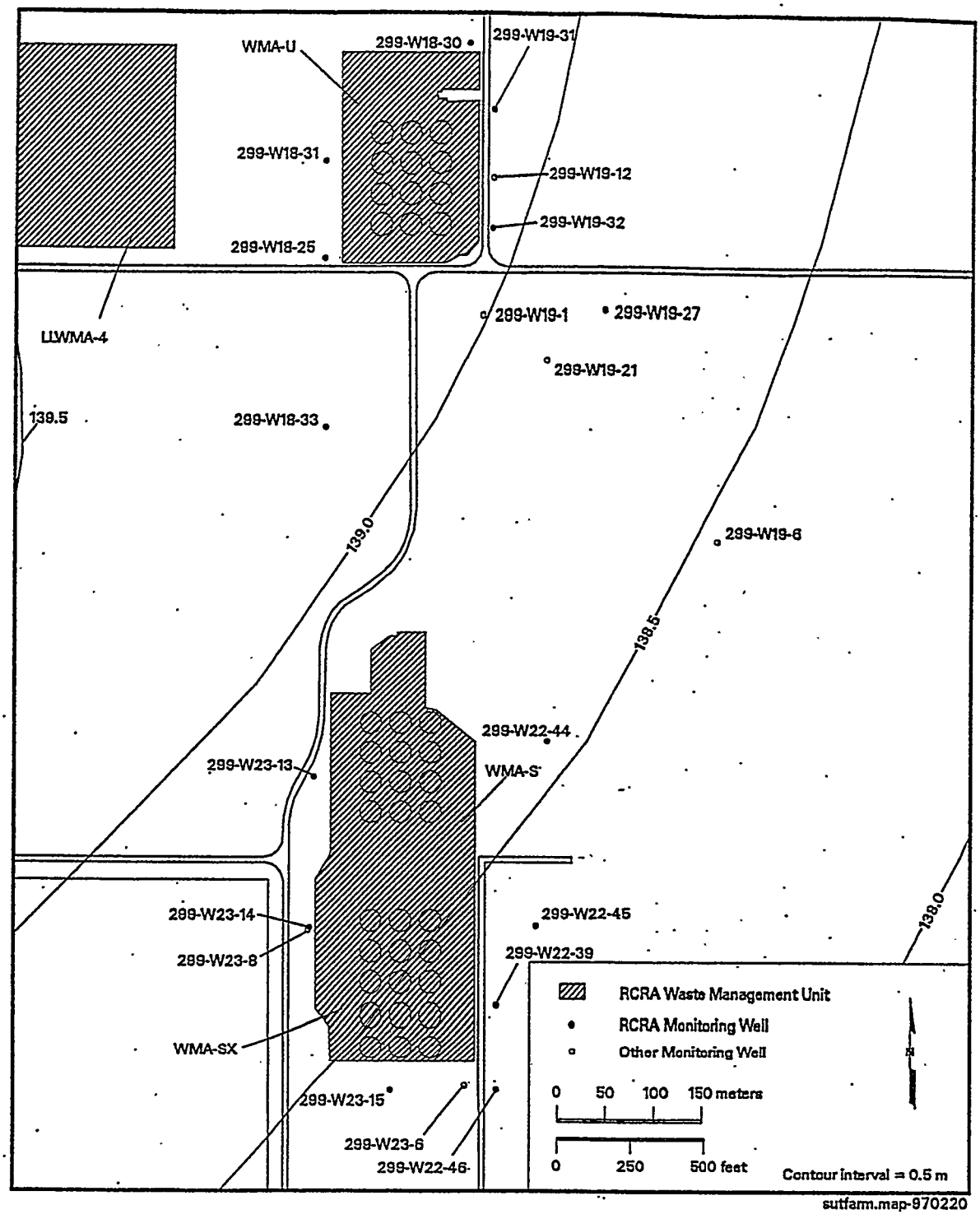

Figure 1. Water Table Map for U-Tank Farm Area.

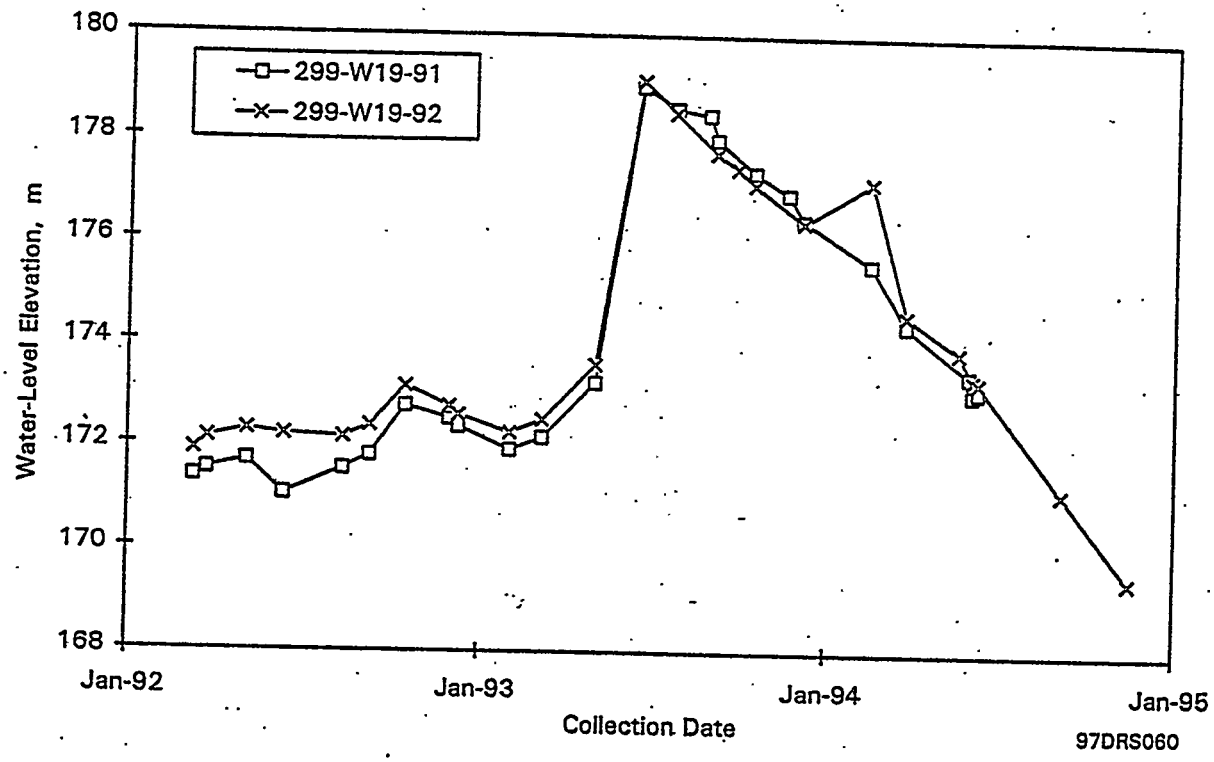

Figure 2. Hydrographs for Wells Monitoring Perched Water Table Beneath the U-14 Ditch.

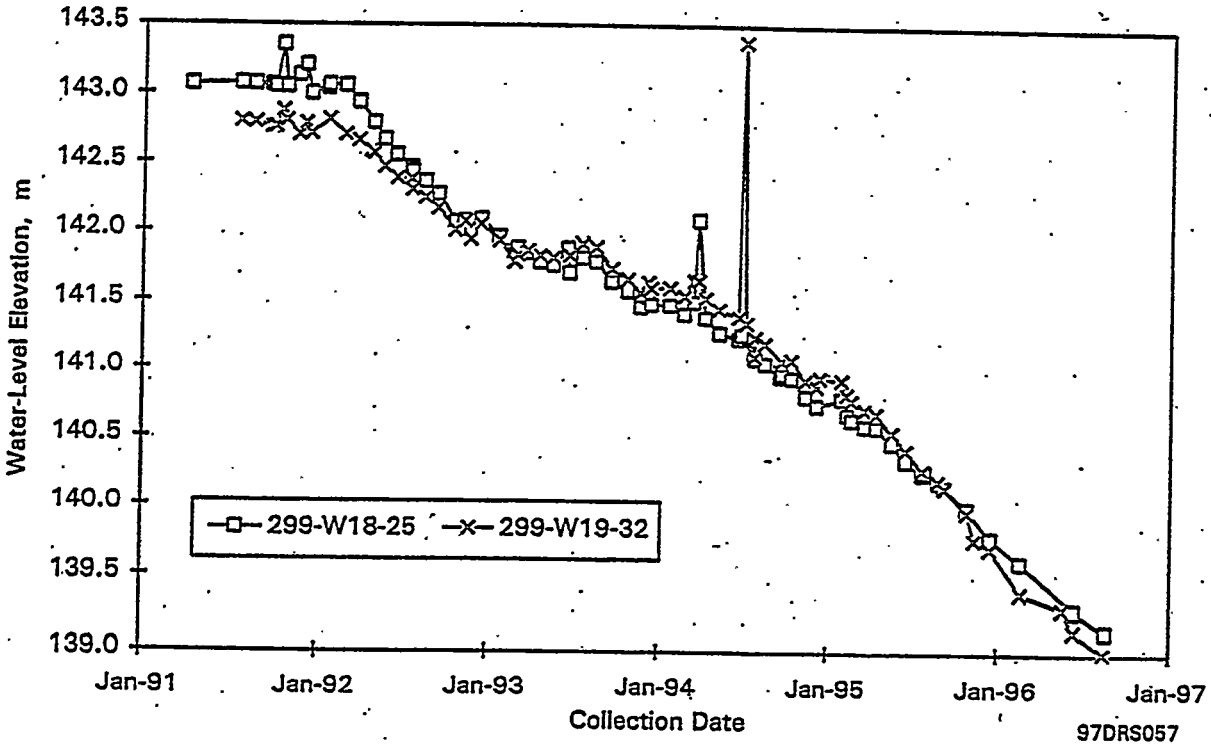

Figure 3. Hydrographs for U-Tank Farms Monitoring Wells 299-W18-25 and 299-W19-32.

