GJO-96-2-TAR
GJO-HAN-6

Vadose Zone Characterization Project at the Hanford Tank Farms

BY Tank Farm Report

February 1997

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U.S. Department of Energy

Work Performed Under DOE Contract No. DE-AC13-96GJ87335 for the U.S. Department of Energy
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Prepared for
U.S. Department of Energy
Richland Operations Office
Richland, Washington

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Albuquerque Operations Office
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Grand Junction, Colorado

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

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Executive Summary

The U.S. Department of Energy Grand Junction Office (GJO) was tasked by the DOE Richland Operations Office (DOE-RL) to perform a baseline characterization of the contamination distributed in the vadose zone sediment 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, 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 about the vadose zone contamination with borehole geophysical logging methods and documenting that information in a series of reports. Data from boreholes surrounding each tank are compiled into individual Tank Summary Data Reports. The data from each tank farm are then compiled and summarized in a Tank Farm Report. This document is the Tank Farm Report for the BY 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. Sixty-nine boreholes surrounding the 12 BY Tank Farm SSTs were logged. Logging was completed in October 1995, and the last Tank Summary Data Report for the BY Tank Farm was issued in April 1996.

Log data were analyzed by identifying man-made contaminants in the sediment and by calculating the equivalent, uniformly distributed radionuclide concentrations. Vertical profile plots or logs of the contamination concentration 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 contamination 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.

Prepared as a part of this characterization project, the BY Tank Farm Report is the final document that presents an overall perspective of the vadose zone contamination in the entire BY 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 BY Tank Farm geology and hydrology give the reader an understanding of the potential environmental implications of the presence of the contamination. The geology and hydrology information were obtained from data in previously published Hanford contractor documents.

Background information regarding BY 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 BY 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 instrument calibration and data reduction.

The spectral gamma log data show cesium-137 (^{137}Cs) is the most abundant and highest concentration radionuclide detected throughout the BY Tank Farm. Cobalt-60 (^{60}Co) was also detected in fairly extensive distributions, but in much lower concentrations than ^{137}Cs; ^{60}Co was often detected at the bottoms of boreholes. Other gamma-emitting radionuclides detected are antimony-125 (^{125}Sb) and europium-154 (^{154}Eu).

Models of the ^{137}Cs and ^{60}Co contamination plumes were developed; however, the occurrences of ^{125}Sb and ^{154}Eu were not abundant enough to correlate these nuclides among the boreholes. The geostatistical structures of the ^{137}Cs and ^{60}Co 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 ^{137}Cs and ^{60}Co contamination distributions, potential inaccuracies and uncertainties in the model are presented so that the limitations of the visualizations are recognized.

The estimated assay uncertainty of the log data points calculated from spectra 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 or around the borehole and not distributed in the formation. Interpretations suggest the occurrence of such conditions in several boreholes where it is suspected contamination has fallen down and settled at the bottom of boreholes, creating false deep, low-concentration plumes, as seen in 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 conditions result in 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, these visualizations confirm the listed integrity status of the tanks. In some instances, such as tank BY-111, the visualizations defined a ^{60}Co contamination plume, that when interpreted with insight gained from historical information, raises questions as to the integrity of this tank.

The highest concentrations of ^{137}Cs contamination in the BY Tank Farm boreholes were detected on the southeast side of tank BY-103, supporting the designation of this tank as an assumed leaker. Both ^{137}Cs and ^{60}Co were detected in borehole 22-03-05 below a zone of ^{137}Cs contamination with concentrations so high that they caused the detector to saturate. Several other high ^{137}Cs concentrations were detected in the BY Tank Farm boreholes; however, these concentrations were associated with near-surface contamination resulting from surface spills, pipe leaks, or the proximity of the boreholes to pipes containing contamination. ^{137}Cs contamination was detected throughout the lengths of several boreholes, but the concentrations were usually 1 picocurie per gram (pCi/g) and less.

^{60}Co contamination was detected around all the tanks in the BY Tank Farm that are known to have leaked. Concentrations were usually less than 10 pCi/g; however, the vertical distributions were extensive. ^{60}Co contamination was often detected above the bases of the tanks and also near the ground surface. This contamination was often associated with zones of elevated ^{137}Cs contamination near the ground surface, indicating sources from spills or leaks or the proximity of the boreholes to contaminated pipelines.

^{60}Co contamination was often detected alone below the tank bases within fine-grained sediments of the Hanford formation, and the visualizations show extensive areal distribution of the ^{60}Co contamination relative to the ^{137}Cs contamination. This wide distribution is most likely indicative of the higher mobility of ^{60}Co, which may be enhanced by its chemical combination within the constituents of the tank waste.

The presence of plumes of ^{60}Co contamination beneath the southern portion of tank BY-110 raises question as to the integrity of this tank. Historical documentation reveals evidence of potential for leakage (tar rings and unexplained liquid-level decreases); however, neither this information nor the recent characterization data confirm leakage.

^{60}Co contamination on the west side of tank BY-111 strongly implies that this tank has leaked in the past. Historical documentation records liquid-level decreases coincident with increases in gamma-ray intensities in monitoring boreholes around the west side of this tank. Therefore, on the basis of these data, it is recommended that this tank be reclassified a leaker.

A majority of the monitoring boreholes in the BY Tank Farm extend to a depth of about 100 feet (ft), and the log data from several of the boreholes indicated significant ^{60}Co contamination at the bottoms of the boreholes. In the deepest borehole logged in the BY Tank Farm, borehole 22-00-03, ^{60}Co was detected at a depth of 145 ft, at the bottom of the borehole. The maximum depth extent of the BY Tank Farm ^{60}Co contamination plumes is not known; therefore, any impacts of the vadose zone contamination on the groundwater cannot be directly determined. The depth to groundwater beneath the BY Tank Farm is about 250 ft, which is significantly deeper than all of the tank monitoring boreholes.

Correlation of geologic data acquired during drilling of groundwater monitoring boreholes with data during the tank farm characterization was attempted. The contacts between the Hanford formation sequences are sometimes difficult to establish. The contact between the Ringold

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

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. 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.

Additional logging characterizations would complement the data provided in this initial investigation, 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 to correlate lithology between boreholes at the present time, and main lithologic changes were positively identified. Moisture information may assist correlation of the minor plumes because water acts as a driving force for contaminant migration.

At least one new borehole should be installed in the BY Tank Farm to define the lower extent of the ^{60}Co contamination plume(s). In most of the BY Tank Farm, the present monitoring boreholes limit the vadose zone investigation to a depth of about 100 ft.

In order to provide additional pertinent characterization information, concentrations of radionuclides that decay without gamma emission or decay by emission of gamma rays too low in energy to be detected, particularly the higher-risk nuclides such as plutonium, strontium, and technetium, should be identified and evaluated. It is also important to obtain samples of the vadose zone sediment for geochemical analyses, which may include analyses for both organic and inorganic waste constituents.

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

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

1.0 Introduction

The BY Tank Farm is located in the north-central portion of the 200 East Area of the Hanford Site (Figure 15-1). This tank farm consists of 12 single-shell tanks (SSTs), each with an individual capacity of 758,000 gallons (gal). These tanks currently store high-level nuclear waste that was primarily generated from the chemical processing of irradiated uranium fuel reactor materials. Five of the 12 tanks are listed in Hanlon (1996) as "assumed leakers" and are known to have leaked various amounts of high-level radioactive liquid into the vadose zone sediments.

In 1994, the U.S. Department of Energy Richland Operations Office (DOE-RL) requested the DOE Grand Junction Office (GJO), Grand Junction, Colorado, to conduct a baseline characterization of contamination in the vadose zone at all the SST farms by performing spectral gamma-ray logging of boreholes surrounding the tanks. The BY Tank Farm geophysical logging was completed, and the results of this baseline characterization are presented in this report.

The vadose zone characterization project was undertaken in an attempt to determine the nature and extent of contamination in the vadose zone around the SSTs. Existing monitoring boreholes in the BY Tank Farm were logged with high-purity 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 the contamination in the vadose zone around the BY Tank Farm tanks.

Data acquired in this characterization work establish a baseline of the current vadose zone contamination conditions and present a limited assessment of the extent of the contamination. This work is an integral part of a larger project to characterize the vadose zone around the tanks, 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).

2.0 Purpose and Scope

2.1 Purpose of the Project

The purpose of this baseline characterization is to identify the radioactive contaminants and determine their spatial distributions to the extent possible using the existing boreholes. 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. The economic viability of the project is based on the limitation of only quantifying the gamma-emitting contaminants. In addition, utilizing the existing boreholes is economical, but is also limiting because the boreholes are located to serve leak detection, not to determine the contaminant distribution. 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.

An integral objective of this project is to identify 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 an objective 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 BY 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 during the course of this project; therefore, the assessments of the vadose zone contamination are based on the limited distribution of existing boreholes. Most of these boreholes extend only 100 feet (ft) down into the vadose zone, while the groundwater is approximately 250 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 strictly a practice of sound economy. It is prudent to log the existing boreholes, develop a contamination model on the basis of those data, and determine the model uncertainty before conducting a more rigorous and far more 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 BY 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 rays are not assayed. In addition, information such as moisture content and formation density could be of significant value in assessing vadose zone contamination distribution; however, it is unknown whether meaningful results could be obtained with the current technology in the casing configuration of the BY Tank Farm boreholes.

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, accuracy, and 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. These data, with associated uncertainties and documented quality controls, are available to all Hanford decision makers.

2.3 Regulatory Basis

The operation and eventual closure of the SST farms are governed by both Federal and State laws, primarily RCRA; the National Environmental Policy Act (NEPA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and portions of the *Washington Administrative Code* (WAC).

To prevent regulatory duplication and to enhance the progression of the cleanup at the Hanford Site, an attempt has been made to combine the RCRA-, CERCLA-, and State-legislated regulations under a regulatory framework described in an agreement among the three involved government agencies: the U.S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (Ecology), and DOE as operator of the tanks. This agreement is the Hanford Federal Facility Agreement and Consent Order (Ecology et al. 1996) and is called the Tri-Party Agreement (TPA). Under the TPA, Ecology is the lead regulator overseeing DOE activities in both the operation and closure of the tanks.

The SSTs are currently regulated as RCRA hazardous-waste tank systems and are considered to be RCRA treatment and storage (TS) units. As allowed in RCRA, Washington State uses WAC 173-303 to implement the RCRA regulations for the Federal Government.

Currently, DOE operates the SST TS units under an interim status permit issued by Ecology. It was not possible to immediately close the tanks or to comply with all the interim status requirements. Therefore, the interim status permit was issued as a part of a negotiated plan for eventual tank closure, even though the SSTs do not meet all the requirements under WAC 173-303 for interim status facilities.

The TPA now provides the regulatory framework and specific major milestones for both interim operation actions and for SST closure. The objective of current work at the SSTs involves both activities related to both the closure process and to ensuring safe interim operation of the tanks.

The SST farm closure process essentially follows a RCRA closure process as outlined in Section 6.3 of the TPA, but because of the expense and complexity involved with closing the tank farms, the tank closure process is scheduled to occur over a 20-year time period. An SST farm closure work plan (DOE 1996b) addresses the content of a closure plan as outlined in TPA Milestone M-45-06.

The SST farm closure process must address and encompass the entire tank farm, including the tank waste, tank structures, residual waste in the tanks, ancillary tank farm equipment, and sediment contaminated by leaked tank waste. Closure alternatives, including alternatives for remediating contaminated sediment, will be selected under the NEPA process. Implementation of closure decisions will be permitted under WAC 173-303 "dangerous waste regulations." Data acquired during the tank farm vadose zone characterization project will provide some of the basic information on the vadose zone contamination to support the NEPA process for closure and the permitting process under WAC 173-303. The closure work plan specifically identifies the need for characterization of the vadose zone contamination.

Interim operations essentially involve ensuring the safe interim storage of the tank waste until the waste can be removed during the closure process. Portions of WAC 173-303 provide the major regulations that govern and specify interim actions or operations. Some interim actions are specified by the TPA, and other activities are based on sound tank management practices.

The vadose zone characterization work is being accomplished as an interim operation action, because RCRA regulations require DOE to know the nature and extent of contamination released from the tanks. In addition, DOE is required to know the extents of the historical releases as well as the effects of any current or future releases. Various regulations also require tank monitoring for leak-detection purposes and for environmental monitoring reasons. Data obtained in the vadose zone characterization project provide a baseline for that monitoring.

Another regulatory aspect of SST farm closure relates to waste classification. SST waste is classified as high-level waste (HLW). Disposal of HLW is regulated by the U.S. Nuclear Regulatory Commission (NRC). NRC has authority to reclassify the radioactive portion of residual waste remaining in the tanks following retrieval and waste that may have leaked to the soil as non-HLW. In this case, regulatory authority for disposal of the radioactive component would pass to DOE and regulatory requirements would be performed in accordance with DOE Order 5820.2A, *Radioactive Waste Management.* A decision by NRC to classify residual waste and contaminated soil as non-HLW will rely on characterization data and modeling to assess long-term risk to the public and the environment.

Another major class of requirements consists of DOE Orders, which are not regulations but internal directives mandated by DOE. DOE Orders tend to focus on the radiological aspects of the SSTs, but they also require compliance with RCRA, CERCLA, and NEPA for nonradiological hazardous substances. DOE Orders require several types of environmental monitoring around the tanks (DOE Orders in the 5400 series deal with radiation protection of the public and the environment) as well as tank-specific monitoring (DOE Order 5820.2A, *Radioactive Waste Management*). The vadose zone characterization project is designed to help satisfy several requirements of these DOE Orders.

2.4 Purpose of Report

This report presents a summary of the results of the spectral gamma logging characterization at the BY Tank Farm that were originally reported in individual Tank Summary Data Reports, and it provides models of the ^{137}Cs and ^{60}Co contamination distributions. The models correlate the individual borehole logs in three dimensions and help to identify contamination plumes, relationships between the plumes, and the sources of the contamination. Section 9.0, "Development of the ^{137}Cs and ^{60}Co Contamination Model," documents model development, identifies assumptions and model parameters, and explains the uncertainty associated with the model.

This report provides a brief overview of the BY Tank Farm, including background information, a history of the tank farm, geologic and hydrologic reviews, and descriptions of waste sites adjacent to the BY Tank Farm.

This report specifically identifies some of the potential impacts on the environment from the contamination that is identified in the baseline characterization so these impacts can be evaluated in a quantitative manner in either the Environmental Impact Statement (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. However, that does not imply that it is not necessary to characterize other radionuclides in more comprehensive characterizations.

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 its specific activity and/or biological toxicity.

Long-term risks arise primarily from a potential pathway whereby an individual or environmental receptor is exposed by ingesting contaminated groundwater and from a pathway involving direct exposure to contaminated sediment that is uncovered or otherwise brought to the surface in the distant future, after the end of an institutional control period. Long-term risk scenarios are usually evaluated by using vadose zone contaminant-transport modeling to produce performance assessments that estimate potential doses for different pathways. Radionuclides of concern would be those with long half-lives and those that are mobile in the vadose zone and could contribute to groundwater contamination.

Short-term risk scenarios involve inhalation of radionuclides or direct exposure to workers during remediation or other operations that would uncover or bring the vadose zone contamination to the surface in the near future. The radionuclides of concern are those that are easily suspended in air and the high specific-activity radionuclides that present an exposure problem.

Boothe (1996) presents a review of the radionuclide inventory of the tank wastes and the risk levels associated with each radionuclide.

Many radionuclides in the original tank wastes that have short half-lives have since decayed away and are no longer detectable, or are detected but the plumes are fractions of the original contamination leaked into the vadose zone. Some of the radionuclides of interest are identified in the following sections.

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 usually present at high concentrations. This radionuclide is a man-made isotope that originated as a high-yield fission product (approximately 6.1 percent out of 200 percent of the original fission atoms) 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 metastable 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 detection 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 contaminant in the vadose zone around the SSTs. ^{137}Cs is easy to detect and quantify with passive gamma logging and was detected in every borehole in the BY 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 strongly adsorbed to the sediment, particularly if pH values are greater than 4.0 as is typical of the Hanford sediment.

In groundwater, ^{137}Cs is present as a univalent cation and migrates faster at high pH, but both granitic and basaltic rock tend to retard its migration (Carboneau et al. 1994b). ^{137}Cs is also retained by clay sediment. The EPA-mandated maximum contaminant level (MCL) for ^{137}Cs in groundwater is 200 picocuries per liter (pCi/L).

At Hanford, ^{137}Cs is the most abundant contaminant in the vadose zone, but it is detected in groundwater samples at only a few locations. At one such location, the B-5 Injection Well in the 200 East Area, ^{137}Cs-contaminated liquids were injected directly into the near-surface aquifer. ^{137}Cs contamination was also detected in groundwater samples collected beneath the 216-BY Cribs. Several million gallons of radiological liquid wastes were discharged to the cribs. Later characterization of these sites indicated that the ^{137}Cs contamination plumes may not have migrated far from the sources. Because of the apparent low mobility of ^{137}Cs in the groundwater at Hanford, detection of ^{137}Cs-contaminated groundwater requires placement of sampling wells close to the contamination source.

^{137}Cs is absorbed by humans and animals through the digestive tract and behaves chemically in the body in a manner similar to potassium (Carboneau et al. 1994b).

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 in the decay 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 1979). These gamma rays make the presence of ^{60}Co easy to detect and to quantify with passive gamma measurement equipment. The MDL under the BY Tank Farm logging conditions was about 0.15 pCi/g.

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 also because it has a high specific activity (1.1 x 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. ^{60}Co appears to be highly mobilized by the presence of cyanide or ferrocyanide compounds (Dresel et al. 1995), which are constituents of some of the SST wastes in the BY Tank Farm.

Measurements of vadose zone contamination at Hanford (Brodeur et al. 1993) suggest ^{60}Co is more mobile in the vadose zone than europium or antimony and much more mobile than ^{137}Cs. 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. ^{60}Co was detected throughout the BY Tank Farm, and plumes of ^{60}Co contamination were detected under all BY tanks designated "leakers."

In the saturated zone (groundwater), ^{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. In the 200 East Area, ^{60}Co was detected in groundwater samples collected near the 216-BY Cribs at about 75 pCi/L. The 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 highly 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 would indicate changing conditions of a plume that are due to recharge from precipitation or to new tank releases.

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

Abundant europium radioisotopes 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.

^{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), 1112 keV (13.6 percent), and 1408 keV (21 percent) (Erdtmann and Soyka 1979).

Few references were found describing the mobility of europium in 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.

Of these isotopes, only ^{154}Eu was detected in the BY Tank Farm boreholes. It occurred near ground surface in all five of the vadose zone monitoring boreholes in which it was detected.

^{154}Eu has not been detected in the unconfined aquifer beneath the 200 Areas (Dresel et al. 1995; Johnson 1993) indicating that, at the Hanford Site, it is retained in the vadose zone sediment.

Both ^{152}Eu and ^{154}Eu present short-term exposure risks because of the gamma radiation, but they are not considered a long-term risk because of their relatively short half-lives. The 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 also is a high-yield, long-lived fission product. It has a fission yield of 5.9 percent out of a total yield of 200 percent (Kathren 1984) and 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 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 ^{90}Sr is present in the subsurface at high concentrations (greater than about 2,000 pCi/g), bremsstrahlung radiation or braking radiation may be measured in a borehole with the 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 the spectral gamma-ray detection equipment. Nonconclusive evidence of the presence of ^{90}Sr was observed in three boreholes in the BY Tank Farm; these boreholes are adjacent to tanks BY-103, BY-108, and BY-109.

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.

^{90}Sr 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. In the high-heat and self-boiling tanks (typical of the A and SX Tank Farms), the decay of ^{90}Sr generates more heat than all other radionuclides combined. This heat is the result of the release of high-energy beta particles from the decay of ^{90}Y. ^{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 apparently can replace calcium in carbonate sediment. This chemical relationship has particular significance where calcium carbonate-rich zones are present in the Hanford formation and Ringold Formation sediments, as these zones may effectively inhibit the vertical migration of ^{90}Sr. ^{90}Sr retention in soil increases with an increasing pH value.

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

In groundwater, ^{90}Sr tends to stay in soluble form and migrates farther than other fission products such as ^{137}Cs. ^{90}Sr is often a risk-limiting radioisotope because of the relatively high mobility of ^{90}Sr in both the vadose zone sediment and the groundwater and because of its high health risk relative to other nuclides. The 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 or plutonium 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. However, its percentage of abundance in the waste products increases as the waste ages because it has a long half-life (2.8 years) 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, is easily measured, and is more mobile than some of the other gamma-emitting radionuclides. It poses minimal risk because of its general low abundance, but is easily monitored and tracked for contaminant migration studies because it is a gamma-emitter.

^{125}Sb was detected in the vadose zone sediments in one borehole in the BY Tank Farm. 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 presents a short-term exposure risk because it can be inhaled. The 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 much lower curie content (by many orders of magnitude because) 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. Rudin et al. (1992) state that, if sufficient reducing conditions exist in the sediment, ^{99}Tc will precipitate out of solution as a sulfide or hydrated oxide. If oxidizing conditions exist, ^{99}Tc 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 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 at the BY Tank Farm (refer to Section 4.4, "BY Tank Farm Hydrology," in 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 tanks wastes are primarily ^{238}U and ^{235}U, with minute quantities of ^{232}U, ^{233}U, ^{234}U, and ^{236}U. Uranium isotopes in the irradiated fuel elements are separated from the fission and activation products in chemical processes. Consequently, waste effluent sent to the SSTs usually does not contain much uranium.

^{238}U, by far the most abundant uranium isotope in the waste, occurs naturally in the Earth's crust and is assayed for stratigraphic correlation purposes. It decays through a long and complex decay chain that results in the emission of alpha and beta particles as well as gamma rays. ^{238}U has a long half-life (4.7 x 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). The Tank Summary Data Reports include the ^{238}U logs (based on the ^{214}Bi activity) for all the BY Tank Farm boreholes. ^{238}U was detected throughout a 1-ft-thick interval in borehole 22-11-08, which is adjacent to tank BY-111.

When ^{238}U is not in secular equilibrium with its daughter nuclides, such as occurs 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-234 (^{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 extended 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 7.0 x 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 highly mobile in an acidic hydrologic regime or an oxidizing environment. The sediments of the Hanford and Ringold formations are calcareous and typically result in high pH and moderate Eh values. As a result, 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. The 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 MCL for uranium in groundwater is 20 micrograms per liter (µg/L) or about 13 pCi/L.

3.8 Tritium (^{3}H)

^{3}H is an important radionuclide that is produced in nuclear reactions by ternary fission of uranium and plutonium. ^{3}H is also produced by other various nuclear reactions, including the activation of deuterium and lithium. Boothe (1996) reports approximately 275,000 curies (Ci) of ^{3}H remain in all the single-shell and double-shell tanks at Hanford.

^{3}H has a half-life of only 12.3 years, and it emits a low-energy beta particle with a maximum energy of 18.6 keV. No gamma rays are produced with this decay. Normally a nuclide with such a short half-life presents little to no risk. However, ^{3}H can be a significant short-term risk because it is present as an element in water and is equally as mobile as water in the environment. ^{3}H can migrate through the groundwater and reach a receptor point faster than decay of the nuclide will eliminate it as a risk.

The current proposed MCL for ^{3}H in groundwater is 20,000 pCi/L, although there is a significant ongoing debate about mutagenic effects of ^{3}H to humans.

^{3}H cannot be monitored with gamma detection equipment, but water or moisture content of the unsaturated sediment can be determined by neutron logging methods. On the basis of the ^{3}H content in the water, the total amount of ^{3}H can be estimated.

3.9 Plutonium, Americium-241 (^{241}Am), Neptunium-237 (^{237}Np), Iodine, 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 BY Tank Farm, and it is not intended to discuss these in any detail 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 at 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 pose a high long-term risk mainly because of the mobility of neptunium. See Winberg and Garcia (1995) for a discussion of neptunium.

^{237}Np is produced from the decay of ^{241}Am, and it is produced in a reactor by neutron activation of ^{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 are a short-term exposure problem. However, ^{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 performance assessment 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 MCLs for the ^{129}I and ^{131}I isotopes are 1 pCi/L and 3 pCi/L, respectively.

^{106}Ru is a fission product that was abundant in the Hanford 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 ^{137}Cs, ^{60}Co, or ^{238}U, and not ^{106}Ru were detected with the gross gamma logging systems. The 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), and Lindsey et al. (1992).

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 presents 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 Figure 15-3.

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 oldest to youngest): Imnaha Basalt, Picture Gorge Basalt, Grand Ronde Basalt, Wanapum Basalt, and Saddle 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. 1977). 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 in the uppermost basalt flows.

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 outcrops 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 floodplain conditions.

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

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

The 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 basinwide intervals containing deposits typical of the overbank and lacustrine facies associations (Lindsey 1991).

4.1.1.5 Post-Ringold and Pre-Hanford Sediments

In the vicinity of the 200 West Area, the laterally discontinuous Plio-Pleistocene unit unconformably overlies the Ringold Formation. This unit is as much as 82 ft thick and is divided into two facies, basaltic detritus and pedogenic calcrete. Depending on the location, one or both of 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. The Plio-Pleistocene unit is not present in the 200 East Area of the Hanford Site.

4.1.1.6 Hanford Formation

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

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

The sand-dominated facies consists of fine- to coarse-grained sand and granule gravel. In outcrop, these sediments display plane lamination and bedding and, less commonly, plane bedding and channel-fill sequences. These sands may contain small pebbles or pebble-gravel interbeds less than 8 inches (in.) thick. The silt content of the sands is variable, but where it is low, open framework texture occurs. The sands are typically basaltic, displaying a salt-and-pepper appearance. The sand-dominated facies is transitional between the gravel-dominated facies to the north and the rhythmite facies to the south, and it is present in the 200 Areas. The laminated-sand facies was deposited adjacent to the main flood channelway as it spilled out of the main channel, or it 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 (Baker et al. 1991; DOE 1988). This facies dominates the Hanford formation occurrence along the western, southern, and northern margins of the Pasco Basin, within and south of the 200 Areas.

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

4.1.1.7 Holocene Surficial Sediments

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

4.1.2 Geologic Structure of the Pasco Basin

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

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 accumulations of sediments. The Umtanum-Gable Mountain anticline divides the Pasco Basin into the Wahluke and Cold Creek synclines. The Cold Creek syncline is asymmetrical and is a relatively flat-bottomed structure. The Hanford Site 200 Areas are located on the northern limb of the Cold Creek syncline where the bedrock dips to the south at an angle of approximately 5°. In the vicinity of the BY Tank Farm, approximately 260 ft of sediments of the Hanford formation overlie this structure. Anticlines to the north and south create topographic high areas with outcropping basalt flows of Gable Mountain and Rattlesnake Mountain, respectively (Reidel et al. 1989).

4.2 Geology of the 200 East Area

4.2.1 General Geologic Background

The 200 East Area is situated on a gently sloping low-relief surface that resulted from two geomorphological processes: Pleistocene cataclysmic flooding and Holocene eolian activity. Flooding resulted when glacially created dams failed and drainage from the dammed lakes flowed across the Columbia Plateau. These floods led to deposition of sand and gravel in the waters that were hydraulically impounded (with the formation of Lake Lewis) behind Wallula Gap. Deposition of sand and gravel created Cold Creek bar, a prominent feature on which the

200 East Area is located (Figure 15-4). The northern boundary of the Cold Creek bar is an east-southeast trending erosional channel that formed during waning stages of flooding as floodwaters drained from the basin (Bjornstad et al. 1987).

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

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

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

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

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

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

4.2.2 Geologic Background of the BY Tank Farm

Price and Fecht (1976) provided the initial information about the BY Tank Farm geology on the basis of data collected during the construction of the first monitoring boreholes surrounding the tanks. Cross sections were prepared on the basis of samples acquired during drilling and the driller's log, which recorded drilled materials at 5-ft intervals. Caggiano and Goodwin (1991), Lindsey and Law (1993), and Lindsey et al. (1994) present detailed descriptions and interpretations of the geologic formations in the vicinity of the BY Tank Farm. Those reports provide some of the best geological information because trained geologists were at the drilling sites, and they obtained pertinent sediment samples for laboratory analyses and logged lithologic features in detail.

The most current and highest quality geologic information specific to the BY Tank Farm is obtained from the most recently drilled groundwater monitoring boreholes. Boreholes 299-E33-38, 299-E33-39, and 299-E33-40 were drilled in 1990 and 1991 during a phase of the 200-BP-1 Operable Unit characterization; borehole 299-E33-41 was drilled during the completion of the RCRA-standard monitoring wells for the SSTs in calendar year (CY) 1990; and boreholes 299-E33-42 and 299-E33-43 were drilled during the RCRA monitoring well drilling program for SSTs in CY 1991 and CY 1992. Figure 15-5 shows the location of these and other groundwater monitoring boreholes in relation to the BY Tank Farm and other adjacent facilities. The RCRA standard monitoring boreholes are distinguished from the pre-RCRA well construction requirements in this figure. Boreholes 299-E33-39 and 299-E33-40 are not plotted on Figure 15-5; they are located 600 ft northwest and 800 ft northeast of the BY Tank Farm, respectively.

Appendix A contains lithology information for those boreholes, including summaries of the interpreted lithologic logs; results of laboratory sample analysis of calcium carbonate content and moisture content; diagrams of well construction configuration; gross gamma-ray logs; and man-made radionuclide concentration plots for boreholes 299-E33-38, 299-E33-39, and 299-E33-40. This information (with the exception of the spectral gamma-ray data) is also provided in Caggiano (1992, 1993) and in Pearson (1990) and is available in digital form on the Hanford Environmental Information System (HEIS) database. Spectral gamma-ray geophysical data are available from Rust Federal Services-Northwest Operations (formerly Westinghouse Hanford Company [WHC]) Geophysics Group. The most complete and detailed summary of the geologic and geophysical data acquired in boreholes surrounding the BY Tank Farm is provided in the *B Plant Source Aggregate Area Management Study Report* (DOE 1993a).

The lithologic information is the result of field analysis of sediment retrieved during borehole 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 drill-cutting descriptions. All the boreholes 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 the material was removed from the drive barrel. At a minimum, samples were collected every 5 ft, at lithologic changes, and at the discretion of the site geologist.

The gross gamma-ray logs were obtained by logging the boreholes with a logging system operated by Pacific Northwest National Laboratory (PNNL). 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 good and the utility of these logs is limited.

The spectral gamma-ray data acquired in boreholes 299-E33-38, 299-E33-39, and 299-E33-40 were collected with a spectral gamma-ray logging system in the boreholes when they were in a single-casing configuration as they were drilled. This logging system, designated the Radionuclide Logging System (RLS), was operated by WHC; it was put into service in January 1991. No documentation was prepared describing the system or specifications for the analysis software; therefore, the reported concentrations of the radionuclides are not quality assured. Man-made radionuclides were detected around all the boreholes. Sets of data for boreholes 299-E33-38, 299-E33-39, and 299-E33-40 are provided in Appendix A.

4.2.3 BY Tank Farm Geology Description

The BY Tank Farm excavation was constructed in sand and gravel sediments of the Hanford formation. These sediments occur from ground surface to the top of the basalt at a depth of about 260 ft. The excavated materials were used as backfill around the completed tanks.

The surface of the basalt beneath the BY Tank Farm is the eroded surface of the Elephant Mountain Member of the Saddle Mountains Basalt. This basalt lies at a depth of about 260 ft and dips gradually to the south-southwest. Overlying the basalt is a 60-ft-thick unit of muddy sandy gravel and sandy gravel. The bottom 30 ft of this unit is designated the Hanford lower gravel sequence.

Overlying this unit is a thick sequence of muddy sand to sand with minor gravel. These sediments constitute the Hanford fine sequence, which beneath the BY Tank Farm is 140 ft thick. The uppermost unit in the area of the BY Tank Farm, the Hanford upper gravel sequence, consists of about 60 ft of sandy gravel to gravelly sand. This unit is generally more sandy at the bottom and becomes more gravelly toward the top. The contact between the Hanford upper gravel sequence and the Hanford fine sequence is at a depth of 60 ft below ground surface at the BY Tank Farm. This contact is identifiable by increases in ^{40}K concentrations in many of the SGLS KUT plots. The reader is advised to review the Tank Summary Data Reports for the individual tanks in the BY Tank Farm to observe these details.

Moisture (weight [wt] percent) and calcium carbonate (wt percent) samples were collected during drilling of RCRA-standard wells 299-E33-31, 299-E33-32, 299-E33-38, 299-E33-39, 299-E33-40, 299-E33-41, 299-E33-42, and 299-E33-43. Analyses of these data show that the moisture content is normally in the range between 2 and 4 percent. High moisture content (to 20 percent) is observed at intermittent depths and is indicative of silt or silt-rich horizons that are discontinuous and not correlatable among boreholes. These horizons are significant because they can affect the transport of fluids and contaminants, as indicated by their relatively high moisture content. The thin interfingering silty horizons are difficult to identify from the KUT plots because of the variability of the reported concentrations resulting from counting statistics. Therefore, the KUT plots are most useful for gross lithologic changes and well-configuration determinations.

Percentages of calcium carbonate in the sediments did not exceed 2 percent, but were generally less than 1 percent. A test was performed in the field to evaluate the reaction of dilute hydrochloric acid with soil material; the results were documented on the borehole geologic logs. Both the laboratory and field data show intermittent peaks of increased calcium carbonate content that indicate discontinuous nature of the cementation. Cemented sediments could impede fluid migration and redirect migration patterns.

In summary, the contact between the Hanford formation upper gravel and fine-grained sequences in the vicinity of the BY Tank Farm occurs at a depth of about 60 ft below ground surface. This contact occurs near the bottom extent of the tank farm excavation, at the interface between the backfilled materials and the undisturbed Hanford formation sediments.

4.3 Hanford Site Hydrology

4.3.1 Surface Hydrology

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

The Columbia and Yakima Rivers are the primary surface-water features near the Hanford Site. The free-flowing Columbia River borders the Hanford Site on the north and east between the Priest Rapids Dam and the headwaters of Lake Wallula near the 300 Area. The Columbia River's nearest proximity to the BY Tank Farm is about 7 miles (mi) to the northwest.

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 in confined, semiconfined, and unconfined conditions.

The basalt aquifers are generally confined and are located in the sedimentary interbeds of the Ellensburg Formation, in 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 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 suprabasalt sediment aquifer system is contained within the Ringold Formation and the Hanford formation. The top of the aquifer ranges in depth from 1 ft near West Lake and the Columbia and Yakima Rivers to more than 350 ft in the center of the Hanford Site (Lindsey and Law 1993). The base of the unconfined aquifer system is the surface of the uppermost basalt flow. In the western portion of the Hanford Site, the aquifer is generally in gravels of the Ringold Formation (unit E). In the northern and eastern portions of the Hanford Site, the aquifer is generally within the Hanford formation.

Overbank and lacustrine deposits of the Ringold Formation form confining layers above the Ringold fluvial sands and gravels, creating a semiconfined aquifer condition. The suprabasalt 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.

Recharge of the uppermost aquifer is by rainfall and runoff from the hills bordering the Hanford Site, by infiltration from small ephemeral streams, by water infiltration through faults and fractures in the underlying basalts, and by infiltration from the Columbia and Yakima Rivers. Moisture movement through the unsaturated (vadose) zone has been studied at various locations at the Hanford Site. Gee (1987) and Routson and Johnson (1990) concluded that no downward percolation of precipitation occurs in the 200 Areas, where the sediments are layered and vary in texture, and that all moisture penetrating the soil is lost through evapotranspiration. Artificial recharge 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 vary from open-framework gravels of the gravel-dominated facies and interbedded sand and silt of the silt-dominated facies of the Hanford formation to calcium carbonate-rich deposits of the Plio-Pleistocene unit to cemented gravels of the Ringold Formation. These sediments are characterized by numerous lateral discontinuities, such as pinchouts and erosion truncations, and flow patterns are irregular. If clastic dikes are present, they may enhance vertical flow patterns.

4.4 BY Tank Farm Hydrology

The unconfined aquifer is the uppermost aquifer in the area of the BY Tank Farm and is the focus of groundwater monitoring. At the BY Tank Farm, the aquifer is contained in the Hanford formation, which in the vicinity of the BY Tank Farm is divided into three textural units: the upper coarse-grained unit, the middle fine-grained unit, and the lower coarse-grained unit. The unconfined aquifer is located in the lower coarse-grained unit, in sediments consisting of muddy sandy gravel to gravelly sandy mud. The thickness of the saturated zone beneath the BY Tank Farm is about 14 ft. The top of the saturated zone is 246 ft below 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 260 ft below the ground surface.

The direction of groundwater flow in the uppermost aquifer in the 200 East Area outside the B Pond groundwater mound is difficult to establish because of the lack of a prominent hydraulic gradient. The horizontal gradient in the area of the BY Tank Farm is essentially flat (DOE 1995a); therefore, minor shifts in direction may be influenced by discharges to disposal sites. Factors influencing groundwater movement below the BY Tank Farm are a groundwater mound below B Pond east of the 200 East Area and a basalt high to the north of the 200 East Area that restricts groundwater flow to the north (Caggiano and Goodwin 1991). Groundwater flow in the vicinity of the BY Tank Farm is estimated to be generally west-northwestward. However, interpreted data indicate long-term north-northwest migration from the 216-BY Cribs, which are located immediately north of the BY Tank Farm. Contamination resulting from liquid waste discharged to these cribs has been detected north of the 200 East Area. The flow of groundwater in the area of the 216-BY Cribs was generally southward before the Hanford Site was established (Kasza 1993). As the water table rose because of discharges of large volumes of liquid waste during peak operations, the direction of groundwater flow reversed and flow was directed to the north.

Hydraulic properties have been determined by aquifer testing that was conducted in a number of boreholes in the 200 East Area. The transmissivity and hydraulic conductivity were determined by analyzing the results of the aquifer tests; the details of these tests are provided in Connelly et al. (1992). Data were acquired in boreholes 299-E33-28, 299-E33-29, and 299-E33-30, which range in distance from 1,500 to 2,000 ft west-southwest of the BY Tank Farm. Transmissivity ranged from greater than 51,000 to greater than 56,000 square feet per day (ft^2/d), and the hydraulic conductivity ranged between 5,100 to 5,600 feet per day (ft/d). Figure 15-6 presents a hydraulic conductivity map of the 200 East Area.

Measurements of hydraulic conductivity for several samples of the unsaturated zone in Hanford gravel and Hanford sand sequences 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. The reader is advised to consult Connelly et al. (1992) for details regarding these analyses, as well as for the results of the analyses performed on the samples of the Hanford coarse and Hanford fine sequences. Interpretation of the laboratory results indicates a high degree of variability in the moisture retention data for the unsaturated Hanford formation sediments; this variability in moisture retention would result in high variability in hydraulic conductivity for these sediments.

4.5 Groundwater Contamination in the BY Tank Farm Area

The 200 East Area of the Hanford Site was used to chemically process irradiated nuclear fuel and to separate and purify plutonium. Facilities associated with these operations include processing plants and waste disposal facilities, including tank farms, landfills, injection wells, impoundments, cribs, ponds, and ditches. Because of the complexity of the waste handling operations and the closely located facilities in many areas of the 200 East Area, exact sources of groundwater contamination are difficult to determine. Figure 15-5 shows the BY Tank Farm, adjacent tank farms, and associated facilities.

Groundwater beneath several facilities in the 200 East Area is monitored under a RCRA groundwater monitoring program administered by PNNL (formerly by WHC). Included in the monitoring program, which was initiated in 1990, is the Waste Management Area (WMA) B-BX-BY, an area in the 200 East Area that includes the B, BX, and BY Tank Farms. Data acquired for RCRA groundwater monitoring projects at the Hanford Site are reported in quarterly and annual reports. The *Quarterly Report of RCRA Groundwater Monitoring Data for Period July 1, 1995 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.

Monitoring 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. Groundwater radiological contamination plume data in Dresel et al. (1995) and DOE (1995a) were reviewed as part of the baseline characterization project. Interpretation of these data indicates the presence of elevated gross beta, ^{99}Tc, and ^{129}I concentrations in the groundwater in the vicinity of the BY Tank Farm. In these reports, the data were compiled into maps depicting gross beta, ^{99}Tc, and ^{129}I contamination plumes, copies of which are provided in Appendix A. The reader is advised to consult Dresel et al. (1995) and DOE (1995a) for details regarding the data and for discussions concerning the accuracy of the interpretations.

In addition to regulatory requirements of RCRA pertaining to SSTs, facilities adjacent to tank farms are monitored under CERCLA requirements for past-practice facilities. Sites regulated by CERCLA in the vicinity of the BY Tank Farm are the 216-B-5 Reverse Well and the 216-BY Cribs. The 216-B-5 Reverse Well is located more than 1,000 ft south of the BY Tank Farm and is not shown on Figure 15-5; the 216-BY Cribs are located immediately north of the BY Tank Farm. These cribs are located within the CERCLA 200-BP-1 Operable Unit; the 200-BP-5 Operable Unit was established to address the contamination in the groundwater beneath the 216-BY Cribs.

Kasza (1993) provides a compilation of historical data regarding the 216-BY Crib operations and presents cross sections of theoretical plume development and movement, as well as plan views of contamination plumes resulting from liquid wastes discharged to the cribs. The contaminants discharged to the 216-BY Cribs flowed northward, and these contaminants presently extend well into the 600 Area, north of the cribs.

The exact source of the contaminants in the groundwater below the BY Tank Farm cannot be definitively established because of the proximity of the farm to several other waste storage and disposal facilities that are known to have contributed to groundwater contamination. The same constituents that were discharged and stored in the SSTs were also discharged to trenches, cribs, and ponds, although at lower activities (however, at significantly large volumes). The large volumes of liquids discharged to the 216-BY Cribs resulted in a groundwater mound below the cribs and a northward movement of groundwater evidenced by the contamination plume that exists north of the BY cribs. Contamination below the BY Tank Farm resulting from tank leakage may also have moved into the area of the 216-BY Cribs.

5.0 BY Tank Farm Background

5.1 Construction

The BY tanks were constructed between 1948 and 1949 in the north-central portion of the 200 East Area (Figure 15-1). The BY Tank Farm is the second generation of tanks at Hanford and was built to store high-level radiological waste generated from chemical processing of irradiated uranium fuel. These second generation tanks were essentially the same design as the original T, U, B, and C tank designs, except that the BY tanks had increased waste-volume capacity.

One large rectangular excavation about 40 ft deep of a volume of approximately 285,000 cubic yards of material was constructed for all the BY Tank Farm tanks. The excavation was constructed in a slope that fell gradually to the north. The excavation was developed as close to the final grade as possible with earth-moving equipment, then completed with hand tools (shovels) 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 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 backfill was distributed uniformly to prevent excessive unbalanced loading against the completed tank structures. The tanks were covered with about 10 ft of backfill material (Brevick et al. 1994b). An additional volume (in excess of that excavated) of approximately 10,000 cubic yards of material was required to provide the required cover over the completed tanks because the BY Tank Farm was constructed on northward-sloping terrain.

The BY Tank Farm consists of 12 SSTs, each with a capacity of 758,000 gallons (gal). The tanks are 75 ft in diameter and approximately 40 ft in height with domed tops and concave bottoms. The bases of the tanks are approximately 50 ft below the finished grade. Figure 15-7 presents a plan view of the BY Tank Farm showing the 12 tanks and the vadose zone monitoring boreholes surrounding them. The actual locations of the monitoring boreholes are in the centers of the borehole designations (e.g., in the center of the "01" in the borehole designation 22-01-03).

The base of each tank is a steel-reinforced concrete circular pad with a radius of 41.5 ft; each base required approximately 320 cubic yards of concrete. The concrete was worked in place around the reinforcement with a mechanical vibrator and was formed to specific dimensions and curvature by a revolving screed. Following curing of the concrete, the top of the curved surface of the tank bases was coated with a three-ply asphalt waterproof membrane. A 3/4-in.-thick gunite layer reinforced with 2-in. by 2-in. welded fabric was applied over the membrane for protective purposes. The asphaltic membrane is a potential source of organic compounds that may contribute to organic liquid or vapor within the tanks.

The tank structure 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 is 3/4 in.; the thickness of the bottom plating section of the wall liner is 5/16 in.; and the section of top wall plating is 1/4 in. thick. Six steel angle stiffeners are welded horizontally around the interior of the tank walls. 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. The knuckle sections allow for expansion of the base liner. The specifications for liner plating and structural steel construction are outlined in General Electric Company (1948). All seam welds of the tank-liner plating were radiographically examined (x-rayed) during construction of the tanks to verify weld integrity.

All interior surfaces of the steel liner were sandblasted and coated with primer. The exteriors of the walls were covered with a three-ply asphaltic membrane and then a protective layer of reinforced gunite. The steel tank shell forms the inner form for the concrete tank shell.

The walls of the tank are reinforced concrete about 1 ft thick. The concrete was poured in a continuous operation. Wooden forms were used to hold the wet concrete on the outside wall, while the steel liner acted as the inner form. 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. Approximately 270 cubic yards of concrete (in three placements) were required for a complete tank wall.

The presence of tar rings on the interior walls of several of the BY Tank Farm tanks after several decades of tank use raised a question about the integrity of the tanks. The source of the tar was identified as the asphaltic sealant material that entered the tank interior either through the lead flashing seal at the top of the steel liner or through corrosion pitting of the liner itself. Lead flashing was installed at the top of the steel tank liner to prevent condensate runoff from the inside of the dome from flowing outside the liner. Once tar rings were discovered, waste levels were maintained below the level of the tar rings. The tanks in which tar rings were identified and the heights of the tar rings above the tank bottoms are as follows: tank BY-102, 240 in. (Welty

1988); tank BY-106, 270 in. (Deichman 1977b); tank BY-107, undocumented measurement (Deichman 1977a; Walser 1974); tank BY-109, 235 in. (Welty 1988); tank BY-110, 266 in. (Jensen 1975); and tank BY-111, 257 in. (Garbrick 1977).

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, a concrete hardening agent. All dome risers and encasements were treated with applications of coal-tar primer and enamel and were 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 were placed on top of the backfilled sediments to provide protection and to retard establishment of vegetation that could bring subsurface contamination up to the ground surface. The gravel layer also helped prevent or reduce radiological exposure to personnel from contaminated near-surface sediment and pipelines. Unfortunately, the lack of vegetation inhibits evapotranspiration of precipitation and thereby promotes infiltration of precipitation into the subsurface at the farm. The infiltration of precipitation could promote movement of contaminants through the vadose zone.

The BY 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 BY-101, BY-102, and BY-103, where BY-101 cascades into BY-102 and tank BY-102 cascades into BY-103. The height of the cascade line outlets above 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 25 ft below 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. The BY Tank Farm was initially operated as a backup to the BX Tank Farm, and the tanks are connected to the end tanks of the BX Tank Farm in the following configuration: tank BX-103 to tank BY-101; tank BX-106 to tank BY-104; tank BX-109 to tank BY-107; and tank BX-112 to tank BY-110 (Brevick et al. 1994b).

Each tank was equipped with two sets of spare 3-in.-diameter inlet nozzles. These nozzles are located at azimuths of 150° and 210° at the same height as the cascade-line connections to the tanks.

The domes of the tanks are penetrated by several risers that allow access to the tank interiors. These risers contain piping that connects the tanks to each other and to other facilities on the Hanford Site, allowing wastes to be transferred between tanks farms. The BY Tank Farm contains piping for transfer of liquids and ventilation lines that were constructed for specific waste treatment processes, such as sluicing and the in-tank solidification (ITS) campaigns. All the BY Tank Farm tanks contain a 12-in.-diameter saltwell that penetrates the tank waste and allows pumping of interstitial liquids. The details of the arrangement of the piping systems in the BY Tank Farm are illustrated in as-built drawings H-2-70886* and H-2-70887.

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 over 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 from the fuel elements. 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 composition of the wastes in the BY 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. The volumes prepared by Brevick et al. (1994a and 1994b) specifically address the BY Tank Farm.

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, 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 1 shows current waste quantities for each tank, current monitoring methods, and some historical information.

The BY Tank Farm was placed into service in 1950. Four tanks in the BY Tank Farm were connected to the end tanks in the BX Tank Farm and received waste in cascade from the BX tanks. Tanks BY-101 through -106 received and stored B Plant metal waste after the BX Tank Farm tanks were full. Tanks BY-107 through BY-110 received and stored B Plant first-cycle waste and U Plant waste. Tanks BY-111 and BY-112 were used to store metal waste. Tanks BY-101, -103, and -111 received ferrocyanide wastes from other BY tank transfers. Tank BY-112 received a direct transfer of waste from U Plant. Brevick et al. (1994a and 1994b) provide details regarding the waste inventories of the BY Tank Farm tanks throughout the service lives of the tanks.

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*As-built drawings can be obtained from the Lockheed Martin Services, Inc. Microfiche Library, Richland, Washington.

Table 1. General BY Tank Information

Tank	Total Waste Volume (1,000 gal)[a]	Drainable Liquid (1,000 gal)	Current Leak Detection Method	Tank Monitoring Methods[a]	Leaker (Y/N)[a]	Original Leak Indication
BY-101	387	5	LOW[b]	Manual tape	N	
BY-102	277	11	LOW	Manual tape	N	
BY-103	400	15	LOW	Manual tape	Y	Borehole gamma
BY-104	406	18	LOW	Manual tape	N	
BY-105	503	192	LOW	Manual tape	Y	Borehole gamma
BY-106	642	200	LOW	Manual tape	Y	Tar rings Borehole gamma
BY-107	266	25	LOW	Manual tape	Y	Liquid level Borehole gamma
BY-108	228	9	None	Manual tape	Y	Borehole gamma
BY-109	423	28	LOW	Automatic FIC[c]	N	
BY-110	398	9	LOW	Manual tape	N	
BY-111	459	0	LOW	Manual tape	N	
BY-112	291	8	LOW	Manual tape	N	

[a]Information from Hanlon (1996).
[b]LOW = liquid observation well.
[c]FIC = Food Instrument Corporation liquid-level measurement gauge

Sluicing operations were conducted in waste tanks by using high-pressure water to dissolve and suspend tank waste to facilitate removal by pumping. Sluicing operations were conducted in waste tanks for a twofold purpose: to recover uranium from tank waste and to concentrate tank waste during ITS campaigns. Tanks BY-101 through BY-106 and tanks BY-111 and BY-112 were sluiced in 1954 and 1955 for uranium recovery (Brevick et al. 1994b).

The ITS campaigns used in-tank evaporation systems to evaporate water from the waste, leaving behind concentrated waste solids. These processes used hot-air sparging and electrical heaters to heat the waste. Several tanks in the BY Tank Farm were used for evaporator feed staging and/or evaporator-bottoms receiving during the ITS#1 and ITS#2 campaigns. ITS#1 began operations in March 1965; ITS#2 started operations in February 1968. Concentration of the waste during the ITS campaigns produced a significant amount of salt cake that was saturated with drainable liquid. All the tanks in the BY Tank Farm were saltwell pumped to remove the liquid wastes.

Both the ITS operations were terminated in 1974. Agnew (1995 and 1996) present details regarding the ITS operations. Ferrocyanide-scavenging operations were conducted on metal waste and first-cycle decontamination waste to remove the long-lived fission product ^{137}Cs from the waste, enabling disposal of supernatant to the ground. These ferrocyanide-scavenging operations resulted in a significant reduction in the volume of waste stored in the underground waste storage tanks. The metal waste contained uranium and about 90 percent of the fission products, while the first-cycle waste contained approximately 10 percent of the fission products. Ferrocyanide-scavenged waste was transferred to and stored in BY Tank Farm tanks. Tanks BY-106, -107,-108, and -110 were used as primary settling tanks for scavenged waste. The waste was allowed to settle for a minimum of 7 days and then sampled. If the ^{137}Cs and ^{90}Sr concentrations were within applicable discharge requirements, the supernatant was decanted to the 216-B-43 through 216-B-49 Cribs. Although most of the ^{137}Cs was effectively precipitated in the tanks, some ^{137}Cs was left in the supernatant along with cyanide species, and both were discharged to the cribs. The accumulated scavenged sludge was transferred to tanks BY-104 and -105 (Borsheim and Simson 1991). The last scavenged waste was transferred from U Plant to the BY Tank Farm in June 1957.

At high temperatures (430 to 550 °F), ferrocyanide can release large quantities of heat when combined with nitrate (NO_3^{-1}) and nitrite (NO_2^{-2}), which are major components of the tank waste. Tanks containing more than 1,000 gram-moles of ferrocyanide are on a watch list because the contents of the tanks have the potential for chemical reactivity. Tanks BY-103, -104, -105, -106, -107, -108, -110, -111, and -112 are on the watch list for ferrocyanide; the temperatures in these tanks are monitored weekly through thermocouple trees located within the tanks. The most recent data from Hanlon (1996) indicate that the highest temperature for the BY Tank Farm waste was recorded in tank BY-106; the temperature of waste in tank BY-106 was 123 °F, which is below the maximum criteria limit for the watch list tanks. The reader is advised to consult Hanlon (1996) for these criteria.

Sixty-three tons of cement was added to tank BY-105 in 1972 to absorb liquids when the tank was suspected of leaking. Because of the chemistry (high alkalinity and high salt content) of the liquids in the tank waste, the cement did not set; it is unknown if this process was repeated in any other Hanford tanks.

The BY Tank Farm tanks primarily received coating waste from dissolved aluminum-clad fuel elements, metal waste containing all the uranium and 90 percent of the fission products activity, and first-cycle waste that contained 10 percent of the original fission products activity. Table 2 provides estimates from Anderson (1990) of the major chemical constituents of the waste at the time it was placed in the BY Tank Farm tanks.

From a heat-generation standpoint, ^{90}Sr and ^{137}Cs are the highest heat producers, with minor heat produced from other fission products. Ten years after the waste was placed in the tanks, ^{90}Sr and ^{137}Cs are the only fission products still producing any significant heat. Because ^{90}Sr emits a beta particle with an energy much higher than the beta particle from ^{137}Cs, ^{90}Sr generates more heat than ^{137}Cs.

Table 2. General Chemical Composition of BY Tank Waste Feed (from Anderson 1990)

Waste	Composition	Volume
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
	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
	Na	4.8 M
	Pu	1%
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.
[b] lb/gal = pound per gallon.

From an environmental risk standpoint, concentrations of ^{99}Tc, uranium isotopes, plutonium, and even ^{3}H are probably the most important radionuclides, even though they are only present in the tanks in relatively small quantities.

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.

Currently, a relatively large program is devoted to determining the physical and chemical properties of the waste 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 1994b) and Agnew (1995) will be available in the future. The best information to date on tank radionuclide content and chemistry is most likely found in the current version of the Brevick documents. Work on determining the chemical and radiological content of the tanks is ongoing.

Determining which tanks have leaked, the quantity and composition of the contamination released, and the spatial distribution are of concern for Hanford decision makers. Five of the 12 BY Tank Farm tanks are currently listed as "assumed leakers" (Hanlon 1996). Assumed leakers are identified on Figure 15-7 with a red "Leaker" designation. The reasons the tanks were declared 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 BY 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 documentation of tank waste-level measurements revealed that increases in tank liquid levels were observed in several tanks in the BY Tank Farm; these increases in liquid level were designated "intrusions." When intrusions were identified, the piping associated with the affected tank was surveyed for leaks and other evidence of direct discharge into the tank. The intrusions were most often related to runoff from natural meteorological events that resulted in flooding at the surface in the BY Tank Farm. Intrusion of water from flooding could enter the tanks through drains in the pump pits or through other tank facilities that were built on top of the tank domes. Often, intrusions were unexplained.

Nine unplanned releases (UPRs) within or adjacent to the BY Tank Farm are documented. Table 3 provides a synopsis of these releases, and Figure 15-5 shows the locations of the unplanned releases within the BY Tank Farm and in adjacent areas. This information was obtained from DOE (1993a). The referenced sources of this information are the Hanford Site Waste Information Data System (WIDS) database and the Hanford Environmental Sites Database (ESD), which replaced the WIDS database. The descriptions of the individual sites were derived from WIDS database information. Neither source of information contains documentation of all unplanned releases associated with operations at the BY Tank Farm. Several undocumented spills or leaks were identified at ground surface within the BY Tank Farm from log data acquired with the SGLSs.

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

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

Table 3. Documented Unplanned Releases Near or Within the BY Tank Farm

UPR No.	Location	Date	Coordinates E Washington State Plane	Coordinates N Washington State Plane	Description	Reference
UPR-200-E-9	216-BY Cribs flush tank	1955	573608	137603	11,000 gal of TBP scavenged supernatant overflowed the 216-BY Flush Tank associated with the 216-BY Cribs. Contaminated soil was excavated and placed adjacent to the 216-BY-43 Crib.	ESD
UN-200-E-43	Roadway from BY Tank Farm to burial grounds	1972	573313.7	137514.6	Loss of liquid from BY-102 tank pump being transferred to burial grounds. 1,000 to 100,000 counts/minute (cts/min) detected. Contamination was cleaned up immediately.	ESD
UPR-200-E-63	Contaminated vegetation at the 216-BY Cribs	1981	573650.4	137652.2	Vegetation absorbed radionuclides to activity of 100,000 cts/min and was spread by wind to surrounding areas. The vegetation was removed and the area was sprayed to control future growth.	ESD
UPR-200-E-89	Airborne contamination from the BX Tank Farm	1978	573490.5	137651.6	Unplanned release from the BX Tank Farm allowed particulate matter to accumulate west of the 216-B-57 Crib. The road was overlain with new asphalt.	ESD
UPR-200-E-105	Manifold header at tank BY-107 in the BY Tank Farm	1952	573605.3	137461.5	Approximately 23,000 gal of first-cycle liquid waste escaped from the header. The area was covered with concrete.	ESD
UPR-200-E-110	Tank (pump) pit of tank BY-112 in the BY Tank Farm	1955	573490.8	137514.6	Approximately 2,500 ft^2 of soil was contaminated to a level of 22 roentgens per hour (R/h).	ESD
UPR-200-E-116	Pump for tank BY-112 in the BY Tank Farm	1972	573597.6	137499.6	An unknown volume of caustic flush water containing ^{137}Cs, ^{90}Y, and ^{90}Sr sprayed from the pump. Radiation levels up to 3 R/h were measured 6 in. above the waste.	ESD
UPR-200-E-134	SST BY-103 in the BY Tank Farm	1973	573659.3	137530.9	5,000 gal of PUREX coating waste leaked from the BY-103 tank.	ESD
UPR-200-E-135	SST BY-108 in the BY Tank Farm	1955 to 1972	573597.3	137499.6	5,000 gal of TBP waste leaked from the BY-108 tank.	ESD

5.3 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 5.5, "Gross Gamma Logging," presents a discussion of previous gross gamma logging programs that were used to detect contamination in the vadose zone.

Solid- and liquid-level measurements continue to be made by direct access to the top of the waste inside the tanks through surface riser ports built into the domed tops of the tanks. Instruments lowered down to the waste surface to determine level measurements include simple instruments like weighted hand-held measurement tapes, sparker probes, electronic tapes, and more recently automated "ENRAF" gauges manufactured by ENRAF Incorporated. Welty (1988), Scott (1993), and Catlin (1980) present descriptions of the precision of the measurements or potential problems likely to be encountered with each instrument. Sealed fiberglass and tefzel casings were also inserted into the waste sludge 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 sondes (Geiger-Mueller detectors) to measure the variations in gamma flux and neutron-neutron sondes to measure variations in the hydrogen content profile. Measurements with these sondes 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, self-supporting sludge in the tanks and the liquid is only found in the interstices or pores of the solid material. Thus, 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 was recently procured at Hanford and reportedly will soon be used to monitor the interstitial liquid levels in the tanks.

Ultimately, to perform an assessment of the vadose zone contamination the questions about tank monitoring that need to be answered are (1) have the tanks leaked, (2) how much contamination has leaked from the various tanks, (3) what is or was the precision of the leak detection, (4) what is the accuracy of the leak-volume estimation, and (5) what is the chemical and radiological composition of the contamination that leaked?

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 because, in addition to uncertainties or errors in 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.

5.4 Vadose Zone Monitoring Boreholes

All the SST farms, including the BY 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 sondes were lowered into the boreholes to detect the presence of contamination in the sediment around the tanks. The locations and identification of the boreholes surrounding tanks in the BY Tank Farm are shown on Figure 15-7.

The majority of the boreholes in the BY Tank Farm are 100 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.

Borehole 22-02-07 (also designated 299-E33-09) near tank BY-102 was drilled in 1949 to a depth of 275 ft to intersect groundwater. This borehole was modified in 1978 to the present configuration, which consists of double casing throughout the entire length of the borehole. This borehole was not logged because the level of the radioactivity in the vicinity of the borehole exceeded the allowable level under the Radiation Work Permit (RWP), which regulated radiological safety aspects of the tank farm characterization logging.

The construction of most boreholes is documented in the form of drilling 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. The drilling logs provide information regarding when and how the boreholes were drilled and document the occurrences of radiological contamination that were encountered during drilling. All the drilling logs are available in borehole archive files maintained by the Hanford Well Services Group.

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 of the sediments 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 in 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.

A small concrete collar was installed at the ground surface around all the boreholes to prevent water from moving down the outside of the casing. The collar helps prevent water and material from moving down the outside of the casing; however, the collar would not be an effective surface seal if there are large voids at depth or a significant volume of water at the surface and water could flow around the collar and down the casing. The surface collar on the vadose monitoring boreholes is the only seal between the casing and formation.

Floodwater could drain down the borehole, pick up contaminants at some intermediate level, and carry them farther downward. This scenario may have occurred in the BY Tank Farm because increases in liquid levels (intrusions) were recorded for several tanks even though they were isolated from input through piping. A volume of surface water that would produce a measurable rise in the liquid level in a tank could most likely drive contamination down the outside of the casing.

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 floodwater from the 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 tops 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 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 can settle at the bottom of the hole. This is evident as a slightly elevated contamination activity at the bottom of the borehole. When low-level contamination is present at the bottom of a borehole with contamination-free regions above it, it is relatively conclusive evidence that the contamination is on the inside of the borehole casing and not associated with vadose zone contamination.

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

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

5.5 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 was 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 BY 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 detected 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 these 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) were used for many years in one form or another but are not theoretically rigorous and are no longer considered to be appropriate for the task (GAO 1992). Calculations of contaminant migration were made on the basis of changes in gamma-ray flux instead of on radionuclide concentrations, but the logging instrumentation was not properly calibrated to a radionuclide concentration response. Therefore, an instrument count rate or even a gamma-ray flux in a borehole could not be related to a leak from a tank. Because there is an empirical nature to the calculations, 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 at least has 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). That program was not designed to determine the nature and distribution of contamination and was not intended to be used to monitor the movement of the contamination through the vadose zone. Consequently, those data do not provide a good historical record of the vadose zone contamination and do not adequately identify migration of the contamination. However, the gross gamma log 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 gross gamma log data were effectively used to detect ^{60}Co contamination and identify leakage from several BY Tank Farm tanks.

Review and visual comparison of gross gamma log profiles over time have been useful to determine if contamination has moved 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 is not recommended. Small changes in the position of the borehole probe between loggings 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 shows that a positive gross gamma response can be expected only when ^{137}Cs is present at 10 pCi/g or higher. ^{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 BY Tank Farm. Leak-detection monitoring is conducted through acquisition of in-tank measurements within LOWs and/or by manual tape gauging 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 immediate vicinity of the BY Tank Farm, and descriptions of these facilities are provided in the following sections. Figure 15-5 shows the locations of these waste sites. Only sites that could have had an effect on the groundwater or vadose zone contamination are considered. Groundwater monitoring wells adjacent to these sites are monitored under a sitewide monitoring program and reported in annual reports, such as Dresel et al. (1995). Groundwater monitoring is not performed at these sites under the RCRA groundwater monitoring program because these facilities are inactive. However, the 216-B-43 to 216-B-50 facilities, which are known as the 216-BY Cribs, are monitored under the requirements of CERCLA. No vadose zone monitoring or characterization has been conducted at these facilities, other than some previous limited gross gamma logging.

Geophysical logging of monitoring boreholes was conducted as early as 1958 at the facilities related to B Plant operations, which included all the facilities surrounding the BY Tank Farm, and the farm itself. Several subsequent evaluations of the log data were performed, including Fecht et al. (1977) and Chamness (1986), which are cited in the following sections. DOE (1993a) provide comprehensive descriptions of these studies, the methodology of gross gamma logging, and interpretations of the data. That report also presents an evaluation of individual management waste units such as cribs, ponds, trenches, and ditches. Brodeur et al. (1993) provides summaries of several management waste units that include waste discharge histories, plan views of the sites, and geophysical log data acquired in the monitoring boreholes.

The Hanford ESD provided the radionuclide inventories presented in the following site descriptions; the radionuclide inventories were calculated (decayed) through December 31, 1989.

6.1 216-B-7A and 216-B-7B Cribs

The 216-B-7A and 216-B-7B Cribs are located approximately 500 ft southeast of the BY Tank Farm.

These facilities consist of two wooden structures each 12-ft long by 12-ft wide by 4-ft high, which are located in a 14-ft-long by 14-ft-wide by 14-ft-high excavation. The structures are constructed of 6-in. by 6-in. timbers and are open in the interior (e.g., not filled with gravel). The 216-B-7A and 216-B-7B Cribs are located side-by-side about 20 ft apart and were filled simultaneously by a T-fitting in a 3-in.-diameter steel inlet pipe.

The 216-B-7A and 216-B-7B Cribs were put into service in October 1946 and were removed from service in May 1967. Throughout their operational life, these cribs received 11.5 million gal of liquid waste from the 224-B Building via overflow of the 201-B Settling Tank and cell drainage and other liquid waste from the 221-B Building. The waste was low salt, neutral to basic, and contained transuranic (TRU) and fission products. The radionuclide inventory consists of 43 Ci of ^{137}Cs, 2,000 Ci of ^{90}Sr, 4 g of plutonium, and 600 Ci of uranium.

Boreholes 299-E33-18, 299-E33-58, 299-E33-59, and 299-E33-75 are used to monitor the 216-B-7A and 216-B-7B Cribs. Fecht et al. (1977) evaluated the historical gross gamma-ray log data acquired in some of these boreholes and determined that elevated gross gamma-ray activity due to the presence of contamination was present to a depth of about 100 ft below the cribs. It was not determined in this evaluation whether or not this contamination had migrated vertically or horizontally in the vadose zone sediments since first identified in the gross gamma-ray logs. The groundwater beneath these cribs is contaminated, but it is uncertain if the cribs were sources of the contamination.

Borehole 299-E33-18 was logged with the WHC RLS in September 1992. The presence of ^{137}Cs was detected in one zone from the ground surface to a depth of 30 ft. The presence of ^{60}Co was detected at two isolated locations deep in the borehole; however, it was not detected at the bottom of the borehole. No other man-made radionuclides were detected.

6.2 216-B-8 Crib and 216-B-8 Tile Field

The 216-B-8 Crib and 216-B-8 Tile Field are located approximately 500 ft east of the BY Tank Farm.

The crib is a 12-ft-long by 12-ft-wide by 7-ft-high hollow wooden structure constructed of 6-in. by 6-in. timbers; the structure was placed in a 14-ft long by 14-ft wide by 22.5-ft deep excavation. The tile field is 300 ft long and 100 ft wide and consists of a system of piping placed over 4 ft of gravel; there is 6 in. of gravel above the piping. The bottom of the tile field excavation is 4 ft below grade, and the sides of the excavation are sloped at a ratio of 1:1.5. The

216-B-8 Crib was attached to the cascade series of tanks B-110, B-111, and B-112 in the B Tank Farm.

The 216-B-8 Crib was put into service in April 1948, and it was removed from service in July 1953. Data presented in the Hanford ESD indicate that the 216-B-8 Crib received 7.2 million gal of liquid waste throughout its service life that consisted of second-cycle waste supernatant, cell drainage, and other liquid waste from facilities in the 221-B Building. The waste was high salt, neutral to basic, and contained TRU waste and fission products. The radionuclide inventory of the waste consists of 20 Ci of ^{137}Cs, 6 Ci of ^{90}Sr, 3 g of plutonium, and 0.015 Ci of uranium.

Boreholes 299-E33-15 and 299-E33-16 are used to monitor the 216-B-8 Crib. Fecht et al. (1977) reviewed the historical gross gamma-ray log data acquired in the monitoring boreholes. Elevated gamma-ray activity was identified from the ground surface to a depth of about 130 ft. Elevated gamma-ray activity was identified below the 216-B-8 Tile Field to a depth of 50 ft. There was no positive evidence that the contamination in the sediments beneath the 216-B-8 Crib and 216-B-8 Tile Field was migrating horizontally or vertically since first identified by the gross gamma-ray logs. Although elevated gamma-ray activity has been identified in the groundwater beneath the 216-B-8 Crib, there is no positive determination that the crib is a source of the contamination associated with this activity. It is difficult to determine the direction of groundwater movement below the crib because the hydraulic gradient is essentially flat. Because of the proximity of the several waste disposal facilities in the area around the 216-B-8 Crib, no conclusive determination can be made as to which facility or facilities are contributing to the groundwater contamination.

Borehole 299-E33-15 was logged with the WHC RLS in September 1992; only the upper 25 ft of the borehole was logged. The presence of ^{137}Cs was detected from the ground surface to a depth of 2 ft. No man-made contamination was detected below this depth.

6.3 216-B-11A and 216-B-11B Cribs

The 216-B-11A and 216-B-11B Cribs are located approximately 600 ft southeast of the BY Tank Farm. These cribs consist of two 4-ft-diameter by 30-ft-long corrugated steel culverts buried vertically, 10 ft below ground surface. The culverts are perforated on 6-in. centers at 12-in. vertical intervals along all but the bottom 6 in. of length of the culvert. The culverts are placed in an 8-ft-diameter excavation that is filled with 3-in.-diameter rock. This structure is also referred to as a reverse well or underground injection well.

The 216-B-11A and 216-B-11B Cribs were put into service in December 1951 and were removed from service in December 1954. Throughout their operational life they received 7.8 million gal of processed condensate liquid waste from the 242-B Evaporator. The waste was low salt, neutral to basic, and contained TRU waste. The radionuclide inventory of the 216-B-11A and 216-B-11B Cribs consists of 20 Ci of ^{137}Cs, 2 Ci of ^{90}Sr, 4 g of plutonium, and 0.0045 Ci of uranium.

Boreholes 299-E33-19 and 299-E33-20 are used to monitor the 216-B-11A and 216-B-11B Cribs. Fecht et al. (1977) reviewed historical gross gamma-ray logs acquired in these boreholes. During that review, it was determined that radiological contamination from the wastes discharged to the 216-B-11A and 216-B-11B Cribs did not significantly migrate from the disposal site into the vadose zone (after the contamination was identified by gross gamma-ray logging). Elevated gamma-ray activity was identified within a thin zone of silty material at a depth of about 100 ft below the cribs. It was postulated that the contamination reached this depth because a shallower barrier to fluid migration may have been penetrated during the construction of the reverse wells. The validity of this conclusion cannot be verified.

Although elevated gross gamma-ray activity was identified in the groundwater beneath the 216-B-11A and 216-B-11B Cribs, no conclusive evidence was available to determine that these cribs were the source of the contamination. The water table in this area is flat and it is difficult to determine the direction of groundwater movement, thus the source of the groundwater contamination is unknown.

Borehole 299-E33-20 is located immediately south of the 216-B-11A and 216-11B Cribs. It was logged in 1992 with the WHC RLS. The presence of ^{137}Cs was detected at a depth of 240 ft, and ^{60}Co contamination was detected at a depth of 255 ft. The concentrations of the ^{137}Cs and ^{60}Co contamination were 1 and 2 pCi/g, respectively. The depth to groundwater at the time of logging was 234 ft.

6.4 216-B-35 Through 216-B-41 Trenches

The 216-B-35 through 216-B-41 Trenches are located about 250 ft southwest of the BY Tank Farm. Each of the seven trenches is 252 ft in length, 10 ft wide, and 10 ft deep. The side slopes of the excavations were at a ratio of 1.5:1.

The trenches were in operation between December 1953 and December 1954. The trenches received first-cycle supernatant waste from the 221-B Building and first-cycle bottom supernatant waste from the 242-B Waste Evaporator. Throughout their service lives, the trenches received 3.5 million gal of liquid waste. The major radionuclides in the wastes were ^{137}Cs, ^{90}Sr, plutonium, and uranium. When the designed retention capacities of the trenches were met, the trenches were backfilled and all related piping was removed. The "retention capacity" refers to the soil column's predicted ability to absorb and retain the radionuclides. The data in the Hanford ESD indicate that the operational service life of an individual trench was about 1 month.

The trenches are monitored by boreholes 299-E33-8, 299-E33-21, and 299-E33-10. Additional monitoring boreholes are located both outside and within this trench complex. Borehole 299-E33-21 was logged with the WHC RLS in August 1992. The presence of ^{137}Cs was detected from the ground surface to the maximum survey depth of 279 ft at concentrations ranging from 5,000 pCi/g near the surface to about 5 pCi/g throughout much of the borehole. ^{60}Co contamination was detected at depths from 188 to 278 ft at concentrations of less than 2 pCi/g. The depth to groundwater at the time of logging was 261 ft.

Fecht et al. (1977) evaluated the historical gross gamma-ray logs acquired in the monitoring boreholes and identified elevated gamma-ray activity from the ground surface to a depth of about 60 ft. There was no evidence to conclude that the contamination was migrating vertically or horizontally in the vadose zone since it was first identified by the gross gamma-ray logging; however, the activity associated with the contamination was decreasing over time. Elevated activity was observed in the groundwater beneath the 216-B-35 through 216-B-41 Trenches, but Fecht et al. indicated that there was no conclusive evidence to determine that the trenches were the source of the contamination. The 216-BY Cribs or BY Tank Farm were speculated as sources of the contamination. However, a review of the old gross gamma-ray logs shows contamination throughout the depth extent of the monitoring boreholes, indicating that waste from the cribs contributed to the groundwater contamination. Through observations of the gross gamma-ray data acquired in several groundwater monitoring boreholes adjacent to the 216-B-35 through 216-B-41 Trenches, the contamination appeared to be moving in a southerly direction in the unconfined aquifer along the top of the basalt.

Borehole 299-E33-21 was logged with the WHC RLS in August 1992. The presence of ^{137}Cs was detected from the ground surface to a depth of 279 ft, the total depth of the borehole. Maximum ^{137}Cs activity of more than 5,000 pCi/g was detected between 11 and 24 ft. ^{60}Co contamination was also detected between depths of 188 and 278 ft. No other man-made radionuclides were detected. The depth to groundwater at the time of logging was 261 ft.

Borehole 299-E33-290 is a 50-ft-deep vadose monitoring borehole within the 216-B-35 through 216-B-41 Trench complex, and it was logged with the WHC RLS. The presence of ^{137}Cs was detected in two zones, one of which was at the bottom of the borehole. The ^{137}Cs concentration exceeded 5,000 pCi/g at the bottom of the borehole. ^{60}Co was the only other man-made radionuclide detected in the borehole. It was detected at depths from 31 to 41 ft at concentrations less than 1 pCi/g.

