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Vadose Zone Characterization Project at the Hanford Tank Farms

SX Tank Farm Report

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

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Contents

Contents (continued)

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Tables

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Prepared by:

J.R. Brodeur, Technical Lead
Rust Geotech, Hanford

7-19-96
Date

Concurrence:

C.J. Koizumi, Technical Lead
Rust Geotech, Grand Junction Projects Office

7-22-96
Date

J.F. Bertsch, Project Manager
Rust Geotech, Hanford

7-19-96
Date

Approved by:

M.C. Butherus, Program Manager
Rust Geotech, Grand Junction Projects Office

7/22/96
Date

V. Cromwell, Project Manager
U.S. Department of Energy
Grand Junction Projects Office

22 Jul 96
Date

C. Ruud, Project Manager
U.S. Department of Energy
Richland Operations Office

9/27/96
Date

Executive Summary

The U.S. Department of Energy Grand Junction Projects Office (GJPO) 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 SX Tank Farm.

Logging operations used high-purity germanium detection systems to provide laboratory-quality assays of the gamma-emitting radionuclides in the formation. Logging of all boreholes in the SX Tank Farm was completed in August 1995, and the last Tank Summary Data Report for the SX Tank Farm was issued in January 1996.

Log data were analyzed by identifying the gamma-emitting radionuclides in the sediment and calculating their concentrations, assuming the radionuclides were uniformly distributed in the formation. Vertical profile plots or logs of the contamination concentration versus 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, summarize 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 SX Tank Farm Report is the final document discussing the vadose zone contamination in the entire SX 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 SX Tank Farm geology and hydrology give the reader an understanding of the potential environmental implications. The geology and hydrology information was obtained from data in previously published Hanford contractor documents.

Background information on the SX 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 short review and discussion of nearby waste sites is also provided.

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

The spectral gamma log data show ^{137}Cs is the most abundant and highest concentration nuclide detected throughout the SX Tank Farm. Other gamma-emitting radionuclides detected include ^{60}Co, ^{152}Eu, and ^{154}Eu. These radionuclides were detected at or near the ground surface with the exception of one borehole, where ^{60}Co was detected below the base of the tanks.

A model of the ^{137}Cs contamination was developed. No other nuclides were abundant enough for correlation among boreholes. The geostatistical structure of the ^{137}Cs model is based on the observed contamination distribution. Visualizations of the computed model show three-dimensional solid-surface representations of the contamination from any view angle. Because those visualizations are interpretations of the actual ^{137}Cs contamination distribution, potential inaccuracies and uncertainties in the model are reviewed so that the visualizations are not necessarily taken at face value.

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

The most significant inaccuracies in the model result from potential situations where the contamination is actually only within the borehole and not uniformly distributed in the formation. Interpretations suggest the occurrence of such conditions in several boreholes where it is postulated contamination has fallen down and settled at the bottom of boreholes, creating a false deep, low-concentration plume, 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. Again, this is a case where the contamination is not uniformly distributed in the formation as is assumed by the calibration condition.

A visualization of the near-surface contamination was prepared. The concentration data in this visualization are not accurate because the source geometry is not the same as the calibration condition. However, the surface-contamination visualization effectively shows the zones of high surface contamination. Surface or near-surface contamination zones are located in the regions between tanks SX-108, SX-109, SX-112, and SX-111 and on the southwest side of tank SX-112.

Visualizations were prepared showing the contamination around each tank, usually from more than one viewpoint. These visualizations show the sources of the contamination, in almost all cases, confirm the current listed leak-status of the tanks. The vadose zone contamination distribution for tank SX-102, however, indicates tank SX-102 may have leaked at some time in the past and should be listed as a leaker on the basis of the log data. However, the vadose zone

contamination distribution for tank SX-104 indicates tank SX-104 has not leaked and may not be a leaking tank as it is listed.

A review of the historical gross gamma logs for all the boreholes within the SX Tank Farm was conducted as a part of the vadose zone characterization. As a result, a dynamic contamination distribution was identified on the west side of tank SX-109, possibly indicating a continuation of a previous leak. That area will require routine monitoring in the future.

The deepest zone of contamination and the zone of greatest concern in the SX Tank Farm is the contamination plume identified at 125 feet (ft) around borehole 41-12-02 near tank SX-112. High levels of contamination have reached the maximum vertical extent of this borehole, and the proximity of the contamination to the groundwater cannot be established. It is believed this contamination is actually within the sediments and not simply the result of contamination migrating down the casing. This belief is based on the assumption that the contamination was present in the deep vadose zone when the borehole was deepened from 75 to 125 ft in 1972. Contamination was detected by sediment sampling during the drilling process and by gross gamma logging after the borehole was deepened. In addition, contamination zones detected at the 100-ft depth in this hole correlate with contamination reported at that same depth in other nearby boreholes, suggesting that the major portion of the plume is somewhat continuous in depth in the horizontal dimensions. Therefore, this contamination plume is not confined to the region around that single borehole.

Other major contamination plumes in the SX Tank Farm can all be attributed to leaks from specific tanks or to surface contamination, and the visualizations proved to be an excellent means of identifying the contamination sources. A minimum-maximum plume visualization was also prepared to show the observed uncertainty of the contamination distribution.

For the zones of higher ^{137}Cs concentration, the model provides a representation of the contamination distribution. However, for some of the lower-concentration zones, and in particular those low-concentration zones at the bottom of the boreholes, the contamination model and the visualizations may not be accurate representations of the real ^{137}Cs distribution in the vadose zone sediment. Rather, they may be false, low-concentration plumes that resulted from contamination that was blown down the insides of borehole casings.

Because the monitoring boreholes only extend to a depth of 125 ft and the maximum vertical extent of the largest of all SX Tank Farm plumes is not known, the impacts of the vadose zone contamination on the groundwater cannot be determined.

This vadose zone characterization project is the first such attempt at a comprehensive characterization of the SX Tank Farm. This project resulted in the logging of a total of 95 boreholes with the spectral gamma-ray logging systems. Log plots were published in Tank Summary Data Reports prepared for each tank, and the contamination baseline database was developed. The distribution of nongamma-emitting radionuclides was not determined with this project, but other such data can now be correlated with the assayed nuclides.

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. It is also recommended to field additional instrumentation that can be used to assay the high-concentration zones in the boreholes or the horizontal laterals beneath the tanks.

Additional logging characterizations are recommended, including measurements that can determine formation moisture content and bulk density. Additional vadose zone characterizations are needed to determine concentrations of nongamma-emitting radionuclides, particularly the higher risk nuclides such as plutonium and technetium. It is also important to obtain sediment samples to determine the geochemistry of the vadose zone sediments.

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

1.0 Introduction

The SX Tank Farm is located in the southwest portion of the 200 West Area of the Hanford Site (Figure 1). This tank farm consists of 15 single-shell tanks (SSTs), each with an individual capacity of 1 million gallons (gal). These tanks currently store high-level nuclear waste that was primarily generated from what was called the oxidation-reduction or "REDOX" process at the S-Plant facility. Ten of the 15 tanks are listed in Hanlon (1996) as "assumed leakers" and are known to have leaked various amounts of high-level radioactive liquid to the vadose zone sediment. The current liquid content of each tank varies, but the liquid from known leaking tanks has been removed to the extent possible.

In 1994, the U.S. Department of Energy Richland Office (DOE-RL) requested the DOE Grand Junction Projects Office (GJPO), Grand Junction, Colorado, to perform a baseline characterization of contamination in the vadose zone at all the SST farms with spectral gamma-ray logging of boreholes surrounding the tanks. The SX 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 to the extent possible with the passive gamma logging method and with the depth and spatial coverage of the existing boreholes. Existing monitoring boreholes in the SX Tank Farm were logged with high-purity intrinsic germanium (HpGe) spectral gamma-ray logging systems (SGLSs) to produce an assay of the gamma-emitting radionuclides in the sediment surrounding the boreholes. These data were then used to develop a three-dimensional model of the distribution of the contamination in the vadose zone around the SX 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 impacts 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. This limited assessment also provides DOE with a sound basis for determining if further characterization is necessary.

Radionuclide concentration logs for individual boreholes were compiled and presented in 15 individual Tank Summary Data Reports (DOE 1995k, 1995l, 1995m, 1995n, 1995o, 1995p, 1995q, 1995r, 1995s, 1995t, 1995u, 1996f, 1996g, 1996h, 1996i).

2.0 Purpose and Scope

2.1 Purpose of the Project

The purpose of this baseline characterization effort is to quantify the contamination distribution to determine the nature and extent of the contamination as much as possible using the existing

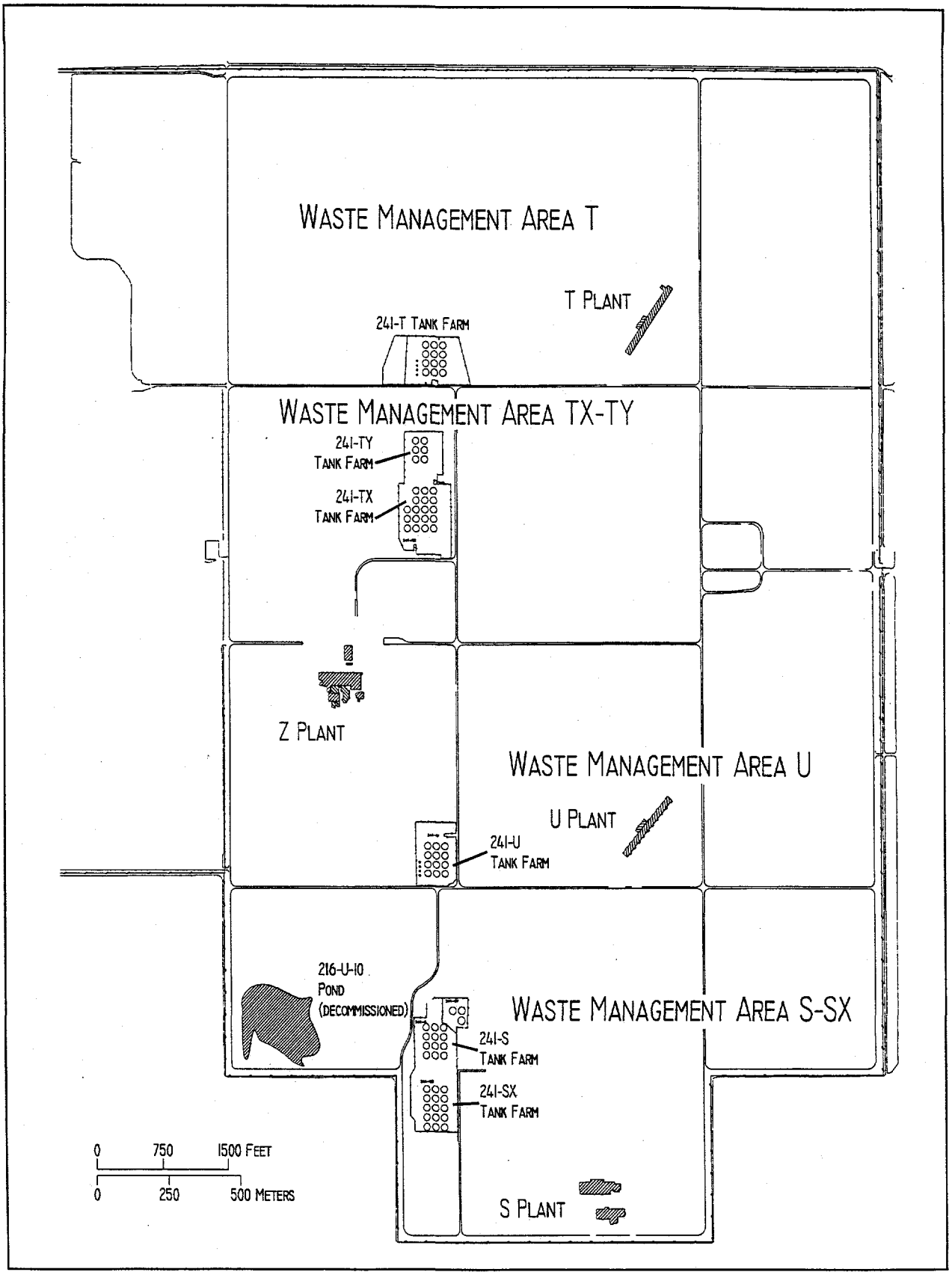

Figure 1. Map of the 200 West Area Showing the SX Tank Farm

boreholes. Because only passive gamma logging methods are used, only gamma-emitting radionuclides are assayed. The gamma-ray signatures of the radionuclides that may have leaked from the tanks can be detected through the 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. Results presented in this report provide a basis from which a more comprehensive characterization of the contamination distribution can be developed to present a better determination of the nature and extent of the contamination.

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

It is also a purpose of this project to produce a baseline measurement of the contamination concentration around the individual boreholes and a baseline of the contamination distribution around the SX 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 comparisons in the future for radionuclide migration studies and to provide a baseline for identification, verification, and quantification of possible future tank leaks.

An additional objective of this project is to provide more site-specific geologic information by generating logs of the naturally occurring ^{40}K, ^{238}U, and ^{232}Th concentrations, which can be used to identify changes in the lithology that can influence moisture and contaminant migration. These 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 new 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. These boreholes extend only 100 to 125 feet (ft) into the vadose zone, while the groundwater is approximately 210 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 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 vadose zone contamination. The historical information helps to identify potential sources of contamination and to explain the nature and extent of the contamination identified by the new spectral gamma log data.

This project is limited in scope to passive spectral gamma-ray logging data acquisition methods. As a result, radionuclides that do not decay with the emission of gamma-ray photons are not assayed. In addition, other logging methods such as moisture content logging or formation density logging cannot be used because the borehole configuration is not conducive to the production of meaningful results with the current technology.

The scope of the project also includes preparation of reports that provide the results to current and future Hanford Site personnel and identification of the quality of the data in terms of precision and accuracy as well as quality assurances. Documentation on procedures, instrument calibration, quality assurance, and data analysis methods has been prepared (DOE 1994d, 1994e, 1995d, 1995e, 1995f, 1995g, 1995h, 1995i, 1995j, 1996b, 1996c, 1996d, 1996e). All reports and the log data are available from Hanford databases. By making these data available and quantifying the uncertainty associated with the data, decision makers can make use of these data in the future.

2.3 Regulatory Basis

The operation and eventual closure of the SSTs are governed by both Federal and State laws, primarily the Resource Conservation and Recovery Act (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 enhance the progress 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, the SST TS units are operated by DOE 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 focus of current work at the SSTs involves work both related to the closure process and to ensuring safe interim operation of the tanks.

The SST 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 tanks, the tank closure process is scheduled to occur over a 12-year time period. A SST closure work plan (DOE 1996a) addresses the content of a closure plan as outlined in TPA Milestone M-45-06.

The 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 contaminated sediment that has leaked from the tanks. Closure alternatives, including alternatives for remediating contaminated sediment, will be selected under a 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 impacts of the historical releases as well as the impacts 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 closure relates to waste classification. SST waste is classified as high-level waste (HLW). Disposal of HLW is regulated by the Nuclear Regulatory Commission (NRC). The 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 the DOE and would be carried out in accordance with DOE Order 5820.2A. A decision by the 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 regulations 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) and 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 SX Tank Farm that were originally reported in individual Tank Summary Data Reports, and it provides the first basic model of the ^{137}Cs contamination distribution. The model correlates data from the individual borehole logs in three dimensions and helps to identify contamination plumes and their sources. Section 9.0 documents model development, identifies assumptions and model parameters, and explains the uncertainty associated with the model.

This report provides brief introductory information regarding the SX Tank Farm, including background information, a history of the farm, geology and hydrology reviews, and a description and review of adjacent waste sites.

This report also identifies some of the potential impacts on the environment from the contamination that is identified in the baseline characterization, so the impacts can be evaluated quantitatively in either the EIS or the SST closure plan as more definitive data become available.

3.0 Radionuclides of Interest

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

Short-term risk scenarios involve inhalation of radionuclides or direct exposure to workers during remediation or other operations that would uncover or bring the vadose zone contamination to the surface in the near future. The radionuclides of concern are those that are

easily suspended in air and the high specific-activity radionuclides that present an exposure problem.

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

Many radionuclides in the original tank wastes that have short half-lives have since decayed away and are no longer detectable. 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 such as Dresel et al. (1995) and Johnson (1993).

3.1 ^{137}Cs

^{137}Cs is one of the highest specific activity radionuclides in the tank wastes and is present in 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 separation process.

^{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-volt [keV]) to produce ^{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 detection equipment. The minimum detectable activity (MDA) of ^{137}Cs for the SGLS when logging with 100-second (s) counting times is about 0.1 picocurie per gram (pCi/g).

Because of its long half-life and relatively high concentration in the tank waste, ^{137}Cs is the most abundant radionuclide in the vadose zone around the SSTs. This contaminant is easy to detect and quantify with passive gamma logging and was measured in almost every borehole in the SX Tank Farm. ^{137}Cs is reported to have a high sorptive capacity in sediment. However, in the presence of competing positive ions such as from the dissolved radioactive salts present in the SSTs, the sorption of ^{137}Cs decreases (Carboneau et al. 1994b). At low concentrations, ^{137}Cs is more strongly adsorbed to the sediment, particularly at pH values greater than 4.0 that are 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 detected contaminant in the vadose zone, but it is detected in the groundwater at few locations. At one such location, the B-5 Injection Well in the 200 East Area, ^{137}Cs was injected directly into the near-surface aquifer. Later characterization of the resulting groundwater plume showed that the ^{137}Cs contamination did not migrate far from the injection well source. 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 was also detected in the groundwater in one borehole adjacent to the SX Tank Farm, but it is not yet known if the ^{137}Cs is in the formation or strictly the result of contamination that migrated down the monitoring borehole.

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

3.2 ^{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 ^{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 quantify with passive gamma measurement equipment. The MDA under the SX 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 because it has a high specific activity (1.1×10^3 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 ethylenediamine-tetra-acetic 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 mobilized by the presence of cyanide or ferrocyanide compounds, which are present in some of the SSTs, but not in the SX Farm tanks.

Measurements of vadose zone contamination at Hanford (Brodeur et al. 1993) suggest that ^{60}Co is more mobile in the vadose zone than europium or antimony, and it is much more mobile than cesium. However, this mobility may be a result of the chemical properties of the effluent in which the ^{60}Co was released at the Hanford crib sites. ^{60}Co was detected at low concentrations in only a few boreholes in the SX Tank Farm, and no conclusions can be made about its mobility in the soil at the SX Tank Farm on the basis of gamma-ray logs.

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. However, in the 200 East Area, ^{60}Co was detected in groundwater samples near the BY cribs at about 75 pCi/L. Because ^{60}Co is complexed with cyanide compounds in this area, it is highly mobile (Dresel et al. 1995). 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

Abundant europium radioisotopes in the tank wastes include the isotopes ^{152}Eu and ^{154}Eu. Of these isotopes, only ^{154}Eu was detected in any of the SX Tank Farm vadose zone monitoring boreholes. ^{154}Eu originates from the activation of ^{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 ^{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 ^{152}Sm and by beta particle emission to ^{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 the vadose zone sediment. Monitoring results at approximately 50 crib sites at Hanford showed that europium is more mobile than ^{137}Cs but not as mobile as ^{60}Co (Brodeur et al. 1993). However, this conclusion is based strictly on a comparison of the contaminant distribution patterns at the crib sites, which may differ considerably from the distribution patterns at the SSTs in terms of types and concentrations of waste and how the effluent was released to the vadose zone. Brodeur et al. (1993) did not consider potential lithologic control over the migration and deposition of europium.

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

^{152}Eu was detected in a few SX Tank Farm vadose zone boreholes with an MDA of about 0.2 pCi/g using the data acquisition parameters specified in the Tank Summary Data Reports. All indications are that ^{154}Eu is retained in the vadose zone at Hanford.

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.

3.4 ^{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 ^{90}Y, which has a short half-life (15.7 s), and to stable ^{90}Zr. The beta particle emitted in the decay of ^{90}Y has a high energy (2.2 million-electron-volt [MeV]) and is usually associated with the parent radionuclide, ^{90}Sr.

Because the beta particle from ^{90}Sr is so energetic when 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.

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

Strontium is a divalent (Sr^{2+}) element that mimics the chemistry of calcium. It forms an ionic bond with negatively charged elements and is easily dissolved in water. When released into the

sediment, dissolved in liquid effluent, it will readily adsorb onto sediment grains or clay particles and it 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 waste that is typical in the SX Tank Farm, 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 for the SX Tank Farm, because it is likely that the caliche (carbonate-rich) zone between the Hanford formation and the Ringold Formation at about 150 ft 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.

3.5 ^{125}Sb

^{125}Sb is another fission product, but its yield from slow neutron fission of ^{235}U or ^{239}Pu is only about 0.02 percent (out of 200 percent of the fission atoms) and does not account for a large percentage of the total fission product. 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 ^{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 has an MDA of about 0.8 pCi/g using the SX Tank Farm logging data acquisition parameters, although no ^{125}Sb was detected in the vadose zone at the SX Tank Farm.

^{125}Sb is an important radionuclide for vadose zone characterization and monitoring work because it can be abundant, it is easily measured, and it is more mobile than some of the other gamma-

emitting radionuclides. It poses minimal risk because of its general low abundance, but it is easily monitored and tracked for contaminant migration studies because it is a gamma emitter.

No information was available on the mobility of ^{125}Sb either in vadose zone sediment or in groundwater. Brodeur et al. (1993) observed that ^{125}Sb was more mobile than ^{137}Cs, and it was detected deeper in the vadose zone than ^{137}Cs.

^{125}Sb presents a short-term exposure risk because it can be inhaled.

3.6 ^{99}Tc

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

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

^{99}Tc has a half-life of 2.1×10^5 years, which is one of the reasons for its high risk rating in long-term performance assessments. It decays by 293-keV beta emission to stable ^{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, technetium will precipitate out of solution as a sulfide or hydrated oxide. If oxidizing conditions exist, technetium will be present as a pertechnetate ion, which studies have shown will migrate at a rate of 88 percent of the groundwater velocity or greater.

The 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 SX Tank Farm (refer to Section 4.4 of this report, "SX Tank Farm Groundwater Contamination").

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 performance assessments.

Uranium isotopes in tanks wastes primarily include ^{238}U and ^{235}U, with minute quantities of ^{232}U, ^{233}U, ^{234}U, and ^{236}U. Uranium isotopes in the irradiated fuel elements are separated from the

fission and activation products in chemical processes. Consequently, waste effluent sent to the SSTs usually does not contain much uranium. The U Tank Farm is an exception because it received much of the waste from the U Plant, which was not a primary separations processing facility.

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

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 ^{234m}Pa. This gamma ray is not as intense as the gamma rays from ^{214}Bi and ^{214}Pb, but, when necessary, the logging data acquisition parameters can be enhanced to obtain adequate assay statistics. With the data acquisition parameters used in the SX Tank Farm, chemically separated ^{238}U can be expected to have an MDA level of about 10 pCi/g.

^{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 7.0×10^8 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 by 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 has been studied and is well known; the uranium Eh-pH diagram is a standard for geochemistry text books. Therefore, the behavior of uranium in the vadose zone and groundwater is well known, as are remediation processes. 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 sediment. 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.

No ^{238}U concentrations in excess of the naturally occurring background (about 0.5 pCi/g) were measured in the vadose zone sediment beneath the SX Tank Farm.

3.8 ^{3}H

^{3}H is produced primarily from activation of lithium, but it is also produced as a low-yield fission product from the fission of both ^{235}U and ^{239}Pu and from deuteron-deuteron reactions. 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 very 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. At Hanford, ^{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. Therefore, it would be important in a comprehensive characterization of the vadose zone to determine and to monitor moisture content.

3.9 Plutonium, ^{241}Am, Iodine, ^{237}Np, and ^{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 SX 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 problem. 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, produced from the decay of ^{241}Am, is produced in a reactor by neutron capture by ^{238}U and subsequent decay to ^{237}Np. ^{237}Np emits a gamma ray with an energy of 311 keV and can be

detected using the SX Tank Farm logging data acquisition parameters to a lower level of about 2.0 pCi/g. The presence of ^{237}Np at a site is an indication that ^{241}Am is probably also 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.

^{106}Ru is a fission product that was abundant in the nuclear waste. It decays to ^{106}Rh, which in turn, immediately decays to ^{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 very low levels and is probably not detectable. ^{106}Ru was thought to have been a primary target nuclide for vadose zone leak-detection schemes, but spectral gamma data show that in most cases, ^{137}Cs and not ^{106}Ru was detected with the gross gamma logging systems. Recent analysis of the gross gamma log history from the boreholes of SX Farm reveals only one borehole with a decay history that is indicative of past presence of ^{106}Ru.

4.0 Geology and Hydrology

4.1 Regional Geology

The geology of the Hanford Site has been described in detail in numerous documents, each emphasizing particular areas or formations depending on the focus of the particular project. Delaney et al. (1991), Reidel et al. (1992, 1994) and Lindsey et al. (1994a) provide the most up-to-date summaries of the 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 Saddle Mountains create the northern boundary of the Pasco Basin; the Hog Ranch-Naneum Ridge anticline forms the western boundary; the Yakima Ridge, and the Rattlesnake and Horse Heaven hills are to the south. All of these uplifts are major structural anticlines within the basalt bedrock. The eastern side 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 underlying bedrock at Hanford is comprised of a series of basalt flows that are a part of the Columbia River Basalt Group. These flows are of Miocene Age and extend from north-central Washington, south into Oregon, and east into Idaho. These basalt flows are massive flood basalt that are generally of tholeiitic composition. The thickest flows are more than 100 ft thick, with sedimentary interbeds present 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. All flows contain primary fractures developed from the cooling of

the basaltic lavas; their orientation and spacing differ depending on the position within the flow. Thinner flows and the flow tops and bottoms can be highly fractured or brecciated.

The geologic structure of the Pasco Basin area is dominated by a series of east-west trending anticlines and synclines; the 200 Areas are situated on the north limb of the Cold Creek syncline. 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), Reidel and Fecht (1981), and Rockwell (1979) present additional information about the Columbia River Basalt Group.

Overlying the basalt flows of the Columbia River Basalt Group are the Ringold Formation, the unnamed Plio-Pleistocene unit, the informal Hanford formation, and Holocene-Age deposits. Rockwell (1979), Reidel et al. (1992), Delaney et al. (1991), Lindsey (1991), and Lindsey et al. (1991, 1994a, and 1994b) present extensive descriptions and discussions of these formations.

The Ringold Formation is a sedimentary sequence of Miocene Age to Pliocene Age that originated primarily from fluvial, lacustrine, and pedogenic sedimentation processes. This formation is as much as 600 ft thick and extends across the Hanford Site. It consists of uncemented to locally well-cemented clay, silt, fine- to coarse-grained sand, and pebble to cobble gravel. Lindsey (1991, 1995) and Lindsey et al. (1994a, 1994b) group the Ringold Formation into five separate facies on the basis of lithology, petrology, stratification, and pedogenic alteration: fluvial gravel, fluvial sand, overbank-paleosol, lacustrine sediment, and basaltic alluvium. The distribution of facies associations within the Ringold Formation forms the basis for stratigraphic subdivision (Lindsey 1991, 1995).

The lower half of the Ringold Formation is dominated by fluvial gravel facies association and is informally referred to as the Wooded Island. The Wooded Island is subdivided into several subunits that consist wholly or partially of fluvial gravel. These subunits are referred to as unit A, units B/D, unit C, and unit E, in ascending order. The subunits of the lower Ringold Formation are separated by interbedded fine-grained deposits that are typical of the overbank-paleosol and lacustrine facies association.

Interstratified deposits of fluvial sand and overbank-paleosol facies association overlie the Wooded Island Member and are informally referred to as the Taylor Flat Member. The Taylor Flat Member, in turn, is overlain by a lacustrine facies association strata informally referred to as the Savage Island Member. The Taylor Flat and Savage Island Members correspond to what is commonly referred to as the upper Ringold unit.

The Plio-Pleistocene unit overlies the Ringold Formation and separates the Ringold Formation and Hanford formation. The Plio-Pleistocene unit consists of a sequence of laterally discontinuous and intercalated fluvial, alluvial, eolian, colluvial, pedogenic carbonate, and lacustrine deposits. The facies are described as calcium carbonate-rich strata, alluvial deposits, stratified silts (previously referred to as Early Palouse soil), and massive silt identified as loess.

The informal Hanford formation consists of uncemented gravel, sand, and silt deposited by Pleistocene cataclysmic flood waters. This formation is thickest in the central Hanford Site, where it can as much as 350 ft thick. The Hanford formation is divided into three facies (gravel-, sand- and silt-dominated) that are gradational with each other. Lindsey (1991), Lindsey et al. (1992, 1994a, 1994b), and Reidel et al. (1992) provide detailed discussions of the Hanford formation lithology.

The Hanford formation is cross-cut by clastic dikes that consist of layers of silt, sand, and granule gravel. These clastic dikes generally cross-cut the bedding as alternating vertical to subvertical intrusion, although they do locally parallel bedding.

Holocene surficial deposits consist of a mix of silt, sand, and gravel deposited by a combination of eolian and alluvial processes. These Holocene deposits form a thin veneer across much of the Hanford Site.

4.2 SX Tank Farm Geology

4.2.1 Geology Data

Caggiano and Goodwin (1991), Lindsey (1993), and Lindsey et al. (1994b) present detailed descriptions and interpretations of the geologic formations in the vicinity of the SX Tank Farm. Price and Fecht (1976) provide additional information, including the first farm-specific geology descriptions and borehole lithology logs.

The best SX Tank Farm-specific geologic information is obtained from the most recently drilled groundwater monitoring boreholes. Data from boreholes 299-W23-14, 299-W23-15, 299-W22-39, 299-W22-45, and 299-W22-46 provide the best information for the SX Tank Farm. Appendix A contains lithology information for those boreholes, including copies 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 a set of ^{40}K, ^{238}U, ^{232}Th, and total gamma logs for borehole 299-W22-39. Except for the spectral gamma-ray logs, this information 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. Figure 2 shows the location of the groundwater monitoring boreholes in relation to the SX Tank Farm and other nearby facilities. The SX Tank Farm vadose zone monitoring boreholes shown in Figure 2 are identified in Figure 11.