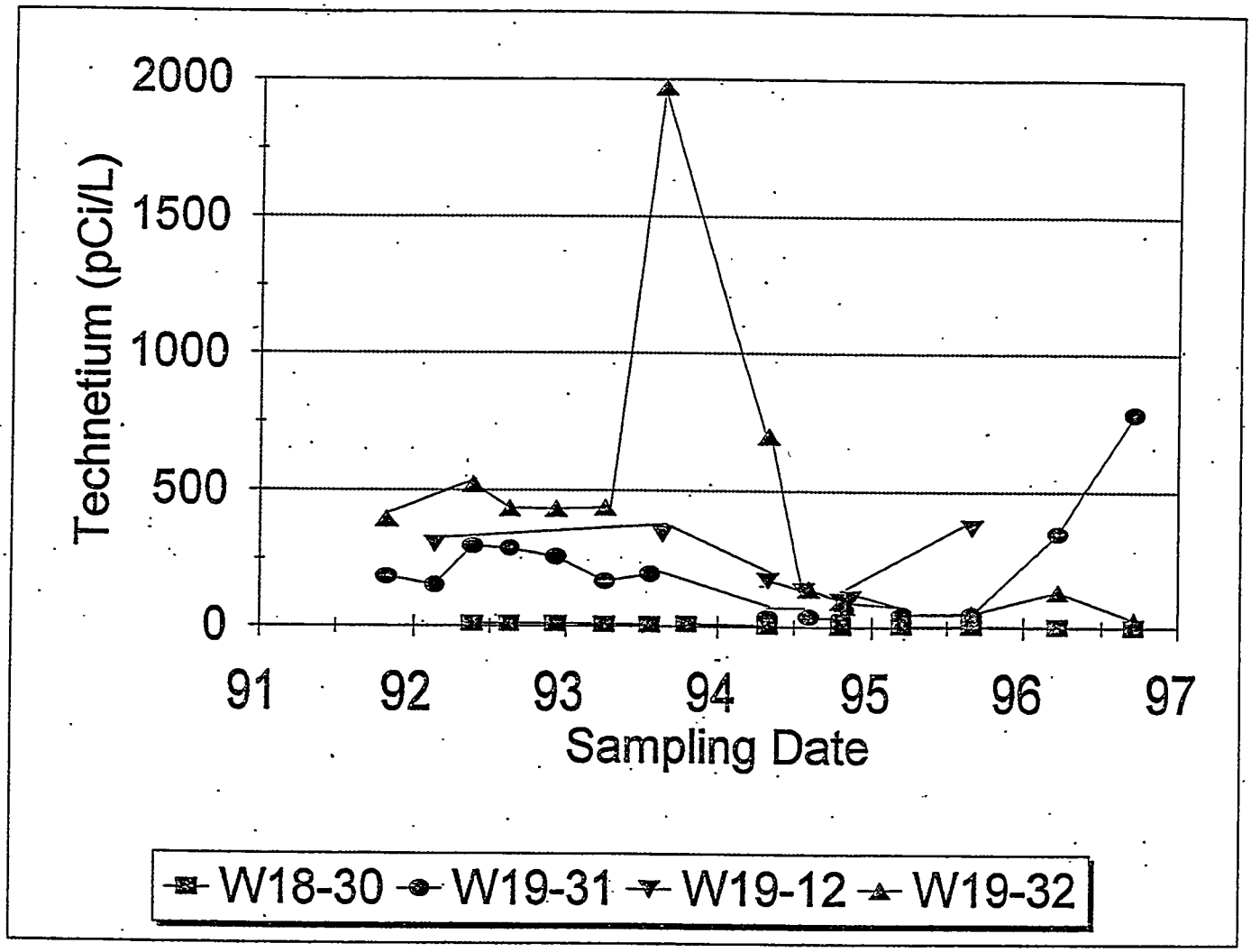

Figure 4. Plots of Technetium-99 Activities in Monitoring Wells Downgradient to the U-Tank Farm.

Appendix C

U Tank Farm Correlation Plots

The reader is advised to consult the appropriate TSDRs for explanations regarding what may appear to be discrepancies between TD drilled (as indicated on the following correlation plots) and the maximum depth logged for several boreholes in the U Tank Farm.