6.5 216-B-43 Through 216-B-50 Cribs

The eight 216-B-43 through 216-B-50 Cribs are located approximately 250 ft north of the BY Tank Farm and are structured identically; they are also referred to as the 216-BY Cribs. Each crib consists of four 4-ft-diameter concrete pipes that were placed vertically on a bed of gravel 5 ft thick. The four pipes were arranged in a square with the pipe centers spaced 15 ft apart. These eight cribs were constructed in a 30-ft-long by 30-ft-wide by 15-ft-deep excavation. The upright concrete pipes were fed simultaneously from an 8-in.-diameter steel pipe that extended from the main crib feed line in a chevron piping pattern.

Cribs 216-B-43 through 216-B-49 were in service from November 1954 to December 1955. These cribs received scavenged TBP supernatant waste from the 221-U Building and the BY Tank Farm. The supernatant waste was the liquid remaining in the BY Tank Farm waste tanks after precipitation of ^{137}Cs and ^{90}Sr. Crib 216-B-50 was in service from January 1965 to January 1974 and received waste storage tank condensate from facilities located in the BY Tank Farm during the ITS#1 and ITS#2 campaigns. The cribs receiving the scavenged supernatant waste contained ferrocyanide and nitrate wastes. A total volume of 23.5 million gal of liquid waste was discharged to the 216-B-43 through 216-B-50 Cribs. The major radionuclides in the waste were ^{137}Cs, ^{90}Sr, uranium, and plutonium. Additional details regarding the wastes discharged to the 216-B-43 through 216-B-50 Cribs are presented in DOE (1993a) and DOE (1993b).

These cribs are monitored with several monitoring boreholes that are identified on Figure 15-5. Fecht et al. (1977) and Chamness (1986) evaluated the early gross gamma-ray logs of these boreholes. Fecht et al. (1977) identified high levels of gamma-ray activity beneath the cribs from near the ground surface to groundwater; the intensities of the gamma-ray activities were observed to have decreased since the cribs were removed from service. Although no evidence of migration was observed since the high gamma-ray intensities were first identified in the gross gamma-ray logs, Fecht et al. (1977) concluded that contamination from waste discharged to the cribs had reached groundwater. Chamness (1986) reviewed the gross gamma-ray log data and identified trends of decreasing activities in the monitoring boreholes.

An extensive project was conducted in 1991 to characterize the distribution of the contamination in the vadose zone beneath and around the cribs. Several boreholes were drilled through the cribs, and three boreholes were drilled to groundwater to assess the extent of migration of the liquid waste discharged to the cribs.

Several monitoring boreholes located within the 216-B-43 through 216-B-50 Crib complex have been logged with the WHC RLS. Borehole 299-E33-03 is located near the 216-B-45 Crib and was logged in September 1991. The presence of ^{137}Cs was detected in three intervals at a maximum depth of 121 ft. The presence of ^{60}Co contamination was detected from a depth of 30 ft to the maximum survey depth of 232 ft. Concentrations of ^{125}Sb and ^{154}Eu were also detected, but the intervals of these occurrence were less extensive and these concentrations were less intensive than those of either the ^{137}Cs or the ^{60}Co contamination. The depth to groundwater at the time of logging was 221 ft.

Borehole 299-E33-05 is located near the 216-B-47 Crib and was logged with the WHC RLS in September 1991. The presence of ^{137}Cs was detected intermittently throughout the borehole and near the bottom of the borehole. The presence of ^{60}Co was detected in two thick intervals, the lower of which was at the bottom of the borehole; the presence of ^{125}Sb was also detected. The depth to groundwater at the time of logging was 224 ft.

Borehole 299-E33-13 is located southeast of the 216-B-43 through 216-B-50 Crib complex and was logged with the WHC RLS in September 1991. The presence of ^{137}Cs was detected deep in the borehole at depths from about 208 to 220 ft. ^{60}Co contamination was detected from a depth of 94 ft to the bottom of the borehole. No other man-made radionuclides were detected. The depth to groundwater at the time of logging was 221 ft.

During the characterization of the 216-BY Cribs, several boreholes were drilled through the cribs, and three boreholes (located in cribs 216-B-43, 216-B-49, and 216-B-57) were drilled to groundwater; samples of the groundwater were collected at the maximum depth drilled in these three boreholes. The analyses of these samples indicated the presence of ^{137}Cs, ^{60}Co, Pu, ^{99}Tc, and several other radionuclides. The reader is advised to consult the *Phase I Remedial Investigation Report for 200-BP-1 Operable Unit,* Volumes 1 and 2 (DOE 1993b), for additional details.

6.6 216-B-51 Crib

The 216-B-51 Crib is located about 600 ft northeast of the BY Tank Farm. This crib is constructed of three sections of 5-ft-diameter concrete pipe stacked vertically at depths from 1 ft above to 14 ft below the ground surface. The pipe was filled with gravel in the bottom 13 ft of its length. A perforated 4-in.-diameter steel pipe runs down the center of the structure and is the discharge inlet of the crib. A surface cover consisted of treated lumber. This type of structure is also referred to as a French drain or underground injection well.

The 216-B-51 Crib was in service from January 1956 to January 1958 and received 260,000 gal of flush drainage from the BC Crib pipeline. The estimated radiological content of the 216-B-51 Crib is less than 10 Ci total beta.

6.7 216-B-57 Crib

The 216-B-57 Crib is located 250 ft northwest of the BY Tank Farm. This crib consists of a 12-in.-diameter corrugated pipe approximately 200 ft long within an excavation 200 ft long by 15 ft wide by 10 ft deep. The side slopes of the excavation were at a ratio of 1.5:1. The pipe was placed in the excavation following placement of a 4-ft-thick layer of gravel. The facility was backfilled and stabilized with a 2-ft-thick layer of clean fill material. This type of structure was also known as an enclosed trench.

The 216-B-57 Crib entered service in February 1968 and was removed from service in June 1973. Throughout its operational life, the 216-B-57 Crib received 22.3 million gal of liquid waste as waste storage tank condensate from the BY Tank Farm during the ITS#1 campaign. The major waste constituents are 230 Ci of ^{137}Cs and 2 Ci of ^{90}Sr.

Fecht et al. (1977) reviewed the historical gross gamma-ray log data acquired in borehole 299-E33-24, which is located immediately adjacent to the 216-B-57 Crib, and observed increasing gamma-ray activity resulting from continuing waste disposal to the 216-B-57 Crib. Fecht et al. concluded that contamination from the waste discharged to the crib had not reached groundwater.

Borehole 299-E33-24 was abandoned in 1992 during a crib stabilization project. Before it was abandoned, it was logged with the WHC RLS. The presence of ^{137}Cs was detected in three intervals; the deepest interval was at the bottom of the borehole at a depth of 246 ft. The presence of ^{60}Co was also detected near the bottom of the borehole. The depth to groundwater at the time of logging was 232.5 ft, indicating the presence of these two radionuclides in the groundwater and the influence of the 216-B-57 Crib discharges on groundwater contamination.

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 sonde, a logging cable and delivery system, and surface computer electronics mounted in a cabin on a heavy-duty truck chassis. Figure 15-8 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 detections systems that made production of higher efficiency detectors more economical.

The detectors, which are housed in downhole cylindrical sondes, 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 sondes 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 15-9 shows a sonde equipped with 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 sonde position in the borehole is measured with a digital rotary encoder mounted on a sheave wheel hanging from a boom (Figure 15-9). The boom is used to position the sonde over the borehole.

The surface instrumentation, which is mounted in standard instrument racks inside the rear cabins of the logging trucks, consists of a high-count-rate nuclear spectroscopy amplifier interfaced to a computer-controlled multichannel analyzer. Spectral log data are recorded by the computers on hard disks.

All instrumentation control, winch control, tool positioning, safety interlocks, and other functions are under computer control using a data acquisition and control program supplied 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

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 cylindrical concrete monoliths with large homogeneous regions where the concrete is enriched with known concentrations of ^{40}K, ^{238}U, and ^{232}Th. 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 sonde is placed in the middle of the zone of enriched concrete, the measurement geometry is such that a homogeneous, isotropic medium of known radionuclide concentration is simulated. The response of the detector to the medium of the calibration zone is recorded, and the mathematical relationships between radionuclide concentration and count rate response are computed. The mathematical relationships constitute the system calibration factors.

During the base calibration, calibration factors were calculated to enable direct conversion of specific photon peak count rate responses to ^{40}K, ^{238}U, or ^{232}Th 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 concentrations of man-made radionuclides that are not present in the calibration models, such as ^{137}Cs or ^{60}Co. Figure 15-10 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 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 field calibration models are essentially identical to the national standards in Grand Junction. They 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 ^{40}K, ^{238}U, and ^{232}Th and by recalculating the energy versus efficiency functions shown in Figure 15-10. 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 are incorporated in the analysis of borehole log data.

The second field calibration was performed after the BY Tank Farm logging work was completed and is reported in DOE (1996c). The data acquired during the second field calibration demonstrate there was no statistically significant change in the performance of the system.

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 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 BY 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. These data show no statistically significant trend over time, verifying the stability of the systems and consistent performance.

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 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 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 interval stations 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 concentration, 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 adjustment of the gain may be required throughout an 8-hour 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 a Paradox database created specifically for the log data; 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 project 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 and/or damage.
- 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 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 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 15-11 shows a flow chart of the data analysis process that is also provided in the data analysis manual. The office computer system consists of six 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 presented in Section 7.4, "Data Management" and in the records management plan.

Analysis begins by converting all of 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 "PCMCA/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 identified 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 data from all depths for the spectra for the particular photon peak.

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). Finally, all environmental corrections are applied to the data to correct for casing, water-filled boreholes, dead-time, etc. The output files are saved as *.rlg files, which contain depths, radionuclide concentrations, uncertainties, and the minimum detection limit (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 as a function of depth using somewhat consistent plot formats.

Statistical uncertainties derived from the logging and calibration data by standard uncertainty propagation methods are also converted to equivalent concentrations to produce an estimate 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 with 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 is created to document the analysis of the borehole log data. It is created using the Paradox database program with data from the vadose zone characterization database.

The Log Data Report provides information about the borehole construction and casing configuration and about 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 accompanies the log plots so that others may independently interpret the results.

Upon completion of the data analysis, 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 under way. 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 69 boreholes in the BY 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.

The instrumentation was calibrated at the base calibration facility (DOE 1995e) before logging began in the BY Tank Farm, and it was recalibrated 6 months later in the first biannual recalibration (DOE 1996g), which was after the completion of the BY Tank Farm logging. There was virtually no difference in the performance of the instrumentation between the two calibrations.

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

Some assumptions regarding the borehole casing thicknesses were used in data analysis. Often the surfaces of the casings were 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 and is different from the value assumed for data analysis.

A maximum radiation flux from ^{137}Cs from which a meaningful spectrum could be recorded was about 8,000 pCi/g. However, data acquisition procedures have been refined to raise that maximum to a slightly higher value.

For a counting time of 100 s, the MDL for ^{137}Cs is consistently between the 0.1- and 0.2-pCi/g level. The MDL differs slightly for each spectrum depending upon 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 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 was detected and the source radionuclide was identified, the peak count rate was automatically converted to an equivalent concentration in picocuries per gram.

In the BY Tank Farm, the most abundant gamma-emitting radionuclide contaminants in the vadose zone by orders of magnitude were ^{137}Cs and ^{60}Co. ^{137}Cs contamination was detected in every borehole, and the presence of ^{60}Co was detected in several boreholes throughout large depth intervals. ^{60}Co contamination was detected at the bottom of several boreholes. Other nuclides detected were ^{152}Eu, ^{238}U, and ^{125}Sb; concentrations of these nuclides were generally detected near the ground surface as a result of surface spills or the proximity of the borehole to near-surface piping. However, an interval of ^{125}Sb contamination resulting from leakage from tank BY-103 was detected in borehole 22-03-06, along with ^{137}Cs and ^{60}Co contamination. ^{238}U was detected in borehole 22-11-08 in a 1-ft interval at a depth of 61 ft.

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

8.3 Log Plots

Log data results are presented in the Tank Summary Data Reports as 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 (^{40}K, ^{238}U, and ^{232}Th), and a combination plot showing logs of the man-made and naturally occurring radionuclides 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. Plots of the man-made correlation plots for the boreholes surrounding each tank are provided in Appendix B of this report. These plots contain the logs for the man-made contamination detected in the boreholes surrounding each tank. They are the plots that were used for correlation purposes in the Tank Summary Data Reports (see Section 8.4).

The log plots and the nuclide-specific data files for each borehole are maintained in the vadose zone characterization 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 within the BY Tank Farm. Each report provides a mechanism for reporting the results of the spectral gamma logging, and it 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 help nontechnical personnel understand the effect that contamination from 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 a discussion of 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 a particular tank is the source of contamination, this indication 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 BY Tank Farm Tank Summary Data Reports listed in Section 16.0, "References," of this report for information on a specific borehole.

9.0 Development of the ^{137}Cs and ^{60}Co Contamination Models

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

Creating the visualizations required developing models of the ^{137}Cs and ^{60}Co contamination distributions, which are the two 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. Explanation about the known and possible errors and inaccuracies with the contamination models allows 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 BY 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 variation in data. It is an empirical analysis of the data and application of the results of the analysis 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. Journel and Huijbregts (1978) and David (1977) explain the theory and application of geostatistics as applied to the development of such a model.

The radionuclide concentration data that constitute the spectral gamma-ray log data reported in the Tank Summary Data Reports for the BY 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 BY Tank Farm, the most abundant contaminants were ^{137}Cs and ^{60}Co. Other nuclides were detected but were not abundant enough to be used to define the leaks or were isolated distributions of contamination. Therefore, the contamination models were based on the ^{137}Cs and ^{60}Co distributions, and the visualizations depict only these two contaminants.

9.1 Geostatistical Structural Model

The initial stage in developing an empirical model of the ^{137}Cs and ^{60}Co 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 both the ^{137}Cs and ^{60}Co data.

The EVS software performs the geostatistical structural analysis by calculating three-dimensional variograms, which 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 and ^{60}Co contamination.

The total data domain of the calculations encompassed all vadose zone boreholes within the BY Tank Farm. The domain was extended in the north-south and east-west directions to include the maximum and minimum horizontal borehole coordinate values. Borehole depths were converted to elevations, and 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 mathematical model that is called a spherical model using a least-squares fitting algorithm. The spherical model defines the geostatistical structure. The general equation for a spherical variogram model is

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

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

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. This value was determined through trial and error and produced sill values and horizontal and vertical ranges that appeared to be representative of the contamination distribution. This value means that the horizontal continuity is 10 times greater than the vertical continuity.

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 0.45° from the vertical for the ^{137}Cs contamination model, and an angle 0.2° from the vertical for the ^{60}Co model. These low principal-component axis angles indicate 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 32 ft and a sill value of 1.5. In real terms, the range is multiplied by 10 (the anisotropy factor) to produce 320 ft, which is the distance at which the correlation of two data points is strictly random. Figure 15-12 presents an example of the ^{137}Cs variogram used as the structural model.

The calculated variogram for ^{60}Co contamination that was used to represent the geostatistical structure in the horizontal direction had a range value of 60 ft and a sill value of 0.3. In real terms, the range is multiplied by 10 (the anisotropy factor) to produce 600 ft, which is the distance at which the correlation of two data points is strictly random. Figure 15-13 presents an example of the ^{60}Co variogram used as the structural model.

The range of the vertical variogram for ^{137}Cs contamination was also calculated to be 32 ft, but it had a slightly lower sill value of 1.3. This range shows a spatial relationship between two data points to 32 ft in the vertical direction, such that 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 0.45° from the vertical, proving that the assumption of horizontal-to-vertical anisotropy is a good assumption and that the horizontal axes are isotropic.

The range of the vertical variogram for the ^{60}Co was also calculated to be 60 ft, and it had a slightly lower sill value of 0.26. This range shows a spatial relationship between two data points to 60 ft in the vertical direction, such that knowledge of one point will decrease the mean estimation uncertainty of the other. The axis of the data has an angle of 0.2° from the vertical, proving the assumption of horizontal-to-vertical anisotropy is a good assumption and that the axes are isotropic.

The geostatistical structural analysis produced the equations for the variograms that were used to define the ^{137}Cs and the ^{60}Co 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 on the basis of 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 10 placed 10 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 10 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 moved down along the inside or outside of a borehole.

For data sample points with less than detectable concentrations of ^{137}Cs, a value of 0.1 pCi/g was 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. The lowest concentration that is visualized and presented in Section 10.0, "Discussion of Results," is 0.5 pCi/g for the ^{137}Cs contamination plumes and 0.2 pCi/g for the ^{60}Co contamination plumes.

Similarly, in regions where the radionuclide concentration was so high that the detection system became saturated, the value of 8,000 pCi/g was placed in the database for the kriging operation. A maximum value of 5,000 pCi/g was used in the visualizations. This setup has minimal effect on the BY Tank Farm data because there were few zones of high concentrations that saturated the detector.

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 only extend 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 contamination visualized, the isolevel, is 0.5 pCi/g. It was discovered that ^{137}Cs concentrations as low as 0.5 pCi/g are appropriate in terms of identifying a tank leak or a leak source. Below 0.5 pCi/g, data have too high an uncertainty to be used to track the plumes, and there is a strong possibility that low-level contamination that has migrated down the inside of the boreholes will create false plumes.

The isolevel for the ^{60}Co contamination visualization was 0.2 pCi/g. The distribution of the ^{60}Co data was best displayed at this concentration. Lower isolevels produced confusing visualizations because low ^{60}Co concentrations were observed in several of the BY Tank Farm boreholes, and much of this ^{60}Co contamination was probably not related to tank leakage.

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

The visualizations presented in this report are based on assignments of ^{137}Cs and ^{60}Co concentrations to blocks bound by data point nodes. The error of each concentration assignment is estimated by the program and also assigned to the blocks. This estimation of the error of the concentration assignment is based on the variance of the data points. The error estimation is important because it identifies the potential accuracy of the block concentration assignment and, ultimately, it reflects the accuracy of the entire model. The magnitude of the concentration estimation error and the potential accuracy of the model are probably best understood by examining the maximum-minimum plume visualizations.

However, problems occur with data sample points, and there is no mechanism to consider those problems or include them in a block-concentration assignment error. The EVS software is similar to other software packages: if inaccurate data are used as input to the calculations, inaccuracies will result in the model. With proper interpretation of data and the contamination distribution model, problems resulting from inaccurate data can be identified and potential inaccuracies in the model can be explained.

Because the geostatistical analysis is an empirical analysis method and the calculated error estimation is also based on the empirical analysis method, the maximum-minimum plume visualizations should provide a good representation of the potential grade-assignment error. A more rigorous geostatistical structural analysis would be desirable. The data samples are 0.5 ft apart in the vertical direction, creating an ideal database for a 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 on only those data. Future assessments may help to refine and validate the variograms that are the basis of the geostatistical structure of the data.

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.

One of the greatest concerns in preparing the ^{137}Cs and ^{60}Co contamination models is that the contamination is not actually distributed within the sediments but 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.

There are cases where the apparent concentration is not an actual representation of the vadose zone contamination and the concentration estimation error will not be valid. This possibility was considered by properly 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.

It must be understood that even if there are borehole migration effects that bias the borehole log data, much of that bias will be removed from the plume visualizations because of the high horizontal-to-vertical anisotropy emphasis applied by the software in the modeling process. In effect, the anisotropy factor increases the influence of adjacent boreholes so plumes that are highly localized around one borehole are not correlated with contamination in other boreholes and continuous plumes are not generated for such a situation.

In areas of high ^{137}Cs concentrations (greater than 8,000 pCi/g), the detection system was saturated and data acquisition was not possible with the current detector. Those zones present a problem because it is useful to know that the contamination level is high, but it is difficult to incorporate that information into a mathematical model of the contamination. The high contamination levels were incorporated by recording the high-intensity zone as a contaminated zone and placing the value of 8,000 pCi/g in the borehole database within the zone of detector saturation. The problem with this method is that it puts a bias in the variogram because the variance between two data points in a borehole suddenly becomes zero. The result is a variogram (particularly the variogram in the vertical direction) that may not properly represent the spatial structure. With the exception of the high ^{137}Cs concentrations detected in borehole 22-03-05 that were related to leakage from tank BY-103, other intervals of high ^{137}Cs concentration detected in the BY Tank Farm boreholes were near the ground surface and related to nontank contamination.

At the other extreme, there may be low-intensity radionuclides that went undetected 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 BY Tank Farm in a cost-effective manner and detecting contamination at low concentrations while still doing a reasonable job of characterizing the high-contamination zones. The current contamination distribution models do not include gamma-emitting radionuclides that are less than the detection levels realized with the data acquisition configuration explained in Section 7.0 "Spectral Gamma Logging Measurements," of this report.

The calibration of the logging system assumes a homogeneous medium of contamination that is effectively infinite, 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 very bottom of the boreholes or where the concentration changes rapidly with depth. The data acquisition interval used to log the BY 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 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 sediment 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.

The inaccuracies of the data used for the models have a potential to cause inaccuracies in the models. These potential problems are identified and considered in the interpretation and are discussed in Section 10.0.

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 to ensure consistent depth measurements. Radionuclide concentration values measured at the surface are not accurate for two reasons. One reason is that the calibration of the logging systems makes the assumption of a homogeneous infinite medium, but this is not the case when the detector is located at 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 what is actually present in the formation.

The other reason the concentration is not valid is because most of the boreholes were constructed with a small concrete collar around the borehole casing at ground surface. 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 concentration to be lower than what is actually present in the formation.

Because the ^{137}Cs 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 ^{137}Cs in the sediment. The ^{137}Cs concentration may be higher or lower by an unknown amount. However, for most of the length of the boreholes, the models are accurate representations of the distribution and intensity of the contamination in the vadose surrounding the tanks in the BY Tank Farm.

At depths below about 5 ft, the near-surface inaccuracies are negligible. Figure 15-14 presents a visualization of the near-surface contamination at a depth of 5 ft. This visualization is a view from above the BY Tank Farm. Both the ^{137}Cs and ^{60}Co contamination shown on Figure 15-14 are horizontal planes of contamination 1 ft thick; the tops of the planes are 5 and 6 ft below the ground surface, respectively. Because the ^{137}Cs contamination was widespread and sometimes masked the ^{60}Co plumes, this offset was used to allow the ^{60}Co contamination to be seen. ^{137}Cs contamination is present throughout the BY Tank Farm. The highest concentration is seen on the southeast side of tank BY-103. ^{60}Co contamination was detected over tank BY-112; this contamination is related to documented surface spills of waste at this tank.

Surface areas of ^{137}Cs contamination with concentrations greater than 1,000 pCi/g were observed in several areas in the BY Tank Farm. The most intense areas were above tanks BY-101, BY-102, BY-104, BY-105, BY-107, and BY-108. Documented unplanned releases that occurred at tanks BY-107 and BY-112 were associated with problems with tank ancillary equipment and piping. ^{60}Co contamination along with ^{137}Cs contamination was detected at ground surface near tank BY-112 and is most likely associated with two documented releases of radiologically contaminated waste materials. Some of the high gamma-ray count rates detected at the surface may be from near-surface contamination in pipelines that traverse the BY Tank Farm in many locations. The pipelines are covered with gravel and/or soil material, but the gravel thickness may not be sufficient to attenuate all the gamma rays. High count rates near tanks BY-101 and BY-102 are associated with an inactive evaporator that is located on the surface between these tanks. The radiation field around the evaporator exceeded the limitations of the RWP for the logging operations, and borehole 22-02-07, which is located within an exclusion zone surrounding the evaporator, could not be logged.

High-intensity near-surface contamination was measured in several boreholes at depths ranging from 2 to 7 ft. Boreholes 22-05-01, 22-08-01, 22-08-02, and 22-12-03 exhibited zones of extremely high dead time in this depth range, where the logging tool essentially shut down and no data were acquired. Concentrations of ^{137}Cs, ^{60}Co, and ^{154}Eu were detected in a single zone between depths of 2 and 8 ft in borehole 22-12-03. In the other three boreholes, only the presence of ^{137}Cs was detected above and below the high dead-time zones. These contaminants may be related to a pipeline containing waste materials; therefore, the calculated concentrations of these radionuclides may only be approximate because of the nonuniform distribution of the contamination within the piping.

The ^{137}Cs contamination distribution model shows that the surface contamination has generally migrated downward from 10 to 40 ft below the ground surface and diminished in intensity. This distribution is apparent in the log profiles provided in the Tank Summary Data Reports for individual tanks in the BY Tank Farm and in the visualizations presented in this report. Low concentrations (less than 1 pCi/g) of ^{60}Co contamination were detected in several boreholes along with the ^{137}Cs contamination.

The most likely scenario(s) for the contamination from the ground surface to a depth of about 40 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. Contaminated sediments at the 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.

Most of the monitoring boreholes have a small circular concrete pad around the borehole casing at 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 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 or leak of contaminated material or a natural meteorological event that produced flooding at the tank farm surface, contamination could have migrated downward or previously deposited contamination may have been driven down the borehole-created pathway within the sediments.

Regions of contamination actively migrating downward from the ground surface have not been identified in the gross gamma log data recorded for the past 20 years at Hanford. Contamination detected near the surface with the gross gamma logging system has been relatively stable and has not moved any significant distance. The database extends from the mid-1970s to the early 1990s.

Future development of a spectral-shape factor analysis of the gamma-ray spectra recorded near the surface may provide additional data for analysis of the distribution of contaminants around the boreholes. A shape-factor analysis calculates the count rate ratio between the low-energy Compton continuum to the count rate in the full energy peak. This ratio decreases as the source changes from an infinite medium distribution to a borehole-restricted distribution. When ^{137}Cs is uniformly distributed in the formation, the photon flux at the detector has a large Compton downscatter component and the shape factor is high. When ^{137}Cs is confined to the casing, there is less scattering medium between the source and detector, so the photon flux a the detector has a smaller Compton downscatter component and the shape factor is low. 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 but has migrated down the outside of a borehole casing.

10.2 Tank-by-Tank Discussion

The following discussions are related to the results of the geostatistical modeling that were performed with data acquired in the BY Tank Farm boreholes. The visualizations are provided in Section 15, "Figures for the BY Tank Farm," in the order in which they are discussed. All the visualizations are presented in true scale; there is no exaggeration in either the horizontal or vertical dimensions.

Figures 15-15 and 15-16 present the data used in the geostatistical models and allow the reader to compare the individual borehole ^{137}Cs and ^{60}Co contamination concentration data with the ^{137}Cs

and ^{60}Co contamination plume visualizations. The data in these figures are presented as hexagons that are colored and sized according to the ^{137}Cs and ^{60}Co concentration data and are presented in the spatial position in which the data were collected. The borehole identification numbers allow correlation with the plan map presented in Figure 15-7 and the BY Tank Farm correlation plots provided in Appendix B.

Visualizations were prepared that show occurrences of ^{137}Cs and ^{60}Co contamination plumes with concentrations above 0.5 pCi/g. The ^{137}Cs contamination plumes were made transparent to allow viewing of the distribution of the ^{60}Co plume; these visualizations provide insight into the continuity of the ^{60}Co contamination. Figures 15-17, 15-18, 15-19, and 15-20 present these visualizations from several view points.

The most widely cited visualizations present both the ^{137}Cs and ^{60}Co contamination plumes. The ^{137}Cs contamination plume concentrations are presented logarithmically in a range from 0.5 to as high as 10,000 pCi/g. The ^{60}Co contamination plumes are presented logarithmically in a range from 0.2 to as high as 1,000 pCi/g. These visualizations were used in the tank-by-tank discussion that follows.

In the following sections, waste-level measurements are presented relative to their depth below the ground surface. These measurements are derived from illustrations and measurements provided in Brevick et al. (1994a and 1994b).

10.2.1 Tank BY-101

Tank BY-101 is designated a sound tank with no detected leaks. It currently contains 278,000 gal of salt cake, 109,000 gal of sludge, and 5,000 gal of drainable liquid (Hanlon 1996) and is monitored with moisture detection instruments inside a LOW.

Figures 15-21, 15-22, and 15-23 show the contamination distribution in the vadose zone sediments surrounding tank BY-101. The views are from the southeast, from the northeast, and from the southwest, respectively, and all views are from below the tanks. These visualizations were created by applying a north-south cut face in the BY Tank Farm data domain west of the BY-101-to-BY-103 row of tanks.

The highest concentration of ^{137}Cs contamination occurs at ground surface, and most of this contamination decreases at depth, with the exception of a zone of ^{137}Cs contamination detected in borehole 22-01-10 at depths from 28 to 42 ft. This contamination is shown on Figures 15-20, 15-21, and 15-22 as a continuous plume of contamination on the west side of the tank. The ^{137}Cs concentrations are relatively low (10 pCi/g) when compared to the ^{137}Cs concentrations detected in the other boreholes surrounding tank BY-101, and the plume is defined by the data acquired in borehole 22-01-10. This ^{137}Cs contamination may be a combination of contaminated materials that were driven downward during borehole drilling and migration of contamination down the inside or outside of the casing. Elevated gamma-ray count rates that were recorded in 1985 at the ground surface between tanks BY-101 and BY-104 indicated a localized leak or spill. The highest count rates were recorded in borehole 22-01-10 and borehole 22-04-01, which is adjacent to tank BY-104. The plume defined by the contamination detected during logging is based on borehole conditions and should be disregarded as an actual contamination plume.

Low ^{60}Co concentrations were detected near the ground surface in borehole 22-01-07 in the southwest quadrant of the tank and more extensively at depths from 25 to 85 ft in borehole 22-01-04 in the southeast quadrant of the tank. All ^{60}Co concentrations were less than 0.5 pCi/g. The most likely source of the ^{60}Co contamination in borehole 22-10-04 is subsurface piping, possibly the cascade line between tanks BX-103 and BY-101. The near-surface contamination probably resulted from a spill or leak.

Low concentrations of ^{137}Cs contamination at the bottom of the tank BY-101 boreholes resulted in a false tabular contamination plume at the base of the visualization. This increased ^{137}Cs contamination is recorded in the logs of all the boreholes and is probably contamination that entered the inside of the casing, migrated downward, and settled at the bottom of the borehole.

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

10.2.2 Tank BY-102

Tank BY-102 is designated a sound tank with no detected leaks. It currently contains 277,000 gal of salt cake with 11,000 gal of drainable liquid (Hanlon 1996) and is monitored with a moisture detection probe in an LOW.

The contamination present in the vadose zone surrounding tank BY-102 is presented in Figures 15-21, 15-22, and 15-23. The views are from the southeast, from the northeast, and from the southwest, respectively, and all views are from below the tanks. These visualizations were created by applying a north-south cut face in the BY Tank Farm data domain west of the BY-101-to-BY-103 row of tanks.

Surface contamination was detected in all the boreholes, and the contamination plume(s) extend below the top of the tank to a depth of about 35 ft. The ^{137}Cs concentrations decrease with depth, and the contamination is most likely the result of contaminated sediments that were driven downward during borehole drilling or contamination from surface leaks or spills that migrated down the pathway between the outside of the casing and the sediments. The ^{137}Cs contamination is most likely a combination of both of these processes. Flooding at the ground surface from natural events may have driven surface or near-surface contamination deeper into the vadose zone.

On the northern side of tank BY-102, the ^{137}Cs contamination plume is more extensive vertically. This plume is defined by data acquired in adjacent boreholes 22-02-01 and 22-02-09 and in boreholes 22-03-05 and 22-03-06, which are associated with and adjacent to tank BY-103. This plume is most likely related to leakage from tank BY-103. The ^{137}Cs contamination peak in borehole 22-02-01 at a depth of 45 ft correlates with a lithologic change to finer-grained and probably less permeable sediments. ^{137}Cs contamination associated with leakage from tank

BY-103 probably migrated downward to this horizon in the vicinity of tank BY-102. However, it is not conclusive to dismiss the possibility that tank BY-102 was the source of this contamination.

Low ^{60}Co concentrations were detected in the boreholes surrounding tank BY-102 at depths as shallow as 20 ft and as deep as 100 ft, the bottom depth of several of the boreholes. The shallow occurrences are likely indicative of leakage from pipelines or migration down the inside or the outside of the casing. The most extensive and higher ^{60}Co concentrations were detected north of tank BY-102 and are associated with leakage from tank BY-103; ^{60}Co contamination is not present above high concentrations of ^{137}Cs but is located with and below the ^{137}Cs contamination. This distribution is probably indicative of the greater mobility of ^{60}Co relative to ^{137}Cs.

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

10.2.3 Tank BY-103

Tank BY-103 is designated an assumed leaker. It currently contains 395,000 gal of salt cake, 5,000 gal of sludge, and 15,000 gal of drainable liquid (Hanlon 1996). High gross gamma-ray count rates observed in borehole 22-00-03 in 1969 resulted in a questionable integrity designation for the tank. In 1971, leakage was confirmed when the contamination plume was detected in newly constructed borehole 22-03-05. The liquid operating level was dropped to 13 ft to permit continued operation of the tank as an evaporator bottoms receiver for the ITS campaign(s).

This tank received metal wastes in cascade from tank BY-102 in 1950 and was full in 1951. The waste was sluiced for uranium recovery in 1954, and it was eventually emptied in 1954 through transfers to other tanks. The tank then received U Plant waste that was considered scavenged waste awaiting reprocessing; this waste was ultimately sent to the CR Process Vault. From 1957 to 1970, tank BY-103 contained PUREX high-level waste, U Plant waste, and coating waste. During the mid-1960s, the tank was used for in-tank decanting and solidification during the ITS campaign(s). From 1968 to 1971, tank BY-103 also contained organic wash waste and evaporator bottoms waste. In the early 1970s, the waste contents of tank BY-103 underwent processing during the ITS operations. The tank was declared a leaker in 1973 with a leak volume estimated to be less than 5,000 gal. No reference was located defining the basis of this estimation.

The contamination present in the vadose zone surrounding tank BY-103 is shown on Figures 15-21, 15-23, 15-24, and 15-25. The first three views are from below the tank from the southeast, from the southwest, and from the northwest, respectively. A north-south cut face was inserted in the BY Tank Farm data west of the BY-101-to-BY-103 row of tanks. Figure 15-25 is a view of only tank BY-103 and was prepared with two cut faces that intersect perpendicularly outside the southwest quadrant of the tank. This view was created to view the core of the contamination plume on the southwest side of tank BY-103.

All the visualizations show that plumes of low concentrations of ^{137}Cs contamination almost completely envelope tank BY-103, the exception is the southwest portion of the tank. The contamination detected from SGLS logging begins at the ground surface and extends to the bottoms of 10 of the 11 boreholes that surround the tank. Occurrences of ^{60}Co and ^{154}Eu contamination were detected along with ^{137}Cs contamination in one borehole (22-03-09) in a localized zone. This contamination most likely originated at or near the ground surface and migrated downward along the inside or the outside of the casing or was driven downward during borehole drilling.

The most extensive contamination plume in terms of highest ^{137}Cs concentrations was measured in borehole 22-03-05 on the southeast side of tank BY-103, where concentrations were high enough to cause data acquisition problems because of high detector dead time between depths of about 25 and 45 ft. The ^{137}Cs concentration within this interval is about 180,000 pCi/g, on the basis of comparison with Tank Farms gross gamma-ray log data that were acquired with less sensitive sondes (DOE 1996j). ^{137}Cs and ^{60}Co concentrations were detected immediately below the high dead-time zone to a depth of 100 ft, which is the total depth of borehole 22-03-05. Low concentrations of ^{125}Sb occur within this plume; this radionuclide was detected in several boreholes on the eastern side of tank BY-103. Data for ^{125}Sb concentrations are not shown on the visualizations because of limited occurrence. This large contamination plume resulted from leakage from tank BY-103 that spread in a southerly direction and is seen in the visualizations beneath the southern half of the tank. The total depth extents of both the ^{137}Cs and the ^{60}Co contamination in this plume are not known because the contamination was detected at the bottoms of the boreholes.

The plume of ^{60}Co contamination under the west side of tank BY-103 may be related to the leakage from tank BY-103, or it may have originated from leakage from tank BY-106. Tank BY-106, which is adjacent to tank BY-103 to the west, is also a known leaker.

^{137}Cs contamination was detected at the maximum depth logged in the boreholes on the north side of the tank BY-103. When this low-level contamination was processed by the modeling program, a false plume was defined at the base of the visualizations. This contamination most likely entered the inside of the casing, migrated downward, and settled at the bottom of the borehole.

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

10.2.4 Tank BY-104

Tank BY-104 is designated a sound tank. It currently contains 366,000 gal of salt cake, 40,000 gal of sludge, and 18,000 gal of drainable liquid; this tank is monitored with a moisture probe through an LOW.

The contamination present in the vadose zone surrounding tank BY-104 is presented on Figures 15-26, 15-27, and 15-28. These views are from below the tank from the southwest, from the northeast, and from the south, respectively. The first two figures were created with two north-south cuts in the BY Tank Farm data domain on the east and west sides of the BY-104-to-BY-107 row of tanks. Figure 15-28 was created with one east-west cut on the south side of the BY Tank Farm data domain and shows several tanks adjacent to tank BY-104.

A large plume of low-concentration ^{137}Cs contamination surrounds the northern two-thirds of tank BY-104 and is defined by data acquired in adjacent boreholes 22-04-01 and 22-04-09 and in boreholes surrounding adjacent tank BY-101 to the east and tank BY-105 to the north. Historical gross gamma-ray data indicate that a surface spill or leak in the vicinity of tank BY-104 resulted in elevated activity at the ground surface in all the boreholes; the activity was most intense in borehole 22-04-01 and in borehole 22-01-10, which is adjacent to tank BY-101. This contamination appears to have migrated down the inside or outside of the casing and may have been superimposed on pre-existing contamination; therefore, this contamination plume is defined on the basis of borehole-created anomalies and is a false plume.

A slight plume of ^{60}Co contamination visible on the west side of tank BY-104 was defined by data from boreholes 22-04-07 and 22-04-09 below a depth of 90 ft. This is a leading edge of the ^{60}Co plume resulting from leakage from tank BY-107. The depth extent of the ^{60}Co contamination in both of these boreholes is undefined, as ^{60}Co contamination is present at the bottoms of these boreholes. The plume of ^{60}Co contamination above this plume is defined from data from borehole 22-07-05, which is adjacent to tank BY-107.

The ^{137}Cs contamination that was detected at the bottoms of the boreholes is represented as a false tabular-shaped contamination plume at the base of the visualization.

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

10.2.5 Tank BY-105

Tank BY-105 is designated an assumed leaker. It currently contains 459,000 gal of salt cake, 44,000 gal of sludge, and 192,000 gal of drainable interstitial liquid (Hanlon 1996). The waste level is about 16 ft from the bottom of the tank, or about 32 ft below the ground surface. Tanks BY-105 and BY-106 are the only SSTs at the Hanford Site that are known leakers that still contain a significant amount of drainable liquid.

Tank BY-105 was first suspected of leaking in 1974 when radiation levels in borehole 22-05-09 increased from previous levels. The volume of liquid in the tank was reduced, and 63 tons of Portland cement was added to the tank to absorb the liquid and stop the leak. A leak-volume estimation of 8,000 gal was derived through questionable methods that assumed that the total leak volume from 19 tanks (including BY-105) in eight different tank farms was equally distributed (Baumhardt 1989).

Tank BY-105 received metal waste in cascade from tank BY-104 in 1951. The waste was sluiced for uranium recovery in 1954. This tank received U Plant waste from other tanks in the

BY Tank Farm in 1954 and intermittently to 1966. Coating waste was sent to the tank from 1962 to 1967. The waste in the tank was processed through the ITS campaigns from 1967 to 1974, when the tank was removed from service when it was identified as leaking.

The contamination present in the vadose zone surrounding tank BY-105 is presented on Figures 15-26, 15-27, and 15-29. The views are from below the tank from the southwest, from the northeast, and from the north-northwest, respectively. Two north-south trending cut faces were inserted in the BY Tank Farm data domain on the east and west sides of the BY-104-to-BY-106 row of tanks.

The ^{137}Cs contamination plumes surrounding tank BY-105 on the north and south sides are defined by the data acquired in boreholes 22-05-01 and 22-05-05, respectively. The profiles of the ^{137}Cs concentration plots for these two boreholes suggest that the distributions of the ^{137}Cs contamination may have resulted from downward migration of contamination from surface or near-surface spills or leaks because the ^{137}Cs concentrations decrease with increasing depth. In addition, some of the contamination may have been driven downward during borehole drilling. The high dead time corresponding to high ^{137}Cs concentrations at the ground surface reported in logs for borehole 22-05-01 is indicative of a significant surface spill.

The low ^{137}Cs concentration contamination plume underlying tank BY-105 at the bottoms of the visualizations is defined by increased ^{137}Cs concentrations that were detected at the bottoms of the boreholes. These increased ^{137}Cs concentrations are most likely the result of contamination that migrated down the inside of the casings and settled at the bottoms of the boreholes. This is a false contamination plume.

^{60}Co contamination plumes are shown on the figures as entering the area beneath tank BY-105 from the north and the southwest. Both of these plumes appear to have originated from leakage from tanks other than tank BY-105. The Tank Farms gross gamma-ray log history for borehole 22-05-09 is shown on Figures 15-30 and 15-31. These logs indicate that the highest gamma-ray intensity peak, at a depth of 69 ft in 1975, migrated over time, spread vertically slightly, then eventually decayed in place so that by 1985 no elevated gamma-ray anomalies are observed in the gross gamma-ray logs. Evaluation of the gross gamma-ray log data relative to the decay rates of individual peaks indicates that radionuclides with half-lives shorter than ^{60}Co (5.27 years) are not present. The plume, which has been shown through the spectral gamma-ray data to be ^{60}Co contamination, was active from 1975 to 1985. It has been stable since 1985. It appears, therefore, that the source has stabilized.

The source of the ^{60}Co contamination may be from leakage from tank BY-105, or from adjacent tanks BY-106 or BY-107; all these tanks are designated leakers. The data are inconclusive to determine a positive source of the vadose zone contamination beneath tank BY-105.

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

10.2.6 Tank BY-106

Tank BY-106 is designated an assumed leaker. This tank currently contains 547,000 gal of salt cake, 95,000 gal of sludge, and 200,000 gal of drainable liquid (Hanlon 1996). The waste level is about 20 ft from the bottom of the tank.

The first waste received in tank BY-106 in 1953 was first-cycle waste. Beginning in 1954, this tank received U Plant waste intermittently until 1967, when the tank served as a settling tank for ferrocyanide-scavenged waste. Supernatant from this process was discharged to cribs and trenches. Coating waste was transferred to tank BY-106 from the early 1960s to 1970. During the late 1960s, wastes in tank BY-106 were processed during the ITS campaign(s), and the tank received evaporator bottoms and feed wastes. Operations in tank BY-106 were restricted in 1977.

The integrity of tank BY-106 became questionable in 1977 when tar rings were observed on the walls in the interior of the tank at a depth of about 26 ft, 22.5 ft above the tank bottom (Deichman 1977b). It was speculated that tar on the outside covering of the tank may have seeped through pitting caused by corrosion of the steel tank liner. Elevated radiation count rates were measured in four of the five boreholes surrounding tank BY-106. A leak-volume estimation of 8,000 gal was based on the assumption that tank BY-106 leaked the same amount as the average of the several other tanks in eight different tank farms (Baumhardt 1989).

A large ^{137}Cs contamination plume is shown on Figures 15-26, 15-27, and 15-29 in the northwest quadrant of tank BY-106. These figures are views from below the tank from the southwest, from the northeast, and from the north-northwest, respectively; these visualizations were created with two north-south trending cut faces on the east and west sides of the BY-104-to-BY-106 row of tanks. This plume is primarily defined by two boreholes, 22-06-01 and 22-06-11. The ^{137}Cs concentration plot profiles suggest that the ^{137}Cs contamination may have migrated down the inside or the outside of the borehole casings or may have been in the surface sediments before borehole drilling and been carried down as the borehole was drilled.

A ^{137}Cs contamination plume on the southern side of tank BY-106 is defined primarily by log data from borehole 22-06-07. This borehole was perforated at depths from 40 to 100 ft, and ^{137}Cs contamination was detected throughout this interval, indicating that contamination outside the casing may have migrated inside the casing through the perforations. This is a false contamination plume.

Leakage of waste from tank BY-106 is clearly indicated by the ^{60}Co contamination plume originating on the southeast side of the tank next to borehole 22-06-05. This plume is extensive beneath tank BY-106, and as shown on the visualizations, the plume spreads to the east and west.

The greatest extent of distribution and the highest concentration of ^{60}Co contamination were detected in borehole 22-06-05; this borehole is probably closest to the leak source. The Tank Farms gross gamma-ray logs for borehole 22-06-05 show the ^{60}Co contamination increasing in intensity from 1975 to 1978, then spreading out along the borehole as the peaks decayed at a rate consistent with the 5.27-year half-life of ^{60}Co. Since about 1980, the ^{60}Co contamination has been stable and has decayed in place. The Tank Farms gross gamma-ray logs show that the ^{60}Co contamination plume was extensive all around tank BY-106, but much of it has since decayed.

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

10.2.7 Tank BY-107

Tank BY-107 is designated an assumed leaker. This tank currently contains 206,000 gal of salt cake, 60,000 gal of sludge, and 25,000 gal of interstitial liquid (Hanlon 1996). The level of the solids is about 8 ft above the dished tank bottom; the liquid level is slightly more than 5 ft above the dished tank bottom.

Tank BY-107 was identified as a leaker in 1974 when a significant liquid-level decrease was measured in the tank. Subsequent evaluation of the liquid loss estimated a leak volume of more than 15,000 gal. Concurrent with the decreased liquid level, an increase in the radiation intensity at a depth of 29 ft was measured in borehole 22-07-02 with the Tank Farms gross gamma-ray logging system. The liquid waste volume was immediately reduced, liquid-level readings stabilized, and the tank was considered stable at the reduced volume. Although borehole radiation intensities appeared to stabilize, intensities again increased. The increases were attributed to migration of old contamination that was present in the sediments. Details of the environmental conditions causing the apparent redistribution of the contamination are described in the Tank Summary Data Report for tank BY-107 (DOE 1996n). The volume of the leak was estimated at more than 15,000 gal; the method used to estimate the leak volume is unknown.

Occurrence Reports in 1974 (Walser 1974) and 1977 (Deichman 1977a) documented the presence of tar rings on the interior walls of tank BY-107; however, neither report stated the depth or height location(s) of the tar rings.

Tank BY-107 received first-cycle waste from 1950 to 1955. During that time period, waste was cascaded to BY-108 and also transferred to other tanks. The tank received first-cycle and U Plant waste from 1953 to 1956; it then became a receiver for ferrocyanide-scavenged waste. From 1956 until 1968, the tank received U Plant and coating wastes; from 1969 to the end of its service life, the tank wastes consisted of evaporator bottoms waste from the ITS campaign(s).

Figures 15-32, 15-33, and 15-34 show the contamination distribution below tank BY-107. The figures are views from below the tank from the southwest, from the southeast, and from the northwest, respectively; these visualizations were prepared with two north-south trending cut faces on either side of the BY-107-to-BY-109 row of tanks. Figures 15-33 and 15-34 show a ^{137}Cs contamination plume on the north and west sides of tank BY-107; this plume is primarily defined by log data from boreholes 22-07-01, 22-07-09, and 22-07-10. Log data for boreholes 22-07-09 and 22-07-10 show continuous ^{137}Cs contamination at concentrations of 100 pCi/g from the ground surface to as deep as 45 ft. ^{137}Cs contamination was detected in boreholes 22-07-01 and 22-07-09 continuously from the ground surface to the bottoms of both of these boreholes. This ^{137}Cs plume is most likely related to an unplanned release (UPR-200-E-105) that leaked approximately 23,000 gal of liquid waste from a manifold header at tank BY-107. The location of the header is not known; however, the ^{137}Cs concentration plots of several boreholes surrounding tank BY-107 show peaks of increasing ^{137}Cs concentrations at a depth of about 20 ft, suggesting that the contamination distribution may have resulted from runoff from the domed tank top.

The tabular plume of ^{137}Cs contamination that is most distinct at the base of the visualization under the southwest portion of tank BY-107 is based on data acquired at the bottom of the boreholes. Increasing ^{137}Cs contamination that was detected at the bottoms of several boreholes surrounding tank BY-107 probably resulted from contamination that entered the inside of the boreholes casings and settled at the bottoms. This is a false plume that was defined strictly on borehole conditions.

An extensive plume of ^{60}Co contamination underlies tank BY-107 and is most likely related to leakage from the tank. The most continuous distribution of this contamination begins slightly below the tank base; however, some occurrences of ^{60}Co were detected above the tank base. In borehole 22-07-02, ^{60}Co contamination is present near the ground surface. This contamination is not observable on the figures because it is blanketed by the ^{137}Cs contamination plume. The cause of the complicated nature of the ^{60}Co contamination distribution is discussed in the Tank Summary Data Report for tank BY-107; increased moisture in the sediments resulting from operational activities may have caused redistribution of pre-existing contamination.

Historical Tank Farms gross gamma-ray logs from the boreholes surrounding this tank show elevated activities at almost all the locations where low concentrations of ^{60}Co contamination were currently detected. Some of the ^{60}Co contamination migrated downward in the early 1970s; since then, this contamination has remained stable and decayed in place. The maximum depth extent of the ^{60}Co contamination plume is not known because ^{60}Co contamination was detected at the bottoms of all the boreholes in which it was detected.

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

10.2.8 Tank BY-108

Tank BY-108 is designated an assumed leaker. This tank currently contains 74,000 gal of salt cake, 154,000 gal of sludge, and 9,000 gal of interstitial liquid (Hanlon 1996). The current waste level is about 7.5 ft above the bottom of the tank, or about 40 ft below the ground surface. Tank BY-108 was declared an assumed leaker in 1972 with an estimated leak volume of less than 5,000 gal. The justification for the designation of the tank's integrity and the method used to calculate the leak volume are not known.

Tank BY-108 received first-cycle waste by cascade from tank BY-107 from 1951 through 1953. It received U Plant waste from 1953 through 1959 and became a scavenged-waste receiver in 1954, during which time wastes were discharged to cribs and trenches. From 1959 through 1968, the tank received U Plant and coating wastes. From 1968 to 1972, the end of its service life, the tank received evaporator bottoms waste from the ITS campaign(s).

Figures 15-33, 15-34, and 15-35 show extensive ^{137}Cs contamination surrounding tank BY-108. These figures are views from below the tank from the southeast, from the northwest, and from the northeast, respectively; they were created with two north-south trending cuts on either side of the BY-107-to-BY-109 row of tanks. The highest ^{137}Cs concentrations were detected on the north-northeast side of the tank in boreholes 22-08-01 and 22-08-02, where ^{137}Cs concentrations near the ground surface saturated the detector. These high concentrations may be related to the proximity of the boreholes to piping, and the ^{137}Cs contamination detected may be within the pipeline. The nonextensive distribution of contamination below the high count-rate zones indicates that the contamination may be fixed (i.e., within a pipe). ^{137}Cs contamination distribution profiles in most of the other boreholes surrounding tank BY-108 suggest that the ^{137}Cs plume is defined by occurrences of ^{137}Cs contamination that migrated down the casing or was driven down during drilling.

The ^{137}Cs plume development on the southwest side of the tank is deeper than elsewhere around the tank. This deeper extension of the ^{137}Cs contamination plume is defined from data collected in boreholes 22-08-07 and 22-08-09. Borehole 22-08-07 was perforated at depths from 40 to 100 ft, and ^{137}Cs contamination occurs throughout the perforated interval, indicating contaminated sediments most likely entered the casing through the perforations. Borehole 22-08-09 has a distribution profile that suggests ^{137}Cs contamination migrated down the inside or the outside of the casing.

Increased ^{137}Cs contamination concentrations were detected at the bottoms of most of the boreholes; therefore, a continuous but false ^{137}Cs contamination plume was defined by the modeling program.

An extensive plume of ^{60}Co contamination is present around and beneath tank BY-108. The ^{60}Co contamination occurs within depths corresponding to historical tank waste levels and, therefore, is most likely the result of tank leakage. In addition, several intermittent occurrences of low ^{60}Co contamination that resulted from surface spills or leaks were detected near the ground surface. These occurrences are not shown on the figures because they are masked by the ^{137}Cs contamination. The depth extent of the ^{60}Co contamination plume is undefined because concentrations of ^{60}Co were detected at the bottoms of several boreholes, although at low concentrations.

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

10.2.9 Tank BY-109

Tank BY-109 is designated a sound tank. It currently contains 340,000 gal of salt cake, 83,000 gal of sludge, and 28,000 gal of interstitial liquids (Hanlon 1996); the liquid level is monitored with a moisture probe through an LOW. The current waste level is about 14 ft above the bottom of the tank, or about 34 ft below the ground surface. The solid waste surface is measured with a manual FIC gauge.

Figures 15-32, 15-34, and 15-35 are views from below the tank from the southwest, from the northwest, and from the northeast, respectively; they were created with two north-south trending cut faces on either side of the BY-107-to-BY-109 row of tanks. These figures show a ^{137}Cs contamination plume that extends to depths below the depth of the BY-109 tank base along the sides of the northern half of the tank. However, the ^{137}Cs contamination does not extend beneath the tank. Several boreholes along the northern side of the tank have continuous distributions of ^{137}Cs contamination that define this plume. Logs from borehole 22-09-02, which is located in the northeast quadrant of tank BY-109, showed the most continuous distribution of ^{137}Cs contamination with concentrations less than 100 pCi/g. The concentration profiles for these boreholes and the visualizations suggest that the source of the contamination plume is downward migration of surface contamination.

The contamination on the northwest side of the tank may be related to an unplanned release (UN-200-E-110) at the pump pit of tank BY-112, which is adjacent to tank BY-109 to the west. The volume of the release was not estimated; however, an estimated volume of 2,500 cubic ft of soil was contaminated. A narrow interval of increased ^{137}Cs concentration (1,000 pCi/g) was detected in borehole 22-09-08 at a depth of 23 ft. This borehole is located near borehole 22-12-03, in which a corresponding but thicker zone of ^{137}Cs contamination was detected at a depth of about 23 ft. In addition, contamination consisting of ^{137}Cs, ^{60}Co, and ^{154}Eu occurred in borehole 22-12-03 at a depth of 5 ft above and below a zone of contamination that saturated the detector. All this contamination is probably related to the waste released in the pump pit above tank BY-112.

Elevated concentrations of ^{137}Cs contamination, most likely resulting from downward migration on the inside or the outside of the casing, were detected in most of the boreholes surrounding tank BY-109. Small isolated plumes of ^{137}Cs contamination were defined by these data; these are false plumes.

Intermittent ^{60}Co contamination plumes occur below tank BY-109 and are most likely related to the unplanned release at tank BY-112. Logs of the boreholes on the west side of tank BY-109 were used to define these ^{60}Co plumes.

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

10.2.10 Tank BY-110

Tank BY-110 is designated sound. It currently contains 295,000 gal of salt cake, 103,000 gal of sludge, and 9,000 gal of interstitial liquid (Hanlon 1996). The liquid level in the tank is monitored with a moisture probe through an LOW.

Figures 15-36, 15-37, and 15-28 are views of the contamination in the vadose zone around tank BY-110. The first two figures are views from below the tank from the southeast and from the southwest, respectively; they were created with one north-south trending cut on the eastern side of the BY-110-to-BY-112 row of tanks. The third figure is a view from the south; the cut face is actually the southern boundary of the BY Tank Farm data domain.

The major ^{137}Cs contamination plume is located on the east side of the tank and is best shown on Figure 15-36. This plume is primarily defined by the data acquired in boreholes around the west side of tank BY-107 because there is only one borehole on the east side of tank BY-110. Data from this borehole, 22-10-05, exhibit a contamination distribution profile typical of downward migration of surface contamination.

The tabular ^{137}Cs contamination plume at the base of the visualization is based on data acquired at the bottoms of several boreholes. Increased ^{137}Cs contamination concentrations were detected as a result of downward migration of contamination that settled at the bottom of the boreholes. These data define a false plume of contamination.

Two plumes of ^{60}Co contamination are shown on the visualizations. The shallow thin plume on the south side of the tank BY-110 may have originated from leakage from the tank, or from leakage from the cascade line connecting tank BX-112 in the BX Tank Farm to tank BY-110. Although tar rings are present on the interior walls of the tank at a depth of about 26 ft, 22 ft above the tank bottom (Jensen 1975), and liquid-level decreases were measured during its service life, no elevated gamma-ray activities were detected in the monitoring boreholes with the Tank Farms logging system. There is no positive determination that tank BY-110 has leaked, although the ^{60}Co contamination appears to have originated from a subsurface source.

The deeper ^{60}Co contamination plume appears to be a westward extension of the contamination plume originating from leakage from tank BY-107. The bottom of this plume is not defined because one of the boreholes defining this plume, borehole 22-07-09, did not completely penetrate the contamination.

The details regarding data used to develop the model in the area of tank BY-110 are presented in the Tank Summary Data Report for tank BY-110 (DOE 1996q).

10.2.11 Tank BY-111

Tank BY-111 is designated sound. It currently contains 438,000 gal of salt cake, 21,000 gal of sludge, and no interstitial liquid (Hanlon 1996); the liquid level is monitored with a moisture probe through an LOW. The present waste level is about 15 ft from the bottom of the tank, or about 33 ft below the ground surface.

Figures 15-37, 15-38, and 15-39 present the ^{137}Cs contamination plume surrounding tank BY-111. The figures are views from below the tank from the southwest, from the northeast, and from the northwest, respectively; they were created with a north-south trending cut face on the eastern side of the BY-110-to-BY-112 row of tanks.

The ^{137}Cs contamination plume is defined from concentration data related to surface or near-surface ^{137}Cs contamination. Some of the contamination migrated down the inside or the outside of the casing, and some may have been driven downward during borehole drilling. A thin interval of contamination at a depth of about 5 ft is correlatable among several of the boreholes surrounding tank BY-111 and borehole 22-08-09, which is adjacent to tank BY-108. This contamination zone contains ^{60}Co and ^{154}Eu in borehole 22-11-05, and only ^{60}Co in borehole 22-11-09. This contamination may related to an undocumented surface spill or piping leak.

An interval of low-level ^{60}Co contamination was detected in borehole 22-11-09 at depths from 25 to 55 ft. Within this ^{60}Co contamination depth interval, tar rings are present on the interior walls of the tank at a depth of about 27 ft, 21 ft above the tank bottom (Garbrick 1977). Tar rings can be an indication of intrusion into the tank's interior of tar coating material that was applied on the outside of the tank liner during construction; the intrusion occurred through corrosion of the tank liner. Leakage of waste from the tank could occur through the corroded liner if the level of the waste in the tank exceeded the level of the tar rings.

Occurrence reports in 1975 and 1978 document liquid-level decreases in tank BY-111, and Tank Farms gross gamma-ray logs acquired in borehole 22-11-09 during this time frame show increases in gamma-ray activities. It appears that this tank has leaked, resulting in the plume shown on Figures 15-37 and 15-39, and the designation of this tank should be changed to a leaker.

The details regarding the data used to develop the model in the area of tank BY-111 are presented in the Tank Summary Data Report for tank BY-111 (DOE 1996r).

10.2.12 Tank BY-112

Tank BY-112 is designated sound. The tank waste currently consists of 286,000 gal of salt cake, 5,000 gal of sludge, and 8,000 gal of drainable interstitial liquids (Hanlon 1996); the liquid level is monitored with a moisture probe through an LOW. The waste surface is about 10 ft above the bottom of the tank, or 39 ft below the ground surface.

The ^{137}Cs contamination plume around tank BY-112 is shown on Figures 15-37, 15-38, and 15-39. The views are from below the tank from the southwest, from the northeast, and from the northwest, respectively; they were created with a north-south trending cut face on the eastern side of the BY-110-to-BY-112 row of tanks.

The ^{137}Cs contamination plume surrounding tank BY-112 is from surface contamination that migrated downward. The ^{137}Cs concentrations are greatest near borehole 22-12-03, which is most likely near the source(s) of two unplanned releases associated with tank BY-112. These releases, UN-200-E-110 and UPR-200-E-116, occurred at the pump pit of the tank; however, details regarding the volumes of waste discharged and affected surface volumes were not documented.

The small plume of ^{60}Co contamination shown on Figure 15-39 near the ground surface on the eastern side of the tank BY-112 is related to the previously described unplanned releases.

The details regarding the data used to develop the model in the area of tank BY-112 are presented in the Tank Summary Data Report for tank BY-112 (DOE 1996s).

10.3 Major Subsurface Contamination Zones

10.3.1 ^{137}Cs Contamination

The major subsurface ^{137}Cs contamination plumes that occur at the bases of the tanks in the BY Tank Farm are shown on Figure 15-40. Several of the plumes are associated with known leaking tanks and these plumes were discussed in the previous sections of this report; however, ^{137}Cs contamination plumes identified around tanks BY-101, BY-104, BY-110, and BY-111 are exceptions.

A plume of ^{137}Cs contamination is shown on Figure 15-40 between tanks BY-101 and BY-104, but this plume is actually present from the ground surface to depths well below the tank bases. The extent of this plume is presented in Figures 15-21, 15-27, and 15-28. ^{137}Cs contamination detected in two boreholes on the south side of tank BY-101 at a depth of about 25 ft may be related to leakage from the cascade pipeline between tanks BX-103 (BX Tank Farm) and BY-101.

Logs of boreholes 22-01-10 and 22-04-01 define the ^{137}Cs contamination plume on the northwest side of tank BY-101. These two boreholes have ^{137}Cs contamination throughout their entire length. Contamination that is transported down the outside of the borehole casing usually has a pattern of decreasing contamination concentration with depth. This pattern is disrupted in these two boreholes by increases in contamination at a depth of about 25 ft. The increase is slight in borehole 22-04-01, but it is a distinct ^{137}Cs contamination peak almost 15 ft thick in borehole 22-01-10. This occurrence of ^{137}Cs contamination may have resulted from leakage from piping, because piping crosses the BY Tank Farm at all directions, or it may have resulted from runoff from the tank's domed top of ^{137}Cs contamination from a surface spill. Data acquired with SGLS logging are inconclusive to determine if either tank BY-101 or tank BY-104 leaked.

The ^{137}Cs contamination plume on the northeast side of tank BY-110 (see Figures 15-37 and 15-38), which is designated a nonleaking tank, is defined by log data from boreholes 22-07-09 and 22-07-10, which are associated with tank BY-107. There are no boreholes on the east and northeast side of tank BY-110 to define ^{137}Cs contamination plume development adjacent to and beneath this tank, or to confirm that tank BY-110 leaked. However, occurrences of ^{60}Co at the depth of the tank base raise question as to the integrity of this tank; a discussion of these ^{60}Co concentrations is presented in Section 10.3.2, "^{60}Co Contamination."

The ^{137}Cs contamination plume on the northeast and east sides of tank BY-111, which is depicted on Figures 15-37 and 15-38, most likely resulted from a combination of a surface spill or a leak that contaminated sediments that were carried downward later during borehole drilling. Elevated

^{137}Cs concentrations were measured from the ground surface to a depth of 5 ft in all the boreholes surrounding tank BY-111, suggesting a surface spill or leakage from a pipeline buried near the ground surface.

^{137}Cs contamination was detected at the bottoms of almost all the boreholes in concentrations over the isolevel of 0.5 pCi/g. These occurrences defined tabular ^{137}Cs contamination plumes at the base of the visualizations in several areas of the BY Tank Farm. The occurrence of these plumes resulted from low-level contamination that migrated down the inside or the 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. Discussions with tank farm operations personnel disclosed that monitoring boreholes often filled with water and had to be pumped before conducting routine gross gamma-ray surveillance logging.

10.3.2 ^{60}Co Contamination

^{60}Co has a relatively short half-life of 5.27 years. Because a majority of the tank farm operations in the BY Tank Farm were conducted from the early 1950s to the late 1970s, a most conservative estimate of 4 half-lives have expired since operations ceased in the tank farm. Less than 10 percent of the ^{60}Co contamination that leaked into the vadose zone around the BY Tank Farm remains in the vadose zone sediments.

^{60}Co contamination was detected in a large number of the BY Tank Farm monitoring boreholes. Many of these ^{60}Co contamination occurrences were low concentrations. When a low-isolevel cutoff of 0.1 pCi/g was used to process data, the ^{60}Co plume distributions were confusing and not well defined in the visualizations. Therefore, an isolevel concentration of 0.2 pCi/g was used to present the ^{60}Co plume distribution. Low levels of contamination that were questionable and possibly related to tank leakage but eliminated from the visualizations were discussed previously in Section 10.2 "Tank-by-Tank Discussion."

^{60}Co contamination was detected below every BY Tank Farm tank that was designated as a leaker. Concentrations of ^{60}Co contamination were generally less than 10 pCi/g; however, both the depth extent and areal distribution of the ^{60}Co contamination were extensive. The widespread distribution of the ^{60}Co contamination was most likely related to its enhanced mobility, which was due to the chemical composition of the ^{60}Co component of the waste and the types of sediments through which the waste migrated. The majority of the ^{60}Co contamination was detected in the fine-grained sediments of the Hanford formation.

In cases where the spectral gamma-ray log data showed zones of low concentrations of ^{60}Co in the vadose zone sediments, the intensities of anomalies in the older Tank Farms gross gamma-ray logs were observed to decrease over time at a rate consistent with the decay rate for ^{60}Co for those zones.

Tank BY-110 is designated sound. However, ^{60}Co contamination was detected in the upper portion of the Hanford fine sequence in boreholes 22-10-05 and 22-10-07, while in boreholes 22-07-09 and 22-10-10, ^{60}Co contamination was detected lower in the Hanford fine sequence.

These plumes are shown on Figures 15-36 and 15-37. There is no ^{60}Co contamination above this deeper zone with the exception of an isolated occurrence in borehole 22-07-09 at a depth of 40 ft. This ^{60}Co contamination did not migrate down from the ground surface but most likely resulted from a subsurface source. This source may be from leakage from tank BY-110 or from the cascade pipeline connecting tank BX-112 (BX Tank Farm) with tank BY-110; however, the data are not conclusive for positive determination.

As discussed in Section 10.2.11, the integrity of tank BY-111 is questionable. ^{60}Co contamination was detected in borehole 22-11-09 at depths that correlated with tar rings on the interior tank wall of the tank. These small isolated plumes of ^{60}Co contamination are shown on Figures 15-37 and 15-39. Tank waste stored above the level of the tar rings may have leaked from the tank through corrosion at the tar rings. Documented liquid-level decreases coincided with elevated gross gamma-ray activities measured in borehole 22-11-09. The intensities of the peaks in the gross gamma-ray logs for this borehole decrease at a rate consistent with the decay rate of ^{60}Co.

The depth extent of the ^{60}Co contamination is not defined because it was detected at the bottoms of several boreholes. The deepest occurrence of ^{60}Co contamination was detected in borehole 22-00-03 at a depth of 145 ft, which was the total depth of the borehole. It appears that the ^{60}Co contamination moves readily through the fine-grained sediments and would be found deeper in the vadose zone sediments than ^{137}Cs.

10.4 Geologic Correlations

Gamma-ray logs of naturally occurring ^{40}K, ^{238}U, and ^{232}Th radionuclide concentrations were generated to determine correlatable lithologic features in the upper vadose zone at the BY Tank Farm. These logs are provided in the Tank Summary Data Report for each tank.

When logging with 100-s stationary measurements, ^{238}U and ^{232}Th logs had relatively high uncertainty and showed essentially no correlation. The reason for this lack of correlation is because variations in lithology within the Hanford formation are mostly grain-size variations with little compositional variation, and minimal concentration changes were measured for the ^{238}U and ^{232}Th radionuclides.

However, the profiles of the ^{40}K concentration plots indicate good correlation among boreholes of the contact between the Hanford upper gravel and Hanford fine sequences. This contact ranges from a depth of about 48 ft in the eastern portion of the BY Tank Farm to as deep as 60 ft in the western portion of the tank farm. The contact is distinct in some boreholes, while in others it is gradational. Figures 15-41 and 15-42 present visualizations of the geostatistical processing of ^{40}K concentrations greater than 18 pCi/g; this ^{40}K concentration cutoff was determined from the ^{40}K concentration plots for the boreholes. These visualizations show a geostatistical correlation of the data in regions where the measured ^{40}K concentration is above the calculated average.

In the eastern portion of the BY Tank Farm, the contact between the Hanford upper gravel and Hanford fine sequence almost coincides with the bottom of the tank farm excavation at a depth of about 48 ft. In the western portion of the BY Tank Farm, this contact is about 12 ft below the excavation bottom. The details regarding the determinations of these contacts are provided in data that were acquired during the drilling of several groundwater monitoring wells around the BY Tank Farm. These data are provided in Appendix A, "Geology and Hydrology Data From Groundwater Monitoring Boreholes" with the geophysical borehole logging data acquired in these boreholes.

The bottom of the Hanford fine sequence is well below the bottoms of the BY Tank Farm monitoring boreholes that define the vertical extent of the ^{40}K data on Figures 15-41 and 15-42. In the vicinity of the BY Tank Farm, the bottom of the Hanford fine sequence occurs at a depth of about 240 ft, where the Hanford lower coarse sequence is encountered.

In several regions of the BY Tank Farm, the presence of ^{60}Co contamination within the Hanford fine sequence but not above it indicates that the Hanford fine sequence promotes horizontal migration of fluids. The reader is advised to review the combination plot profiles for the boreholes surrounding tanks BY-103, BY-105, BY-107, and BY-108 that are provided in the Tank Summary Data Reports for these tanks. In some of the boreholes, the ^{60}Co contamination occurs at the contact between the Hanford upper coarse and Hanford fine sequences; but in several boreholes, the highest and most continuous ^{60}Co contamination occurs deeper in the Hanford fine sequence at the bottoms of the boreholes. For several of the boreholes, the vertical extent of the ^{60}Co contamination is unknown because the boreholes did not completely penetrate the contamination plumes.

10.5 Potential Effect of Adjacent Cribs

The distribution of ^{137}Cs and ^{60}Co contamination shown on Figure 15-40 indicates that the contamination has remained relatively close to the leak sources. It has been postulated that the Hanford fine-sequence sediments may promote lateral migration, but as is shown on Figure 15-40 this movement appears to be minimal, even for ^{60}Co contamination that may have enhanced mobility because of its chemical composition. The more continuous nature of both the ^{137}Cs and ^{60}Co contamination in the southern portion of the BY Tank Farm may be related to the cascade line connections between the BX and BY Tank Farms that may have leaked.

The potential effects that surrounding waste disposal sites may have had on the vadose zone contamination in the BY Tank Farm is unknown because the lateral extent of the contamination beneath the tank farm is unknown. Contaminant movement may be assessed by observing the extent of contamination detected in boreholes outside specific disposal facilities. Borehole 299-E33-38, located south of the 216-BY Cribs, and borehole 299-E33-40, northwest of the 216-BY Cribs, were drilled in telescoping casing configurations that minimize contaminant carry down during drilling. Log data collected with the WHC RLS indicated the presence of ^{60}Co contamination at depths from 51 to 196 ft in borehole 299-E33-38, and at depths from 94 to 185 ft in borehole 299-E33-40. This contamination originated from waste discharged to the 216-BY Cribs and shows lateral movement of the ^{60}Co contamination from the cribs into the area of these boreholes. The lateral migration of this ^{60}Co contamination was promoted through discharge of significantly large volumes of waste to the vadose zone sediments, much more than was estimated to be lost to the vadose zone through waste tank leaks. This contamination may have moved into the area beneath the BY Tank Farm as the groundwater mound from the discharge of liquid waste was developing under the 216-BY Cribs. Contamination from these cribs would be intersected much deeper in boreholes in the BY Tank Farm because ground surface at the BY Tank Farm is about 40 ft higher than ground surface at the cribs. The 100-ft depth extent of many of the monitoring boreholes in the BY Tank Farm prevents detection of vadose contamination that may have originated from the 216-BY Cribs and migrated into the vadose zone beneath the BY Tank Farm.

Cribs adjacent to the BY Tank Farm received large volumes of liquid wastes as early as 1946 (216-B-7A and 216-B-7B) and as late as 1974 (216-B-50). Wastes discharged to the soil column at these facilities contained the same constituents as the wastes stored in the tanks in the BY Tank Farm; however, improvements in chemical processing reduced the radiological activity of the wastes discharged to the ground at the cribs compared to the intensity of the waste contained in the tanks. Both ^{137}Cs and ^{60}Co, the most abundant contaminants in the vadose zone at the BY Tank Farm, were detected in groundwater samples collected east of the BY Tank Farm in a monitoring borehole for the 216-B-11A and 216-B-11B Cribs (borehole 299-E33-20); south of the BY Tank Farm in a monitoring borehole for the 216-B-35 through 216-B-41 Trenches (borehole 299-E33-21); and north and northwest of the BY Tank Farm in several monitoring boreholes for the 216-B-43 through 216-B-50 Cribs (299-E33-03 and 299-E33-05) and 216-B-57 Cribs (299-E33-24). The adjacent facilities have had a significant effect on the quality of the groundwater beneath the BY Tank Farm, but this contamination most likely is indistinguishable from any contamination contribution from the BY Tank Farm.

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 BY Tank Farm are ^{137}Cs and ^{60}Co. Only minor quantities of ^{125}Sb and ^{154}Eu were detected, mostly near the ground surface in isolated occurrences that could not be correlated among boreholes. A thick zone of ^{125}Sb detected near tank BY-103 appears to be associated with leakage from that tank. Other gamma-emitting radionuclides may have been present at the time the tanks leaked, but they have decayed to such low levels they can no longer be detected with current logging methods. Because these nuclides were not detected, they probably are not present in quantities above any significant health and safety risk levels.

Radionuclides are undoubtedly present in the vadose zone beneath the BY 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 to find ^{99}Tc, ^{90}Sr, isotopes of plutonium and uranium, ^{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.

11.2 Extent of Migration

Historical Tank Farms gross gamma-ray log data that were reviewed during preparation of the Tank Summary Data Reports for the BY 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 activities were related to ^{60}Co contamination; decreases in activity were related to the decay of the ^{60}Co radionuclide because of its short half-life, while depth changes reflect the mobility of ^{60}Co in the vadose zone.

The occurrences of the ^{60}Co contamination are extensive, but the concentrations are low. Most of the ^{60}Co concentrations were about 1 pCi/g; however, zones to 10 pCi/g were detected. Because of the low concentrations, subtle changes would not be detected with the gross gamma-ray logging system. Until a second logging of the ^{60}Co contamination zones is performed and the results compared with the initial characterization log data, the present stability of the ^{60}Co contamination cannot be determined.