The lithologic information is the result of field analysis of sediment samples retrieved during borehole drilling operations. This information is the best information obtained to date because greater emphasis was placed on obtaining good lithologic information, and well-qualified geologists examined and prepared the sample descriptions. All the boreholes were drilled with a cable tool drill rig and the samples were obtained from bailings, core barrels, or cuttings as composite samples, generally from 5-ft regions. As a result the samples were not "intact" samples but composite samples from the 5-ft drilling intervals.

The gross gamma-ray logs were obtained by logging the boreholes with a logging system operated by Pacific Northwest National Laboratory. 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 very low-efficiency detector, the log responses were not good and the utility of these logs is limited.

Only borehole 299-W22-39 was logged with a spectral gamma-ray logging system when the borehole was drilled. This logging system, called the Radionuclide Logging System, was put into service in January 1991; borehole 299-W22-39 was the first hole logged with the new system. No documentation was prepared for the system or the analysis software at the time, and the reported concentrations of the radionuclides are not quality assured. However, no man-made radionuclides were detected around the borehole, and the naturally occurring radionuclide concentrations reported are useful for the intended purpose of showing variations in the lithology. This set of 1991 logs is useful for comparing with the potassium, uranium, and thorium logs obtained from the SX Tank Farm vadose zone monitoring boreholes.

Data from laboratory analysis of sediment samples collected during drilling were used to prepare the calcium carbonate and moisture content pseudologs in Appendix A. These data are not spatially continuous because a 5-ft data sampling interval was used to obtain these data.

Figures 3, 4, and 5 present simplified stratigraphy, the $CaCO_3$ distribution, and the moisture distribution, respectively, in the vicinity of the SX Tank Farm.

4.2.2 Geology Description

The excavation for the SX Tank Farm was made in a combination of pebble gravel and sand assigned to the uppermost Hanford formation, unit H1, and the fine to coarse sand and interbedded silt of the Hanford formation unit H2. The excavation was about 55 ft deep, and the backfill material was a heterogeneous mix of slightly gravelly to silty sand. The thickness and extent of any original surface eolian deposits cannot be determined from the drilling log.

Interpretations of the borehole sample data obtained from boreholes inside and outside the SX Tank Farm place the contact between the upper Hanford unit H1 and the lower Hanford unit H2 in those areas within a depth of 20 ft below the base of the tank farm. At the SX Tank Farm, unit H1 is dominated by coarse to granule sand and lesser pebble gravel formed from a complex interfingering of gravel and sand dominated facies. The relative abundance of gravelly facies decreases from the northwest to the south. As gravel content decreases, unit H1 interfingers with the more sand-rich strata of unit H2.

The Hanford H2 unit is about 120 to 150 ft thick in this area and consists of sand-dominated facies with interbedded silt lenses. Some laterally discontinuous silt-rich interbeds are reported in this area, and these high-silt content zones may have higher moisture content and $CaCO_3$ content than the surrounding sand-dominated material. The depositional facies are discontinuous in both the horizontal and vertical extents, and little correlation is possible between boreholes in terms of the minor differences between such features as the silty sand and sandy silt layers.

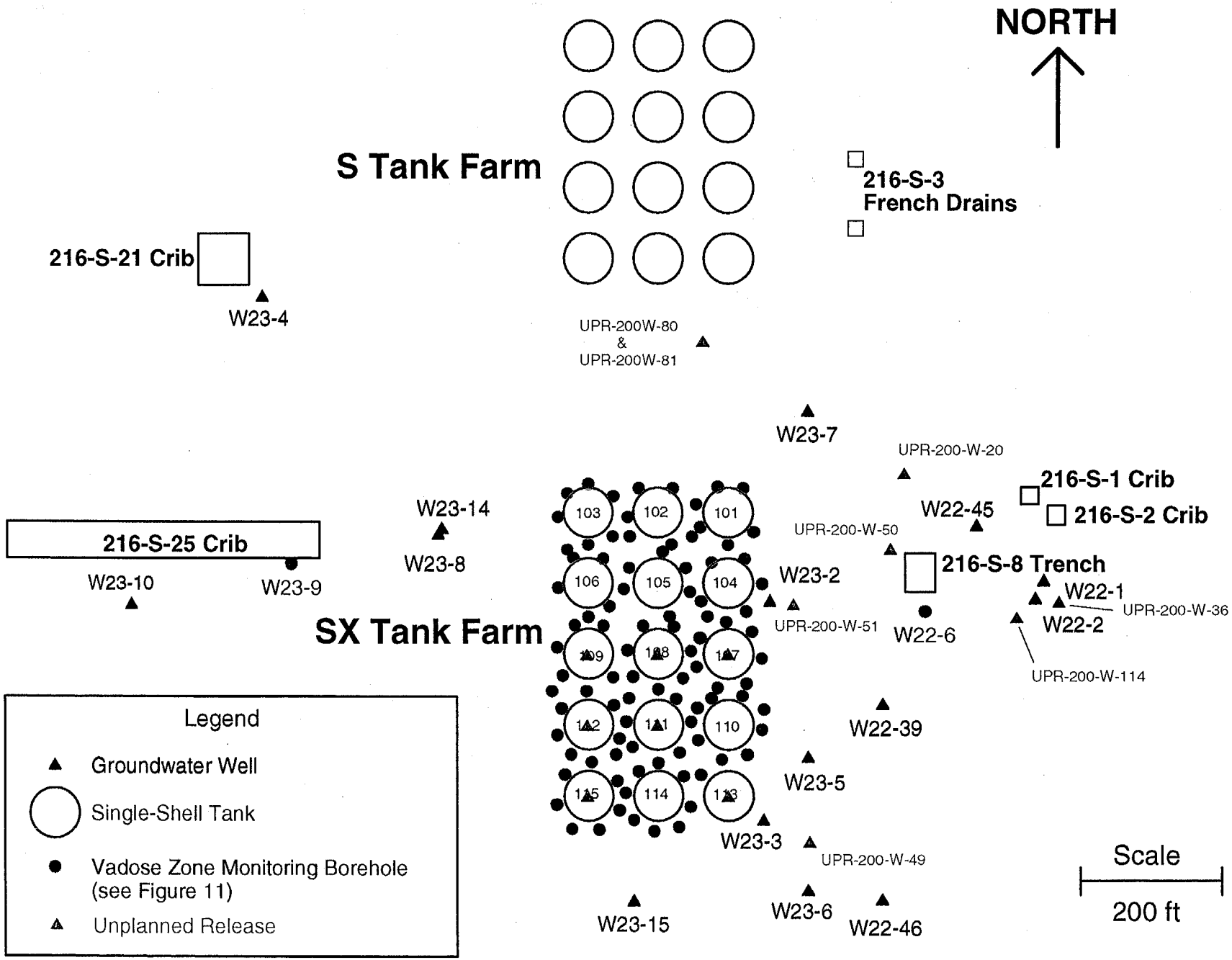

Figure 2. Map of the SX Tank Farm Area

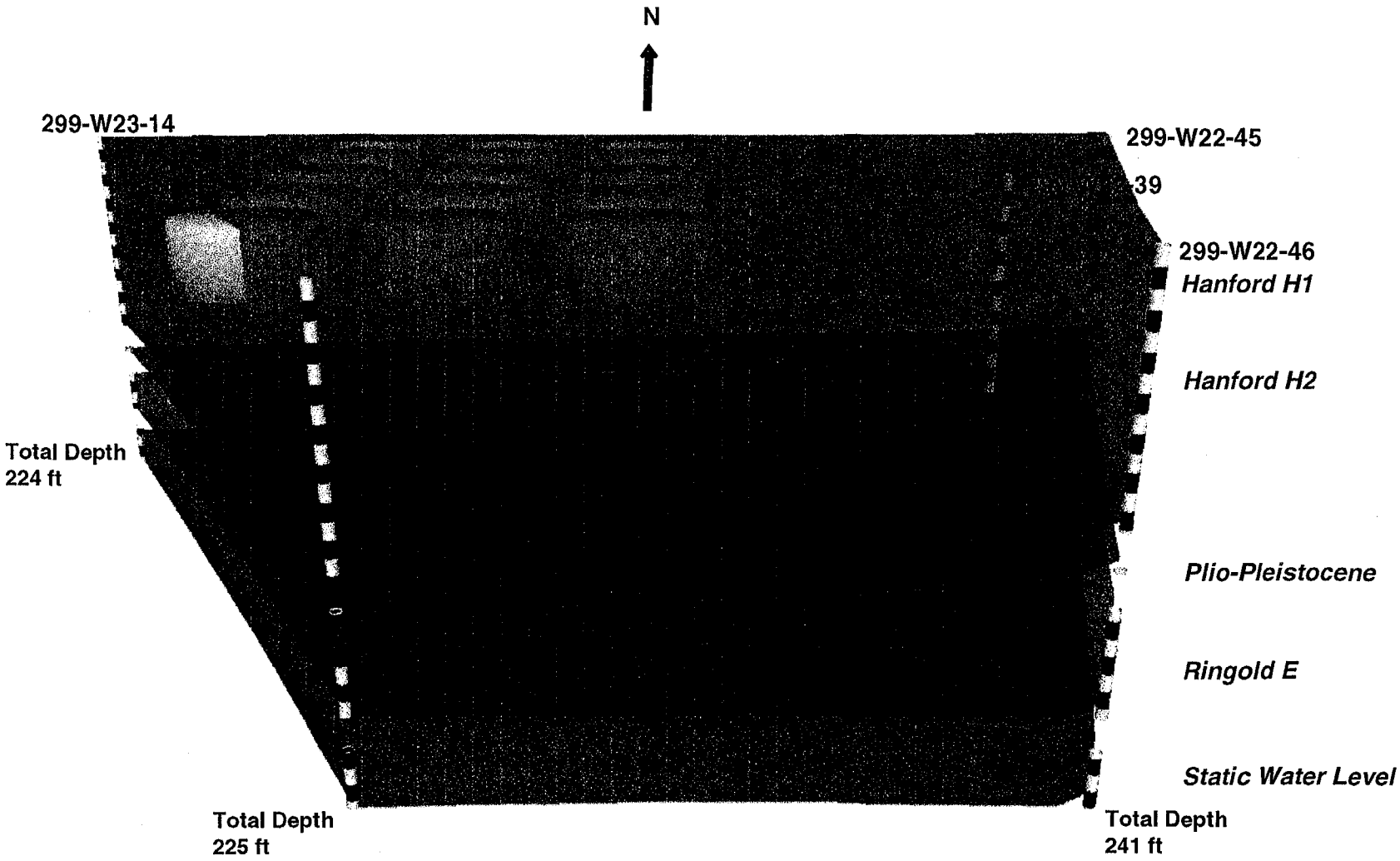

Figure 3. Generalized Stratigraphy of the SX Tank Farm

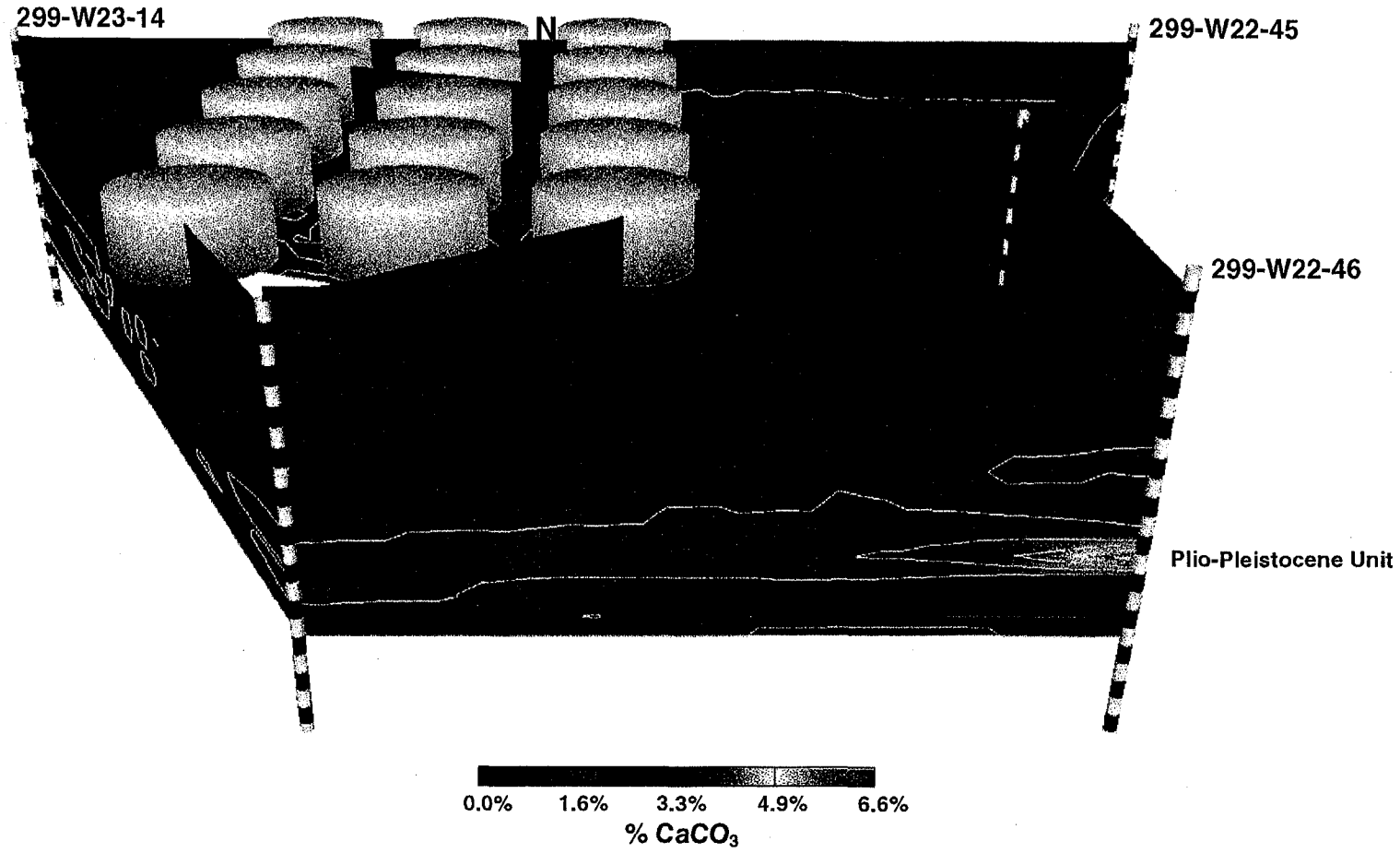

Figure 4. SX Tank Farm Vadose Zone $CaCO_3$ Distribution

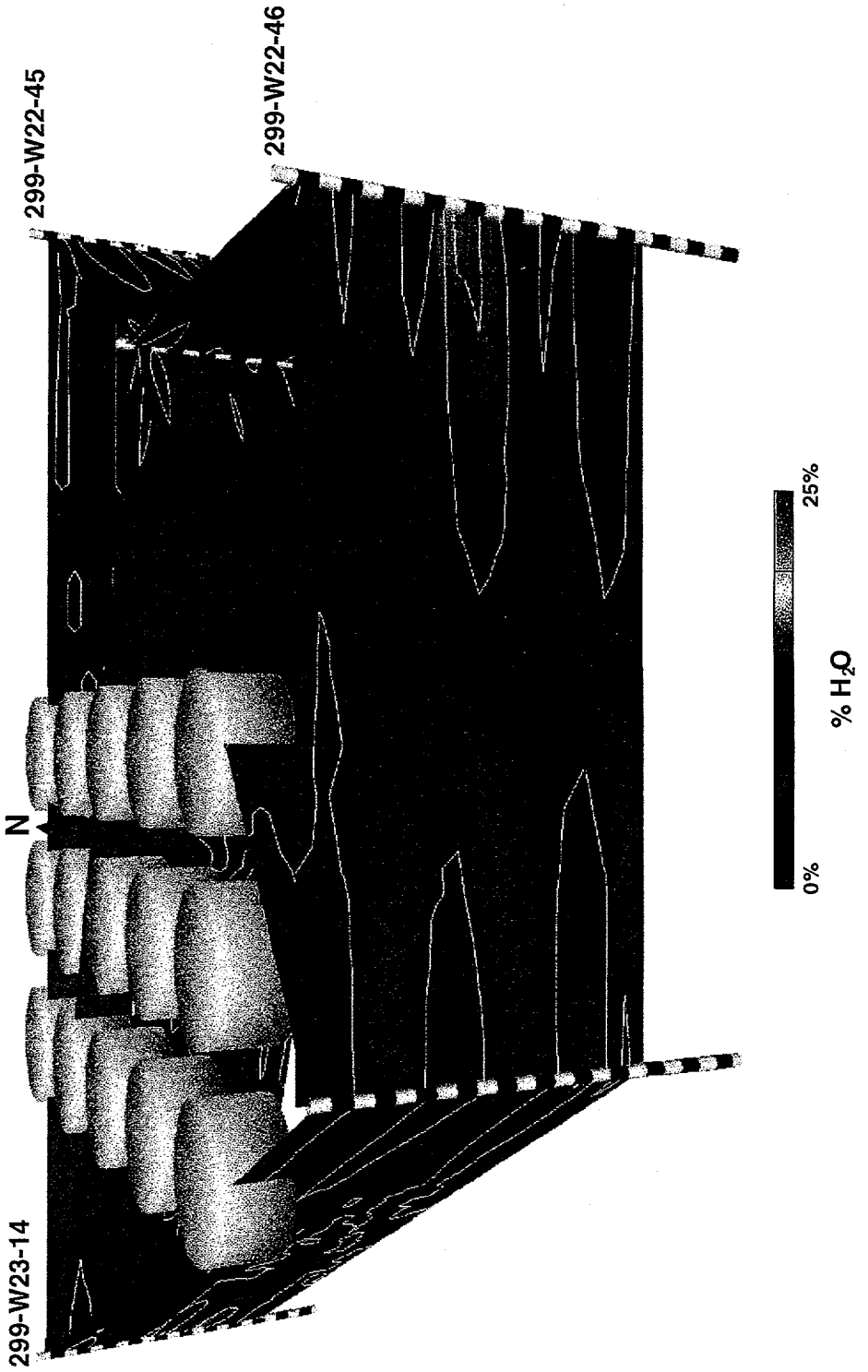

Figure 5. SX Tank Farm Vadose Zone Moisture Distribution

Some variation in the natural gamma-ray flux is seen in the spectral gamma-ray logs of borehole 299-W22-39, which is within the Hanford fine unit. An increase in the ^{40}K activity is indicated at about 57 ft, particularly with the total gamma log. This increase in gamma activity corresponds to a change in lithology from sand to silty sand and gravel. Another increase in total gamma activity is present at about 125 ft, which is also within the Hanford fine unit. According to the lithology log, this depth corresponds to an increase in silt content.

The Plio-Pleistocene unit underlies the Hanford unit H2 layer at a depth of about 140 ft. This unit is composed of a series of thin lacustrine silt and clay layers. $CaCO_3$ layers present beneath the lacustrine silt are not continuous horizontally; rather, they are observed in outcrops to be lenticular in shape, interfingering with adjacent $CaCO_3$-rich and $CaCO_3$-poor strata.

Erosional truncations and breaches by clastic dikes may be present in the Plio-Pleistocene unit, although this is not demonstrated by data from drilling logs. These discontinuities are impossible to detect unless intercepted by a drillhole. Within the SX Tank Farm area, the presence of discontinuities within the Plio-Pleistocene unit should be expected. Figure 4 shows the $CaCO_3$ content of the vadose zone sediment and clearly identifies the Plio-Pleistocene unit.

The surface of the lacustrine silt layer and the top of the Plio-Pleistocene unit is shown in Figure 3 and ranges in depth from 135 to 155 ft at the SX Tank Farm. The borehole data from recently drilled groundwater wells show the Plio-Pleistocene unit to be anywhere from 1.5 to 38 ft thick.

The $CaCO_3$ zone of the Plio-Pleistocene unit is shown on gamma-ray logs as a very low ^{40}K concentration and a low total gamma activity anomaly, as shown in borehole 299-W22-39 at 145 ft (see Figure A-1 in Appendix A). The overlying lacustrine clayey silt material is sometimes shown in gross gamma logs as an anomalously high gamma activity zone, with its upper contact with the Hanford formation as a more gradational contact.

Analyses of sediment samples obtained during drilling of the most recent groundwater monitoring wells reveal high moisture content within or above the Plio-Pleistocene-unit depth region. The moisture content logs available are those of the sediment samples from the groundwater wells. No calibrated geophysical moisture content tools were operational at Hanford at the time these boreholes were drilled. Figure 5 shows the variation in moisture content in the vadose zone as determined from the samples.

The depth of the carbonate-rich interval of the Plio-Pleistocene unit varies from 140 to 150 ft. The precision of that data is ± 5 ft, because samples were generally combined into 5-ft interval samples. The carbonate interval dips slightly, approximately 1° to 2° to the west, as calculated from the depth information on the $CaCO_3$ pseudologs, assuming that the carbonate layer is continuous.

The Ringold unit E is the uppermost portion of the Ringold Formation immediately beneath the Plio-Pleistocene unit from about 145 to 150 ft in depth (see Figure 3). The Ringold unit E, which is as much as 100 ft thick at the SX Tank Farm, is composed of sandy, silty, gravel to silty,

coarse sand interbedded with discontinuous sand layers. This unit is of fluvial origin and is composed of gravel in a quartzo-feldspatic sand and silt matrix.

Drilling logs do not show the occurrence of extensive cementation in the upper portion of the Ringold E gravels in the SX Tank Farm area. This characteristic is consistent with some of the first published information on this area reported in Price and Fecht (1976).

Ringold unit E overlies the Ringold lower mud unit. This unit is dominated by massive, silty paleosols and laminated lacustrine silts and sands. The top of the lower mud unit is about 350 ft beneath the surface of the SX Tank Farm and its thickness is not known because it is deeper than the deepest groundwater monitoring boreholes. The high silt and clay content in the lower mud unit indicates this unit should be and generally is impermeable, creating the bottom of the unconfined aquifer. Connelly et al. (1992) report this unit to be 20 to 30 ft thick in the southern region of the 200 West Area.

As determined from the lithology of regional deep water wells, beneath the Ringold mud unit is the Ringold A unit. The Ringold unit A is a coarse-grained sandy gravel unit and is reported to be about 25 ft thick in the SX Tank Farm area. This unit is sometimes cemented with a carbonate, silica, or iron cement. Some of the older references refer to the Ringold A and the Ringold mud units as the Lower Ringold.

The uppermost basalt flow of the Columbia River Basalt Group, the Elephant Mountain Member, is at a depth of 550 ft. This lava flow constitutes the base of the suprabasalt aquifer system and separates the Ringold A aquifer from the uppermost aquifer in the basalt confined aquifer system.

4.3 SX Tank Farm Geohydrology

The unconfined aquifer beneath the SX Tank Farm is located at 210 ft, within the Ringold unit E, beneath the Plio-Pleistocene unit (see Figure 3). The base of the unconfined aquifer is believed to be the top of the Ringold lower mud unit.

A semiconfined or locally confined aquifer may exist below the unconfined aquifer within Ringold unit A, bound on the bottom by the uppermost basalt layer. The permeability and areal extent of the semiconfined aquifer, if it exists, is dependent on the degree and continuity of cementation of the Ringold A unit.

The permeability of the Ringold E, the location of the unconfined aquifer, has been calculated using data from pump and slug tests. Figure 6 presents a hydraulic conductivity map calculated from borehole data obtained in the south portion of the 200 West Area. This map shows that the SX Tank Farm is located within or on the edge of a region where the unconfined aquifer has a low permeability. However, this map is a gross generalization of the permeability because the low permeability zone is only defined by data from two drill holes. The existence of a low-permeability zone would account for some of the irregular contamination plume shapes found in this area, as discussed below.

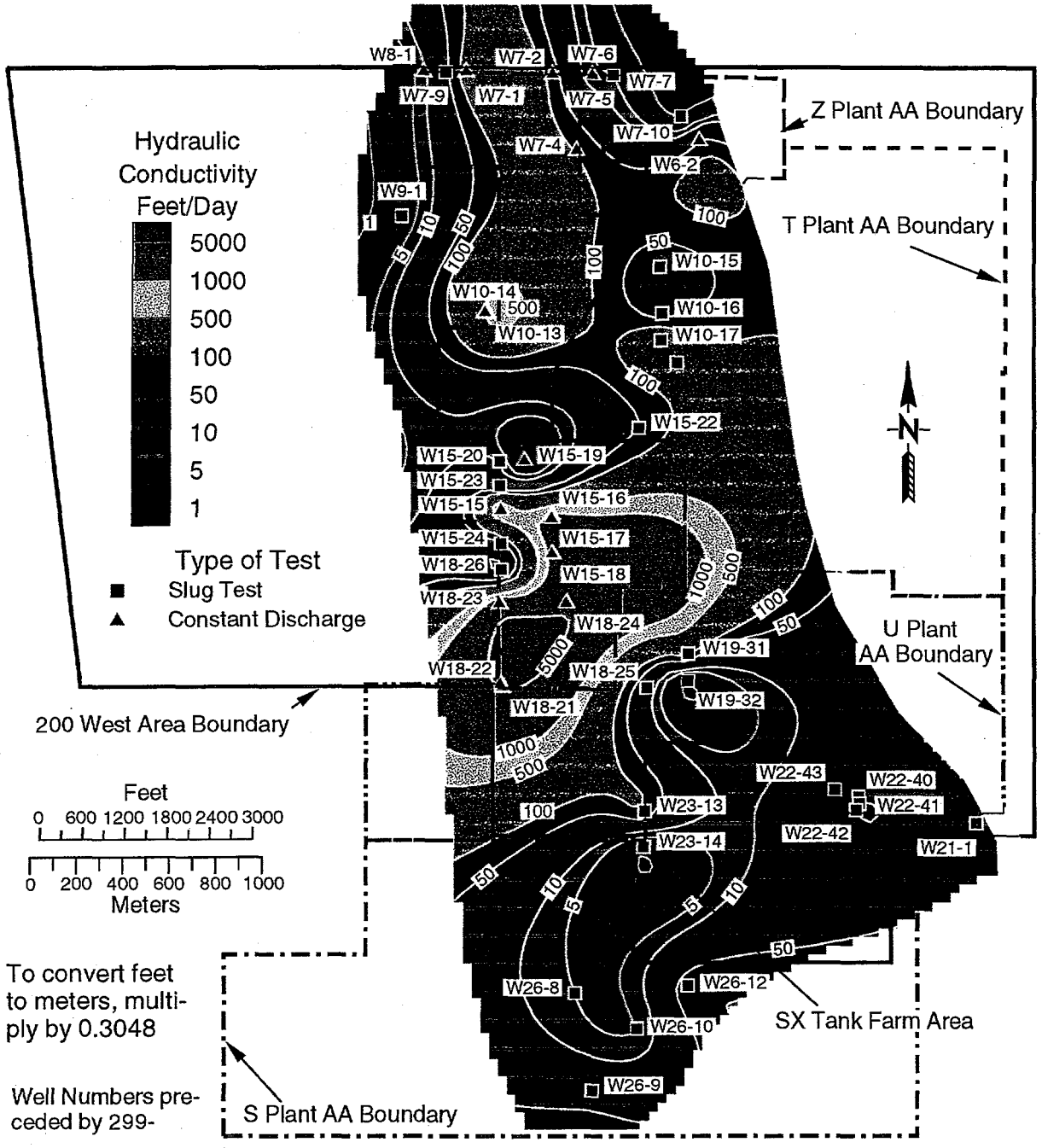

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Figure 6. Unconfined Aquifer Hydraulic Conductivity Map of the 200 West Area

The general groundwater flow direction in the unconfined aquifer is to the southeast. Figure 7 (from Connelly et al. 1992) presents a water table map.

The unsaturated zone above the unconfined aquifer has a characteristically low moisture content between 3 and 7 mass percent, except for the region just above the Plio-Pleistocene unit. This unit can create local perched water zones with measured moisture contents as high as 20 percent.

Regions above the Plio-Pleistocene unit are influenced by infiltration, and the variations in moisture content reflect variations in the sediment grain size and clay content. The porosity of the sediment (pore volume) is not known. Some hydraulic conductivity values have been calculated on the basis of laboratory tests of sediment samples (Connelly et al. 1992). The accuracy of those values is not known, but considering that the samples are highly disturbed, these data likely do not represent in-situ conditions.

There have been extensive studies of the infiltration rate at Hanford, including computer-transport modeling and field experiments at lysimeters and other controlled environments. Some of those studies include Routson and Johnson (1990), Gee (1987), and Gee et al. (1992). It has been determined that the sand or silty soils and the native vegetation at Hanford act to evapotranspire essentially all of the precipitation and the net recharge is near zero. Measurements of the changes in moisture content of sediment at some of the controlled experimental facilities such as field lysimeter facilities indicate almost no change in mositure storage below the vegetation root zone under normal precipitation conditions.

However, the SX Tank Farm is covered with gravel, essentially eliminating evapotranspiration, and the effect of the gravel cover on the infiltration rate has not been established. In addition, no field measurements have been made of moisture content of the vadose zone sediment beneath the SX Tank Farm, and no measurements have been made of the changes in moisture content. Tests of the net infiltration through a gravel cover have been made with lysimeters but they have not been verified at the SX Farm.

4.4 SX Tank Farm Groundwater Contamination

Groundwater beneath the SX Tank Farm is monitored for contaminants under a RCRA groundwater monitoring program conducted by Westinghouse Hanford Company (WHC). Data are reported in quarterly reports (WHC 1995) and annual reports (DOE 1994a) of the RCRA groundwater monitoring program. The current groundwater monitoring program was implemented in compliance with requirements in 1992, and the groundwater monitoring data are used in this report.