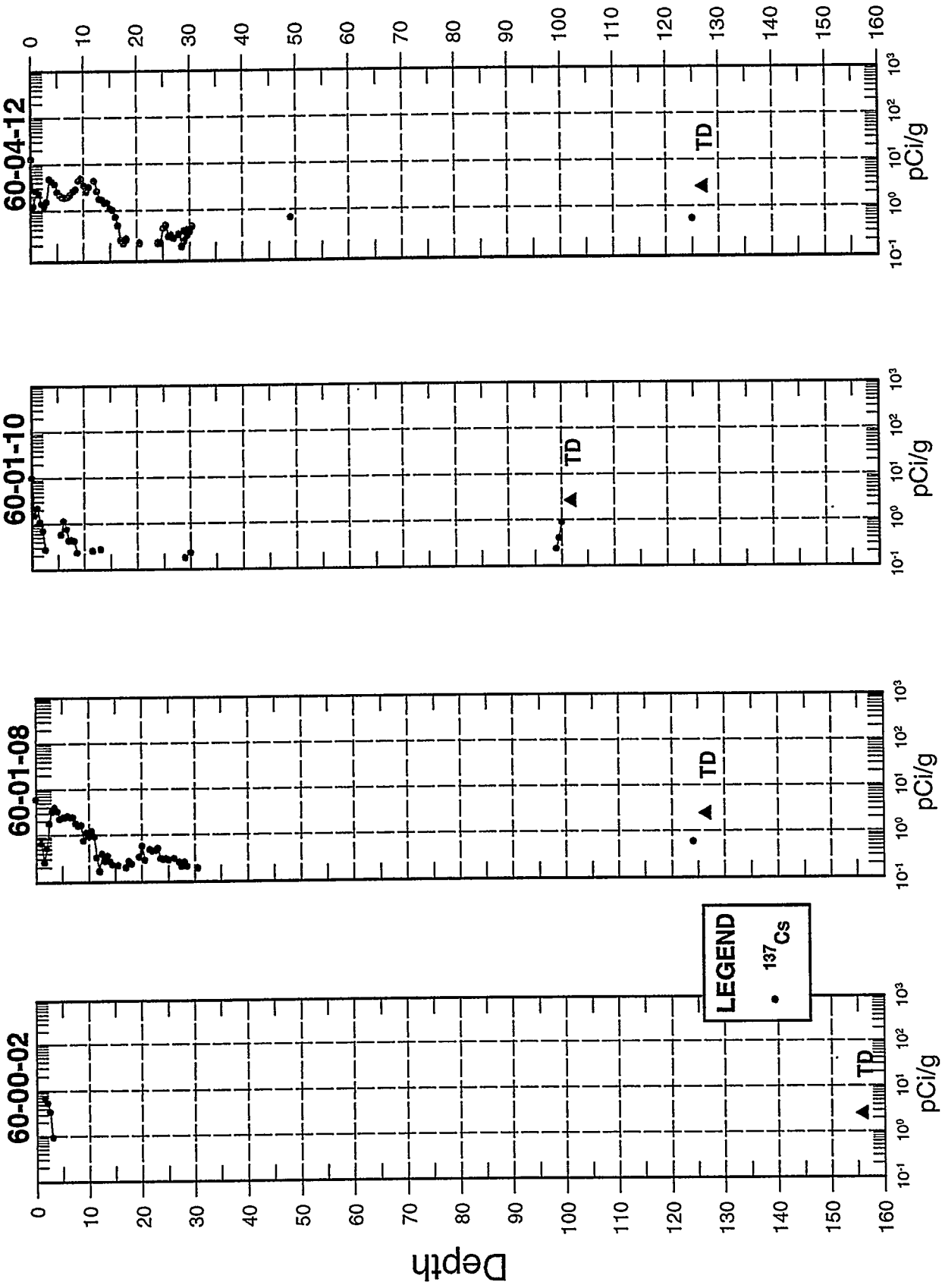

Figure C-1. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-101

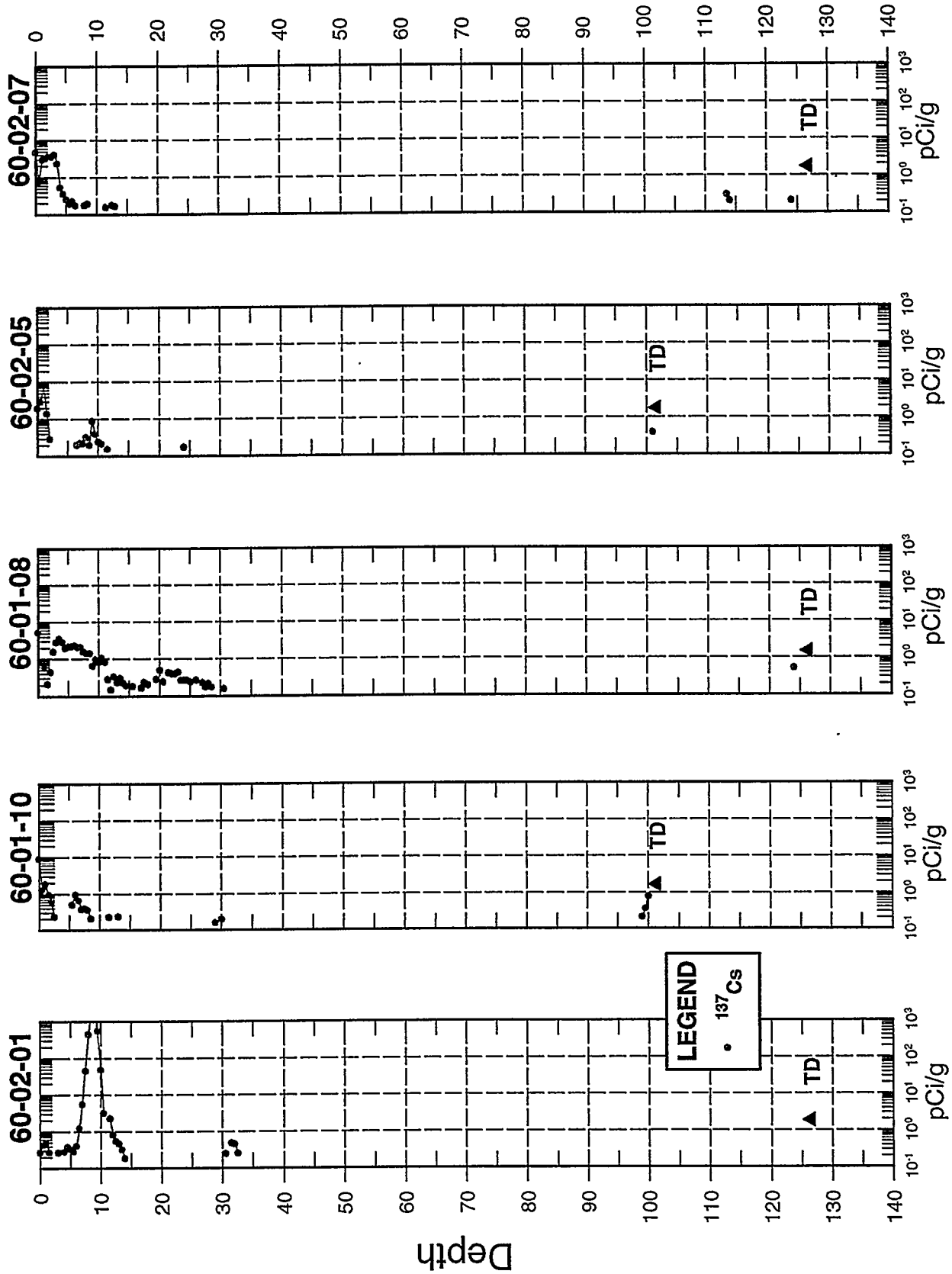

Figure C-2. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-102

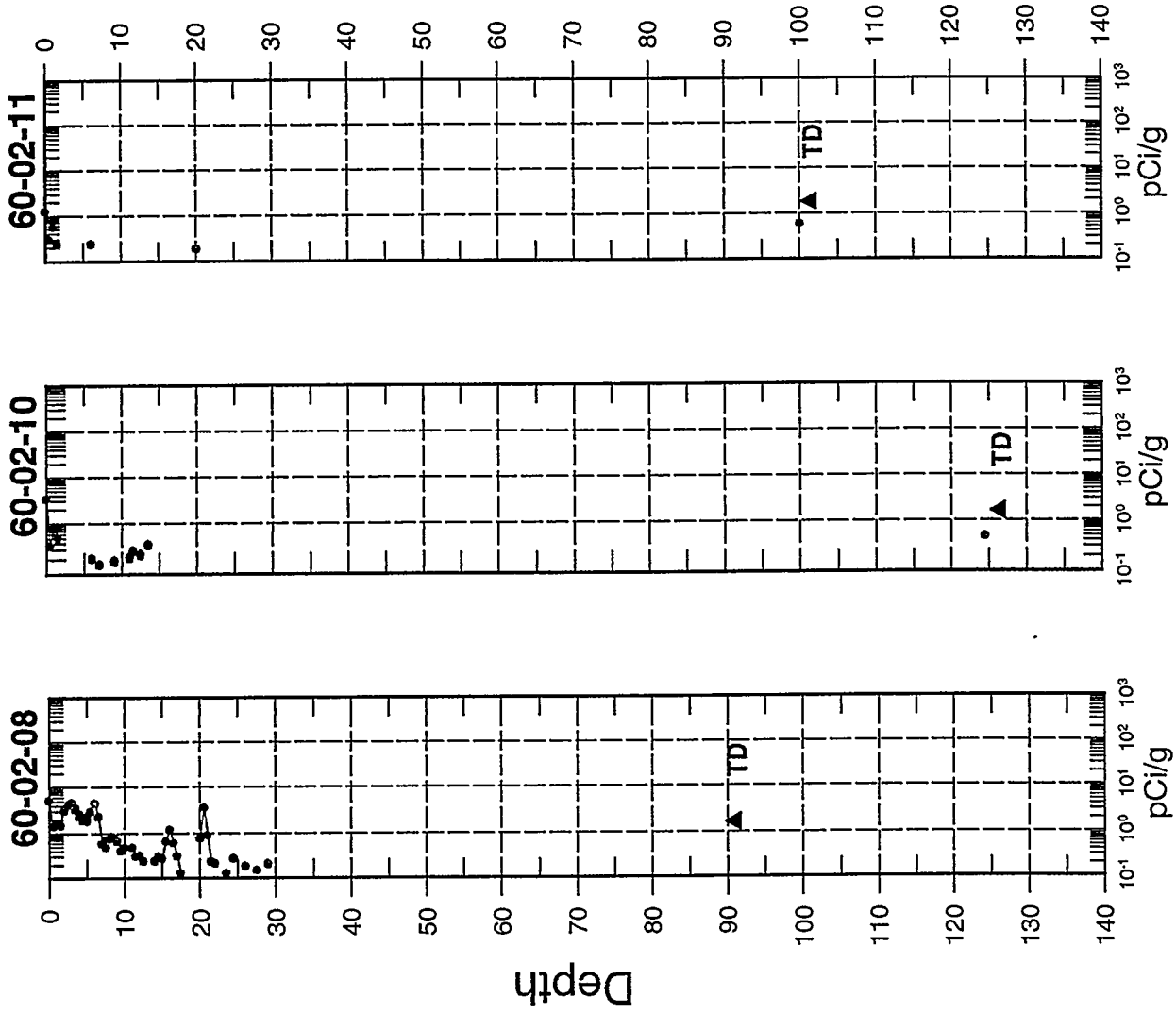

Figure C-2 (continued). Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-102