The historical Tank Farms gross gamma log data collected in intervals of ^{137}Cs contamination indicate minor changes in intensity from first detection, which for most of the boreholes was 1974, to the most recently acquired data. Where decreases have been associated with ^{137}Cs contamination zones, it is suspected that ^{60}Co contamination is associated with the ^{137}Cs contamination. Although ^{137}Cs is not suspected to be very mobile in the subsurface, it has migrated deep in the vadose zone beneath several adjacent facilities. Further evaluation of the mobility of this radionuclide can be assessed through detailed monitoring with the sensitive HPGe detectors.

11.3 Stability of Contamination

The only data available at this time to quantify or to determine the long-term stability of the contamination in the vadose zone beneath the BY Tank Farm are from the Tank Farms gross gamma-ray logging. Review of older gross gamma-ray logs indicates that contaminant movement has occurred in the past in some boreholes, but it has remained stable since about the mid-1980s. This activity was related to movement of the ^{60}Co contamination through the vadose zone. Because of the low sensitivity and the poor spatial control of those logging systems, 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 contaminant migration has occurred. Until that evidence is produced, the possibility of contamination migrating in the formation 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 and ^{60}Co contamination distributions in the vadose zone at the BY Tank Farm has not established that leakage of waste from the BY tanks 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 presence of ^{137}Cs and ^{60}Co in the groundwater beneath the BY Tank Farm has been identified in samples from several groundwater monitoring boreholes at adjacent facilities. Several of these facilities were used to discharge significant volumes of liquid waste to the soil column that contained the same radionuclide constituents as the wastes in tanks at the BY Tank Farm so the groundwater contamination cannot be positively traced to BY Tank Farm tank leaks.

12.0 Use of Data/Interfaces

12.1 Operations

The vadose zone characterization of the BY Tank Farm was completed to support the operation of the SSTs; that is the primary use of the data. A baseline is now established that defines the contamination in the vadose zone; this baseline will be used for comparison to future monitoring data to determine if changes have occurred and to assess the potential causes of the changes.

Most SSTs containing any appreciable amount of liquid 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.

If a leak occurs, however, it is useful to confirm the leak with other monitoring methods, such as detection of 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.

DOE is also required by RCRA to determine the nature and extent of contamination resulting from leaks from the tanks. These determinations have been accomplished for the past leaks, to the degree possible under the constraint that the logged boreholes were drilled in locations suitable for tank leak monitoring, not for determination of the extent of contamination by leaks. Also, a significant portion of the vadose zone has not been characterized because of the depth limitation of the monitoring boreholes. Now that a baseline is established, the nature and extent of contamination from new leaks can be determined, within restrictions imposed by borehole locations.

Operation of the SSTs also requires knowledge of the condition of the subsurface to determine if and where an excavation can take place and to determine the potential for personnel exposure. The vadose zone contamination distribution model provides some of this basic information.

Color visualizations of ^{137}Cs and ^{60}Co contamination models are published in this report, illustrating the contamination around the tanks (see Section 15.0, "Figures for the BY Tank Farm"). In addition, the ^{137}Cs and ^{60}Co contamination models are available with the visualization software so that a visualization of any area of the BY 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.

12.2 Tank Remediation and Waste Retrieval

The final disposition of the tank waste and remediation of the SST facilities is governed by RCRA. As required by RCRA, an SST closure plan will be prepared. Preparation of the closure plan or plans for SSTs will be based on closure decisions to be reached through the NEPA process. Closure alternatives that will be evaluated through the NEPA process include two alternatives that would likely involve soil remediation (clean closure and modified closure) and one alternative that would not involve soil remediation (landfill closure).

This baseline characterization of the 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 may also be required to satisfy the data needs of the SST closure process.

Unknown quantities of contamination are expected to leak from the tanks during waste retrieval operations, depending on the waste retrieval method used. Previous studies of the impacts of any waste retrieval operations have assumed that no tank leaks have impacted the groundwater. On the basis of the groundwater monitoring data and the apparent extent of migration of ^{137}Cs and ^{60}Co contamination, this assumption will need to be re-evaluated. The current baseline of the vadose zone ^{137}Cs and ^{60}Co contamination distributions will provide a basis to determine those impacts.

The presence of tar rings within several tanks in the BY Tank Farm will most likely impact future tank farm waste retrieval operations in these tanks because tar rings imply deterioration and/or failure of the tank steel liners. Once tar rings were identified, waste levels were maintained below the tar rings. Tar rings were found on the interior walls of tanks BY-106 and -107, which are known leakers, and tanks BY-102, -109, -110, and -111, which are designated as sound.

12.3 Groundwater Protection and Remediation

Vadose zone contamination is the most significant source of contamination reaching the groundwater at Hanford. 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 BY 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 BY Tank Farm will provide some of the basic data used to build strategies to protect and to 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 and 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. If necessary, the vadose zone characterization data presented in this report can be used to revise that 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 mediums, including surface water, groundwater, and surface and subsurface sediments. For economic reasons, environmental monitoring programs justifiably place more emphasis on monitoring environmental mediums that compose 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 for the BY Tank Farm is the first such characterization report for the BY Tank Farm. It is necessary, therefore, 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 mediums 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). Currently, the Hanford Site environmental monitoring plan does not include references to or requirements for vadose zone monitoring. The next revision of that plan may include vadose zone monitoring.

13.0 Conclusions

Sixty-nine vadose zone boreholes in the BY 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. These Tank Summary Data Reports provide a history of each tank and put the SGLS log data into an appropriate format so they can be used for future tank farm operations and remediation.

Empirical ^{137}Cs and ^{60}Co 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. These tools made it possible to identify ^{137}Cs and ^{60}Co contamination zones, segregate the false plumes from actual vadose zone contamination, identify contamination sources, and relate the contamination to historical events for the various tanks. The information on the contamination distribution beneath the BY Tank Farm can now be used by operations, various monitoring programs, and personnel responsible for tank closure.

The depth extent of the ^{60}Co contamination was not defined. ^{60}Co contamination was detected at the bottom of many boreholes that are 100 ft deep, and it was detected at the bottom of three boreholes (22-00-03, 22-04-09, and 22-06-07) that were as deep as 146 ft (borehole 22-00-03).

The present designation of tank BY-111 is that it is a sound tank. The ^{60}Co contamination detected in borehole 22-11-09, along with other historical information, suggests that the tank has leaked in the past, possibly in the upper portion of the tank wall liner where tar rings were found. Based upon the findings presented in this report, the designation of tank BY-111 should be reconsidered.

^{60}Co contamination was detected in boreholes on the southern side of tank BY-110. This tank also has tar rings on the interior walls of the tank, and liquid-level decreases were recorded during the tank's service life. However, the behavior of the contamination over time cannot be determined because the Tank Farm logging with the gross gamma-ray systems detected no gamma-ray anomalies in the monitoring boreholes in which ^{60}Co was detected with the SGLSs. This contamination may be the result of leakage from the cascade line connecting tanks BX-112 and BY-110 or leakage from the tank.

Although questions remain about the true nature and extent of the ^{137}Cs and ^{60}Co contamination and the integrity of tanks designated sound is questioned, a high-quality database has been established for the ^{137}Cs and ^{60}Co contamination distribution beneath the BY Tank Farm tanks. Future monitoring can be conducted to determine if the contamination is moving, where the contamination is going, and if additional sources are present. This 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 in a more comprehensive manner. There is a paucity of available historical information about the tanks, and access to these data is limited.

Much of the Tank Farms gross gamma-ray log data have never been assessed. Time-sequence analyses of all the boreholes should be performed to attempt to track the movement of the contamination through the vadose zone to the locations where it was presently detected with the SGLSs.

Some comprehensive work on collecting historical data was performed and is presented in the 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. theorized that significant surface spills occurred at the surface of the BY 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. The 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.

The unplanned release information reviewed for the BY Tank Farm provided some insight on the contribution of these releases to the contamination plumes around specific tanks. These data are important information that could provide positive indications about the validity of the integrity designations for tanks. The WIDS database information was reviewed to describe facilities adjacent to the BY Tank Farm that may have contributed to contamination distribution around the tanks and affected the quality of the groundwater beneath the tanks. The WIDS database no longer exists but has been replaced by the Environmental Sites Database. The most obvious improvement over the WIDS database is the addition of several categories of references regarding regulatory information, waste inventories, and unplanned releases.

14.2 Improvements to Spectral Gamma Logging

It is recommended that a spectral-shape factor analysis method be implemented in order to distinguish between contamination distributed in the formation from contamination on the inside or outside of the borehole casing. This method is not a simple analytical technique that produces unequivocal interpretations; it will produce mixed results in some cases. However, data interpreted with an understanding of the inaccuracies and uncertainties of the theoretical basis of the method will help explain some of the contamination distribution patterns, sometimes conclusively. The main area of interest for implementing this analysis is the contamination that is speculated to be on the inside or the outside of the casings. Development of a spectral-shape factor analysis system has been initiated.

14.3 Additional Logging Characterizations

Other borehole geophysical methods are recommended for development and implementation at the Tank Farms to provide better characterization data (i.e., moisture, porosity, carbonate). Borehole geophysical methods are emphasized for characterization, although they do not provide all the required characterization data, because these methods are cost effective and safe and because numerous boreholes that allow access to the subsurface already exist.

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 sonde. 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. This sonde should have a large interrogation radius and insensitivity to borehole rugosity and gap behind casing, and it should operate effectively in an air-filled, cased borehole. 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 sonde must be developed. It is recommended that such a sonde be developed and used for the additional baseline characterizations of the SST farms.

It is also recommended that a carbon/oxygen log be acquired in the BY Tank Farm boreholes. This type of log might show variations in the calcium carbonate content that change with 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. Calcium carbonate fills pore spaces in sediments, making them more impervious to fluid migration. Implementation of carbon/oxygen logging for vadose zone characterization at the Hanford Site would require calibrating the logging sondes to borehole-specific conditions encountered in the vadose zone and analyzing and interpreting the results.

14.4 Additional Vadose Zone Characterizations

This report describes an initial vadose zone characterization at the BY 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. In addition, there is some degree of uncertainty and skepticism, in some cases, about conclusions regarding the actual distribution of contamination around the boreholes. This uncertainty and skepticism must be resolved. Therefore, it is recommended that additional characterization of the vadose zone be performed.

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

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

Characterization of the upper vadose zone should also conclusively determine the extent of contaminant migration down the outside of the borehole casings. It is impossible to determine, with the present data analysis, if and to what extent contaminants have migrated down the borehole casings in the BY Tank Farm. This type of contamination defined a significant amount of the plume development surrounding the tanks in the BY 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 ^{60}Co contamination. Because of the relatively short half-life of ^{60}Co, it is not a significant health issue; however, characterization would not be complete without determining the low bounds of the vadose zone contamination.

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 the additional information and knowledge acquired during the preparation of this report. As the tanks become older, their integrity diminishes. Several tanks contain sufficient volumes of liquids that if leaked, they would contaminate large volumes of vadose zone sediments. Through a planned monitoring program, failures would be promptly identified.

All the boreholes in the BY Tank Farm should be monitored at least annually to determine if any of the contamination is moving. Considering the age of the tanks, those tanks that still contain a significant volume of liquid should be monitored more frequently because of the potential for leaks.

Several boreholes in the BY Tank Farm have been perforated, and these boreholes may provide a pathway for movement of contamination deeper into the vadose zone sediments. They were drilled when the BY Tank Farm was first constructed, and because contamination is spread throughout the inside of the casings, they are not suitable for monitoring subtle changes in contamination concentrations or distributions. These boreholes should be abandoned under current WAC requirements.

Tank BY-101

Borehole 22-01-04 should be monitored for changes in the ^{137}Cs and ^{60}Co contamination concentrations and their distributions. The source of the contamination detected in this borehole is unknown: tank BY-101 is presently designated sound. The waste contained in this tank consists of 109,000 gal of sludge, 278,000 gal of salt cake, and 5,000 gal of drainable interstitial liquid.

Tank BY-102

Monitoring of borehole 22-02-01 is recommended because the ^{137}Cs contamination detected in this borehole occurs at the depth of the bottom of the tank. Borehole 22-02-09 should be monitored between depths of 40 and 50 ft, where elevated total gamma count rates were not consistent with the observed ^{137}Cs and ^{60}Co contamination concentrations and the presence of ^{90}Sr is suspected. Tank BY-102 is presently designated sound containing 277,000 gal of salt cake, with 11,000 gal of drainable interstitial liquid.

Tank BY-103

Borehole 22-03-05, in which high concentrations of ^{137}Cs that saturated the 35-percent efficiency detector were encountered, should be logged with a lower efficiency detector for more complete characterization of the contamination zone. Tank BY-103 is a confirmed leaker. It presently contains waste consisting of 395,000 gal of salt cake and 5,000 gal of sludge, with 15,000 gal of drainable interstitial liquid. Because the tank still contains 15,000 gal of liquid, the boreholes around this tank should be monitored at least on a quarterly basis.

Tank BY-104

Boreholes 22-04-07 and 22-04-09 should be logged to monitor changes in the concentration and distribution of the ^{60}Co contamination detected at the bottoms of both of these boreholes. Tank BY-104 is presently designated sound, and the ^{60}Co contamination detected in these two boreholes is suspected to be from leakage from adjacent tank BY-107. The waste in this tank consists of 40,000 gal of sludge and 366,000 gal of salt cake, with 18,000 gal of interstitial liquid.

Tank BY-105

The ^{60}Co contamination detected in boreholes 22-05-01 and 22-05-09 should be monitored for changes in concentration and distribution. The contamination appears to have resulted from a leak in tank BY-105, which is designated a leaker. The tank contains waste consisting of 459,000 gal of salt cake and 44,000 gal of sludge, with 216,000 gal of pumpable liquid waste. Because the tank still contains a considerable volume of liquid, all the boreholes surrounding tank BY-105 should be monitored on a monthly basis.

Tank BY-106

All boreholes in the vicinity of tank BY-106, with the exception of 22-06-11, should be monitored at least quarterly for changes in the ^{60}Co concentrations and distributions. Logs for borehole 22-06-05 exhibit a thick zone of ^{60}Co contamination at a depth of 62 ft; this zone in particular should be closely monitored for contaminant movement. Tank BY-106 is designated a leaker; this tank presently contains waste consisting of 547,000 gal of salt cake and 95,000 gal of sludge, with about 200,000 gal of drainable interstitial liquid.

Tank BY-107

Boreholes 22-07-01, 22-07-02, 22-07-05, 22-07-07, and 22-07-09 should be monitored at least quarterly for changes in the ^{60}Co contamination profiles. ^{60}Co contamination was detected at the bottoms of all these boreholes. The contamination in boreholes 22-07-02 and 22-07-05 began at a depth of about 30 ft, well above the base of the tank. Tank BY-107 is designated a leaker; this tank contains 206,000 gal of salt cake and 60,000 gal of sludge. The sludge and salt cake contain 25,000 gal of drainable liquids.

Tank BY-108

Significant ^{60}Co contamination was detected in almost all the monitoring boreholes in the vicinity of this tank. Boreholes 22-08-01, 22-08-02, 22-08-05, 22-08-06, and 22-08-12 should be monitored for changes in the ^{60}Co contamination distribution and concentrations. Contamination was detected at the bottoms of three of these boreholes; therefore, the extent of the contamination is not defined. Tank BY-108 is designated a leaker and presently contains 228,000 gal of waste consisting of 154,000 gal of sludge and 74,000 gal of salt cake. This waste contains 9,000 gal of interstitial liquid.

Tank BY-109

Boreholes 22-09-07 and 22-09-08 should be monitored quarterly to determine if any changes occur in the ^{60}Co contamination. It is suspected that this contamination is related to elevated ^{137}Cs contamination in boreholes 22-09-08, 22-09-11, and 22-12-03. It is speculated that this contamination is related to unplanned releases that occurred over the top of tank BY-112. Tank BY-109 is presently designated sound and contains 423,000 gal of waste consisting of 340,000 gal of salt cake and 83,000 gal of sludge. This waste contains 28,000 gal of interstitial liquid.

Tank BY-110

The ^{60}Co contamination in boreholes 22-10-05, 22-10-07, and 22-10-10 should be monitored quarterly for changes. Two of these boreholes (22-10-05 and 22-10-07) intersected ^{60}Co contamination that may be from leakage from tank BY-110, or from leakage from the cascade line connecting tank BX-112 (BX Tank Farm) to tank BY-110. Tank BY-110 is presently designated sound and contains 295,000 gal of salt cake, 103,000 gal of sludge; this waste contains 9,000 gal of drainable liquids.

Tank BY-111

The contamination detected in the boreholes surrounding tank BY-111 is near the ground surface and is related to surface spills that migrated downward or contamination that migrated down the inside and/or outside of the casing. ^{60}Co contamination detected in borehole 22-11-09 is almost certainly related to leakage from tank BY-111. Tank BY-111 is presently designated sound and contains waste consisting of 438,000 gal of salt cake and 21,000 gal of sludge; there is no drainable or pumpable liquids in the tank. Borehole 22-11-09 should be monitored annually.

Tank BY-112

The contamination in the boreholes surrounding this tank is mainly ^{137}Cs; this contamination is related to two unplanned releases over the top of this tank. Tank BY-112 is presently designated sound and contains 286,000 gal of salt cake and 5,000 gal of sludge; this waste contains 8,000 gal of drainable liquids. None of the boreholes surrounding this tank require additional monitoring.

Borehole Integrity

Several boreholes in the BY Tank Farm have been perforated, and these boreholes may provide a pathway for movement of contamination deeper into the vadose zone sediments. The perforated boreholes are: 22-00-01, 22-00-03, 22-00-10, 22-06-07, 22-08-07, and 22-11-08. These boreholes were drilled when the BY Tank Farm was first constructed, and because contamination is spread throughout the inside of the casings, the boreholes cannot be used to monitor subtle changes in contamination concentrations or distributions. These boreholes should be abandoned under current WAC requirements.

15.0 Figures for the BY Tank Farm

Many of the BY Tank Farm visualizations are printed and copied in color on one side of the page only. This section contains the figures discussed in the text of the report in the order of their presentation.

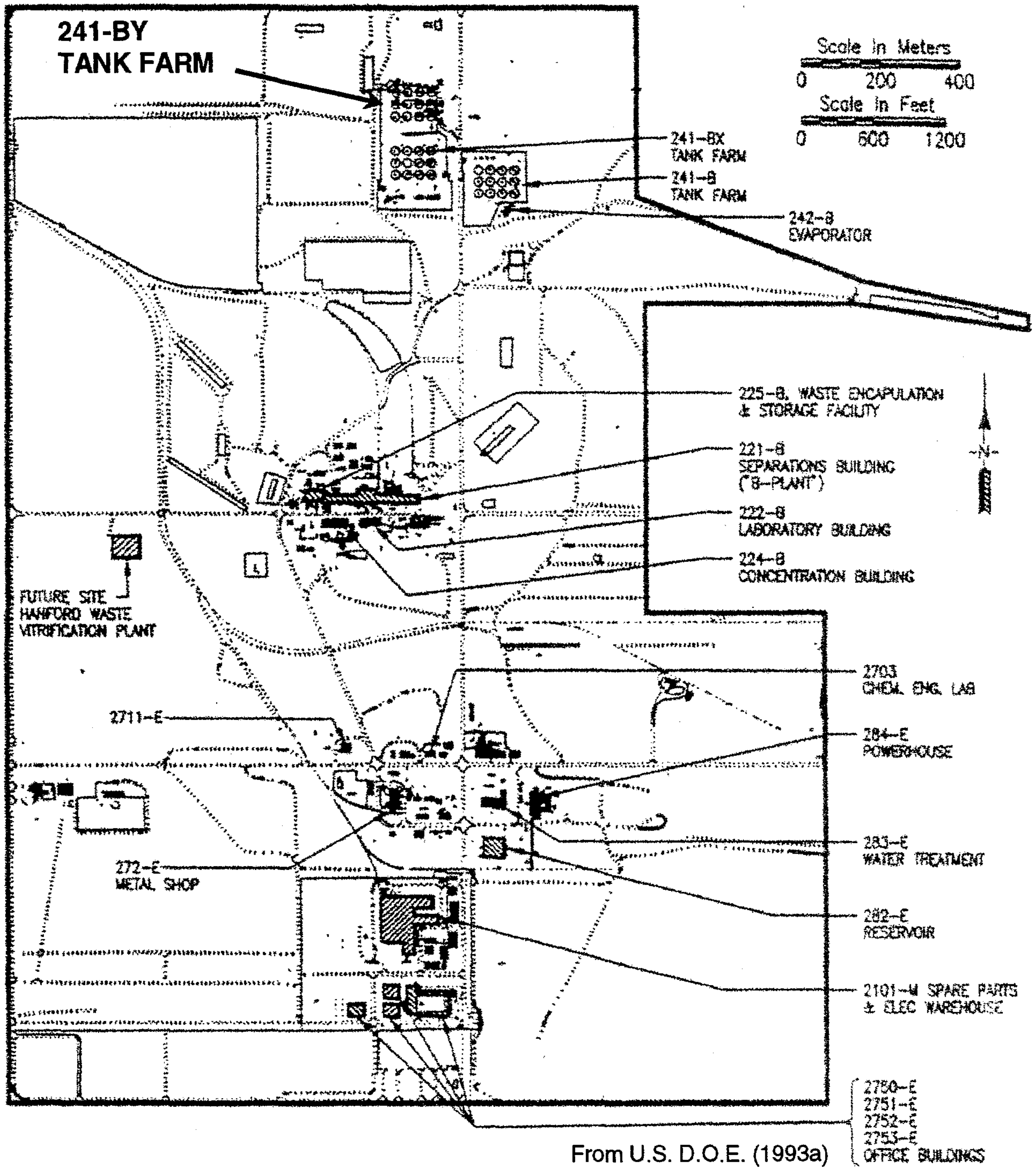
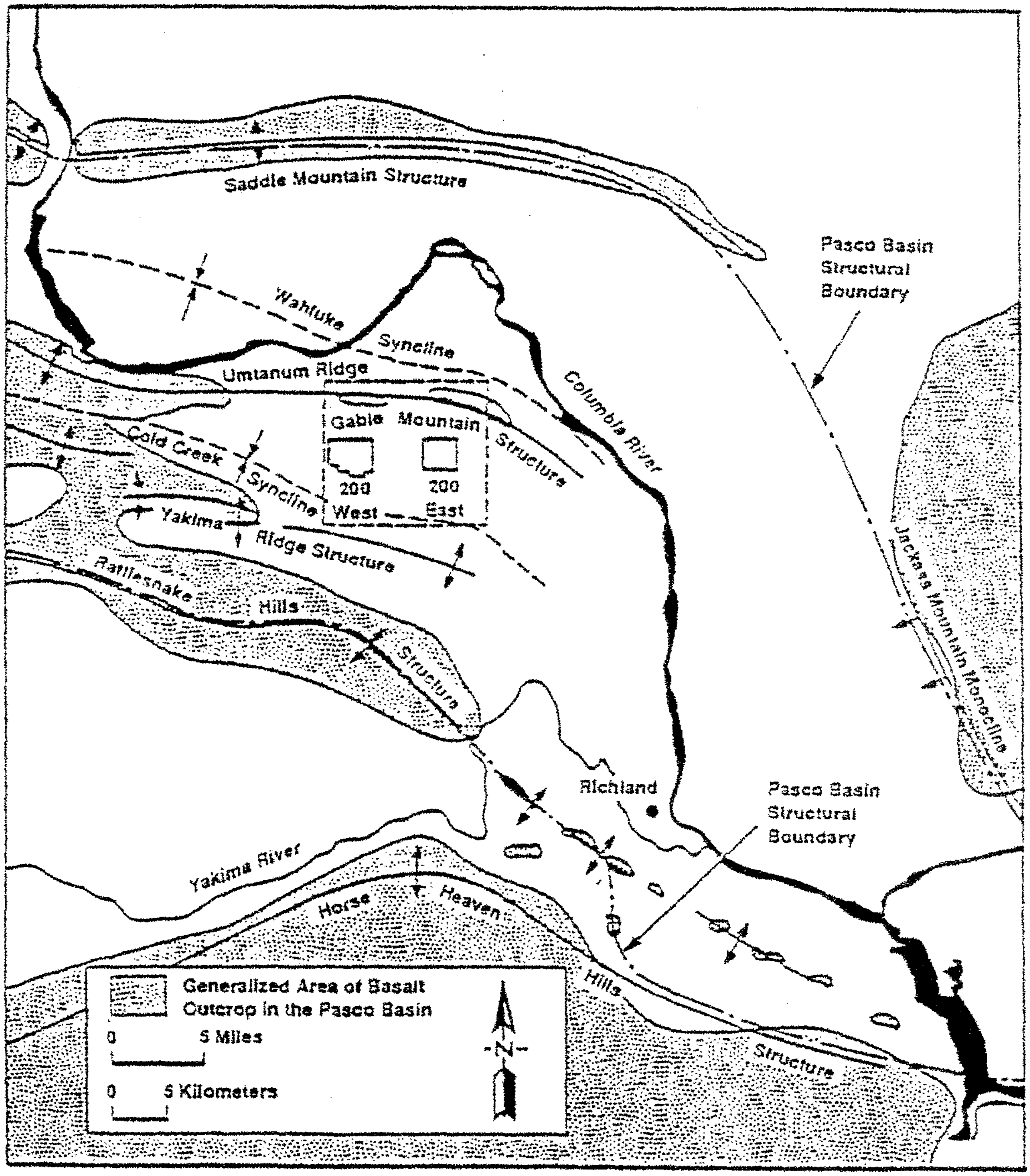
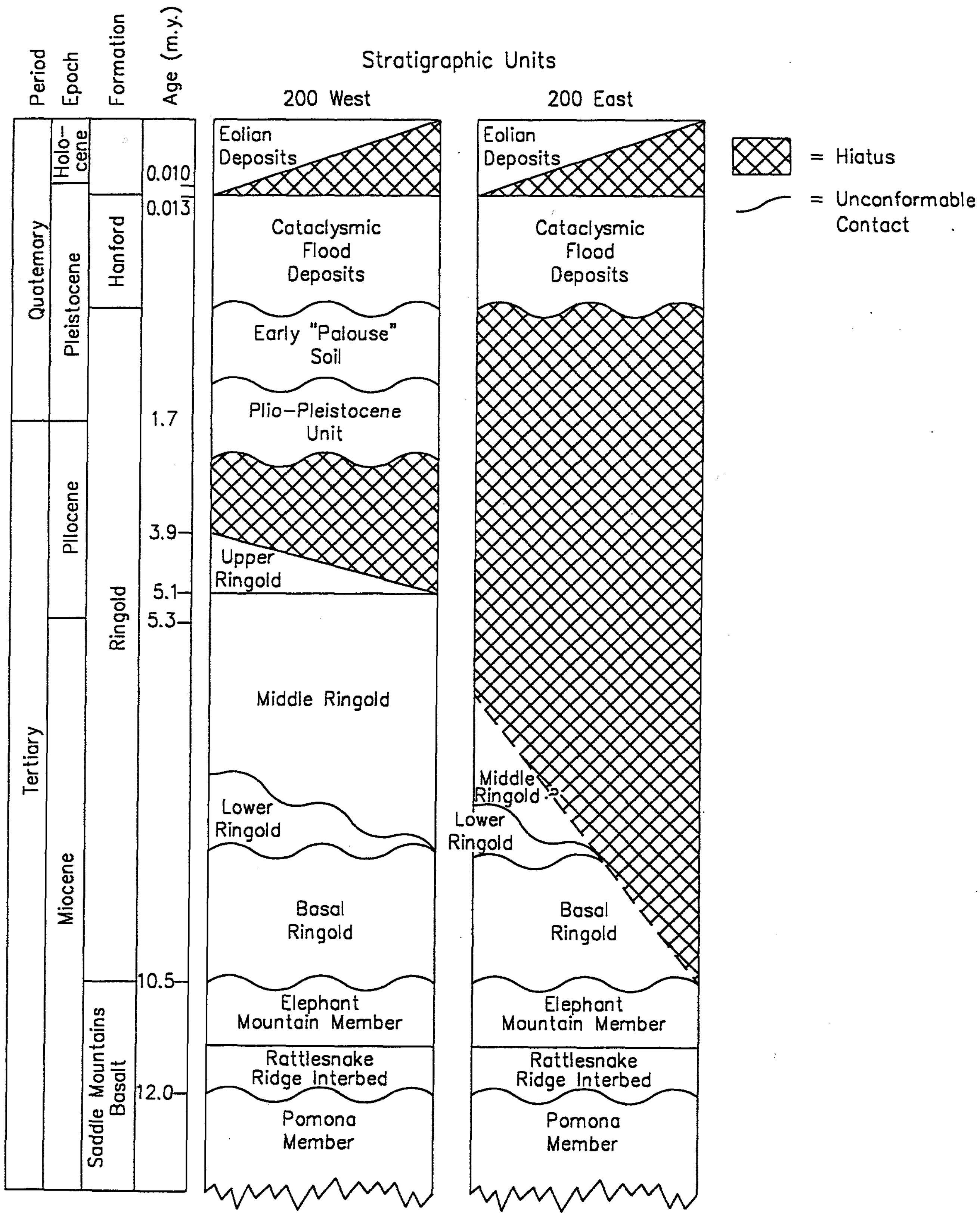


Figure 15-1. Map of the Central Portion of the Hanford Site 200 East Area Showing the Location of the BY Tank Farm



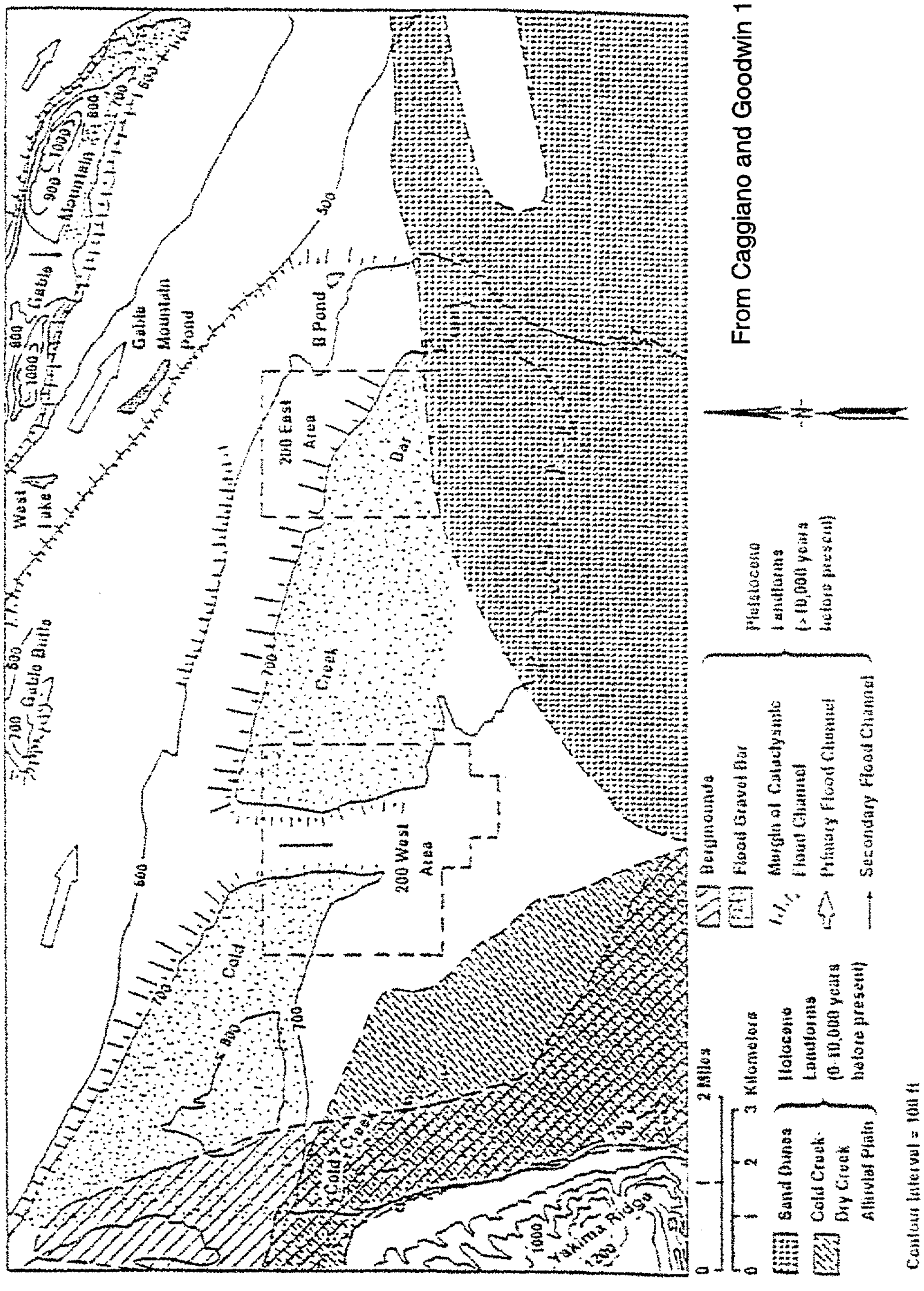
From Caggiano and Goodwin (1991)

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



From Caggiano and Goodwin 1991

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



From Caggiano and Goodwin 1991

Figure 15-4. Geomorphological Map of the 200 East and 200 West Areas at the Hanford Site

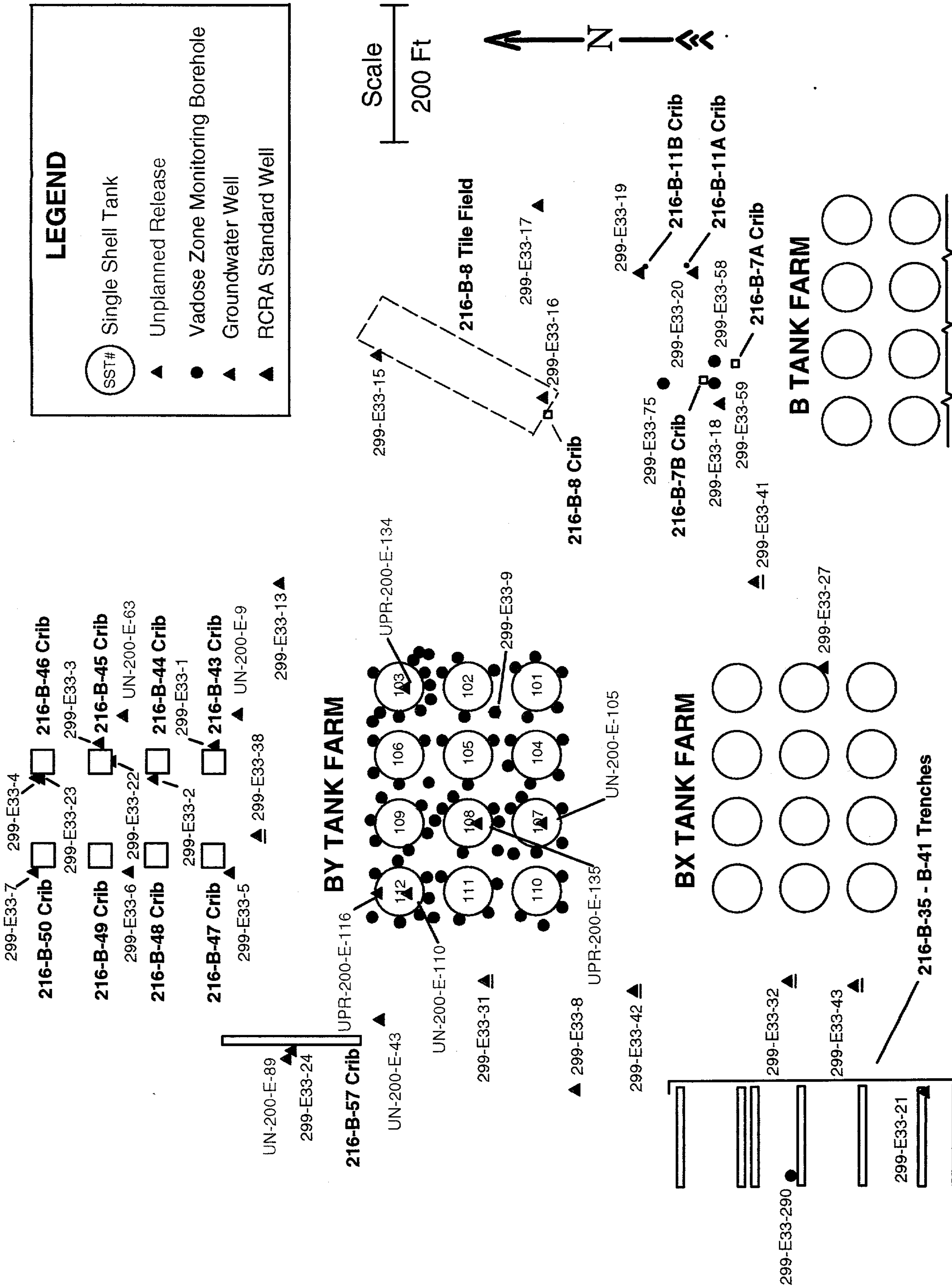
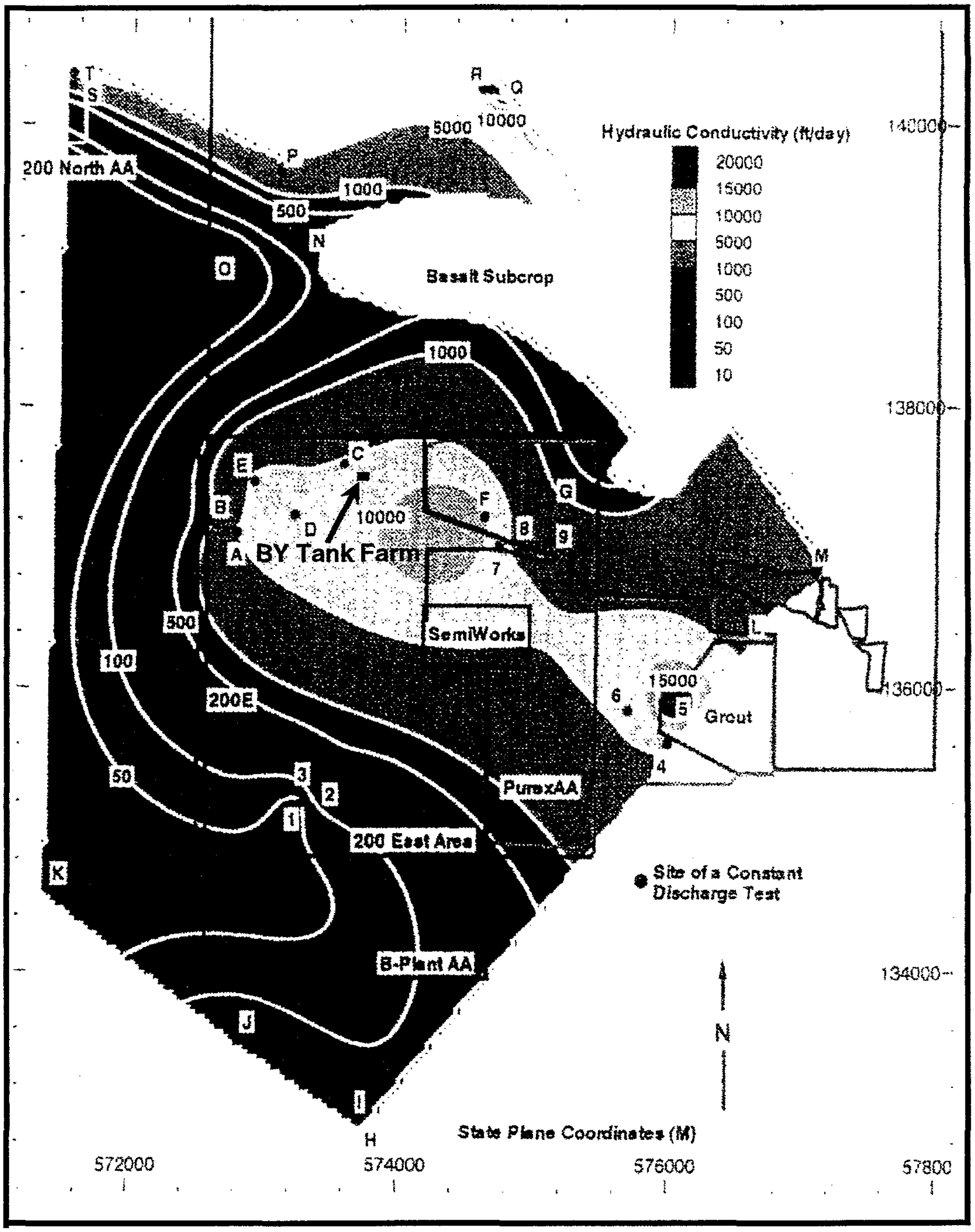


Figure 15-5. Plan Map of the Hanford Site BY Tank Farm, Adjacent Monitoring Boreholes, and Other Facilities



From Connelly et al. 1992

Figure 15-6. Hydraulic Conductivity of the Hanford Site 200 East and Adjacent Areas

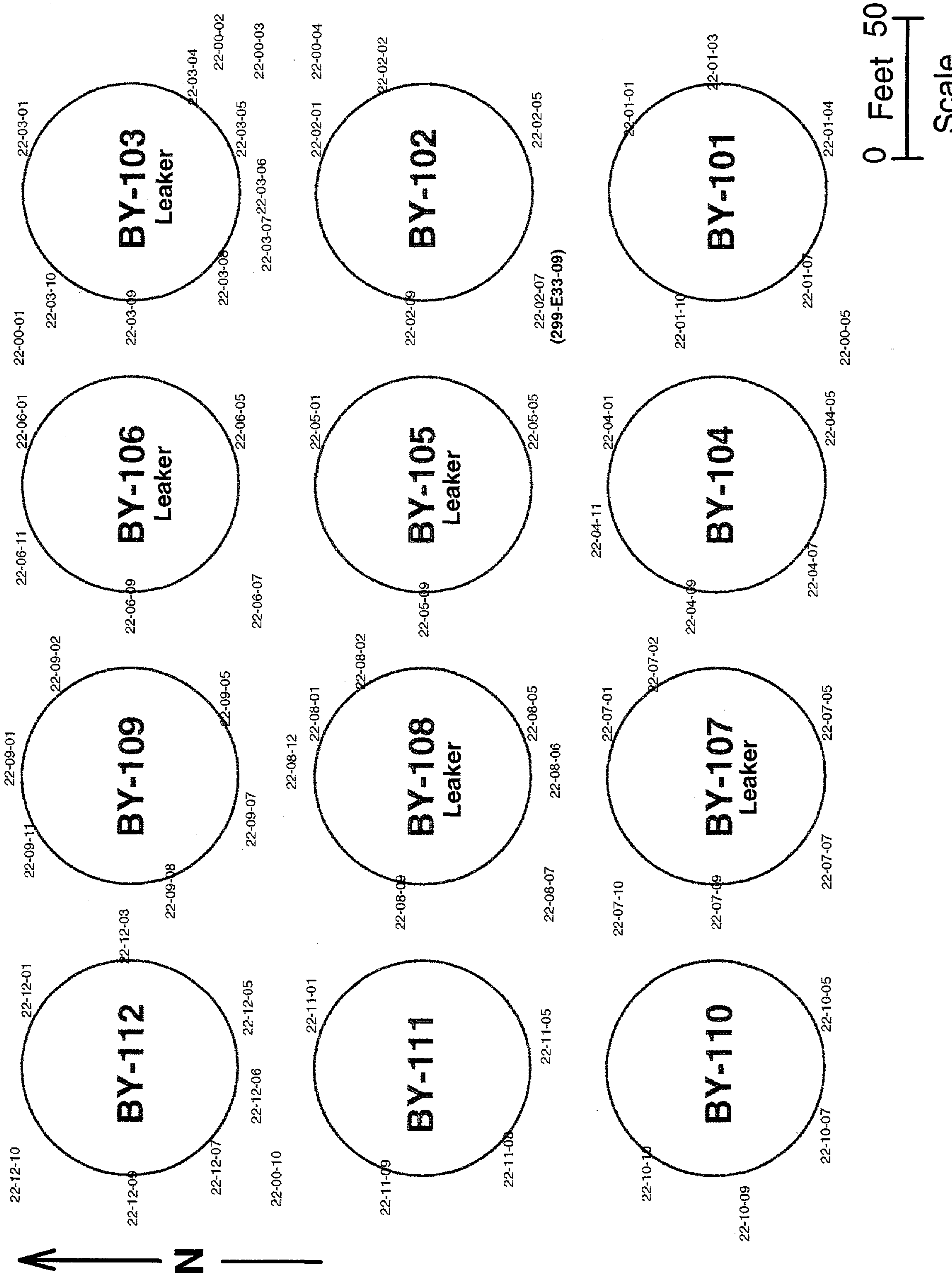


Figure 15-7. Plan Map of the Hanford Site BY Tank Farm Showing Monitoring Boreholes

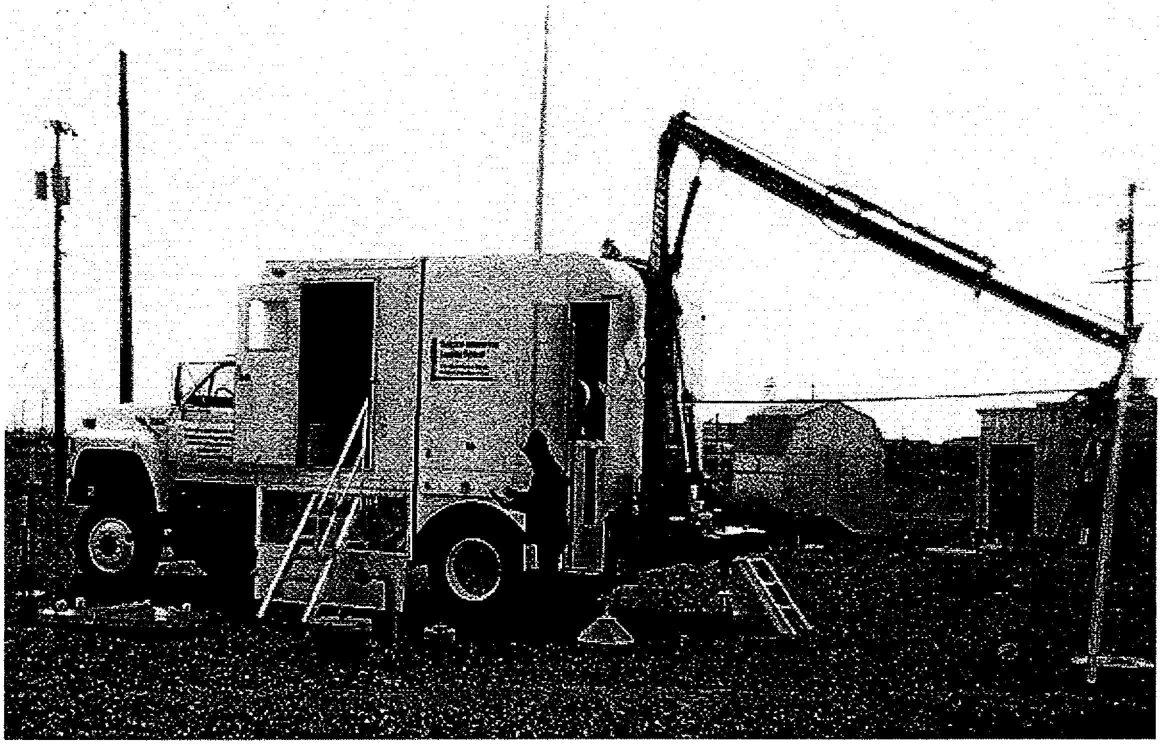


Figure 15-8. View of a Spectral Gamma Logging System Rigged for Logging

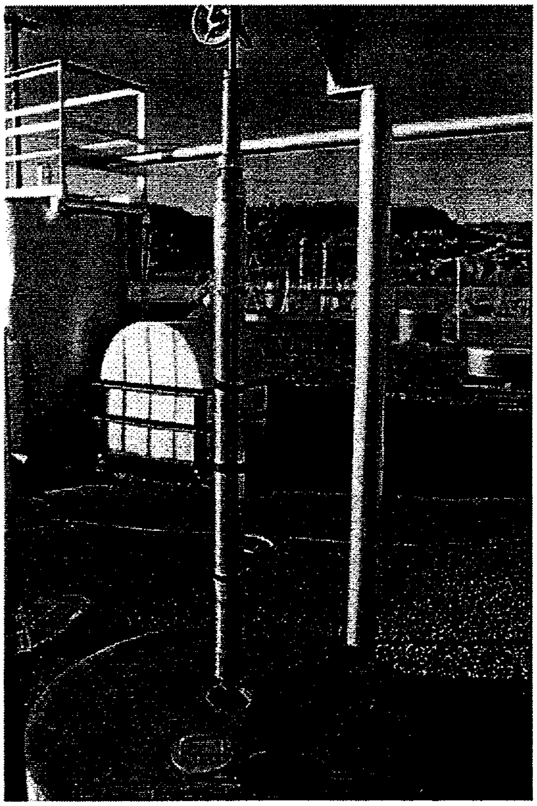


Figure 15-9. Sonde With High-Purity Germanium Detector Suspended Over a Borehole

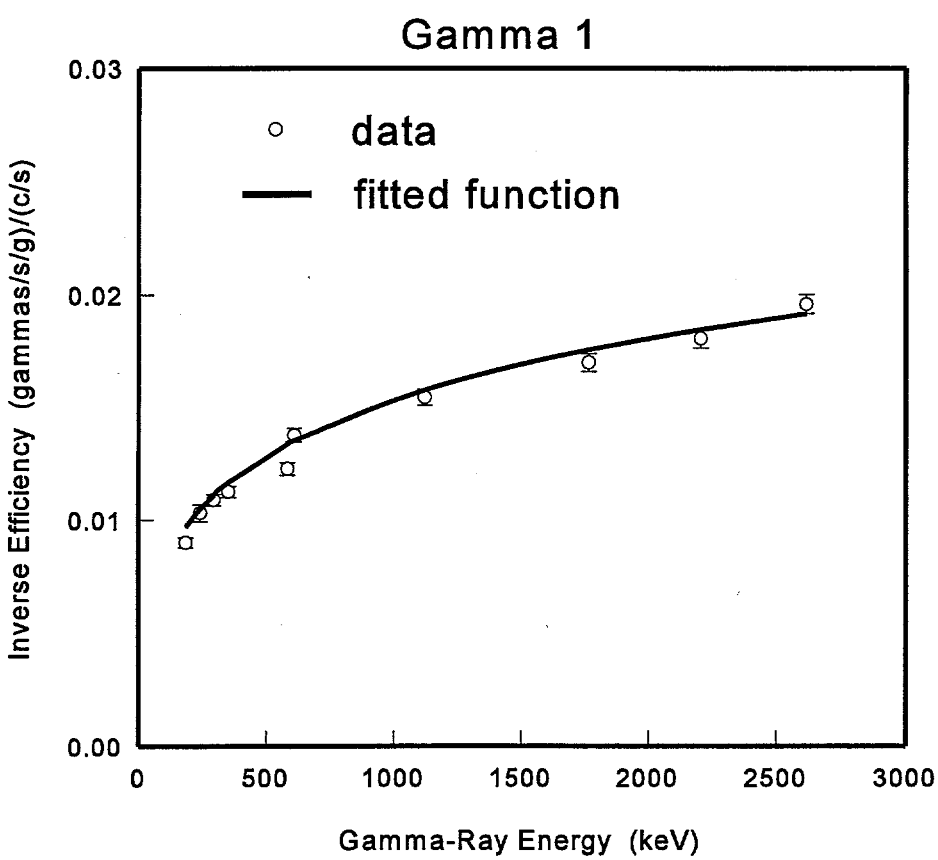


Figure 15-10. SGLS Base Calibration Inverse Efficiency Function

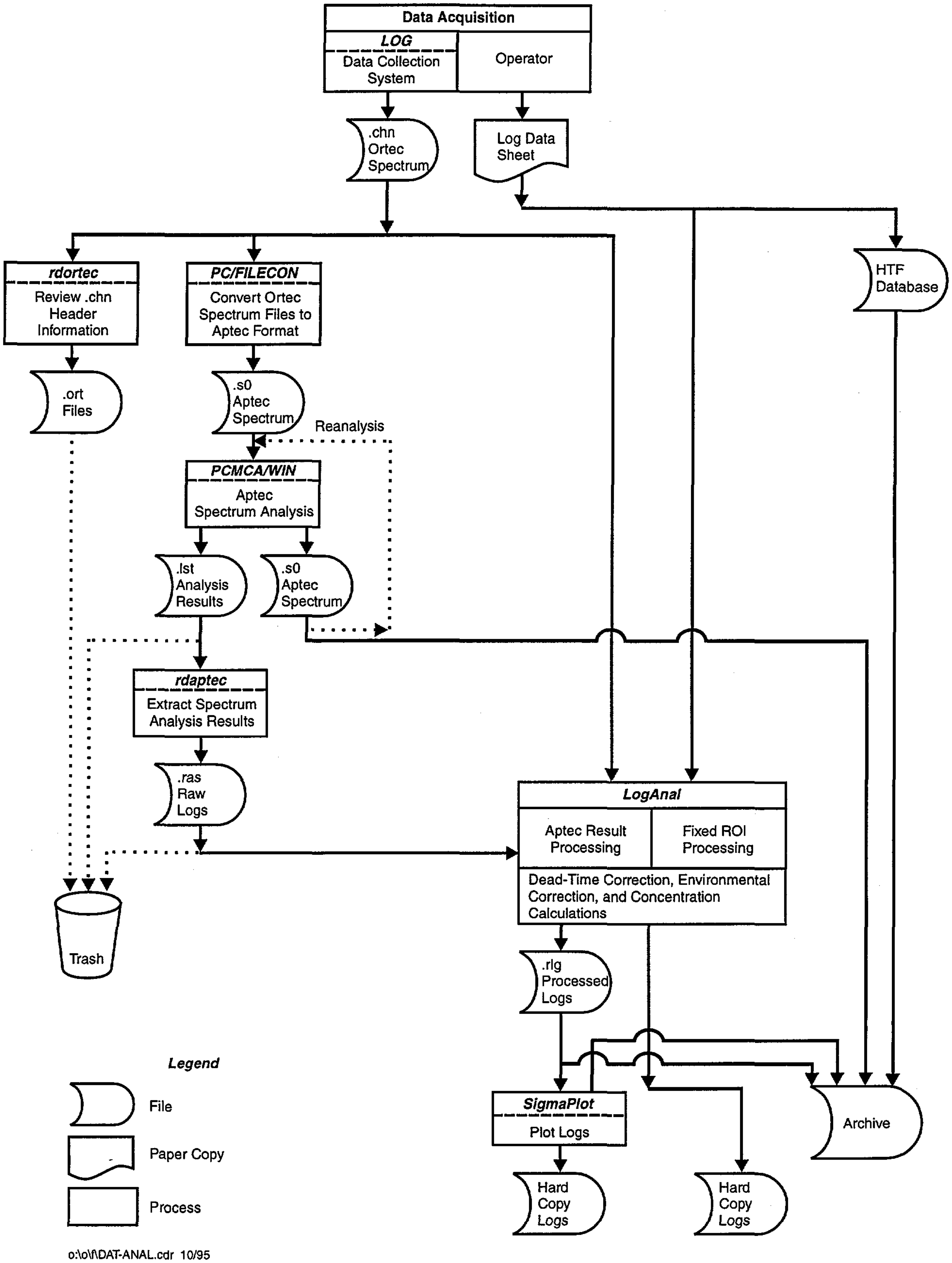


Figure 15-11. Hanford Site Tank Farm Vadose Zone Characterization Project Data Analysis Process

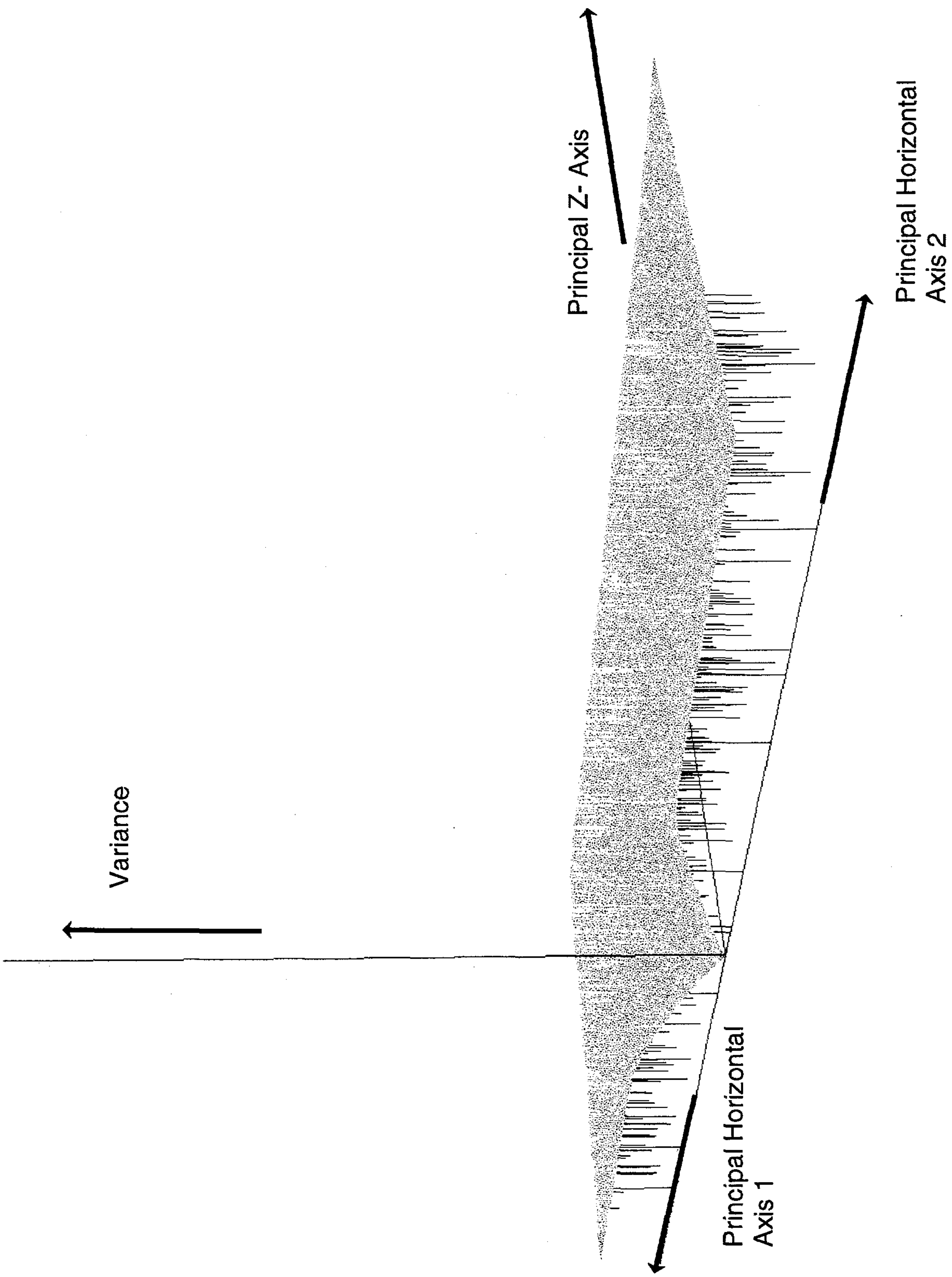


Figure 15-12. Variogram of the ^{137}Cs Contamination Distribution Model

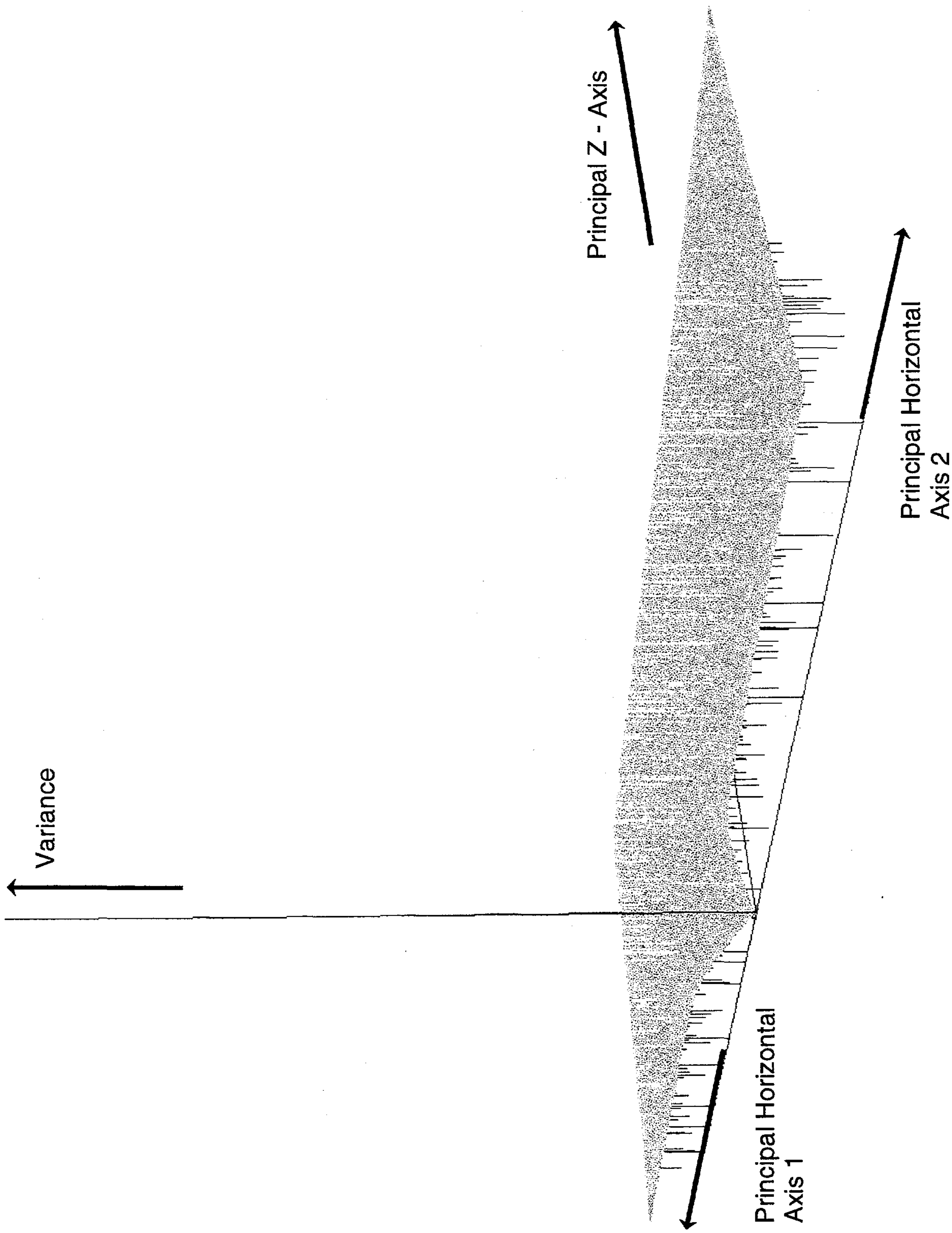
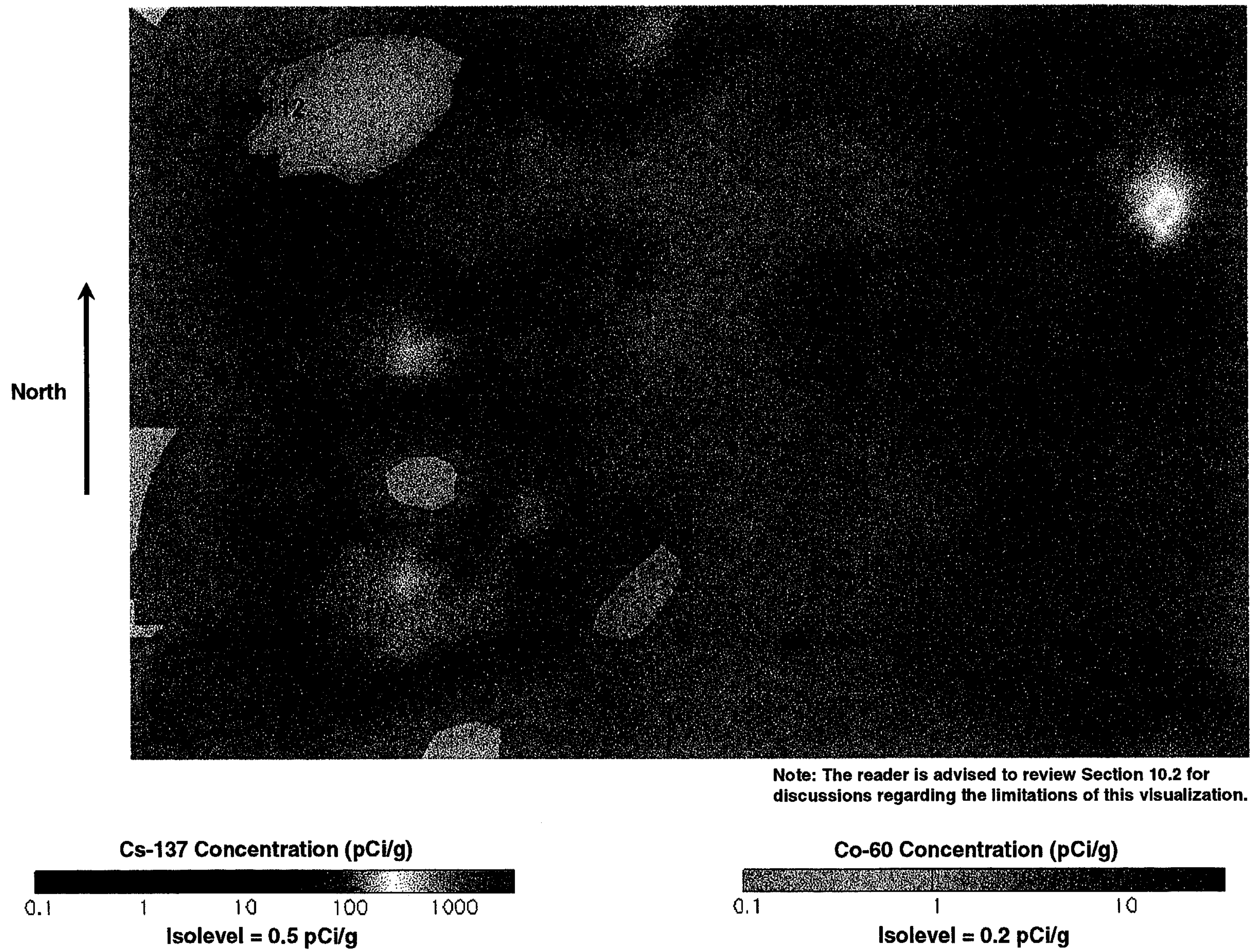


Figure 15-13. Variogram of the ^{60}Co Contamination Distribution Model



Note: The reader is advised to review Section 10.2 for discussions regarding the limitations of this visualization.