The monitoring data and contaminant concentration data reported in the RCRA groundwater monitoring reports are also compiled with other groundwater monitoring data from adjacent facilities and used to prepare groundwater elevation and contamination maps for Hanford publications. Maps in Connelly et al. (1992), Dresel et al. (1995), and DOE (1993) provide the best depictions of contaminant plumes beneath the SX Tank Farm.

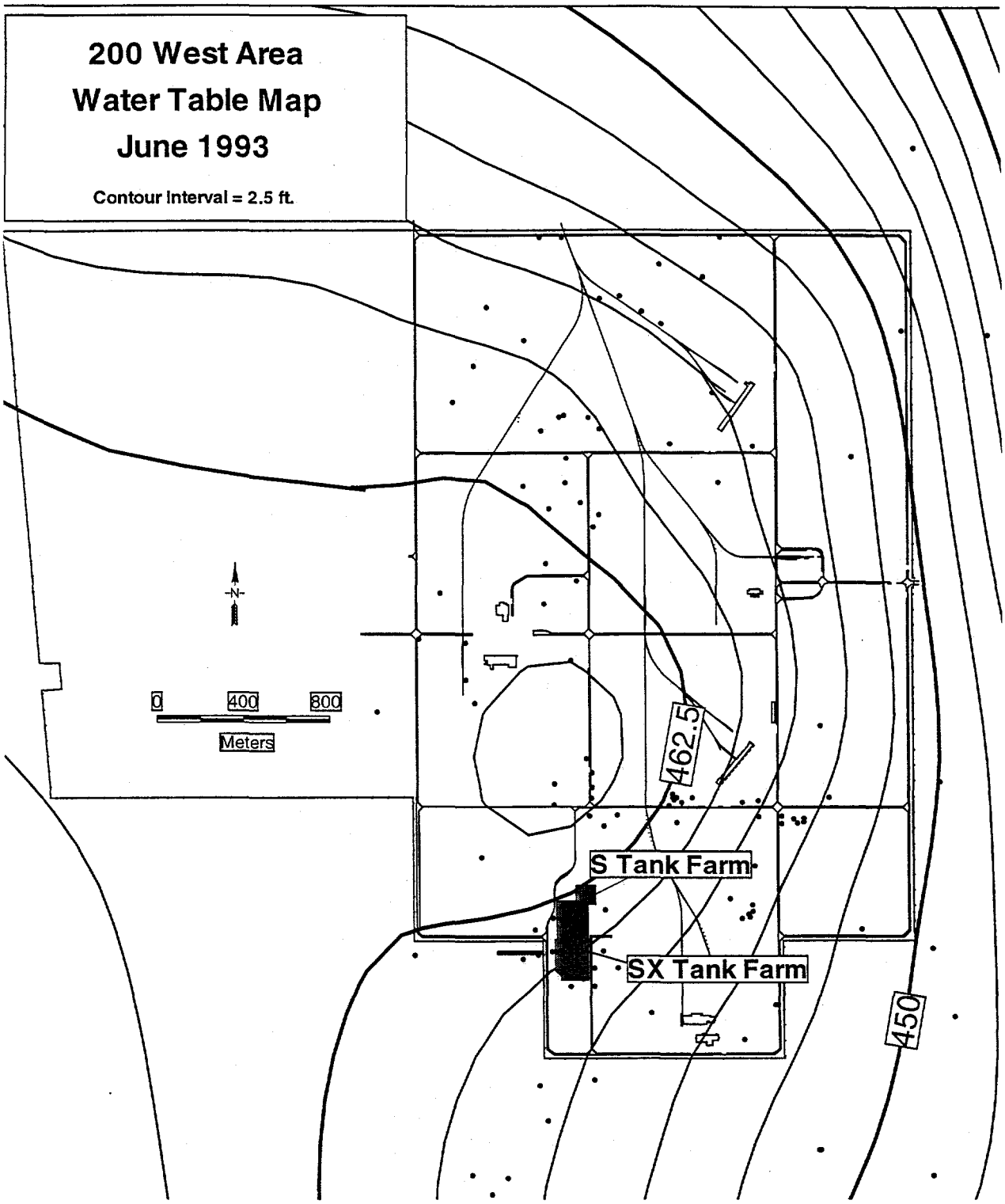


Figure 7. Unconfined Aquifer Water Table Map for the 200 West Area (From Connelly et al. 1992)

As a part of the vadose zone baseline characterization project, the groundwater contamination plume maps from DOE (1993) and Dresel et al. (1995) were reviewed. Those plume maps showed elevated ^{3}H, ^{99}Tc, and gross beta concentrations in the groundwater beneath the SX Tank Farm (Figures 8, 9, and 10, respectively). The maps are interpretations of the contamination plume data; DOE (1993) and Dresel et al. (1995) explain the accuracy of those interpretations.

The pattern and distribution of the contamination that leaked from tanks in the SX Farm raised concerns that it may have contributed to groundwater contamination. As a result, an assessment of the groundwater contamination conditions was made by the Hanford personnel, and an occurrence report was written (WHC 1996). The assessment of the groundwater contamination is provided in two memoranda included in Appendix B.

The conclusion in WHC (1996) was that there were not enough spatial and temporal groundwater monitoring data to identify conclusively the exact source or sources of the contamination in the unconfined aquifer. The first review of the areal distribution of contaminants led to the conclusion that "...the areal distribution of wells exhibiting changes in ^{99}Tc with time in the last 10 years suggest the possibility that some of the leaking tanks within the 241-SX Tank Farm may be contributing to degradation of groundwater quality. However, the data require further analysis and investigation ..." (see Appendix B).

Additional study of the data and calculations of the U/Tc ratios led to the conclusion that "...the data indicate that it is not possible to reject the hypothesis that SST WMA (Waste Management Area) S-SX is the source. However, the possibility cannot be ruled out that a past-practice disposal site within the fence line of the WMA is responsible rather than the tanks themselves." (see memorandum in Appendix B from Dr. Vernon Johnson to Mr. Casey Ruud.)

As there are no reported past-practice disposal sites within the fence line of the SX Tank Farm, the study of the U/Tc ratios indicates that the ^{99}Tc concentration in the groundwater probably originated from the SX tanks.

As a result of the questions raised in the first draft of the SX Farm Report, a more extensive investigation and assessment of the groundwater contamination plume beneath has begun. That investigation is outlined in a Groundwater Assessment Plan (Caggiano 1996). Initial results of the investigation have revealed the presence of chromium in the groundwater that could only have originated from the S or SX Tank Farms.

The source or sources of the contaminants in the groundwater beneath the SX Tank Farm remains inconclusive at this time for some of the constituents. Additional data analysis and sampling to be conducted under the assessment plan are designed to resolve some of the uncertainty. The Tank Farms vadose zone characterization project will provide a critical component to the comprehensive understanding of the fate and transport of contaminants from the SX Tank Farm.

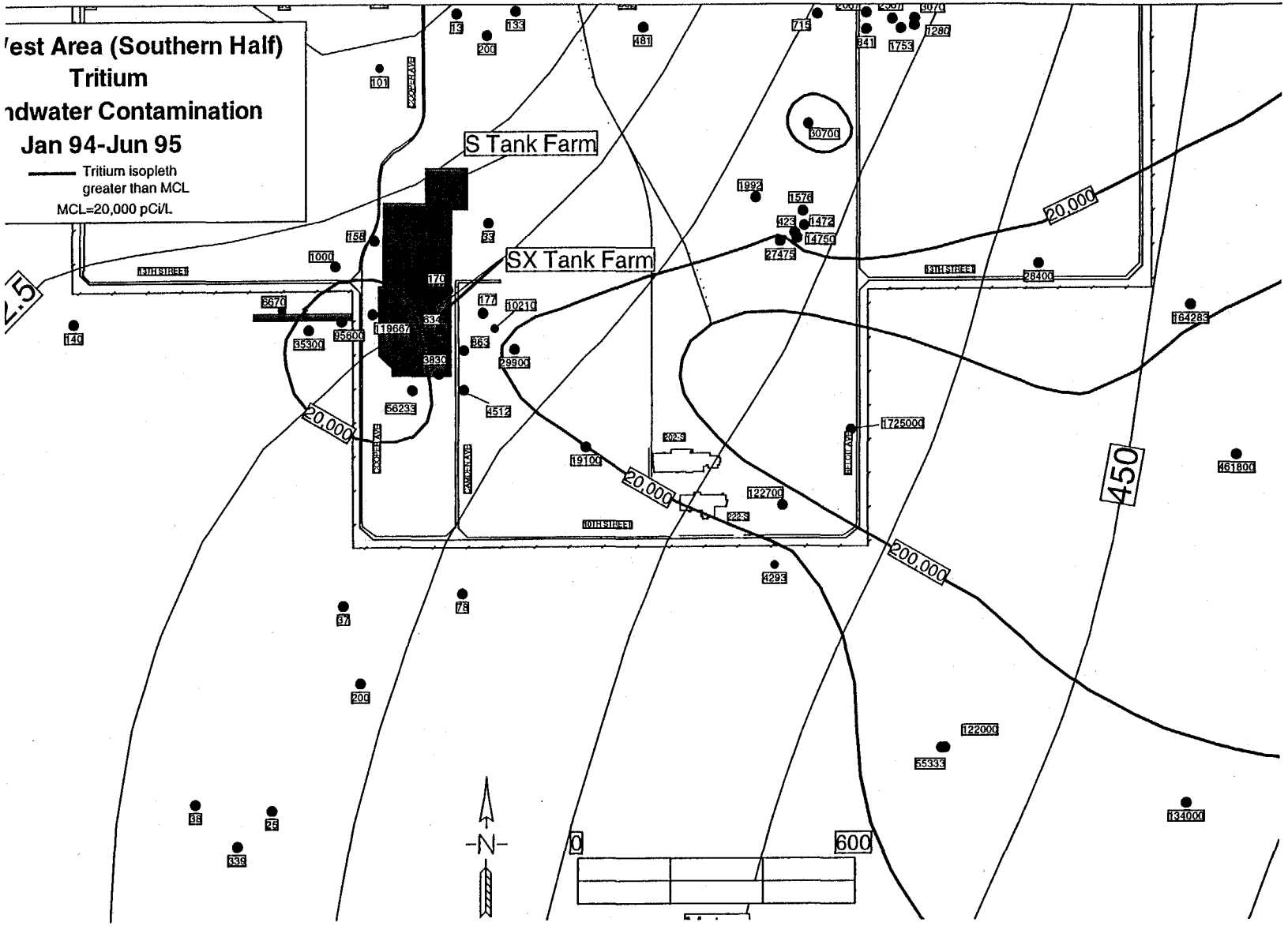


Figure 8. ^{3}H Concentrations in the 200 West Area Groundwater

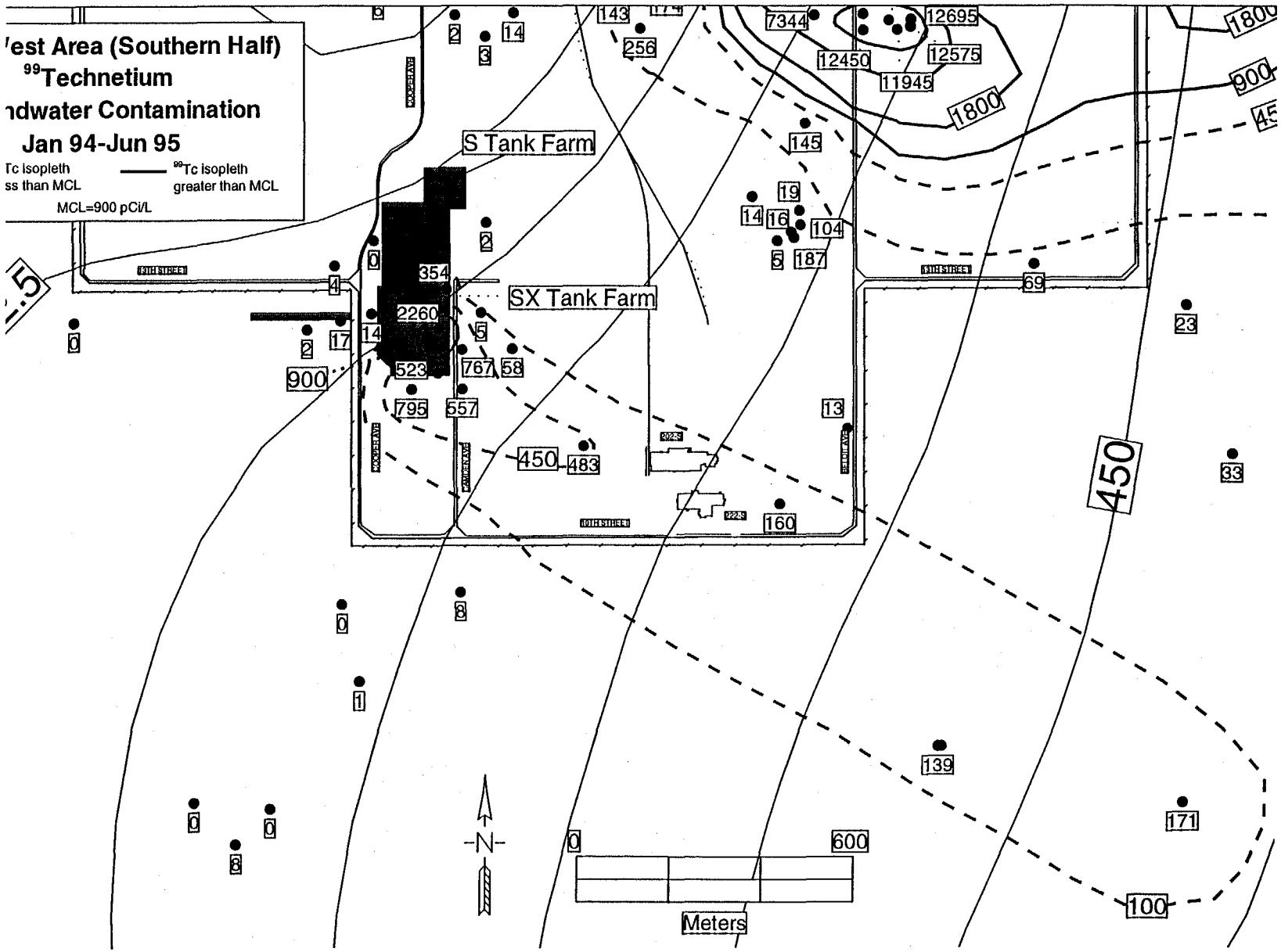


Figure 9. ^{99}Tc Concentrations in the 200 West Area Groundwater

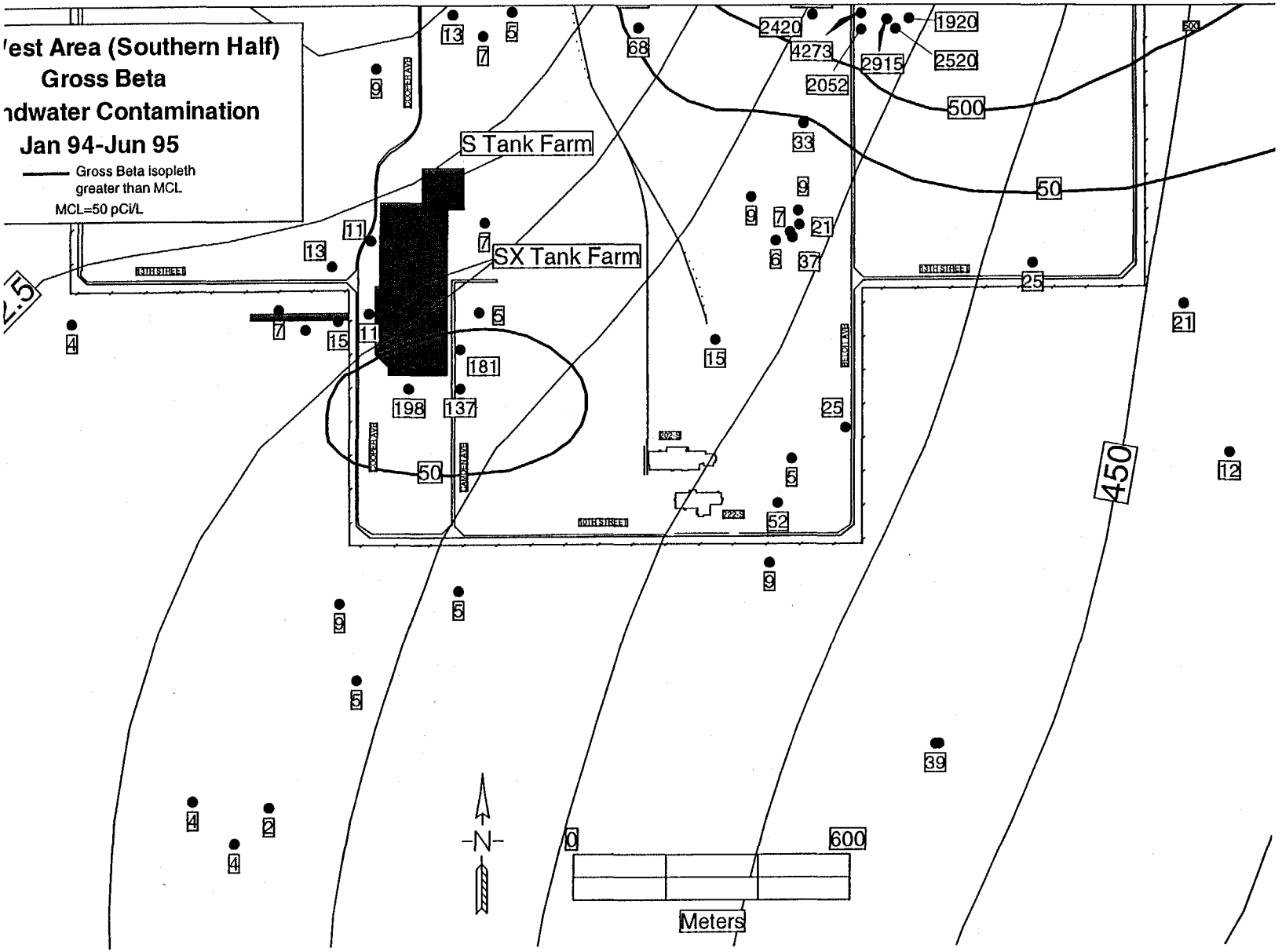


Figure 10. Gross Beta Activity in the 200 West Area Groundwater

5.0 SX Tank Farm Background

5.1 Construction

The SX tanks were constructed between 1953 and 1954 in the central part of the 200 West Area (Figure 1). The SX Tank Farm is the third generation of tanks at Hanford and was built with the intention that the tanks would contain hot, self-boiling waste from the REDOX facility. The SX tanks were located far enough away from the REDOX facility that operation would not be disrupted if problems were encountered at the farm.

One large excavation was made for the construction of all the SX Farm tanks. The bottom grade for the tanks was established and the material was compacted before the concrete bases of the tanks were poured. After the tanks were constructed or as the tank sides were being built, the original excavated material was backfilled around the tanks in 4- to 5-ft lifts and compacted. The tanks were covered with about 7 ft of backfill material.

Several inches of gravel was placed on top of the backfill sediment. The intent of placing gravel on the surface was to prevent wind erosion and establishment of vegetation that could bring subsurface contamination up to the surface. The ground layer also helped prevent personnel from being exposed to contaminated near-surface sediment. Unfortunately, the lack of vegetation inhibits evapotranspiration of precipitation and thereby promotes drainage of precipitation into the subsurface at the farm. This infiltration drainage is a potential source of water that could promote movement of contaminants through the vadose zone.

The SX Tank Farm consists of 15 SSTs, each with a 1,000,000-gallon (gal) capacity. These tanks are the largest of all SSTs at Hanford. The tanks are 75 ft in diameter, approximately 44.5 ft tall with domed tops, and they are covered with about 7 ft of overburden. The base of the original construction excavation and corresponding base of the tanks is about 51.5 ft below the ground surface. Figure 11 presents a plan view of the SX Tank Farm showing the 15 tanks and the vadose zone monitoring boreholes. The actual locations of the monitoring boreholes is in the center of the borehole designation (e.g., in the center of the "15" in the borehole designation 41-15-02).

The tanks were constructed with a carbon steel liner surrounded by a reinforced concrete shell. They are called SSTs because they have only one steel shell. The construction specifications are identified as HW-4957 (GE 1953) and they are shown on "as built" Hanford drawing number H-2-39512*.

Each tank has a nominal diameter of 75 ft. The base of each tank consists of a steel-reinforced concrete circular pad with a radius of 41.5 ft. The edges of the base are about 2 ft thick, and the center is 8 inches (in.) thick, with the tank bottom dished toward the center. The upper surface of

*As built drawings can be obtained from the WHC Microfiche Library, Richland, Washington.

the concrete base was coated with a 3/8-in. asphaltic waterproofing membrane. This membrane consisted of three plies of cotton fabric; each saturated with asphaltic compound. The waterproofing membrane was covered with 2 in. of fine sand and cement grout. A 3/8-in. steel liner was laid on top of the grout as separate sheet panels that were flush welded together.

As was later determined, the asphaltic membrane within the tank base may have contributed to, or caused, the steel liners of the bases on some of the tanks to bulge. In the SX Tank Farm, tanks SX-107, -108, -109, -112, and -113 were inspected in 1969 to determine if the bottoms had bulged (Godfrey and Schmidt 1969). Of those five tanks, four had bulges in the bottom: tanks SX-107, -108, -112, and -113. It is not known if the tanks that were not inspected have bulged bottoms, and the exact cause of the bulge is not known.

The bulges were a concern because they could degrade the structural integrity of the tanks. A study of the problem in 1958 suggested the bulge was not caused by thermal expansion of the steel but by an increase in the vapor pressure beneath the liner. The vapor pressure could have been caused by the vaporization of water entrapped between the liner and the concrete base or by vaporization and off-gasing of the asphaltic coating (Brownell 1958).

The asphaltic membrane is also a potential source of organic compounds that must be considered when reviewing the tanks for inclusion on the organic tank watch list (see Hanlon 1996, Table A-1).

The walls of the tanks sit on top of the thick outer rim of the concrete base. Tank construction photographs show the steel liner of the tank walls was put in place before the concrete was poured and was used as the inner form for the wet concrete. The steel liner was placed on top of the steel base and butt welded to the base as shown in section detail on as-built drawing H-2-39511. Some SSTs in other tank farms were constructed with a rounded steel knuckle that was flush welded to both the steel liner of the base and to the steel liner of the wall. The rounded knuckle was thicker on some SSTs, which allowed for some expansion of the base liner. The fact that the steel liner in the base of the SX tanks could not expand may be a factor that contributed to containment failures of some of the SX Farm tanks.

The concrete walls of the tank were poured as a continuous operation. Wooden forms were used to hold the wet concrete on the outside wall, with the steel liner acting as the inner form. Before the concrete was poured, the tank was filled with water to provide hydrostatic pressure and to prevent the steel from buckling under the pressure of the concrete.

The bottom portion of the reinforced concrete wall is 2 ft thick. About 14 ft from the bottom, the thickness of the wall decreases to 15 in. A separate as-built drawing (H-2-39512) shows the steel reinforcement in the concrete.

All interior surfaces of the steel liner were coated with a "red lead" paint. The top of the steel liner is located about 31 ft above the tank bottom. A 16-in.-wide horizontal steel expansion member is welded to the top of the liner and to the steel reinforcement in the concrete. This expansion member allows vertical thermal expansion between the steel and concrete.

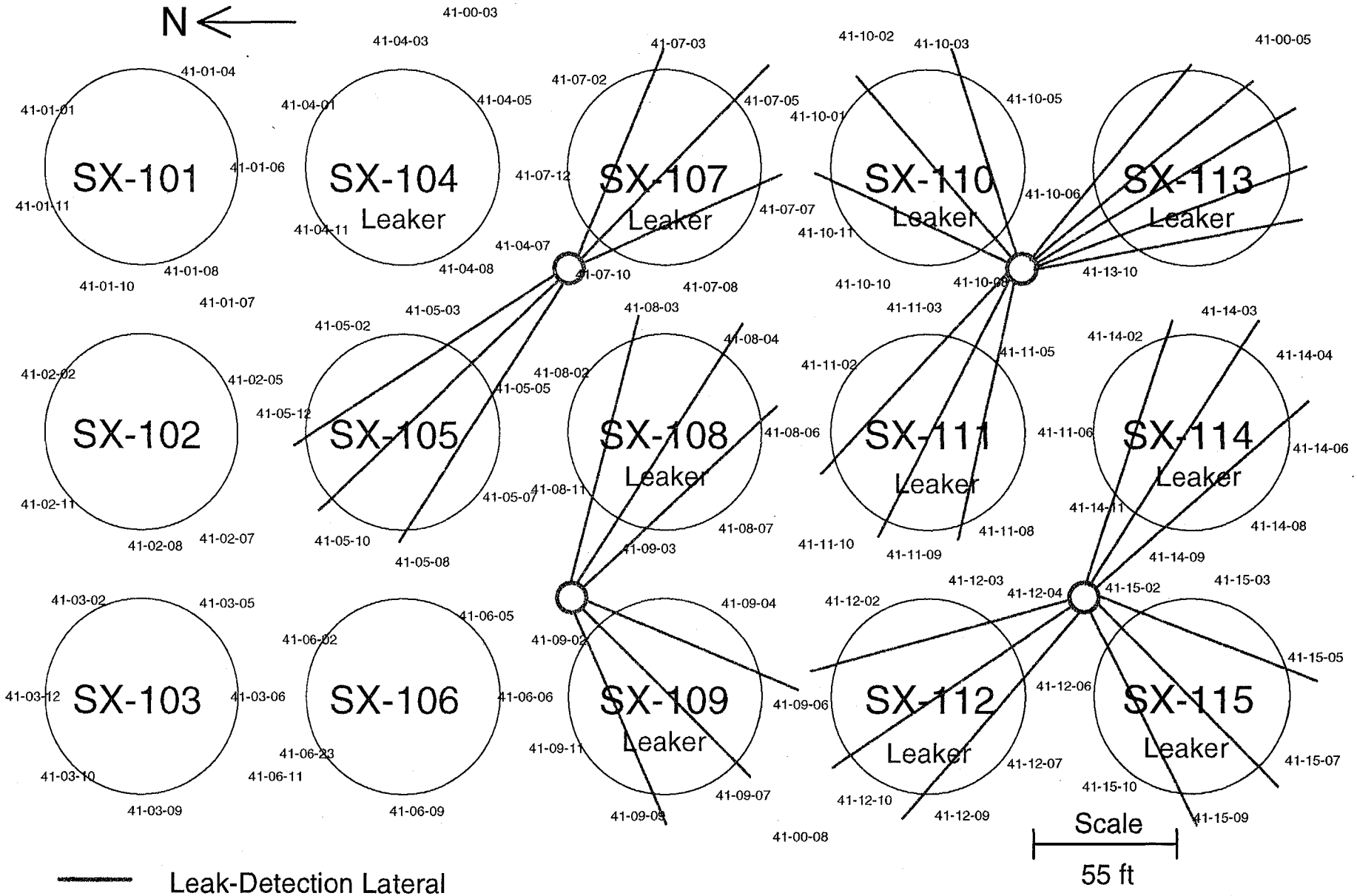


Figure 11. Plan Map of the SX Tank Farm Showing Boreholes and Laterals

The domes of the tanks were constructed with reinforced concrete. The inside surface of the dome above the steel liner was coated with Lapidolith, which is a concrete hardening agent.

The SX tanks have cascading fill lines with three tanks in a cascade: the cascade flow from the easternmost tank fills the middle tank, and the cascade flow from the middle tank fills the westernmost tank. For example, one tank cascade series consists of tanks SX-101, SX-102, and SX-103, where waste from SX-101 cascades into SX-102 and then into SX-103. The cascade lines are located about 30 ft above the bottoms of the tanks, 10 ft below the top of the tank liner, and approximately 19 ft below the ground surface. The second tank in a cascade series has a base elevation that is lower than the first, allowing liquid to flow into it from the first tank; likewise, the third tank is positioned slightly lower than the second tank.

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 height of the cascade line outlets from the tank bottoms establishes the maximum capacity of the tanks. The cascade inflow lines leading to the first tank in the cascade series originate from the 241-SX-151 Diversion Box (see as-built drawing H-2-73208).

Each tank also has an inflow line set at either a 45° or a 135° azimuth on the tanks at the same height as the cascade inflow lines. These inflow lines are 3-in.-diameter pipelines leading from the 241-SX-151 Diversion Box located in the northeast portion of the SX Tank Farm.

The tanks also have pipelines connecting the top centers of the tanks, where a pump is presumably located, to the 241-SX-152 Transfer Box. These lines are used to pump out the tanks.

Other pipelines in the SX Tank Farm are labeled "vapor manifold" lines and "sludge cooler" lines on the drawings. Lines connections and their uses are difficult to determine from the old drawings. Presumably, the sludge cooler lines allow injection of air into the tank sludge. Only tanks SX-109 to SX-115 have sludge cooler lines. All the tanks appear to have "vapor manifold" lines that are connected to a manifold box located above tank SX-112; the manifold box connects to the 241-SX-402 Condenser Building.

Drawing H-2-73208 also shows a "drywell" located near the 241-SX-401 Condenser Building at coordinates N35348.0, W75970.0. This borehole is connected to a 3-in. drain pipe that originates at the condenser valve pit on top of the SX-106 tank. The drain pipe is labeled "plugged in pit," indicating the line was plugged after construction and probably used for drainage of construction water. Another pipeline from this borehole leads to the 241-SX-401 Condenser Building. It is not known what was disposed of in this borehole or how long the borehole was used.

5.2 History and Tank Contents

Anderson (1990) provides general information about the contents of the SX 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. These volumes were prepared by Brevick et al. (1994a and 1994b) and specifically address the SX Tank Farm.

In those two Brevick et al. documents, the authors have compiled most of the available monitoring information on the tanks, and they have provided good 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 in quarterly reports. Hanlon (1996) is an example of one of those reports. Table 1 shows current tank quantities and some historic information.