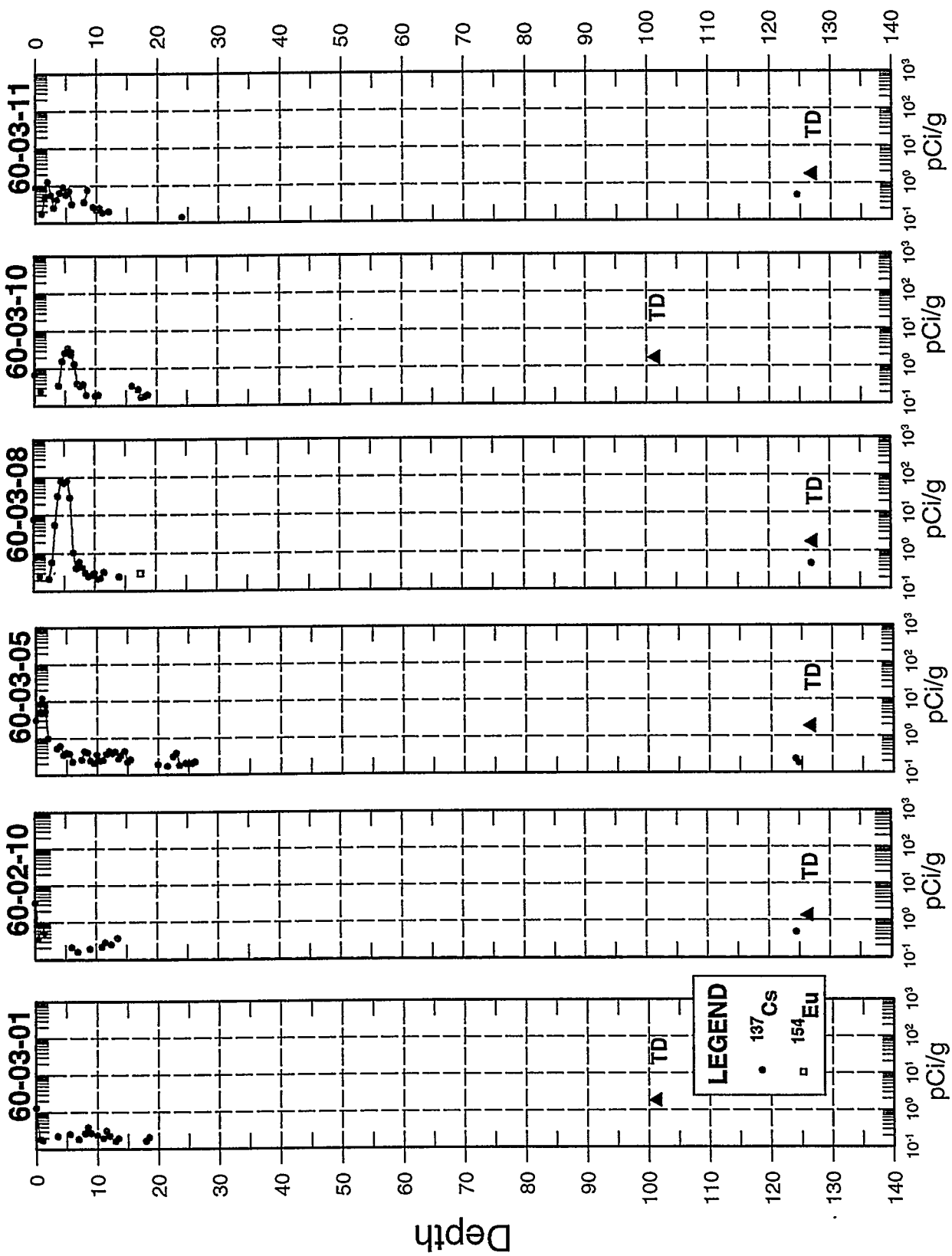

Figure C-3. Correlation Plot of ^{137}Cs and ^{154}Eu Concentrations in Boreholes Surrounding Tank U-103

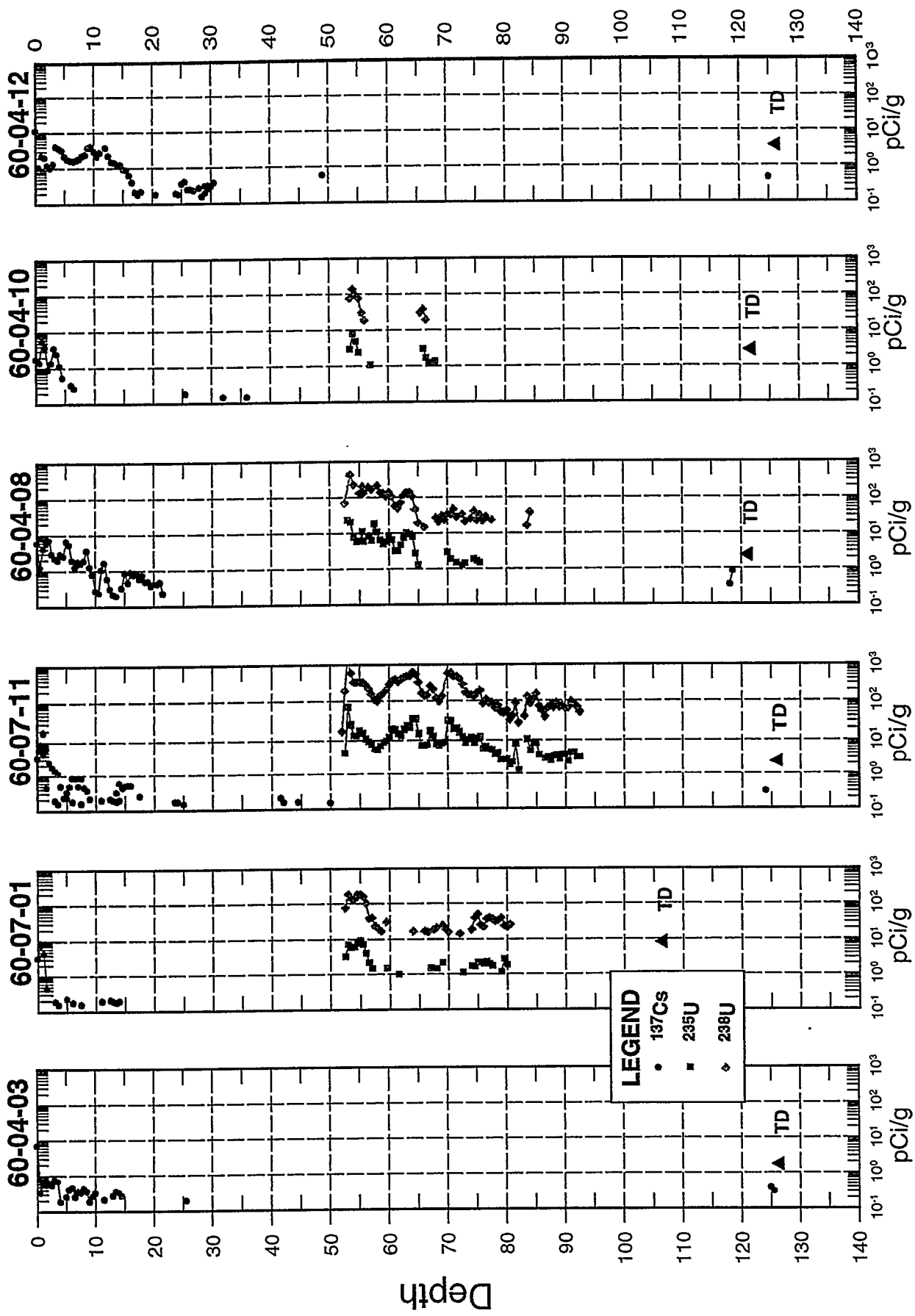

Figure C-4. Correlation Plot of ^{137}Cs, ^{235}U, and ^{238}U Concentrations in Boreholes Surrounding Tank U-104