Figure 15-14. Plan View of ^{137}Cs and ^{60}Co Contamination at a Depth of 5 Ft Below Ground Surface at the BY Tank Farm

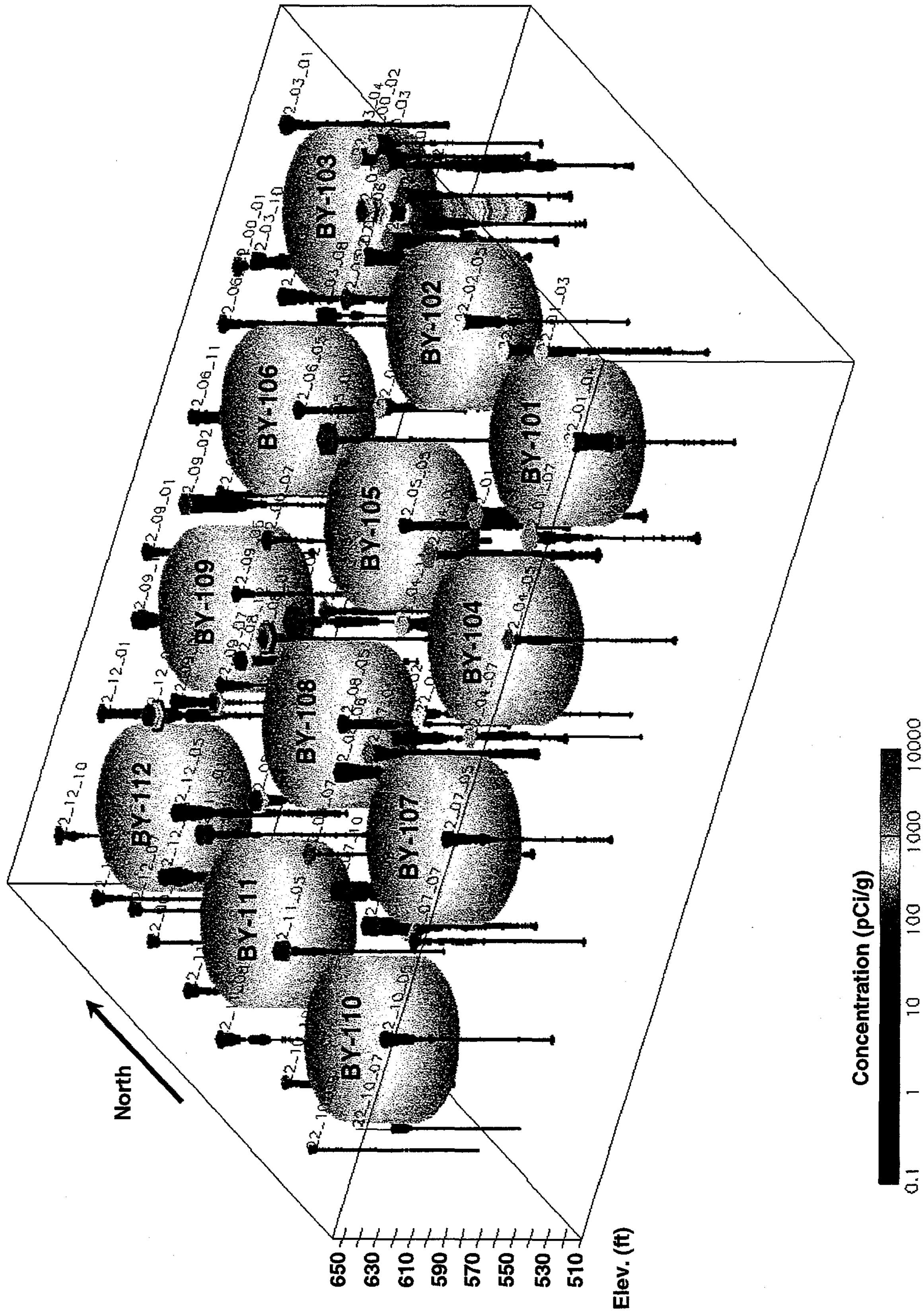


Figure 15-15. Isometric Plot of the ^{137}Cs SGLS Data Acquired at the BY Tank Farm

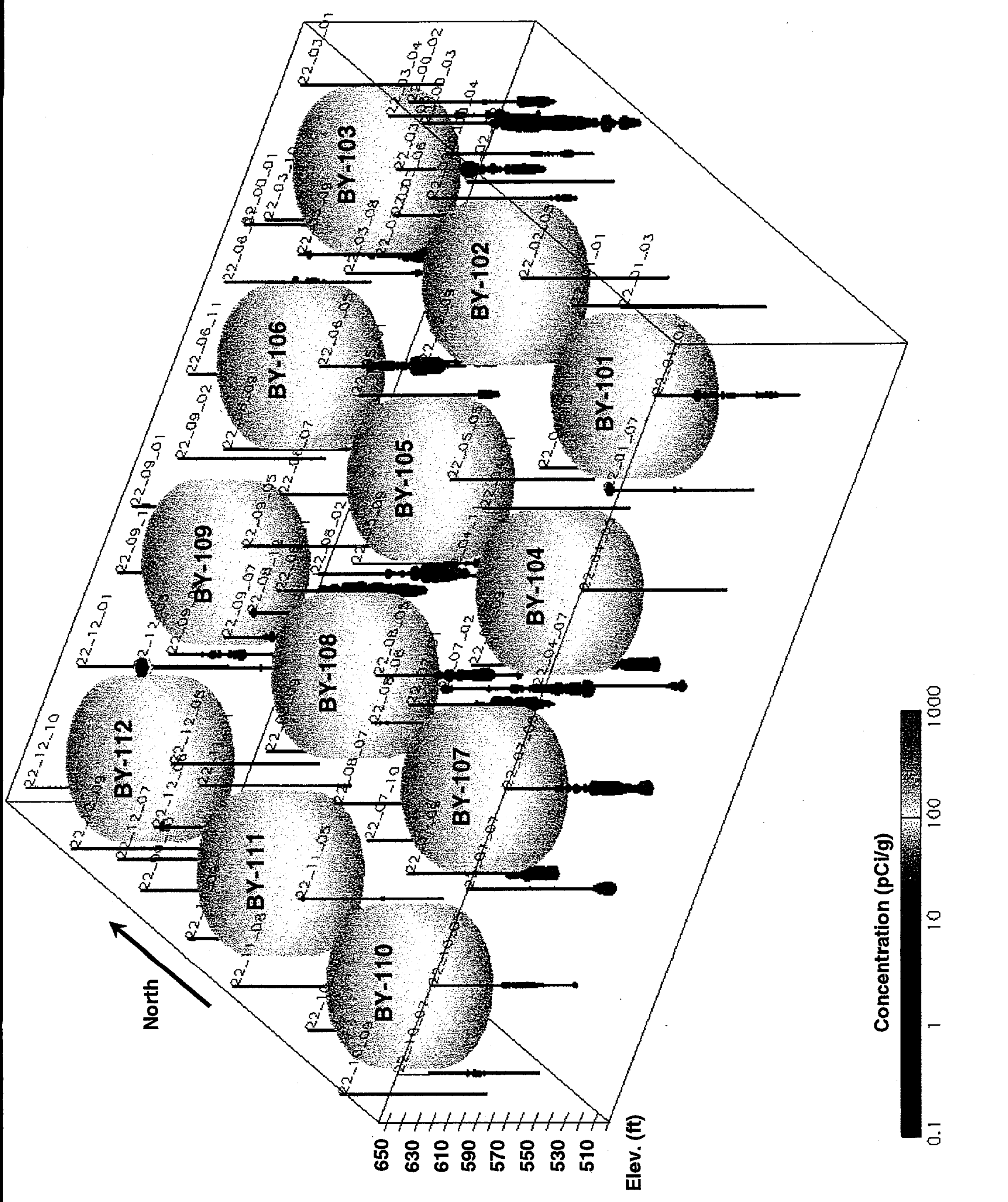


Figure 15-16. Isometric Plot of the ^{60}Co SGLS Data Acquired at the BY Tank Farm

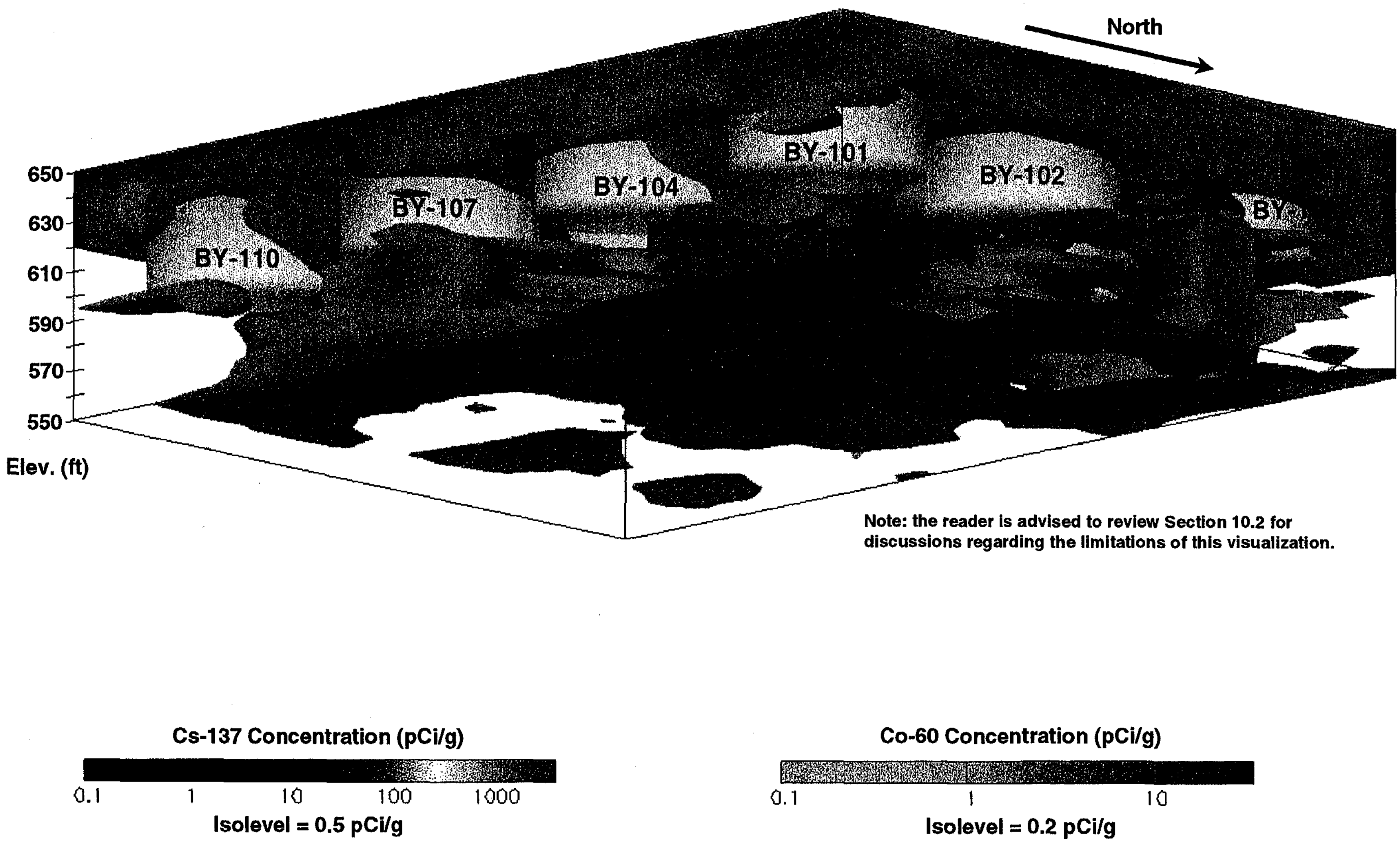


Figure 15-17. Visualization of the BY Tank Farm Contamination With Transparent ^{137}Cs Plumes Viewed From Below the Tanks From the Southeast

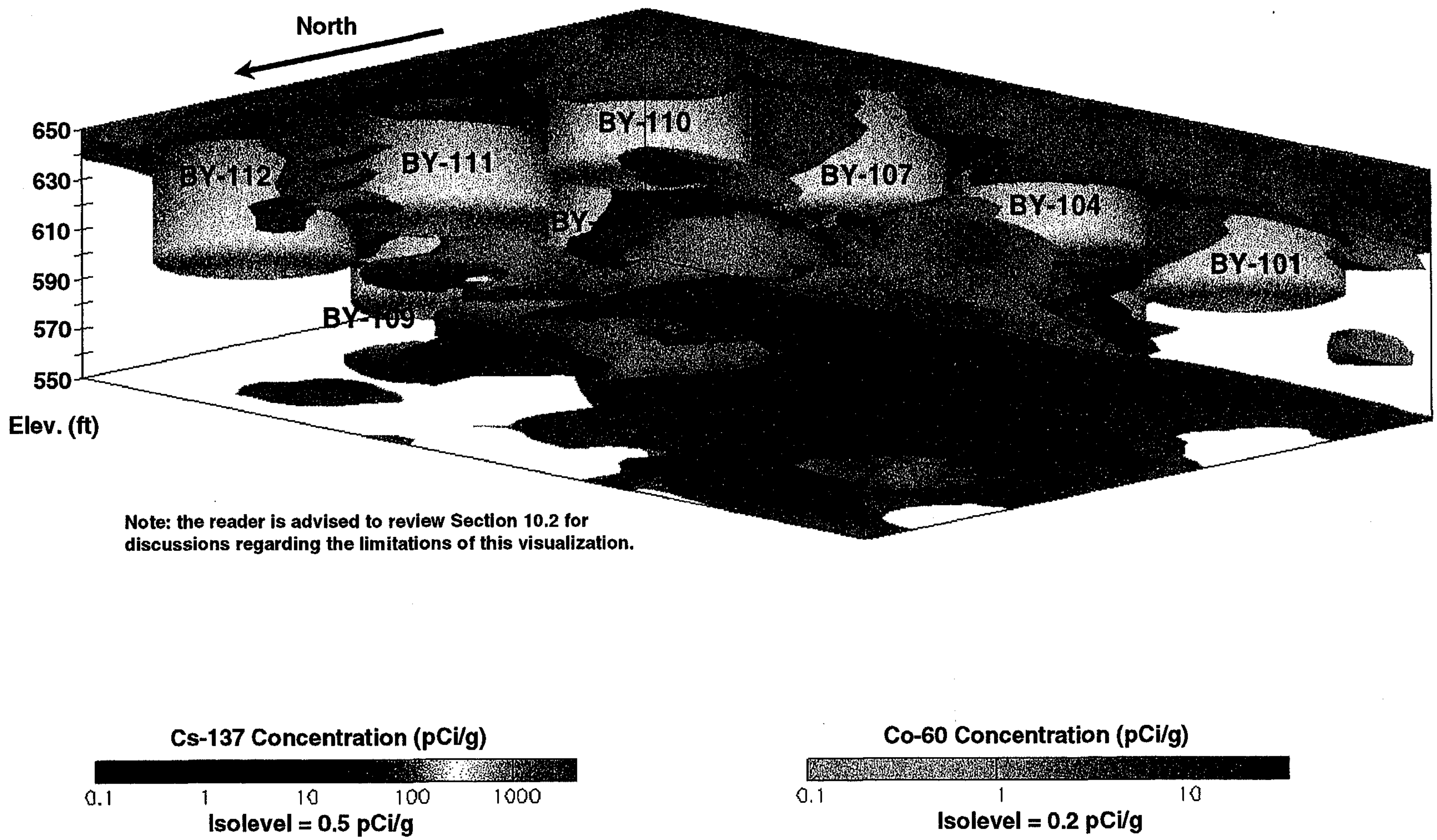


Figure 15-18. Visualization of the BY Tank Farm Contamination With Transparent ^{137}Cs Plumes Viewed From Below the Tanks From the Southwest

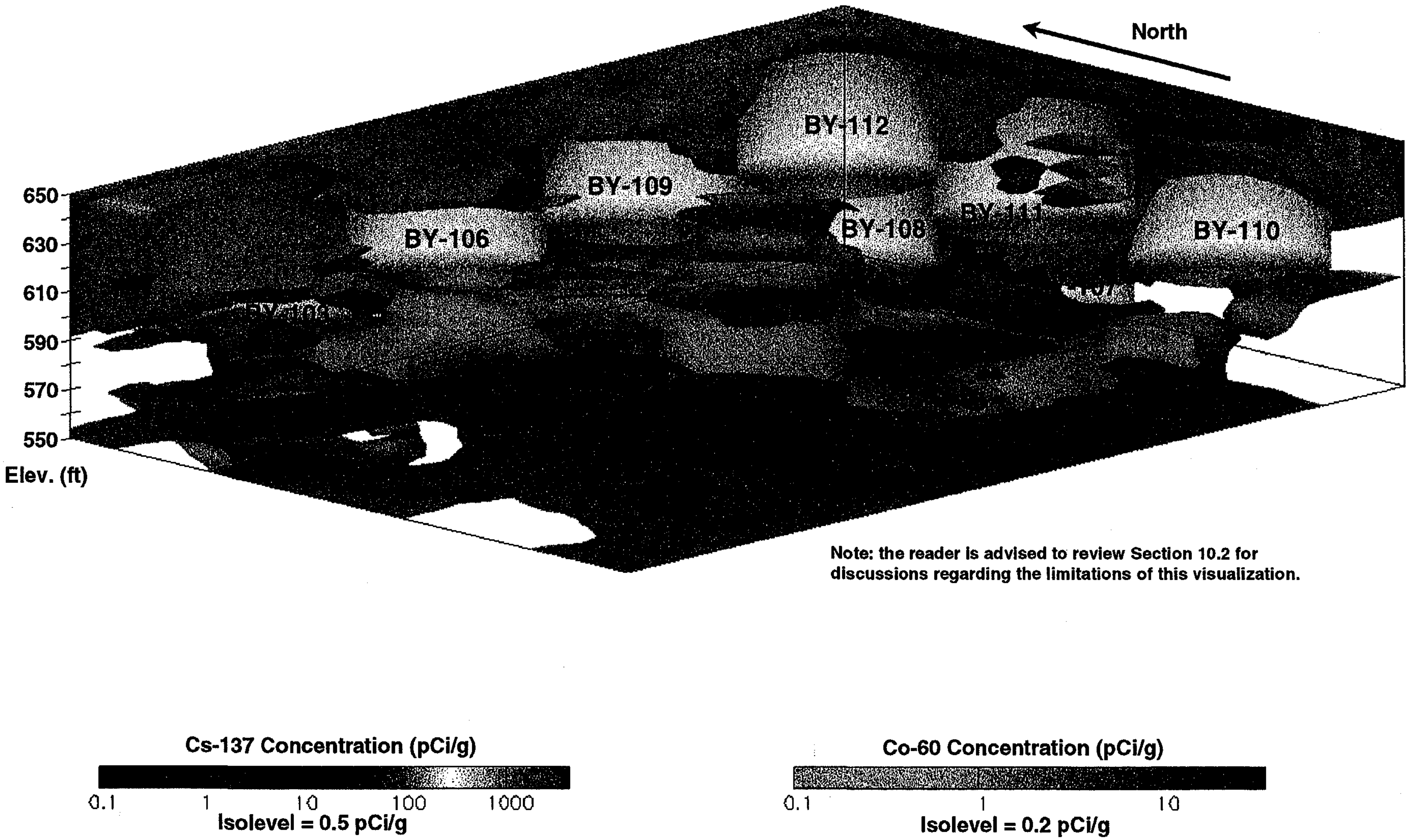


Figure 15-19. Visualization of the BY Tank Farm Contamination With Transparent ^{137}Cs Plumes Viewed From Below the Tanks From the Northwest

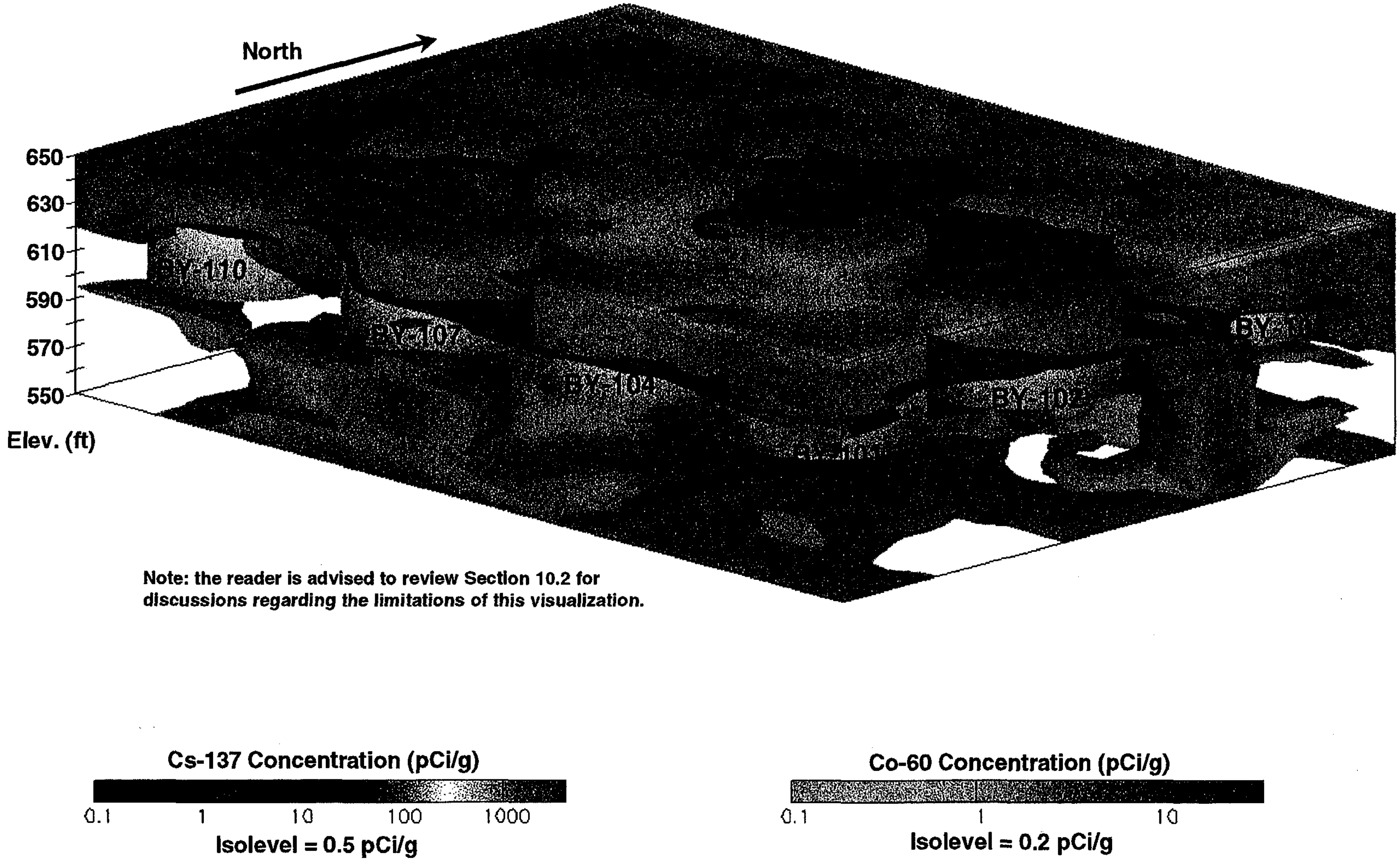


Figure 15-20. Visualization of the BY Tank Farm Contamination With Transparent ^{137}Cs Plumes Viewed From Above the Tanks From the Southeast

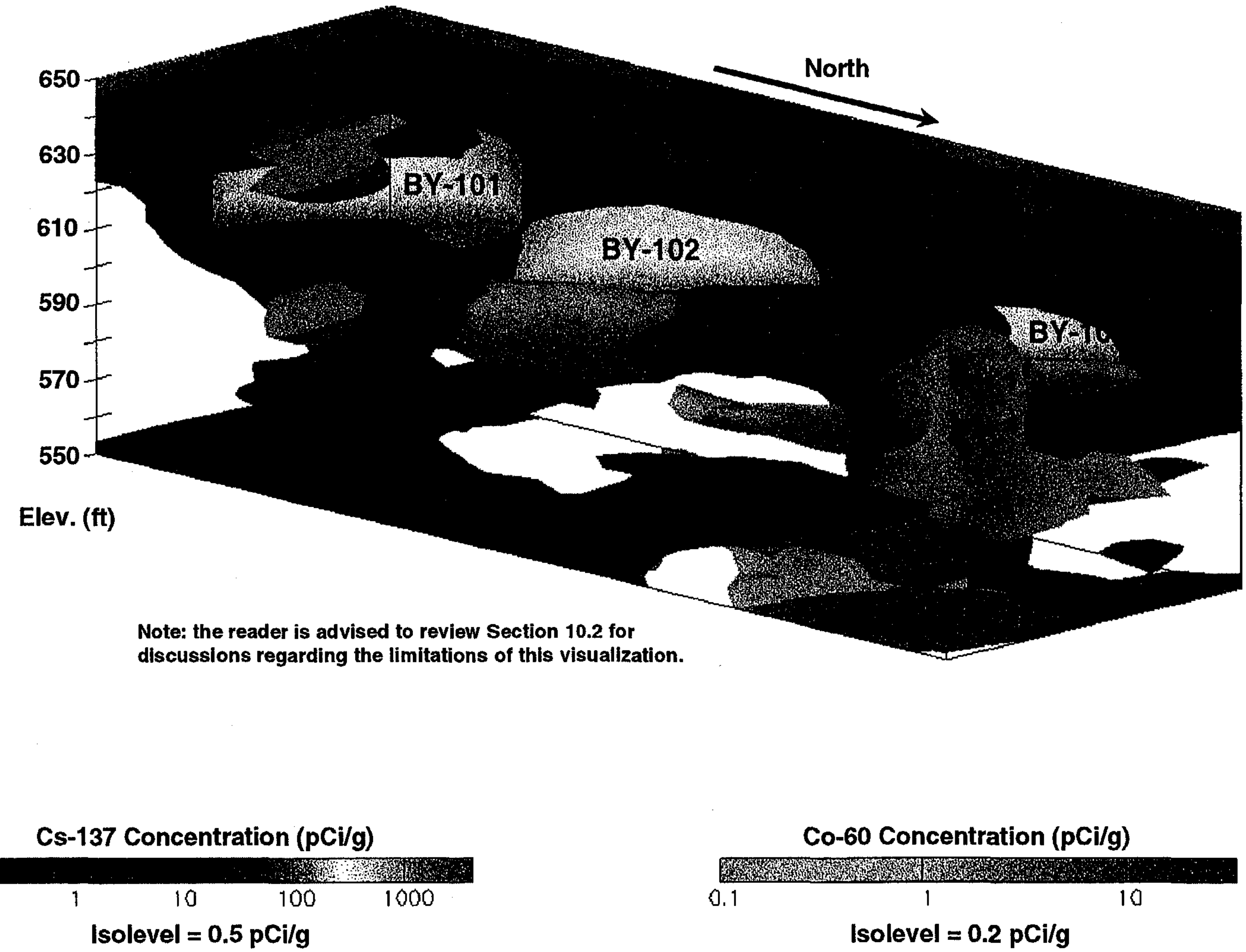


Figure 15-21. Visualization of Tanks BY-101, -102, and -103 Viewed From Below the Tanks From the Southeast

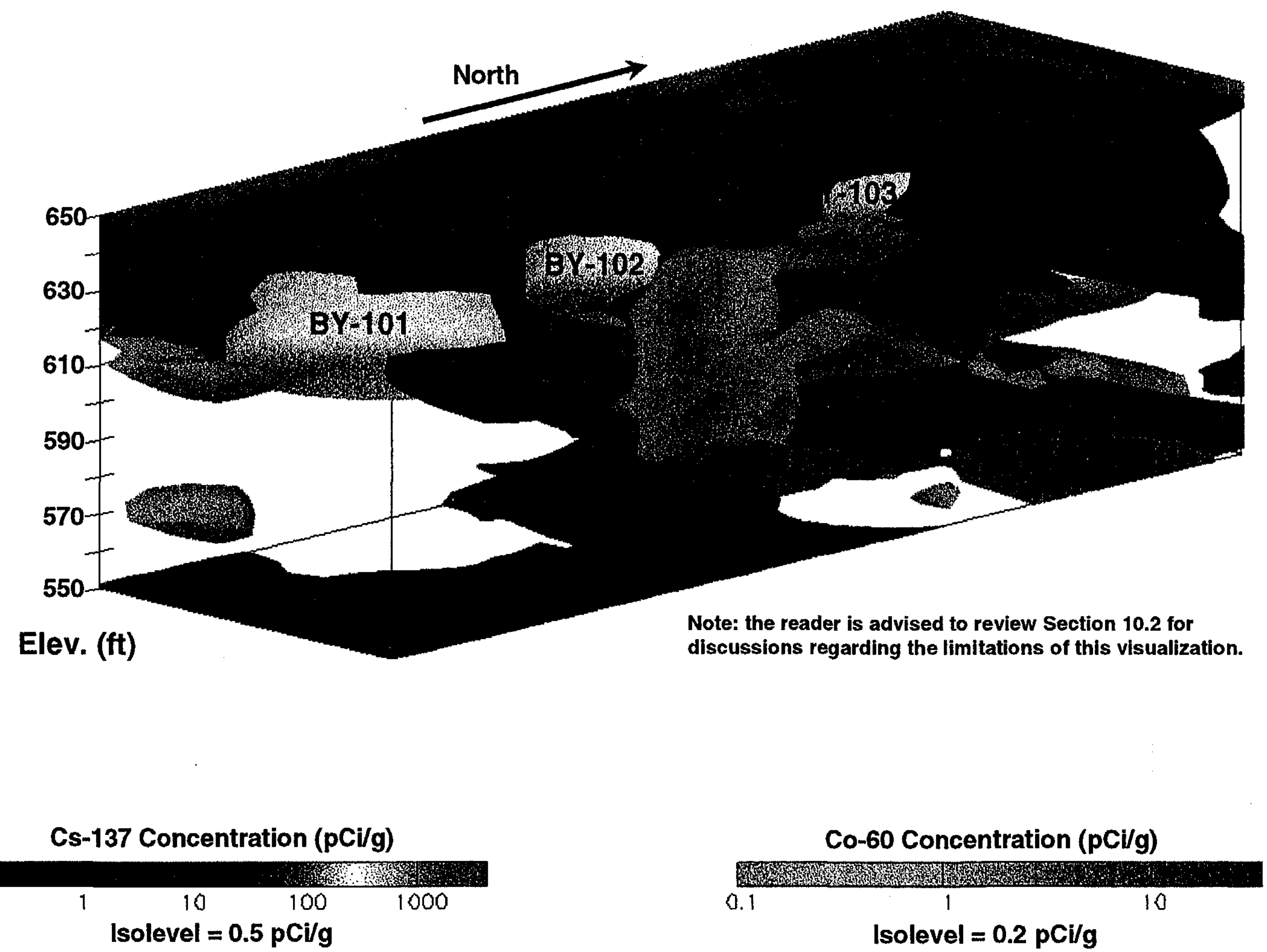


Figure 15-22. Visualization of Tanks BY-101, -102, and -103 Viewed From Below the Tanks From the Northeast

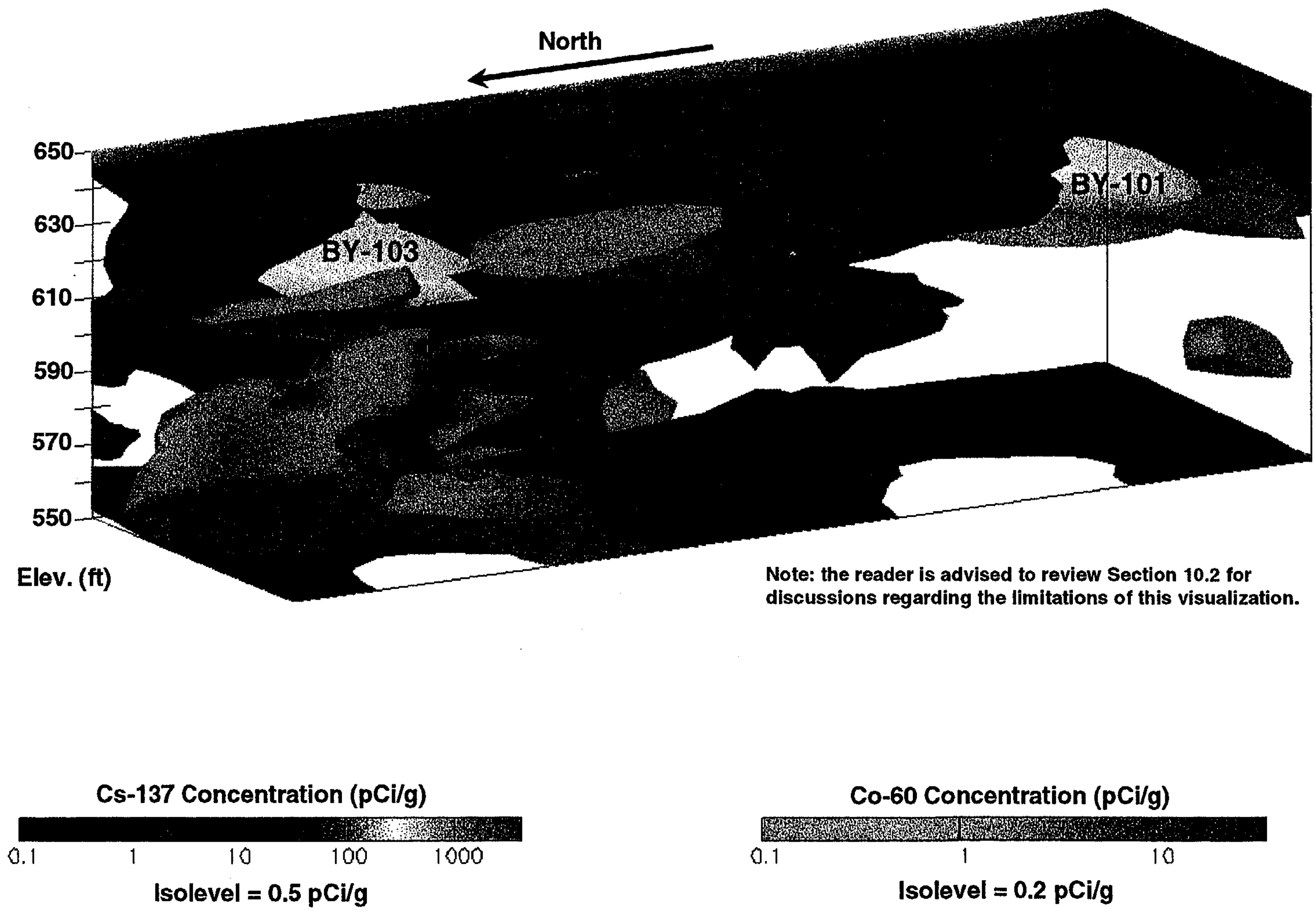


Figure 15-23. Visualization of Tanks BY-101, -102, and -103 Viewed From Below the Tanks From the Southwest

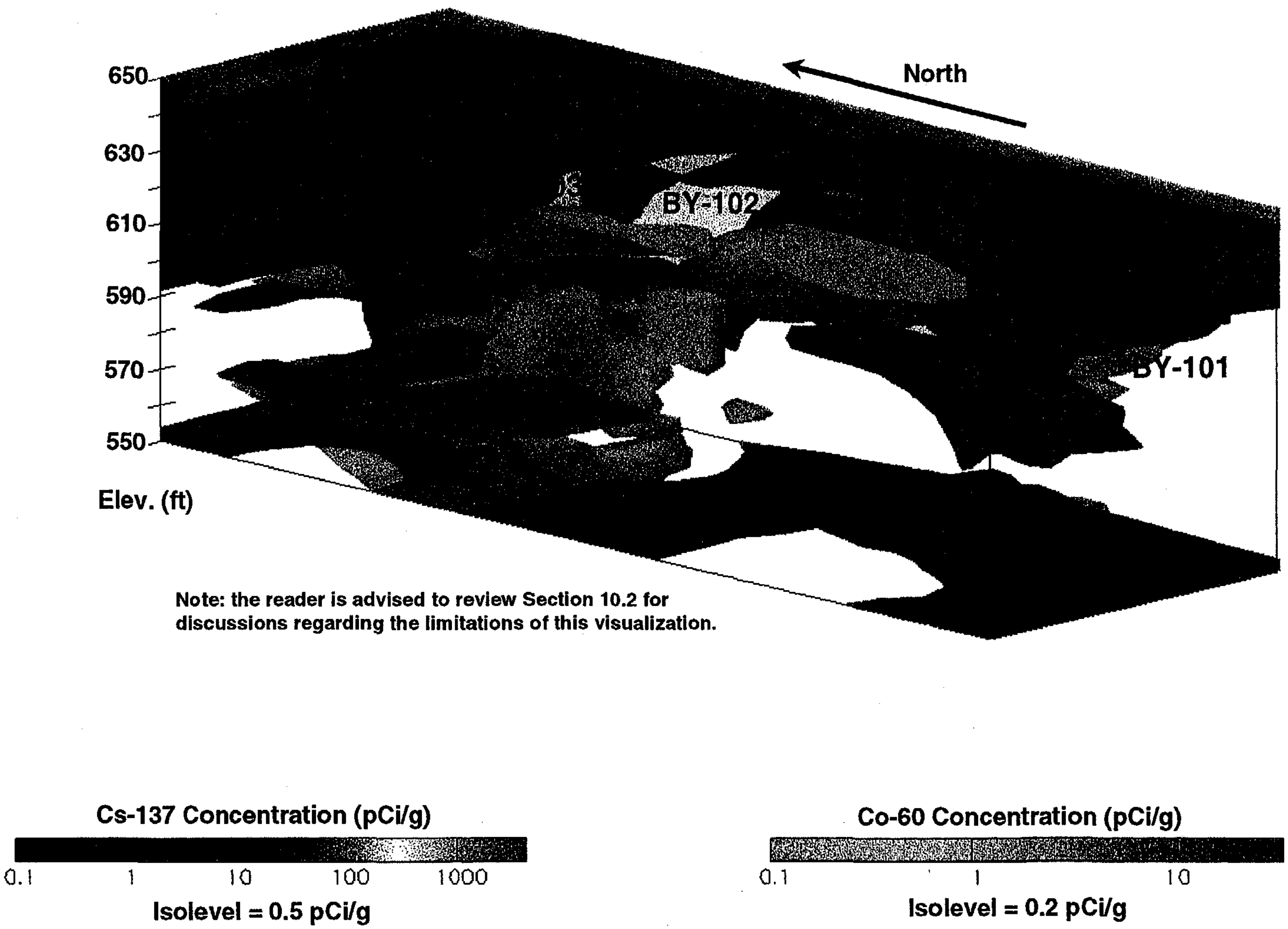
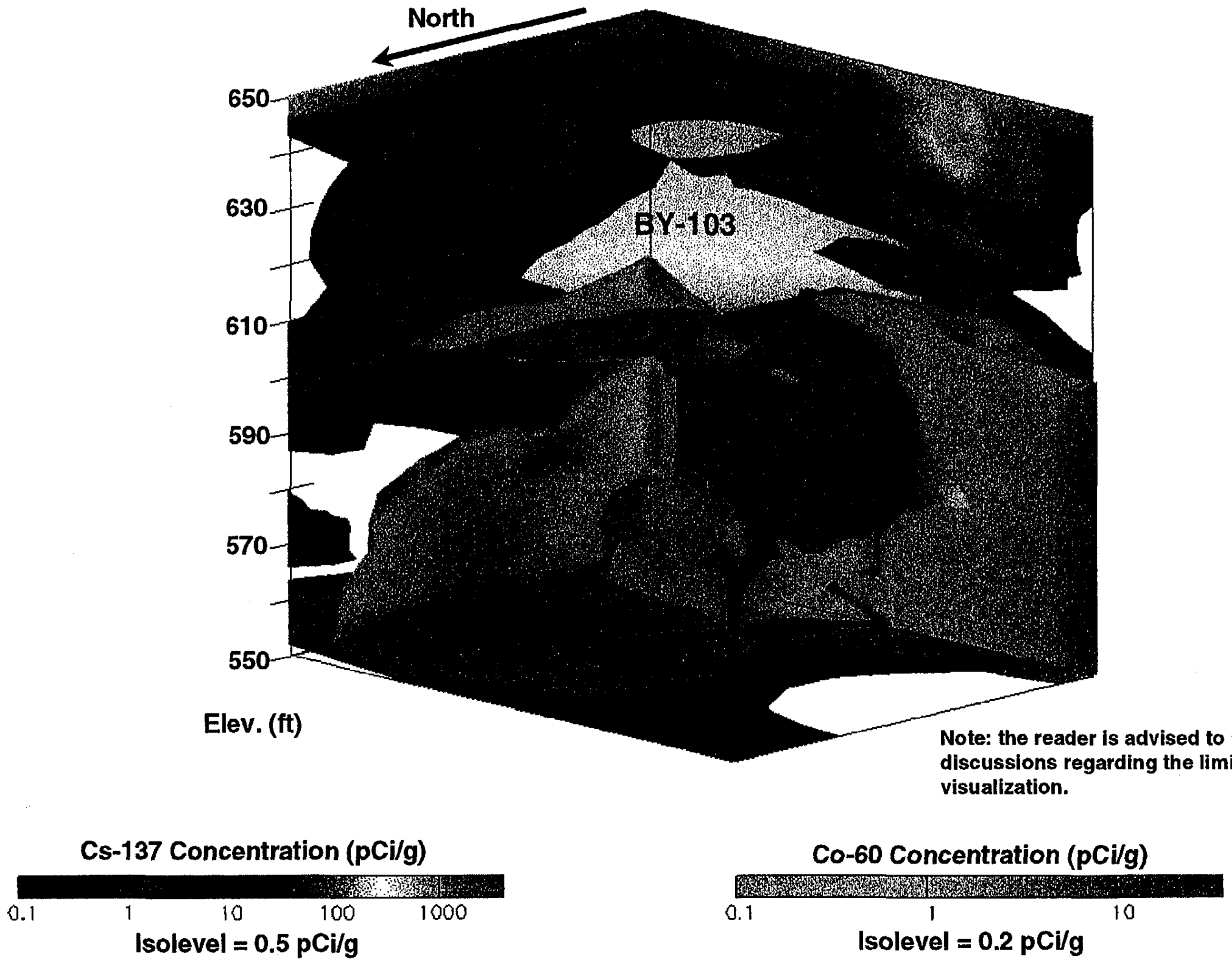


Figure 15-24. Visualization of Tank BY-103 Viewed From Below the Tank From the Northwest



Note: the reader is advised to review Section 10.2 for discussions regarding the limitations of this visualization.

Figure 15-25. Visualization of Tank BY-103 Viewed From Below the Tanks From the Southwest

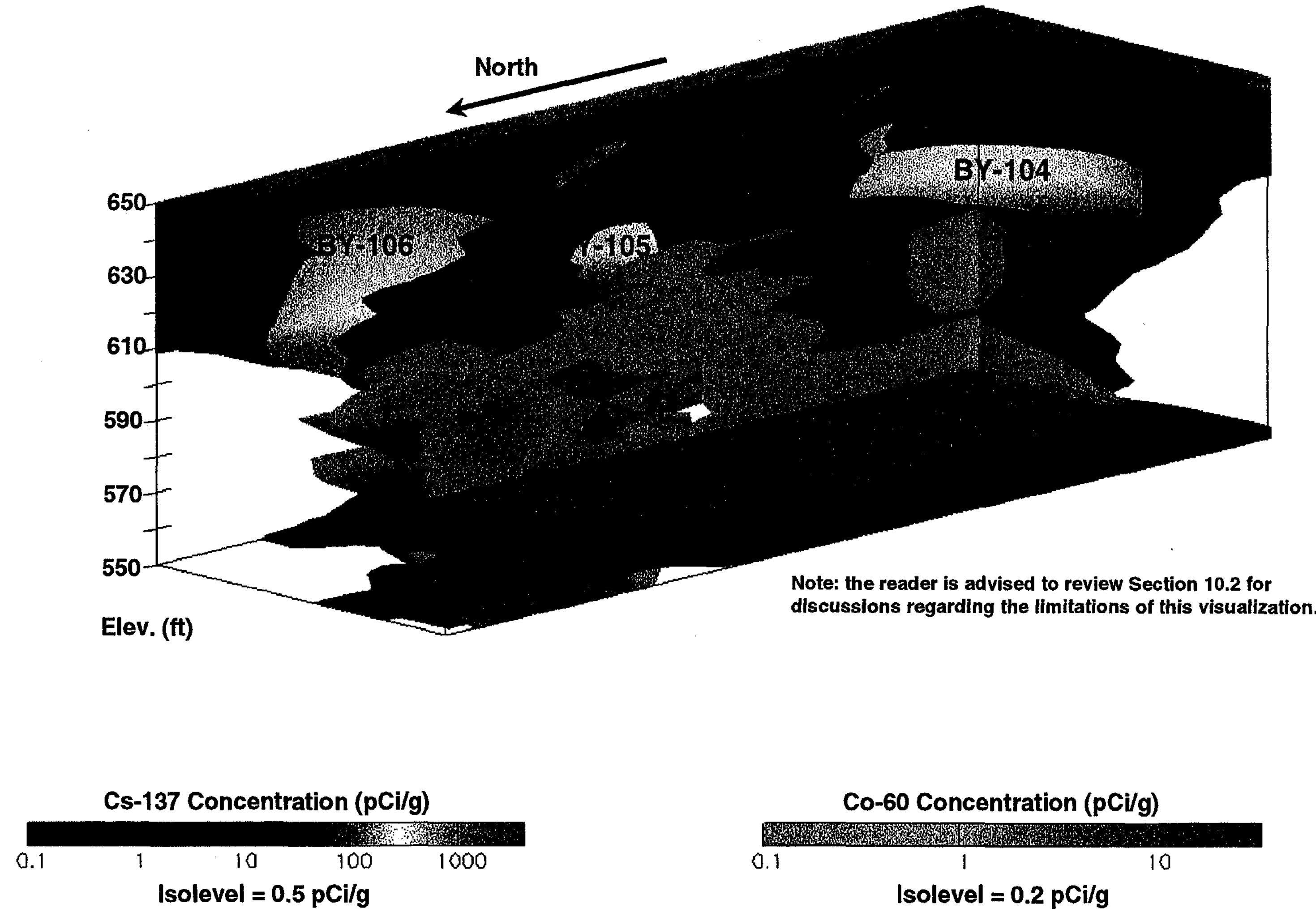


Figure 15-26. Visualization of Tanks BY-104, -105, and -106 Viewed from Below the Tanks From the Southwest

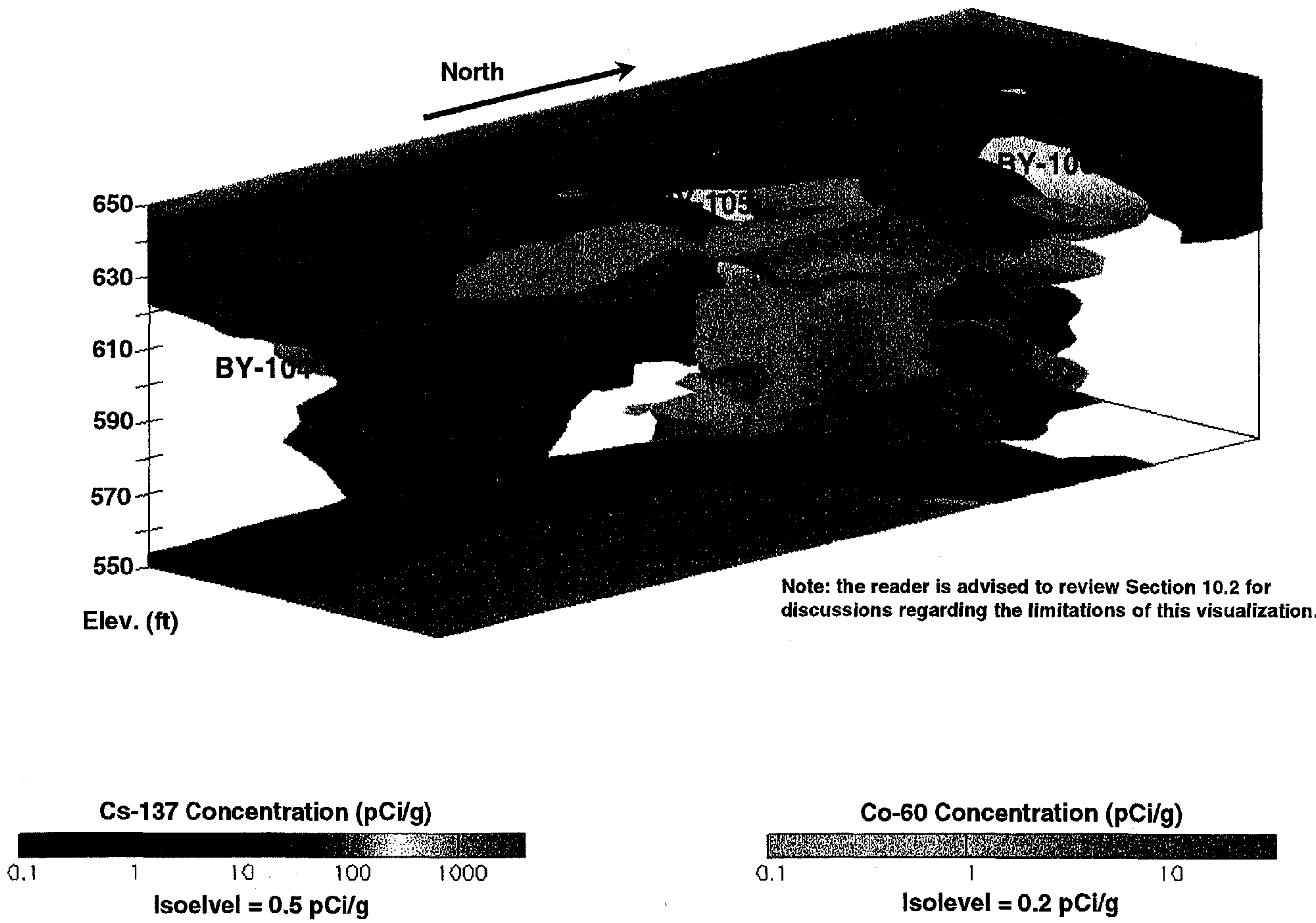


Figure 15-27. Visualization of Tanks BY-104, -105, and -106 Viewed From Below the Tanks From the Northeast

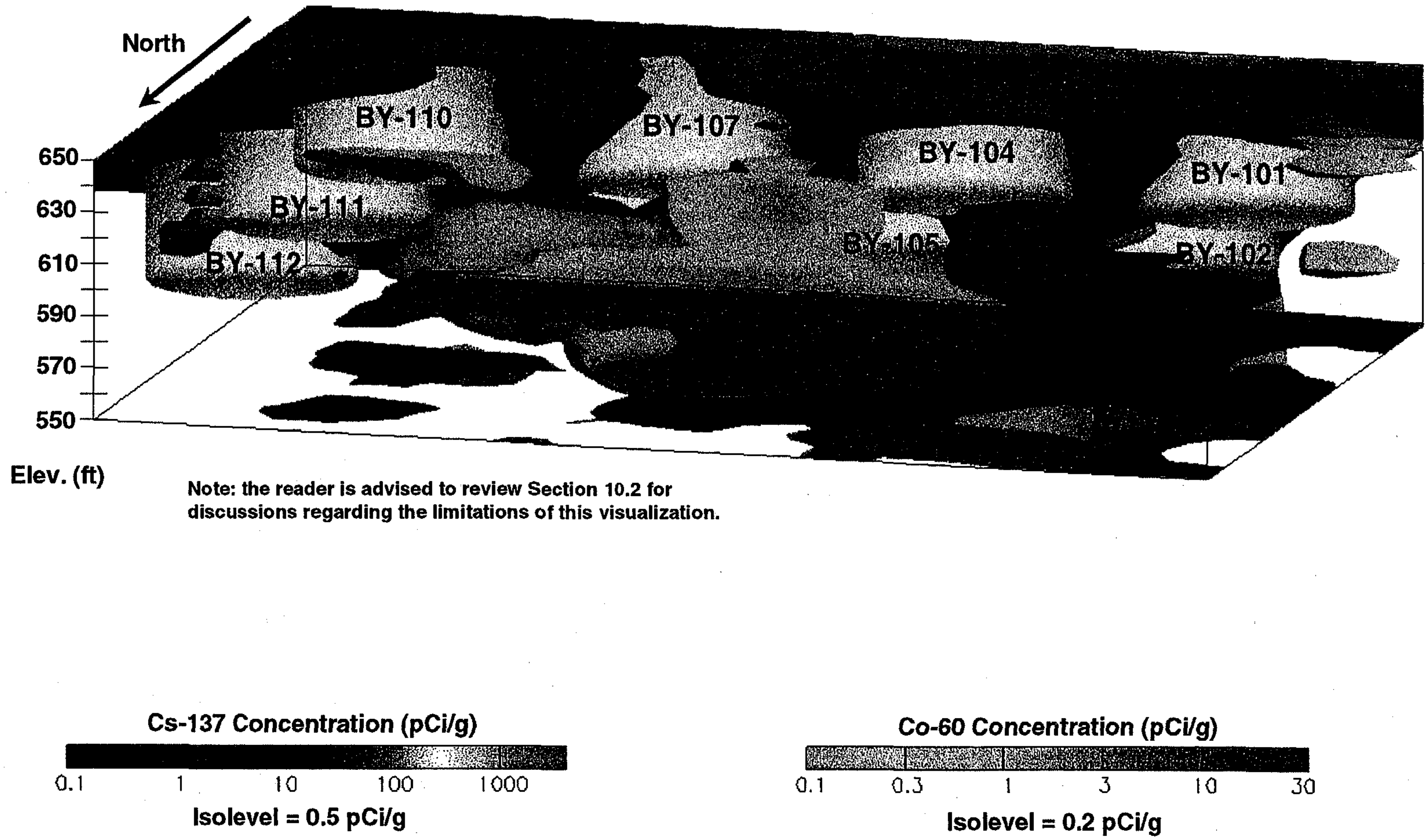


Figure 15-28. Visualization of Tanks BY-104, -105, and -106 Viewed From Below the Tanks From the South

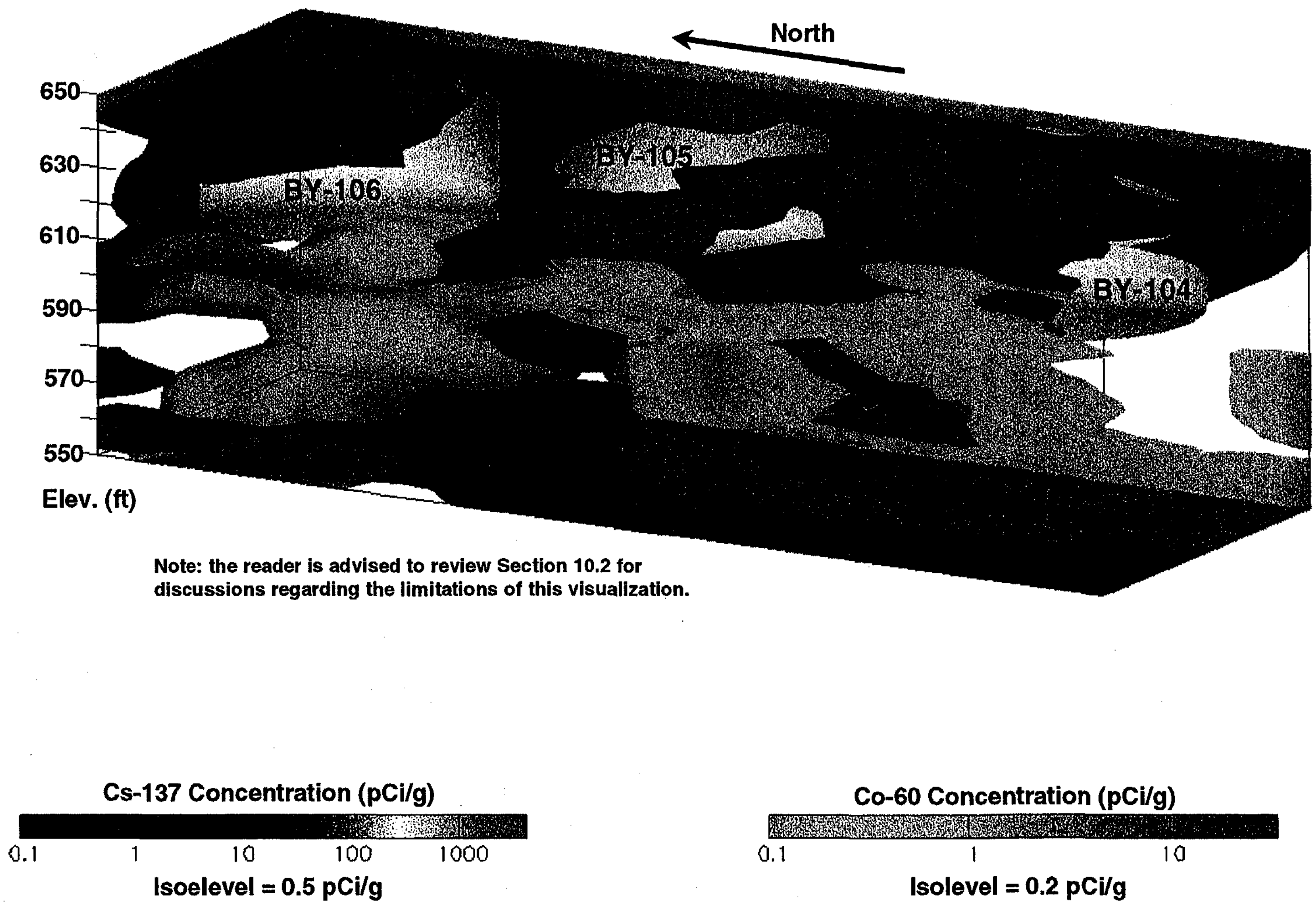


Figure 15-29. Visualization of Tanks BY-104, -105, and -106 Viewed From Below the Tanks From the North-Northwest

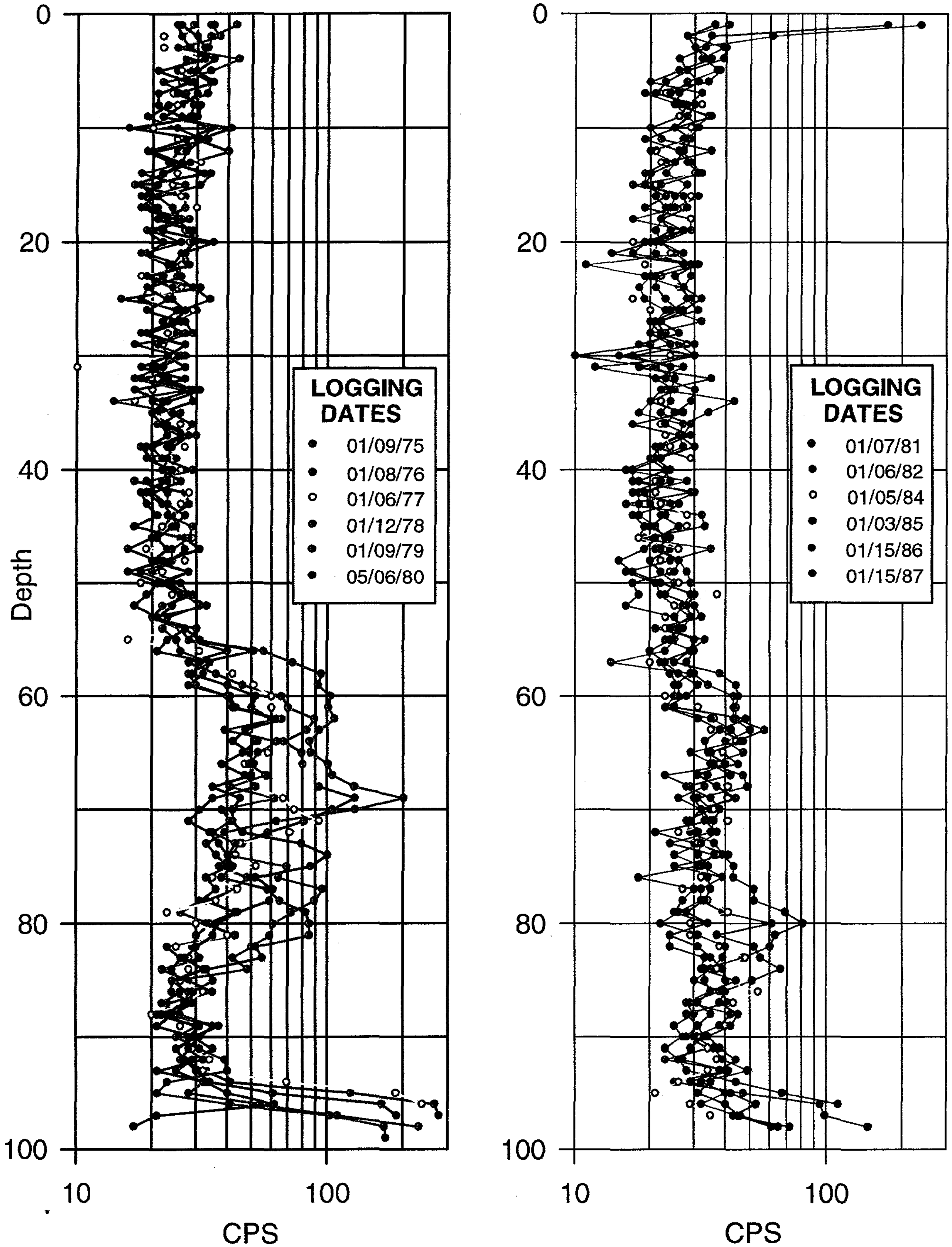


Figure 15-30. Historical Tank Farms Gross Gamma-Ray Logs for Borehole 22-05-09 From 1975 to 1987

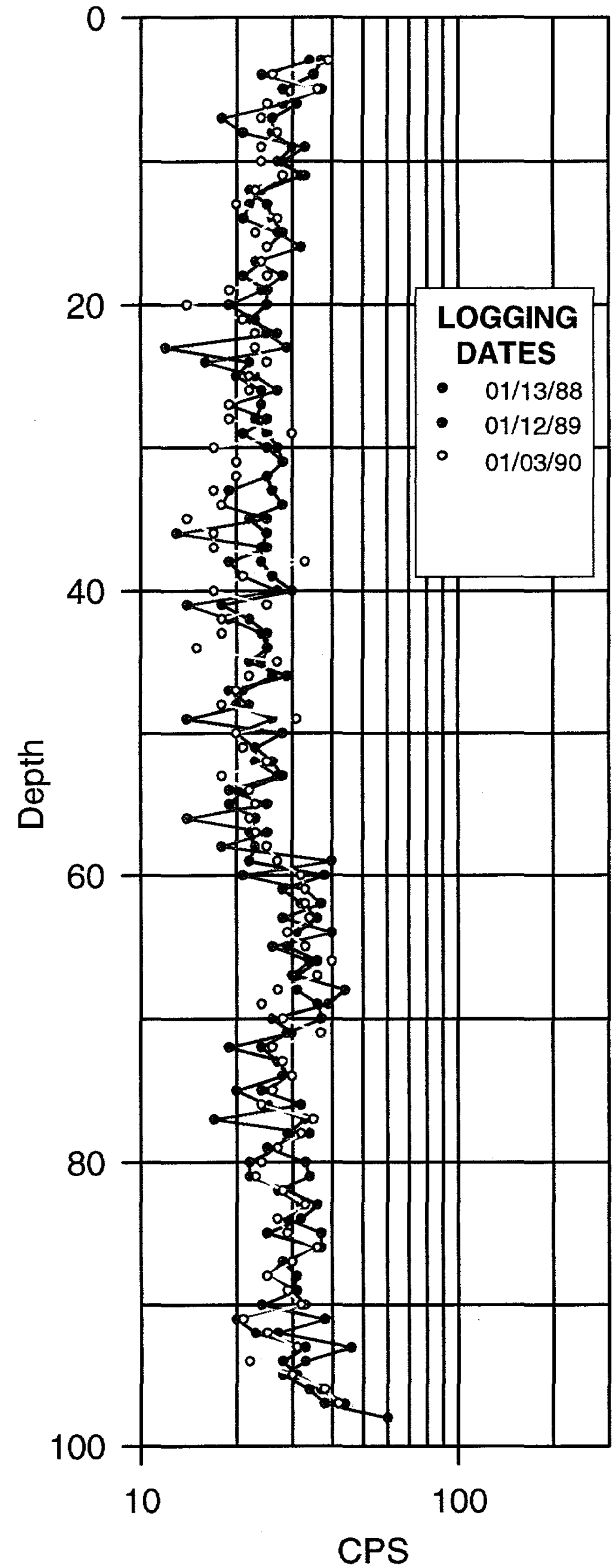


Figure 15-31. Historical Tank Farms Gross Gamma-Ray Logs for Borehole 22-05-09 From 1988 to 1990

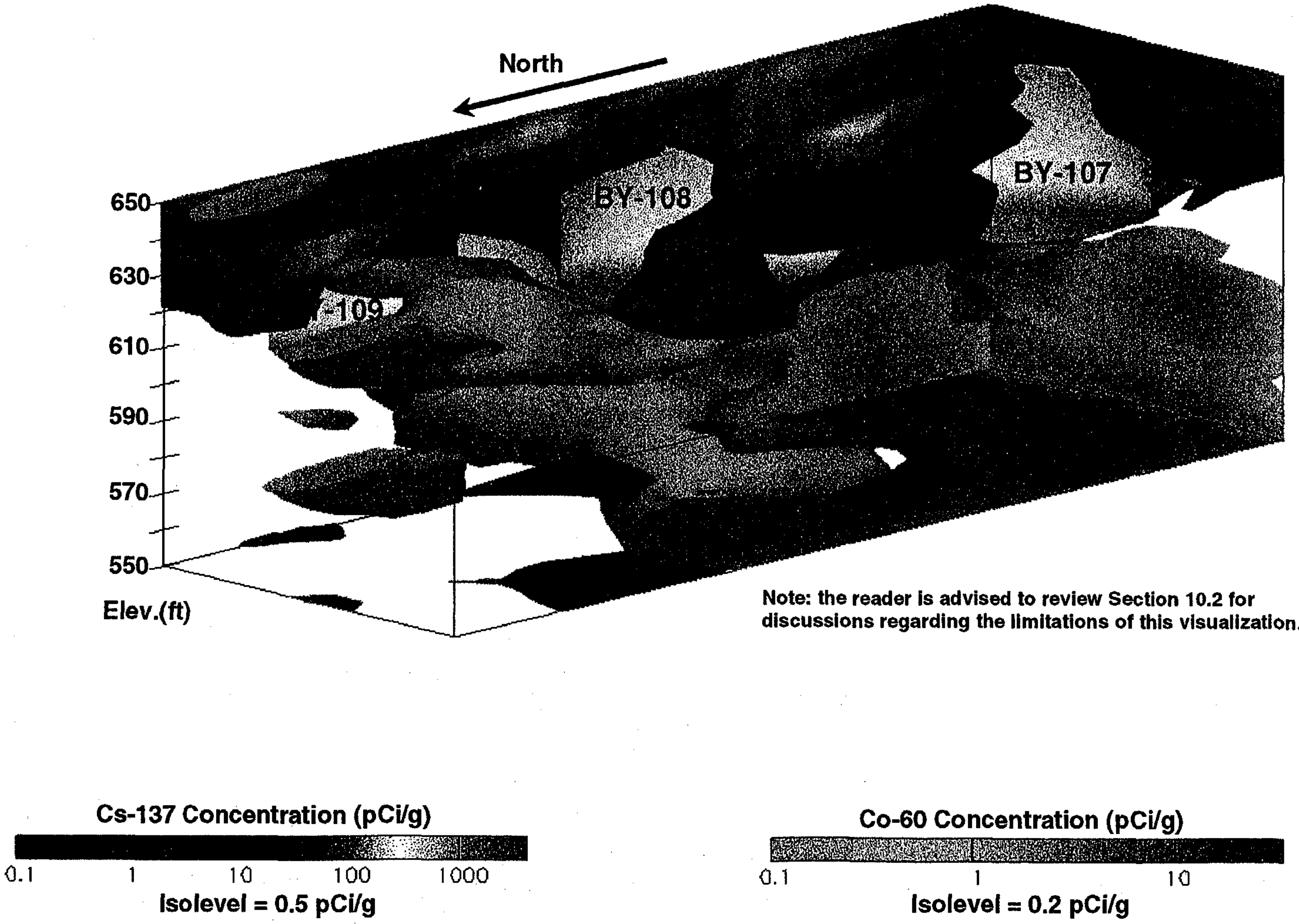


Figure 15-32. Visualization of Tanks BY-107, -108, and -109 Viewed From Below the Tanks From the Southwest

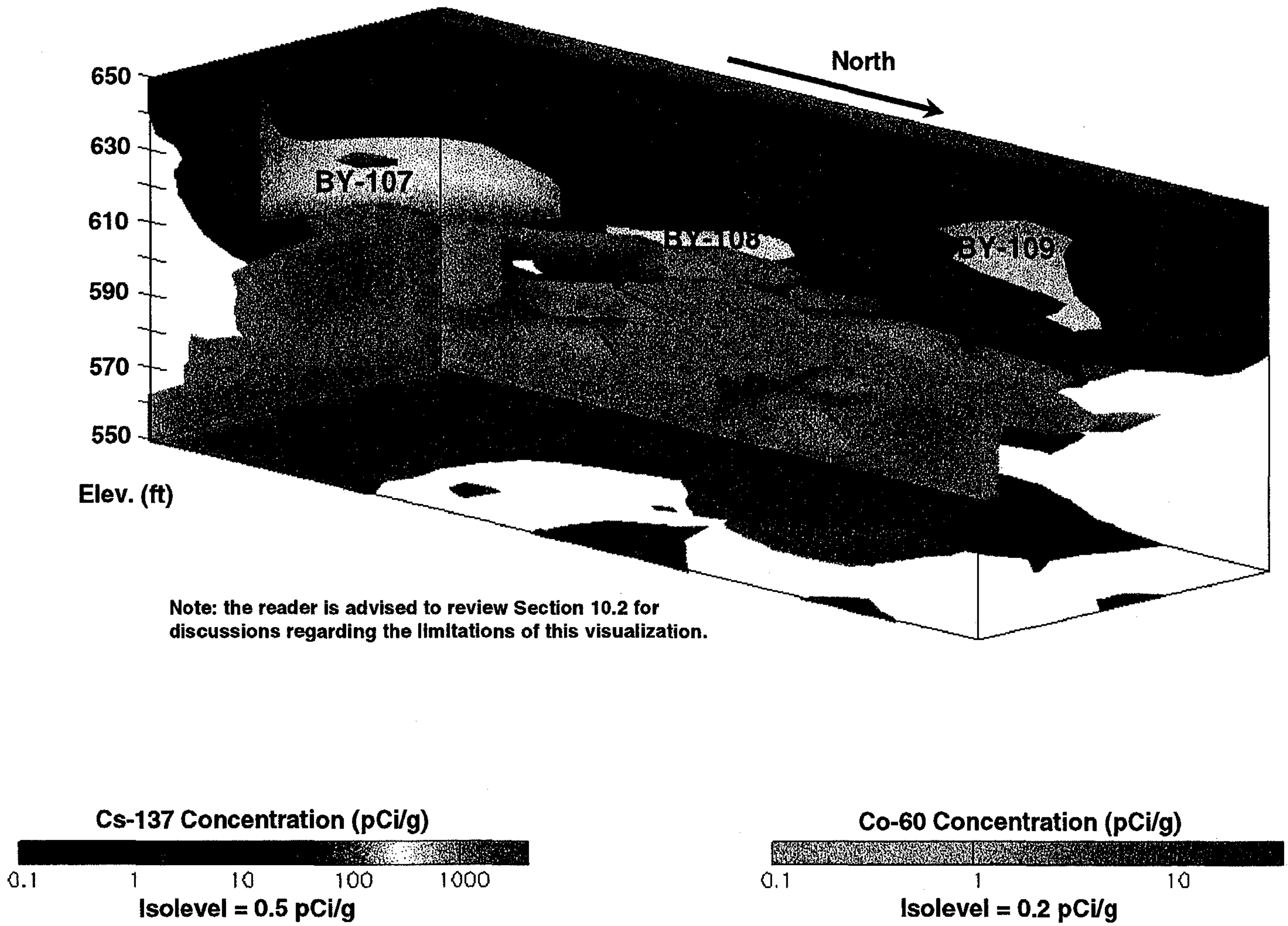


Figure 15-33. Visualization of Tanks BY-107, -108, and -109 Viewed From Below the Tanks From the Southeast

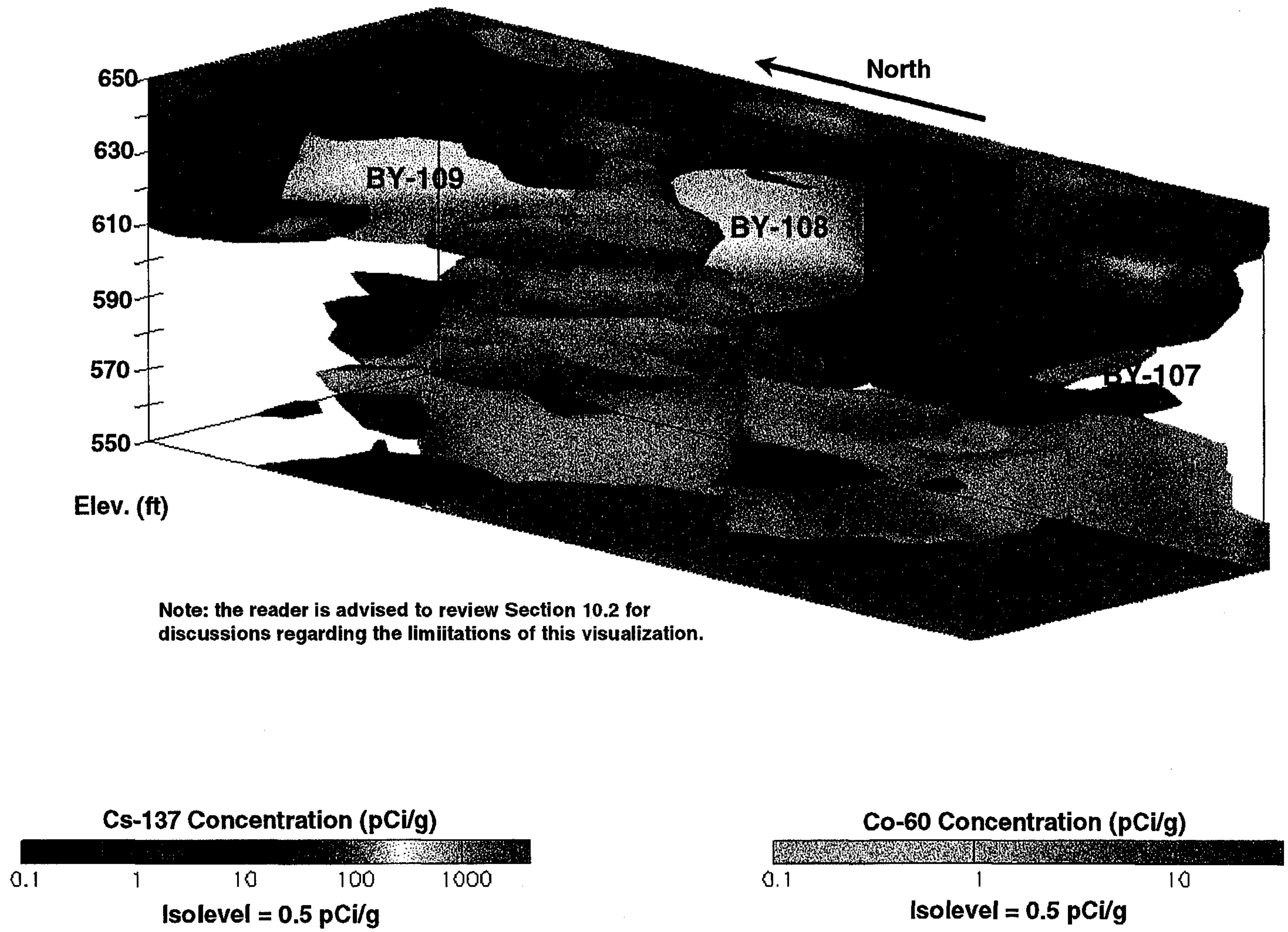


Figure 15-34. Visualization of Tanks BY-107, -108, and -109 Viewed From Below the Tanks From the Northwest

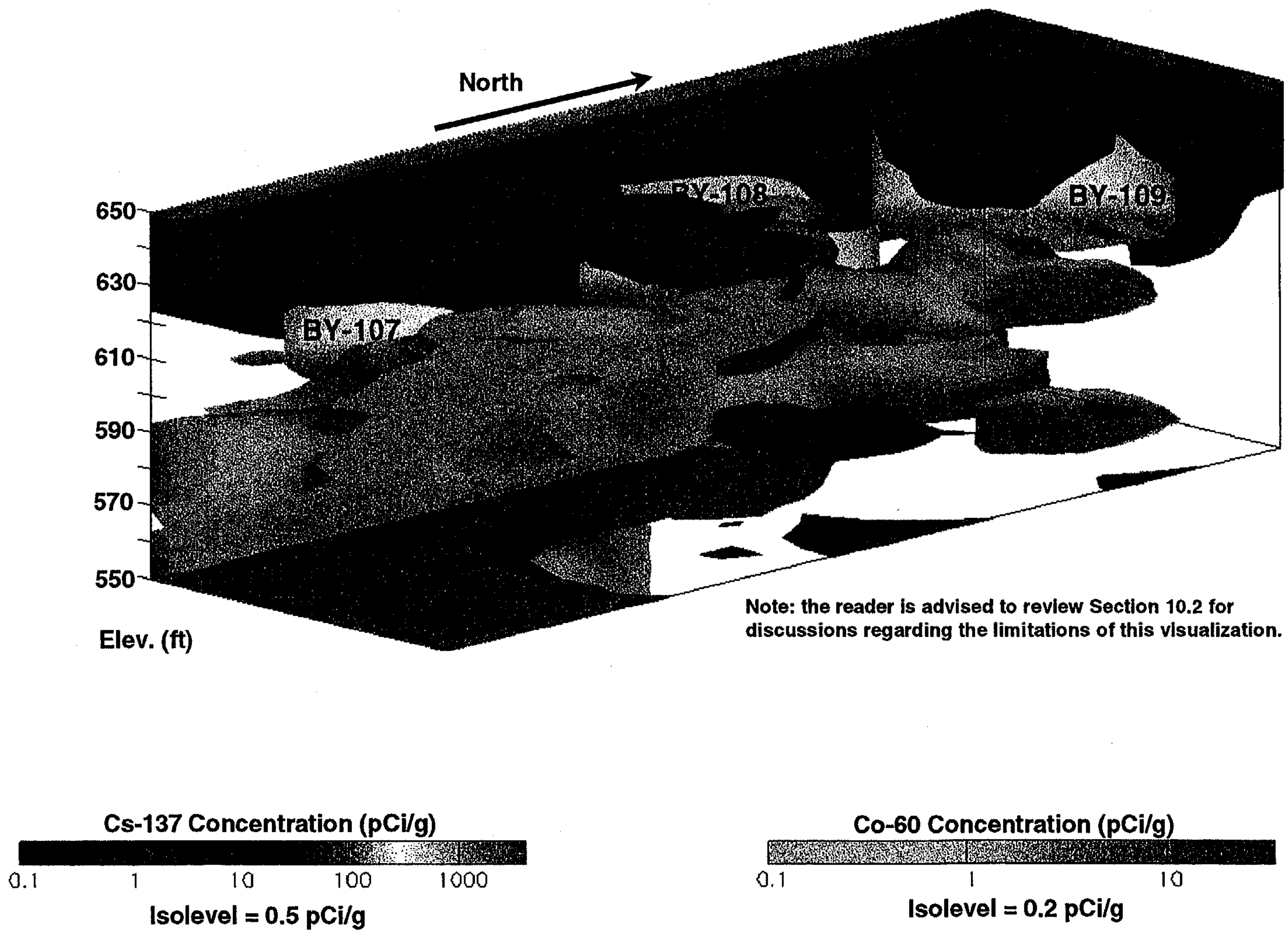


Figure 15-35. Visualization of Tanks BY-107, -108, and -109 Viewed From Below the Tanks From the Northeast

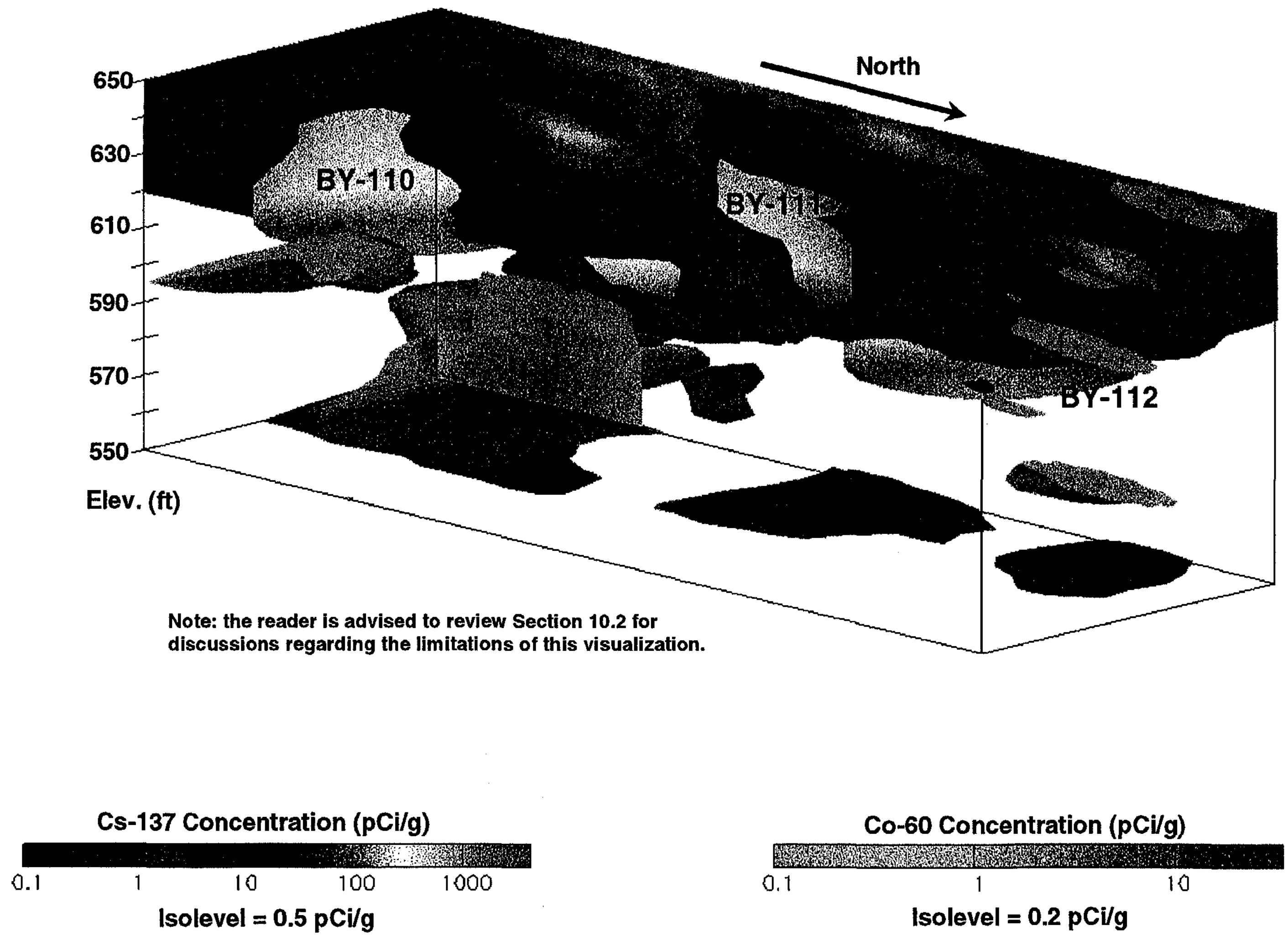


Figure 15-36. Visualization of Tanks BY-110, -111, and -112 Viewed From Below the Tanks From the Southeast