The SX Tank Farm was first placed in service in 1954, after construction of the tanks was completed. Tanks SX-101 to SX-105 received REDOX waste and first-cycle condensate; all SX tanks but tank SX-106 were full of liquid by early 1954. Tank SX-106 received slurry waste and apparently was used as lag storage of "customer waste." This lag storage accounts for large variations in liquid levels in this tank during the early years of service (see liquid-level data in Brevick et al. 1994a, Appendix C). In later years, tanks SX-101 to SX-106 received bottoms waste and the concentrated effluent from the 242-S Evaporator.

Tanks SX-107 to SX-115 all received the REDOX high-level boiling waste and salt waste; these tanks were filled beginning in 1955 at the height of the operation of the REDOX facility. All these tanks were eventually declared to be "assumed leakers" and removed from service.

The REDOX waste the SX tanks received was predominantly the high-level component of the process waste or coating waste from dissolution of the aluminum- or zircaloy-cladding. Table 2 provides estimates from Anderson (1990) of the major chemical constituents of the waste at the time it was placed in the SX Farm tanks.

The major salts in all of the tanks are sodium nitrate and sodium nitrite. Minor cations are iron, aluminum, manganese, uranium, and lead. Minor anions are sulfate, carbonate, phosphate, and hydroxide.

All the fission and most of the activation products in the fuel were found in the waste stream by process design. Short-lived products have since decayed away. Currently, the most active radionuclides in the high-level waste and, thus, the most easily detected are ^{90}Sr and ^{137}Cs, with ^{137}Cs the most abundant in terms of activity per volume. Other gamma emitters, such as ^{60}Co and isotopes of europium and uranium are present, but at small quantities. 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

Table 1. General SX Tank Information

Tank	Total Waste Volume (1,000 gallons [gal])[a]	Drainable Liquid (1,000 gal)[a]	Current Leak Detection Method[a]	Tank Monitoring Methods[a]	Leaker (Y/N)[a], Leak Date	Original Leak Indication
SX-101	456	146	LOW[b]	LOW; ENRAF gauge	N	
SX-102	543	183	LOW	LOW; ENRAF gauge	N	
SX-103	652	233	LOW	LOW; ENRAF gauge	N	
SX-104	614	201	LOW	LOW; ENRAF gauge	Y, 1988	· Liquid-level decrease
SX-105	683	261	LOW	LOW; ENRAF gauge	N	
SX-106	538	255	ENRAF gauge	LOW; ENRAF gauge	N	
SX-107	104	5	None	Manual tape	Y, 1964	· Lateral gamma · Borehole gamma
SX-108	87	5	None	Manual tape	Y, 1962	· Liquid-level decrease · Lateral gamma · Borehole gamma
SX-109	244	48	None	Manual tape	Y, 1965	· Lateral gamma · Borehole gamma
SX-110	62	0	None	Manual tape	Y, 1976	· Liquid-level decrease
SX-111	125	7	None	Manual tape	Y, 1974	· Lateral gamma
SX-112	92	3	None	Manual tape	Y, 1969	· Liquid-level decrease · Lateral gamma
SX-113	26	0	None	Manual tape	Y, 1962	· Liquid-level decrease · Lateral gamma
SX-114	181	14	None	Manual tape	Y, 1972	· Lateral gamma · Borehole gamma
SX-115	12	0	None	Manual tape	Y, 1965	· Liquid-level decrease · Lateral gamma · Borehole gamma

[a]Information taken from Hanlon (1996).
[b]LOW = liquid observation well.

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

Waste	Composition	Volume
Aluminum-clad fuel coating	$NaAlO_2$	1.2 M[a]
	NaOH	1.0 M
	$NaNO_3$	0.6 M
	$NaNO_2$	0.9 M
	Na_2SiO_3	0.02 M
	SpG	1.19
	Pu	0.4 %
	U	0.4 %
Zircaloy-clad fuel coating	$ZrO_2 \cdot 2H_20$	0.1 M
	NaF	0.7 M
	$NaNO_3$	0.02 M
	KF	0.01 M
	U	0.001 lb/gal[b]
	Pu	0.001 lb/gal
	pH	10
REDOX high-level process	$NaAlO_2$	1.2 M
	NaOH	0.69 M
	$NaNO_3$	4.83 M
	Na_2CrO_7	0.066 M
	$Cr(OH)_3$	0.045 M
	$Na_2(SO_4)$	0.031 M
	$Fe(OH)_3$	0.016 M
	SpG	1.29
	U	0.05 %
	Pu	0.04 %

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

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.

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 tank wastes in relatively small quantities.

More specific information about the contents of each tank is available in Agnew (1995) and in Agnew et al. (1996). When tank-specific summaries of tank contents were compiled for publication in Brevick et al. (1994a and 1994b), historic information such as tank operations logs was still classified and was not included in those documents.

Currently, a relatively large program is devoted to determining the physical and chemical properties of the waste in the tanks. That work, combined with a revision of the tank contents historical information in Brevick et al. (1994a and 1994b), will be available in the future. The

best information so far on tank radionuclide content and chemistry is probably in the current version of the Brevick documents. Work is ongoing to determine the chemical and radiological content of the tanks.

Determining which tanks have leaked, the quantity and composition of the contamination released, and the spatial distribution of the contamination are of concern for Hanford decision makers. Ten of the 15 SX Farm tanks are currently listed as assumed leakers (Hanlon 1996). Compared to other farms, this is a high percentage of leaking tanks. The large percentage of leaking tanks may be due to the nature of the waste that was placed in the tanks or may be the result of the tank design or construction methods. Assumed leakers are designated on Figure 11 with a red "Leaker" designation.

The reasons the tanks were declared leakers vary; each leaking tank is discussed in a Tank Summary Data Report. Table 1 presents general information about the SX tanks.

Hanlon (1996) provides estimates of the volumes of liquid that leaked from the SX 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 SX Farm tanks may have been nothing more than 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 decreases 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.

There are a total of 15 unplanned releases in the vicinity of the SX Tank Farm. Nine of these are within or immediately adjacent to the SX Tank Farm. Table 3 provides a synopsis of the unplanned releases and Figure 2 shows their locations. This information was obtained from the *S Plant Aggregate Area Management Study Report* (DOE 1991). The referenced source of this information is the Hanford Site Environmental Sites Database (formerly the Waste Information Data System [WIDS] database). Because the database does not yet include the unplanned releases associated with the SSTs, the original source of information on the unplanned releases is not known.

Table 3. Documented Unplanned Releases (UPRs) Near the SX Tank Farm

UPR No.	Location	Date	Coordinates East	Coordinates North	Description	Reference
UPR-200-W-20	Around the 241-S-151 Diversion Box	1953	75410.2 (566913.5)	35608.0 (134314.9)	· Leakage from the 241-S-151 Diversion Box contaminated an area near the 241-SX Tank Farm	None
UPR-200-W-36	The 216-S-1 and 216-S-2 Crib area	1955	75186.6 (566981.1)	35423.0 (134258.4)	· Contamination spread from 216-S-1 and 216-S-2 Cribs via a ruptured test well	None

Table 3. Documented Unplanned Releases (UPRs) Near the SX Tank Farm

UPR No.	Location	Date	Coordinates East	Coordinates North	Description	Reference
UPR-200-W-49	241-SX Tank Farm, outside of southeast corner	1958	75547.7 (566871.9)	35077.0 (134153.0)	· Release from the 241-SX Tank Farm caused contamination of approximately 46 square meters outside the southeast corner of the tank farm. · Unknown beta/gamma readings up to 150 milliroentgen per hour (mR/h) were noted, with a single spot with readings up to 10 rad/h. · Remedial actions not identified.	None
UPR-200-W-50	East 241-SX Tank Farm	1958	75430.0 (566907.5)	35499.0 (134281.7)	· A release from 241-SX Farm resulted in the contamination of an area of approximately 2 acres east of the tank farm. · Unknown beta/gamma readings of 40,000 counts per minute. · Remedial actions not identified.	None
UPR-200-W-51	A narrow strip of ground south of 241-S-151 Diversion Box, across 10th St, and ~100 yards beyond the area fence	195?	75570.9 (566864.9)	35419.0 (134257.3)	· Leakage from the 241-S-151 Diversion Box contaminated the ground · Beta/gamma with readings to 50 mR/h within 100 ft of the diversion box and readings outside the fenced area at ~4,000 counts per minute.	None
UPR-200-W-80	244-S Receiver Tank and areas adjacent to the 241-S and 241-SX Farms	1978	75702.5 (566825.1)	35798.0 (134372.9)	· The 241-S and 241-SX Tank Farms contaminated the 244-S Receiver Tank construction site and other areas adjacent to the tank farms. · Radionuclides known to be present are ^{90}Sr and ^{137}Cs with readings to 60,000 counts per minute. · Remedial actions not identified.	None
UPR-200-W-81	Between the 241-S and 241-SX Tank Farms	1979	75702.0 (566825.1)	35798.0 (134372.9)	· Airborne migration of contamination from the 241-S and 241-SX Tank Farms. · Unknown beta/gamma with readings from 500 to more than 100,000 counts per minute were recorded. · The area was cleaned and released; however, upon detection of subsequent contamination, the area was roped off and reposted as a radiation zone.	None

Table 3. Documented Unplanned Releases (UPRs) Near the SX Tank Farm

UPR No.	Location	Date	Coordinates East	Coordinates North	Description	Reference
UPR-200-W-114	Area east of 241-SX Tank Farm	1980	75248.0 (566962.4)	35399.7 (134251.4)	· Annual surface contamination monitoring performed October 1990 in the vicinity of the 241-SX Tank Farm, 241-SX-151 Diversion Box, and the 241-SX-152 Diversion Box detected contamination from 200 to 450 counts per minute with specks of contamination to 4 mR/h. · Similar conditions were reported during surveys in September 1988 and 1989. · Cleanup operations have reduced but not eliminated particulate contamination.	None
UPR-200-W-140	241-SX-107 SST	1964	75666.0 (566836.0)	35347.0 (134235.3)	· Spill of 19,000 liters (L) (5,000 gal) from the 241-SX-107 SST resulted in the lateral spread of contamination 17 to 18 meters (55 to 60 ft) below the ground surface. · Tank is currently inactive and was removed from service in 1964.	None
UPR-200-W-141	241-SX-108 SST	1962	75769.0 (566804.9)	35347.0 (134235.2)	· Release of approximately 9,100 L (2,400 gal) of supernatant containing REDOX high-level waste and concrete. · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1962.	None
UPR-200-W-142	241-SX-109 SST	1965	75872.0 (566773.9)	35346.0 (134235.1)	· Release of approximately 19,000 L (5,000 gal) of REDOX high-level liquid waste. · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1965.	None
UPR-200-W-143	241-SX-111 SST	1974	75769.0 (566805.0)	35245.0 (134204.1)	· Release of approximately 7,570 L (2,000 gal) of REDOX high-level liquid waste and ion-exchange liquid waste from the 241-SX tanks · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1974.	None

Table 3. Documented Unplanned Releases (UPRs) Near the SX Tank Farm

UPR No.	Location	Date	Coordinates East	Coordinates North	Description	Reference
UPR-200-W-144	241-SX-112 SST	1969	75872.0 (566773.9)	35244.0 (134204.0)	· Release of approximately 114,000 L (30,000 gal) of REDOX high-level liquid waste. · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1969.	None
UPR-200-W-145	241-SX-113 SST	1962	75666.0 (566836.1)	35143.0 (134173.1)	· Release of approximately 57,000 L (15,000 gal) of REDOX high-level liquid waste. · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1958.	None
UPR-200-W-146	241-SX-115 SST	1965	75871.0 (566774.0)	35143.0 (134173.0)	· Release of approximately 190,000 L (50,000 gal) of REDOX high-level liquid waste. · Remedial actions not identified. · The tank is currently inactive and was removed from service in 1965.	None

Seven of the nine unplanned releases within the SX Farm were actual tank leaks and not surface spills. Those releases were included in the unplanned release reporting system and in the database.

The other two unplanned releases were actual surface spills of unknown quantities; these spills were located outside the SX Tank Farm. One release (UPR-200-W-49) was located immediately southeast of the SX Tank Farm, and the other (UPR-200-W-51) was located just east of tank SX-104 (see Figure 2).

The ground surface within the SX Tank Farm may be contaminated to some degree (see Section 10.1), but no documentation was located on any of the surface spills within the SX Tank Farm other than the two documents identified above.

5.3 Leak-Detection Monitoring

The SSTs have been monitored for leak-detection purposes throughout the years with either liquid-level measurements, solid-level measurements, or direct detection of contamination in the vadose zone with gross gamma logging. Section 5.5 presents a discussion of previous gross gamma logging programs used to detect contamination in the vadose zone.

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

Sealed fiberglass and tefzel casings were also inserted into the waste sludge in some of the tanks to allow access for borehole monitoring tools. These sealed casings are called liquid observation wells (LOWs) at Hanford. The monitoring tools used in the LOWs include low-efficiency gamma-ray detection probes (Geiger-Mueller detectors) to measure the variations in gamma flux and neutron-neutron probes to measure variations in the hydrogen content profile. These tools are intended to detect changes in the solid-to-liquid interface level and, thus, changes in the liquid level. They are particularly important for detecting leaks because most tanks now have a relatively solid, 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.

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

For an assessment of the vadose zone contamination, questions about tank monitoring 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, (5) what is the chemical and radiological composition of the contamination that leaked, and (6) what is the extent of the contamination distribution?

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 ENRAF gauges and 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 error of the instrumentation, physical changes can occur with 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 SX Tank Farm, have monitoring boreholes installed around the tanks. These boreholes were installed and used as a part of a tank leak-letection monitoring program where gamma-ray detectors were lowered into the boreholes to detect the presence of contamination in the sediment around the tanks.

The boreholes in the SX Tank Farm range from 75 to 125 ft deep and reach TD well above the groundwater. A few boreholes were drilled around the perimeter of the farm for groundwater monitoring purposes and extend to about 230 ft. Figure 11 shows the locations of all SX Tank Farm monitoring boreholes.

In the early to mid-1950s when the SX Tank Farm was first put into service, 11 vadose zone boreholes were drilled, presumably for monitoring purposes. It is known from drilling logs that at least some of the 11 boreholes were perforated immediately after they were drilled. The others may be perforated and simply not documented. It is not known why the boreholes were perforated. It is possible it was believed the perforations would allow use of beta or alpha radiation detectors. The perforated boreholes still exist and have not been modified.

In the early to mid-1960s, several more monitoring boreholes were drilled. In the early 1970s, a more comprehensive drilling program was undertaken in an effort to obtain better spatial coverage around all the SX tanks. Some of the pre-existing boreholes were deepened or modified in the 1970s.

The construction of most boreholes is documented to varying degrees in the form of drilling logs. Most of the drilling logs provide little description of the operation, and there is no explanation of why the boreholes were constructed as they were. However, the drilling logs do provide information on when the boreholes were drilled, some information about the character of the formation, and reports on any occurrences of contamination in the sediment. At least six boreholes do not have drilling logs. All of the drilling logs are available in borehole archive files maintained by the WHC Well Services Group.

All the vadose zone monitoring boreholes were drilled with a cable-tool drill rig. This type of drill rig uses a weighted drill stem mounted on a cable to drive a shaped, hardened-steel tool bit down into the sediment. A bailer tube is attached to the drill bit, and cuttings are pushed into the bailer as the bit is driven downward. The bailer is used to extract the drill cuttings from the borehole on a wireline cable.

As the drill bit 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 soundness of the sediment being drilled. A carbon-steel casing is then driven down into the slightly undersized, open portion of the borehole, and the drilling process then proceeds over another drilling interval.

With this drilling method, there is a possibility that the borehole wall could collapse along the short open portion of the borehole before the steel casing is driven into place. If formation material does slough off the borehole wall and collapse into the hole, it is removed from the hole with the bailer and a void is created in the borehole. Once the casing is driven into place, that void remains behind the casing.

The potential for voids behind the casing or a highly rugose borehole can create a pathway for migration of contaminants down the outside of the borehole casing. This migration of

contaminants could occur in two ways. Further sloughing of contaminated material could occur between the casing and the formation. However, this sloughing would result in a relatively minor amount of contamination movement..

The other possibility is that a flood at the surface from a large, fast snow melt or from a large surface spill could carry dissolved contaminants down the borehole if the borehole is not sealed at the surface. Floodwater could drain down the borehole, pick up contaminants at some intermediate level, and carry them further downward. The surface floodwater scenario requires saturated flow down the outside of the casing. Under unsaturated conditions, the void behind the casing would not promote vertical migration because the positive pore pressure of the sediment would retain the moisture and prevent it from moving into the borehole.

In addition, when a borehole is drilled through a zone of contamination with a cable tool rig, if sloughing were to occur in the open portion of the borehole as it is being drilled, contamination could be carried down at least to the maximum extent of the drilling interval (4 to 10 ft). However, because most of the sediment is removed from the hole by the bailer 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 the borehole 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 boreholes have a small concrete collar at the surface that is about 1 ft deep and 1 ft in diameter. That collar helps to prevent water and material from moving down the outside of the casing. If there are large voids at depth, the collar would not be an effective surface seal, and water would flow around the collar and down the casing.

Some of the boreholes were modified years after they were drilled. Such modifications include perforating the holes, extending the depth, and placement of surface collars.

All the borehole casings were cut off at the top of the surface collars, and they are at most only a few inches above the surface grade of the farm. Plugs or caps were put into the boreholes to keep dust, contaminants, and water out of the boreholes, but many borehole caps were destroyed by being run over by vehicles or were lost. There is potential for water and contaminated sediment to go down the inside of the borehole casings. If a borehole cap is removed for a significant amount of time, contaminated sand or silt can be blown into the borehole and settle at the bottom of the hole. This is evident as a slightly elevated ^{137}Cs anomaly at the bottom of the borehole. When low-level ^{137}Cs concentrations are present at the bottom of a hole with contamination-free regions above, it is relatively conclusive that the contamination is on the inside of the borehole.

A few SX Tank Farm boreholes were plugged at the bottom by placing a cement plug down the hole with a tremmie tube. A typical bottom plug for the vadose zone boreholes is about 5 ft thick.

Pertinent borehole information is provided in the Log Data Reports that accompany the log plots in the Tank Summary Data Reports. The borehole information in the Log Data Reports is the result of a review of the records for each borehole.

Some perimeter boreholes drilled to monitor the groundwater were also driven with cable-tool drill rigs. These boreholes are double cased with telescoping casings. First, a 10-in.-diameter casing was driven down to a mid-depth of 100 to 120 ft. A 6-in.- or 8-in.-diameter casing was then placed inside the 10-in. casing, and the boreholes were drilled to TD within the unconfined aquifer. Some of these boreholes were later modified by perforating the deeper portions, which were single cased, and placing a yet smaller diameter casing inside of the well and filling the annular spaces with grout. Because the outer casing was perforated, the grout flowed into any voids between the casing and the formation.

The double casings in the groundwater monitoring wells and any grout placed between the casings and formation effectively attenuate the gamma-ray flux to such a degree that unless the formation around the boreholes is very high in gamma-emitting isotope concentration, nothing is detected in the borehole. Also, because the thickness of the grout is not known, there is no way to correct for the grout attenuation, making it impossible to quantify the formation contamination concentration. Therefore, these groundwater monitoring wells are generally not suitable for gamma-ray logging.

In addition to the boreholes around the individual tanks in the SX Tank Farm, lateral (horizontal) boreholes are present under 10 tanks (SX-105, -107, -108, -109, -110, -111, -112, -113, -114, and -115). The lateral boreholes are shown on Figure 11. These laterals, which are about 10 ft below the bottoms of the tanks, radiate outward from four large caissons that extend from the surface to a depth of about 70 ft (Harvey 1970). Gross gamma logging tools used these laterals to access the area under the tanks.

Five laterals were installed beneath tank SX-113 in December 1958 as a prototype leak-detection system. Gross gamma detectors were pushed to the ends of the laterals with a pneumatic device, and logging proceeded from the end of the laterals out to the caisson.

Three laterals were eventually installed under each of the other nine other tanks (SX-105, -107, -108, -109, -110, -111, -112, -114, and -115), but documentation on their construction and configuration has not been located. Only one as-built drawing (H-2-31881) has been located, and it does not identify how the laterals were constructed.

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. Reliance on gross gamma logging was eliminated for all but a handful of SSTs.

None of the laterals are currently being logged with the gross gamma logging system, and the SGLSs did not log these holes. Historical gross gamma logs for some of the laterals were not

available at the time the Tank Summary Data Reports were prepared, but all historical logs are now available.

Gross gamma logs were acquired for all the SX Tank Farm boreholes and laterals 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.

The first gross gamma logging was conducted at Hanford in the 1960s when station measurements were made with Geiger-Mueller detectors 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 counter. The counter 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 hole.

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) versus 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 conducted on these data. If a change was suspected, the borehole was rerun 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 determining a leak had occurred or was occurring (Isaacson 1982), which were used throughout the years in one form or another, 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.

In addition, the logging instrumentation was not properly calibrated to a radionuclide concentration response. Therefore, there is no way to relate an instrument count rate or even a gamma-ray flux in a borehole to a leak from a tank. However, there is an empirical nature to the calculations, and the relative changes in detected count rates 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). This program was not designed to determine the nature and distribution of contamination, and it was not intended to be used to monitor the movement of the contamination. As a result, these data do not provide a good historical record of the vadose zone contamination, and they do not adequately identify migration of the contamination. However, these data are useful for some migration assessment purposes. In regions where the ^{137}Cs contamination levels are high (greater than 10 pCi/g), the gross gamma data can be used to qualitatively assess changes over a period of time. In fact, leaks and changing conditions have been identified in many instances from the gross gamma log data. The region on the west side of tank SX-109 is an example (see Section 10.2).

Review and visual comparison of gross gamma log profiles over time have been useful to determine if contamination is moving or has moved downward or changed in intensity. However, because of the poor spatial resolution of these 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 logging runs can 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. Calculations of the decrease in activity over time can be used in some cases to help identify the isotopes.

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

The laterals beneath the tanks were logged with essentially the same equipment and data acquisition parameters. The laterals used a pneumatic plunger to drive the logging tool to the end

of the lateral and the hole was logged as the tool was pulled out. These data were also visually compared to previous log data to identify changes.

Currently, no gross gamma logging is performed at any of the SX Tank Farm tanks, as specified in the most recent Operating Specification Document (WHC 1994). Current tank leak-detection monitoring is focused on performing in-tank measurements.

6.0 Adjacent Waste Site Information

This section provides a review of the waste facilities in the vicinity of the SX Tank Farm. Figure 2 shows the location of these waste sites. Only those 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 the results are 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 not active. No vadose zone monitoring or characterization has been conducted at these facilities, other than some limited gross gamma logging conducted previously.

6.1 216-S-1 and 216-S-2 Cribs

The 216-S-1 and 216-S-2 Cribs are two 12-ft long by 12-ft wide by 9-ft deep wooden cribs that were used from 1952 to 1956. Located about 400 ft east of the SX Tank Farm (see Figure 2), these cribs began receiving effluent in January 1952 and were closed in January 1956, just after the SX Tank Farm began receiving waste. The cribs received approximately 42 million gal of cell drainage and condensate from the 202-S Building and a minor amount of drainage from the 241-S-151 Diversion Box. Much of the effluent appears to have been acidic (nitric acid), and it corroded some of the monitoring borehole casings, enhancing the potential for downward migration of contaminants to the groundwater.

One estimate of radionuclide content reported in Fecht et al. (1977) shows 1,200 grams (g) of plutonium, 2,300 kilograms (kg) of uranium, as well as an unspecified amount of ^{137}Cs, ^{60}Co, and ^{90}Sr were released at these cribs. Historical gross gamma logs show the contamination has remained relatively close to this crib. Logs of the westernmost borehole, 299-W22-6, do not show elevated activity. In all probability, contamination is present in the vadose zone at this location, but it is not present in high enough concentrations to produce a gross gamma anomaly on the low-sensitivity detection system.

Waste from this crib facility has contributed to the groundwater contamination near the SX Tank Farm (DOE 1993). Because these cribs are located downgradient of the SX Tank Farm, they are not a current source of groundwater contamination beneath the farm. It is possible the groundwater table was temporarily elevated at the time the cribs were receiving waste, creating a local reversal in the groundwater flow direction. However, there is no documented evidence of this at the time the cribs were receiving waste. It is not possible that contaminants could have

migrated through the vadose zone in sufficient quantity to create the contaminant plumes now present under the SX Tank Farm.

Logs from the vadose zone monitoring boreholes located between the cribs and the SX Tank Farm do not show any elevated gross gamma activity, indicating that the vadose zone contamination beneath the 216-S-1 and 216-S-2 Cribs did not migrate horizontally through the vadose zone and did not contribute to the vadose zone contamination beneath the SX Tank Farm. By the time most of the tanks in the SX Tank Farm began receiving waste, the 216-S-1 and 216-S-2 Cribs were retired from service, and there was no longer any water from the cribs moving through the vadose zone in the vicinity of the farm that could cause radionuclide migration.

6.2 216-S-3 French Drains

The 216-S-3 French Drains consist of two 10-ft long by 10-ft wide by 6-ft deep pits that were presumably filled with gravel. They are located just east of the S Tank Farm, approximately 450 ft north-northeast of the SX Tank Farm.

Each pit structure had a pipe from the surface down to the bottom of the structure (6 ft) that was connected to an aboveground pipe. This pipe ran to the S-101 and S-104 tanks, which were equipped with condensers that dumped condensate to the French drains.

These French drains were operated from 1953 to 1956, when they were deactivated by removing the aboveground piping. They received about 1.1 million gal of neutral to basic condensate; this condensate had low radionuclide contamination content. However, the waste contained ^{99}Tc which may be the primary source for the ^{99}Tc found in the groundwater around the S-SX Farm complex (see Section 4.4).

Because of the low contamination content of the liquid released at these structures and its distance from the SX Tank Farm, there is little possibility that the facility affected the vadose zone beneath the SX Tank Farm. However, the possibility that these French drains contributed to the groundwater contamination beneath the SX Tank Farm cannot be ruled out.

6.3 216-S-8 Trench

The 216-S-8 Trench is 100-ft long by 60-ft wide by 25-ft deep. It is located 200 ft directly east of the SX Tank Farm. This trench was used from late 1951 to early 1952 and received start-up waste from the 202-S processing facility (S Plant). About 2.6 million gal of nitrate solution containing essentially no radionuclides was released at this trench. This trench was backfilled in 1952, before the SX Tank Farm was constructed, and the aboveground effluent piping was removed.

Because the trench was used before the SX Tank Farm was constructed and radionuclides were not released at the trench, the past operation of this trench could not have contributed to either the groundwater or vadose zone contamination beneath the SX Tank Farm.

6.4 216-S-25 Crib

The 216-S-25 Crib is a 10-ft wide by 575-ft long by 10-ft deep, gravel-filled crib containing a perforated effluent distribution pipe near the bottom. It is located about 350 ft west of the SX Tank Farm and is oriented in an east-west direction (Figure 2).

The 216-S-25 Crib began operation in November 1973 and was removed from service within the last 2 years, so it is a relatively recent crib facility. The Environmental Sites Database indicates this crib received about 76 million gal of steam condensate from the 242-S Evaporator and cooling water from the SX Tank Farm, all with a low radionuclide content. This crib also received 8 million gal of effluent from a groundwater pump-and-treat operation at the U-1 and U-2 Cribs in the 200 West Area. This operation involved treating the groundwater with an ion-exchange process and disposing of the effluent at the 216-S-25 Crib. The radionuclide content of the effluent is not known.

The groundwater beneath the 216-S-25 Crib is contaminated, but it is not known if the contamination originated from this crib or from the upgradient U Pond, where billions of gallons of effluent were discharged. No vadose zone monitoring has been conducted at this site except for gross gamma logging in the mid-1970s.

This crib facility probably contributed to the groundwater contamination present beneath the SX Tank Farm because it is located upgradient of the SX Tank Farm. The reader is referred to Section 4.4 for a discussion of the SX Tank Farm groundwater contamination.

Because ^{137}Cs was not released at this crib, it is not considered a contributing source to the ^{137}Cs contamination plumes detected in the vadose zone beneath the SX tanks.

It is possible the crib could have contributed to the slightly elevated moisture content of the sediment just above the Plio-Pleistocene unit (see Figure 5), and the moisture may contain some undetected beta-emitting radionuclides, such as uranium daughters or ^{99}Tc. The only way to confirm this hypothesis would be to sample and assay the moisture in the vadose zone just above the Plio-Pleistocene at various locations between the SX Tank Farm and the 216-S-25 Crib.

6.5 216-S-21 Crib

The 216-S-21 Crib, located north of the 216-S-25 Crib, is about 550 ft northwest of the SX Tank Farm and due west of the S Tank Farm. This crib is a 16-ft long by 15-ft wide by 10-ft deep wooden structure placed in a 50-ft by 50-ft excavation and surrounded by gravel.

This crib was used from 1954 to 1969 to dispose of about 23 million gal of condensate from the 401-SX Condenser facility that was serviced through tank SX-106. The pipeline from the condenser to the crib is buried about 9 ft below grade.

Records in the Environmental Sites Database show about 85 Ci of ^{137}Cs and 22 Ci of ^{90}Sr were released at this crib, but no other significant radionuclides. A single monitoring borehole, W23-4, was logged with older gross gamma logging systems. Logs acquired in this borehole show elevated activity had reached a maximum depth of 50 ft, and minimal migration of the plume from the late 1950s to the mid-1970s is indicated.

Because this crib is located upgradient from the SX Tank Farm, it is considered to be a potential source of groundwater contamination (see Section 4.4).

Currently, this facility is not monitored, and characterization of the vadose zone sediment has not been conducted. However, considering that the ^{137}Cs contamination has only migrated to a depth of 50 ft with the release of more than 20 million gal, it is unlikely that there has been any appreciable contamination migration from this site through the vadose zone. Because this crib is located 550 ft away from the SX Tank Farm and the contamination released at the site has not migrated to a significant depth, it is highly unlikely that vadose zone contamination has migrated from this crib to the SX Tank Farm.

As with the 216-S-25 Crib, it is possible that some of the water released at this site has migrated along the Plio-Pleistocene unit toward the SX Tank Farm if the Plio-Pleistocene unit is continuous in this area.