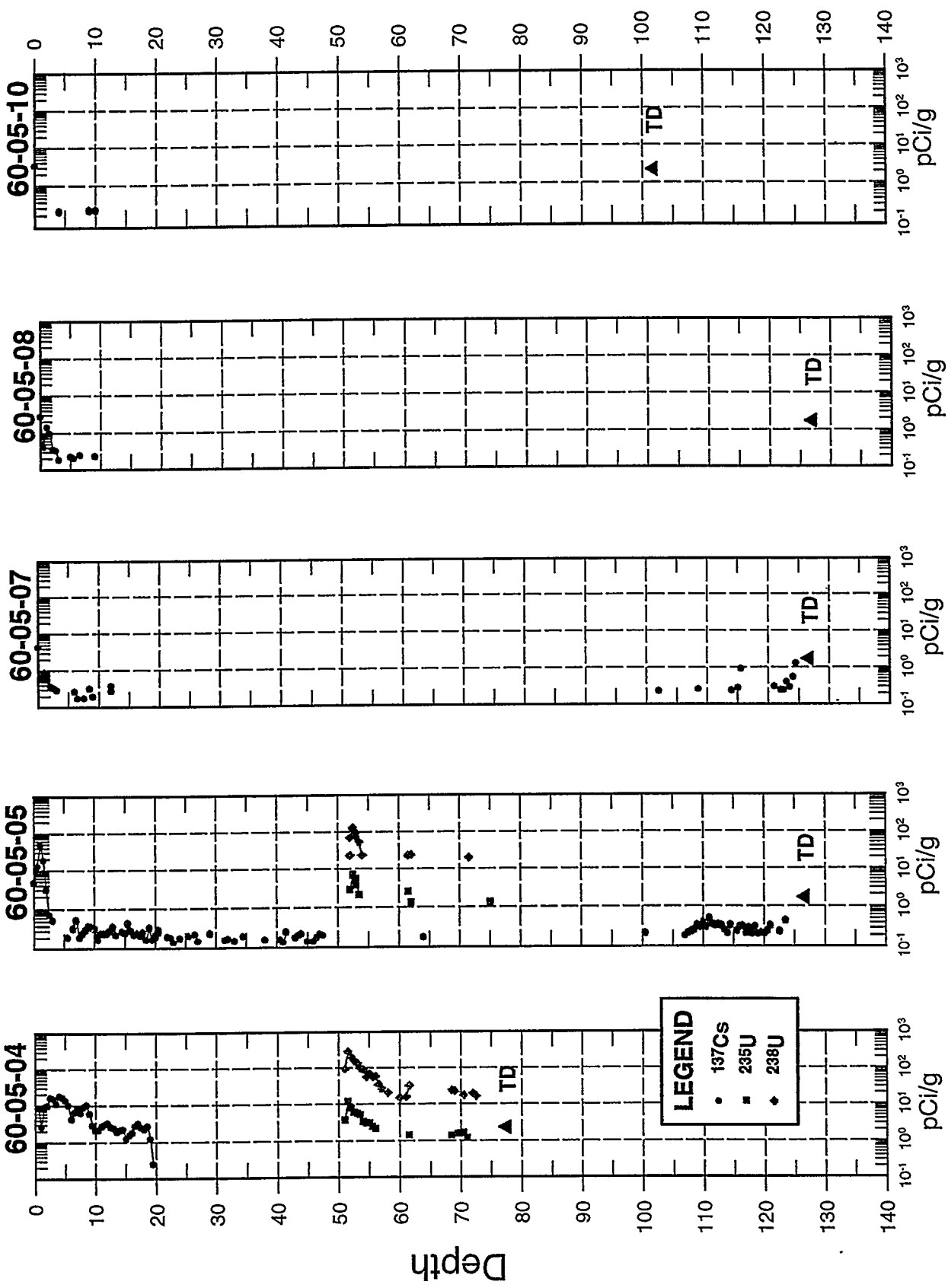

Figure C-5. Correlation Plot of ^{137}Cs, ^{235}U, and ^{238}U Concentrations in Boreholes Surrounding Tank U-105