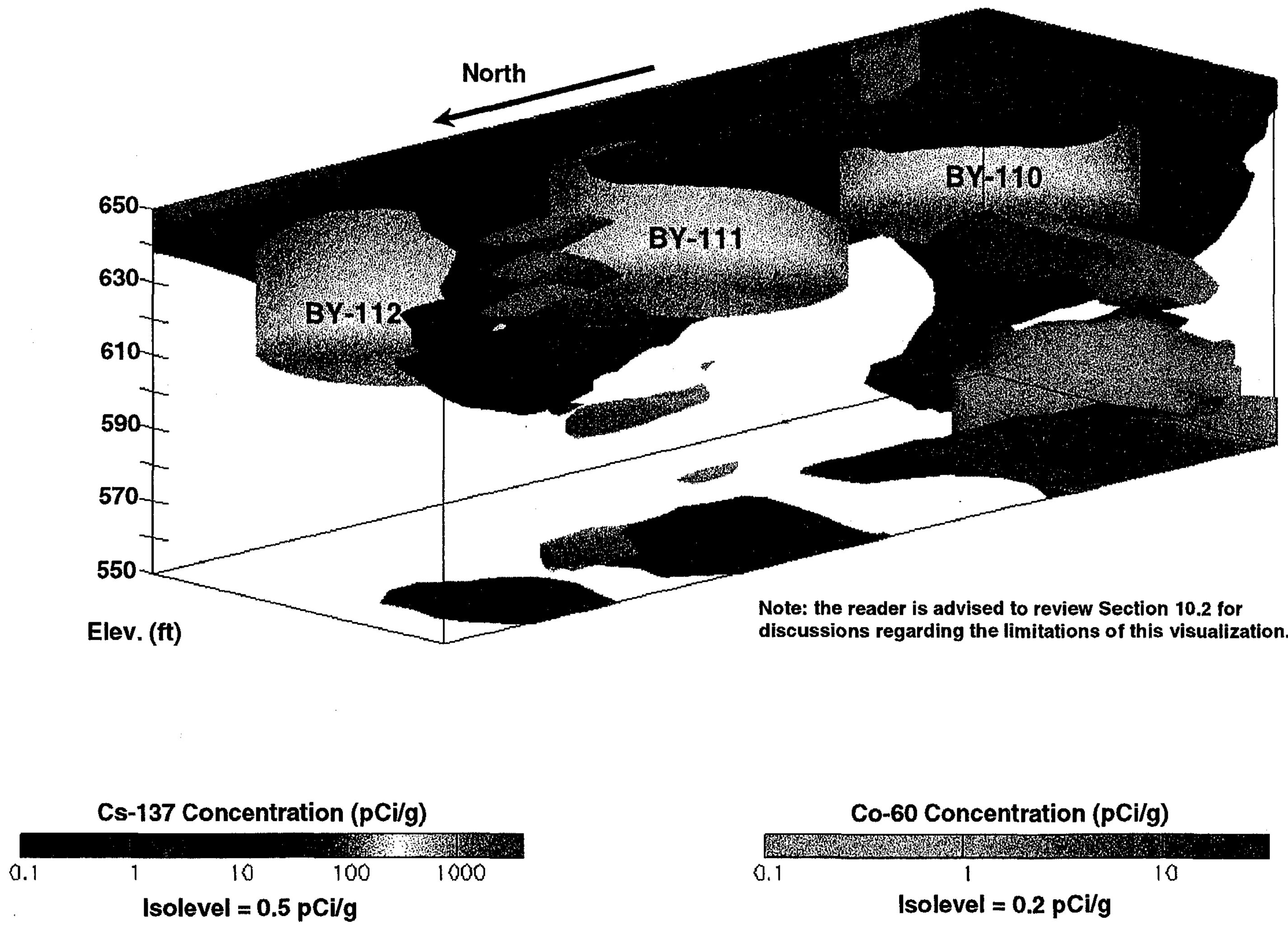


Figure 15-37. Visualization of Tanks BY-110, BY-111, and BY-112 Viewed From Below the Tanks From the Southwest

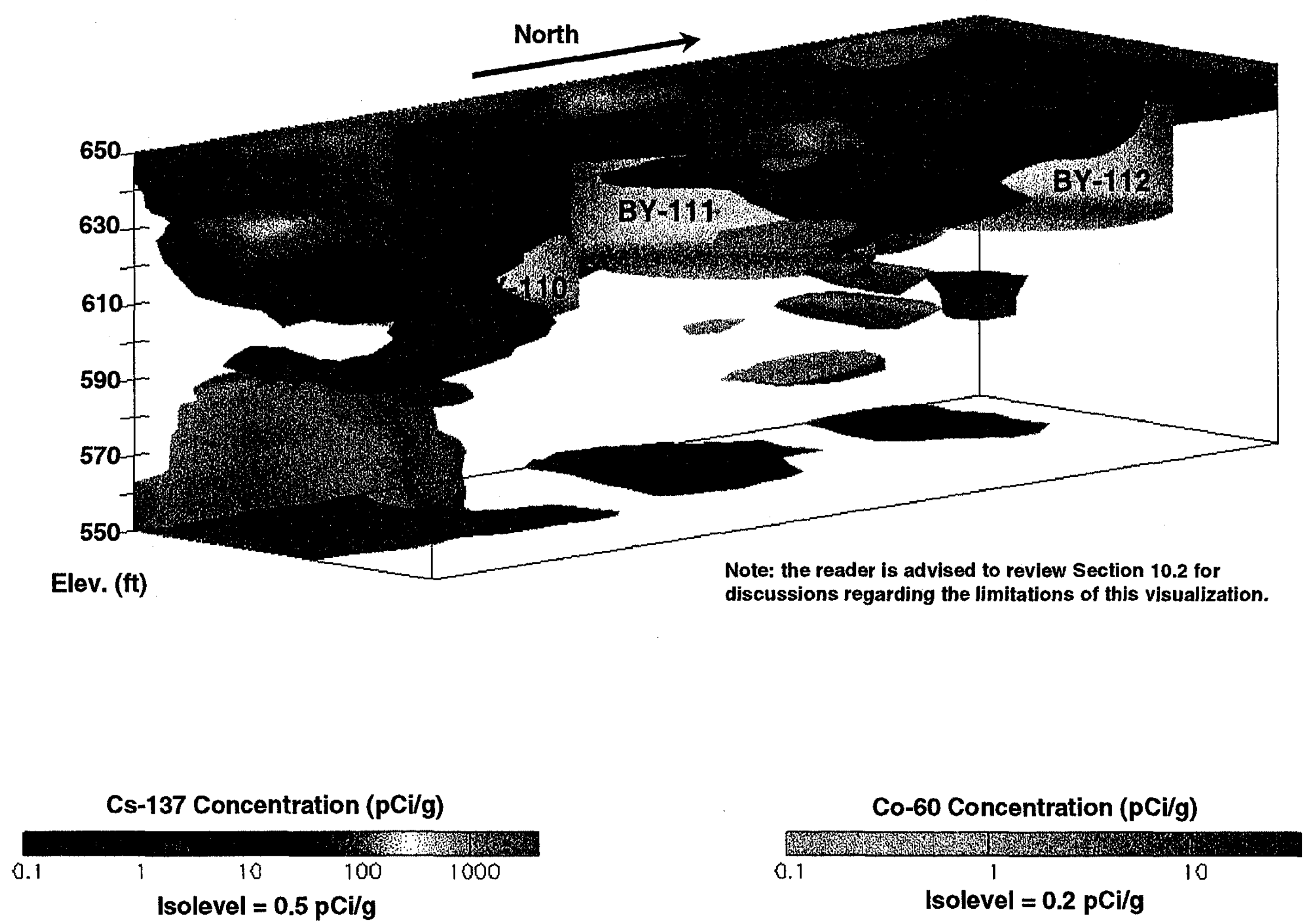


Figure 15-38. Visualization of Tanks BY-110, -111, and -112 Viewed From Below the Tanks From the Northeast

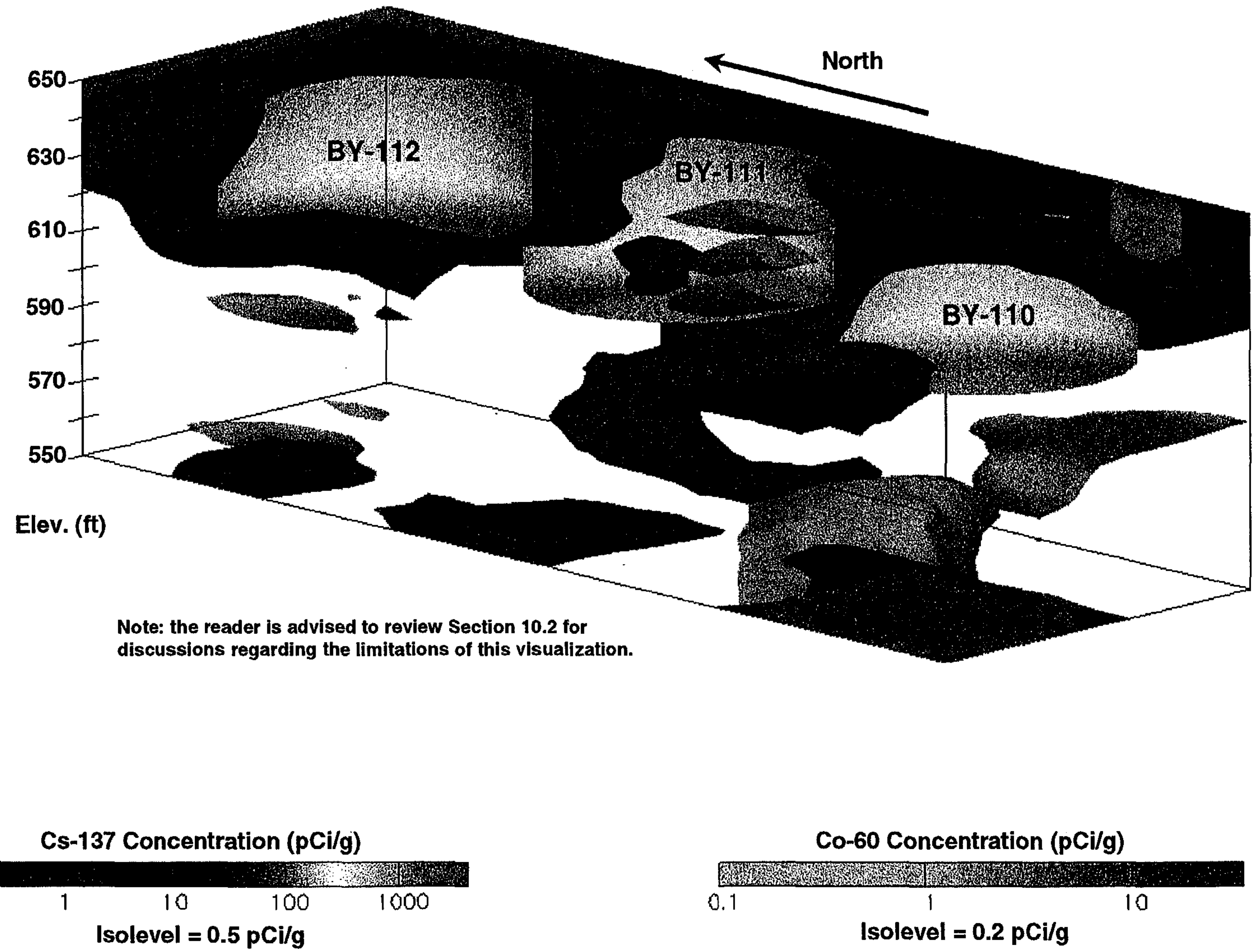


Figure 15-39. Visualization of Tanks BY-110, -111, and -112 Viewed From Below the Tanks From the Northwest

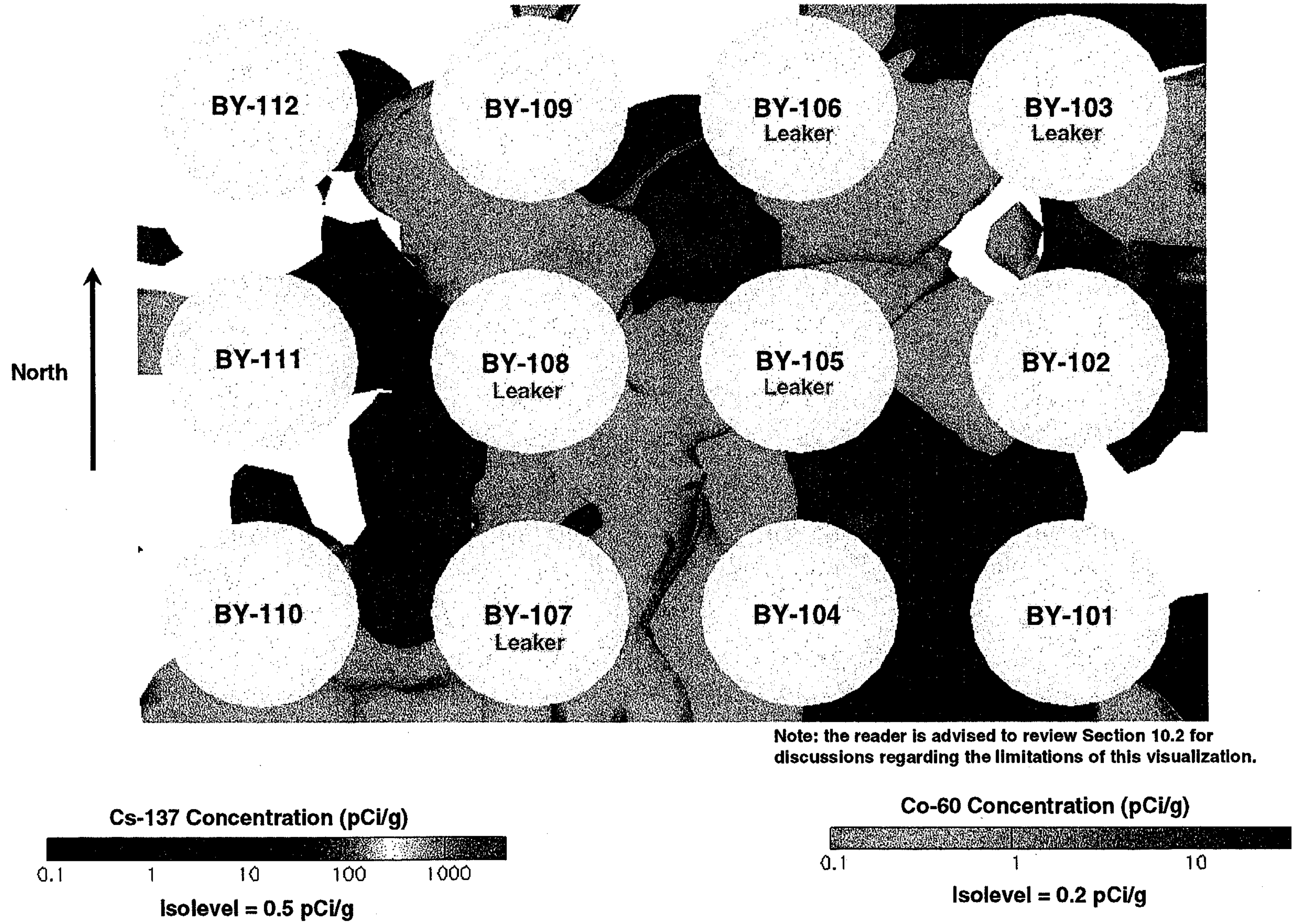
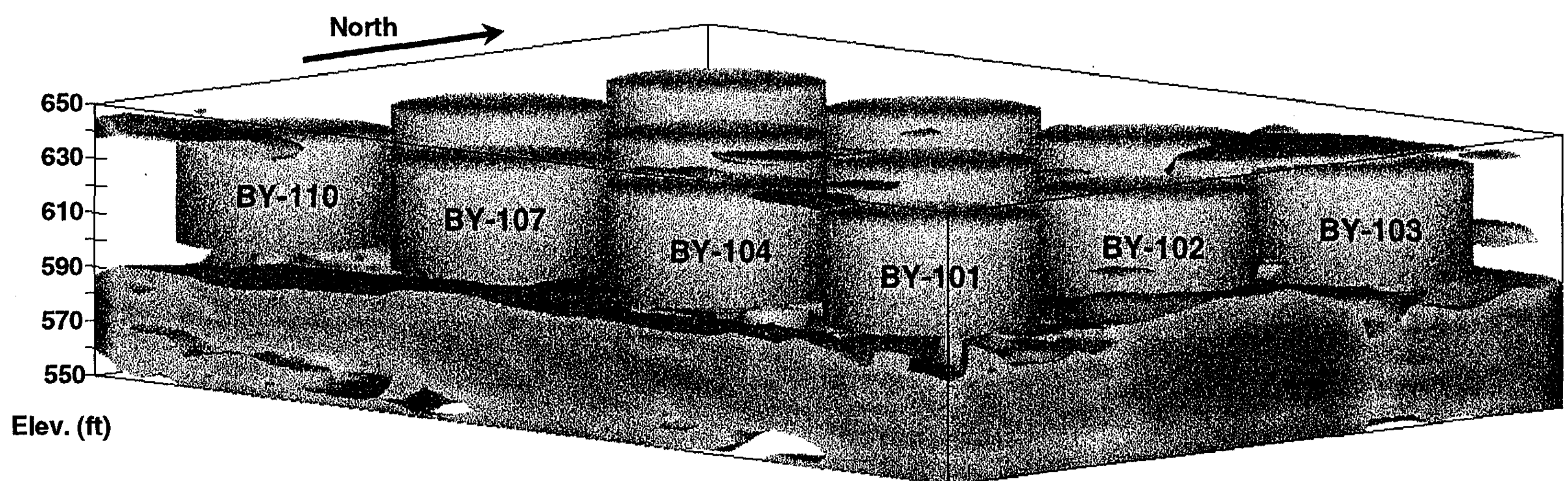


Figure 15-40. Visualization of ^{137}Cs and ^{60}Co Contamination at the Bases of the Tanks in the BY Tank Farm Viewed From Above



Note: the reader is advised to review Section 10.2 for discussions regarding the limitations of this visualization.

Figure 15-41. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g in Sediments Surrounding the Tanks in the BY Tank Farm Viewed From Above the Tanks From the Southeast

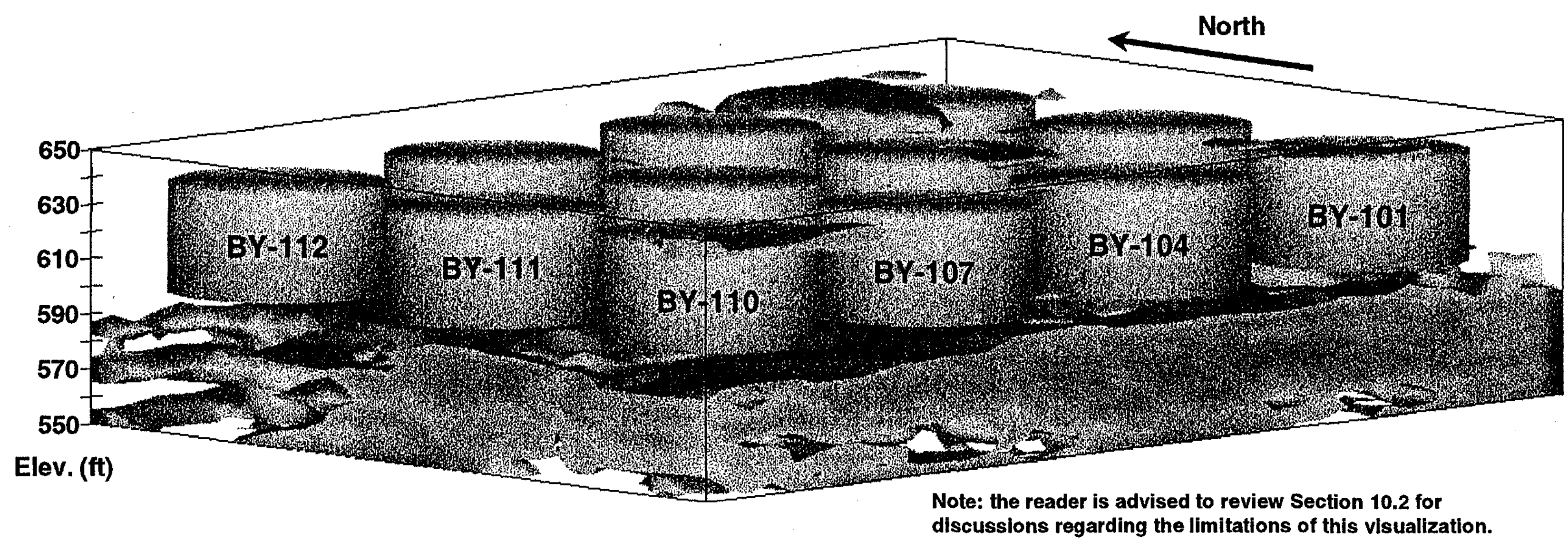


Figure 15-42. Visualization of ^{40}K Concentrations Greater Than 18 pCi/g in Sediments Surrounding the Tanks in the BY Tank Farm Viewed From Above the Tanks From the Southwest

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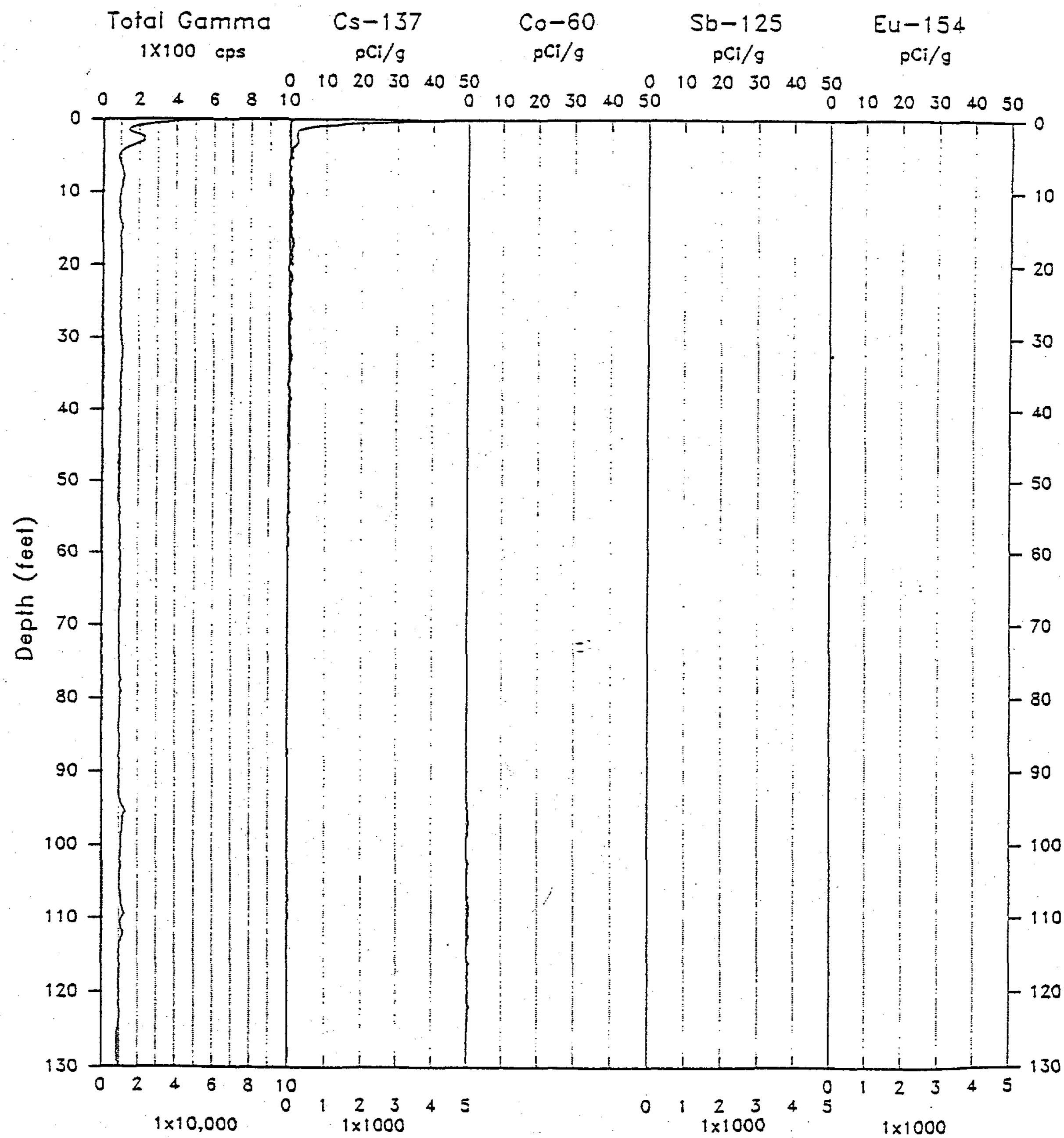
Appendix A

Geology and Hydrology Data from Groundwater Monitoring Boreholes

RLS Spectral Gamma-Ray Borehole Survey

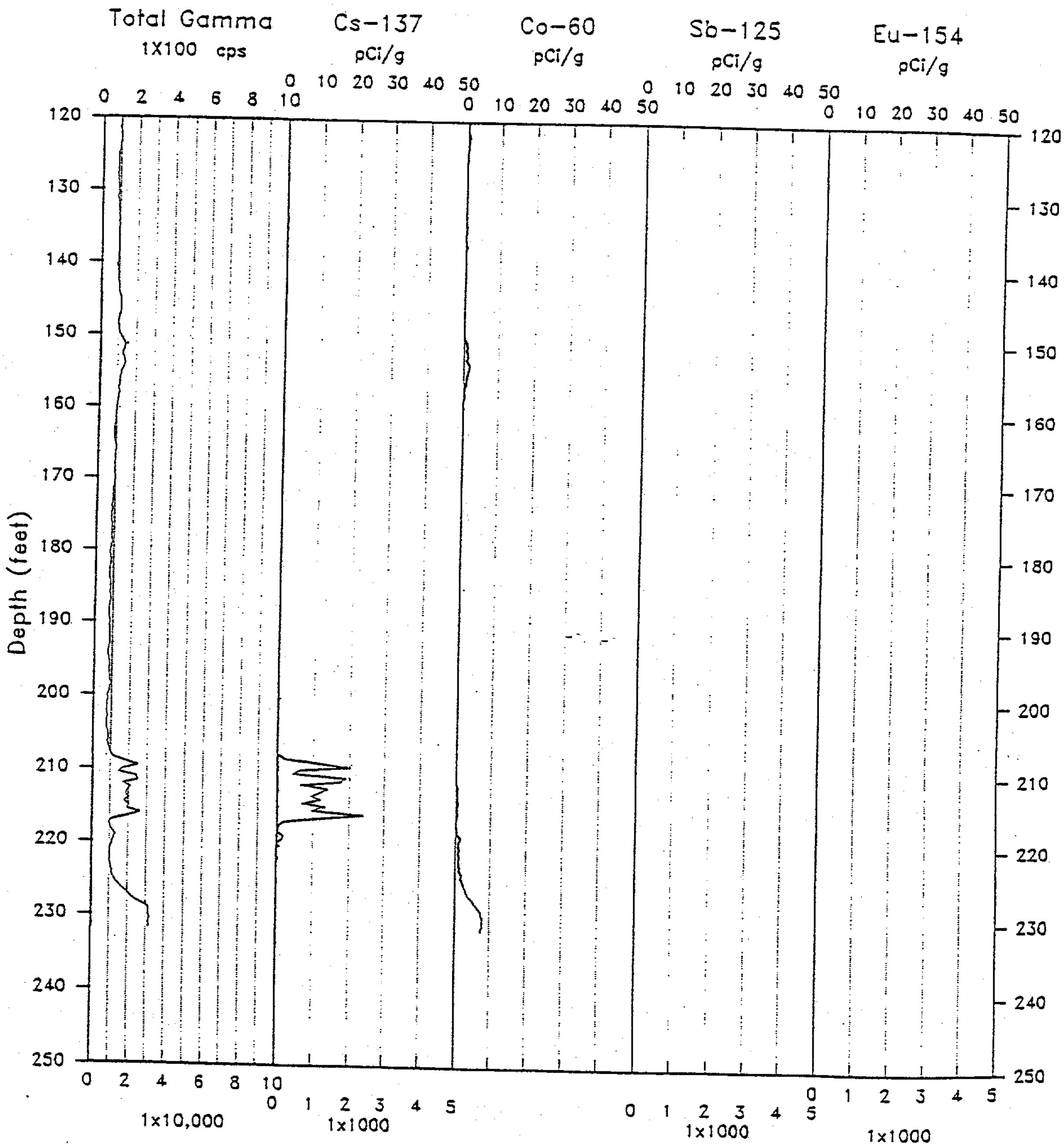
Project: 200-BP-1 Remediation — Log Date: Jul 20, 92

Borehole: 299-E33-13 — Anal. Date: Jul 31, 92



RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1 Remediation Log Date: Jul 20, 92
Borehole: 299-E33-13 Anal. Date: Jul 31, 92



RLS Borehole Survey Report

299-E33-13

Casing	Depth: 232'	Size: 8"	Thickness: 0.325
Water	Depth: 221.2'		
Survey	Depth: 0 - 76'	Mode: MSA 80 sec	Date: 7/20/92
	Depth: 75 - 186'	Mode: MSA 80 sec	Date: 7/21/92
	Depth: 185 - 231'	Mode: MSA 80 sec	Date: 7/22/92

General Notes:
The borehole survey was acquired in support of 200-BP-1 ground water monitoring well remediation. A liner casing will be installed and grouted into place to prevent spread of contamination.

Radon was detected on the logging cable wipes on 7/20/92 at the end of the borehole survey.

Standard Logging Configuration:
Cesium (Cs-137) was encountered in the borehole from 0 to 197 feet. The maximum decay activity detected in the borehole was 20 pCi/g at 211 feet.

Cesium decay activity at the surface appeared to be the maximum observed at any depth location in the survey. However, the values are erroneous because the geometry conditions are significantly different than the calibration standard.

Cobalt (Co-60) was observed in the borehole from 94 feet to the maximum survey depth of 232 feet. The maximum cobalt decay activity detected was 10 pCi/g at 232 feet.

No Antimony (Sb-125) was encountered in the borehole. The plot track is present only for the uniformity of the displayed data.

No Europium-154 (Eu-154) was encountered in the borehole. The plot track is present only for the uniformity of the displayed data.

9 1 1 1 8 7 7 0 3 9 5

Battelle Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E33-31 Geologist AIRHART, GOODWIN, LANIGAN, BLEGEN, BRANDENBERGER Page 1 of 2

Reviewed by [signature] Date 12-14-89

Construction Data: Description	Construction Data: Diagram	Depth in Feet	Geologic/Hydrologic Data: Diagram Litho.	Geologic/Hydrologic Data: Lithologic Description
154' 1/4" of 10" CARBON		5		MUDDY SANDY GRAVEL
STEEL CASING (REMOVED)		10		SANDY GRAVEL
CEMENT GROUT		15		MUDDY SANDY GRAVEL
257' 3/4" of 9" CARBON		20		" " "
STEEL CASING (REMOVED)		25		SANDY GRAVEL
		30		GRAVELLY SAND
		35		" "
		40		" "
		45		SANDY GRAVEL
		50		" "
		55		SAND
		60		SLIGHTLY GRAVELLY SAND
8-20 MESH BENTONITE		65		GRAVELLY SAND
CRUMBLES		70		SLIGHTLY GRAVELLY SAND
235.56'		75		SAND (F-VF)
4" DIA STAINLESS STEEL CASING		80		" "
		85		MUDDY SAND
		90		SAND
		95		SLIGHTLY GRAVELLY SAND
		100		" " "
		105		SAND
		110		"
		115		"
		120		"
		125		SLIGHTLY GRAVELLY SAND
		130		" " "

A-1800-18a rev 4/71

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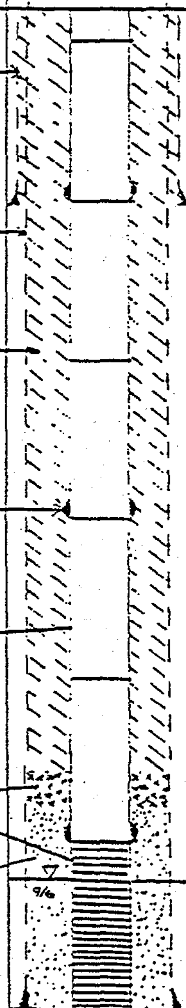
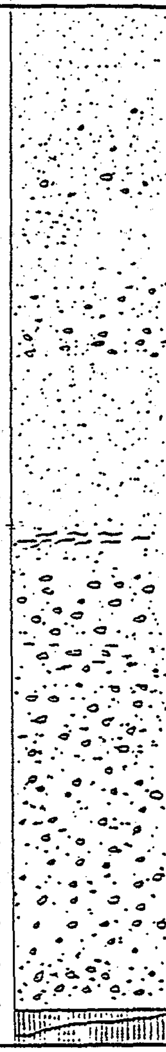
Battelle
Pacific Northwest Laboratories

AS-BUILT DIAGRAM

Well Number 299-E33-31 Geologist AIRHART GOODWIN LANIGAN, BLEGEN, BRANDENBERGER Page 2 of 2

Reviewed by [signature] Date 12-14-94





Construction Data: Description	Depth in Feet	Geologic/Hydrologic Data: Lithologic Description
154' 1/4" w- 10" CARBON	135	SAND
STEEL CASING WITH	140	"
DRIVE SHOE (REMOVED)	145	SLIGHTLY GRAVELLY SAND
	150	" "
257' 3/4" OC 8" CARBON	155	GRAVELLY SAND
STEEL CASING WITH	160	SAND
DRIVE SHOE (REMOVED)	165	SAND
	170	GRAVELLY SAND
8-20 MESH BENTONITE CRUMBLES	175	SANDY GRAVEL
	180	SAND
	185	"
	190	"
FACTORY-WELDED CENTRALIZERS	195	"
	200	" (CLAY LENS @ 200')
235.56'	205	SANDY GRAVEL
4" DIA. STAINLESS STEEL CASING	210	" "
	215	MUDDY SANDY GRAVEL
	220	SANDY GRAVEL
	225	" "
1/4" BENTONITE PELLETS	230	" "
4" STAINLESS STEEL SCREEN (10-SLOT CHANNEL-PACK)	235	" "
20-40 MESH COLORADO SILICA SAND	240	" "
	245	" "
BOTTOM OF 2" CASING AT 255.6' (REMOVED)	250	SANDY GRAVEL
BELOW GROUND LEVEL (RESTING ON BASALT)	255	" "
		BASALT @ 255.6'

A-1800-186 (2/87)

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WESTINGHOUSE HANFORD COMPANY

WELL NUMBER 299-E33-31 AREA 200 East

DATE 8-9-89

LOG RUN #1 LOG TYPE Analog Net Gamma

SURVEY COORDINATES N/A N N/A E

ELEVATION DATUM Top of Casing ELEVATION N/A

LOG MEASURED FROM Surface of Ground

LOCATION DESCRIPTION Outside of 241-BY West Fence, North Well of Pair

GROUND SURFACE ELEVATION NA

SURFACE TEMPERATURE 26.5°C WEATHER Pt. Cloudy, Sc. Showers

BOREHOLE INFORMATION

DRILLER	KEH		
DRILL RIG TYPE	Cable-Tool	BIT TYPE/DIAMETER	8"
BOREHOLE DIAMETER(S)/DEPTH	10" to 155' / 8" to 253'		
DEPTH DRILLER	-NA-	DEPTH LOGGER	252.8'
LIQUID LEVEL	245.18 (T/C)	LIQUID APPEARANCE	Cloudy
TEMPERATURE	18.6°C		

CASING RECORD

TYPE	10" Sch-40, Steel	INTERVAL	~154' to Surface
TYPE	8" Sch-40, Steel	INTERVAL	~253' to Surface
TYPE		INTERVAL	
TYPE		INTERVAL	

WELL SCREEN INTERVAL: -NA-

COMMENTS: Driller Depth Deleted

2nd Casing Log! See Other Data for 1st Run by PNL

Bottom of 10" Casing Approx -154.5

Depth Return Error ~4 in (High)

635

9 0 1 1 8 7 7 0 3 3 9

EQUIPMENT DATA

LOGGING COMPANY PNL

OPERATOR(S) V.L. McGinn

EQUIPMENT BRAND MLS (Gearhart-Owen Ind.) EQUIPMENT TYPE Analog

TOOL TYPE NGI (Nat. Gamma) BASE CALIBRATION DATE 12-88

SERIAL NO. CG 27A97 CALIBRATION REFERENCE WHC-EP-0246

CALIBRATION / PROBE FACTOR 8.53x10⁻² eU ppm/cps

DEAD TIME 7.4 μSec [from EP-0246] WARM UP TIME continuous since 8⁰⁵ AM

LOGGING INFORMATION

LOG INTERVAL FROM -253' TO -3.6'

RERUN(S) -253' to -220'

PRE SURVEY CALIBRATION POSITION 1 ~835 ℓ, FS=5000 (349 eU ppm) POSITION 2 ~342, FS=5000 (135 eU ppm) BACKGROUND ~212, FS=5000 cps (105 c/s)

LOGGING SPEED 5 ft/min

START TIME 10²⁰ AM COMPLETION TIME 11¹⁵ AM

CHART SPEED(S), FT/IN. 10 ft/in

CHART RECORDER HORIZONTAL SCALE, CPS/IN. 50 cps/in, FS=500

RERUN SCALES, CPS/IN. 50 cps/in

TIME CONSTANT(S) 1 sec

POST SURVEY CALIBRATION POSITION 1 ~812, FS=5000 (349 eU ppm) POSITION 2 ~352, FS=5000 (128 eU ppm) BACKGROUND ~20.5 ℓ, FS=5000 (105 c/s)

PERCENT CHANGE: POSITION 1 -0- 0% POSITION 2 -10 ℓ 5.9%

COMMENTS: High Bkgd. due to "Shine" from BY Tank Farm, used FS=5000 Range on Ratemeter. Pre & Post Survey Check is acceptable, due in part to High "Rad. Shine" from BY-Farm

WITNESSED AND VERIFIED BY: [signature] 8/9/89

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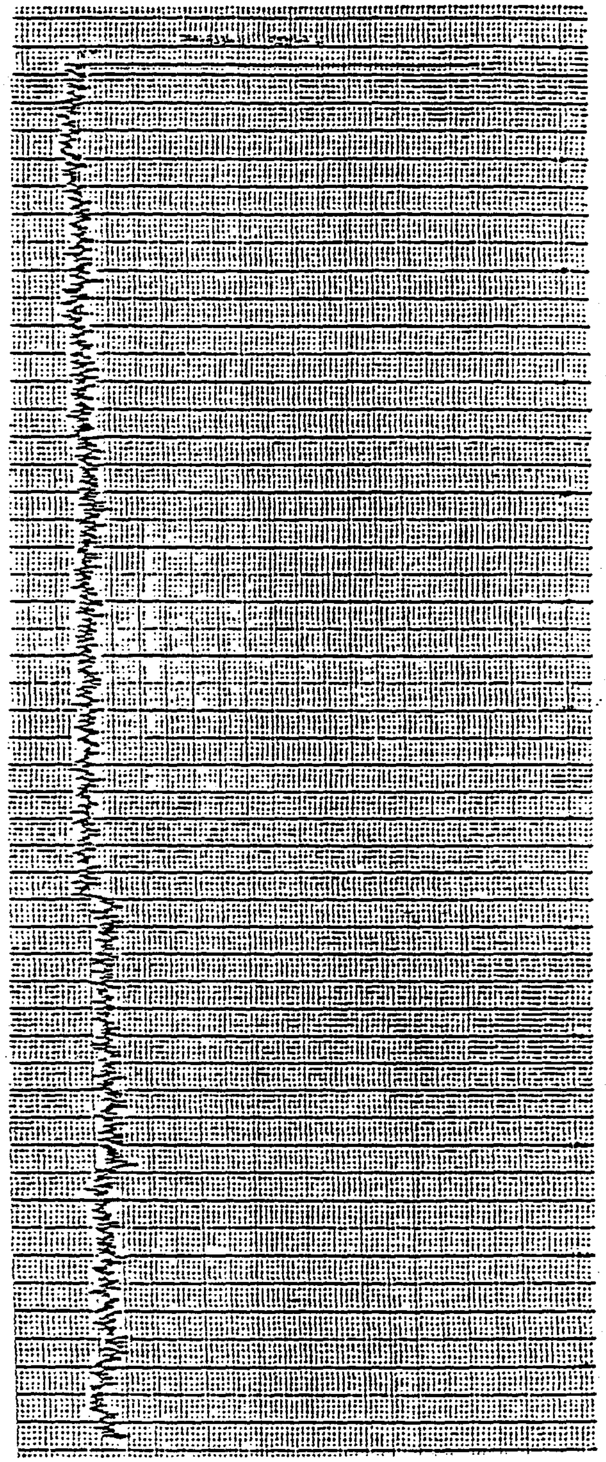

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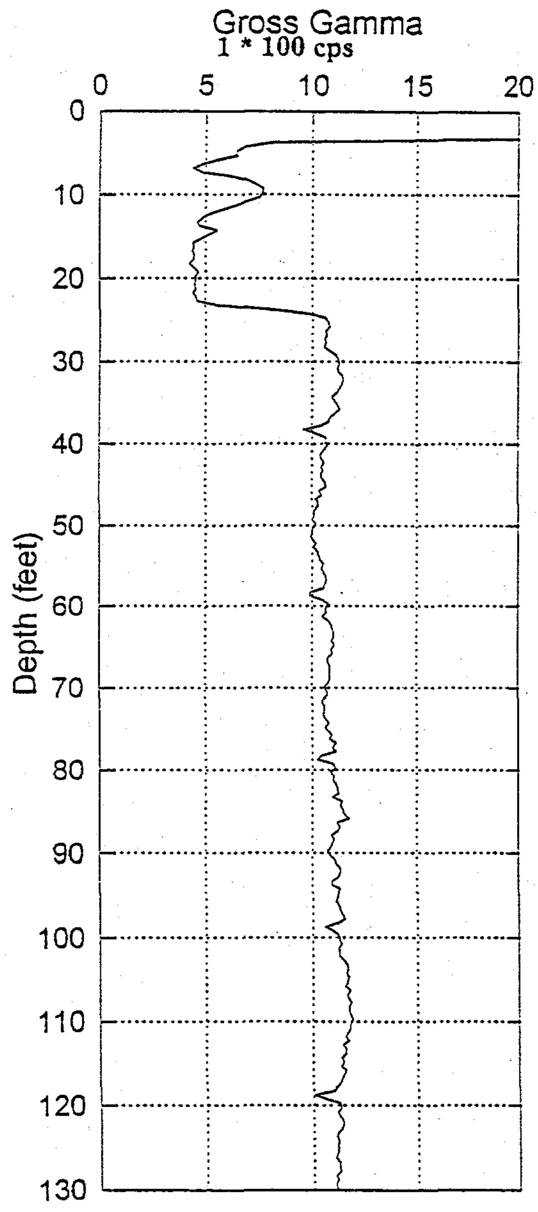
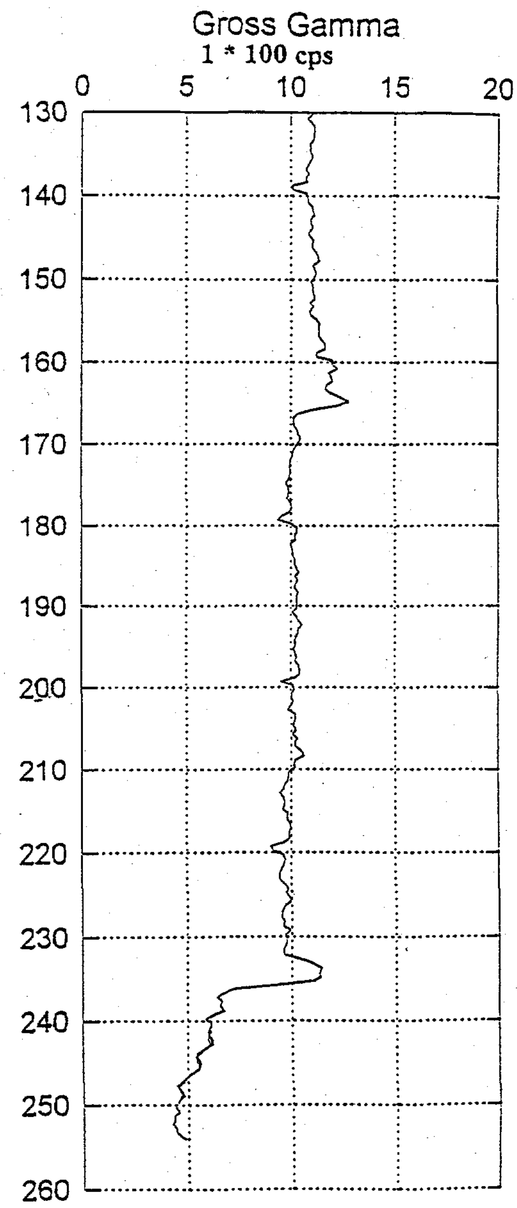
NaI Gamma-Ray Borehole Survey

Location: W of BX Tanks

Borehole: 299-E33-31

Log Date July 31, 1995



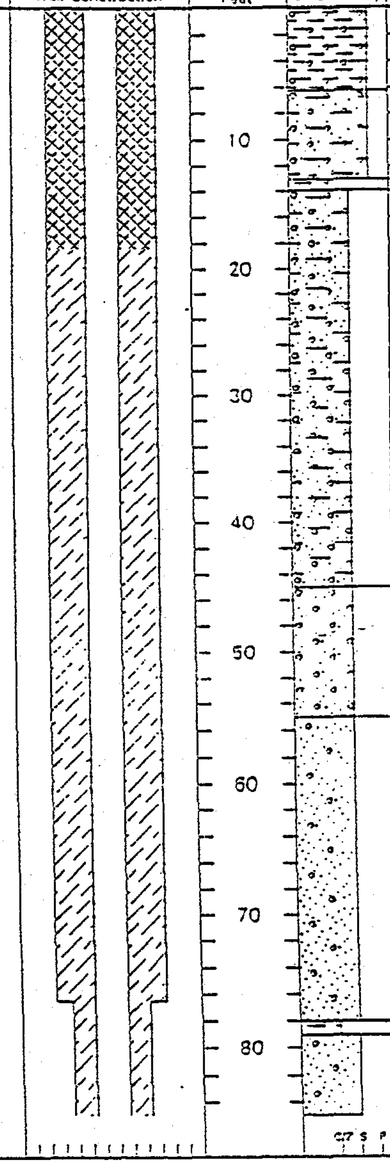


WELL SUMMARY SHEET

Boring or Well No. 299-E33-38
Northing 137594.78 Easting 573591.39
Sheet 1 of 3

Location 200 East	Project 200-BP-1
Elevation 629.97	Drilling Contractor Kaiser Eng. Hanford
Driller Dave Garcia	Drilling Method and Equipment Cable Tool Walker Neer
Prepared by ____ (Sign/Print Name)	Reviewed By ____ (Sign/Print Name) Date ____

CONSTRUCTION DATA — Description / Well Construction | **Depth in Feet** | **GEOLOGIC/HYDROLOGIC DATA** — Graphic Log / Lithologic Description



Construction Data — Description:

- Portland Cement Pad 0-2.7'
- Portland Cement Grout from 2.7 to 18.4'
- 12" Temp. Carbon Steel Casing set at 76.5'

Lithologic Description:

- 0-6.2' silty GRAVEL
- 6.2'-13.1' silty sandy GRAVEL
- 13.1'-13.9' SILT
- 13.9'-45' slightly silty gravelly SAND
- 45'-55' gravelly SAND
- 55'-78' slightly gravelly SAND
- 78'-79' SILT
- 79'-165' slightly gravelly SAND

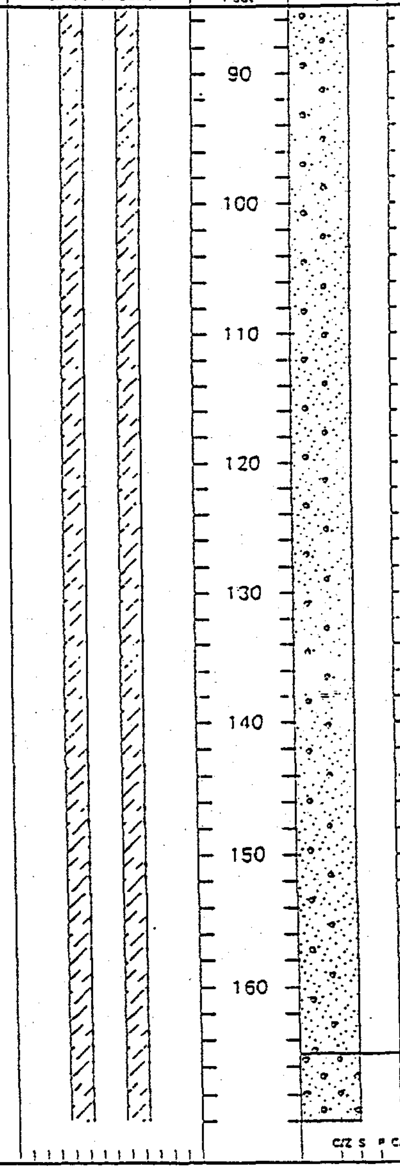
A-1

WELL SUMMARY SHEET

Boring or Well No. 299-E33-38
Northing 137594.78 Easting 573591.39
Sheet 2 of 3

Location 200 East Project 200-BP-1
Elevation 629.97 Drilling Contractor Kaiser Eng. Hanford
Driller Dave Garcia Drilling Method and Equipment Cable Tool Walker Neer
Prepared by ____ (Sign/Print Name) Reviewed By ____ (Sign/Print Name) Date ____

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description



8-20 Mesh Bentonite Crumbles 18.4'-208.1'

slightly gravelly SAND

T-304: 4"ND, schd. 5. SS. Permanent Casing from 0-218.55'

165'-183' gravelly SAND

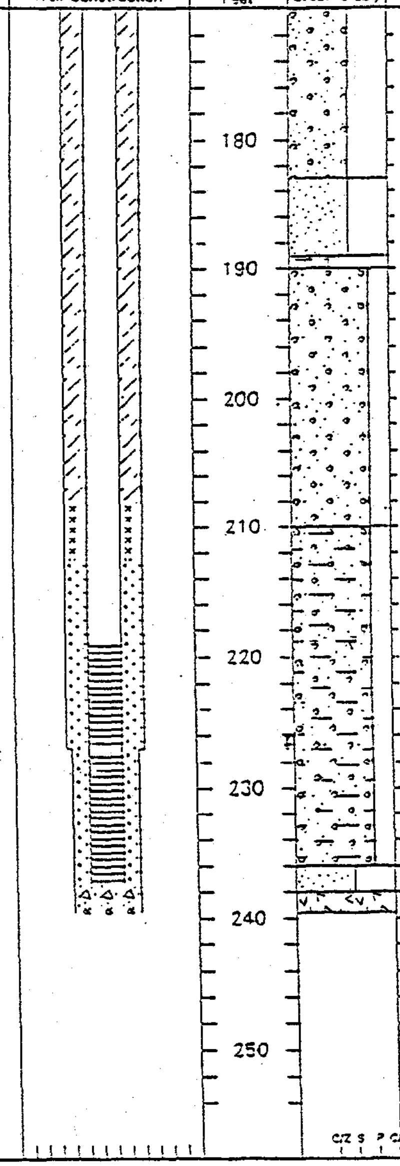
A-2

WELL SUMMARY SHEET

Boring or Well No. 299-E33-38
Northing 137594.78 Easting 573591.39
Sheet 3 of 3

Location 200 East
Project 200-BP-1
Elevation 629.97
Drilling Contractor Kaiser Eng. Hanford
Driller Dave Garcia
Drilling Method and Equipment Cable Tool Walker Neer
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name) Date ______

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description



Construction data – Description:

3/8" Bentonite Pellets 208.1'-212.5'

8-12 Mesh Silica Sand 212.5'-237.3'

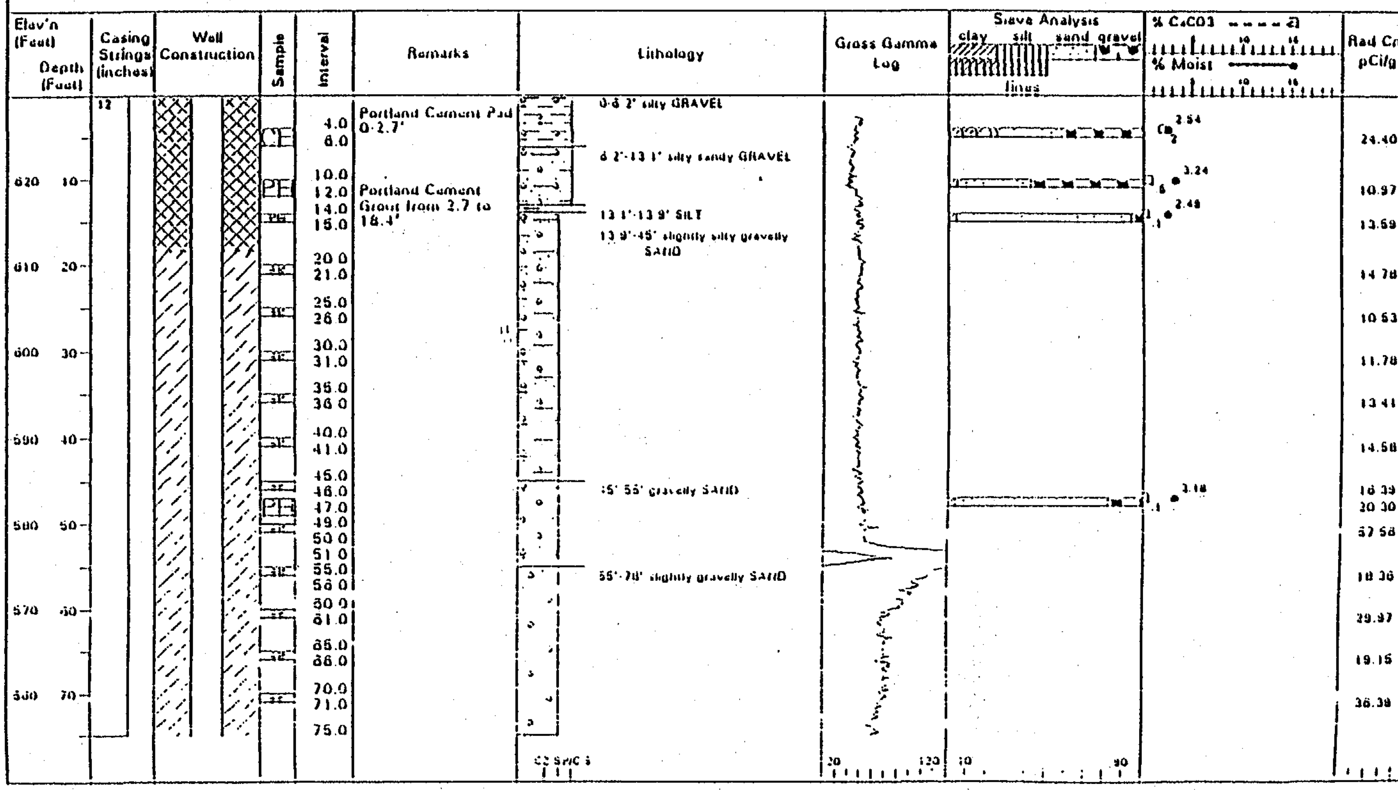
T-304, ss, cont. wire wrap, 4.5" OD x 21.05', 0.020 slot screen from 218.55'-239.6'
10" Temp. Carbon Steel Casing set at 227.0'

8" Temp. Carbon Steel Casing set at 239.6'
Total Depth at 239.6' bls

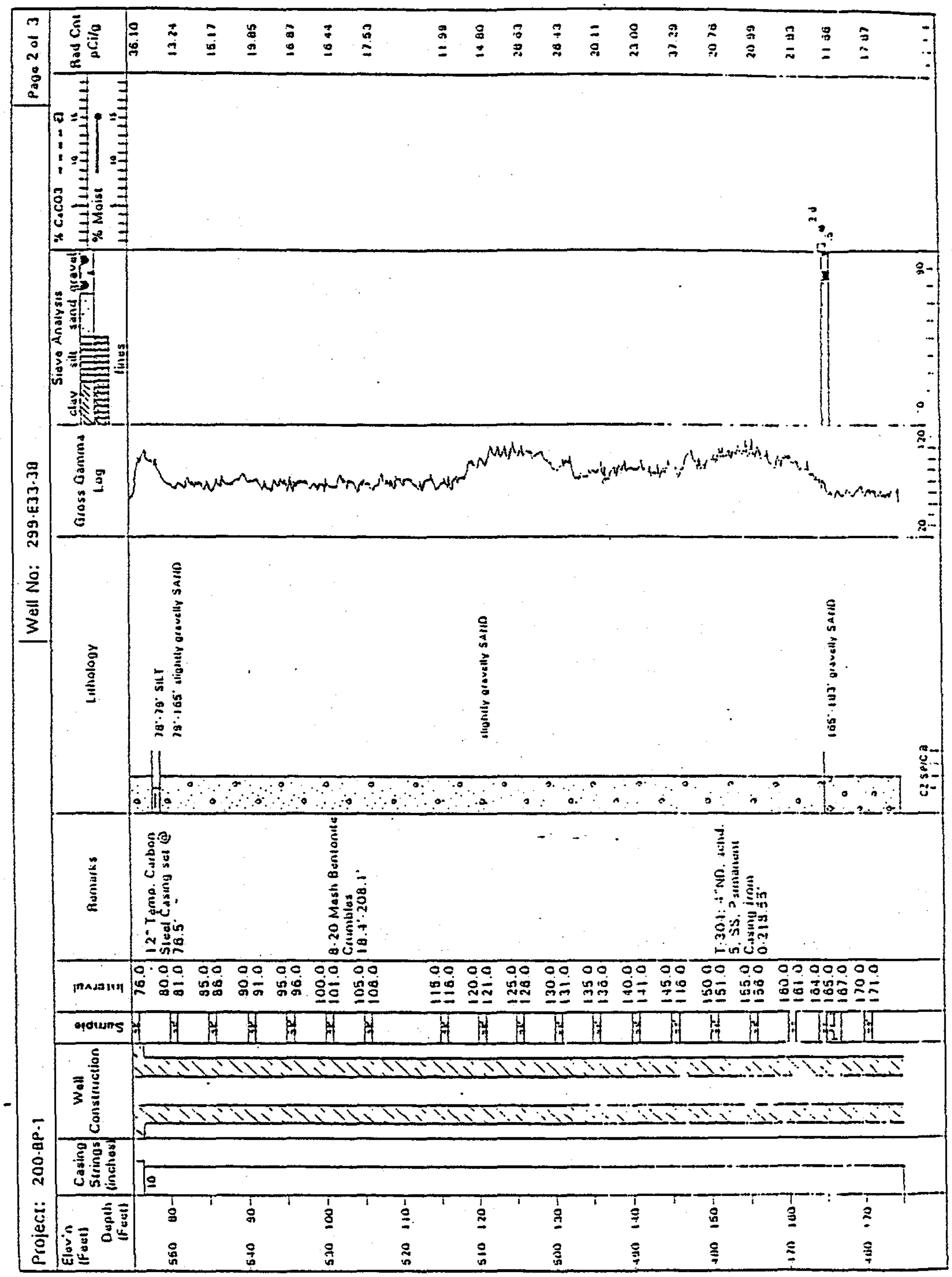
Lithologic Description:

183'-189' SAND
189'-190' SILT
190'-210' sandy GRAVEL
210'-236' silty sandy GRAVEL
static water level at 226.5' 1/10/91
236'-238' SAND
238'-239.6' BASALT

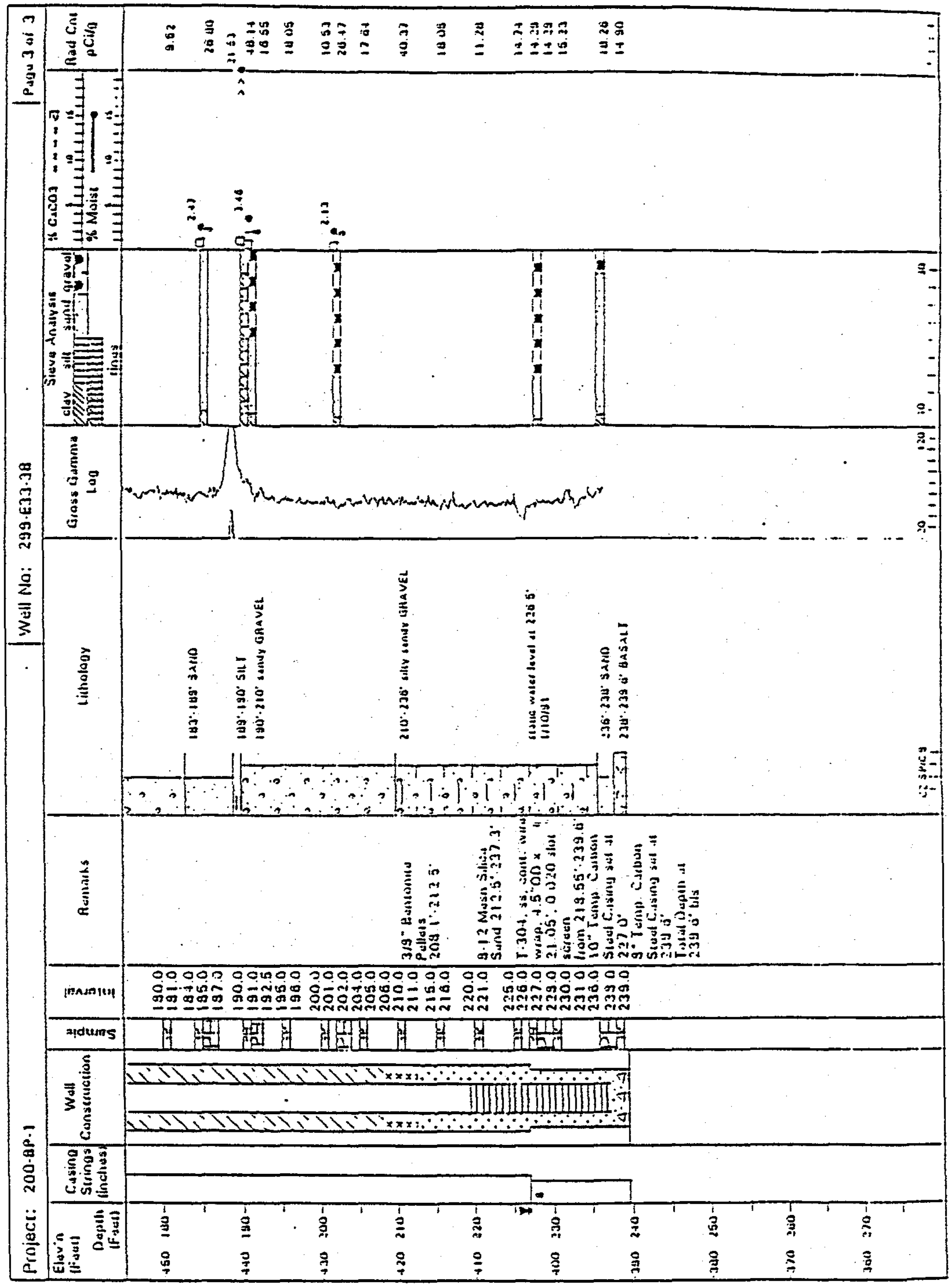
Project: 200-BP-1		Well No: 299-E33-38	Page 1 of 3
Date Started: 11-16-90	Date Completed: 2-1-91	Total Depth: 239.60	Static Water Level: 226.60
Logged By: S. E. Kos	Checked By: S. J. Trent	Surface Elevation: 629.97	Casing Elevation: 631.95
Drilling Co: Kaiser Eng. Hanford	Driller: Dave Garcia	Northing: 137594.78	Easting: 573591.39
Drilling Method: Cable Tool		Drilling Equipment: Walker Neer	
Screen: T-304, SS, cont. wire wrap, 4.5" OD X 21.05', 0.020" slot screen from 218.55'-239.60'			
Filter Pack: 8-12 mesh Colorado Silica Sand from 212.5'-237.3'			
Permanent Casing: T-304, SS, schd. 5, 4" ND, 0-218.55'		Temporary Casing: 12"; 0-76.5'; 10" 0-227.0'; 8"; 0-239.6'	
Comments: Task 6			

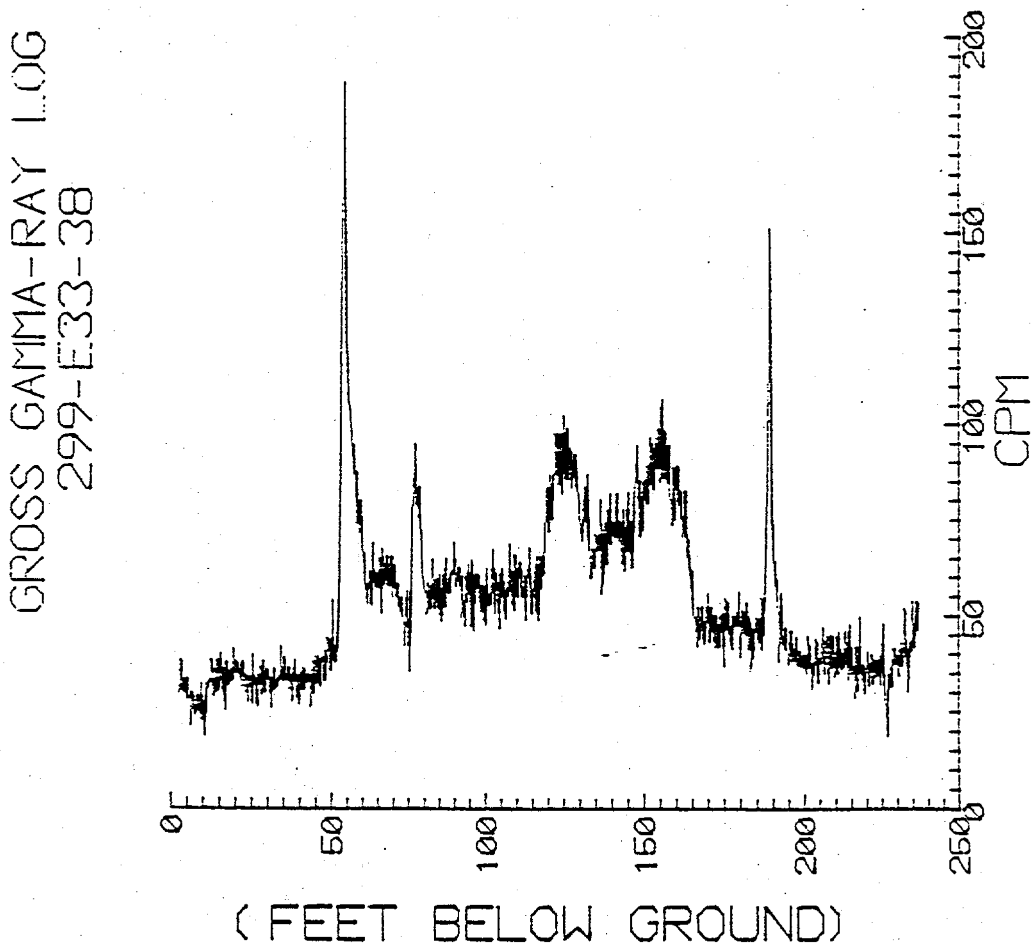


8-1



Project: 200-BP-1
Well No: 299-E33-38
Page 2 of 3
Elev'n (Feet)
Depth (Feet)
Casing Strings (inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
clay silt sand gravel
fines
% CaCO3
% Moist
Rad Cnt pCi/g
12" Temp. Carbon Steel Casing set @ 76.5'
8-20 Mesh Bentonite Crumbles 18.4'-208.1'
78'-79' SILT
79'-165' slightly gravelly SAND
slightly gravelly SAND
165'-183' gravelly SAND


Project: 200-BP-1
Well No: 299-E33-38
Page 3 of 3
Elev'n (Feet)
Depth (Feet)
Casing Strings (Inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
% CaCO3
% Moist
Rad Cnt pCi/g


GROSS GAMMA-RAY LOG
299-E33-38
CPM
0
50
100
150
200
250
(FEET BELOW GROUND)

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

Project: 200-BP-1, B-Cribs

Borehole	299-E33-38				
Coordinates	46,312 N	53,469 W	Feet	(Plant 200 W)
Elevation	631.74 feet		Top of Casing	(Plant 200 W)

Borehole Environment Information

Borehole Fluid Depth none (Feet) from Zero (0.0) Depth Reference of Log

Casing Size I.D. (inch)	Casing Thickness (inch)	Top Depth (feet)	Base Depth (feet)
12	0.38	0	76.5
10	0.38	0	226
8	0.33	0	238

RLS Passive Spectral Gamma Survey Information

Logging Engineers W. Ulbricht R. K. Price
Log Depth Reference at Zero (0.0) depth is Ground Level

Log Date	Archive File Names	Log Mode[1] Speed	Depth Interval (feet) Top	Base	Incr
Dec 21, 90	H2E3338\BPLT	FIXED 0.4 fpm	0	73	0.5
Dec 27, 90	H2E3338\A010	FIXED 0.4 fpm	64	170	0.5
Dec 31, 90	H2E3338\A011	FIXED 0.4 fpm	163	208	0.5
Jan 9, 91	H2E3338\A013	FIXED 0.4 fpm	185	233	0.5

[1] *FIXED: Fixed velocity of Cable Speed; fpm: Feet per minute*

Calibration and Analysis Information

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

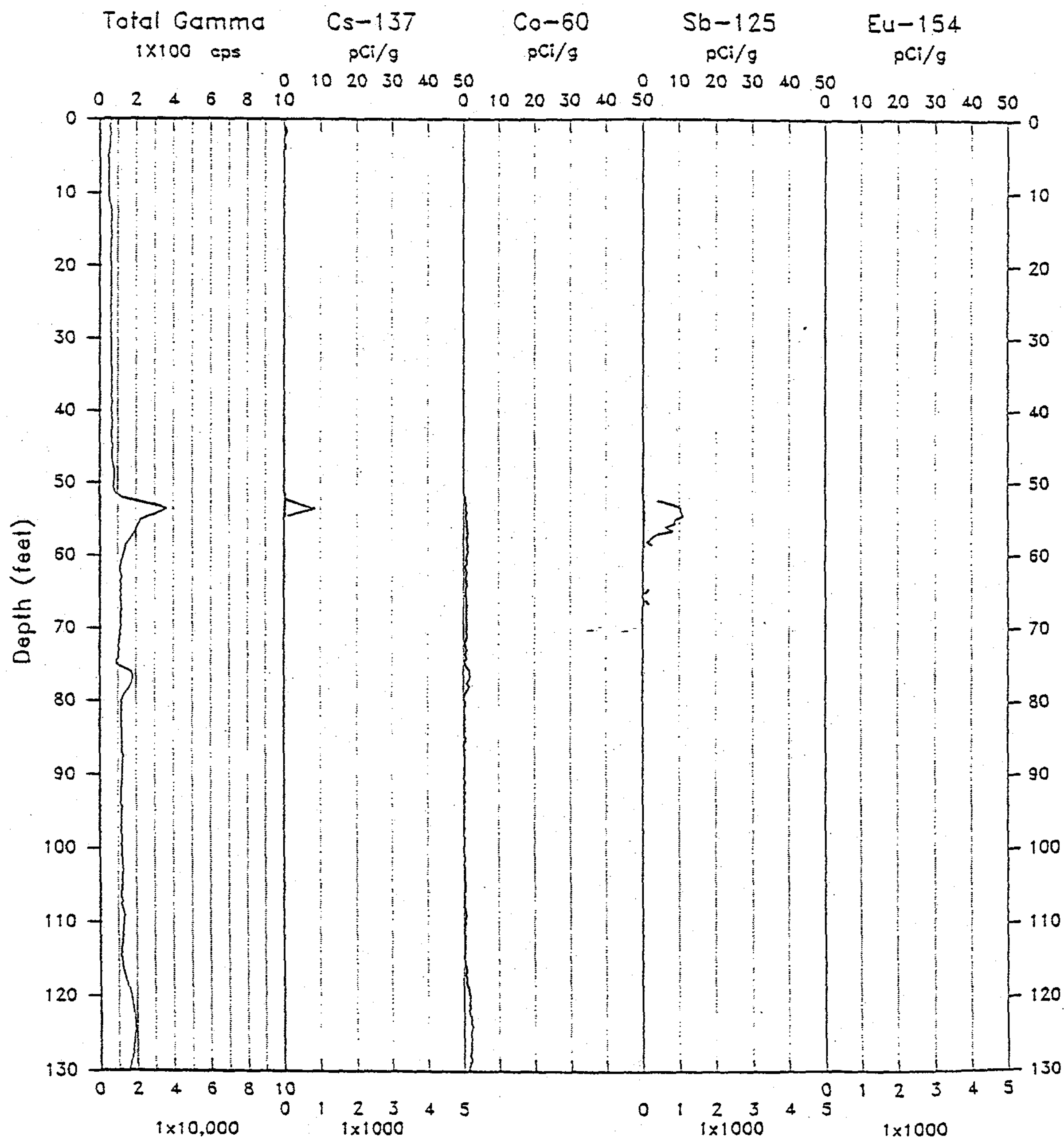
Analyst Names: J. P. Kiesler R. K. Price
Analysis Date: Aug 27, 1992

Analysis Notes: Jan 9 Survey acquired thru double casing to 226 feet
Radionuclides identified: Cs-137, Co-60, Sb-125

RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1 Log Date: Dec 31, 90

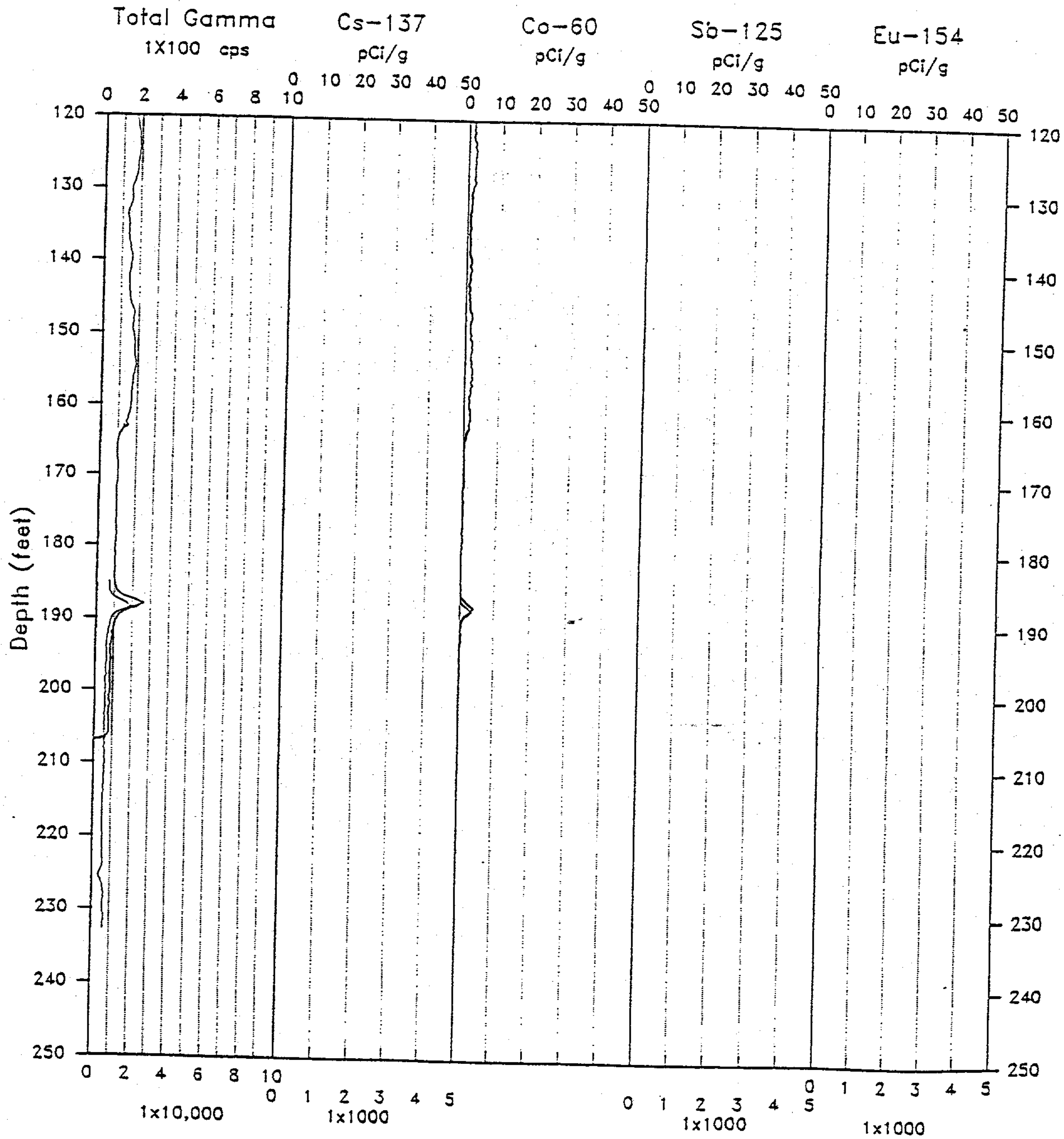
Borehole: 299-E33-38 Anal. Date: Aug 27, 92



RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1
Borehole: 299-E33-38

Log Date: Dec 31, 90
Anal. Date: Aug 27, 92



RLS Borehole Survey Report

299-E33-38   Ground water monitor well

Casing	Depth: 76.5'	Size: 12"	Thickness: 0.38"
	Depth: 226'	Size: 10"	Thickness: 0.38"
	Depth 238'	Size: 8"	Thickness: 0.33"
Water	Depth: 226.3'		
Survey	Depth: 0 - 73'	Mode: Fixed 0.4 fpm	Date: 12/21/90
	Depth: 64 - 170'	Mode: Fixed 0.4 fpm	Date: 12/27/90
	Depth: 163 - 208'	Mode: Fixed 0.4 fpm	Date: 12/31/90
	Depth: 185 - 233'	Mode: Fixed 0.4 fpm	Date: 1/09/91

General Notes:
The maximum calibrated casing correction of 0.40 inches was applied to the survey data of 1/09/91 from 185 to 226 feet. The computed activity for data recorded through multiple casing strings will be underestimated. The survey recorded through single casing should be used.