6.6 U Pond

The 216-U-10 Pond, commonly referred to as the U Pond, was the largest source of water in the southwest portion of the 200 West Area. This pond is located more than 1,000 ft northwest of the SX Tank Farm (the pond is not shown on Figure 2). It covers an area of 960,000 square ft and was operated from July 1944 until 1985. More than 43 billion gal of effluent was released at this site.

The pond was constructed on the ground surface by creating earthen dikes around the perimeter of the pond. Low-level effluent was released into the pond through a pipeline or a ditch and allowed to infiltrate into the vadose zone sediment.

This site received a large variety and types of effluent, including steam condensate, cooling water, chemical sewer waste, storm runoff, general wastewater, evaporator condensate, and other waste. Almost all of this effluent was classified as "low-level waste." In the Environmental Sites Database, the radionuclide inventory estimate for this site shows relatively low concentrations of radionuclides in the effluent.

The large volume of effluent released at the U Pond created a water table mound that had a controlling influence on the local groundwater flow direction and rate from the mid-1950s until it was decommissioned in 1984. Since the pond was decommissioned, the water table elevation has decreased.

No vadose zone monitoring is conducted at this or other retired facilities. In the past, a vadose zone moisture measurement tool could have provided the ability to track the movement of the moisture over time and distance. Because discharges to the U Pond were discontinued in 1985, the vadose zone moisture profile is considered to have reached steady-state conditions and is no longer moving. This profile could be confirmed with temporal field measurements of the moisture content.

Even though a large volume of effluent was released at this site, it is unlikely that it had any effect on the contamination distribution in the vadose zone beneath the SX Tank Farm. Given the current understanding of subsurface lithology, horizontal transport of the water over the 1,000-ft distance from the U Pond to the SX Tank Farm is unlikely. It is also unlikely that the pond contributed to the elevated moisture above the Plio-Pleistocene unit, because the Plio-Pleistocene unit is generally not continuous across long distances, as evidenced by outcrop studies.

The U Pond may be considered the most significant source of contaminants in the groundwater for the southwest portion of the 200 West Area. Some contaminants in the groundwater beneath the SX Tank Farm have originated from U Pond and may have commingled with contaminants from other potential sources (see Appendix B).

7.0 Spectral Gamma Logging Measurements

7.1 Equipment

The logging work in the SX Tank Farm was accomplished with two SGLSs designated for identification purposes as Gamma 1 and Gamma 2 (Figure 12). 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 drawings, software documentation, and specific component manuals, is available in the DOE-GJPO archive files.

Both logging units are completely self-contained systems composed of a downhole detector probe, a logging cable and delivery system, and surface computer electronics mounted in a cabin on the truck.

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 has recently become common for both laboratory and fieldwork because of advances in portable electronic systems and because of developments by the detection systems' manufacturers that made production of higher efficiency detectors more economical.

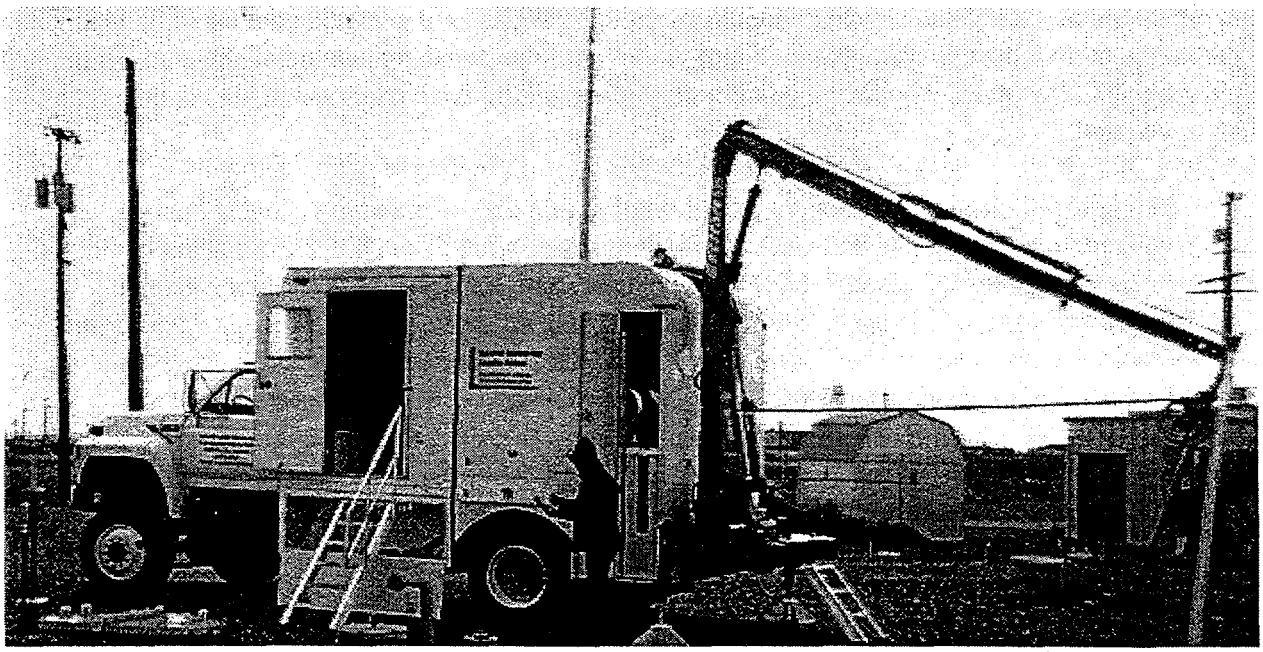


Figure 12. Spectral Gamma-Ray Logging System

The detectors, which are housed in downhole cylindrical probes, are mounted in a region of the housing with a decreased housing wall thickness that limits attenuation of the gamma-ray signal see Figure 13). The downhole probes also contain a high-voltage supply, a preamplifier, and a liquid nitrogen dewar and cryostat assembly. The liquid nitrogen dewar system is needed to cool the detector diode to liquid nitrogen temperatures. The dewar holds sufficient liquid nitrogen to allow logging for about 10 hours without refilling.

The probe 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 in the dewar vaporizes. The vent tube allows the downhole probe to be used in water-filled boreholes.

Probe movement is governed by a servo-controlled hydraulic winch that receives its control signal from the system computer. The probe position in the borehole is measured with a digital rotary encoder mounted on a sheave wheel hanging from a boom (see Figure 12). The boom is used to position the detector over the borehole.

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

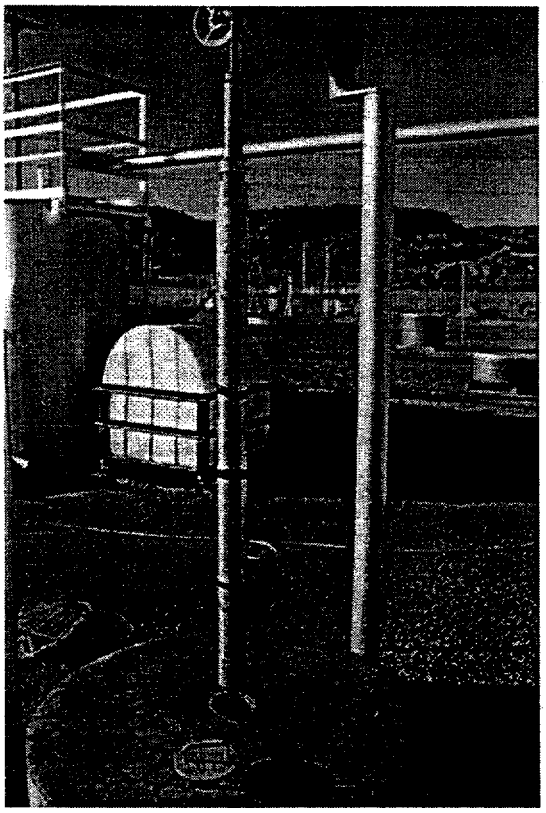


Figure 13. SGLS Downhole Probe

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

7.2 Calibrations

Calibration of the SGLSs is specified in a calibration plan (DOE 1994d) and reported in a calibration report (DOE 1995d). 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 with several processes that include a base calibration, biannual field calibrations, and daily field verifications.

The base calibration was completed in spring 1995 and included initial testing and qualification of the logging systems. This calibration was performed using the DOE borehole calibration models at the DOE-GJPO as standards. These models are concrete cylinders or monoliths with large homogeneous regions where the concrete is enriched with known concentrations of ^{40}K,

^{238}U, and ^{232}Th. Boreholes were drilled through the enriched zones so that a logging tool can be lowered into them. When a logging tool is placed in the middle of the zone of enriched concrete, the measurement geometry is such that a homogeneous, isotropic medium of known radioelement concentration is simulated. The response of the detector to the medium of the calibration zone is recorded, and the mathematical relationships between radioelement 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 concentration of man-made radionuclides that are not present in the calibration models, such as ^{137}Cs or ^{60}Co. Figure 14 presents an example of an efficiency 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 should be for a given formation radionuclide concentration. An environmental correction is applied to the efficiency function and the ^{40}K, ^{238}U, and ^{232}Th conversions to correct for the 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 be determined only once.

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

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 and before any logging operations began. This first field calibration is documented in the base calibration report (DOE 1995d).

Field calibrations are performed biannually at the DOE borehole calibration models at Hanford. They provide confirmation of the performance of the systems, ensuring the quality of data obtained between field calibrations and effectively closing the loop on the calibrations. The field calibrations are designed to quantify the system efficiency and the dead-time correction, because these items are subject to small changes over time and could be appreciably affected in the event of a logging-system malfunction.

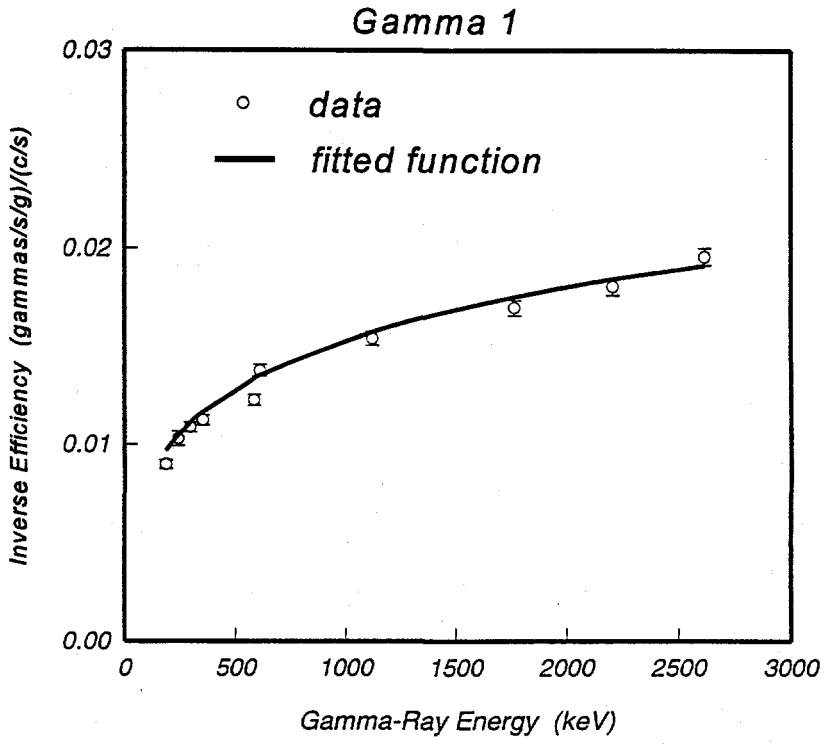


Figure 14. SGLS Base Calibration Inverse Efficiency Function

The field calibration models are essentially identical to the national standards in Grand Junction. They were constructed at the GJPO and eventually moved to Hanford 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 14. The dead-time correction is determined by measuring the system response in calibrations zones that have successively increasing radioelement concentrations.

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

In addition to the base and field calibrations, the performance of an SGLS is verified daily in the field, before and after production of log data. These field verifications are accomplished by recording the system response when the detector, housed in the downhole probe, is surrounded by a cylindrical-shaped gamma-ray source. By placing the detectors in a consistent geometrical relationship with a large, cylindrical field verification photon source, it is possible to verify the

efficiency of the system, as well as other performance factors, such as the energy resolution and system gain.

During the performance of logging at the SX Tank Farm, a significant database on the response of the SGLSs to the field verification sources had not been obtained. Therefore, system-performance acceptance criteria were not available for the field verification. Those criteria were developed after completion of the SX Tank Farm logging and are now being used as a quality-assurance measure that verifies system performance in the field.

Field verification data for the second field calibration were analyzed and are reported in DOE (1996b). These data show no trend over time, verifying the stability of the systems and consistent performance.

7.3 Logging Process and Procedures

The actual data acquisition or logging work is performed according to logging procedures (DOE 1995g). Adherence to these procedures ensures consistent and documented operation of the systems. These procedures do not specify actual data acquisition parameters, because those parameters may vary in the field according to the environment encountered by the logging engineers. 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. Logging procedures specify that all data acquisition parameters are recorded on Log Data Sheets so that the borehole-specific data acquisition parameters and borehole construction information are documented and available for data analysis and interpretation.

Field observations of the borehole conditions are needed for data analysis. Such things as borehole extension above ground surface (if any), casing thickness, number of casings, casing dimensions, etc. are recorded on the Log Data Sheets. Often the casing information cannot be determined in the field because most boreholes have a grout collar covering the casings making it impossible to see the edge of the casing. Also, many casings have been hammered down so the upper edge does not reflect the true casing thickness. As a result, the analysts usually use the published value of the casing thickness for schedule-40 steel pipe. Log Data Sheets are provided to the analysts along with the gross gamma-ray log data.

Logging proceeds after an initial instrumentation warm-up time period and after completion of the presurvey 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 for proper definition of thin zones of contamination, yet it is not overly time consuming or costly.

If high contamination is encountered and the detector dead-time (the time under which the detector is busy processing pulses) increases to a level greater than about 80 percent, the logging engineer will generally change to a real-time logging mode. Although a real-time logging mode was used in zones of high radioelement concentration, the system became saturated and was

unable to record data. Above about 10,000 pCi/g ^{137}Cs concentration, the SGLS becomes saturated and log data cannot be obtained with the current high-efficiency detectors.

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 radioelement concentration.

Each time the system computer is set with specified data acquisition parameters and an automated data acquisition process is executed, it is called 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 transported to the field office, and the data are transferred to the main computer database maintained in the office according to the Records Management Plan (DOE 1995i). Log Data Sheets are completed as the borehole is being logged and are also transferred from the field to the office. Data on the Log Data Sheets are entered into a Paradox database created specifically for 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 1994e) and in the logging procedures (DOE 1995e). All data acquisition operations are governed by a project-specific Quality Assurance Plan (DOE 1996e). The reader is referred to those manuals and other referenced material for more specific information about the characterization project.

7.4 Data Management

All data and records are managed as specified in the Record Management Plan (DOE 1995i). 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 Record Management Plan provides guidance and governs the management of project records from creation to final disposition. This guidance ensures that project records are

- Created, identified, and inventoried.

- Indexed and incorporated into the Vadose Zone Characterization Project Document Log, according to the Vadose Zone Characterization Project File Index specified in the document.

- Controlled to protect against loss, damage, or unauthorized access.
- Retrieved efficiently.
- Disposed of, archived, or transferred according to applicable requirements, procedures, and DOE orders.

The Record Management Plan specifies management requirements for all data, reports, memoranda, and miscellaneous information and governs recording and retention of the data and records, copying data to the computer database, and management and retention of the database. The Record 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 to accurate concentrations. The radionuclide concentration data are put into a log profile format and then plotted.

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

Figure 15 shows a flowchart of the data analysis process that is also provided in the Data Analysis Manual (DOE 1996c). The office computer system consists of five data analysis work stations interfaced with a central server system that contains several gigabytes of nonvolatile memory. Data are copied from field optical disks to hard disk memory on the server according to procedures and protocol discussed in Section 7.4.

Analysis begins by converting all the raw *.chn spectra files into a format that can be read by the spectrum analysis software. 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 as designated by the analyst. These parsed data are put into individual peak files that show the count rate versus depth. One file is created for each nuclide or photon peak, and each file contains the data from all the spectra for that 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 1994d). 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.

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

Statistical uncertainties in logging and calibration data 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. The uncertainty estimation calculation method is provided in detail in the base calibration report (DOE 1995d).

The MDA is also plotted with the concentration values. Calculation of the MDA is described in the Data Analysis Manual (DOE 1996c). The MDA 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 record 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 includes information about the borehole construction and configuration and about how the borehole was logged (log run information). It also includes information about the data analysis process and provides a description of the log plots. The Log Data Report is provided with 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 a permanent data storage as specified in the Data Analysis Manual.

This short synopsis of the data analysis process shows some of the complexities involved with data analysis. The data analysis process is documented in greater detail in the Data Analysis Manual.

Additional work related to analysis of spectrum shapes is currently underway. Theoretical calculations have shown that it may be possible in many cases to identify the location of mono-energetic ^{137}Cs from the shape of the spectrum. 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 through the formation. Shape factor analysis is planned for implementation in Fiscal Year 1998.

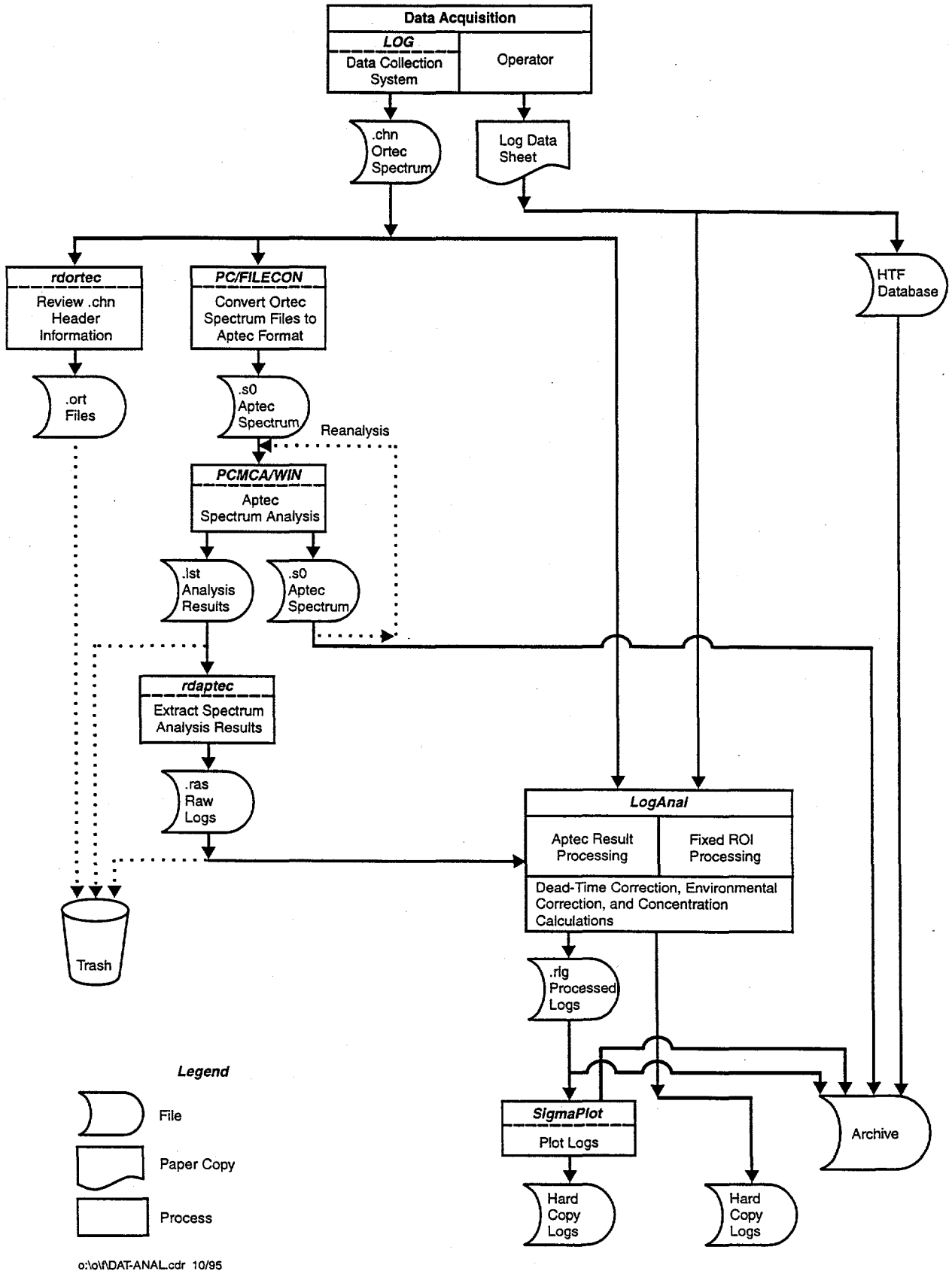


Figure 15. Data Analysis Process

8.0 Log Data Results

8.1 Instrumentation Performance

The two logging systems (Gamma 1 and Gamma 2) logged a total of 95 boreholes within the SX 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 station intervals. In regions where the gamma-ray flux was high, the high-intensity zone was approached from above and below to measure as much of the zone as possible before the equipment became saturated.

The instrumentation was calibrated in the base calibration (DOE 1995d) before logging began in the SX Tank Farm, and it was recalibrated 6 months later in the first biannual recalibration (DOE 1996a). 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. Because this was the first field verification process established for the instrumentation, no acceptance or rejection criteria were available. After developing a history of the performance of the instrumentation, such criteria were developed and are now being used in the field to demonstrate system performance.

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 analysis of the spectra.

Some variation occurred during data analysis regarding the actual casing thicknesses of the boreholes. Often the surface of the casing was obscured by a small concrete pad placed around each borehole, and sometimes the casing thickness recorded in the field appeared to be incorrect. However, the borehole casing thicknesses used to correct the data were always recorded on the individual Log Data Reports (provided with the logs in Appendix A of the Tank Summary Data Reports), and the conversion from count rate to concentration can always be recalculated with another casing thickness.

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

The MDA for ^{60}Co is about 0.15 pCi/g, and the MDA for ^{154}Eu and ^{152}Eu is about 0.2 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 (1) the peak identification routine of the spectrum analysis software detects a peak, (2) the peak area is statistically above the MDA value, and (3) the peak is confirmed with a less intense peak for multiple photon nuclides. When a peak is detected, its count rate is automatically converted to an equivalent concentration value in picocuries per gram.

In the SX Tank Farm, the most abundant gamma-emitting radionuclide contaminant in the vadose zone by orders of magnitude was ^{137}Cs. Concentrations of ^{137}Cs were detected in almost every borehole. Other nuclides detected were ^{60}Co, ^{152}Eu, and ^{154}Eu, but these nuclides were generally detected near the surface as a result of surface spills. ^{60}Co was measured only in one borehole, 41-14-06, where it occurred from the bottom of the tank at the 55-ft depth to about 76 ft below ground surface.

In many instances a small photon peak was measured or suspected, but the peak was not recorded because it did not satisfy the detection criteria. If a man-made radionuclide is actually present, it can only be present at extremely low concentrations.

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. Each borehole has a set of logs that includes 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 along with the total gamma log and the historical gross gamma-ray log from the Tank Farms logging system.

Each set of logs also includes a Log Data Report. The Log Data Report provides 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 individual logs do not provide enough information with which to assess the data; consequently, anyone who reviews these 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 tank are provided in the appendix of the Tank Summary Data Report for the individual tank. Simplified versions of the man-made contamination logs for each of the boreholes are provided in Appendix C of this report. These plots contain the man-made contamination logs from 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 on the vadose zone characterization computer database. These data will eventually be transferred to other Hanford databases to make the information more readily available.

8.4 Tank Summary Data Reports

A Tank Summary Data Report was prepared for each tank in the SX Tank Farm. Each document reports the results of the spectral gamma logging and allows the analyst to place the data into the context of the documented tank history. The purpose of the Tank Summary Data Report is to give nontechnical personnel an understanding of the effect that the various tanks had on the vadose zone sediment.

In addition to the log plots for the boreholes surrounding the tank, a Tank Summary Data Report provides a discussion of each borehole and 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 in the Tank Summary Data Reports shows the contamination logs 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 a particular tank appears to be a source of contamination, that conclusion is stated in the Tank Summary Data Report.

In general, the Tank Summary Data Reports provide a summary of the work, an assessment of the conditions of the vadose zone, and an analysis of the relationship between the vadose zone contamination and the tank. Individual Tank Summary Data Reports are listed in Section 15.0 of this report.

9.0 ^{137}Cs Contamination Model Development

It was desirable to create a visualization of the vadose zone contamination distribution beneath the SX Tank Farm and to make that visualization available by publishing it in this report. Such a visualization can be used for many aspects of the farm operations and management, as well as for the tank remediation programs. Visualization of contaminant distribution is a key product of the vadose zone characterization effort.

Creating a visualization requires developing a model of the ^{137}Cs contamination distribution, the only gamma-emitting contaminant 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 emperical model has errors and inaccuracies–some that are known, and some that may not be known. Explanation about the known and possible errors and inaccuracies are necessary so that users of the model can determine the potential significance or relevance of the contamination model to their concerns.

To develop an empirical model, a mathematical relationship or correlation between discrete data points must be determined. It is necessary to answer the question "Can two data points be correlated?" Therefore, 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 SX Tank Farm.

The best way to correlate discrete data points is to use the tools provided by geostatistics. Geostatistics is simply an analysis and application of the spatial variability of data. It is an empirical analysis of the data and an application of the results of that 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 the model.

The radionuclide concentration data that constitute the spectral gamma-ray log data reported in the Tank Summary Data Reports for the SX Tank Farm were placed in data files that defined the position in space of each data sample point and the nuclide-specific radioelement concentration for that point. At the SX Tank Farm, the most abundant gamma emitting contaminant is ^{137}Cs. Other nuclides were were not abundant enough to be used to define the leaks or distribution of contamination. Therefore, the contamination model was based only on the ^{137}Cs distribution, and the visualizations consist of only the ^{137}Cs contamination.

9.1 Geostatistical Structural Model

The first stage in developing an empirical model of the ^{137}Cs contamination was to determine the geostatistical structure of the data by performing a geostatistical structural analysis. A geostatistical structural analysis answers the question "Can two data points be correlated?" and quantifies the quality of the correlation.

The EVS software performs the geostatistical structural analysis by calculating three-dimensional variograms that are plots of the variance of the data versus 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 changed to produce the most representative geostatistical structure on the basis of the information available to date.

The total domain of the calculations included all vadose zone boreholes within the SX 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 versus distance between data point pairs. Once the variances were calculated, the EVS program fit the data to a spherical model with a least-squares fitting algorithm. The spherical model defines the geostatistical structure. The general equation for a spherical variogram model is

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

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

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.

Horizontal isotropy is assumed, but separate variograms were produced for the horizontal and vertical directions. Initial calculations were made with a horizontal- to vertical-anisotropy of 10. This value produced variograms with large differences between horizontal and vertical ranges and high variances for the sill values. Applying lower horizontal- to vertical-anisotropy ratios produced results with more realistic ranges and lower sill values. Through a trial and error process, the anisotropy ratio was changed to 7, meaning that the horizontal continuity is 7 times greater than the vertical continuity. This adjustment produced lower sill values and horizontal and vertical ranges that better represented the contamination distribution.

During the variogram calculations, the program was allowed to let the Z axis symmetry vary from the vertical direction. The principal component axis that resulted was a structural model with a Z axis that had an angle 0.56° from the vertical. This low principle component axis angle indicates there is almost no deviation from the vertical of the principal axis. This low angle may be a result of the manner in which the sediment was originally deposited and the contamination transport mechanisms.

The calculated variogram that was used to represent the geostatistical structure in the horizontal direction had a range value of 239 ft and a sill value of 1.64. In real terms, the range is multiplied by 7 (the anisotropy factor) to produce 1,673 ft, which is the distance at which the correlation of two data points is strictly random. Figure 16 presents an example of the variogram used as the structural model.

The range of the vertical variogram was also calculated to be 239 ft, but it had a slightly higher sill value of 2.05. This range shows a spatial relationship between two data points to 239 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 0.56° from the vertical, proving that the assumption of horizontal-to-vertical anisotropy is a good assumption and that the horizontal axes are isotropic.

The geostatistical structural analysis produced the equations for the variograms that were used to define the ^{137}Cs contamination concentration model.

9.2 Three-Dimensional Plume Calculation and Visualization

The kriging process calculates mean grade, or in this case, radioelement concentration 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 radioelement concentration for the volume being investigated.