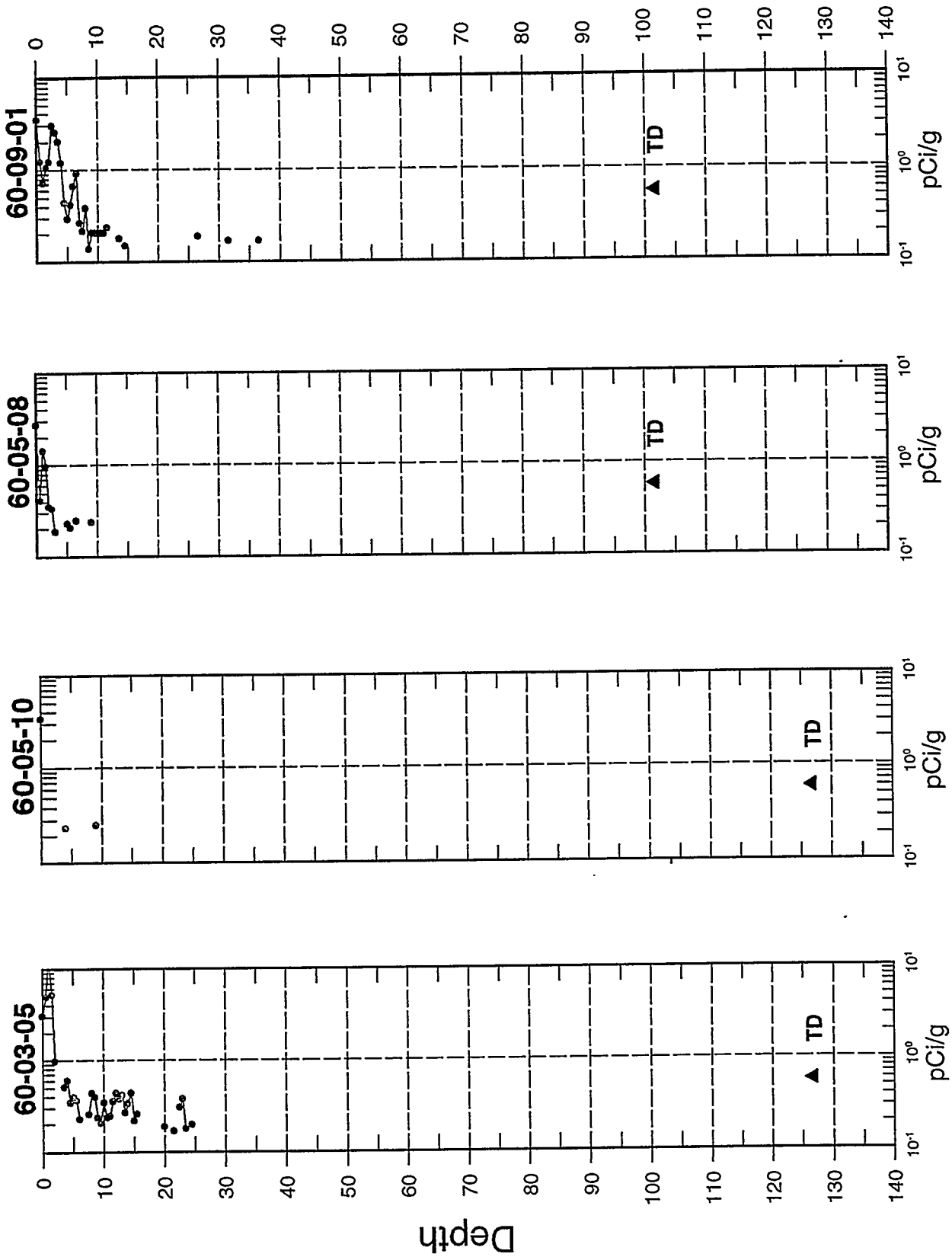

Figure C-6. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-106

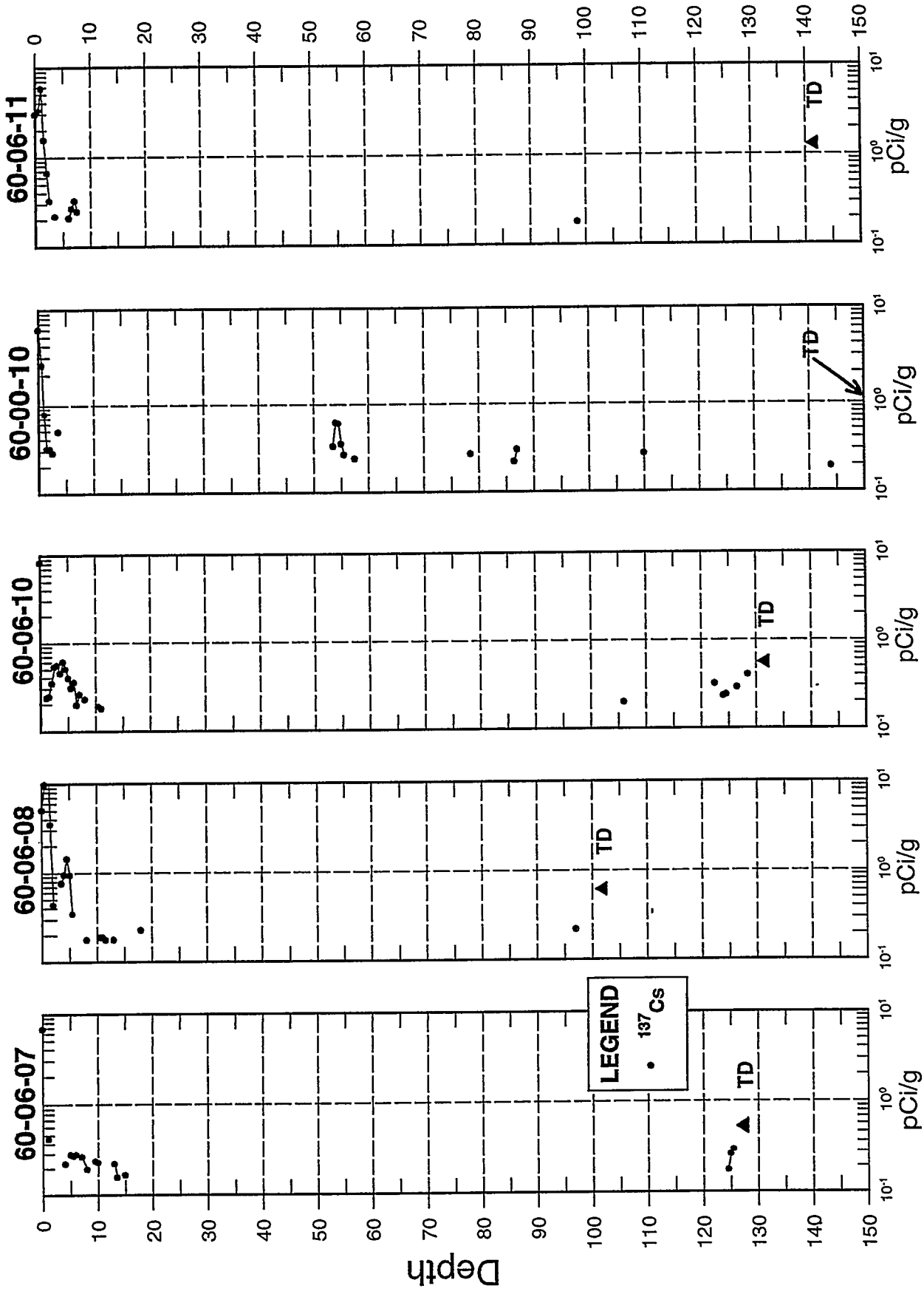

Figure C-6 (continued). Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-106

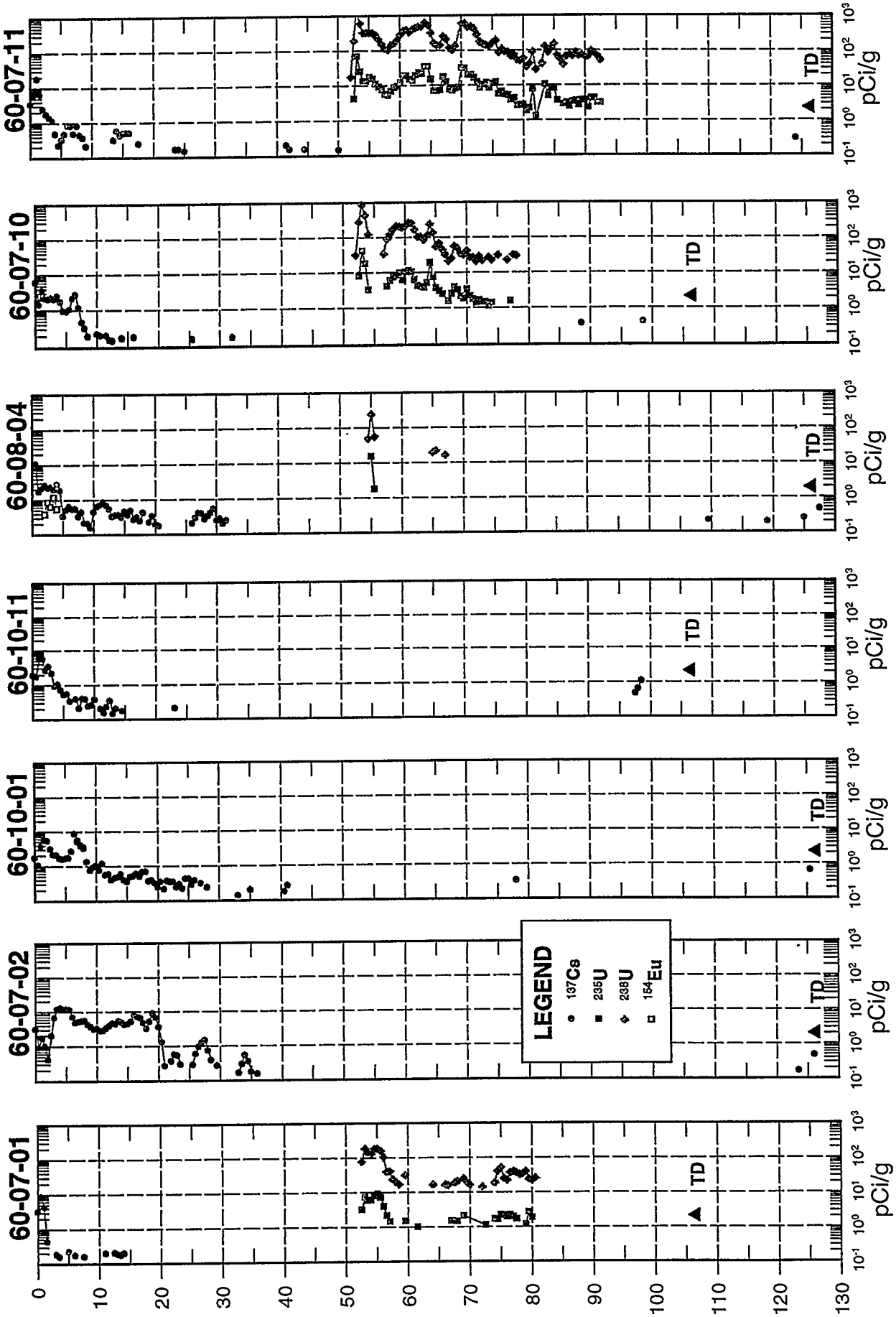

Figure C-7. Correlation Plot of ^{137}Cs, ^{235}U, ^{238}U, and ^{154}Eu Concentrations in Boreholes Surrounding Tank U-107

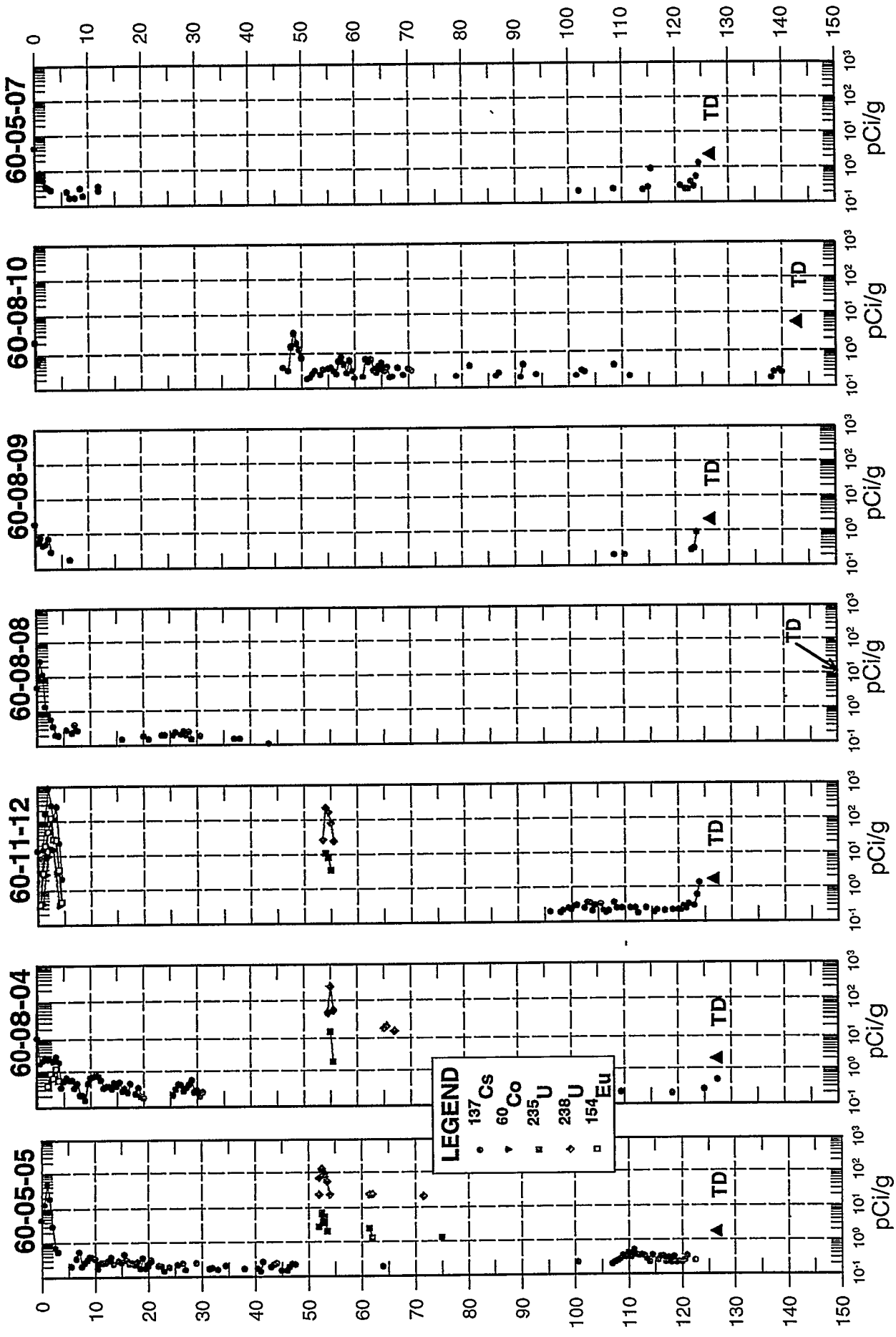

Figure C-8. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, and ^{154}Eu Concentrations in Boreholes Surrounding Tank U-108