Detector depth was checked and reset at 50, 100, and 150 feet. The tool was raised 5 feet at each station before logging resumed. The total gamma activity and calculated radionuclide decay activities agree to within the 2 sigma uncertainties except for the total gamma from 45 to 50 feet.

Depth correlation between the log surveys of 12/31/90 and 1/09/91 are within the reported precision.

Man-made Radionuclides:
Cesium (Cs-137) was encountered in the borehole from 52 feet to 55 feet. The cesium decay activity detected was less than 10 pCi/g.

Cobalt (Co-60) was observed from 51 feet to 196 feet. The maximum cobalt decay activity detected was 4 pCi/g at 188 feet.

Antimony (Sb-125) was encountered in the borehole from 52 feet to 58 feet. The maximum Sb-125 decay activity detected was 11 pCi/g at 54 feet.

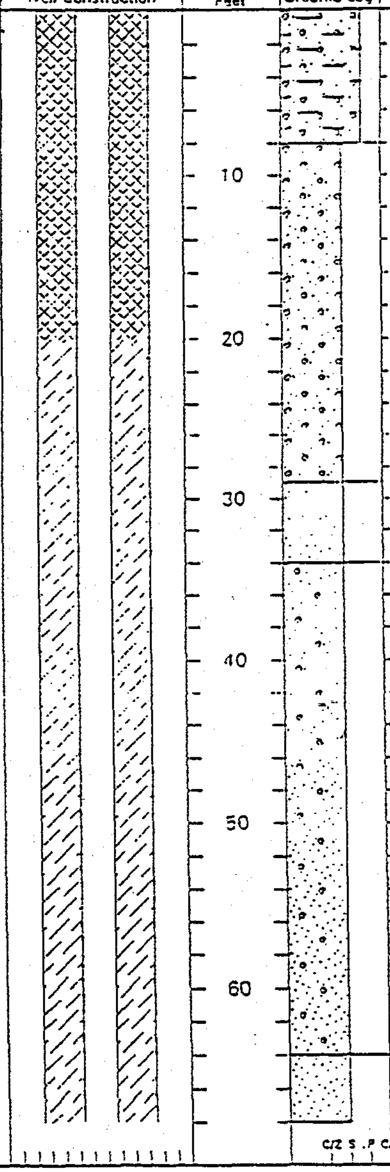
No Europium-154 (Eu-154) was encountered in the borehole. The plot track is present only for uniformity of the displayed data.

WELL SUMMARY SHEET

Boring or Well No. 299-E33-39
Northing 464551.00 Easting 52641.00
Sheet 1 of 4

Location 200 East
Project 200-BP-1
Elevation 620.42
Drilling Contractor Kaiser Eng. Hanford
Driller Tim Gifford
Drilling Method and Equipment Cable Tool Walker Neer
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name) Date ______

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description
Portland Cement Pad 0-2.0'				0-8' silty sandy GRAVEL
Portland Cement Grout from 2.0 to 20.0'		10		8'-29' gravelly SAND
		20		
		30		29'-34' SAND
				34'-64' slightly gravelly SAND
		40		
8-20 Mesh Bentonite Crumbles 20.0' to 199.6'		50		
		60		64'-69' SAND



A-4

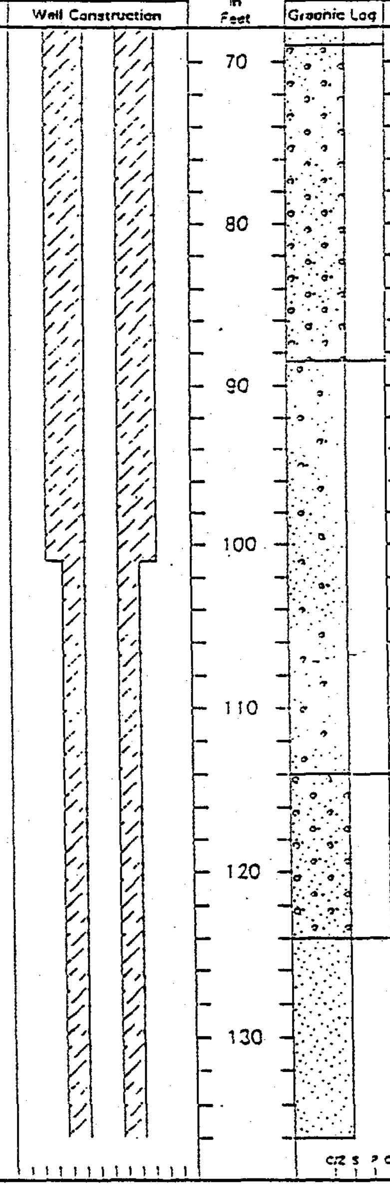
WELL SUMMARY SHEET

Boring or Well No. 299-E33-39
Northing 464551.00 Easting 52641.00
Sheet 2 of 4

Location	200 East	Project	200-BP-1
Elevation	620.42	Drilling Contractor	Kaiser Eng. Hanford
Driller	Tim Gifford	Drilling Method and Equipment	Cable Tool Walker Neer
Prepared by	(Sign/Print Name)	Reviewed By	(Sign/Print Name) Date

CONSTRUCTION DATA | **GEOLOGIC/HYDROLOGIC DATA**

Description	Depth in Feet	Lithologic Description
	70	69'-88.5' gravelly Sand
	90	88.5'-114' slightly gravelly SAND
12" Temp. Carbon Steel Casing set at 101.0'	100	
	110	
	114	114'-124.5' gravelly SAND
	120	
	124	124'-138' SAND
	130	



WELL SUMMARY SHEET	Boring or Well No. 299-E33-39 Northing 464551.00 Easting 52541.00 Sheet 3 of 4

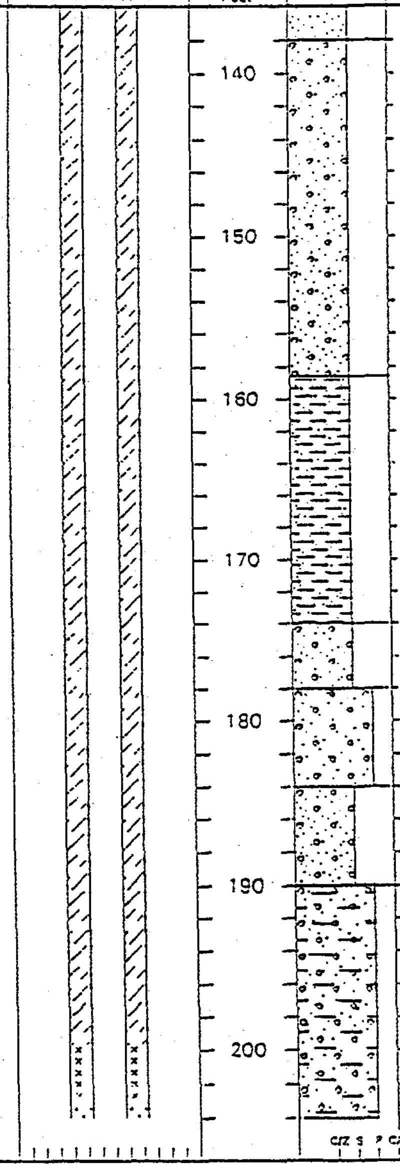
Location 200 East — Project 200-BP-1

Elevation 620.42 — Drilling Contractor Kaiser Eng. Hanford

Driller Tim Gifford — Drilling Method and Equipment Cable Tool Walker Neer

Prepared by ______ (Signature/Name) — Reviewed By ______ (Signature/Name) — Date ______

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description



Construction data – Description:

T-304, 4"ND, SS, schd. 5, Permanent Casing from 0-208.16'

Bentonite Pellets 199.6'-203.1

Lithologic Description:

138'-158' gravelly SAND

158.5'-174.5' silty SAND:

174.5'-178' gravelly SAND:

178'-184' sandy GRAVEL

184'-190' gravelly SAND

190-228.3' silty sandy GRAVEL:

Server User Ids

David Mac Lean	Rust6	D50261	2maclean
John Brodeur	Rust5	J50913	password
Rachel Paxton	Rust4	R40524	r40524
Stan Barry	Rust8	s20104	s20104
Eric Larsen	Rust3	s31104	bronco
Steve Kos	Rust2	s20931	password
Trina Witt	Rust7	s20950	hollydi
Bob Showalter		r50086	

WELL SUMMARY SHEET

Boring or Well No. 299-E33-39
Northing 464551.00 Easting 52641.00
Sheet 4 of 4

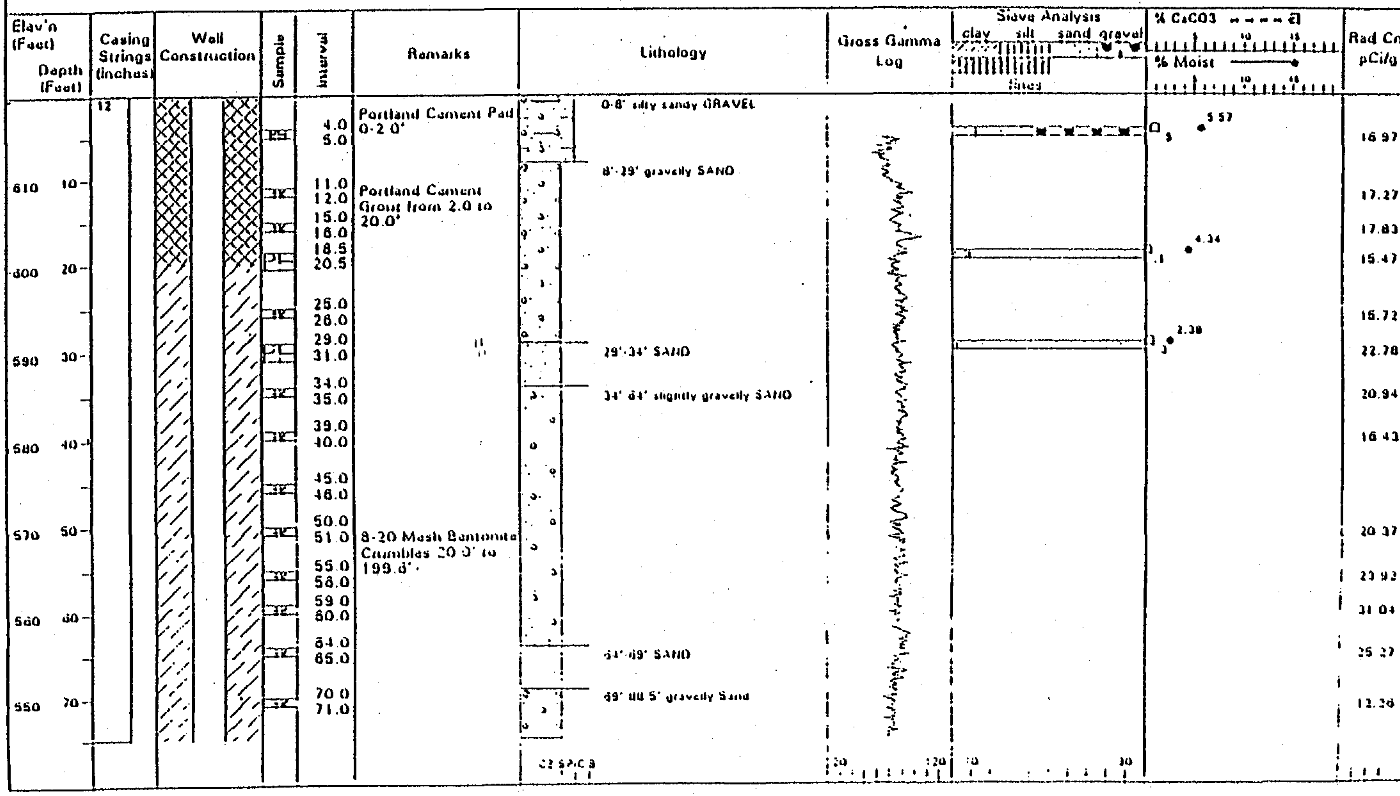
Location 200 East
Project 200-BP-1
Elevation 620.42
Drilling Contractor Kaiser Eng. Hanford
Driller Tim Gifford
Drilling Method and Equipment Cable Tool Walker Neer
Prepared by (Sign/Print Name)
Reviewed By (Sign/Print Name)
Date

CONSTRUCTION DATA: Description	Well Construction	Depth in Feet	GEOLOGIC/HYDROLOGIC DATA: Graphic Log	Lithologic Description
8-12 Silica Sand 20[illegible] 230.1'		210		
T-304, ss, cont. wire wrap, 4.5" OD x 21.04', 0.020" slot screen from 208.16'-229.2'		220		static water at 218.65' 1-17-91
10" Temp. Carbon Steel Casing set at 229.12' Total Depth at 230.1' bls				228.3'-229.5' SAND
		230		229.5'-230.1' BASALT
		240		
		250		
		260		
		270		

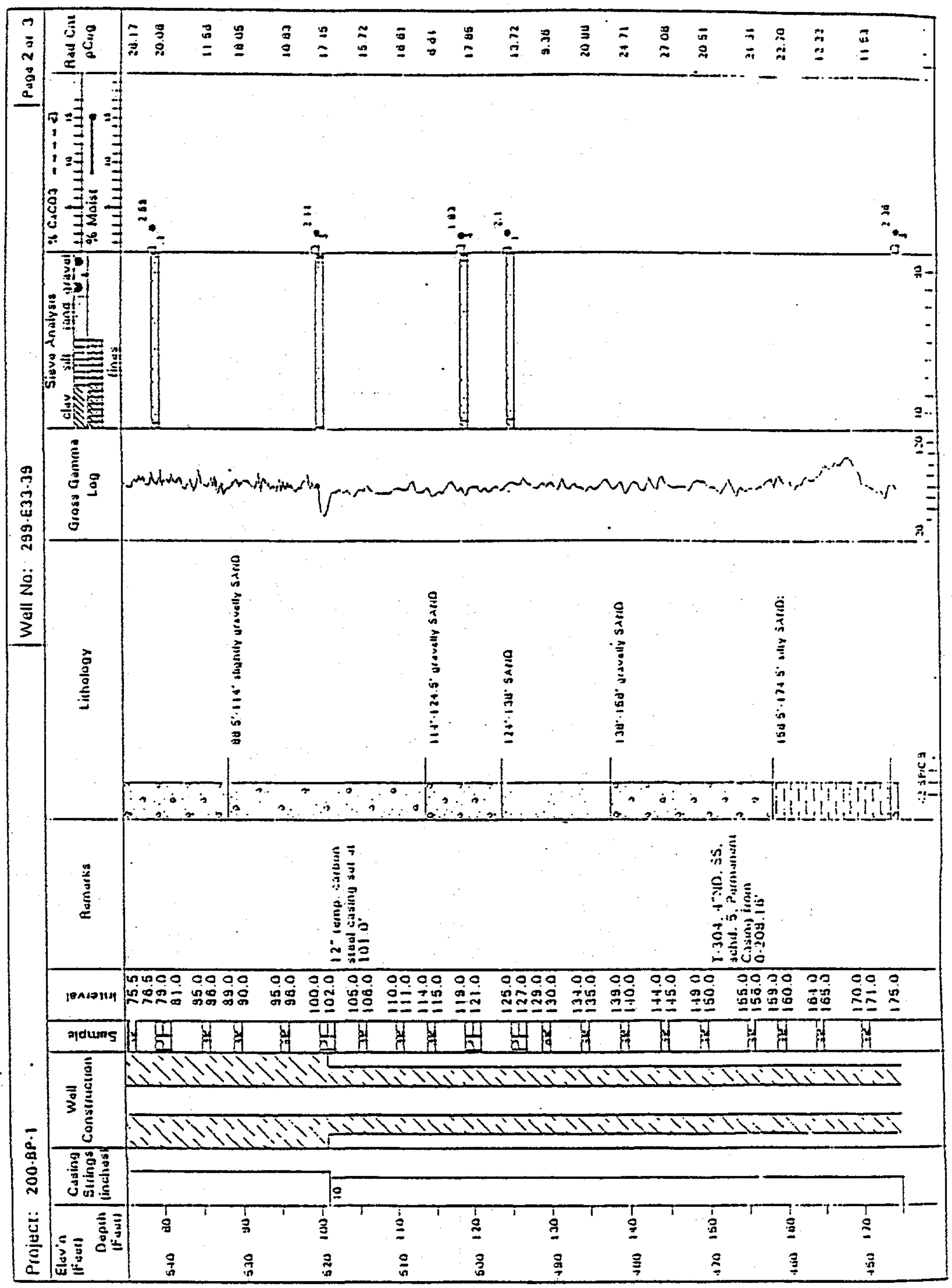
C/Z S P C/B

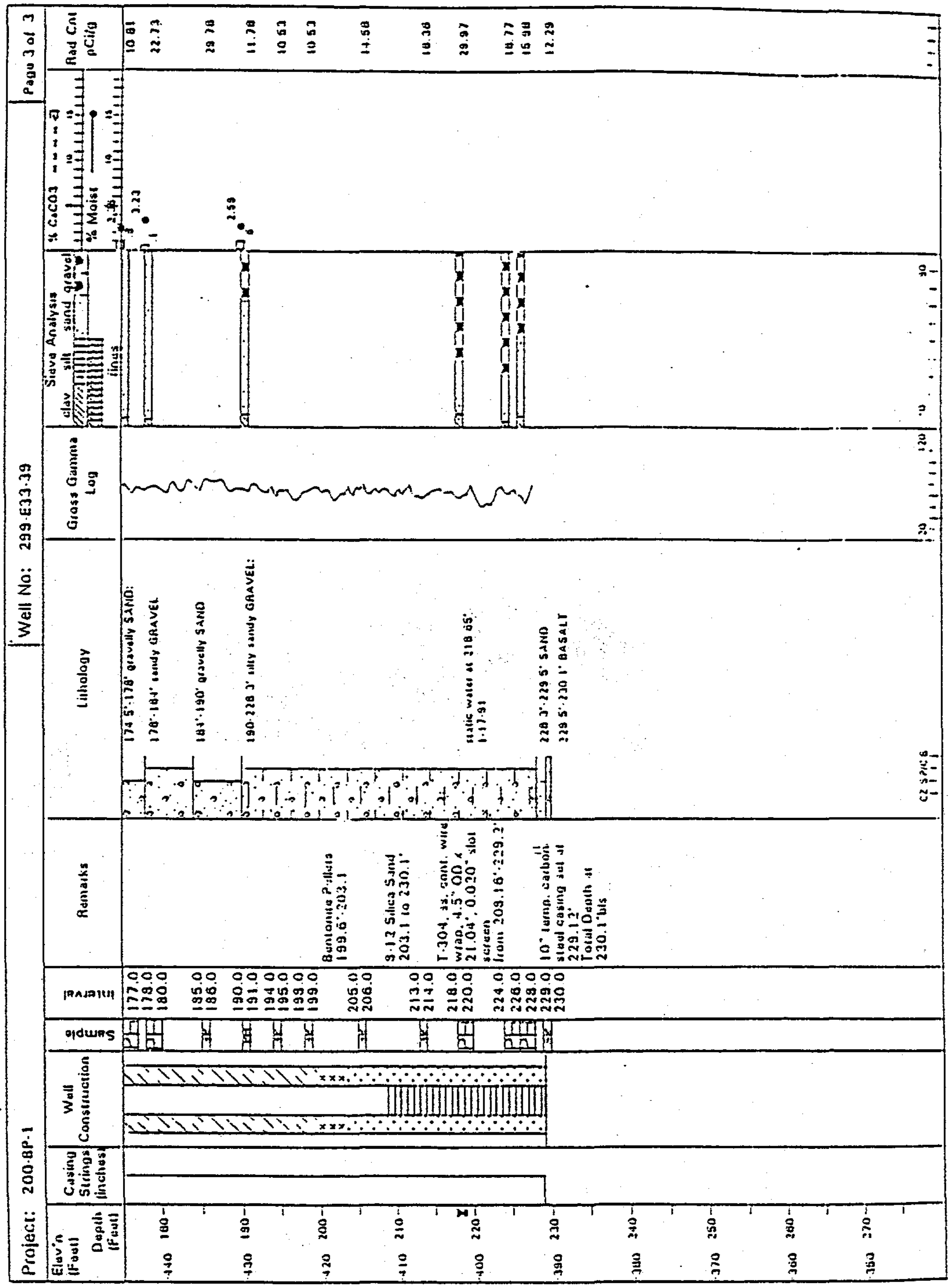
A-7

Project: 200-BP-1		Well No: 299-E33-39	Page 1 of 3
Date Started: 12-3-90	Date Completed: 2-8-91	Total Depth: 230.10	Static Water Level: 218.65
Logged By: J. W. Roberts	Checked By: S. J. Trent	Surface Elevation: 620.42	Casing Elevation: 623.32
Drilling Co: Kaiser Eng. Hanford	Driller: Tim Gifford	Northing: 464551.00	Easting: 52641.00
Drilling Method: Cable Tool		Drilling Equipment: Walker Neer	
Screen: T-304, SS, cont. wire wrap, 4.5" OD x 21.04', 0.020" slot screen from 208.16'-229.20'			
Filter Pack: 8-12 mesh Colorado Silica Sand from 203.1'-229.3'			
Permanent Casing: T-304, SS, schd. 5, 4" ND, 4.5" OD, 0-208.16		Temporary Casing: 12"; 0-101.0; 10", 0-229.12	
Comments: Additional Geologists: W.S. Thompson, D.C. Weekes, K.R. Reynolds			

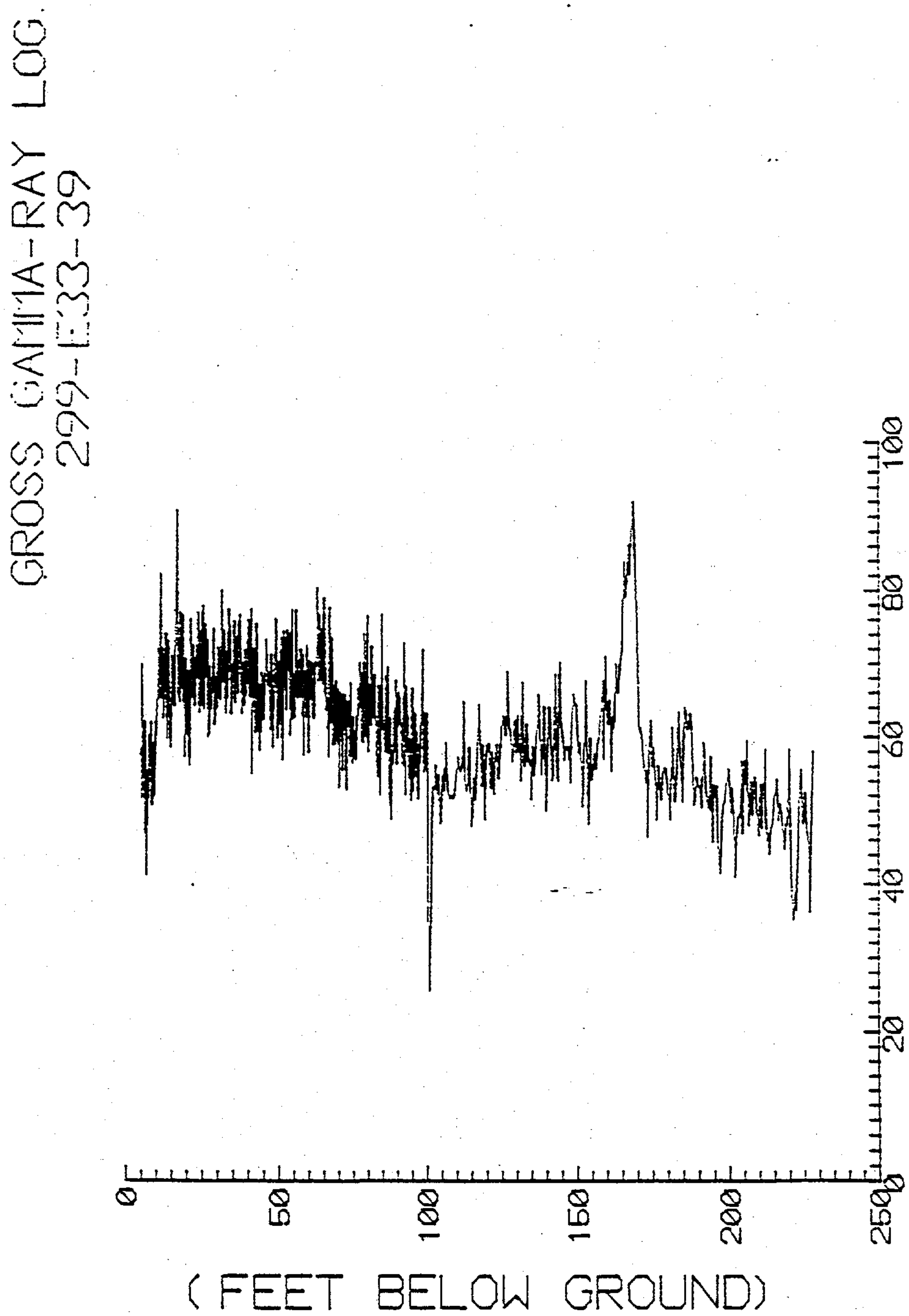


B-4


Project: 200-BP-1
Well No: 299-E33-39
Page 2 of 3
Elev'n (Feet)
Depth (Feet)
Casing Strings (inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
% CaCO3
% Moist
Rad Cnt pCi/g


Project: 200-BP-1
Well No: 299-E33-39
Page 3 of 3
Elev'n (Feet)
Depth (Feet)
Casing Strings (Inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
clay silt sand gravel
fines
% CaCO3
% Moist
Rad Cnt pCi/g
174.5'-178' gravelly SAND;
178'-184' sandy GRAVEL
184'-190' gravelly SAND
190-228.3' silty sandy GRAVEL;
static water at 218.05' 1-17-91
228.3'-229.5' SAND
229.5'-230.1' BASALT
Bentonite Pellets 199.6'-203.1
8-12 Silica Sand 203.1 to 230.1'
T-304, ss, cont. wire wrap, 4.5" OD x 21.04', 0.020" slot screen from 208.16'-229.2'
10" temp. carbon steel casing set at 229.12'
Total Depth at 230.1'bls
177.0
178.0
180.0
185.0
186.0
190.0
191.0
194.0
195.0
198.0
199.0
205.0
206.0
213.0
214.0
218.0
220.0
224.0
226.0
228.0
229.0
230.0
10.81
22.73
28.78
11.78
10.53
10.53
14.58
18.36
29.97
18.77
15.98
12.29

B-6


GROSS GAMMA-RAY LOG
299-E33-39
CPM
0
20
40
60
80
100
0
50
100
150
200
250
(FEET BELOW GROUND)

C-2

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

Project: 200-BP-1 Ground Water Monitoring Well (east of BY-Cribs)

Borehole	299-E33-39			
Coordinates	46,451 N	52,641 W	Feet	(Plant 200 W)
Elevation	623.11 feet		Top of Casing	(Plant 200 W)

Borehole Environment Information

Borehole Fluid Depth 220.2 (Feet) from Zero (0.0) Depth Reference of Log

Casing Size I.D. (inch)	Casing Thickness (inch)	Top Depth (feet)	Base Depth (feet)
12	0.375	0.0	101.0
10	0.375	0.0	229.1

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram R. K. Price
Log Depth Reference at Zero (0.0) depth is Ground Level

Log Date	Archive File Names	Log Mode[1] Speed	Depth Interval (feet) Top	Base	Incr
Jan 03, 91	H2E3339\A012	FIXED 0.4 fpm	0	98	0.5
Jan 21, 91	H2E3339\A017	FIXED 0.4 fpm	90	184	0.5
Jan 22, 91	H2E3339\A018	FIXED 0.4 fpm	185	224	0.5
		FIXED 0.4 fpm	214	224	0.5
		FIXED 0.4 fpm	161	172	0.5

[1]FIXED: Fixed velocity of Cable Speed: fpm: Feet per minute

Calibration and Analysis Information

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

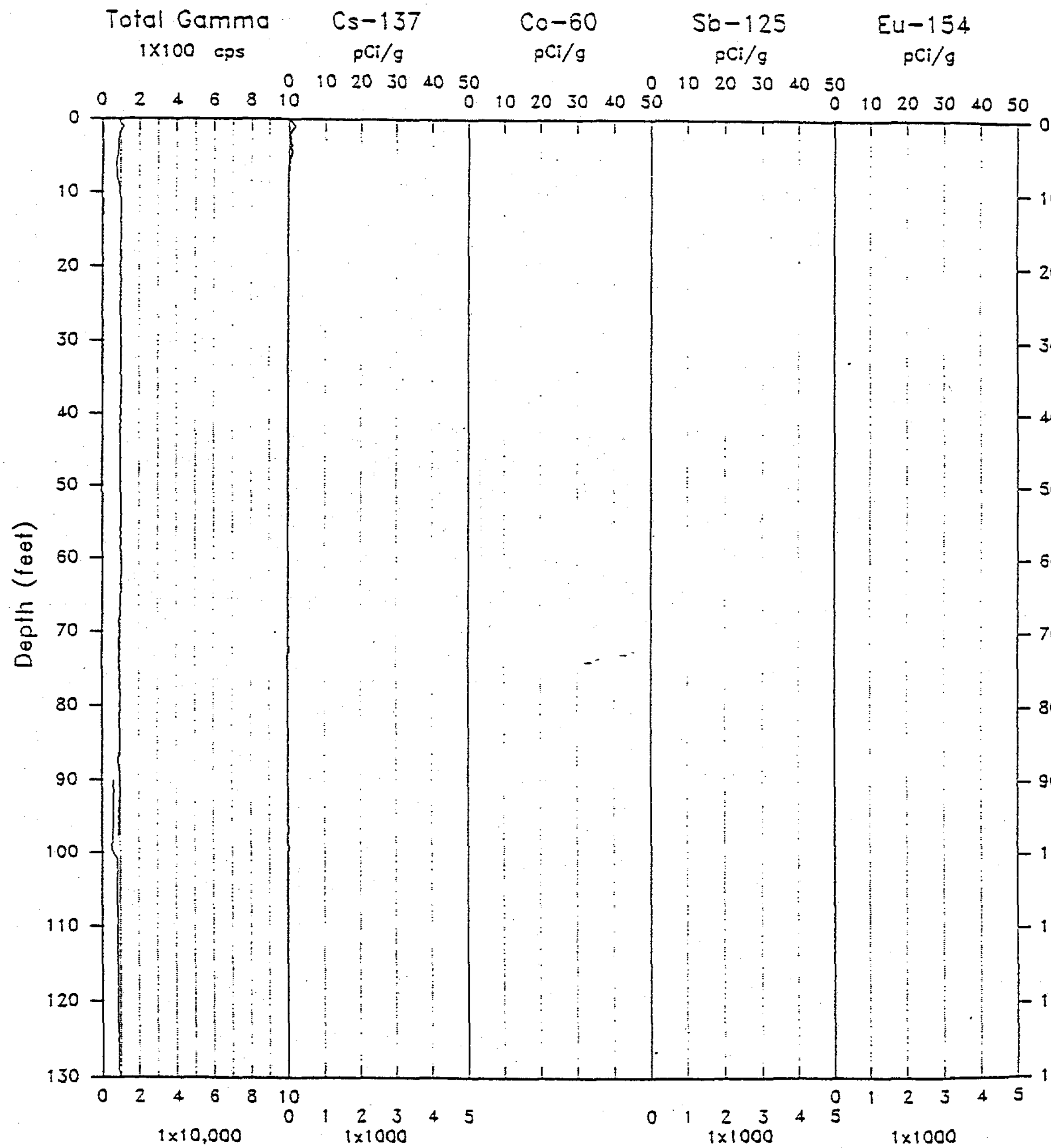
Analyst Names: J. P. Kiesler R. K. Price
Analysis Date: Sept 2, 1992

Analysis Notes: No confirmed man-made radionuclides located below 7 ft
Radionuclides identified: Cs-137

RLS Spectral Gamma-Ray Borehole Survey

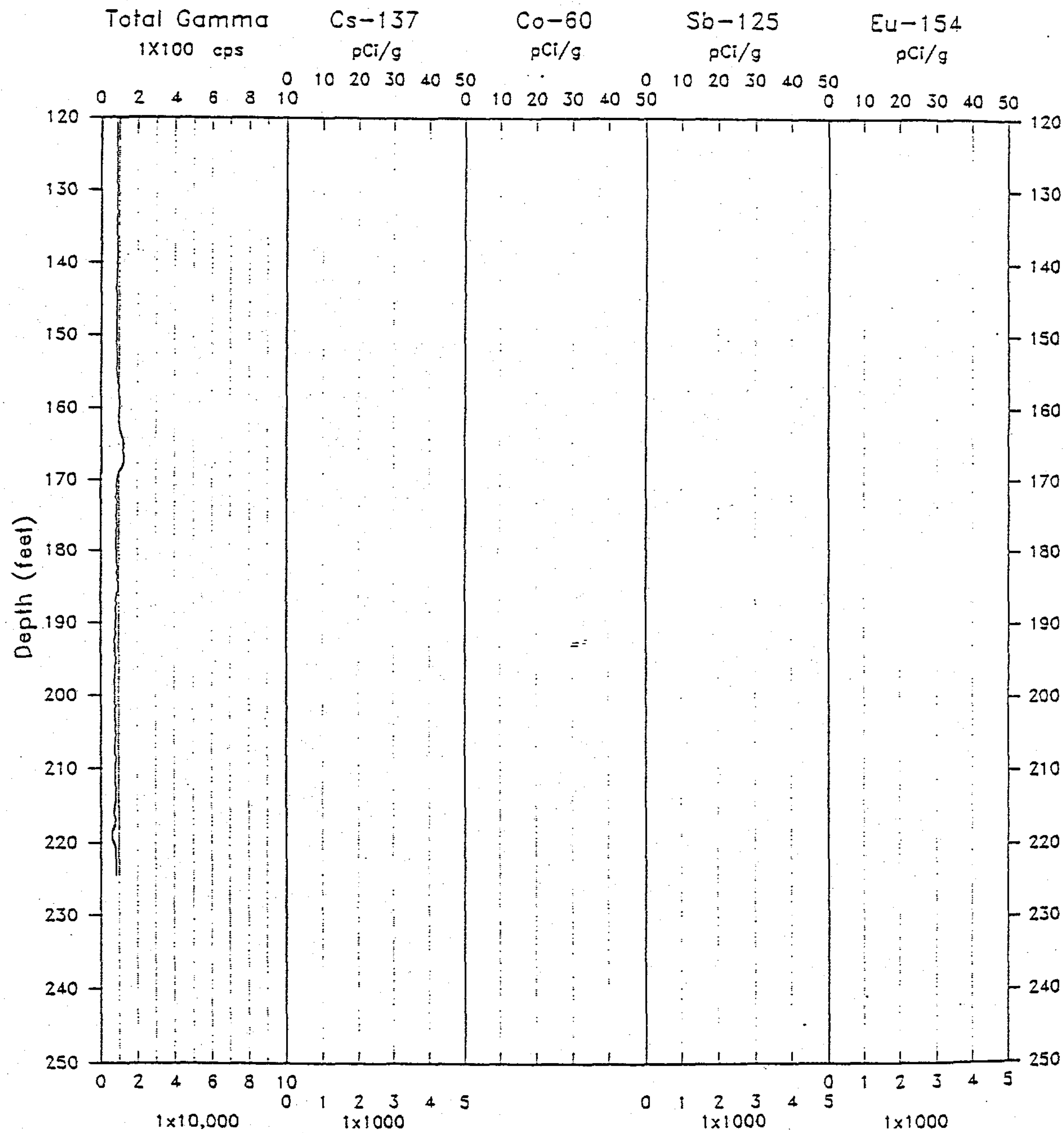
Project: 200-BP-1 Log Date: Jan 22, 91

Borehole: 299-E33-39 Anal. Date: Sep 02, 92



RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1
Log Date: Jan 22, 91
Borehole: 299-E33-39
Anal. Date: Sep 2, 92



RLS Borehole Survey Report

299-E33-39 200-BP-1 Ground Water Monitoring Well (east of BY Cribs)

Casing	Depth: 101. ft		Size: 12 in	Thickness: 0.375 in
	Depth: 229. ft		Size: 10 in	Thickness: 0.375 in
Water	Depth: 220. ft			
Survey	Depth:	0 - 98 ft	Date: 1/03/91	
		90 - 184 ft	Date: 1/21/91	
		185 - 224 ft	Date: 1/22/91	
		214 - 224 ft	Date: 1/22/91	
		161 - 172 ft	Date: 1/22/91	

General Notes:
The data are plotted on two pages. The survey data from 120 feet to 130 feet are plotted on both pages.

The total gamma activity did not exceed 125 cps in the borehole survey.

The Total Gamma recorded a decrease in activity for the second survey (1/21/91) from 90 to 98 feet due to the presence of two casings. The plotted curve is not corrected for casing attenuation.

The increase in Total Gamma activity at the depth interval from 165 feet to 170 feet is due to and increase in the concentration of naturally occuring uranium and thorium.

The repeat intervals from 161 to 172 feet and from 214 to 224 feet demonstrate good system repeatibility of the RLS equipment.

Man-made Radionuclides:
Cesium (Cs-137) was encountered from 0 feet to 7 feet. The maximum activity encountered was 2 pCi/g at 1 foot. No continuous cesium activity was indicated below 7 feet.

No Cobalt (Co-60) was encountered in the borehole. The plot track is present only for uniformity to the displayed data.

No Antony (Eu-152) was encountered in the borehole. The plot track is present only for uniformity of the displayed data.

No Europium-154 (Eu-154) was encountered in the borehole. The plot track is present only for uniformity of the displayed data.

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

Project: 200-BP-1, Ground Water Monitor Well

Borehole	299-E33-40		
Coordinates	137,723.38 N 573,546.44 W	meters	(Lambert NAD'83)
Elevation	624.32 feet	Brass Cap	(NGVD'29)

Borehole Environment Information

Borehole Fluid Depth 217.0 (Feet) from Zero (0.0) Depth Reference of Log

Casing Size I.D. (inch)	Casing Thickness (inch)	Top Depth (feet)	Base Depth (feet)
16.0	0.375	0.0	83.1
12.0	0.375	0.0	228.3
10.0	0.375	0.0	240.0

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram R. K. Price
Log Depth Reference at Zero (0.0) depth is Ground Level

Log Date	Archive File Names	Log Mode,[1] Speed	Depth Interval (feet) Top	Base	Incr
Jan 14, 91	H2E3340\A014	FIXED 0.4 fpm	169.6	237.2	0.5
Jan. 15, 91	H2E3340\A015	FIXED 0.4 fpm	0.0	160.7	0.5
Jan 16, 91	H2E3340\A016	FIXED 0.4 fpm	90.0 155.0	124.5 200.0	0.5 0.5
Feb 8, 91	H2E3340\A024	FIXED 0.4 fpm	215.0	290.5	0.5
Feb 13, 91	H2E3340\A025	FIXED 0.4 fpm	291.0	315.5	0.5

[1] FIXED: Fixed velocity of Cable Speed: fpm: Feet per minute

Calibration and Analysis Information

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

Analyst Names: J. P. Kiesler R. K. Price
Analysis Date: Aug 28, 1992

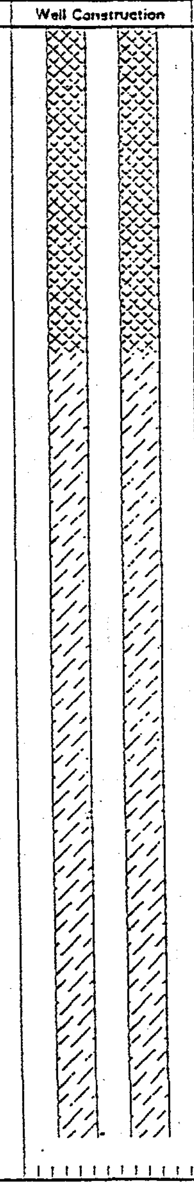
Analysis Notes: Investigated detection of nuclides thru multi casings
Radionuclides identified: Cs-137, Co-60

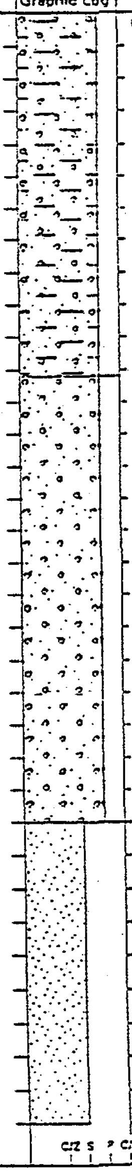
WELL SUMMARY SHEET

Boring or Well No. 299-E33-40
Northing 137723.38 Easting 573546.44
Sheet 1 of 5

Location 200 East
Project 200-BP-1
Elevation 621.26
Drilling Contractor Kaiser Eng. Hanford
Driller Craig Wamsley
Drilling Method and Equipment Cable Tool Bucyrus Erie 60-L
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name) Date ______

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description
Portland Cement Pad 0-2.6'				0-22.5' silty sandy GRAVEL.
Portland Cement Grout from 2.6'-20.1'		10		
		20		22.5'-50' sandy GRAVEL
		30		
		40		
8-20 Mesh Bentonite Crumbles 20.1'-90.4'		50		50'-70' SAND
		60		



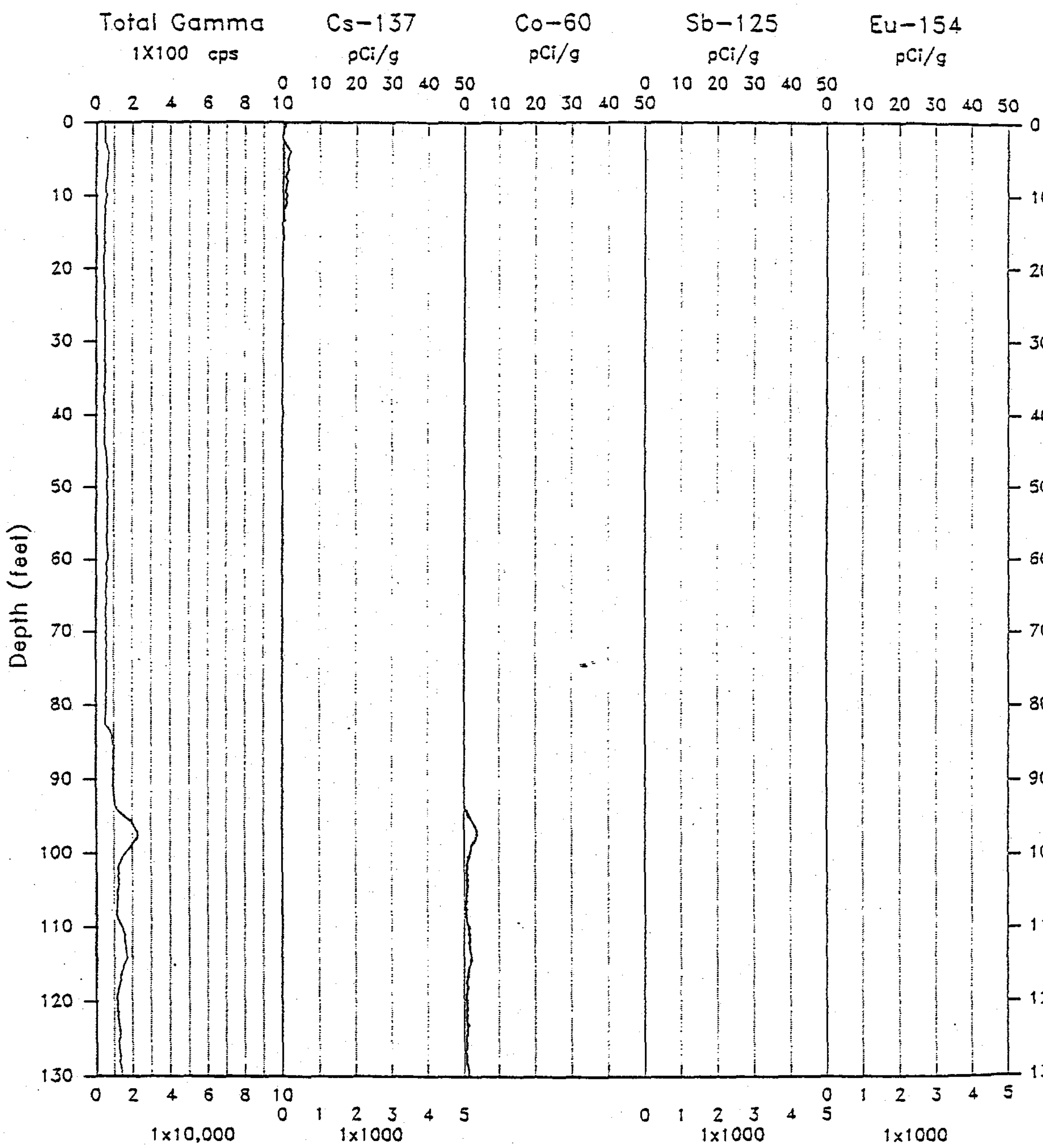


RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1 Log Date: Feb-13, 91

Borehole: 299-E33-40 Anal. Date: Aug-28, 92

16", 12", & 10" Casing

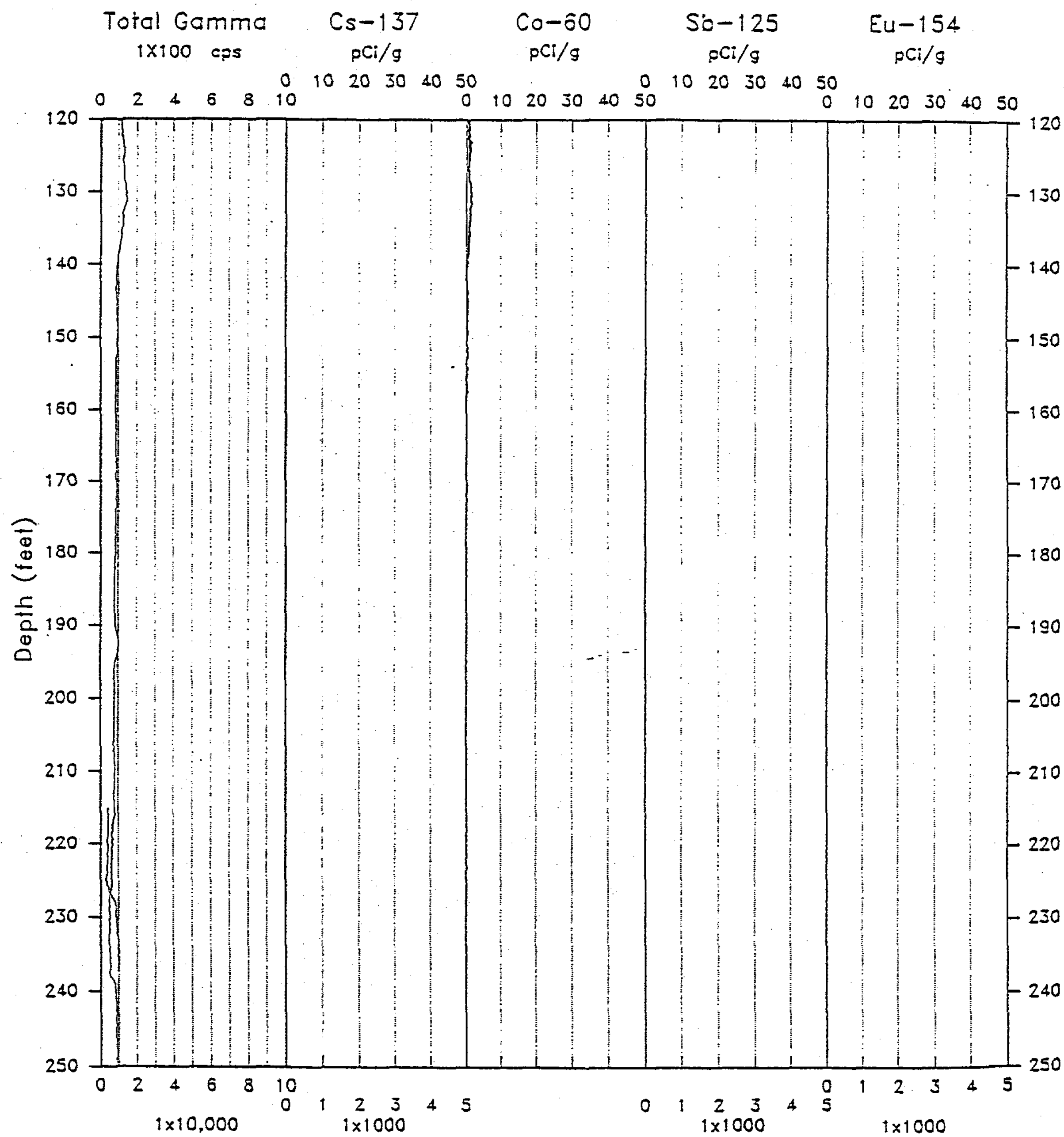


RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1 | Log Date: Feb-13, 91

Borehole: 299-E33-40 | Anal. Date: Aug-28, 92

16", 12", & 10" Casing

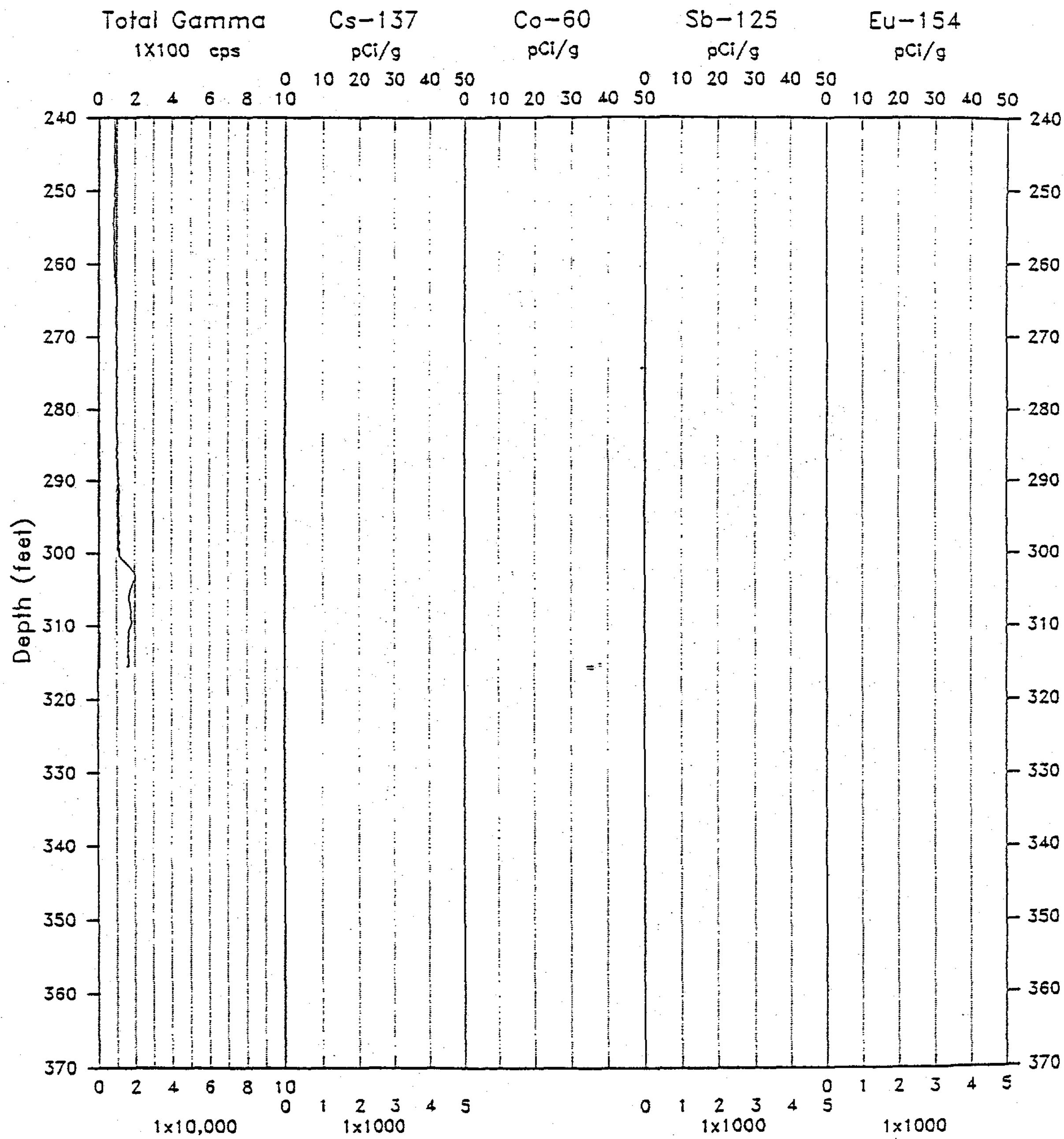


RLS Spectral Gamma-Ray Borehole Survey

Project: 200-BP-1 Log Date: Feb-13, 91

Borehole: 299-E33-40 Anal. Date: Aug-28, 92

16", 12", & 10" Casing



RLS Borehole Survey Report

299-E33-40 Ground water monitor well

Casing	Depth: 83'	Size: 16"	Thickness: 0.38"
	Depth: 228'	Size: 12"	Thickness: 0.38"
	Depth: 240'	Size: 10"	Thickness: 0.38"
	Depth: 318'	Size: 8"	Uncased
Water	Depth: 217'		
Survey	Depth: 169 - 237'	Mode: Fixed 0.4 fpm	Date: 1/14/91
	Depth: 0 - 161'	Mode: Fixed 0.4 fpm	Date: 1/15/91
	Depth: 155 - 175'	Mode: Fixed 0.4 fpm	Date: 1/16/91
	Depth: 184 - 200'	Mode: Fixed 0.4 fpm	(Double casing)
	Depth: 90 - 124'	Mode: Fixed 0.4 fpm	(Double casing)
	Depth: 215 - 300'	Mode: Fixed 0.4 fpm	Date: 2/08/91
	Depth: 290 - 315'	Mode: Fixed 0.4 fpm	Date: 2/13/91

General Notes:
The maximum calibrated casing correction of 0.40 inches was applied to the survey data. The computed activity for data recorded through multiple casing strings will be underestimated.

Man-made Radionuclides:
Cesium (Cs-137) was encountered in the borehole from the surface to 17 feet. The cesium decay activity detected was less than 5 pCi/g.

Cobalt (Co-60) was observed from 94 feet to 185 feet. The cobalt decay activity detected was less than 10 pCi/g.

No Antimony (Sb-125) was encountered in the borehole. The plot track is present only for uniformity of the displayed data.

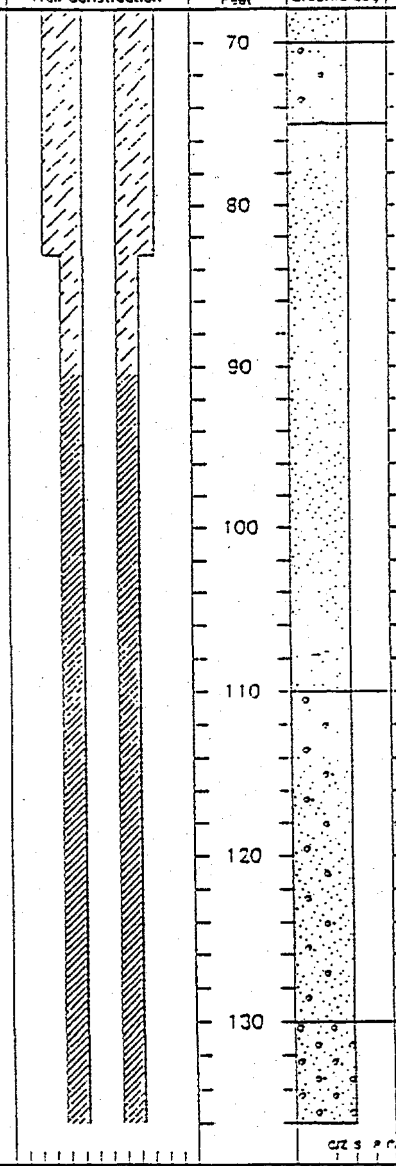
No Europium-154 (Eu-154) was encountered in the borehole. The plot track is present only for uniformity of the displayed data.

WELL SUMMARY SHEET

Boring or Well No. 299-E33-40
Northing 137723.38 Easting 573546.44
Sheet 2 of 5

Location 200 East
Project 200-BP-1
Elevation 621.26
Drilling Contractor Kaiser Eng. Hanford
Driller Craig Wamsley
Drilling Method and Equipment Cable Tool Bucyrus Erie 60-L
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name)
Date ______

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description



16" Carbon Steel Casing set at 83.1'

Bentonite Slurry 90.4'-197.2'

70'-75' slightly gravelly SAND

75'-110' SAND

110'-130' slightly gravelly SAND:

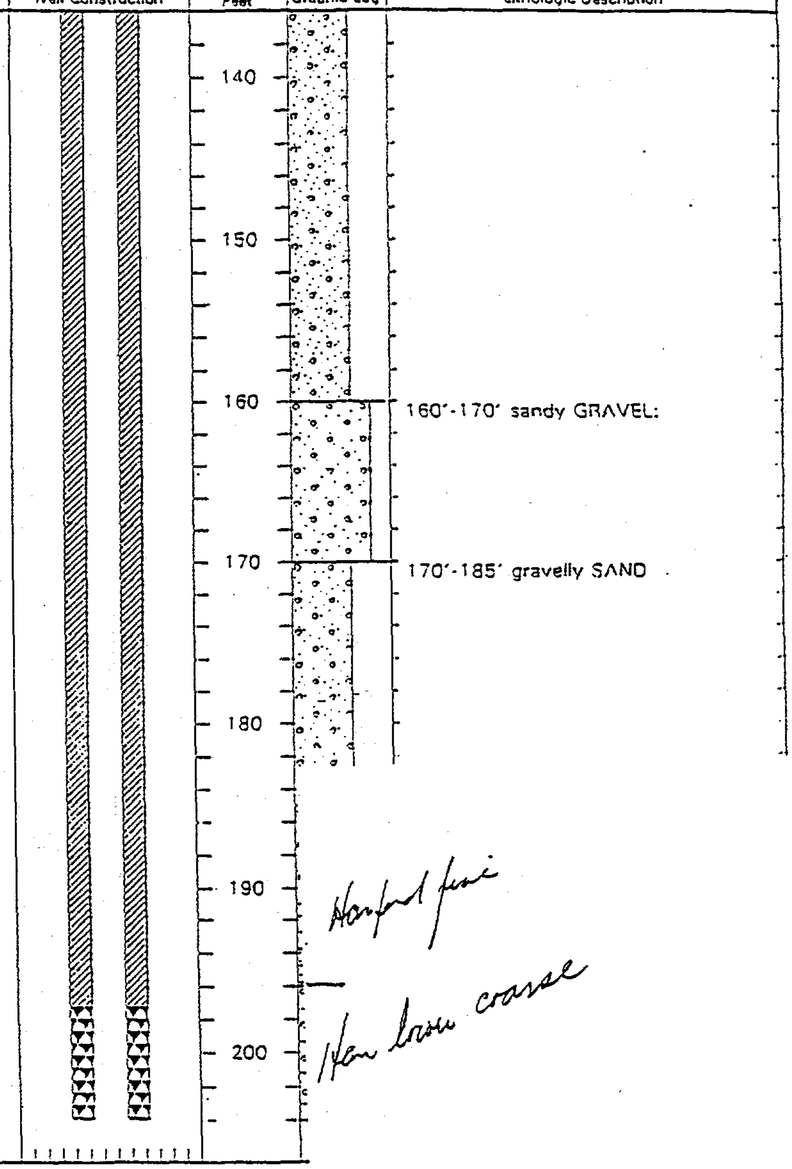
130'-160' gravelly SAND

WELL SUMMARY SHEET

Boring or Well No. 299-E33-40
Northing 137723.38 Easting 573546.44
Sheet 3 of 5

Location 200 East
Project 200-BP-1
Elevation 621.26
Drilling Contractor Kaiser Eng. Hanford
Driller Craig Warnsley
Drilling Method and Equipment Cable Tool Bucyrus Erie 60-L
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name) Date ______

CONSTRUCTION DATA — Description | Well Construction | Depth in Feet | GEOLOGIC/HYDROLOGIC DATA — Graphic Log | Lithologic Description



T-304, 4"ND, SS, schd. 5 Permanent Casing from 0-293.92'

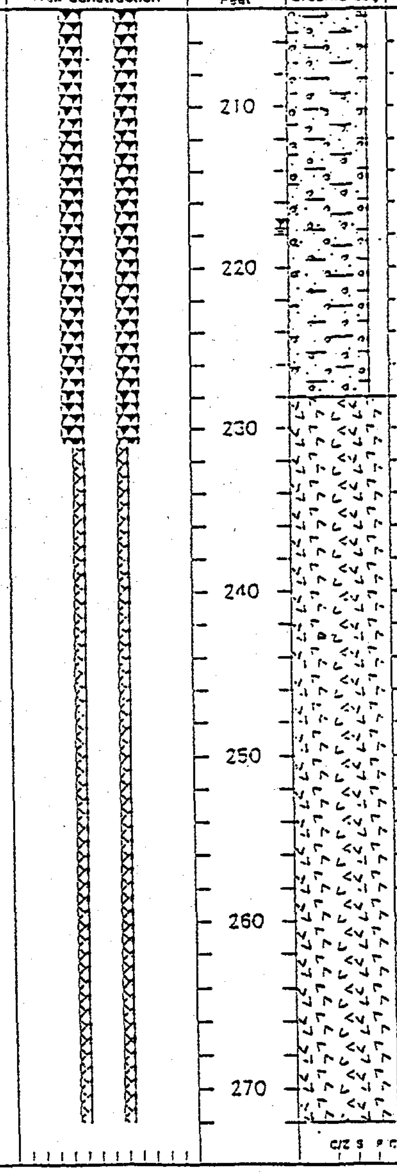
Bentonite Hole Plug from 197.2'-230.9'

WELL SUMMARY SHEET

Boring or Well No. 299-E33-40
Northing 137723.38 Easting 573546.44
Sheet 4 of 5

Location 200 East	Project 200-BP-1
Elevation 621.26	Drilling Contractor Kaiser Eng. Hanford
Driller Craig Wamsley	Drilling Method and Equipment Cable Tool Bucyrus Erie 60-L
Prepared by ______ (Sign/Print Name)	Reviewed By ______ (Sign/Print Name) Date ______

CONSTRUCTION DATA — Description | Well Construction | Depth in Feet | GEOLOGIC/HYDROLOGIC DATA — Graphic Log | Lithologic Description



Construction data (Description):

12" Temp. Carbon Steel Casing set at 228.29'

Cement Grout 230.9'-280.8'

10" Temp. Carbon Steel Casing set at 240.3'

Lithologic Description:

static water contact at 217.6', 4/4/91

228'-305' BASALT

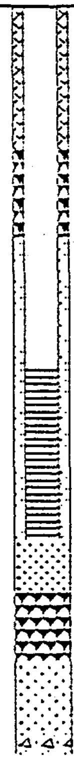
A-11

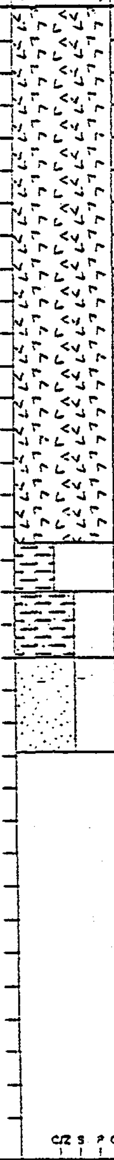
WELL SUMMARY SHEET

Boring or Well No. 299-E33-40
Northing 137723.38 Easting 573546.44
Sheet 5 of 5

Location 200 East
Project 200-BP-1
Elevation 621.26
Drilling Contractor Kaiser Eng. Hanford
Driller Craig Wamsley
Drilling Method and Equipment Cable Tool Bucyrus Erie 60-L
Prepared by ______ (Sign/Print Name)
Reviewed By ______ (Sign/Print Name) Date ______

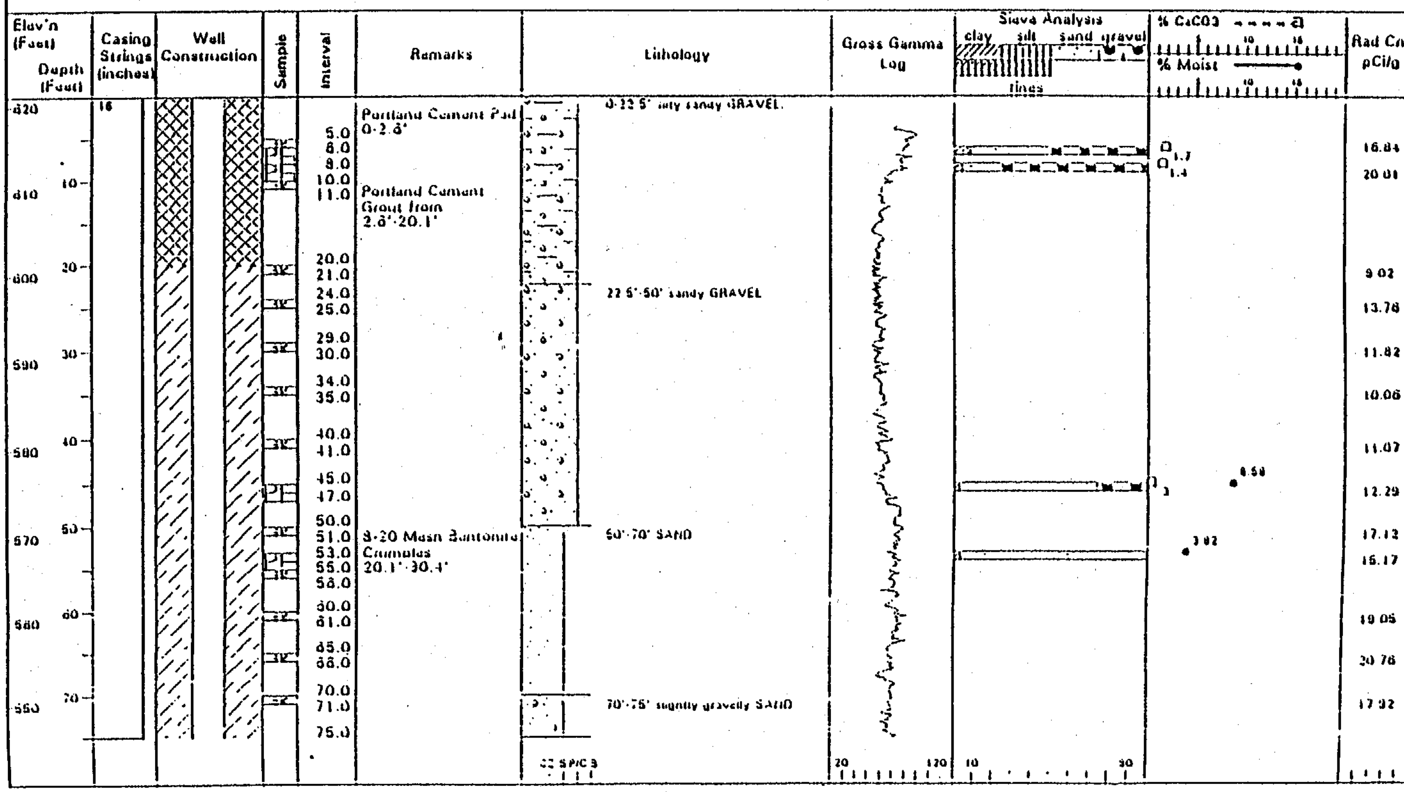
CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Well Construction		Graphic Log	Lithologic Description
Bentonite Hole Plug Chunks from 280.8'-286.1'		280		
20-40 Silica Sand 286.1'-304.6'		290		
T-304, SS, cont. wire wrap, 4.5" OD x 10.98', 0.010" slot screen from 293.92'-304.6'		300		
4-8 Silica Sand from 304.6'-308.1'				305-308' SILT
Bentonite Hole Plug Chunks from 308.1'-312.3'		310		308'-312' silty SAND
8-12 and 4-8 Silica Sand from 312.2'-316.6'				312'-318' SAND:
Total Depth at 318.0' bls		320		
		330		