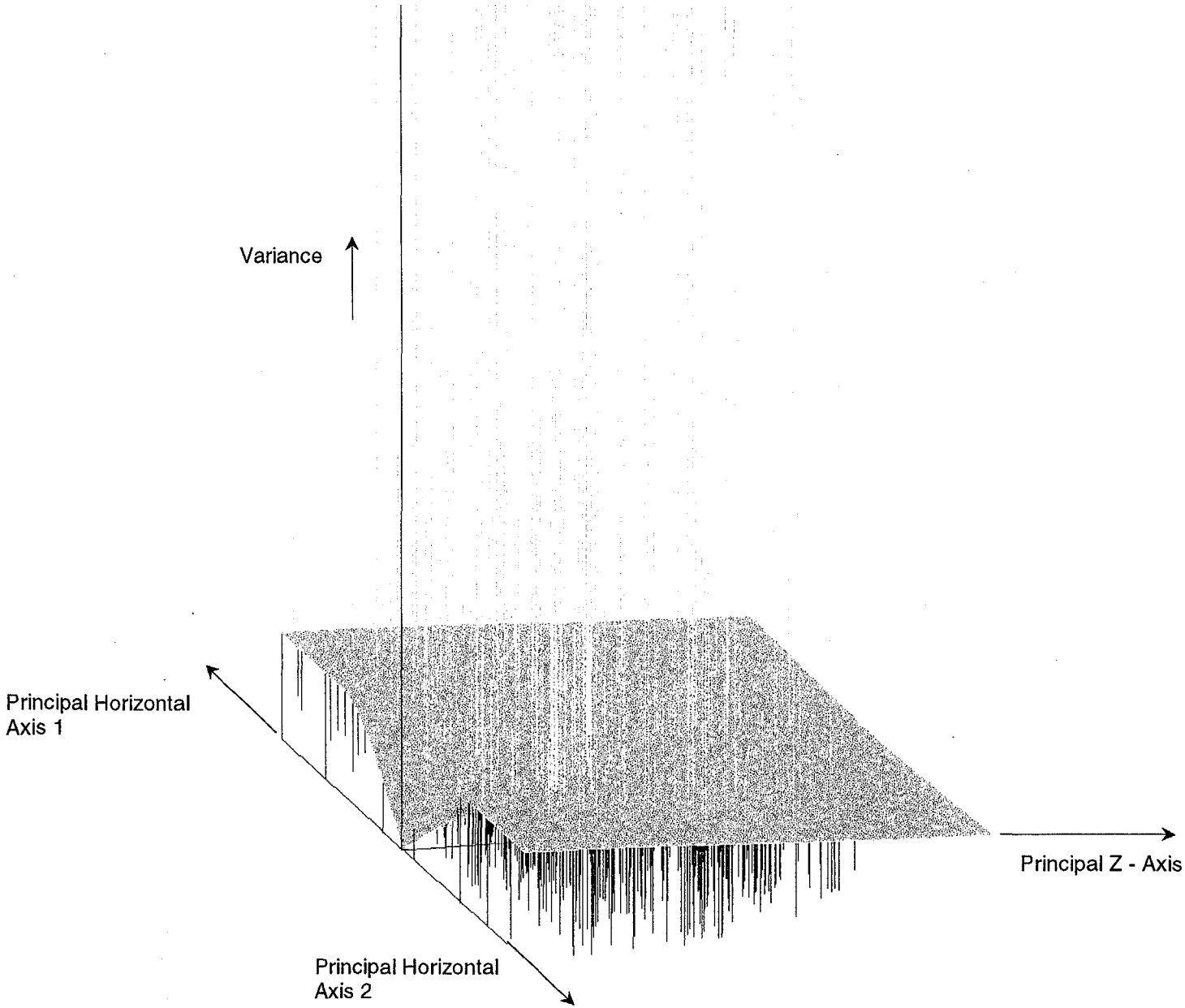


Figure 16. Variogram of the ^{137}Cs Contamination Distribution Model

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

The ^{137}Cs concentration model developed for the SX Tank Farm characterization encompasses the entire tank farm to the depth of the deepest boreholes (140 ft). Adaptive gridding, which was used in these calculations, produces a grid point at every data sampling point where a spectrum was recorded. The gridding process sets up nodes at all data sampling locations and calculates the radionuclide concentration for each grid block.

The kriging process used a maximum reach of 423 ft or a maximum of 10 data points in the calculation of the concentration at every point. The horizontal- to vertical-anisotropy ratio of 7 placed 7 times the emphasis on points within the horizontal plane of a grid point. In that manner, the influence of data points from other boreholes was 7 times greater than data points from within the same borehole as the calculation point. This emphasis helped decrease reliance on data from the same borehole and minimized the potential for a misinterpretation when contamination may have 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 radioelement 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.

Similarly, in regions where the radioelement 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.

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 based on the uncertainty. These data were then fed into the visualization portions 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 out 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 plus 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 requires a cut section

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 so that 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 far close to the actual distribution, except for areas where there are few boreholes.

For most of the discussion presented in Section 10.0, the lowest level of contamination visualized, the "isolevel," is 0.5 pCi/g. It was discovered that ^{137}Cs concentrations as low as 0.5 pCi/g are significant in terms of identifying a tank leak or a leak source. Below 0.5 pCi/g, the data have too high an uncertainty to be used to track the plumes, and there is a strong possibility that low-level contamination has migrated down the inside of the boreholes, thereby creating false plumes.

Minimum and maximum plume pictorials show what is within 1 standard deviation of the mean concentration estimation. These visualizations show the statistical minimum and maximum extents of the plumes on the strict basis of mathematically observed distribution statistics (i.e., the geostatistical structural model).

Visualizations that are based on the mean estimation data were prepared. The program also calculated the uncertainty associated with mean estimation for each block, and maximum-minimum plume pictorials were prepared. Maximum and minimum plume calculations show what could be expected for the plumes in terms of the greatest and smallest extent of contamination that could be expected.

All visualizations are presented in color and 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 an animation requires too much media memory space, but that type of visualization may be available later on a Hanford database.

9.3 Potential Model Uncertainty and Inaccuracies

The visualizations presented in this report are based on assignments of ^{137}Cs 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 bad data are used as input to the calculations, inaccuracies will result in the model. With proper interpretation of the 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 emperical analysis method and the calculated error estimation is also emperical, the maximum-minimum plume visualizations should provide a good representation of the potential grade assignment error. It would be desirable to have a more rigorous geostatistical structural analysis. 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 of several lines of closely spaced boreholes and construction of variograms that are based on only those data. Future assessments may help to refine and to validate the variograms that are the basis of the geostatistical structure of the data.

There is no mechanism to include the uncertainty estimation for the assays at the individual data points. The assay uncertainty estimation calculation is discussed in the base calibration report (DOE 1995d) 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 the individual assay uncertainty estimations 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 of the ^{137}Cs contamination model is that the contamination is actually not distributed within the sediments but is on either the inside or the outside of the borehole casing. At the beginning of model development, an assumption is made that all contamination is distributed within the formation and the EVS software simply processes the data as if the apparent concentration is 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 is 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. Potential problems with each plume are also identified and explained in Section 10.0 in an attempt to understand the limitations of the model.

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 very 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.

A solution to this problem would be to generate and insert random numbers above 8,000 pCi/g into the database for the saturated regions as the radionuclide concentration value and rerun the structural analysis. The concern with this solution is when a horizontal- to vertical-anisotropy factor is applied to the data, the assignment of a random number would have the effect of destroying any horizontal correlation and defeating the purpose of developing a model.

A single value was applied to the saturated regions because a spherical model was used to model the geostatistical structure and the spherical model does not have a zero spacing variance. Therefore, the addition of multiple closely spaced data points with zero variance should have a minimal effect on the spherical variograms. Other methods of treating this type of data will be explored for future Tank Farm Reports.

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 being able to perform the data acquisition for all the boreholes in the SX Tank Farm in a cost-effective manner, and being able to detect contamination at low concentrations while still doing a reasonable job of characterizing the high-contamination zones. Some Tank Summary Data Reports identified zones within the SX Tank Farm that may need relogging with a very high-efficiency detector to identify previously unknown contamination zones. In addition, many zones of very high concentrations of radionuclides need to be logged with shielded, low-efficiency detection systems if it is desired to quantify the actual concentration. The current contamination distribution model does not include gamma-emitting radionuclides that are less than the detection levels realized with the data acquisition configuration explained in Section 7.0 of this report.

The calibration of the logging system assumes a homogeneous medium of contamination that is infinite in horizontal and vertical extents. If the contamination is not on the inside or the outside

of the borehole casing as previously discussed, this assumption is valid for all situations except at the very top and the very bottom of the borehole or where the concentration changes rapidly with depth. The data acquisition interval used to log the SX 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 are discussed in Section 10.1, "Surface and Near-Surface Contamination."

At the bottom of the borehole, most of the boreholes are open and in direct contact with the sediment. As a result, the photons produced within the hole bottom sediment are not attenuated by a casing, but a casing attenuation factor is applied to these data. The reported apparent concentration may therefore be slightly high at the bottom of the borehole.

It must be understood that the inaccuracies of the data used for the model have the potential to cause inaccuracies in the model. Those 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 operation measured the gamma-emitting radionuclide concentrations near the surface when the detector was centered at the 0-ft depth location in the boreholes. Radionuclide concentration values measured at the surface are not accurate for two reasons. The calibration of the logging systems makes the assumption of a homogeneous infinite medium, but this is not the case when the detector is at the surface. Instead, there is only an infinite geometrical half space with gamma rays originating from the formation only on 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 formation material. If there is an appreciable amount of contamination on the surface, which appears to be the case, the reported radionuclide concentration would therefore be higher than what is actually present in the formation.

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

Because the contamination model was developed without attempting to correct for this collar 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, the model is useful for identifying major zones of contamination, and the data are precise and correct relative to other locations within the SX Tank Farm.

Figure 17 presents a visualization of apparent surface contamination for the SX Tank Farm. Note that the visualization shows that the entire surface of the farm has contamination at levels of at least 5 pCi/g and up to about 3,000 pCi/g. ^{137}Cs logs from each of the boreholes (Appendix C) show the apparent concentration levels near the surface.

It is now known from a survey of the surface of the SX Farm (Arthur and Stromswold 1996) that contaminated structures on the surface of the farm are providing the primary source of gamma-ray photons that were detected when the detector was located at surface depth in the boreholes. As a result, the gamma-ray signal from the contamination that was actually in the sediment near the surface was probably lost in the high-intensity noise from the surface structures.

Two high-activity regions were located. One area extends over the top of tank SX-108 to the area between tanks SX-108 and SX-111, near the area where ^{137}Cs contamination was detected deep in the vadose zone. This correlates with the activity of the surface survey and is attributed to the surface ventillation duct work. This does not preclude the possibility that there are also higher levels of contamination in the sediment in this area.

Another high activity zone was detected on the west side of the farm between tanks SX-112 and SX-115. This too correlates with the surface structures and ductwork contamination.

The ^{137}Cs gamma-ray logs and the model developed from them show that the surface contamination has generally migrated downward from 10 to 20 ft below the ground surface. This distribution is apparent in the log profiles and in the visualizations presented in Section 10.2. Of course such a general statement has numerous exceptions, particularly when consideration is given to the possibility that the boreholes may have enhanced the vertical migration of contaminants down the outsides of the boreholes. Several possible cases of borehole migration of contaminants were identified in the Tank Summary Data Reports.

An example of a case where contamination may have moved down the borehole is shown in the gamma-ray log from borehole 41-02-02 (Appendix C) and visualized in Figure 18 (see Figure 11 for the location of borehole 41-02-02). The log and the visualization each show almost continuous contamination from the surface down to about 75 ft. It is possible some of the contamination from the surface has migrated down this borehole and commingled with subsurface contamination below the base of the tank.

However, much of the emphasis on contamination moving down the outside of the casing may be overemphasized. The cable-tool drilling process is completed in the Hanford formation with a minimal amount of open hole because the Hanford formation sediments are not cemented and do not hold together under the continual pounding of the cable tool rigs. This is particularly true of the backfilled sediment around the SSTs. By the time a 75-ft borehole is drilled, gaps around the casing near the ground surface probably would have collapsed and been filled in with the loose, disturbed excavation-backfill sediment.

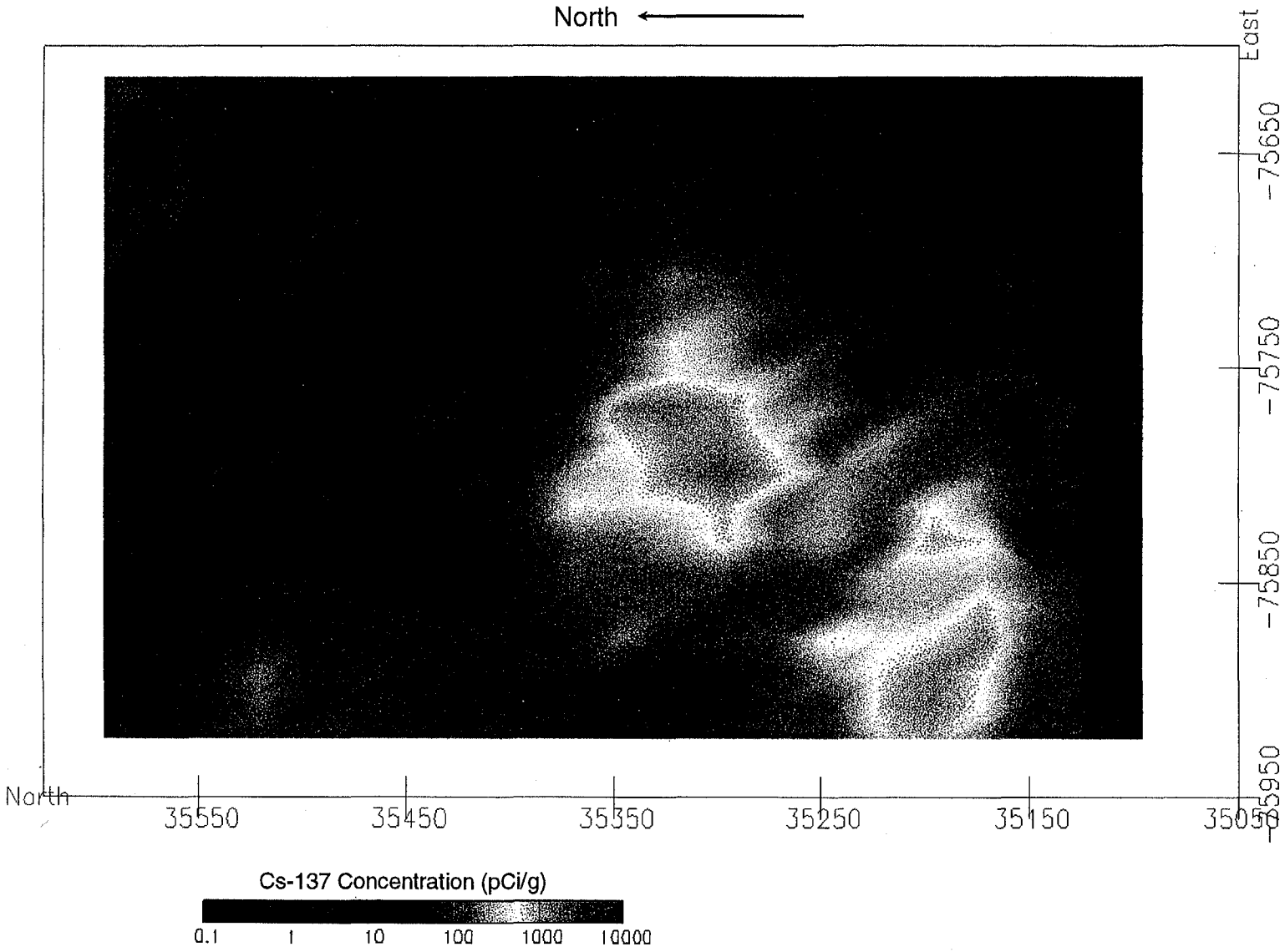


Figure 17. Visualization of Apparent Near-Surface ^{137}Cs Contamination at the SX Tank Farm

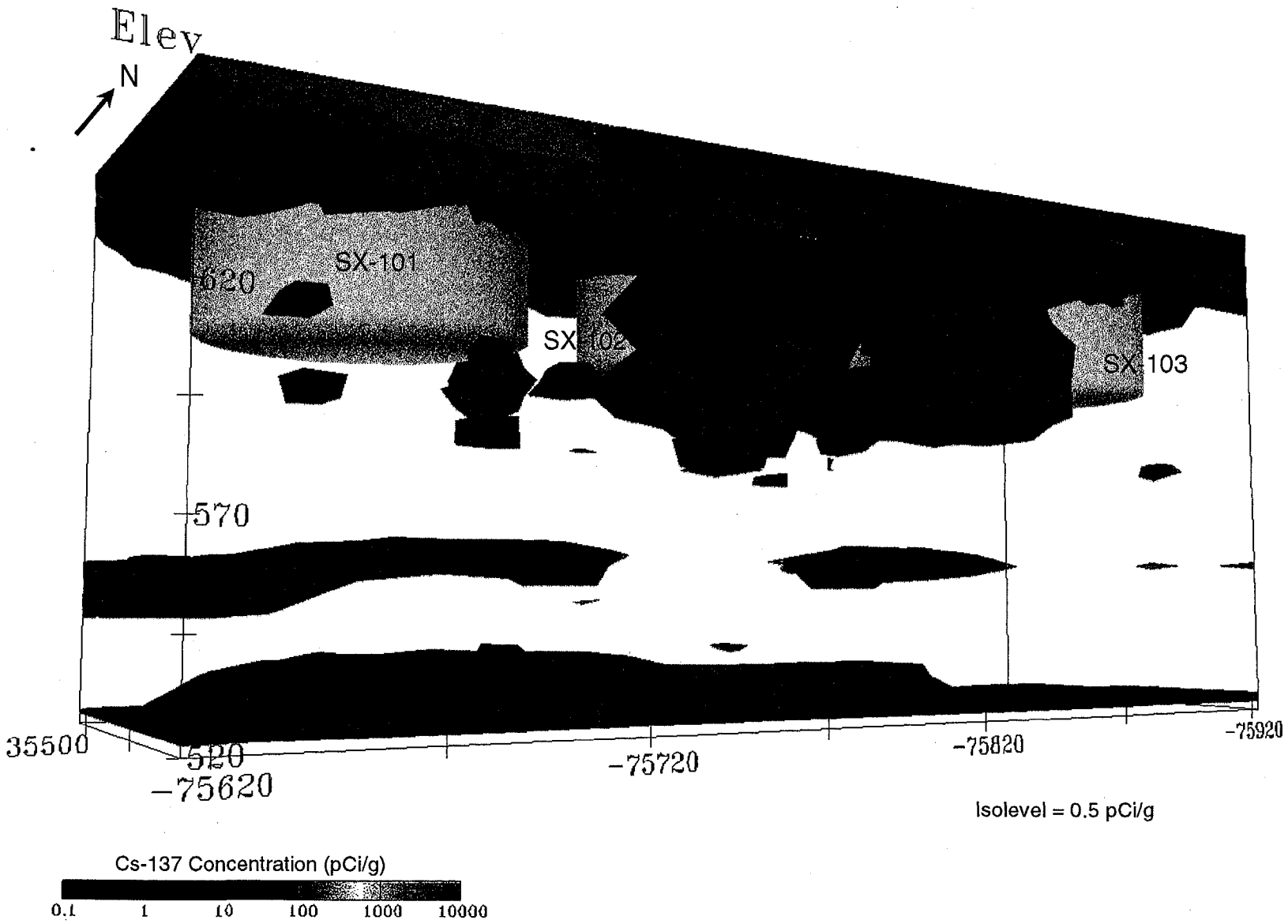


Figure 18. Visualization of Tanks SX-101, SX-102, and SX-103 ^{137}Cs Plume Viewed From the Northeast

In addition, all the boreholes have a surface collar that was put in place after the boreholes were drilled. Any gap between the sediment and the casing would have been filled either by sediment falling down the gap when the collar excavation was dug or by the concrete grout when the collar was poured. It is assumed that the borehole installers did not disregard the potential for contamination movement down the hole and that some care was therefore exhibited in preparing the boreholes.

Under normal unsaturated flow conditions, a gap between the formation and the borehole would inhibit contamination movement rather than promote it. If contamination is to move from the surface down the outside of a borehole, it must be driven by flowing water. In other words, it must occur by pooled surface water that drains from the surface of the farm.

Regions where contamination was actively migrating downward from the surface have not been identified in the gross gamma log data recorded for the past 20 years at Hanford. Contamination that was detected near the surface with the gross gamma logging system has been relatively stable and has not migrated any significant distance. The database extends from the early 1970s to the late 1980s.

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 primary gamma-ray photon peak and the low-energy Compton continuum. When ^{137}Cs is uniformly distributed in the formation, a low shape factor will result because more Compton downscattering would occur within the formation, causing an elevated low-energy continuum. When ^{137}Cs is only distributed on the outside of a borehole casing, a high shape factor will result because there would be a minimal amount of Compton downscattering. A shape factor analysis may provide a more conclusive identification of regions in a borehole where it is suspected that ^{137}Cs is not in the formation and has simply migrated down the borehole casing.

10.2 Tank-by-Tank Discussion

This section presents discussions about the status of each tank in the SX Tank Farm and specific visualizations of the contamination in the vadose zone. Figure 11 shows the locations of the boreholes that provided the data for the visualizations. Appendix C contains the man-made contamination logs for all the boreholes. Individual Tank Summary Data Reports include complete gamma-ray logs for boreholes in the vicinity of specific tanks and a more comprehensive review of the log data.

10.2.1 Tank SX-101

Tank SX-101 is listed as a sound tank with no detected leaks. It currently contains about 146,000 gal of drainable liquid (Hanlon 1996) and is monitored with moisture detection instruments inside a LOW.

Figures 18 and 19 show the contamination distribution in the vadose zone; these views are from below the tanks from the southeast and from the northeast, respectively. A cut face was placed in the visualizations on the south side of the tank between the first row of tanks (SX-101, SX-102, and SX-103) and the second row of tanks (SX-104, SX-105, and SX-106) to show the contamination from the south (see Figure 11).

The deep, low-level contamination plume shown in Figures 18 and 19 at about 530 ft elevation may be the result of low levels of contaminated sediment that blew down the inside and settled at the bottom of the boreholes. All monitoring boreholes in the SX Tank Farm were cut-off flush with the ground surface and many have had the borehole caps destroyed or missing for some time making it plausible that contaminated sediment was blown into the boreholes. This created a "false plume" at the elevation corresponding to the 75 ft bottom depth of the boreholes. The plume shown in these visualizations probably does not exist within the sediment in that region beneath the tanks.

The plume on the south side of tank SX-101 (see in Figure 19) is defined by the data for borehole 41-01-06 (Figure C-1 in Appendix C). Because this borehole log shows continuous contamination from the surface down to 55 ft or just below the base of the tank, this plume may be the result of surface contamination that moved down the outside of the casing and probably does not represent a leak from the tank.

The plume just below the base of tank SX-101 on the west side (see Figure 18) is identified in the log for borehole 41-01-10 (Figure C-1). This plume correlates with the contamination from borehole 41-02-02 and, therefore, indicates it have emanated from tank SX-102.

There is no clear evidence of a subsurface contamination plume that originated from tank SX-101. There is evidence that some of the deeper contamination around this tank may have come from the surface by falling down the inside of the casings or by flood migration down the outside of the casings. A spectral-shape factor analysis would be beneficial in attempting to interpret some of the log data from the boreholes around this tank.

10.2.2 Tank SX-102

Tank SX-102 was listed as a leaking tank for a short time in 1993 on the basis of a liquid-level decrease measured in a LOW. However, the tank was reclassified as sound after reanalysis of the data and an assessment of evaporation thermodynamics suggested the tank had not leaked.

This tank received a variety of waste types from 1954 to 1971, including REDOX waste. Several liquid-level increases and decreases were noted in the 1970s, but apparently no significant or notable decrease was sufficient to determine the tank had leaked.

The ^{137}Cs contamination distribution beneath tank SX-102 is shown on Figures 18, 19, 20, and 21. Figure 20 shows a view from below of the first row of tanks from the southwest. Figure 21 provides a view from below from the northwest. As with Figures 18 and 19, a vertical cut face was placed in Figures 20 and 21, between the first and second row of tanks (see Figure 11).

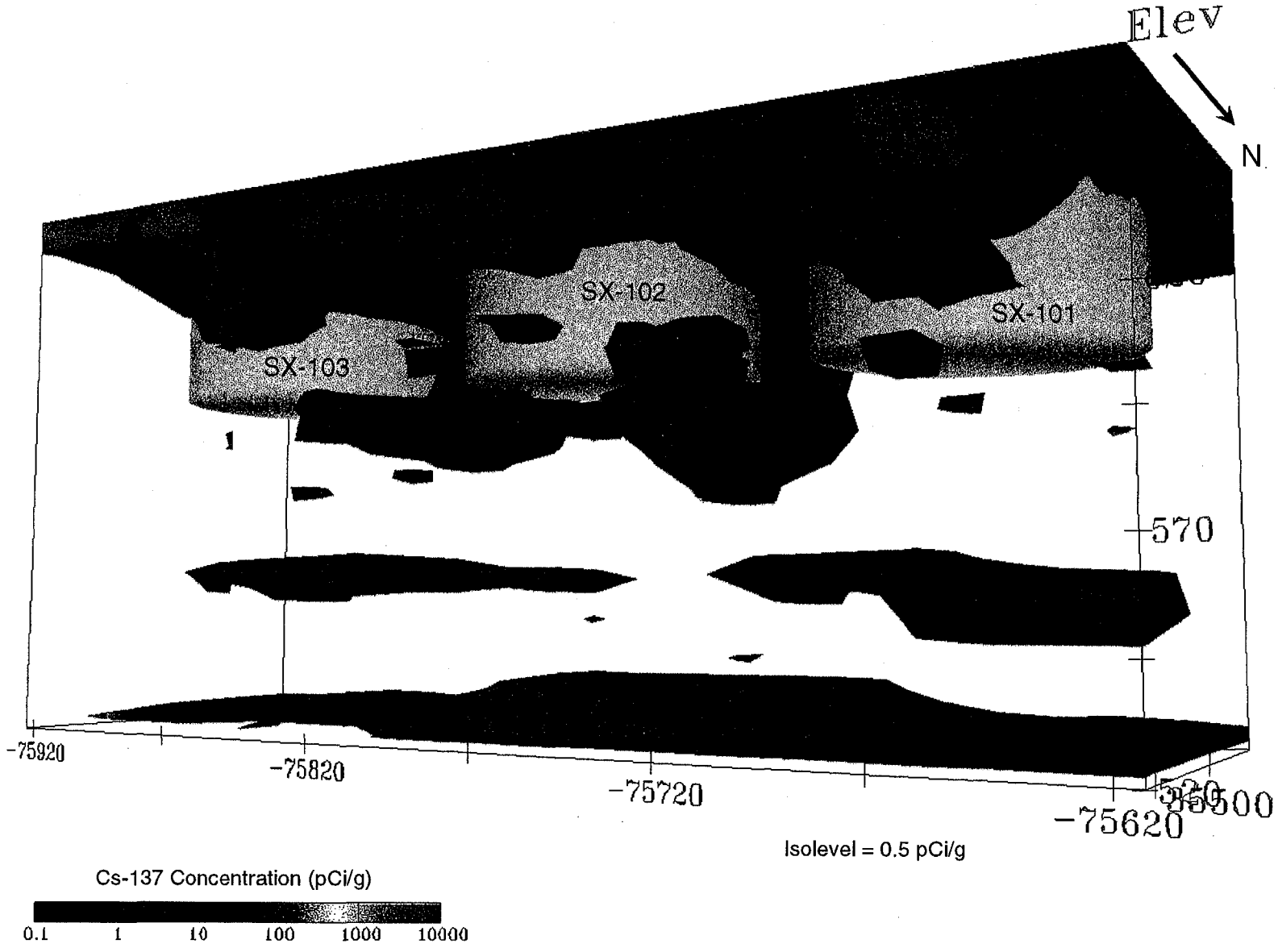


Figure 19. Visualization of Tanks SX-101, SX-102, and SX-103 ^{137}Cs Plume Viewed From the Southeast