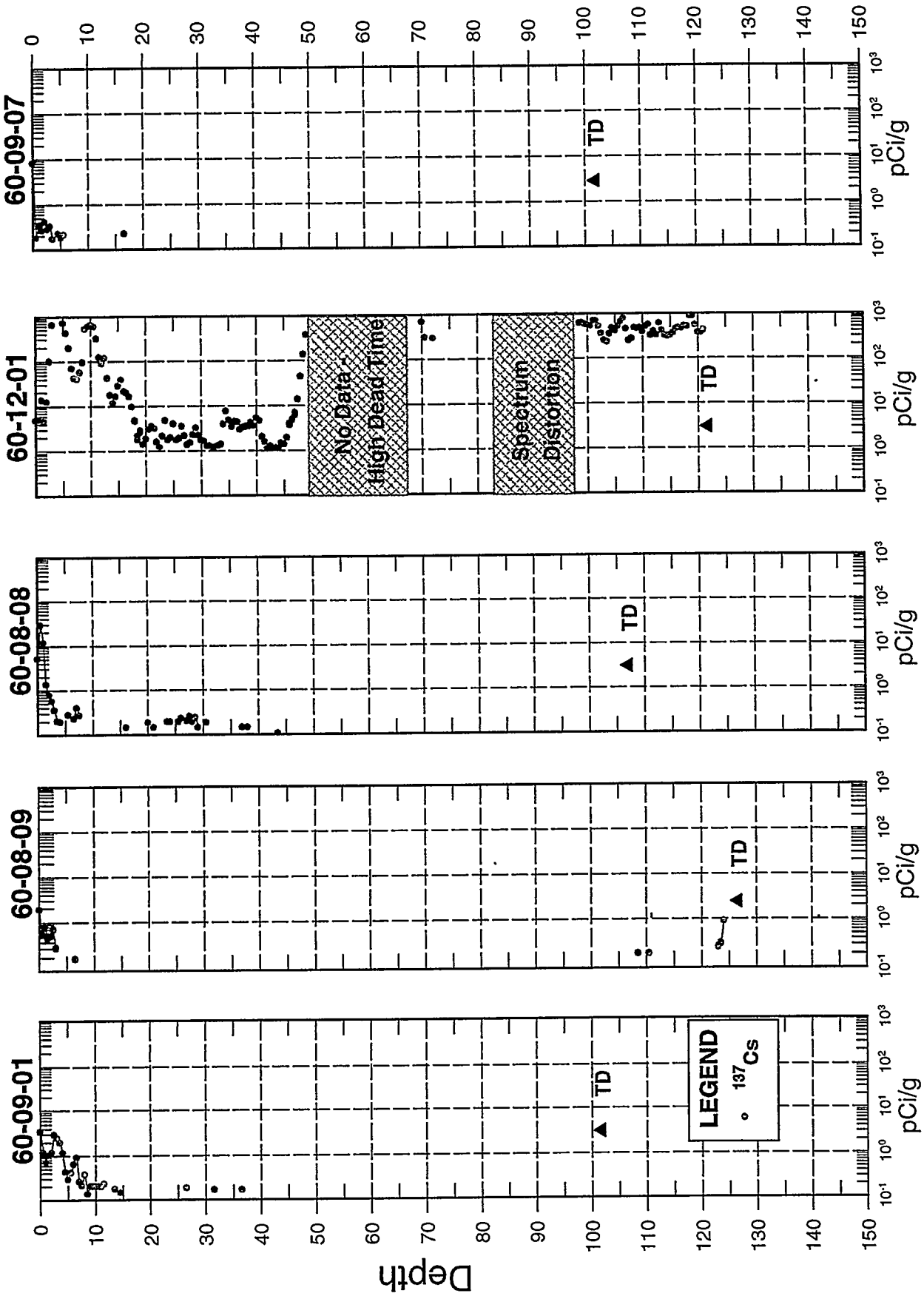

Figure C-9. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-109

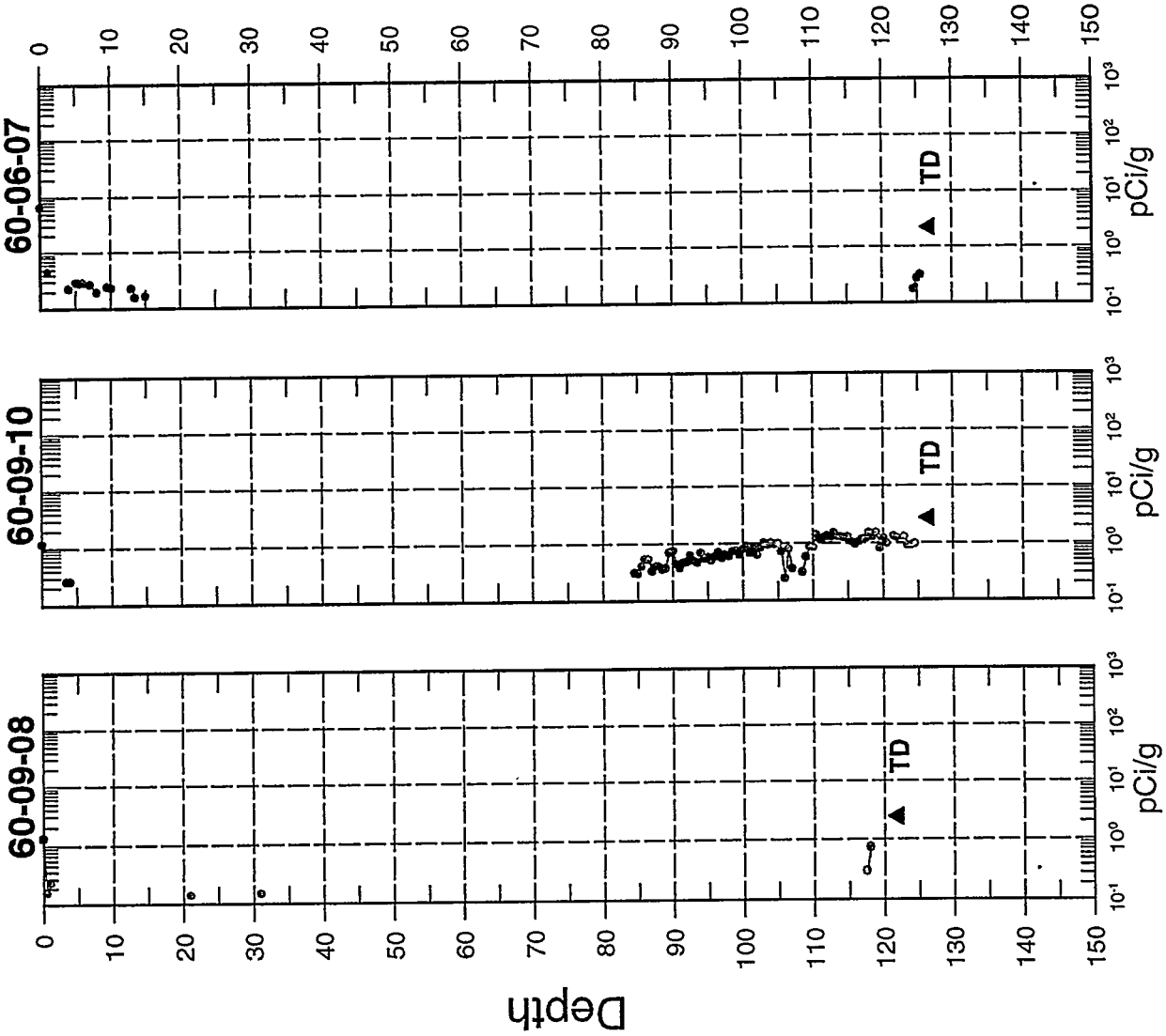

Figure C-9 (continued). Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-109

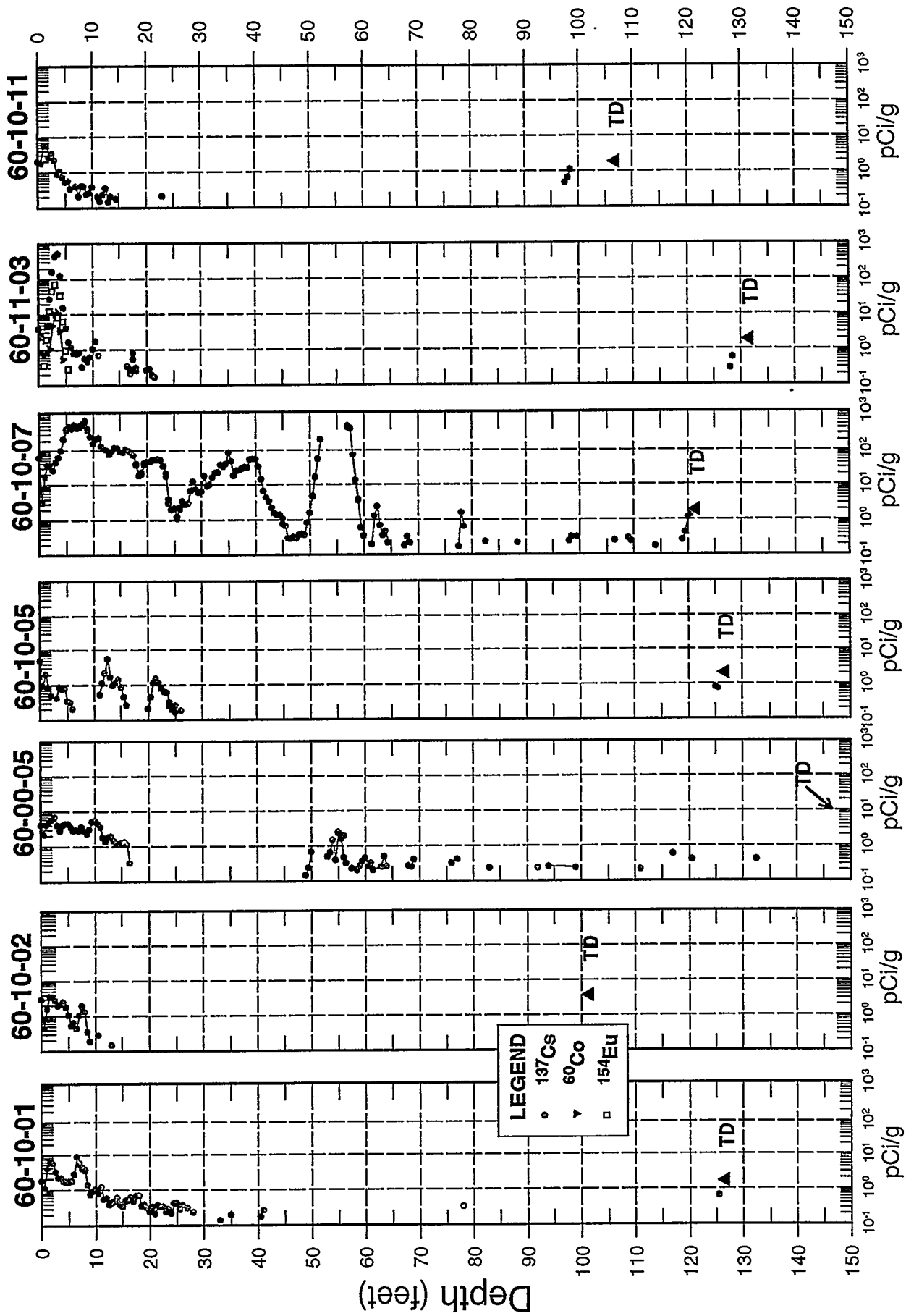

Figure C-10. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank U-110