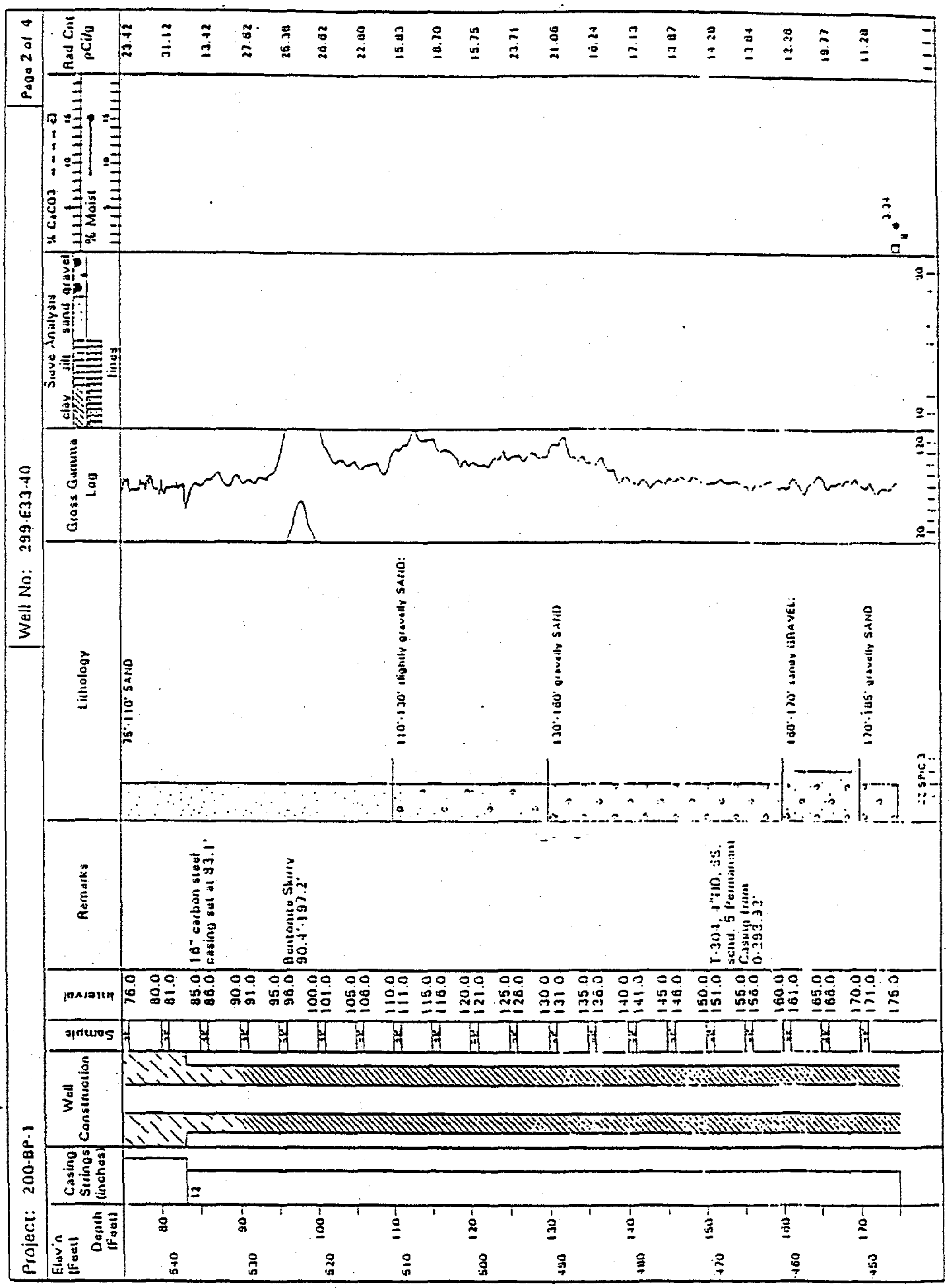


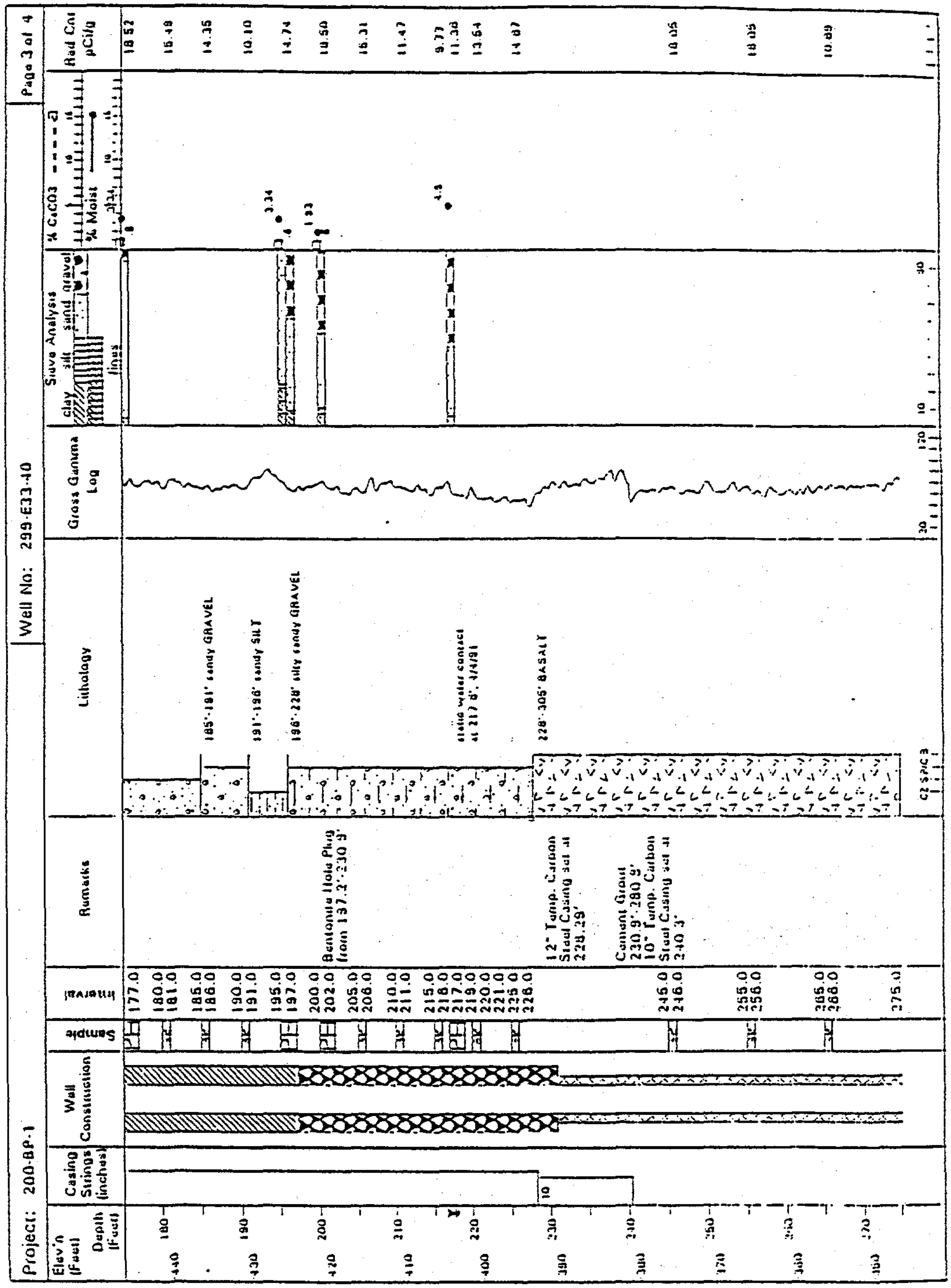
A-12

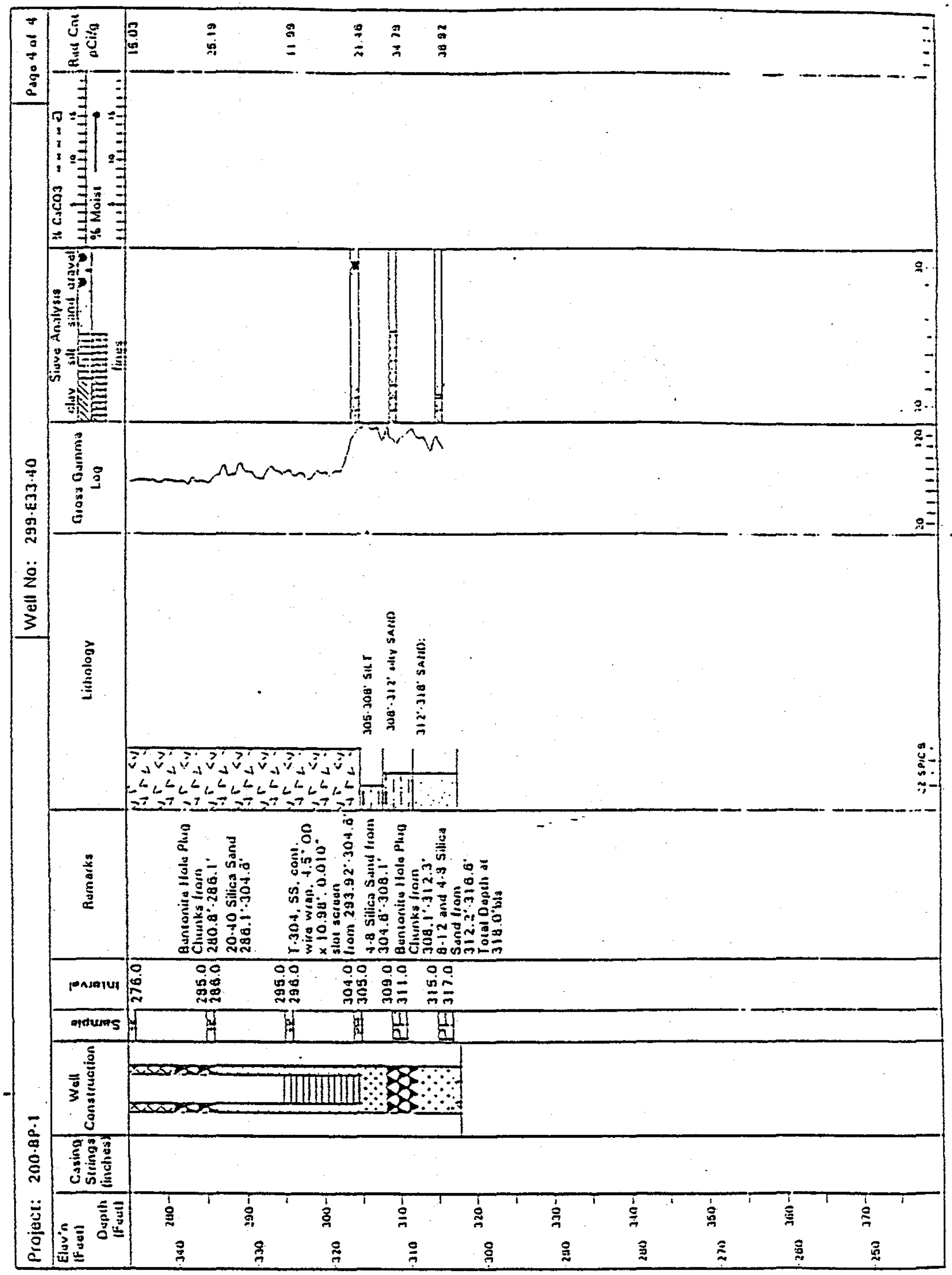
Project: 200-BP-1		Well No: 299-E33-40	Page 1 of 4
Date Started: 11-18-90	Date Completed: 4-1-91	Total Depth: 318.00	Static Water Level: 217.60
Logged By: Ken Hoffmann	Checked By: Steve Trent	Surface Elevation: 621.26	Casing Elevation: 624.32
Drilling Co: Kaiser Eng. Hanford	Driller: Craig Wamsley	Northing: 137723.38	Easting: 573546.44
Drilling Method: Cable Tool		Drilling Equipment: Bucyrus Erie 60-L	
Screen: T-304, SS, cont. wire wrap, 4.5" OD x 10.98', 0.010" slot screen from 293.92'-304.9'			
Filter Pack: 20-40 mesh silica sand from 286.1'-304.6'; 4-8 mesh silica sand from 304.6'-308.1			
Permanent Casing: T-304, SS, schd. 5, 4" ND, 4.5" OD; 0-293.92'		Temporary Casing: 16" 0-83.1; 12" 0-228.29'; 10" 0-240.3'.	
Comments: Task 6			



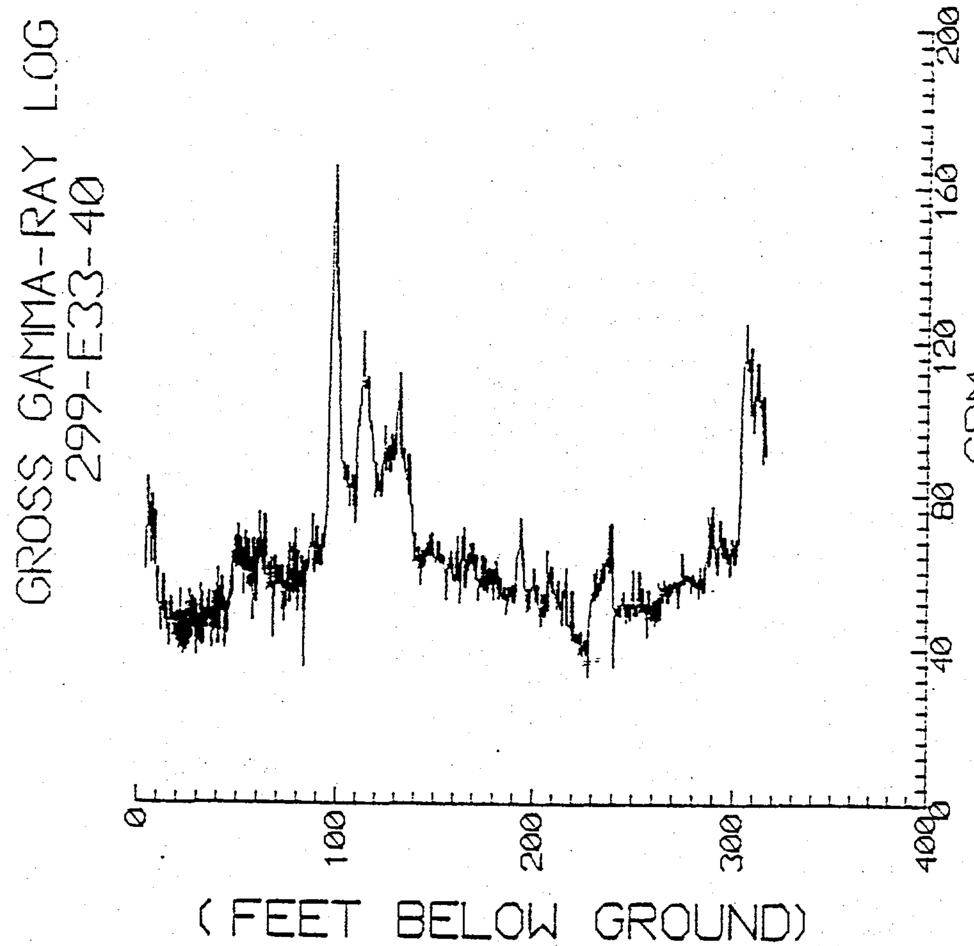
8-7


Project: 200-BP-1
Well No: 299-E33-40
Page 2 of 4
Elev'n (Feet)
Depth (Feet)
Casing Strings (inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
clay silt sand gravel
fines
% CaCO3
% Moist
Rad Cnt pCi/g
18" carbon steel casing set at 93.1'
Bentonite Slurry 90.4'-197.2'
75'-110' SAND
110'-130' slightly gravelly SAND
130'-160' gravelly SAND
160'-170' sandy GRAVEL
170'-185' gravelly SAND


Project: 200-BP-1
Well No: 299-E33-40
Page 3 of 4
Elev'n (Feet)
Depth (Feet)
Casing Strings (inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
clay silt sand gravel
fines
% CaCO3
% Moist
Rad Cnt pCi/g
185'-181' sandy GRAVEL
191'-196' sandy SILT
196'-228' silty sandy GRAVEL
static water contact at 217.8', 4/4/91
228'-305' BASALT
Bentonite Hole Plug from 137.2'-230.9'
12" Temp. Carbon Steel Casing set at 228.29'
Cement Grout 230.9'-280.9'
10" Temp. Carbon Steel Casing set at 240.3'
177.0
180.0
181.0
185.0
186.0
190.0
191.0
195.0
197.0
200.0
202.0
205.0
206.0
210.0
211.0
215.0
216.0
217.0
219.0
220.0
221.0
225.0
226.0
245.0
246.0
255.0
256.0
265.0
266.0
275.0
18.52
15.49
14.35
10.10
14.74
10.50
15.31
11.47
9.77
11.38
13.64
14.07
10.05
10.05
10.89


Project: 200-BP-1
Well No: 299-E33-40
Page 4 of 4
Elev'n (Feet)
Depth (Feet)
Casing Strings (inches)
Well Construction
Sample
Interval
Remarks
Lithology
Gross Gamma Log
Sieve Analysis
clay silt sand gravel
fines
% CaCO3
% Moist
Rad Cnt pCi/g
276.0
285.0
286.0
295.0
296.0
304.0
305.0
309.0
311.0
315.0
317.0
Bentonite Hole Plug Chunks from 280.8'-286.1'
20-40 Silica Sand 286.1'-304.8'
T-304, SS, cont. wire wrap, 4.5" OD x 10.98', 0.010" slot screen from 293.92'-304.8'
4-8 Silica Sand from 304.8'-308.1'
Bentonite Hole Plug Chunks from 308.1'-312.3'
8-12 and 4-8 Silica Sand from 312.3'-316.6'
Total Depth at 318.0'bls
305-308' SILT
308'-312' silty SAND
312'-318' SAND
16.03
25.19
11.99
21.46
34.79
38.92

B-10


GROSS GAMMA-RAY LOG
299-E33-40
CPM
0
40
80
120
160
200
0
100
200
300
400
(FEET BELOW GROUND)

C-3

WELL SUMMARY SHEET

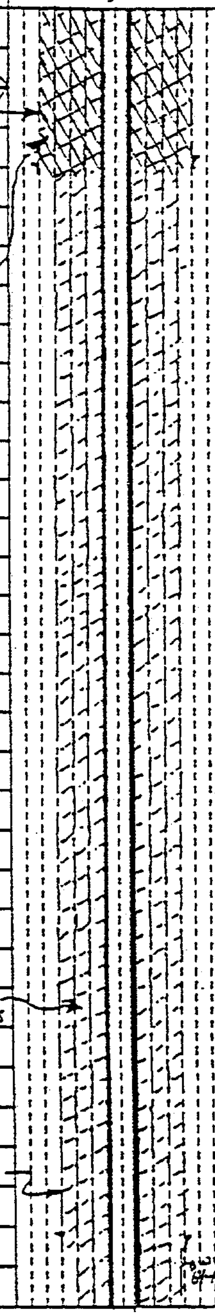
Boring or Well No. 299-E33-41

Sheet 1 of 2

Location: 200 EAST · 241 BX Tank Farm
Project: W017/SST
Elevation: 651.53 BRASS CAP (LAMBERT, NAD-83)
Drilling Contractor: KAISER ENGINEERING, HANFORD
Driller: L.E. Watkins / B.F. Stepdos / M. Thomsen
Drilling Method and Equipment: BE 22W / Cable Tool
Prepared By (Sign/Print Name): D.B. Jones / D Brent Jones Date 3/25/91
Reviewed By (Sign/Print Name): DA Williams Date 8/21/91

CONSTRUCTION DATA — Description	Depth in Feet	GEOLOGIC/HYDROLOGIC DATA — Lithologic Description
12" ø Temporary Carbon steel Casing installed to a depth of 20.0'	0	Slightly Silty Gravelly SAND
		Gravelly SAND
	10	Slightly Silty Gravelly SAND
		Gravelly SAND
Portland Type I & II cement grout from 2.5' to 20.37' BLS	20	Gravelly SAND / Sandy GRAVEL
		SAND-GRAVEL
	30	" "
		(Contact at 34.4) SAND
	40	Slightly gravelly SAND
		SAND
	50	"
		"
	60	
		Slightly gravelly SAND
	70	SAND
		(72-74) sand w/ interbeds of silt/[illegible] Slightly gravelly SAND
		Gravelly SAND
	80	Slightly gravelly SAND
		" " "
	90	" " "
	100	SAND
		"
		"
	110	"
		"
	120	(123-123.7') SILTY SAND
8-20 mesh Bent. Crumbles From 20.37' to 172.6' bls		Slightly gravelly SAND
	130	" " "
		" " "
		" " "
	140	
10" ø temporary carbon steel Casing installed to a depth of 158.66'		SAND
	150	"
		"
		"
	160	"

Diagram:



Graphic Log:

G-21

A-6000-384 (04/90)

WELL SUMMARY SHEET

Boring or Well No. 299-E33-41

Sheet 2 of 2

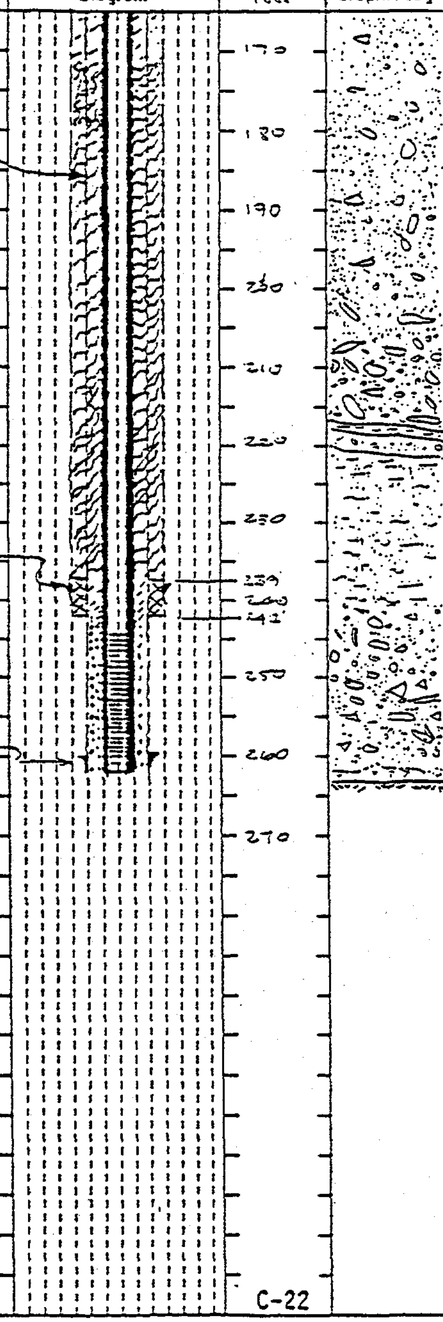
Location 200 EAST : 241 BX Tank Farm — Project W017 / SST

Elevation 657.53 Brass Cap (Lambert NAD-83) — Drilling Contractor Kaiser Engineering, Hanford

Driller L.E. Watkins, B.F. Stroos / M. Thoreson — Drilling Method and Equipment BE 22 W. Cable tool

Prepared By D. ... / D. Jones (Sign/Print Name) Date 3/25/91 — Reviewed By BAW / BA Williams (Sign/Print Name) Date 3/21/91

CONSTRUCTION DATA — Description	Lithologic Description
5-20 mesh bent. crumbles from 20.37' to 172.6' bls	Sand to Slightly Gravelly SAND
Bent. Slurry from 172.6 to 239.9' bls	Gravelly SAND
Granular Bent 239.9' - 243.1' bls	Gravelly SAND
Bentonite	Hanford fine
3" φ Temporary Carbon Steel Casing installed to a depth of 240.09'.	Hanford lower coarse
6" φ temporary Carbon steel Casing installed to a depth of 262.7'	
10 slot S.S screen set from 244.9' - 260.96'	
Sand pack from 243.1' to 262'	



C-22

A-6000-384 (04/90)

Westinghouse Hanford Company	LOG HEADER	Page 1 of 2

Well No. 299-E33-41 Area 200 East Date 2/21/91

Log Run #1 Log Type Gross Gamma

Elevation Datum NGVD-'29 Elevation TOC 654.95

Survey Coordinates 137,369.24 N 573,707.19 E

Log Measured From Ground Surface

Location Description East of BX Tank Farm

Ground Surface Elevation BRASS CAP 651.53

Surface Temperature 14.5°C Weather Clear - Warm

BOREHOLE INFORMATION

Driller Brett Strode

Drill Rig Type Cable Tool Bit Type/Diameter Drive Barrel / 10"

Borehole Diameter(s)/Depth 12"/20.0' 10"/167.0'

Depth Driller 167.0' Depth Logger 167.2'

Liquid Level NA Liquid Density NA

Temperature NA

CASING RECORD

Type 12" Carbon Steel Sch. 40 Interval +0.9'-20.0

Type 10" Carbon Steel Sch. 40 Interval +1.7'-158.66'

Type Interval

Type Interval

Well Screen Interval NA

Comments: Return Error = +0.5' high

Centralizer was used

A-6000-520 (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 7.97 x10⁻⁸ eU (illegible) 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 167.2' To 3.4'

Rerun(s) 135.0' to 120.0' 85.0' to 60.0'

Pre Survey Verification: Position 1 268.8 eU Position 2 44.9 eU Background 335

Base Calibration Difference: Position 1 22.6 eU Position 2 3.6 eU

Logging Speed 5 ft/min Rerun Scales, CPS/in. 50 cps/in

Start Time 1320 Completion Time 1500

Chart Speed(s), ft/in. 10 ft/in.

Chart Recorder Horizontal Scale, CPS/in. 50 cps/in. Time Constant(s) TC-1

Post Survey Verification: Position 1 267.2 eU Position 2 44.1 eU Background 330

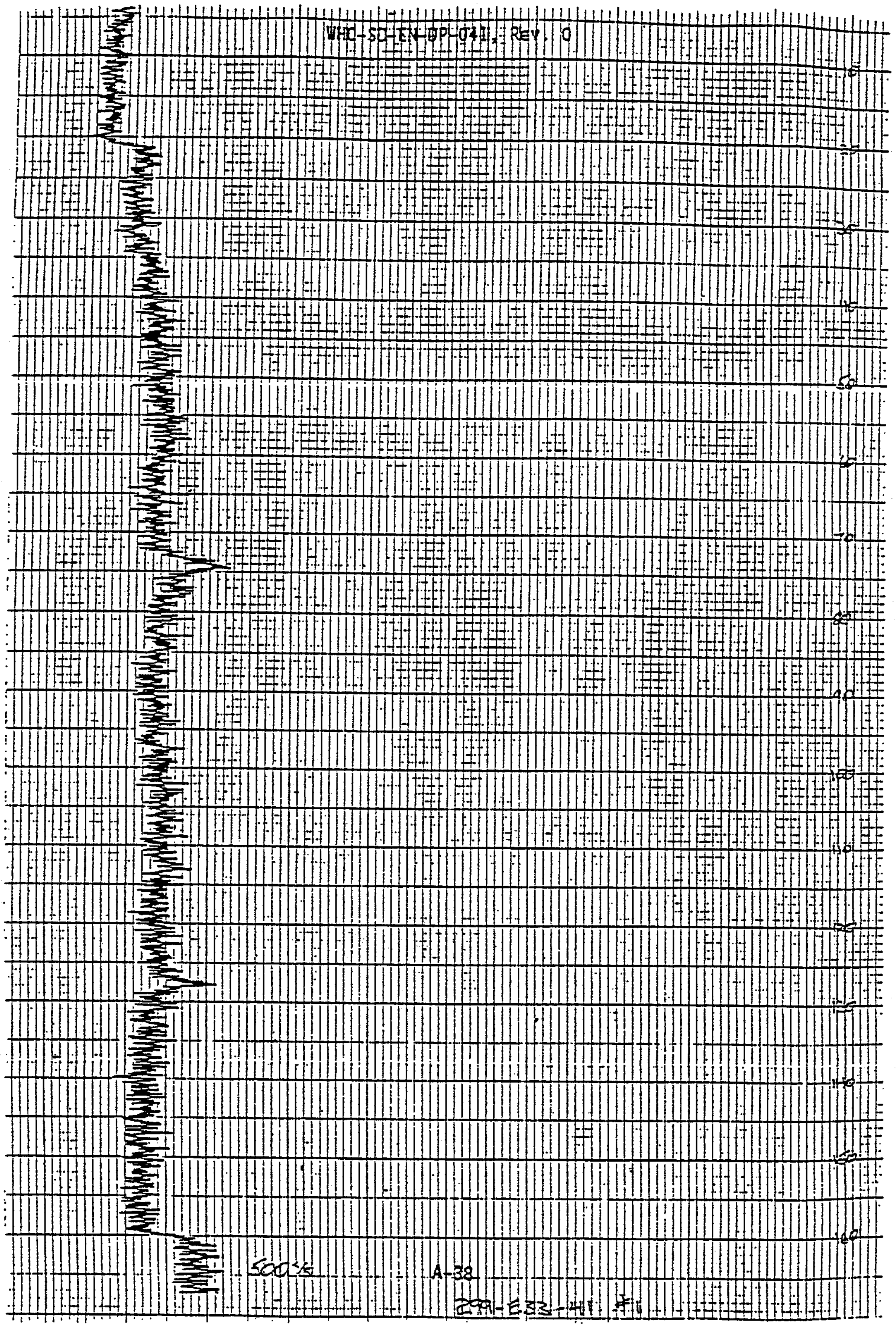
Percent Change: Position 1 0.6% Position 2 1.8%

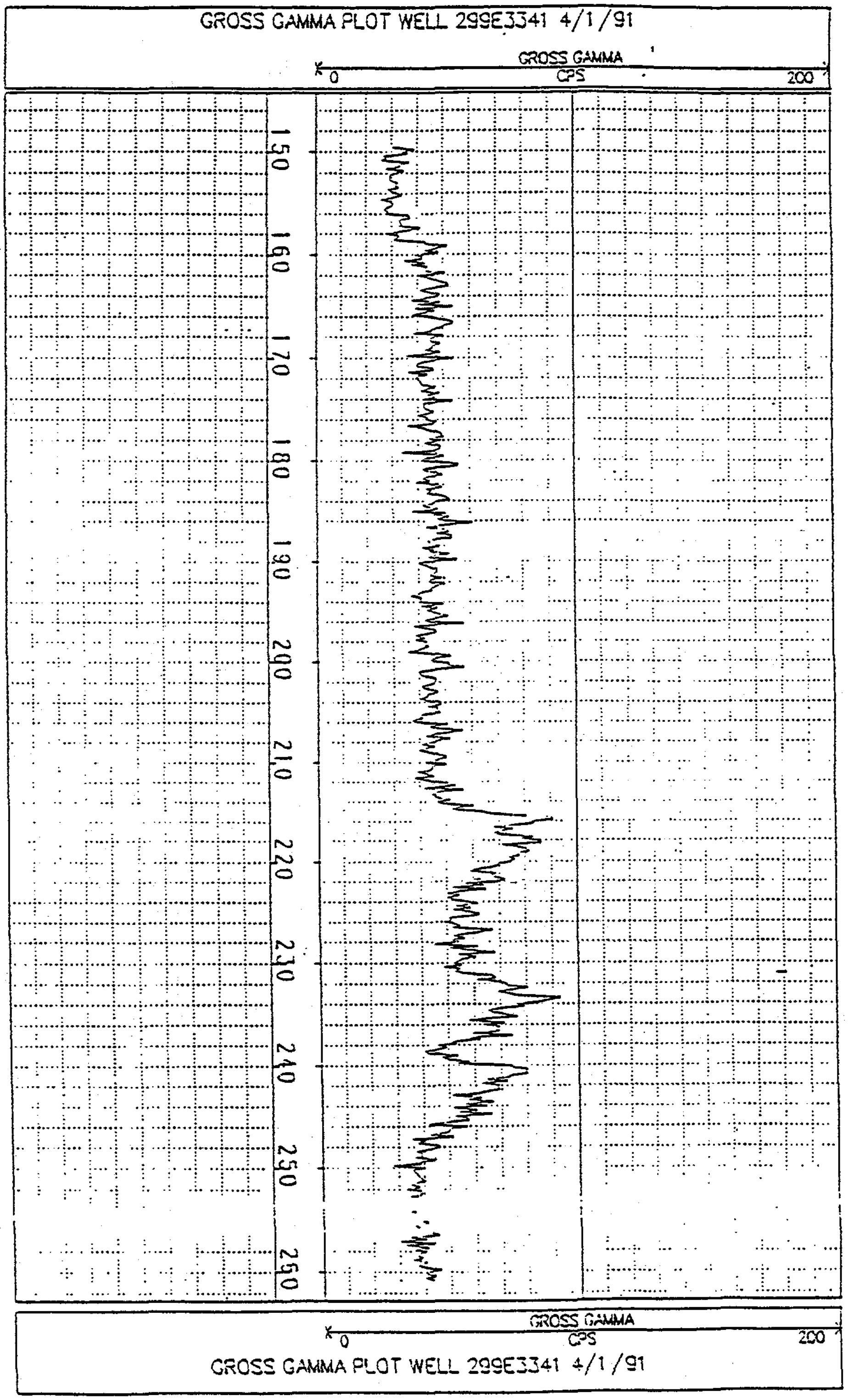
Comments Return Error = +0.5' high

Centralizer used.

A-37

Witnessed and Verified by: (sign and print name) [signature] STEVEN F KOS Date: 2/21/91

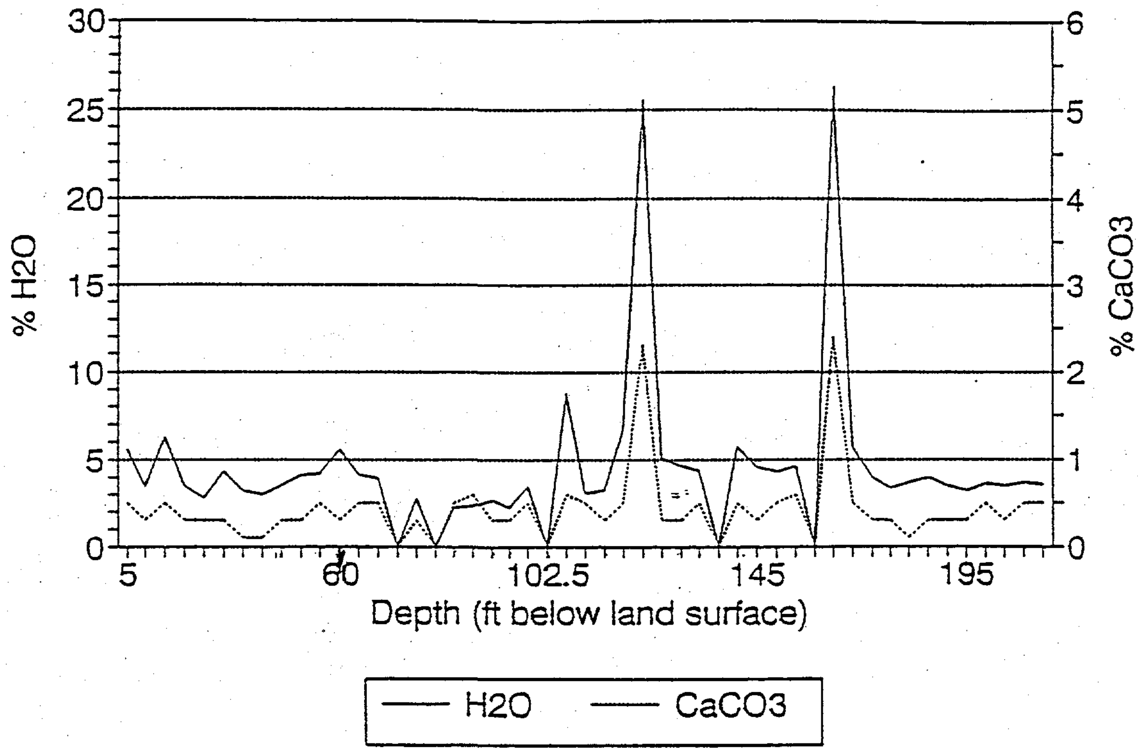

500c/s
A-38
299-E33-41 #1


GROSS GAMMA PLOT WELL 299E3341 4/1/91
GROSS GAMMA
0
CPS
200
150
160
170
180
190
200
210
220
230
240
250
260
GROSS GAMMA
0
CPS
200
GROSS GAMMA PLOT WELL 299E3341 4/1/91

A-39

299-E33-41

Soil Moisture and CaCO3 Content



Well 299-E33-41 Soil Moisture, CaCO3, and Radiological Content

DEPTH (ft)	H2O (%)	CaCO3 (%)	ALPHA (pCi/g)	BETA/GAMMA (pCi/g)
5	5.61	0.5	0.5	23.0
10	3.40	0.3	1.0	14.3
15	6.28	0.5	0.8	25.2
20	3.52	0.3	1.1	32.6
25	2.78	0.3	<D	49.1
30	4.35	0.3	<D	18.7
35	3.21	0.1	4.4	55.3
40	3.01	0.1	1.0	32.0
45	3.53	0.3	3.2	46.5
50	4.15	0.3	0.5	14.9
55	4.18	0.5	0.5	25.6
60	5.61	0.3	0.4	21.4
65	4.11	0.5	0.6	32.3
70	3.89	0.5	0.8	22.2
73	NA	NA	7.6	225.3
75	2.75	0.3	2.5	92.3
78	NA	NA	13.3	228.9
80	2.23	0.5	2.1	50.9
85	2.39	0.6	2.4	42.7
90	2.62	0.3	1.5	37.8
95	2.21	0.3	0.5	34.3
100	3.46	0.5	4.2	45.5
102.5	NA	NA	3.2	52.1
105	8.74	0.6	0.4	36.2
110	3.06	0.5	1.2	62.1
115	3.30	0.3	3.8	71.3
120	6.74	0.5	2.9	54.1
123	25.52	2.3	4.0	105.1
125	5.01	0.3	3.4	66.3
130	4.64	0.3	2.6	52.4
135	4.33	0.5	2.9	55.5
137	NA	NA	16.5	396.2
140	5.72	0.5	2.5	35.0
145	4.53	0.3	1.3	33.2
150	4.26	0.5	3.0	32.2
155	4.64	0.6	2.3	53.3
160	NA	NA	1.1	48.6
164	26.27	2.4	4.5	114.5
165	5.68	0.5	0.6	65.0
170	4.00	0.3	0.3	27.8
175	3.35	0.3	0.7	56.3
180	3.69	0.1	0.6	46.4
185	3.99	0.3	0.6	39.9
190	3.47	0.3	2.5	49.9
195	3.19	0.3	3.2	55.6
200	3.63	0.5	1.3	57.5
205	3.46	0.3	1.0	53.6
210	3.71	0.5	0.8	54.0
215	3.53	0.5	2.5	48.4
218	NA	NA	12.6	384.2
220	NA	NA	5.0	164.5
225	NA	NA	8.8	211.6
230	NA	NA	9.4	177.2
235	NA	NA	13.2	251.4
240	NA	NA	5.6	215.8
244	NA	0.3	1.3	40.4
254	NA	0.5	1.3	53.7
262	NA	NA	0.4	16.2

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

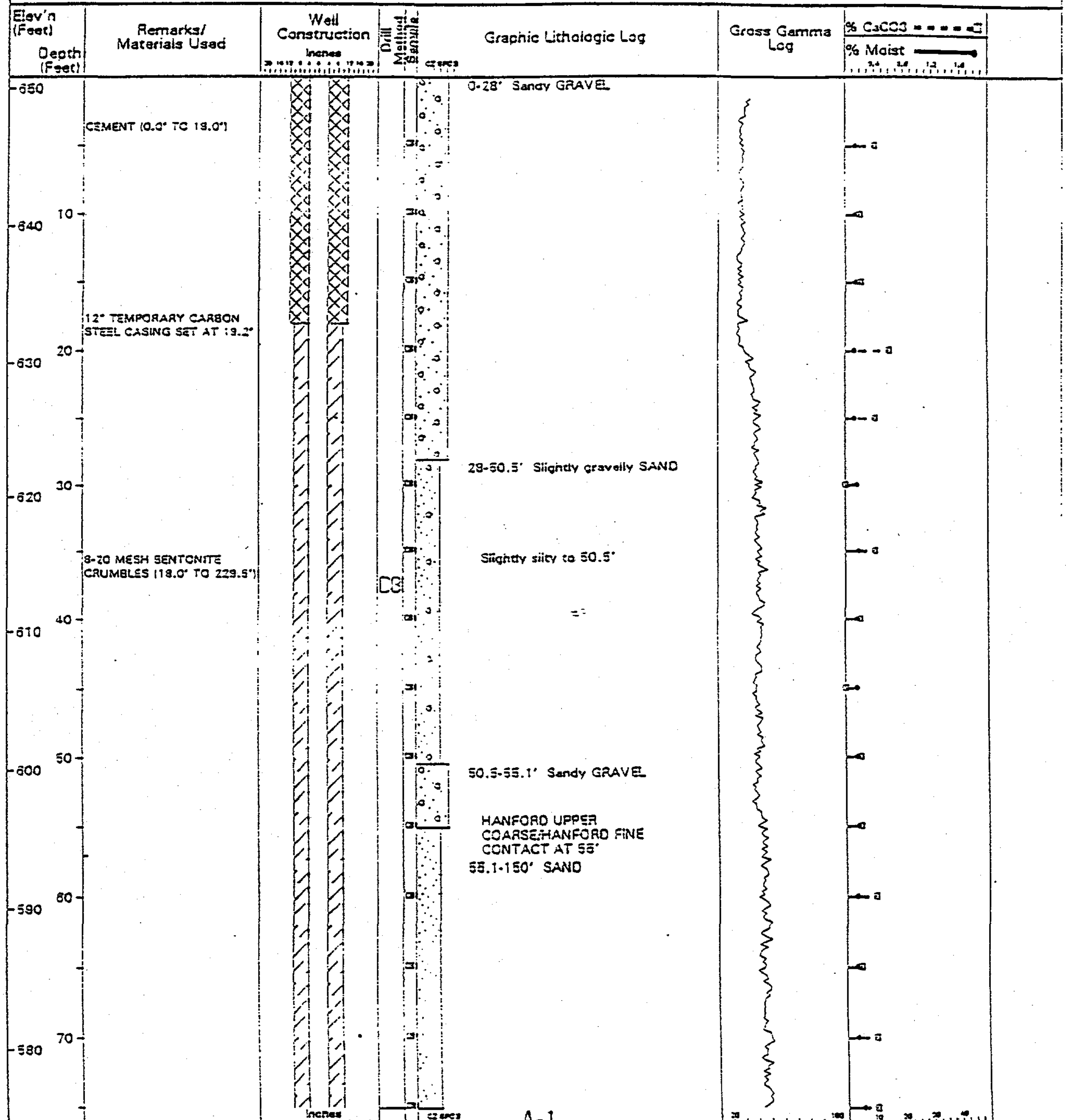
Project: W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION		Well No: 299-E33-42	
		Total Depth: 263.00	Static Water Level: 247.00
Date Started: 8-29-91	Date Completed: 11-14-91	Surface Elevation: 650.98	Casing Elevation: 654.30
Location: BX-BY TANK FARM, 200 EAST		Northing: 137424.38	Easting: 573520.99
Prepared By: R WINN, et al.		Hanford N: 45753.80	Hanford W: 53701.90
Drilling Co: KEH	Driller: J McKNIGHT	Drill Meth: CABLE TOOL	Drill Equip: 8E 22W

Screen: 21.0' OF 4" DIAMETER 20-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 238.5' TO 259.3'

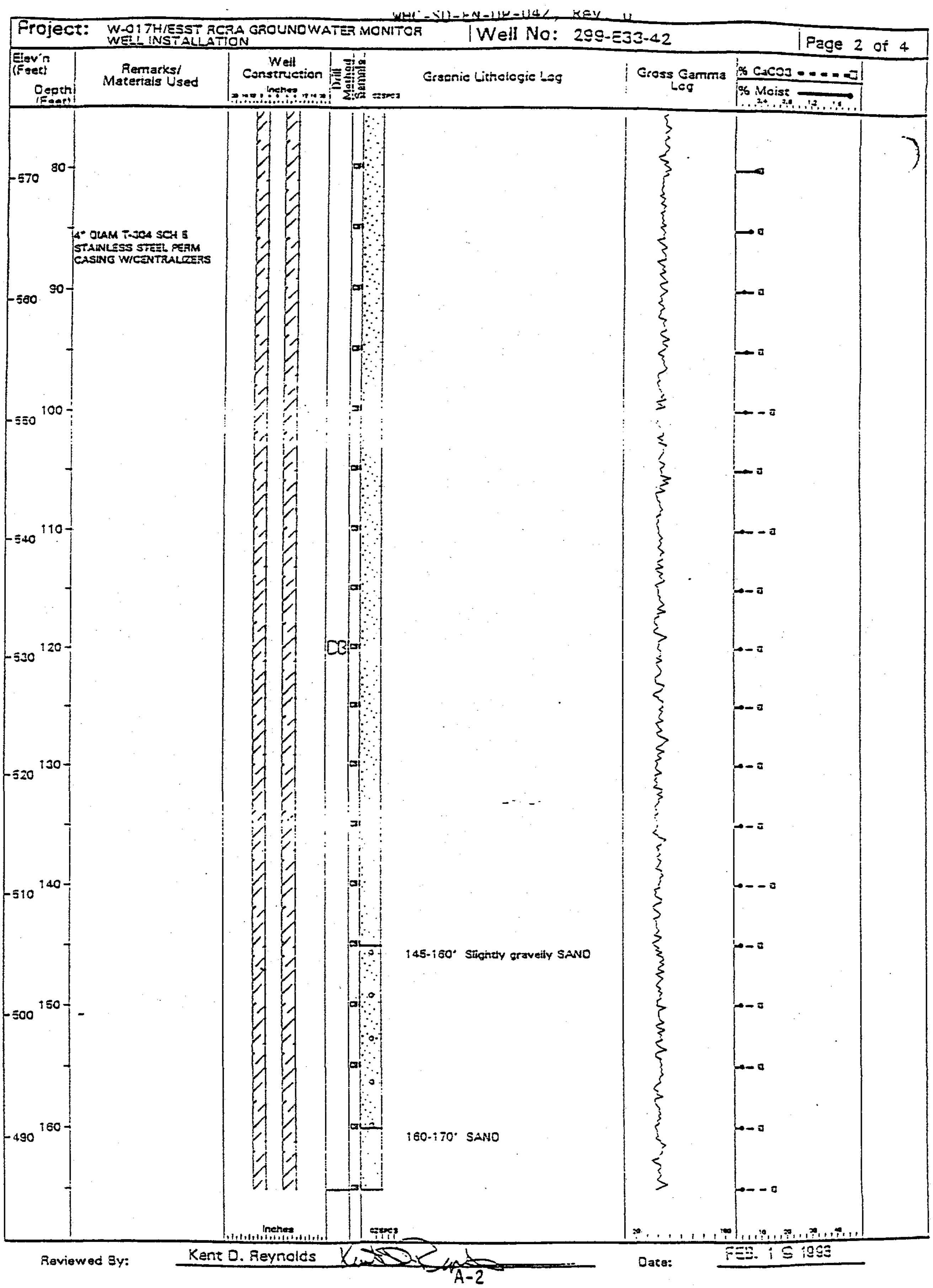
Filter Pack: 10-20 MESH SILICA SAND FROM 233.0' TO 259.9'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 238.5'

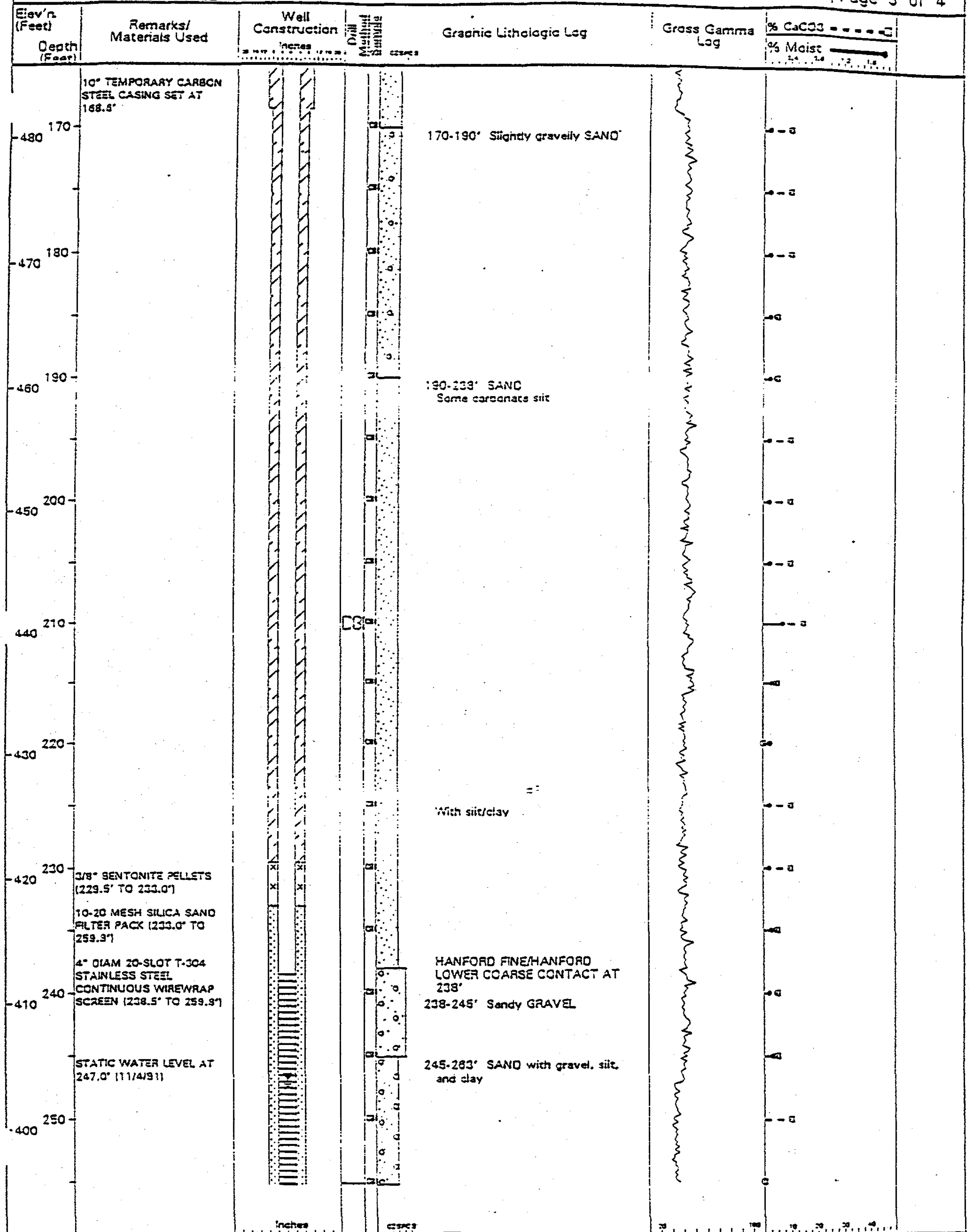
Comments:



Reviewed By: Kent D. Reynolds [signature] Date: FEB. 19 1993


WHC-SD-EN-DP-047, Rev. 0
Project: W-017H/EAST RCRA GROUNDWATER MONITOR WELL INSTALLATION
Well No: 299-E33-42
Page 2 of 4
Elev'n (Feet)
Depth (Feet)
Remarks/ Materials Used
Well Construction
Inches
Drill Method
Sample
Graphic Lithologic Log
Gross Gamma Log
% CaCO3
% Moist
570
80
4" DIAM T-304 SCH 5 STAINLESS STEEL PERM CASING W/CENTRALIZERS
560
90
550
100
540
110
530
120
520
130
510
140
145-160' Slightly gravelly SAND
500
150
490
160
160-170' SAND
Reviewed By: Kent D. Reynolds
Date: FEB. 1 9 1993
A-2

Project: W-017H/EEST RCRA GROUNDWATER MONITOR WELL INSTALLATION | Well No: 299-E33-42 |



Reviewed By: Kent D. Reynolds [signature] Date: FEB. 1 9 1992

A-3

Project: W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION

Well No: 299-E33-42

Elev'n (Feet)	Depth (Feet)	Remarks/ Materials Used	Well Construction	Graphic Lithologic Log	Gross Gamma Log	% CaCO3 / % Moist
390	260	8" TEMPORARY CARBON STEEL CASING SET AT 259.9'		CG		
		SLUFF (259.9' TO 263')				
		TOTAL DEPTH = 263'				
380	270					
370	280					
360	290					
350	300					
340	310					
330	320					
320	330					
310	340					

Reviewed By: Kent D. Reynolds

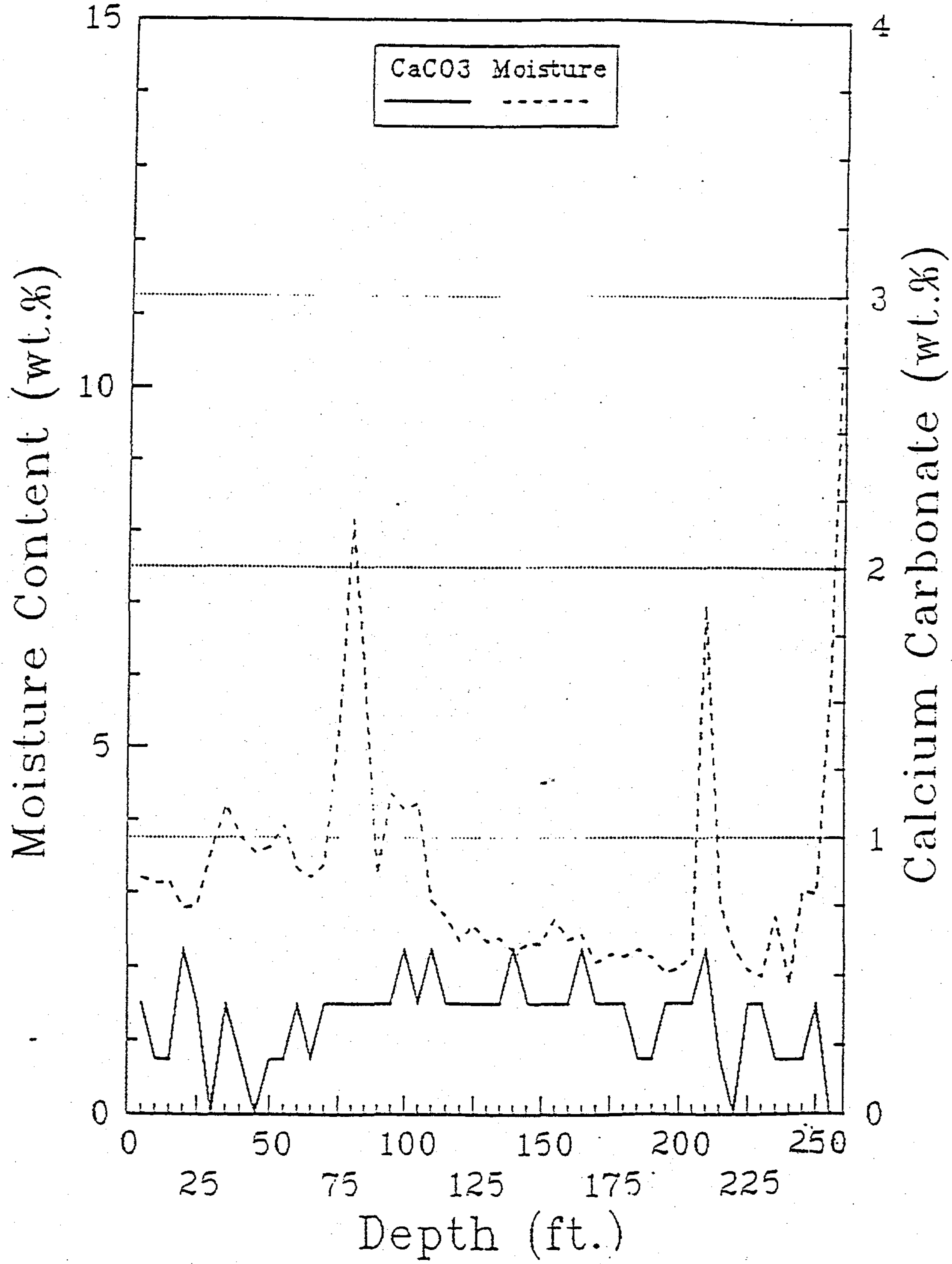
Date: FEB 10 1993

A-4

VALIDATED
SIGNATURE/DATE

183

WELL 299-E33-42



C-1

	A	B	C
1	WELL 299-E33-42		
2			
3	Depth	CaCO3	Moisture
4	ft.	Wt. %	Wt. %
5			
6	5	0.4	3.20
7	10	0.2	3.13
8	15	0.2	3.15
9	20	0.6	2.79
10	25	0.4	2.83
11	30	0	3.58
12	35	0.4	4.20
13	40	0.2	3.75
14	45	0	3.55
15	50	0.2	3.62
16	55	0.2	3.92
17	60	0.4	3.32
18	65	0.2	3.22
19	70	0.4	3.39
20	75	0.4	5.21
21	80	0.4	8.16
22	85	0.4	5.89
23	90	0.4	3.24
24	95	0.4	4.35
25	100	0.6	4.14
26	105	0.4	4.23
27	110	0.6	2.89
28	115	0.4	2.68
29	120	0.4	2.35
30	125	0.4	2.57
31	130	0.4	2.34
32	135	0.4	2.38
33	140	0.6	2.20
34	145	0.4	2.31
35	150	0.4	2.31
36	155	0.4	2.65
37	160	0.4	2.37
38	165	0.6	2.43
39	170	0.4	2.06
40	175	0.4	2.16
41	180	0.4	2.14
42	185	0.2	2.23
43	190	0.2	2.11
44	195	0.4	1.92
45	200	0.4	1.99
46	205	0.4	2.15
47	210	0.6	6.98

3-3

	A	B	C
48	215	0.2	2.86
49	220	0	2.25
50	225	0.4	1.95
51	230	0.4	1.87
52	235	0.2	2.67
53	240	0.2	1.77
54	245	0.2	3.03
55	250	0.4	2.98
56	255	0	5.79
57	260	0	12.2

Project: W-017H/ESST RCRA GROUNDWATER MONITOR WELL INSTALLATION

Well No: 299-E33-43 | Page 1 of 4

Total Depth: 275.30 | Static Water Level: 255.50

Date Started: 8-30-91 | Date Completed: 11-13-91 | Surface Elevation: 659.18 | Casing Elevation: 662.68

Location: BX-BY TANK FARM, 200 EAST | Northing: 137325.43 | Easting: 573523.19

Prepared By: R WINN, et al. | Hanford N: 45429.10 | Hanford W: 53695.60

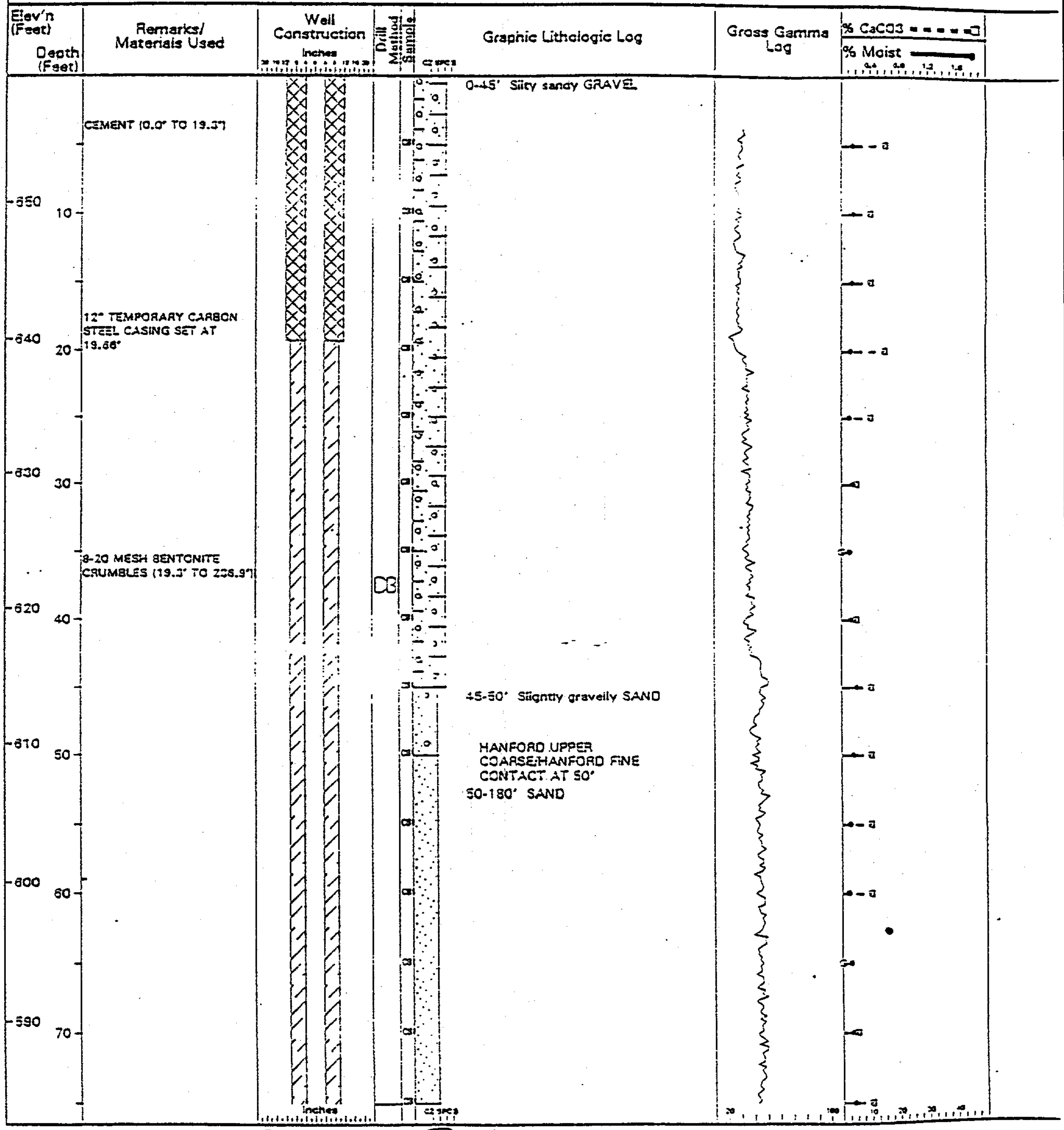
Drilling Co: KEH | Driller: B SMITH. | Drilling Method: CABLE TOOL | Drilling Equipment: BE 22W

Screen: 20.0' OF 4" DIAMETER 20-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 250.22' TO 271.34'

Filter Pack: 10-20 MESH SILICA SAND FROM 246.9' TO 274.9'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 250.22'

Comments:



Reviewed By: KD Reynolds/KD Reynolds A-25 Date: 2/12/93

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

Project: 200 AAMS, NE of BY Tank Farm

Borehole	299-E33-13			
Coordinates	46,278 N	53,093 W	Feet	(Plant 200 W)
Elevation	625.53 feet		Top of Casing	(Plant 200 W)

Borehole Environment Information

Borehole Fluid Depth 221.2 (Feet) from Zero (0.0) Depth Reference of Log

Casing Size I.D. (inch)	Casing Thickness (inch)	Top Depth (feet)	Base Depth (feet)
8.0	0.325	0.0	232.0

RLS Passive Spectral Gamma Survey Information

Logging Engineers R. V. Cram S. E. Kos
Log Depth Reference at Zero (0.0) depth is Ground Level

Log Date	Archive File Names	Log Mode[1] Speed	Depth Interval (feet) Top	Base	Incr
July 20, 92	H2E3313\A208	MSA 80sec LT	0.	76.5	0.5
July 21, 92	H2E3313\A209	MSA 80sec ET	75.0	186.5	0.5
July 22, 92	H2E3313\A210	MSA 80sec LT	185.0	231.7	0.5

[1] MSA: Move-Stop-Acquire LT: Live Time

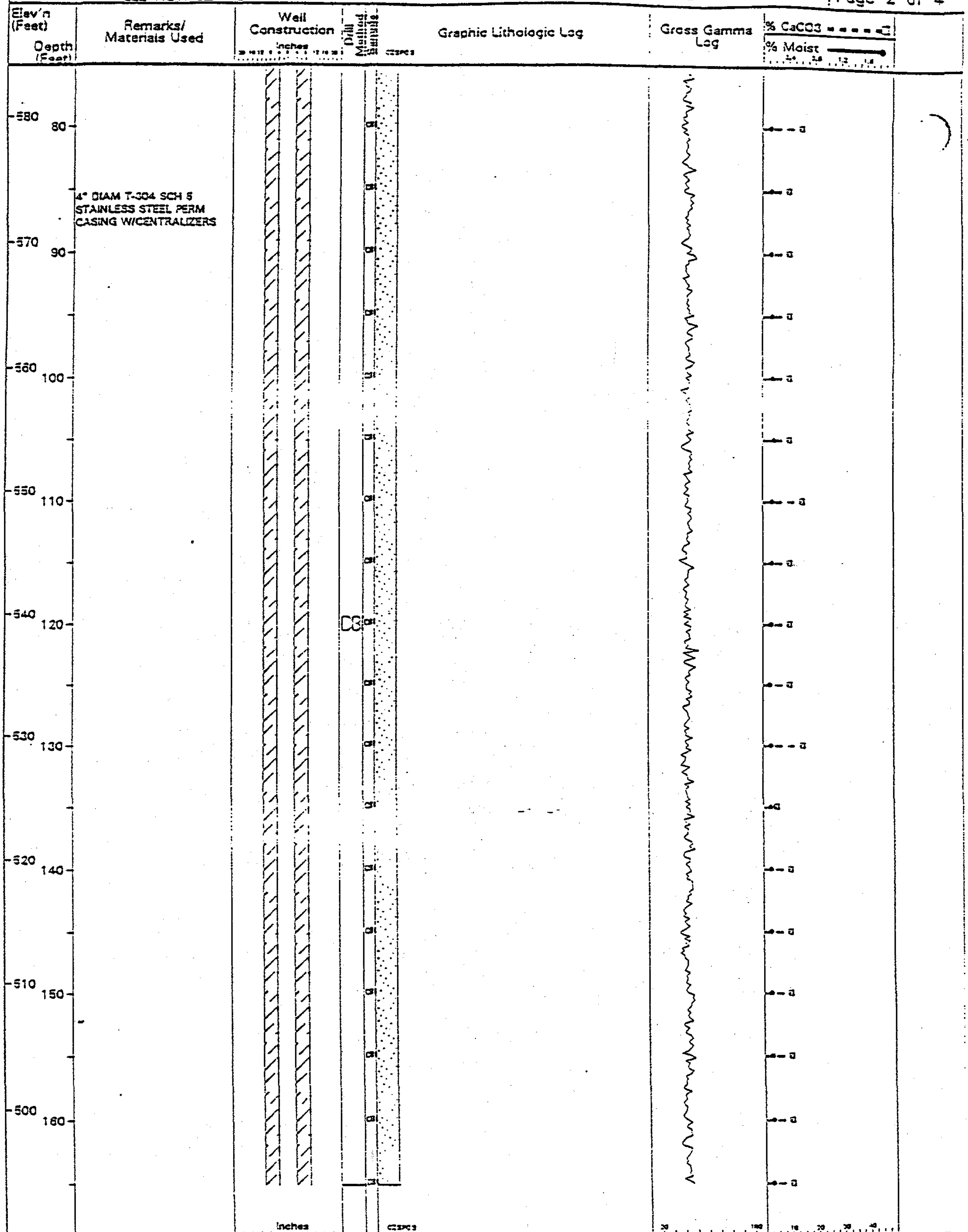
Calibration and Analysis Information

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

Analyst Names: J. P. Kiesler R. K. Price
Analysis Date: July 31, 1992

Analysis Notes: Cesium-137 is the highest at the surface
Radionuclides identified: Cs-137, Co-60

Project: W-017/H/EAST RCRA GROUNDWATER MONITOR WELL INSTALLATION | Well No: 299-E33-43 | Page 2 of 4

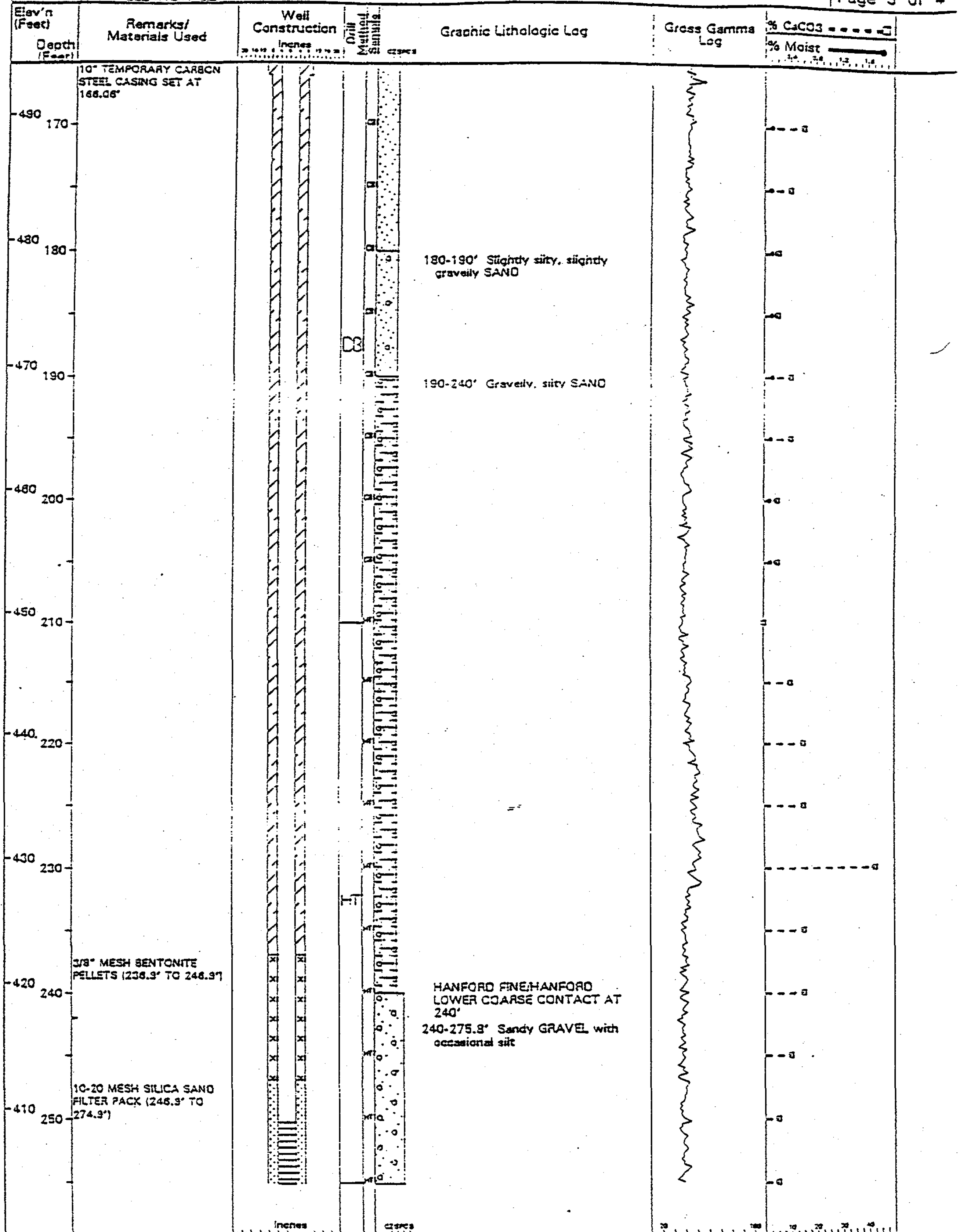


Reviewed By: KD Reynolds / KDR | Date: 2/12/93

A-26

Project: W-017H/EEST RCRA GROUNDWATER MONITOR WELL INSTALLATION

Well No: 299-E33-43



Reviewed By: KD Reynolds / KD Rey

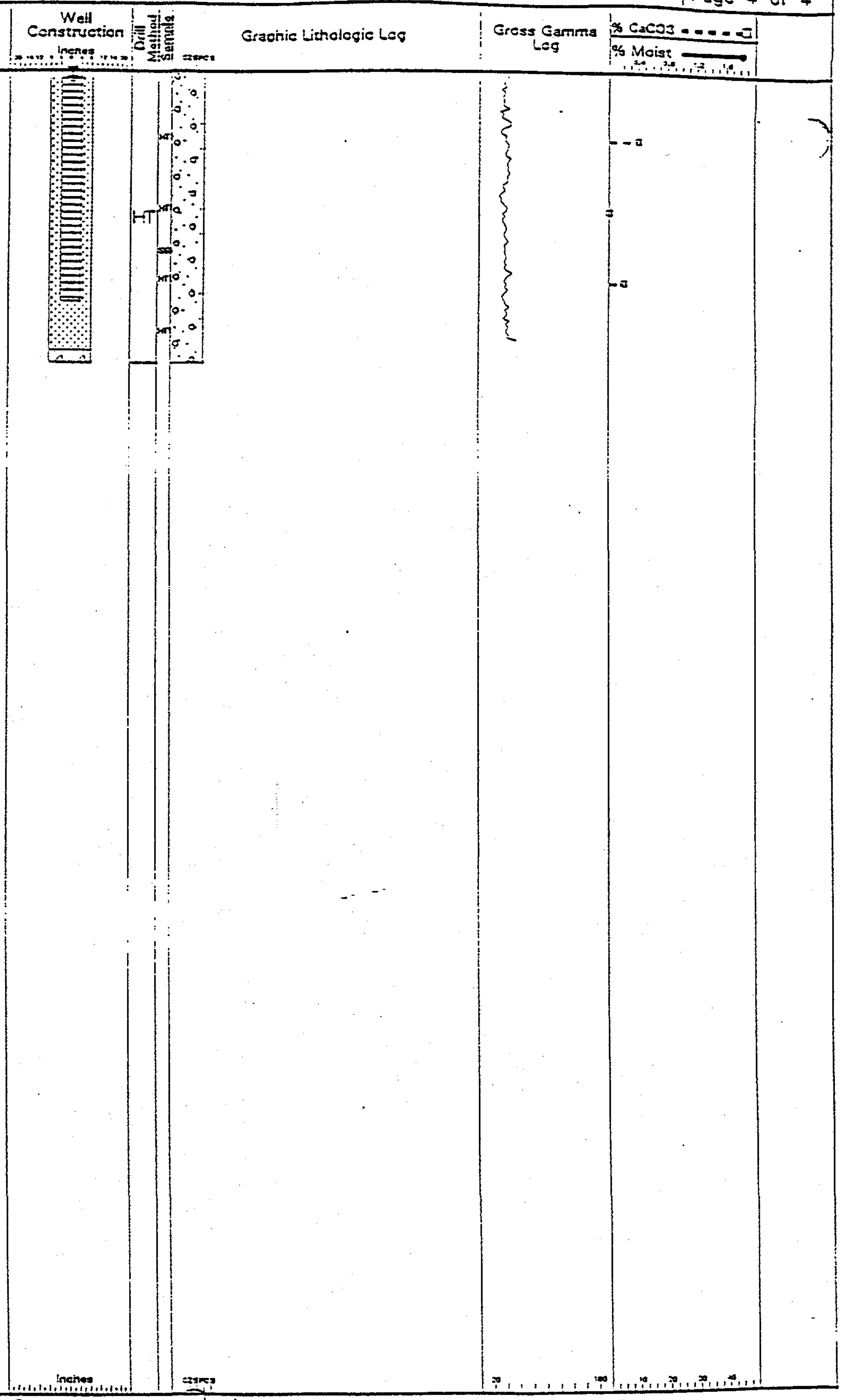
Date: 2/12/93

A-27

Project: W-017H/EEST RCRA GROUNDWATER MONITOR WELL INSTALLATION

Well No: 299-E33-43

Elev'n (Feet)	Depth (Feet)	Remarks/ Materials Used
		STATIC WATER LEVEL AT 258.5' (11/1/91)
400	260	4" DIAM 20-SLOT T-304 STAINLESS STEEL CONTINUOUS WIREWRAP SCREEN (250.22' TO 271.34')
390	270	8" TEMPORARY CARBON STEEL CASING SET AT 273.42'
		SLUFF (274.3' TO 275.8')
		TOTAL DEPTH = 275.8'
380	280	
370	290	
360	300	
350	310	
340	320	
330	330	
320	340	