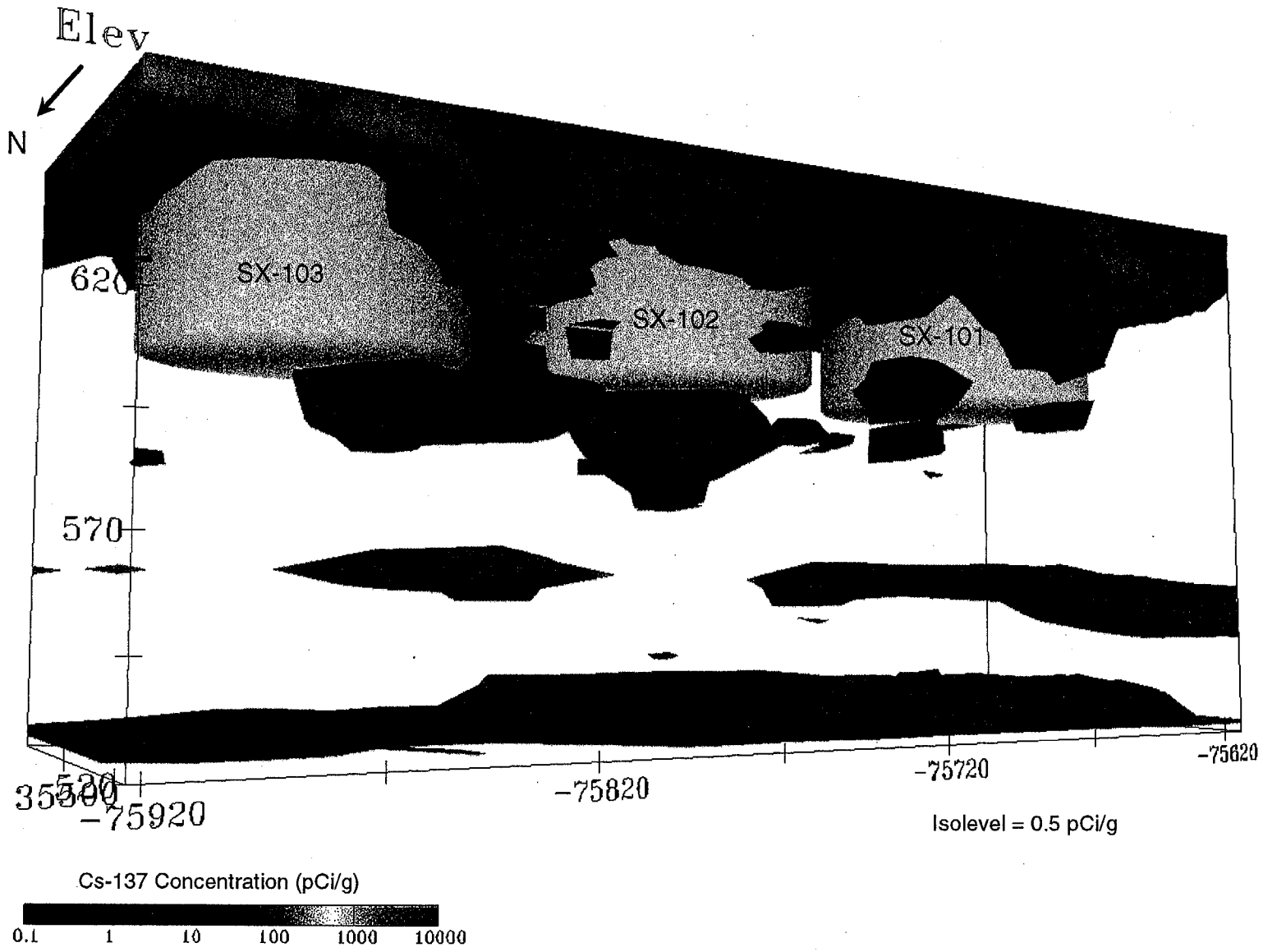


Figure 20. Visualization of Tank SX-102 ^{137}Cs Plume Viewed From the Southwest

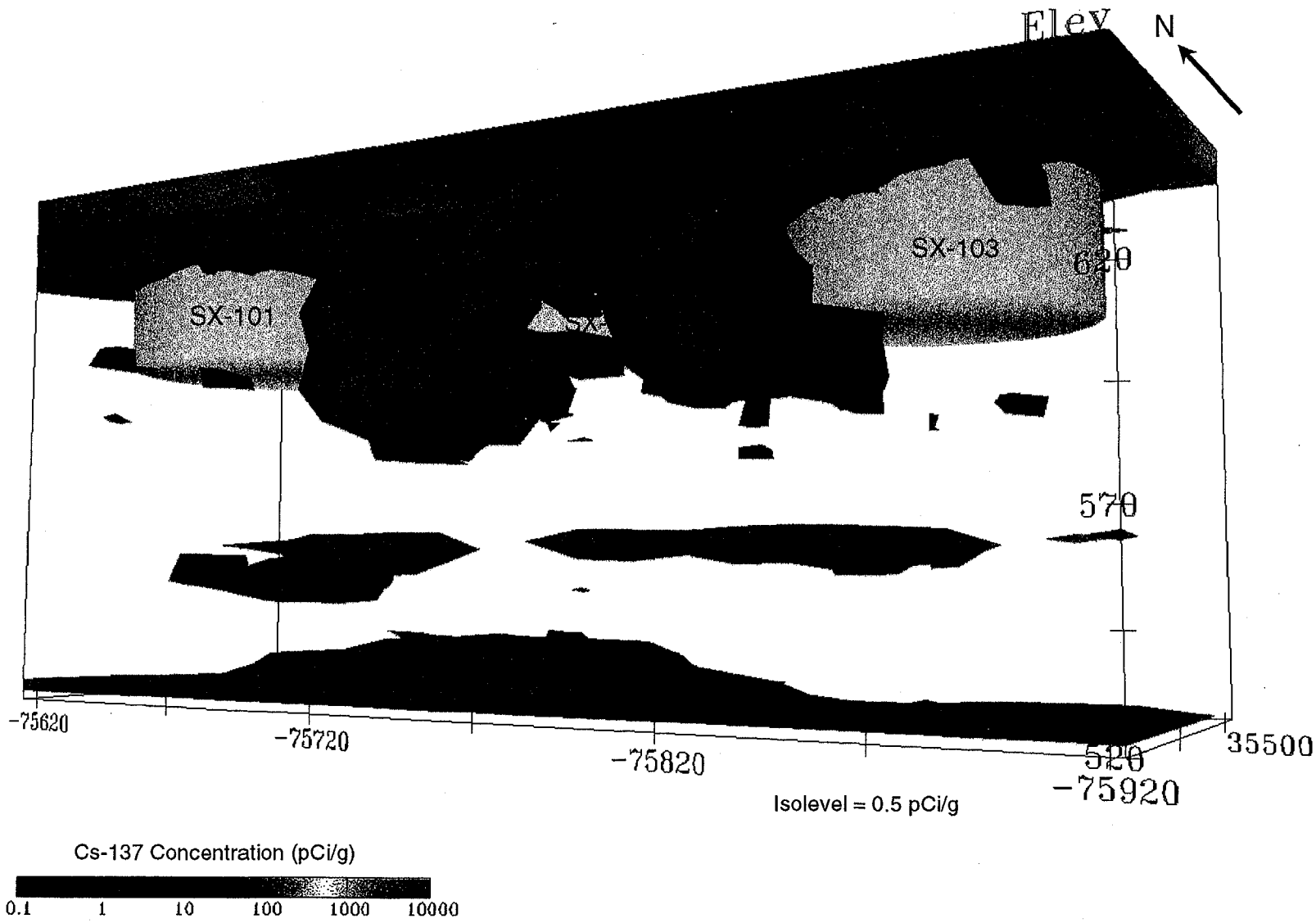


Figure 21. Visualization of Tanks SX-102 and SX-103 ^{137}Cs Plume Viewed From the Northwest

All four visualizations show fairly extensive plumes under the north and the northwest portions of this tank. As stated in the Tank Summary Data Report for this tank (DOE 1995l), the contamination probably extends across the entire bottom of the tank and is the cause for the elevated activity in borehole 41-02-08 at the 50-ft depth, as shown in Figure 21.

An initial spectral-shape factor analysis of the data for borehole 41-02-02, on the northeast side of the tank, was completed as an experiment of this type of analysis. That assessment revealed that some deposition of contamination may have been local to the borehole (i.e., on the outside of the casing). The assessment also revealed that the total gamma anomaly at 50 ft in this borehole may not be caused by ^{90}Sr, as reported in the Tank Summary Data Report. The anomaly is probably caused by a zone of high-concentration ^{137}Cs that is located remote from this borehole. This interpretation will be reassessed and documented when the shape-factor analysis process is completed.

The contamination detected in the vadose zone beneath this tank suggests that this tank had leaked at some time in the past and that the leak created the two plumes beneath the tank seen on the north side of the tank in visualizations presented in Figures 19 and 21. These plumes may be the result of more than one leak. The leaks probably occurred before the mid-1970s because the gross gamma anomalies measured in these boreholes have remained essentially stable.

This tank still contains about 183,000 gal of drainable liquid (Hanlon 1996) and is monitored in the tank through a LOW and with an ENRAF gauge.

10.2.3 Tank SX-103

Tank SX-103 is designated as a "sound" tank. It was first used in 1954 to store nonboiling REDOX waste. Numerous occurrence reports are associated with this tank regarding either increases or decreases in the liquid level. All liquid-level fluctuations have been attributed to instrument malfunctions, waste surface irregularities, or evaporation; no other monitoring method has reported results that suggest the tank might be leaking.

The contamination around tank SX-103 can be viewed on Figures 20, 21, and 22. Figure 22 is a view of the ^{137}Cs contamination from beneath the northwest corner of the farm. The deepest plume shown at an elevation of about 525 ft is most likely the result of contamination that was blown into and collected at the bottom of the 125-ft deep boreholes in the area, such as borehole 41-03-12. This low-level contamination in the bottom of the holes causes the visualization program to generate a false contamination plume at that depth region.

The plume at mid-depth, at an elevation of about 560 ft (see Figure 21), is also the result of contamination that was blown into the boreholes and collected at the bottom. However, these boreholes are only 100 ft deep. The correlation plot in Appendix C from the Tank Summary Data Report for tank SX-103 (Figure C-3) shows slightly elevated ^{137}Cs concentrations at the bottoms of all boreholes around tank SX-103. This plume should also be disregarded, because they are borehole anomalies and probably do not represent the actual formation radionuclide concentration.

The plumes on the northeast and east sides of the tank shown on Figures 21 and 22 probably have been enhanced by contamination that migrated down along the outside of the borehole casings. This migration might be confirmed when a spectral-shape factor study of the data is completed. However, it is entirely likely that a larger plume exists below the base of the tank as shown on Figure 22. The source may be a leak from tank SX-102 and not tank SX-103, but the exact source cannot be determined at this time.

It cannot be conclusively determined from the distribution of contamination in the vadose zone if a leak occurred from tank SX-103. It appears that the vadose zone contamination can be explained as having originated from either the surface or from tank SX-102. A view of the contamination from the northwest side of the tank (Figure 21) shows the plume on the east side of the tank originating from tank SX-102.

Tank SX-103 still contains about 233,000 gal of drainable liquid (Hanlon 1996) and is currently monitored through a LOW and with an ENRAF gauge.

10.2.4 Tank SX-104

Tank SX-104 was classified as a leaking tank in 1987, when a liquid loss occurred that could not be attributed to evaporation. The worst-case estimate of liquid lost from the tank was 5,300 gal on the basis of the liquid-level decrease.

This tank currently contains about 201,000 gal of drainable liquid (Hanlon 1996). It is monitored using an ENRAF gauge, as the floating crust on top of the liquid closely reflects the liquid level. The LOW in the tank had leaked and was recently out of service, but it may be repaired by the time this report is issued.

The vadose zone contamination (Figure 23) does not show any contamination that can be attributed to a source from this tank. Figure 23 is a view of the contamination from the east side of tanks SX-104 and SX-107.

Only one zone of deep subsurface contamination was detected near this tank on the northwest side (Figure 23). This plume is defined by the data from borehole 41-05-02 at about 50 ft. Because the plume is of relatively high concentration and because there are barren zones above the plume, a subsurface source is suspected. It is not known if the source is tank SX-105 or tank SX-102. The plume probably did not originate from tank SX-104.

10.2.5 Tank SX-105

Tank SX-105 was first filled in 1955 and presently contains 683,000 gal of waste; 261,000 gal is drainable liquid (Hanlon 1996). This tank is listed as a sound tank and it is monitored with a LOW and an ENRAF gauge. Laterals were installed under this tank (see Figure 11), and no elevated gross gamma activity has been detected in these laterals.

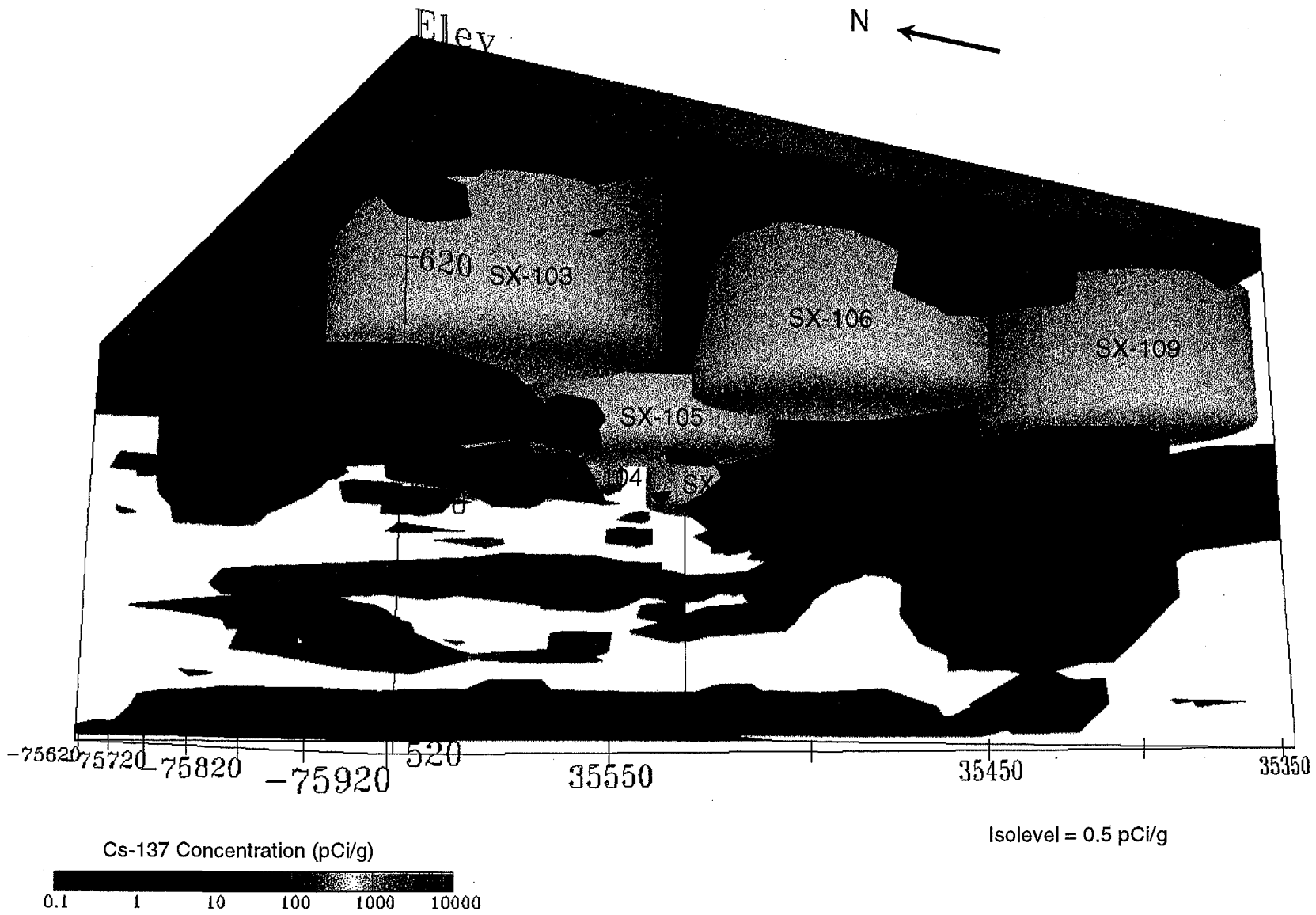


Figure 22. Visualization of Tanks SX-103 and SX-106 ^{137}Cs Plume Viewed From the Northwest

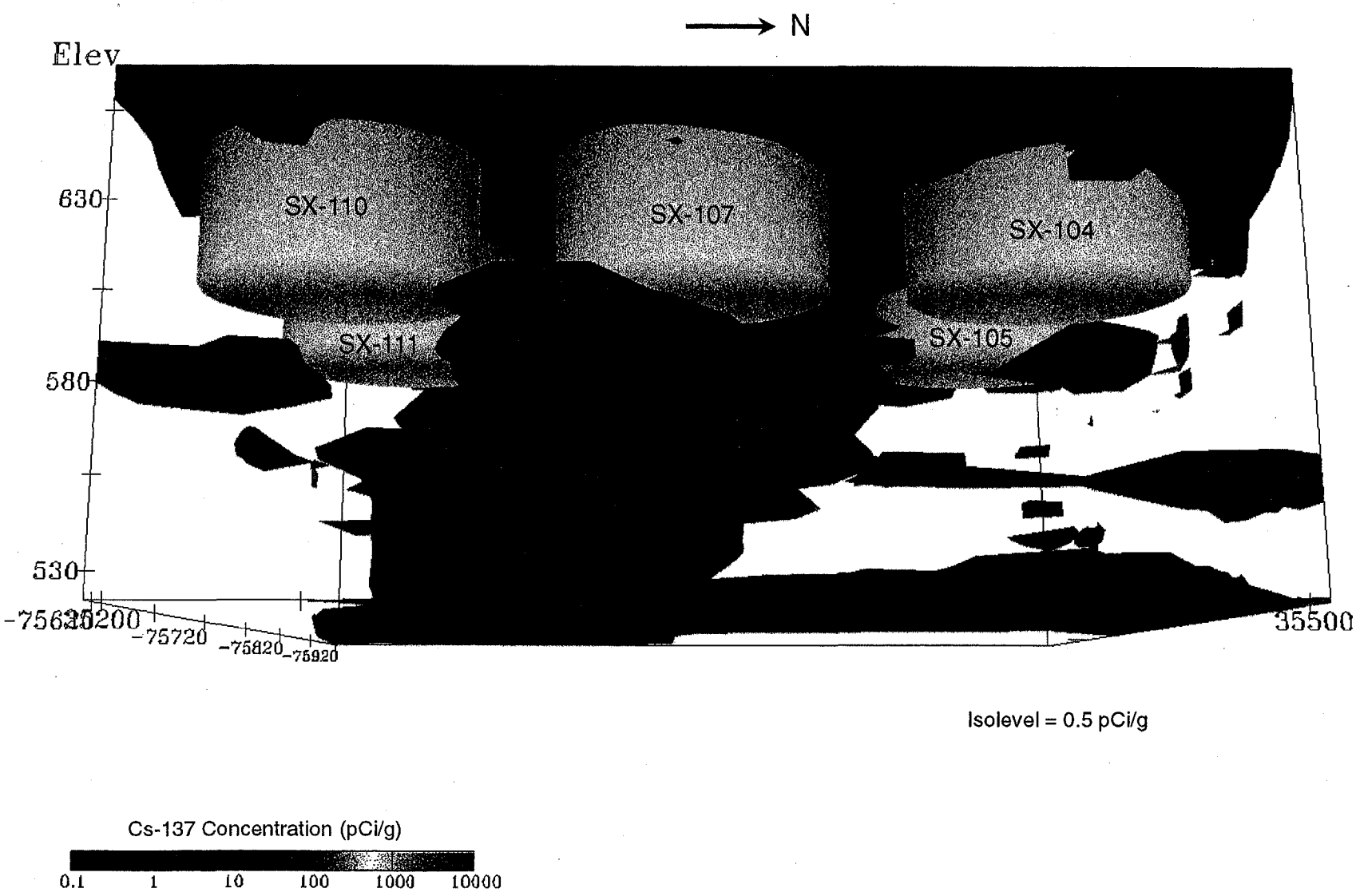


Figure 23. Visualization of Tanks SX-104 and SX-107 ^{137}Cs Plume Viewed From the East

Figures 24 and 25 show the ^{137}Cs contamination around this tank. Both visualizations indicate no significant plumes are present beneath tank SX-105. Figure 24 is a view from the east with a north-south vertical cut in the plume inserted between tanks SX-104 and SX-105 to show the contamination on the east side of tank SX-105. Figure 25 is a view of tank SX-105 from the northwest. Tanks SX-106 and SX-107 were removed to improve the view of tank SX-105.

One zone of contamination is located on the northeast side of tank SX-105 (Figure 24) and documented in the ^{137}Cs log of borehole 41-05-02 (Figure C-5). This contamination zone near the bottom of the tank has a maximum detected concentration of about 5 pCi/g. The source of this small region of contamination is not known, but it is not high enough in concentration to propose that it has a subsurface source. This contamination may have originated from the surface.

The gamma-ray logs from boreholes around this tank do not show any other extensive plumes. Because there are no extensive or high ^{137}Cs concentration plumes beneath this tank, the conclusion is supported that this tank did not leak.

10.2.6 Tank SX-106

Tank SX-106 received REDOX waste in 1954. In 1980, it received a nitric acid/potassium permanganate solution. This tank has not had unexplained liquid-level losses and is classified as a sound tank. It currently contains 538,000 gal of waste with about 255,000 gal of drainable liquid (Hanlon 1996). This tank is monitored with an ENRAF gauge as the primary leak-detection method and with a LOW using a neutron-neutron probe.

Figure 22 shows the distribution of ^{137}Cs contamination around this tank. Essentially, no contamination other than surface contamination was detected in the region beneath this tank. As a result, there is no reason to suspect that this tank has leaked in the past.

The ^{137}Cs logs shown on Figure C-6 do not show any significant levels of contamination other than some near-surface contamination associated with borehole 41-06-02.

10.2.7 Tank SX-107

Tank SX-107 was put into service in 1956 when it received boiling waste from the REDOX facility. This tank was designated a leaker in 1964, but no information regarding the cause of the designation has been found. The listed leak-volume estimate is less than 5,000 gal (Hanlon 1996). The basis of the estimate is not known but may have originated from an estimate of an "average" leak volume and is probably inaccurate.

The bottom liner of this tank has bulged, probably because of the high heat load imposed on the tank. Gross gamma monitoring of the laterals installed beneath the tank revealed zones of high contamination directly beneath the tank. Continued gross gamma monitoring of the laterals and boreholes around the tank showed the plume increased in activity and migrated toward the southwest (Welty 1988). Because this is one of the few contamination plumes that occurred

when the gross-gamma logging program was operational, this plume was detected and monitored over time. A comprehensive review of the gross gamma data may be performed at a later date in an attempt to determine the ^{137}Cs contamination migration rate.

Figures 23 and 26 show the ^{137}Cs plume beneath the tank, which is based on the spectral gamma log data. Figure 23 shows tank SX-107 from the east, and Figure 26 is a view from the southwest. An extensive high-contamination zone was measured beneath the south and the west sides of this tank. The region directly below the tank is also contaminated, as indicated in gross gamma log data from the laterals, but that contamination is not shown in the visualizations because the lateral data could not be used in development of the model.

The distribution of the major plume from tank SX-107 shows the plume has migrated toward the west and southwest, as indicated by the gross gamma monitoring data, to be mixed with a plume from tank SX-108.

The total vertical extent of the high-concentration zones is about 70 ft, as indicated by the spectral gamma log data shown on Figure C-7. However, the maximum vertical extent of the lower concentration radionuclides is not known because the boreholes have not fully penetrated the lower concentration zones.

It is evident from the distribution of contamination in the vadose zone that this tank has leaked. The gross gamma logs obtained in the late 1970s and 1980s first detected this leak, and the gamma-ray logs showed increases in the gamma-ray flux over time.

Tank SX-107 currently contains a minimal amount of drainable liquid, and continued short-term monitoring is probably not necessary. However, it is recommended that this tank be monitored on a long-term basis, possibly about once per year, because of the past dynamic conditions found in the vadose zone.

10.2.8 Tank SX-108

Tank SX-108 is a known leaker. When laterals were drilled beneath the tank in 1962, contamination was detected under the northwest portion of the tank. By 1964, elevated radiation was detected in boreholes 41-08-11 and 41-09-03. In 1965, small sediment-sampling boreholes were drilled between those two boreholes (Raymond and Shdo 1966) in an attempt to define the extent of the contamination.

A leak-volume estimate of 2,400 gal provided in 1965 was based on the contamination distribution. However, this was the first significant attempt to characterize the contamination distribution, and the leak-estimation method was not based on extensive knowledge of or experience with contamination migration in the vadose zone. A leak-volume estimate in 1992 that was based on liquid loss from the tank places the leak volume as high as 35,000 gal, with a lower volume estimate of 2,400 gal (WHC 1992a). The large range is an indication of the imprecision of the leak-volume estimation method.

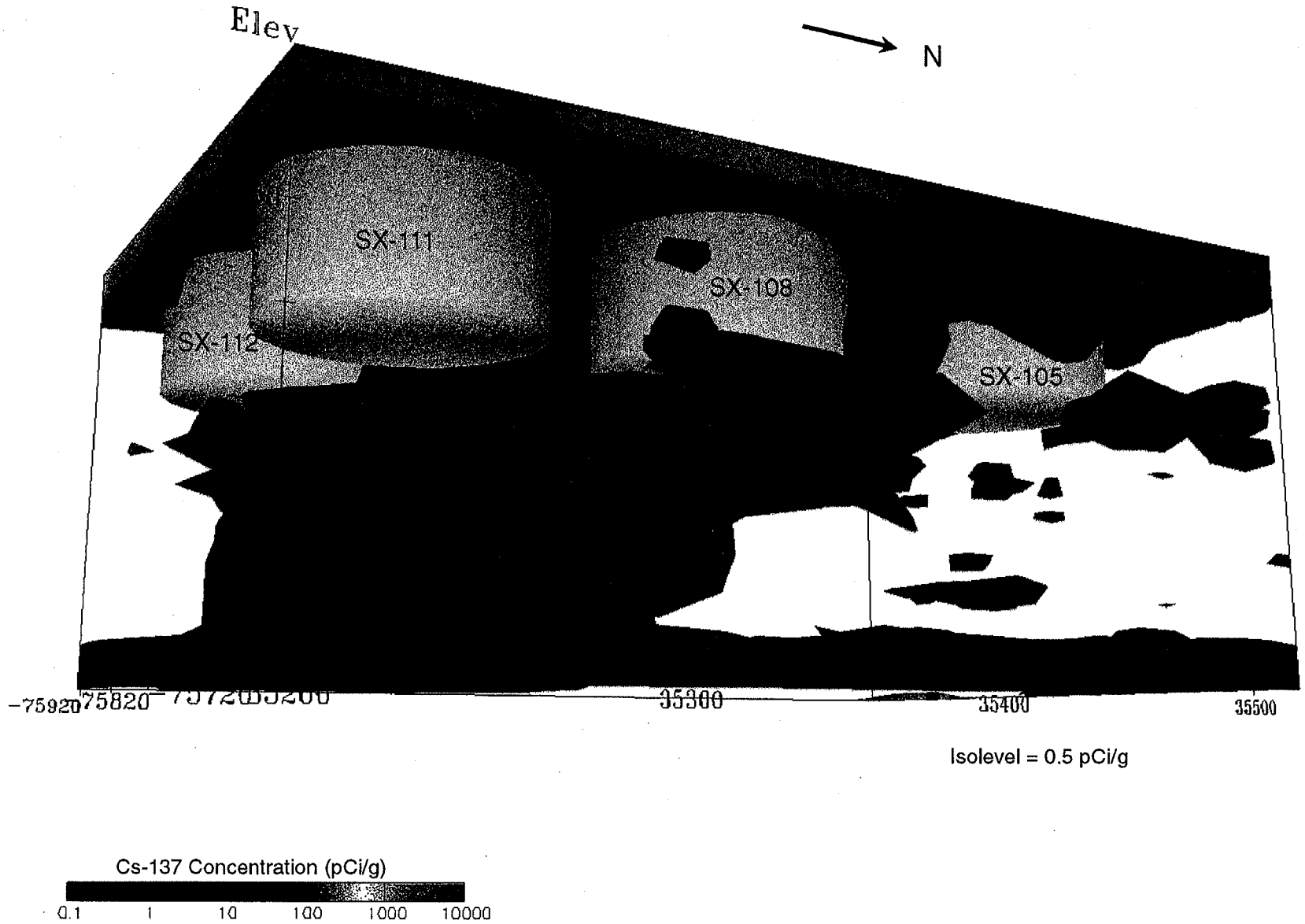


Figure 24. Visualization of Tank SX-108 ^{137}Cs Plume Viewed From the Southeast

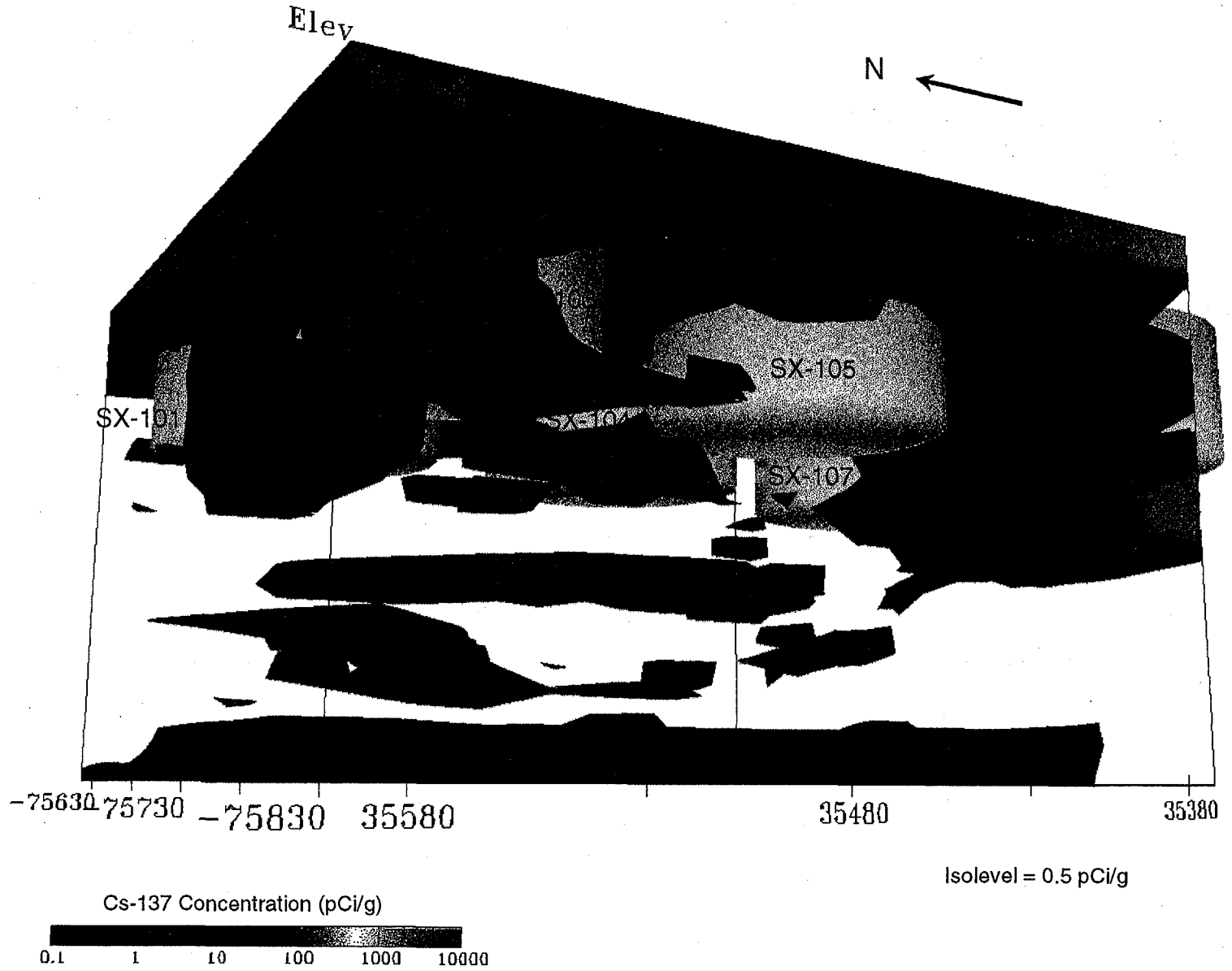


Figure 25. Visualization of Tank SX-105 ^{137}Cs Plume Viewed From the Northwest

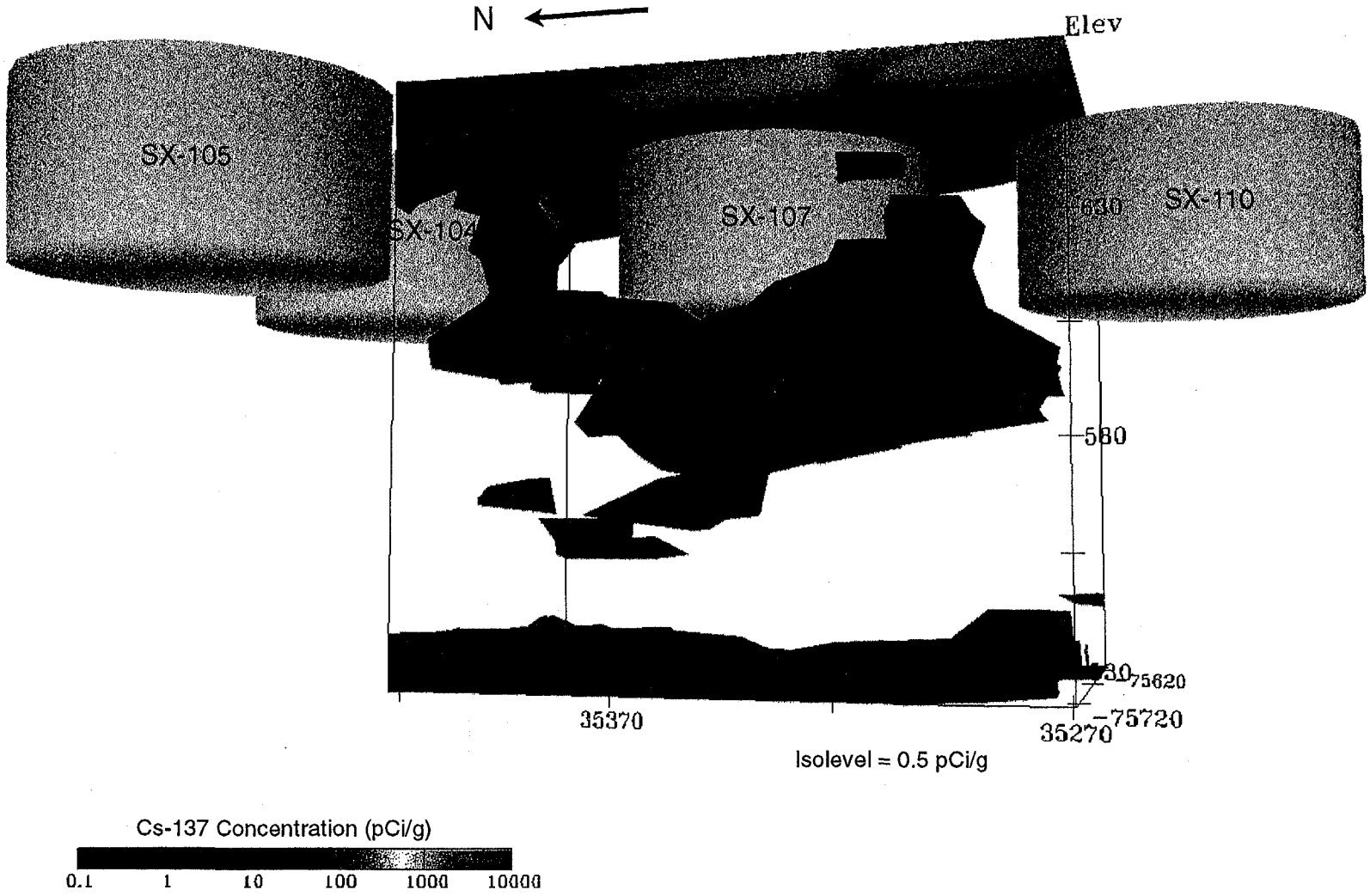


Figure 26. Visualization of Tank SX-107 ^{137}Cs Plume Viewed From the Southwest

Figures 24 and 27 show the current ^{137}Cs distribution in the vadose zone beneath tank SX-108. Figure 24 is a view of the contamination from below the east side of the tank with a cut taken out of the model in the north-south direction to show the contamination distribution just east of tank SX-108.