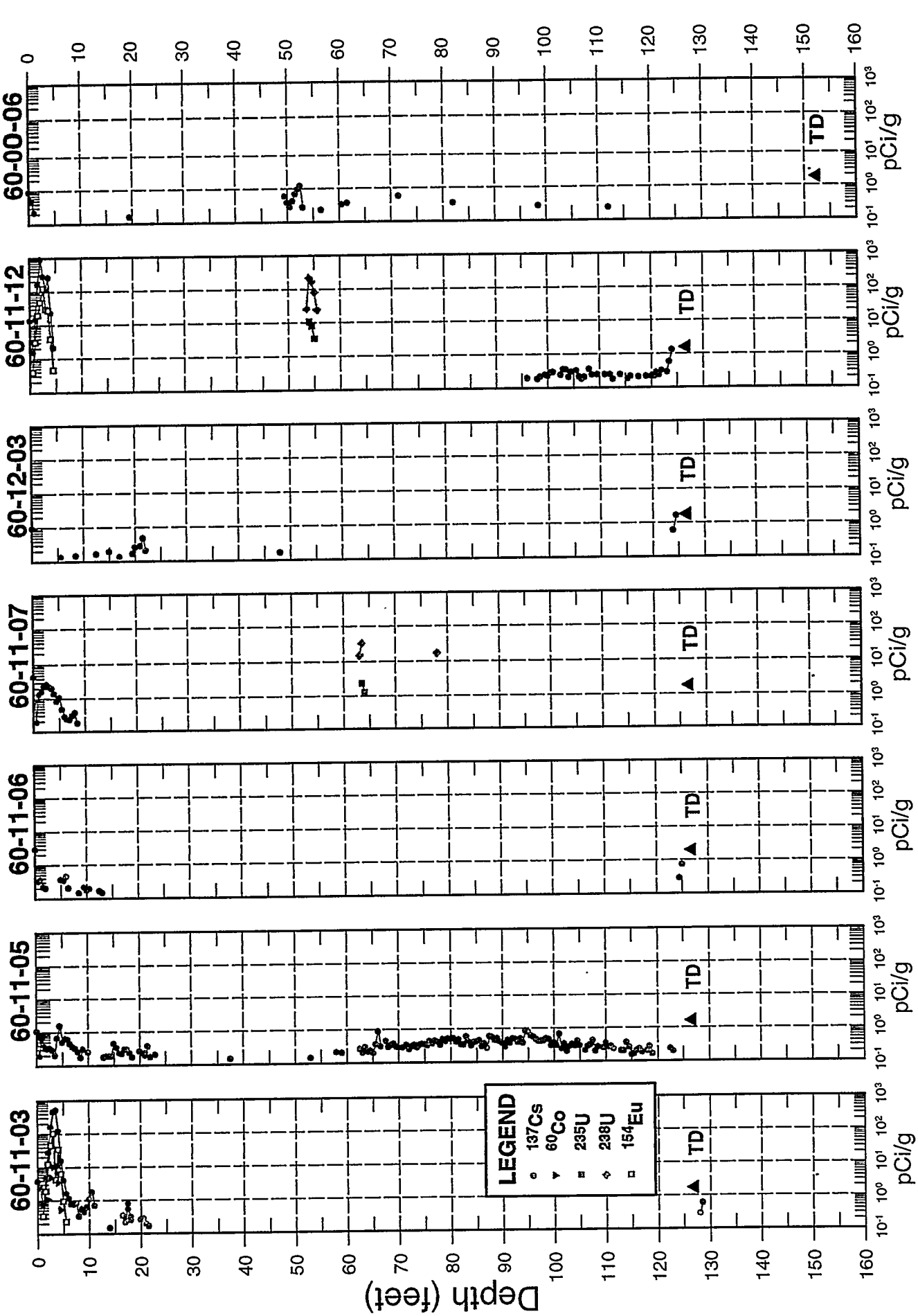

Figure C-11. Correlation Plot of ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, and ^{154}Eu Concentrations in Boreholes Surrounding Tank U-111

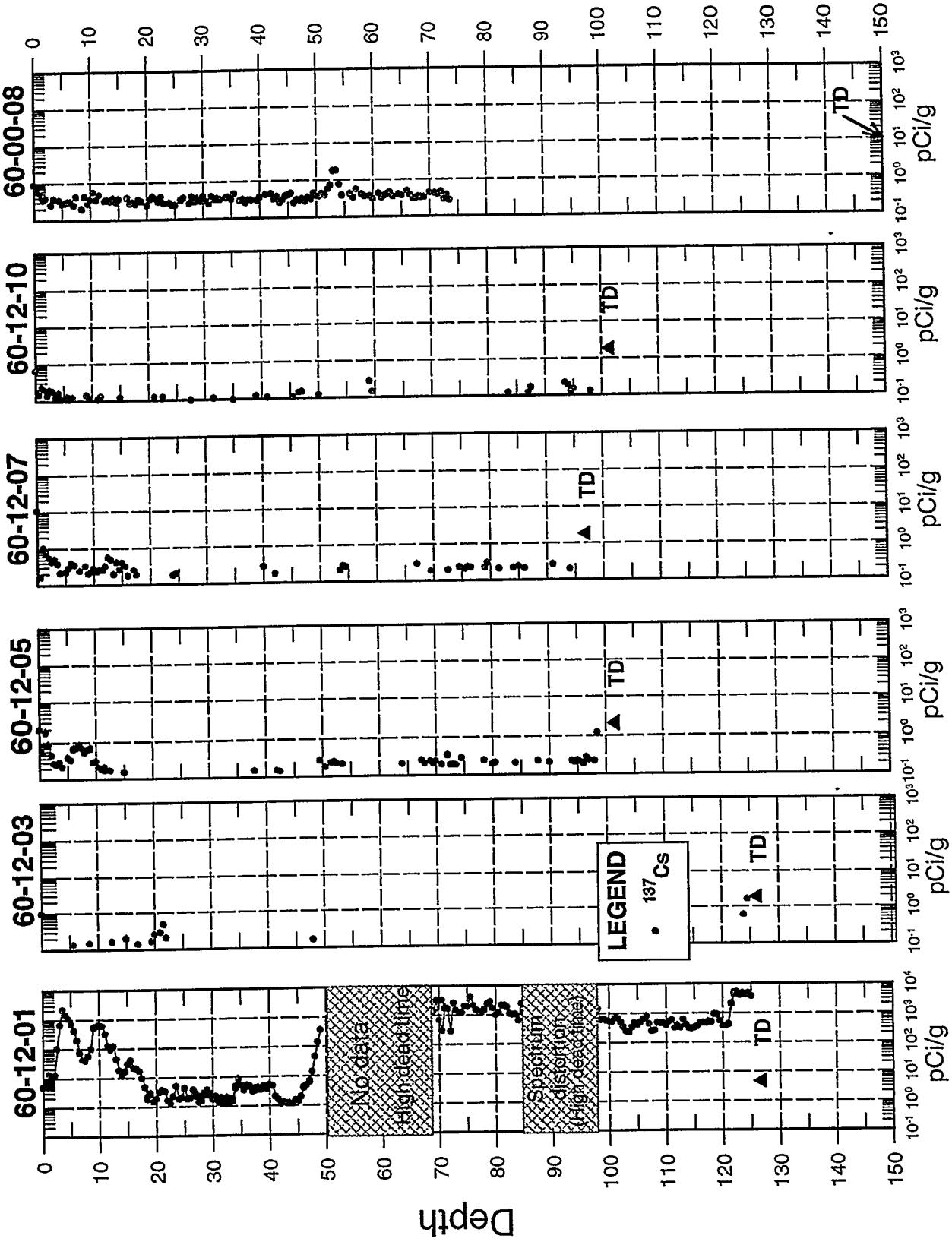

Figure C-12. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank U-112