Reviewed By: KD Reynolds / KD Reynolds

Date: 2/12/93

A-28

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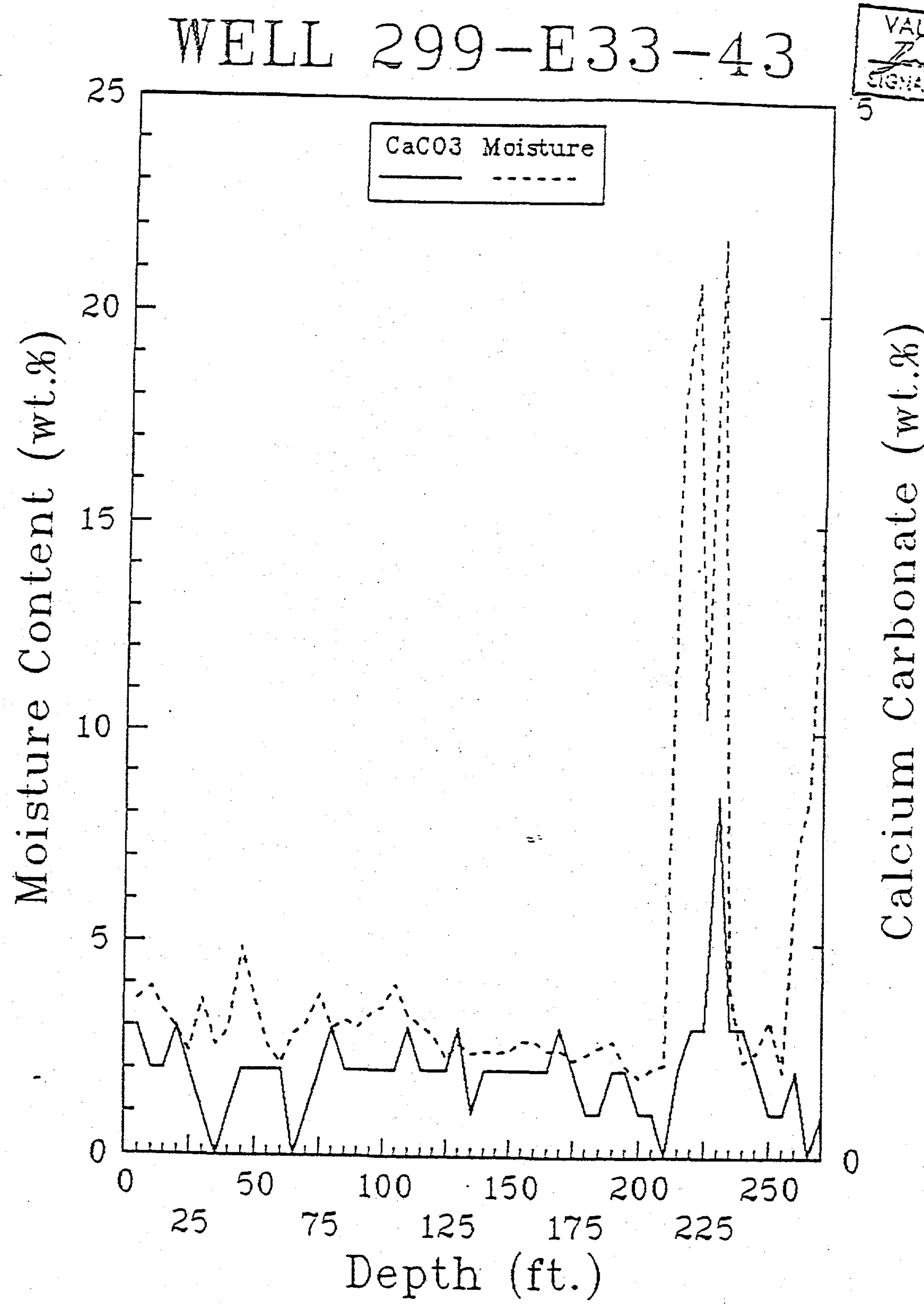
VALIDATED
SIGNATURE/DATE

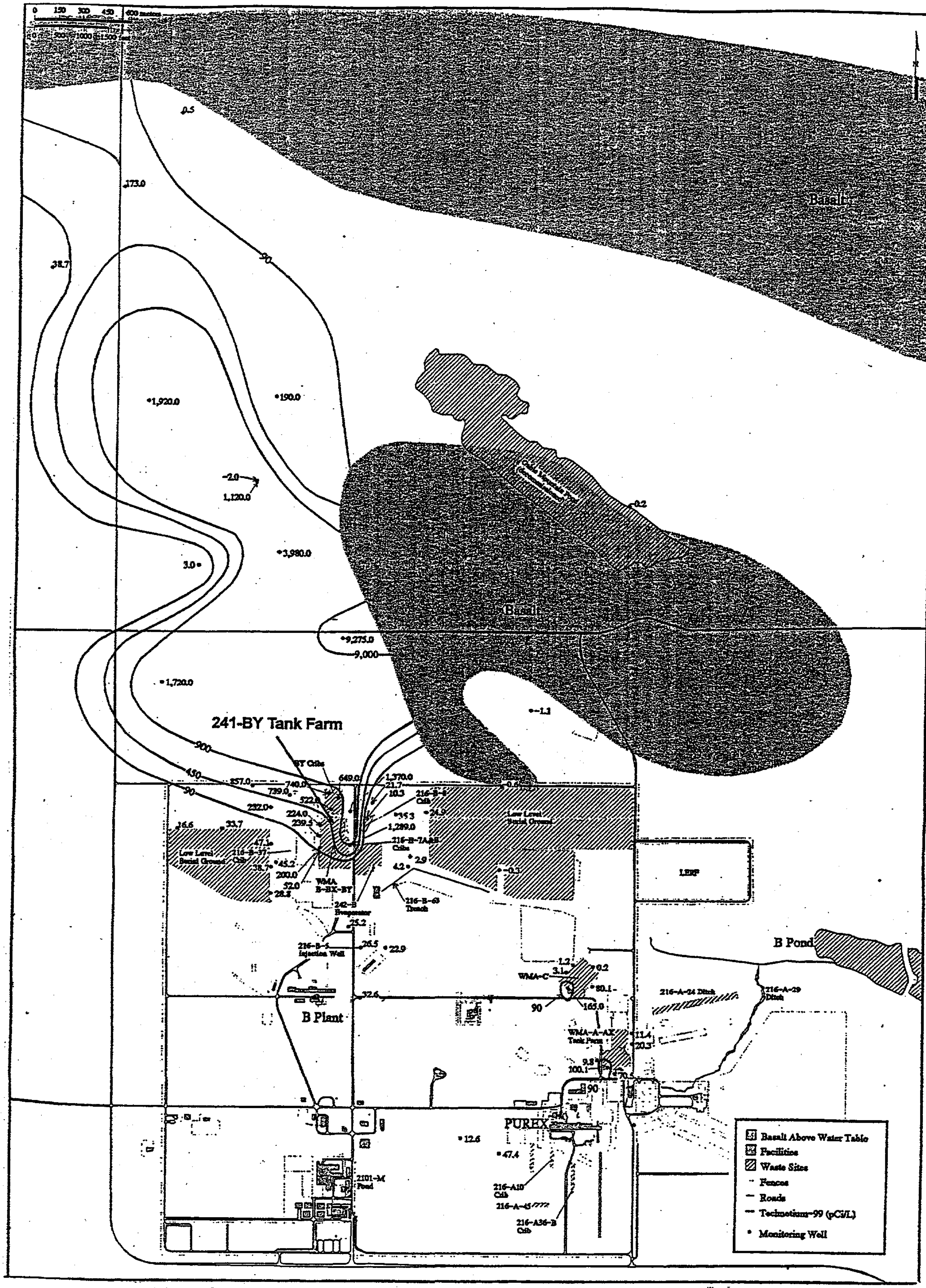


283

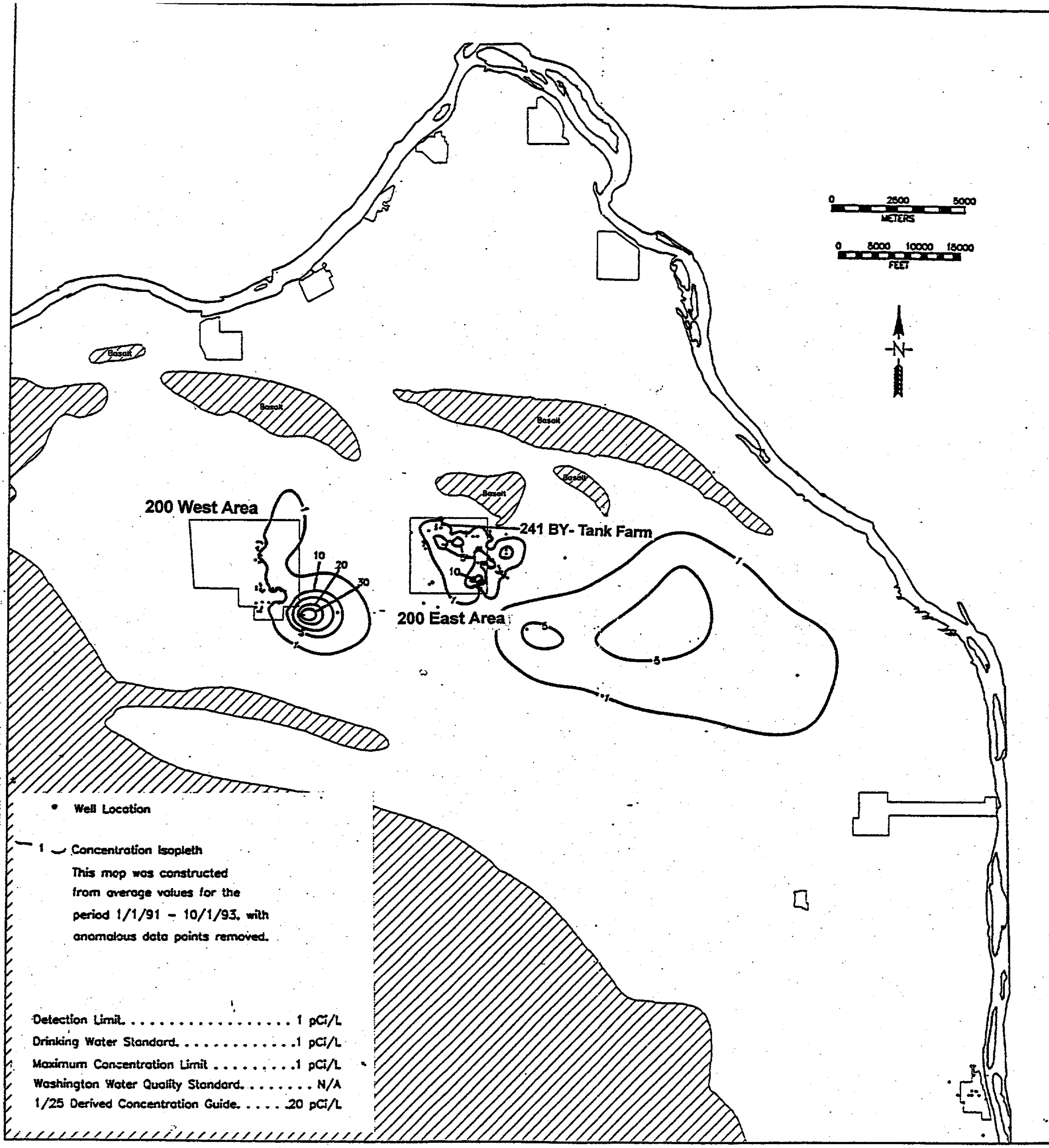
	A	B	C
1	WELL 299-E33-43		
2			
3	Depth	CaCO3	Moisture
4	ft.	Wt. %	Wt. %
5			
6	5	0.6	3.64
7	10	0.4	3.91
8	15	0.4	3.37
9	20	0.6	2.93
10	25	0.4	2.42
11	30	0.2	3.64
12	35	0	2.57
13	40	0.2	2.91
14	45	0.4	4.88
15	50	0.4	3.63
16	55	0.4	2.57
17	60	0.4	2.14
18	65	0	2.83
19	70	0.2	3.08
20	75	0.4	3.76
21	80	0.6	2.98
22	85	0.4	3.17
23	90	0.4	3.00
24	95	0.4	3.31
25	100	0.4	3.48
26	105	0.4	4.00
27	110	0.6	3.28
28	115	0.4	3.04
29	120	0.4	2.84
30	125	0.4	2.28
31	130	0.6	2.62
32	135	0.2	2.40
33	140	0.4	2.44
34	145	0.4	2.41
35	150	0.4	2.47
36	155	0.4	2.68
37	160	0.4	2.71
38	165	0.4	2.47
39	170	0.6	2.48
40	175	0.4	2.25
41	180	0.2	2.38
42	185	0.2	2.54
43	190	0.4	2.68
44	195	0.4	2.11
45	200	0.2	1.85
46	205	0.2	2.07
47	210	0	2.16

	A	B	C
48	215	0.4	17.68*
49	220	0.6	20.76*
50	225	0.6	10.37*
51	230	1.7	21.78*
52	235	0.6	3.97*
53	240	0.6	2.21*
54	245	0.4	2.43*
55	250	0.2	3.21*
56	255	0.2	1.99*
57	260	0.4	7.12*
58	265	0	8.51*
59	270	0.2	15.44*

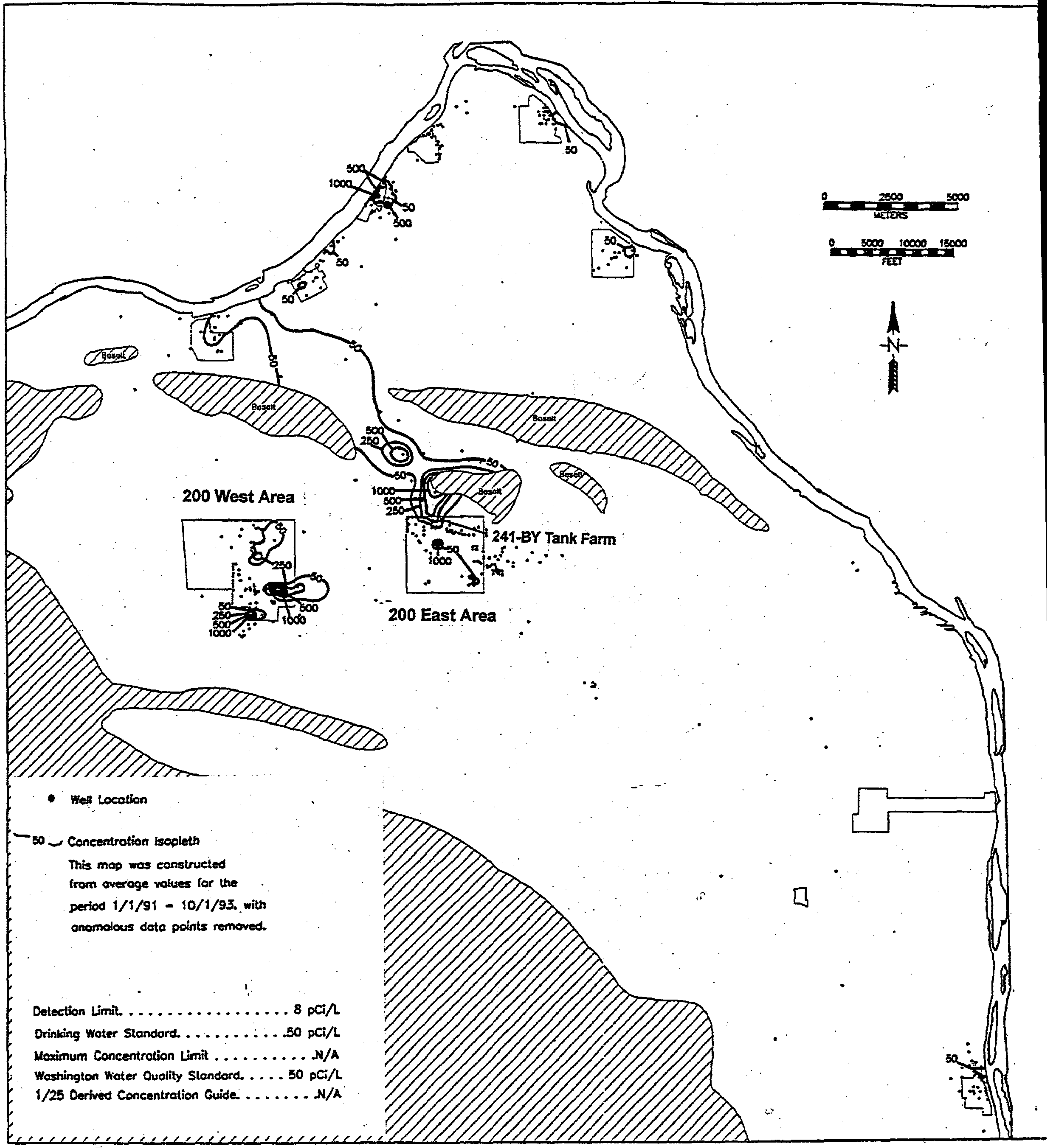
*Collected in interval [illegible] ... groundwater table.



1995 Average Technetium-99 Concentrations in the 200 East Area and Surrounding 600 Area (Revised from Dresel et al. 1995)



Iodine-129 Distribution in the Uppermost Aquifer, Hanford Site
January 1991 through September 1993
Revised from DOE 1995a



Gross Beta Distribution in the Uppermost Aquifer, Hanford Site
January 1991 through September 1993
Revised from DOE 1995a

Appendix B

BY Tank Farm Correlation Plots

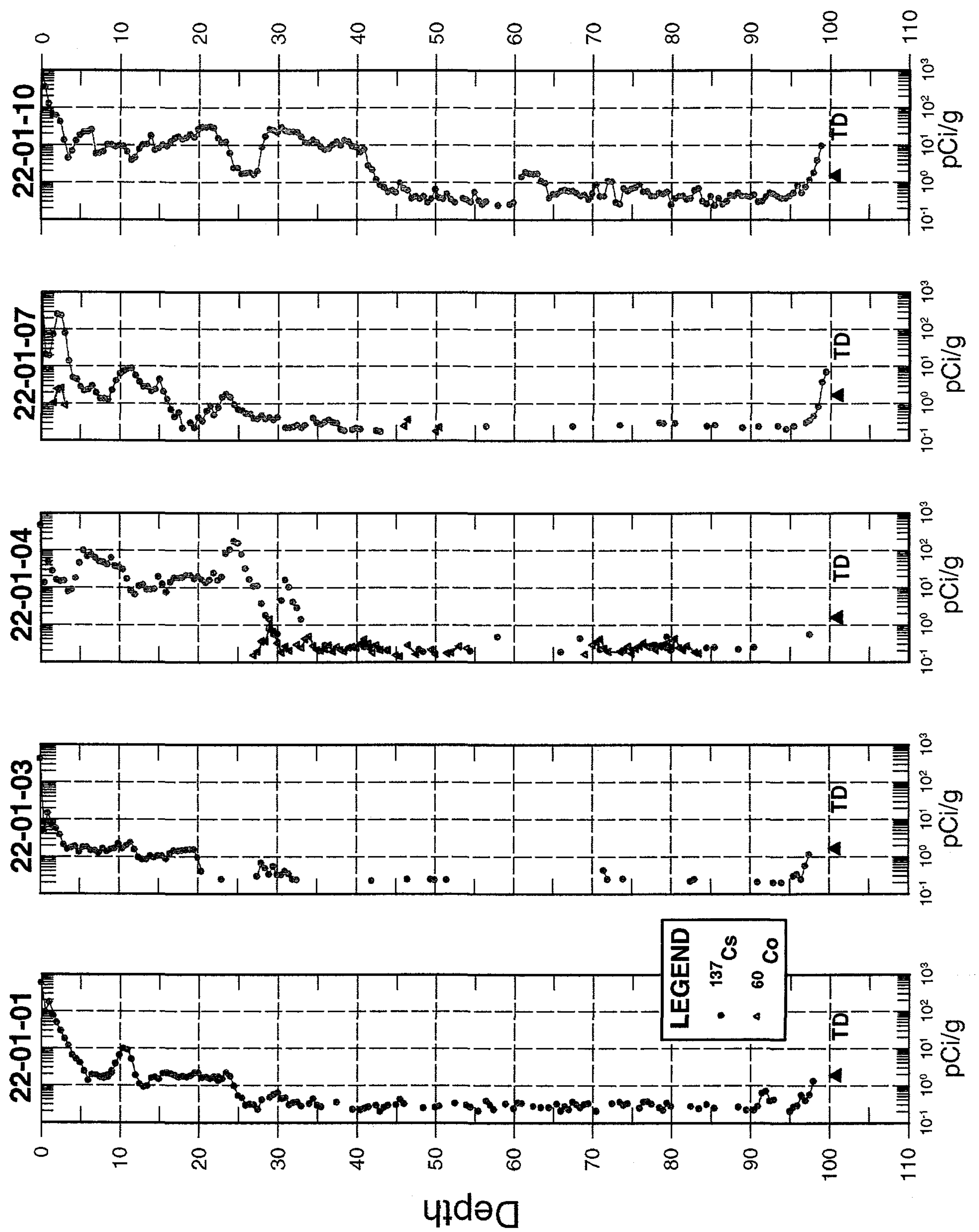


Figure B-1. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-101

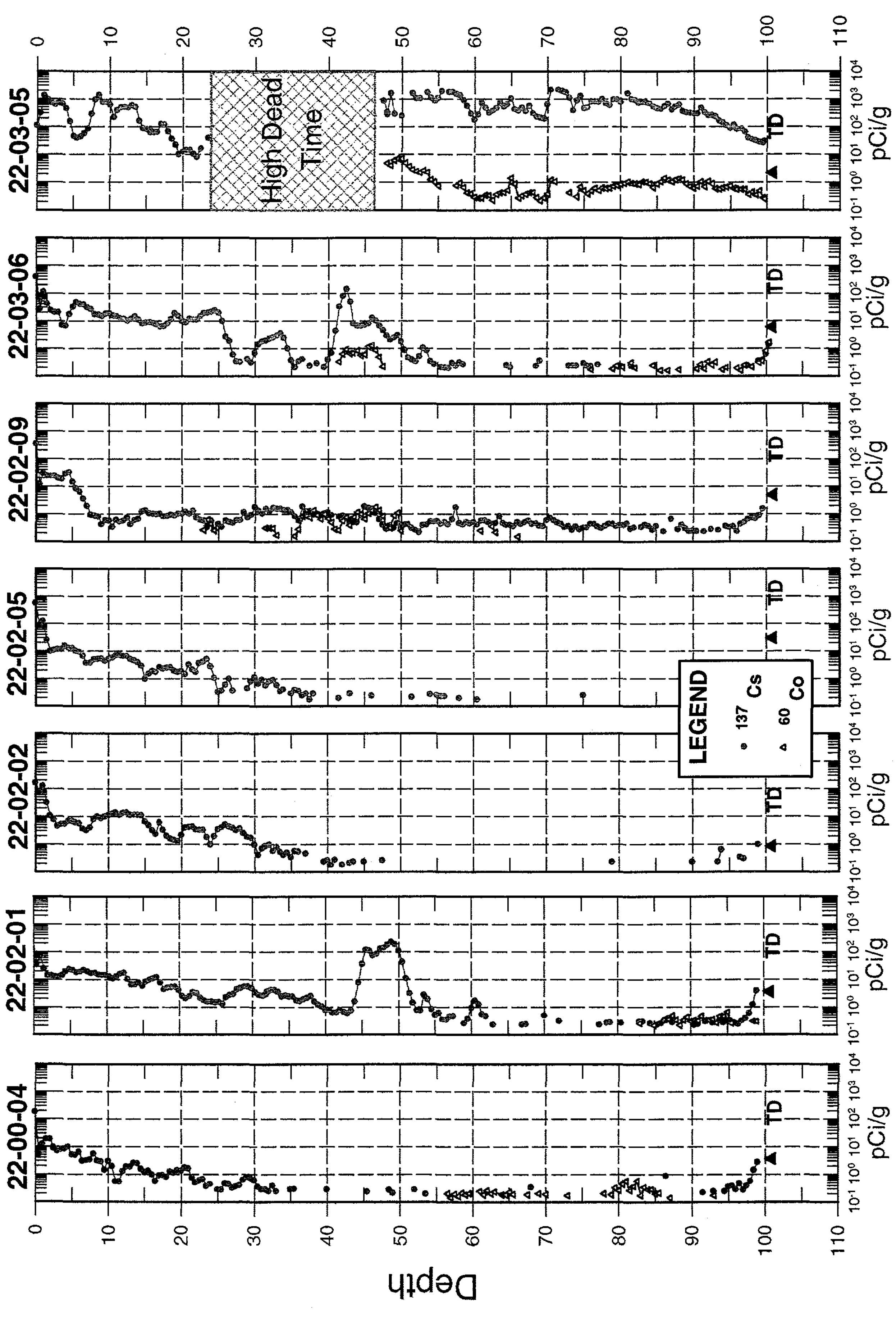


Figure B-2. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-102

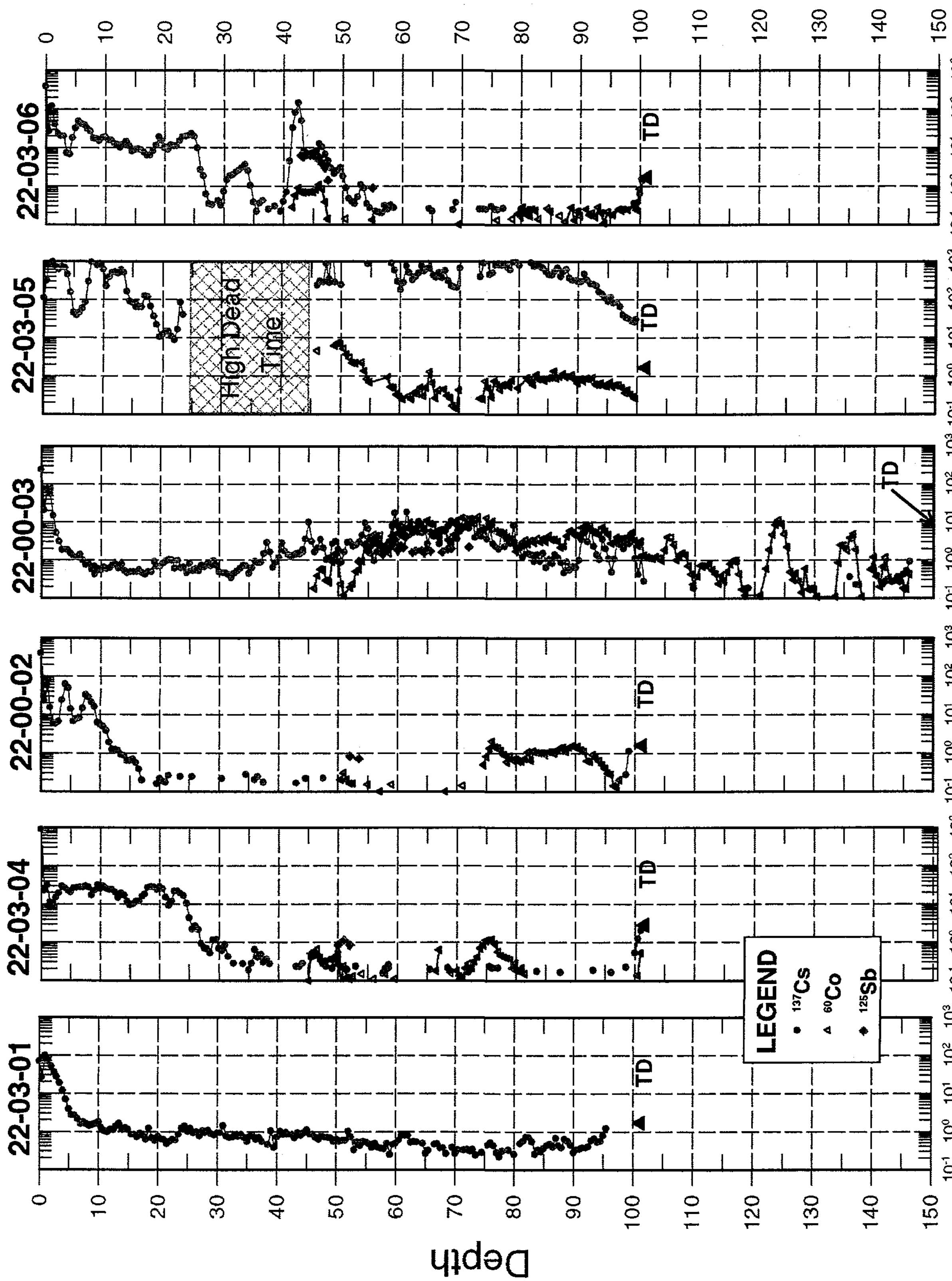


Figure B-3. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{125}Sb Concentrations in Boreholes Surrounding Tank BY-103

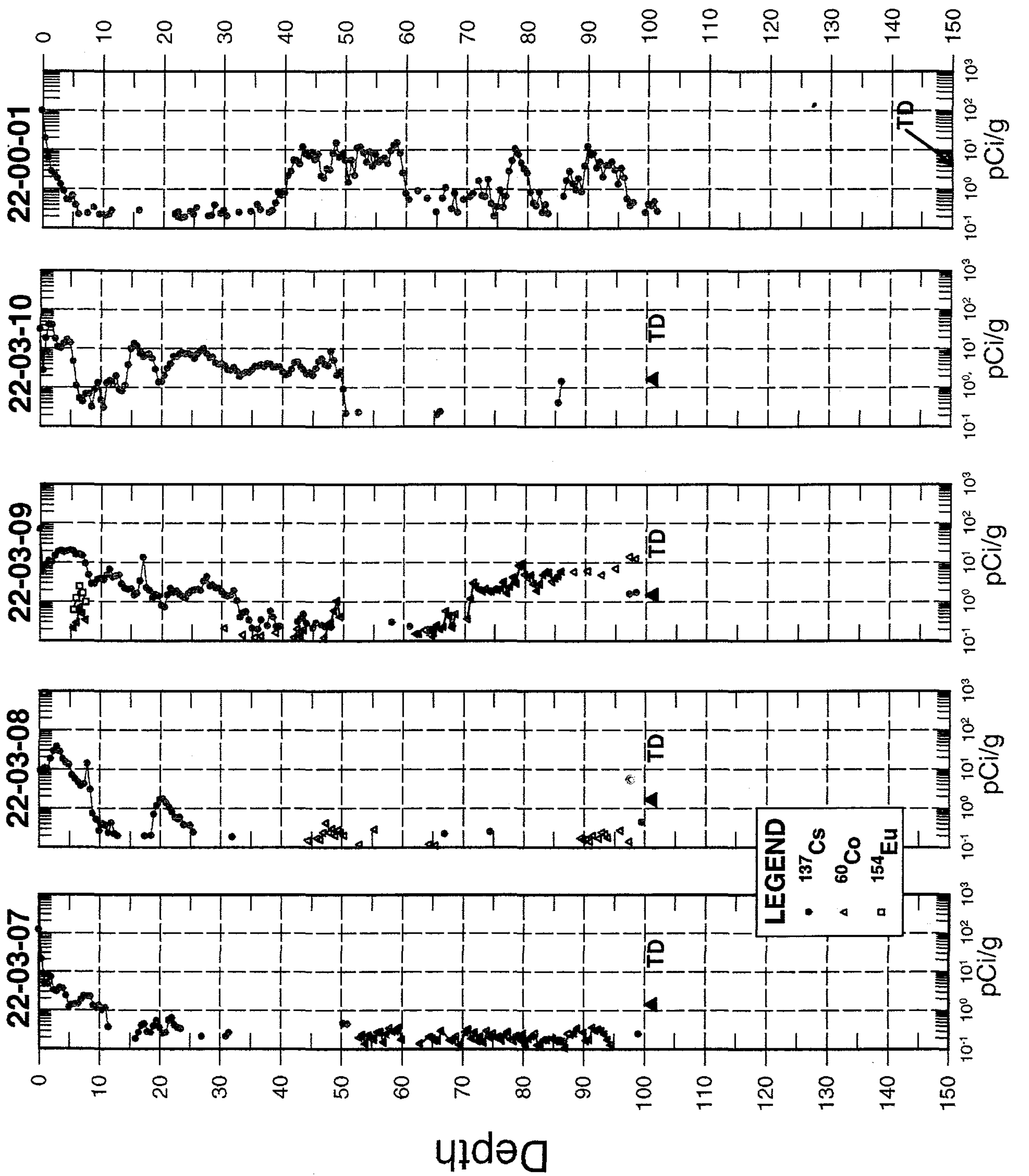


Figure B-3 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-103

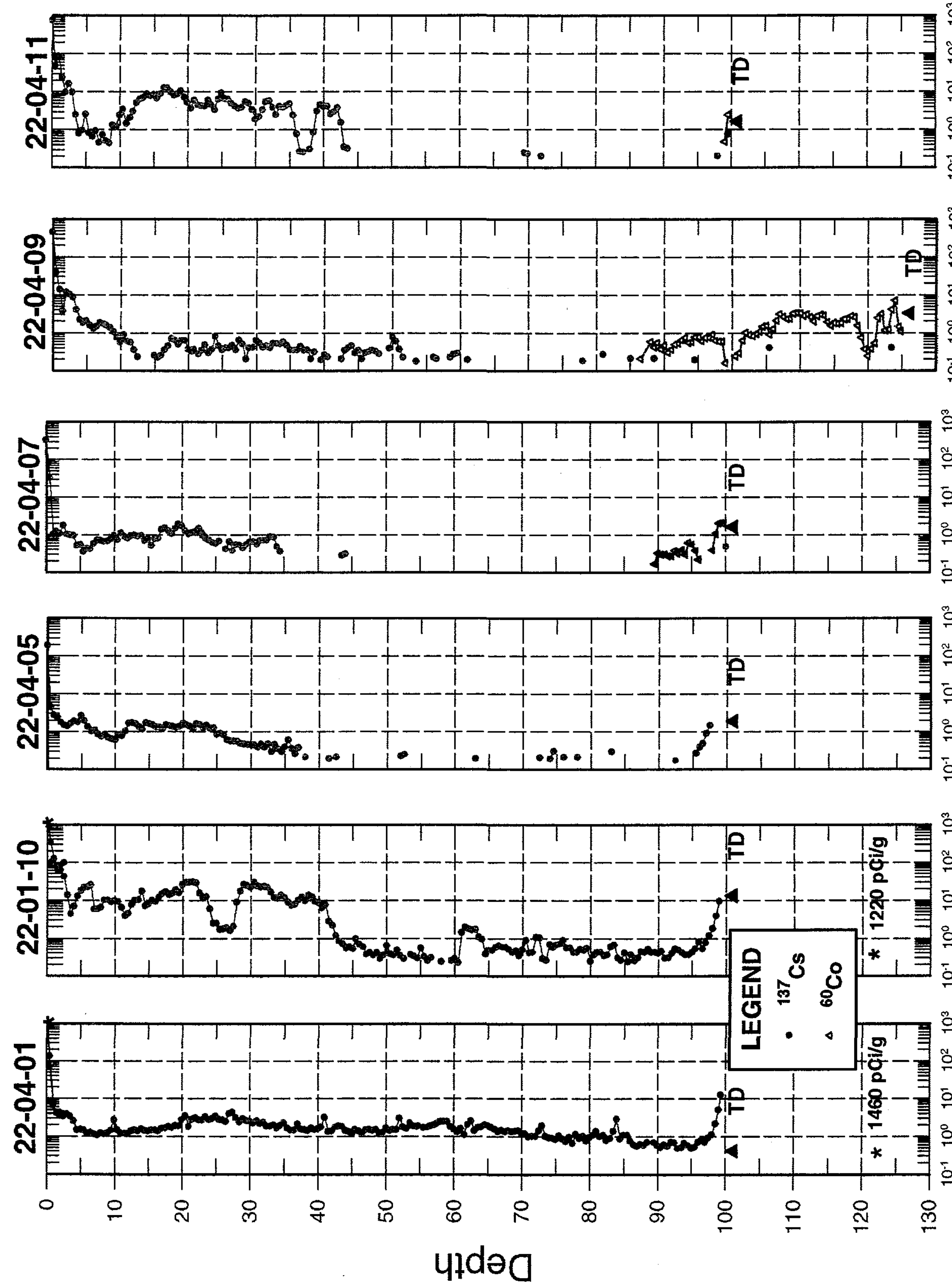


Figure B-4. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-104

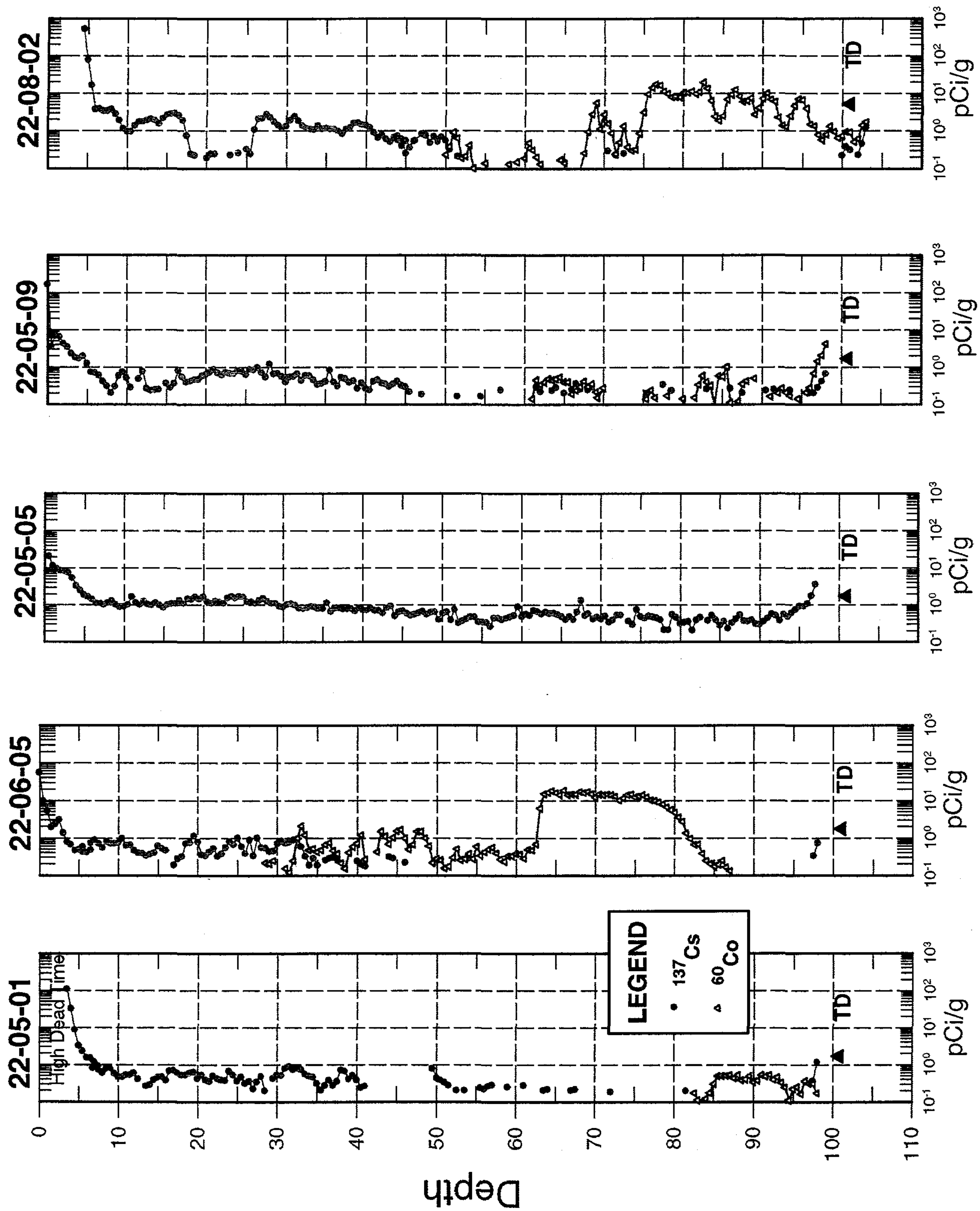


Figure B-5. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-105

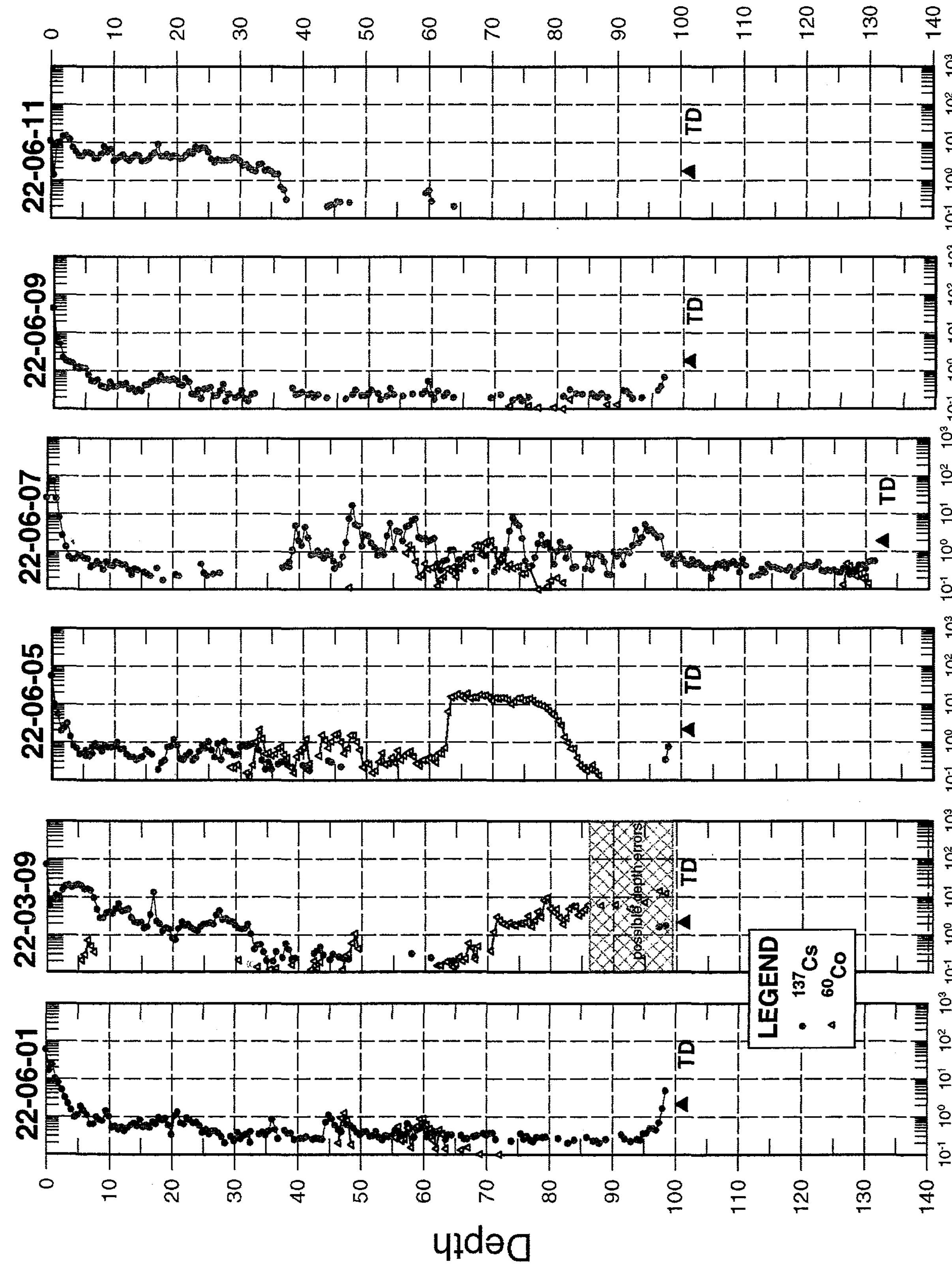


Figure B-6. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-106

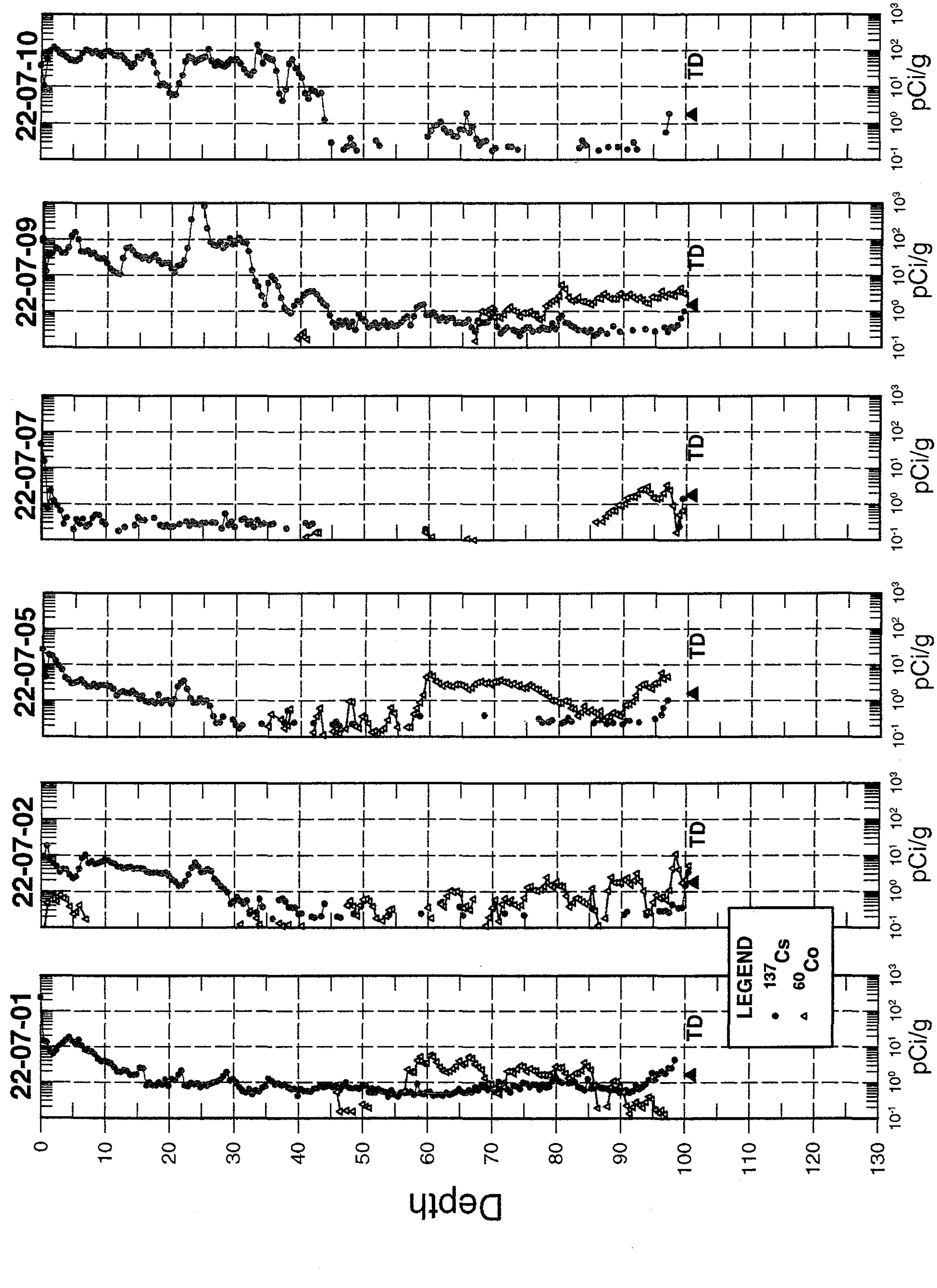


Figure B-7. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-107

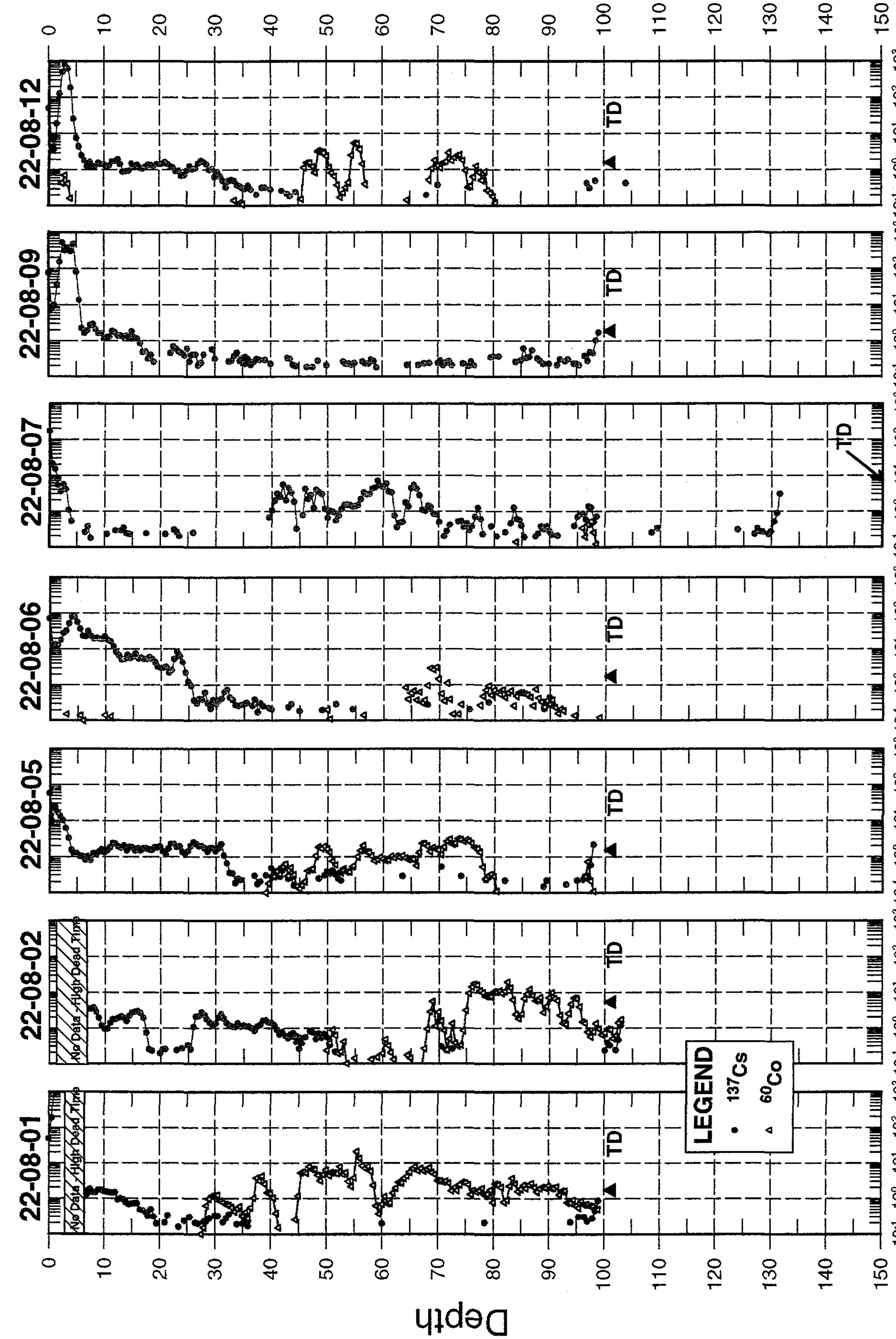


Figure B-8. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-108

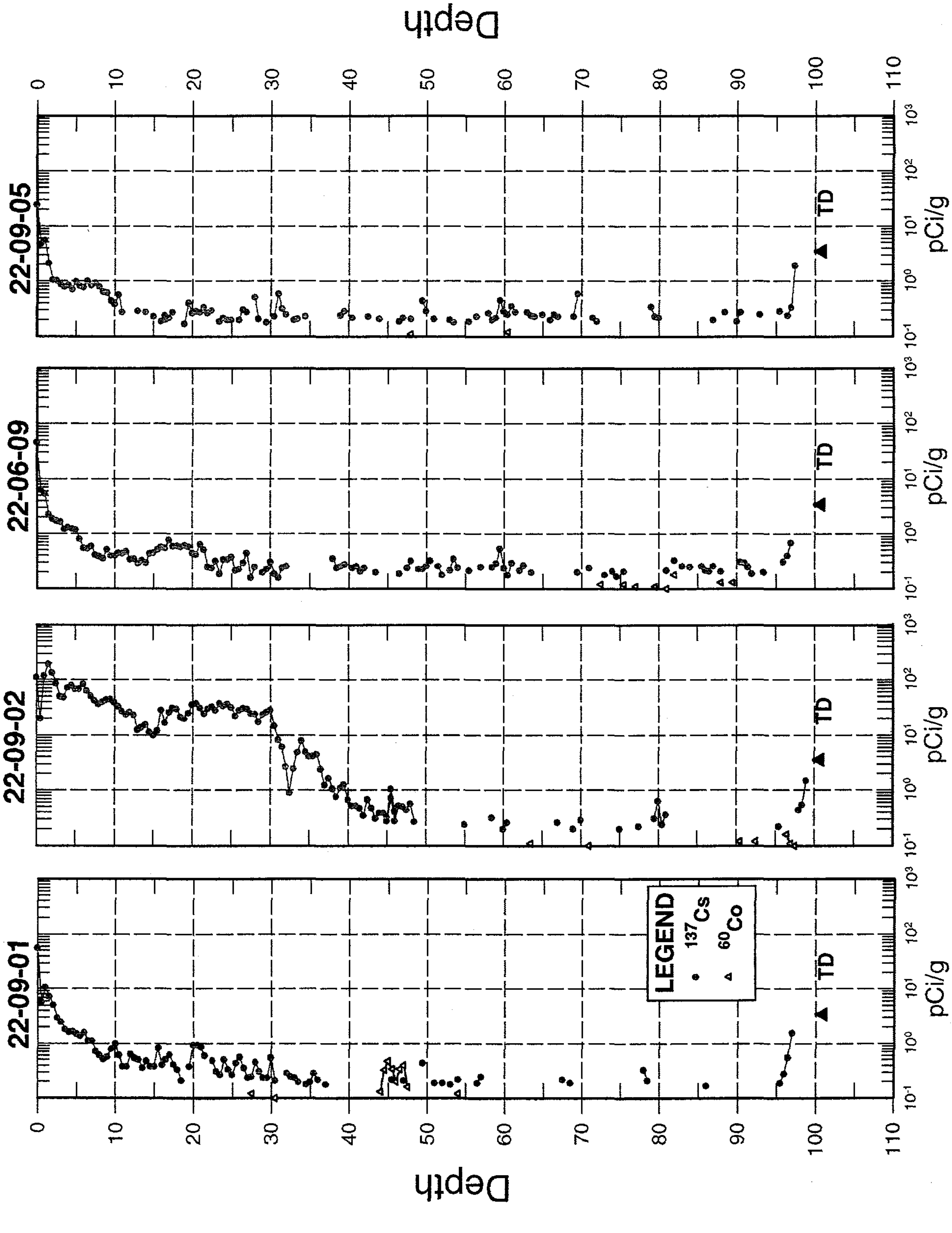


Figure B-9. Correlation Plot of ^{137}Cs and ^{60}Co Concentrations in Boreholes Surrounding Tank BY-109

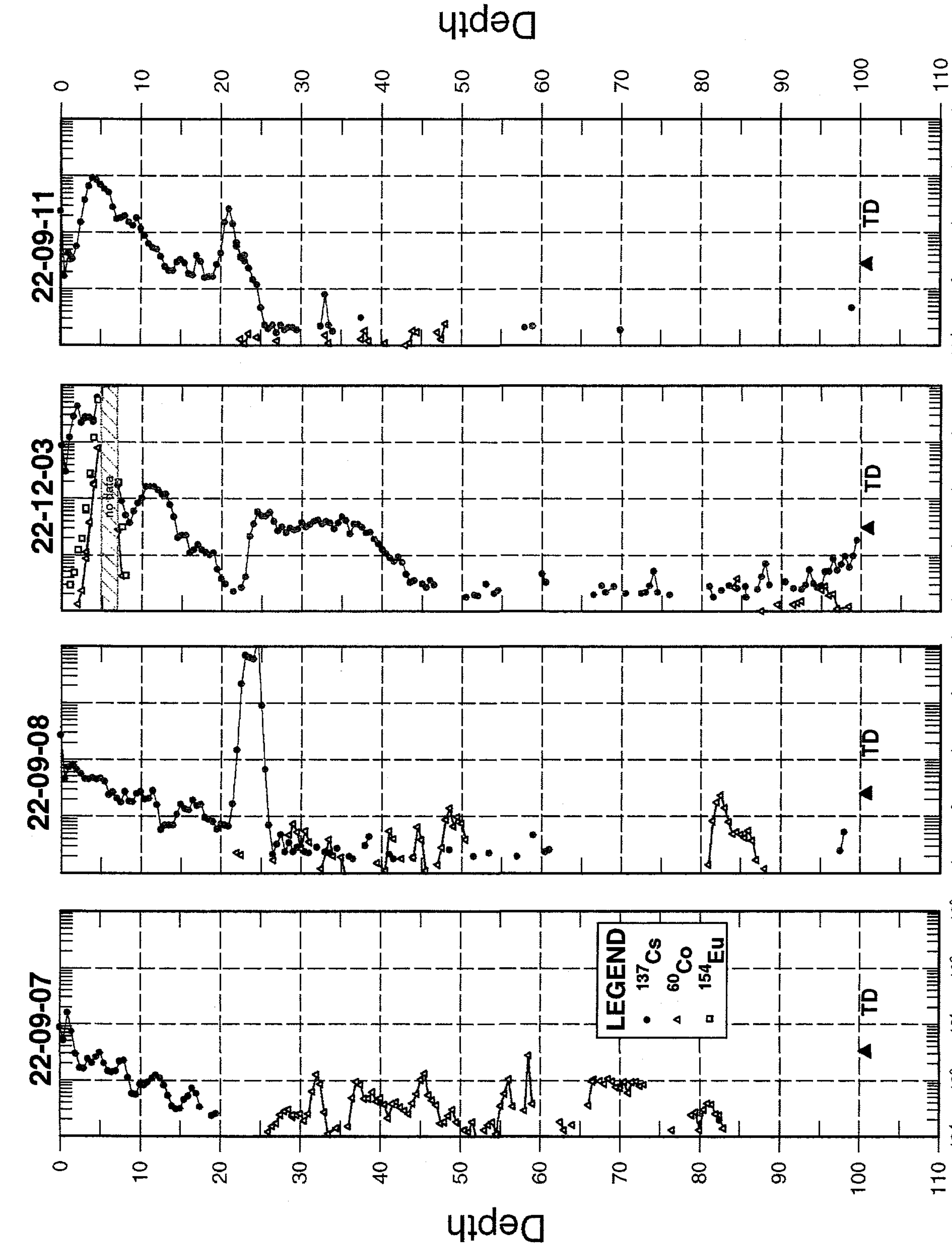


Figure B-9 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-109

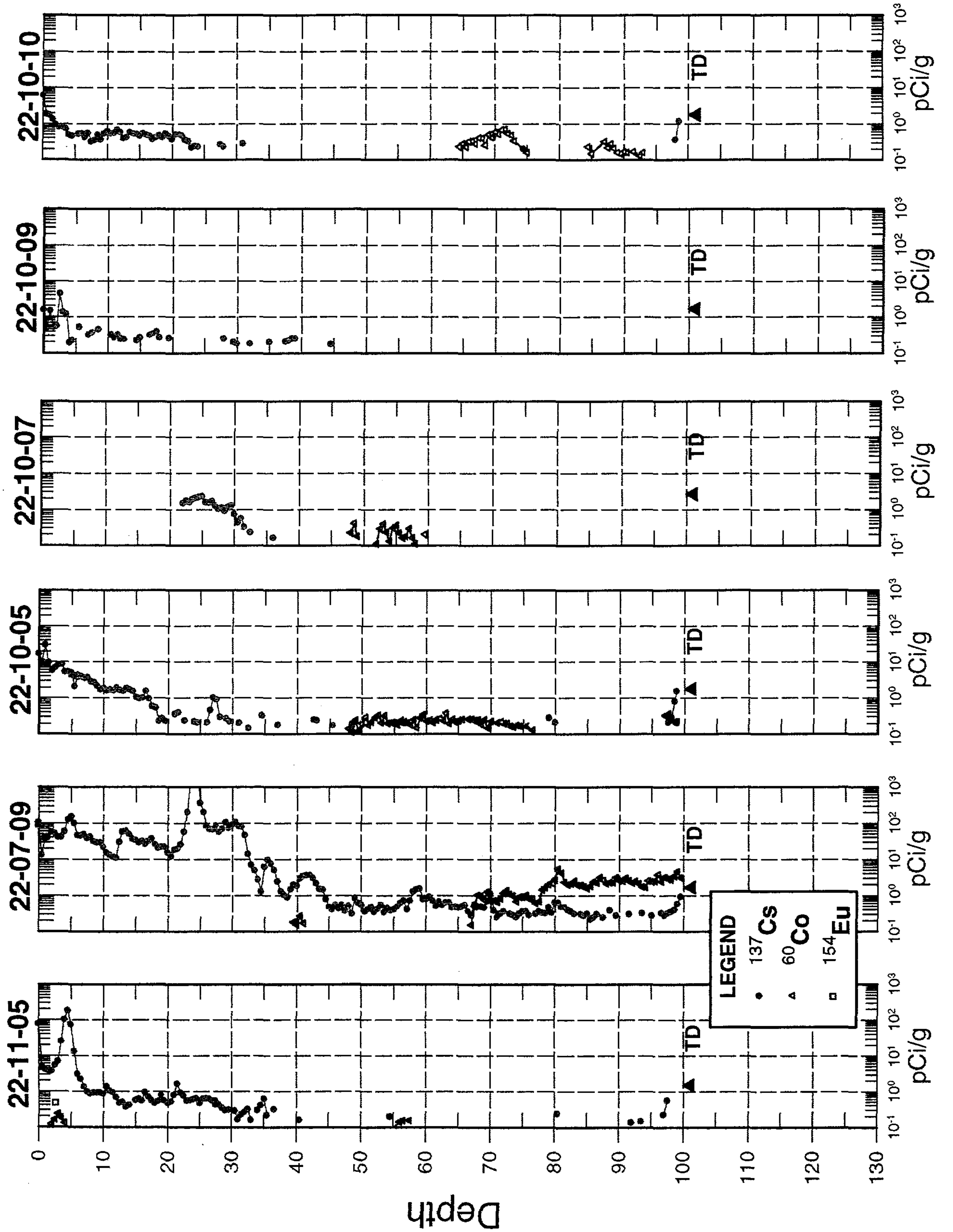


Figure B-10. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-110

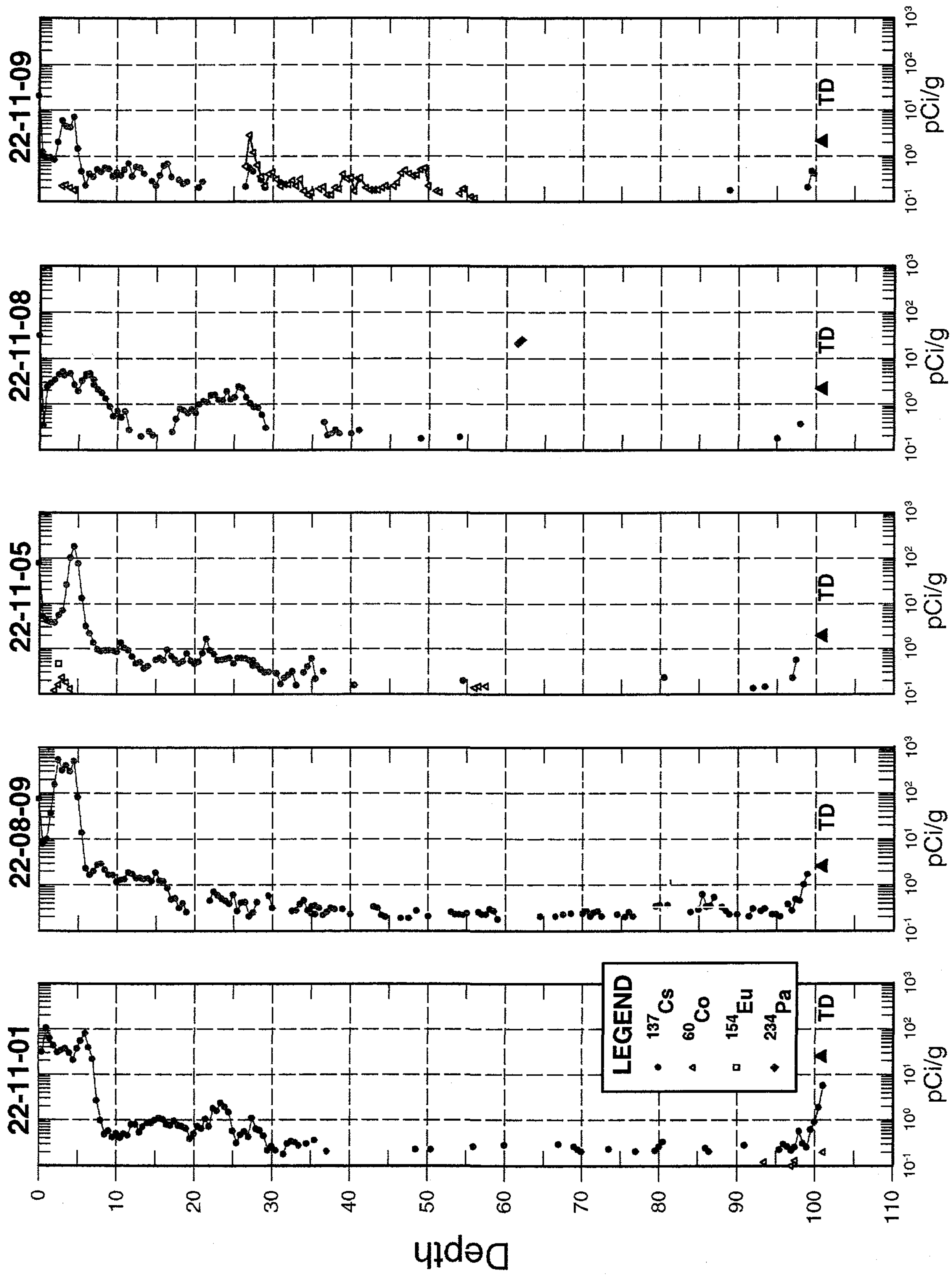


Figure B-11. Correlation Plot of ^{137}Cs, ^{60}Co, ^{154}Eu, and ^{234}Pa Concentrations in Boreholes Surrounding Tank BY-111

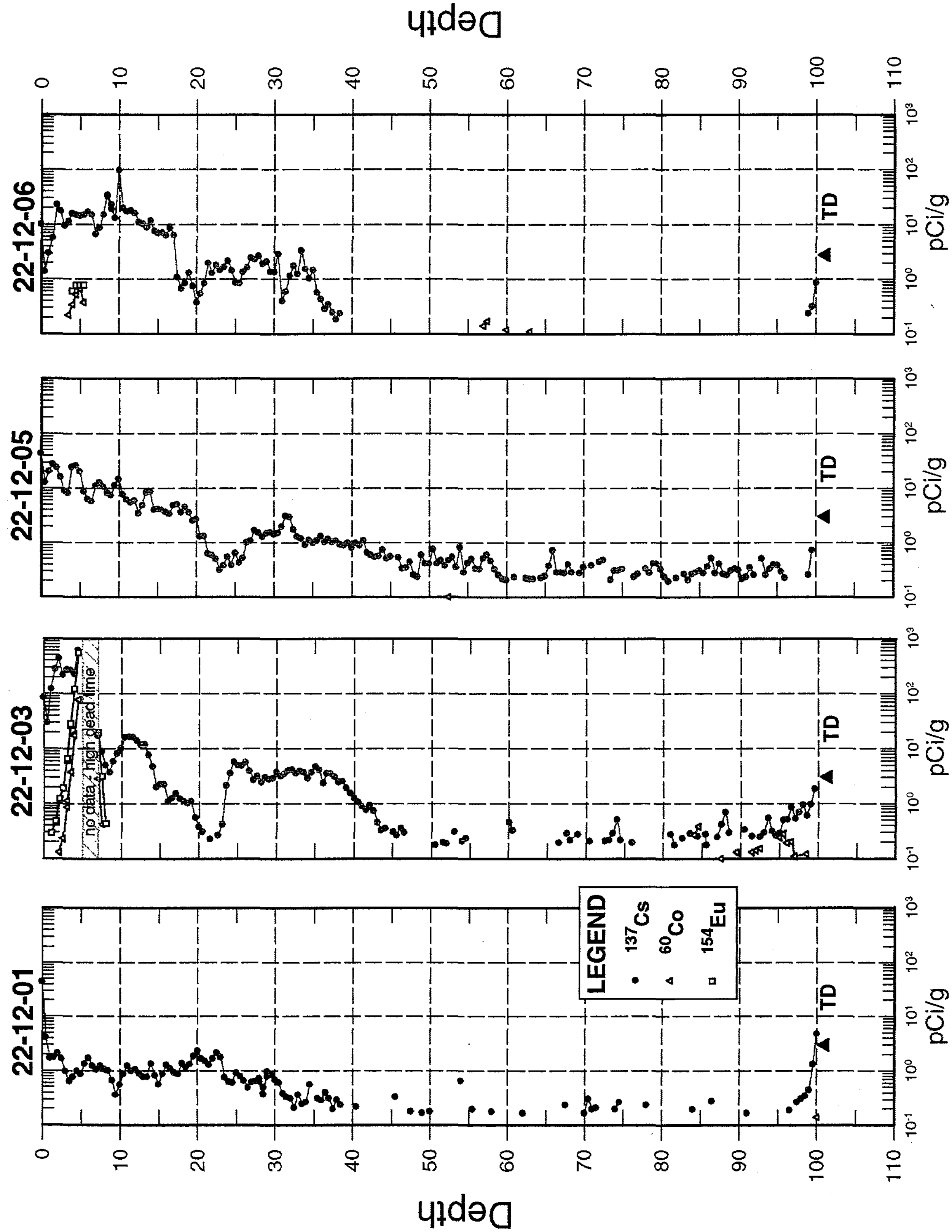


Figure B-12. Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-112

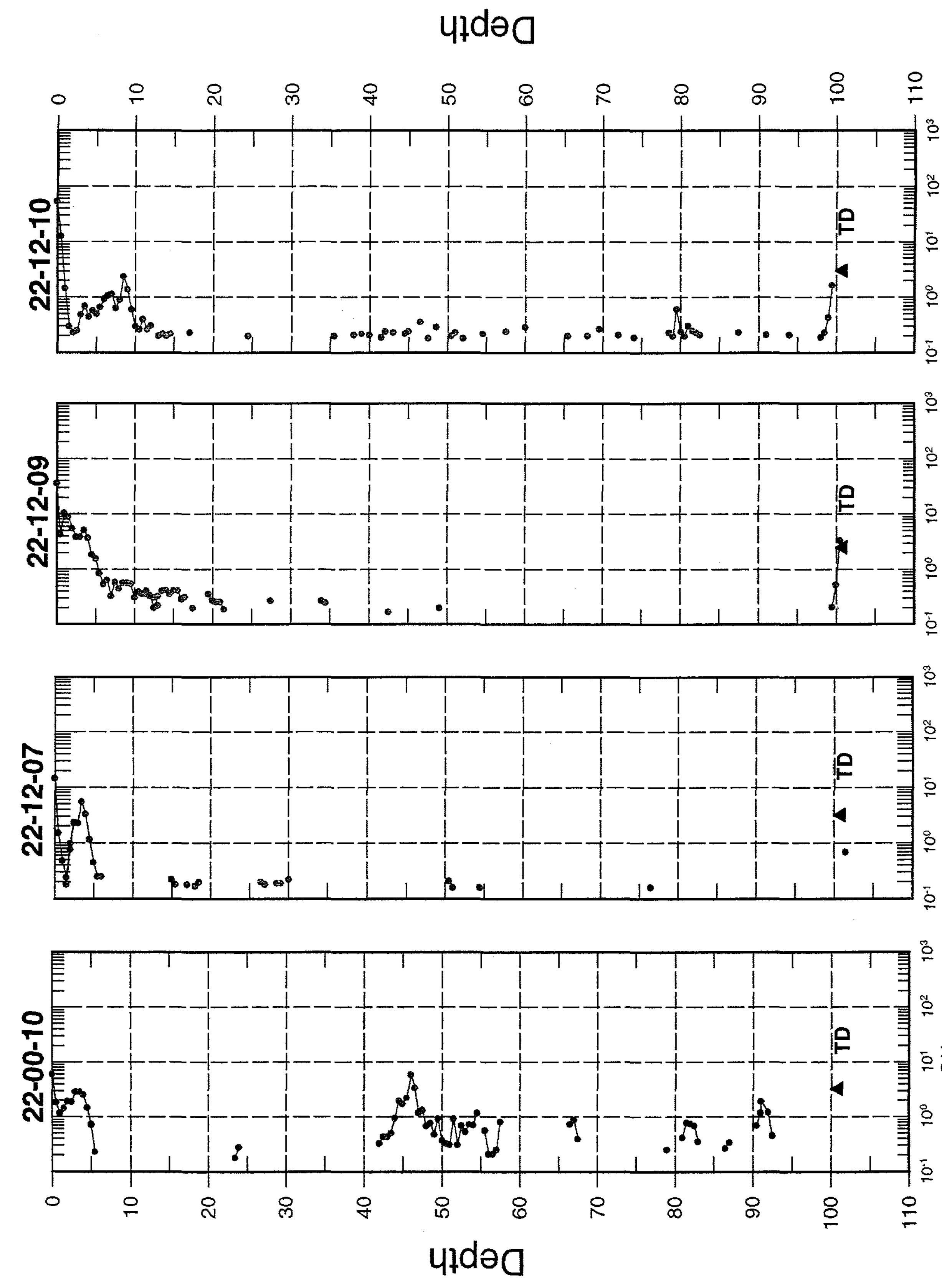


Figure B-12 (continued). Correlation Plot of ^{137}Cs, ^{60}Co, and ^{154}Eu Concentrations in Boreholes Surrounding Tank BY-112