Figure 27 is a view of the contamination from below the west side of the tank with a cut taken out of the model in the north-south direction to show the contamination distribution just west of tank SX-108. In this visualization, the tank is covered by the contamination and it cannot be seen, but its position is shown by the location of the adjacent tanks.

The model of the ^{137}Cs contamination distribution is relatively accurate for tank SX-108. Two small plumes, which can be seen on the east side of tank SX-108 on Figure 24, apparently originated from contamination that leaked from tank SX-107.

Figure 27 shows a continuous, high-concentration plume on the west side of tank SX-108 extending from borehole 41-08-02 on the northeast side of the tank to the entire west side and to the deep extensive plume on the southwest side of tank SX-108. The model shows the contamination from tank SX-108 has commingled with the contamination that originated from tanks SX-109 and SX-112.

The total vertical extent of the plume under the west and southwest sides of the tank is not known because the boreholes do not extend through the vertical extent of the plume. The ^{137}Cs logs for boreholes 41-08-07 and 41-09-03 (Figure C-7) show high concentrations at the bottom of the boreholes. Borehole 41-09-03 may have reached the maximum extent of the high-concentration zone, as the concentration has begun to decrease at the immediate bottom of the borehole. These boreholes would need to be drilled deeper before the vertical extent of the plume can be defined.

This tank has leaked a large amount of radioactive liquid. On the basis of a comparison of the extent and distribution of high-concentration zones around this tank to the contamination around other tanks in the SX Tank Farm, the upper limit of the leak-volume estimate (35,000 gal) is probably more correct than the lower limit (2,400 gal).

This tank currently has an estimated 5,000 gal of drainable liquid in it (Hanlon 1996) and there is no liquid-level monitoring.

10.2.9 Tank SX-109

Tank SX-109 was filled with self-boiling waste in the early 1960s. In January 1965, high activity was detected in two laterals beneath the tank and tank SX-109 was declared an assumed leaker. However, the liquid in the tank was not removed because of a shortage of tank storage space. In April 1965, elevated gamma activity was detected in the third lateral. In late 1965, an additional 26,000 gal of dilute liquid waste was added to the tank.

This tank was pumped in 1969, 1971, and 1974. From 1965 to 1969, about 250,000 gal of liquid was lost from the tank, as determined from data in Brevick et al. (1994a). The amount of liquid leaked to the vadose zone and loss from evaporation is not known. Judging from the extent of contamination in the vadose zone, it is probable that much of the liquid went to the vadose zone. If such a large amount of contamination leaked from this tank, it would be the largest leak from an SST at Hanford.

An analysis of all historical data associated with this tank is required to confirm or reject the supposition of the leak volume from this tank. The current leak volume listed in Hanlon (1996) and reported by Ebasco in WHC (1992b) has no documented technical basis.

All three laterals and all the monitoring boreholes around this tank show some degree of contamination, as shown in the ^{137}Cs concentration logs on Figure C-9. Two large plumes are associated with this tank: one large plume on the east side of tank SX-109 defined by data from boreholes 41-09-03 and 41-09-04 and another plume west and southwest of the tank defined by data from boreholes 41-09-07, 41-00-08, and 41-09-09.

Figure 28 provides a view from the southeast of the plume on the east side of the tank. The contamination detected in boreholes 41-09-03 and 41-09-04 correlates with the contamination detected in nearby boreholes 41-08-07 and 41-12-02, which were all used to define this large plume in the visualization.

The contamination detected in boreholes 41-09-03 and 41-09-04 appears to have commingled with contamination originating from tanks SX-108 and SX-112. This large plume is well defined by log data from the high density of boreholes in this region; data from these boreholes show good correlation. In addition, the empirical geostatistical structure calculated from all of the data within the SX Tank Farm shows that the spatial data correlate.

The total vertical extent of the plume on the east side of tank SX-109 is not known because contamination has reached the bottom of boreholes 41-09-03 and 41-09-04. Borehole 41-09-04 was deepened in January 1972 from 75 to 105 ft, and high levels of contamination were encountered in the drill samples, at least to 93 ft. Gross gamma logging of the borehole immediately after drilling was completed revealed high levels of contamination all the way to the bottom of the hole. According to the gross gamma log records, the shape and character of the contamination profile has not changed significantly since the borehole was drilled. The gross gamma log record is available from DOE records maintained by WHC. Those records could not be reproduced in this report.

The gross gamma log historical data combined with the drilling information indicate that the ^{137}Cs contamination model from which the visualization was created is correct in the depiction of high levels of contamination deep in the vadose zone sediment. The total vertical extent of that contamination at these borehole locations is not known.

A swab from this borehole obtained before logging with the SGLS showed contamination exists inside the borehole casing; the borehole was not logged deeper than 57 ft with the SGLS to

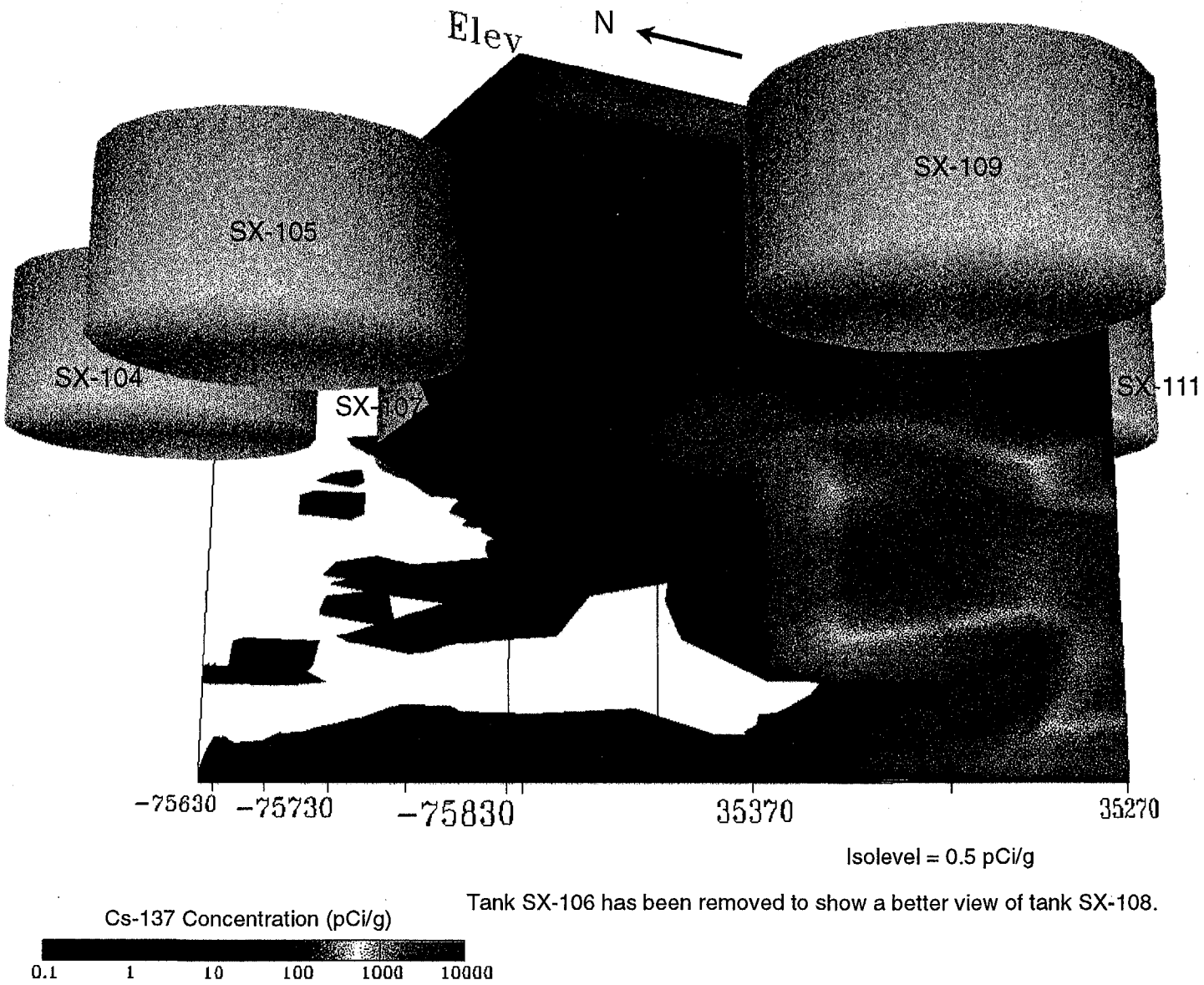


Figure 27. Visualization of Tank SX-108 ^{137}Cs Plume Viewed From the Northwest

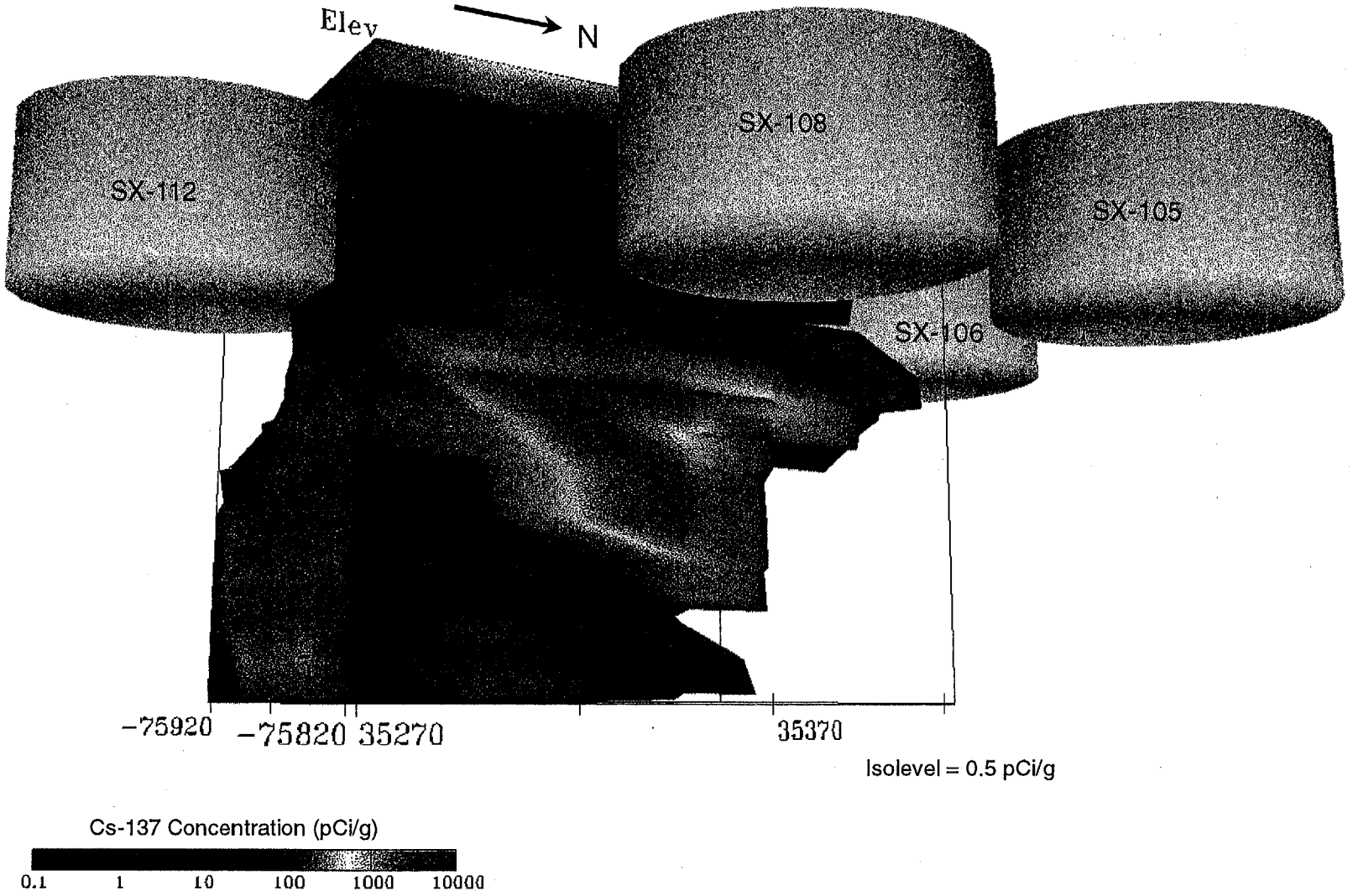


Figure 28. Visualization of Tank SX-109 ^{137}Cs Plume Viewed From the Southeast

prevent contamination of the SGLS tool. This information obtained with the swab suggests that the contamination is not within the vadose zone sediment but is only inside the borehole casing. Such a condition is not likely, however, because both the gross gamma record and the sediment samples obtained during drilling showed contamination was present in the formation at the time the borehole was drilled.

The contamination inside the borehole may have originated from the surface or from a breach in the casing at some intermediate depth. The amount of contamination in the borehole is probably minor compared to the formation contamination, because it has not changed the character of the gross gamma log profile.

Contamination inside the borehole cannot explain the extensive high gross gamma count rate anomalies and the contaminated sediment samples obtained during drilling. Therefore, the high-concentration contamination is assumed to be within the formation.

Some redistribution of the deep contamination may have occurred in the drilling process. If some redistribution did occur, it was a relatively minor amount. The drilling operation would have only carried small quantities of contaminated sediment downward, where it would have been mixed with uncontaminated sediment. As a result, gamma-ray logs would show a decreasing activity trend with depth from the bottom of a region of highly contaminated sediment. There is no mechanism in the drilling process that would transport an extensive amount of contamination downward from 57 to 105 ft to such a degree that contamination is consistently detected at high concentrations along the deeper portion of the borehole.

Figure 29 shows contamination on the west side of tank SX-109. Data from boreholes 41-09-07, 41-00-08, and 41-09-09 all show double spatial peaks in this region. Because the spatial peaks had the same basic shape, it is virtually certain that this contamination can be correlated among the boreholes and that the contamination moved through the vadose zone sediment.

The gross gamma log record indicates this plume migrated toward the west or southwest at least until late 1989. Figure 30 shows some results of gross gamma logging for borehole 41-09-09 from mid-1986 to mid-1989 (see Figure 11 for the location of borehole 41-09-09). The grade-thickness product is the result of a spatial integration or filtering of the data so as to eliminate the short variance resulting from depth indexing problems. Increases in the gross gamma activity were measured in boreholes 41-00-08 and 41-09-09. These increases in activity probably resulted from a continuation of a leak of the liquid remaining in the tank (48,000 gal).

There is no in-tank liquid-level monitoring for this tank, and it is not known if it is possible to monitor the liquid level, because that level may be below a level that can be monitored.

10.2.10 Tank SX-110

Tank SX-110 was the subject of numerous occurrence reports and was suspected of leaking in 1976. Eventually, this tank was designated a leaker after a 3-in. liquid-level decrease occurred that could not be attributed to any other cause. The leak volume estimated for this tank is

5,500 gal, on the basis of the observed liquid loss in the tank (Hanlon 1996). Historical gross gamma logs from the surrounding monitoring boreholes and from the laterals beneath this tank do not show any elevated activity zones that could be attributed to leakage from this tank.

Figures 31 and 32 show the ^{137}Cs contamination around tank SX-110. Figure 31 is a view of the tank and surrounding contamination from below the southeast side of the SX Tank Farm. This figure shows two contamination plumes, one on the southeast side and one on the north side of tank SX-110.

The plume on the north side of the tank most likely originated from tank SX-107 and is not associated with tank SX-110.

The ^{137}Cs plume representation shown by the model under the southeast portion of tank may be the result of contamination inside the borehole. SGLS data from borehole 41-10-03 on the east side of the tank (Figure C-10) show ^{137}Cs contamination from the ground surface to TD. This contamination is all very low concentration. The presence of this contamination from the surface down to TD suggests that it resulted from contaminated sediment that was blown down the inside of the casing. The gamma-ray log also shows slightly elevated activity at the bottom of the hole, which may be characteristic of contamination inside the borehole. This elevated activity at the bottom of the borehole is responsible for the generation of an apparently false plume on the southeast side of tank SX-110 (Figure 31).

No information in the log data or in the ^{137}Cs contamination plume model indicates leakage from this tank.

No leak-detection method is currently used for this tank because it does not contain any drainable liquid (Hanlon 1996).

10.2.11 Tank SX-111

Tank SX-111 was identified as a leaker when elevated activity was detected in 1974 in the laterals beneath this tank. There is no credible estimate of the leak volume for this tank.

Figures 32 and 33 show the ^{137}Cs contamination plumes around this tank. Figure 32 is a view from the northeast, with an east-west cut placed just north of the tank to show the contamination distribution. Figure 33 is a view from the south with tank SX-114 removed to allow a view of tank SX-111.

The ^{137}Cs contamination model developed from the borehole logs does not show any contamination plumes originating from this tank, but it is known from gross gamma logs of the laterals that there is contamination directly below the tank. Because those data could not be incorporated into the model development, the plume beneath the tank is not shown.

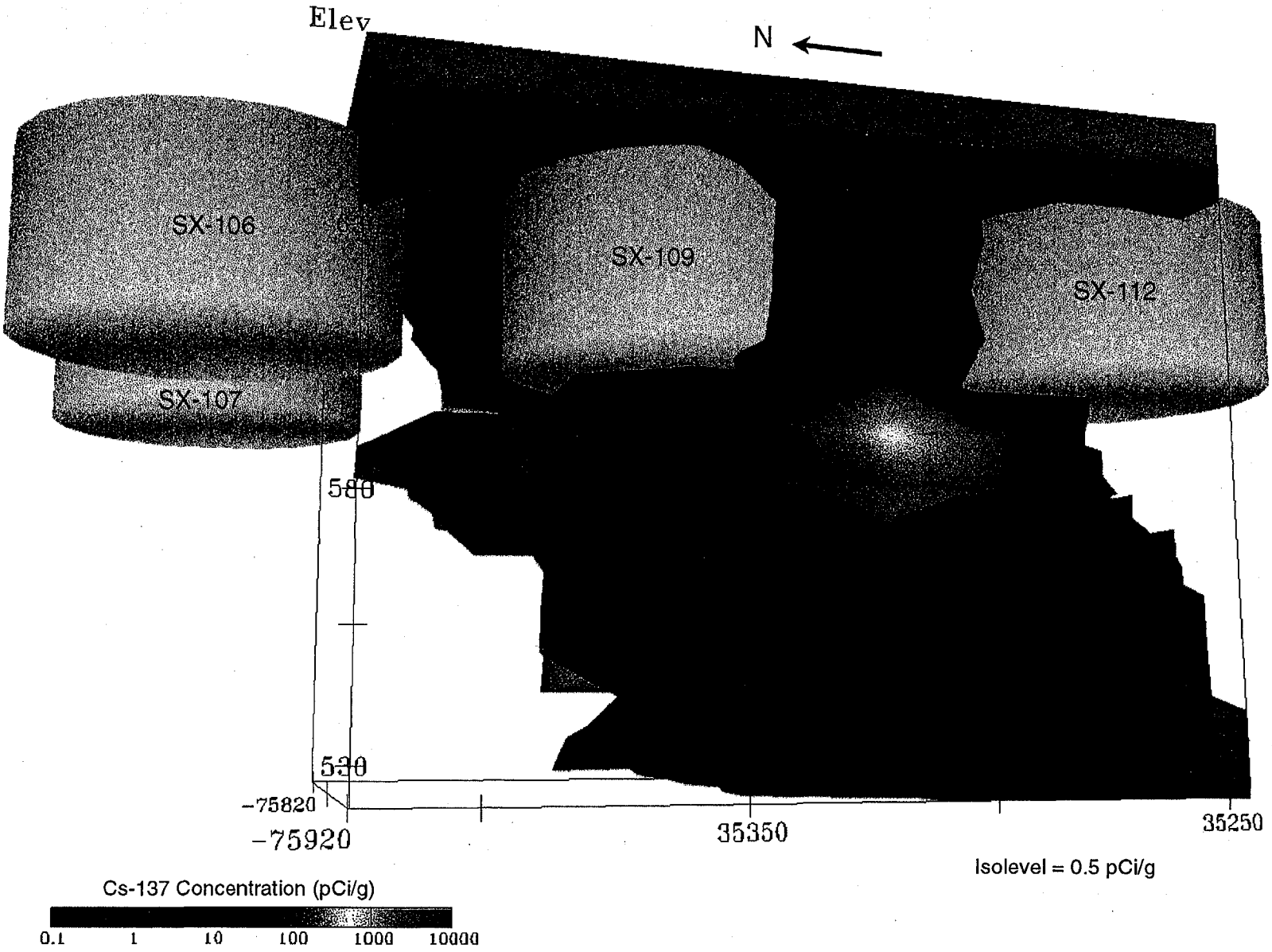
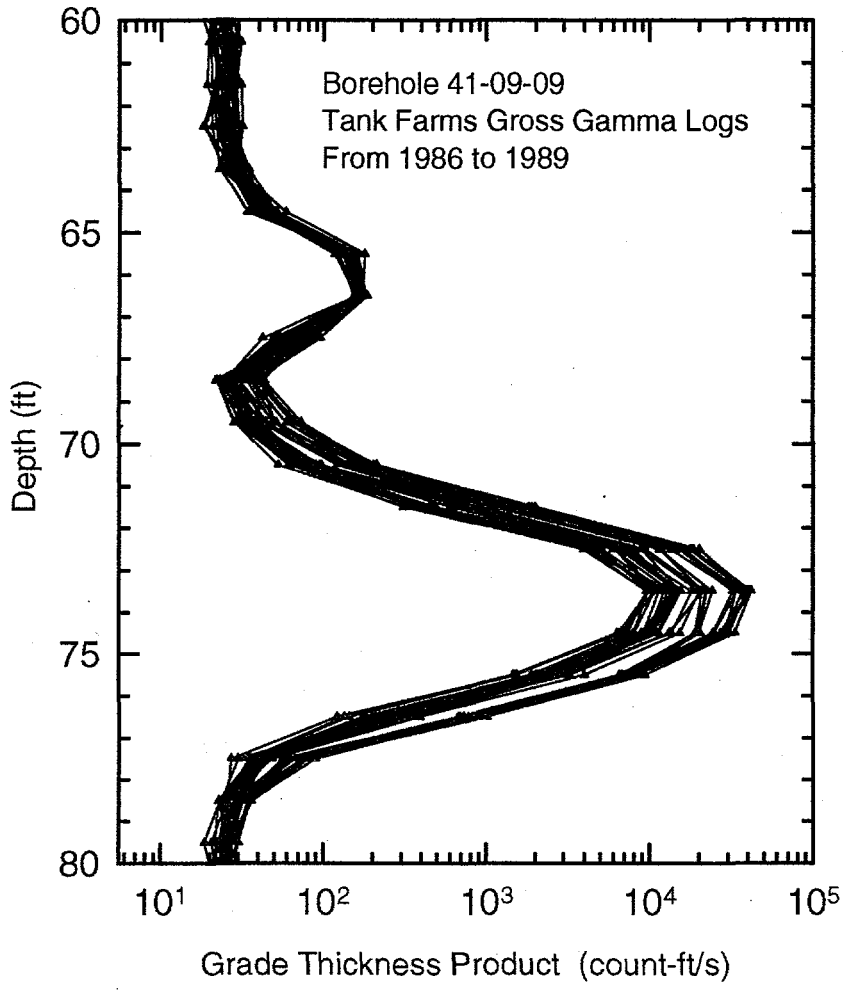


Figure 29. Visualization of Tank SX-109 ^{137}Cs Plume Viewed From the Northwest



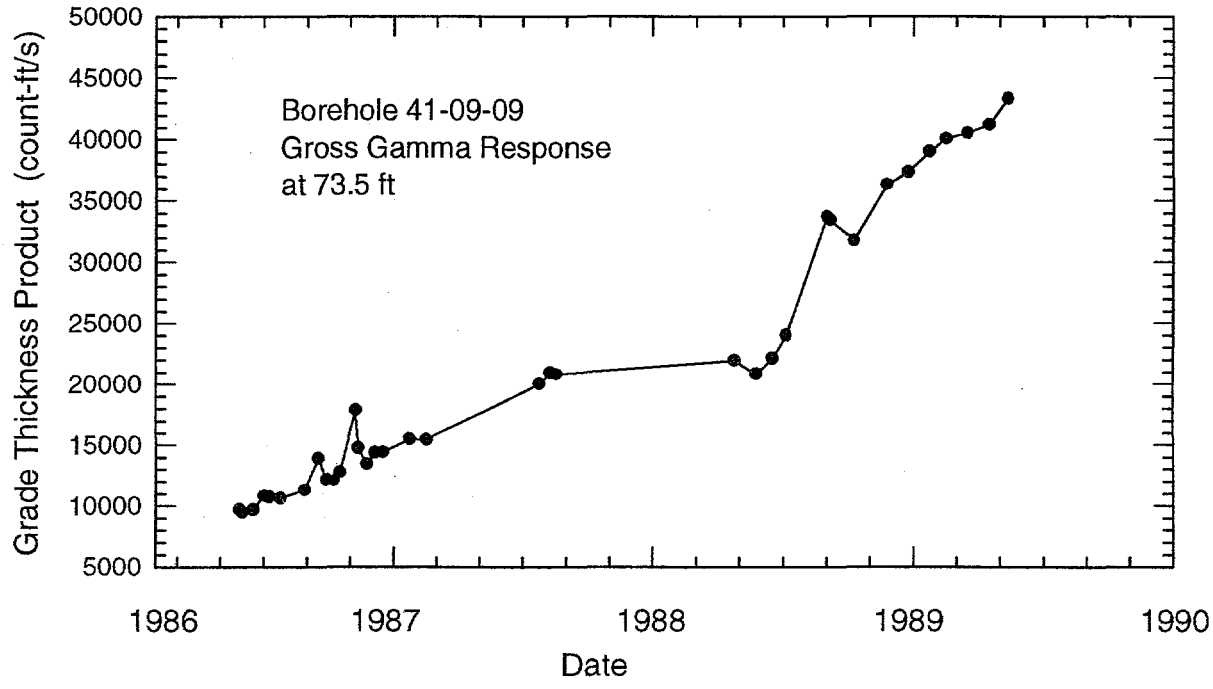


Figure 30. Summary of Gross Gamma Logs for Borehole 41-09-09

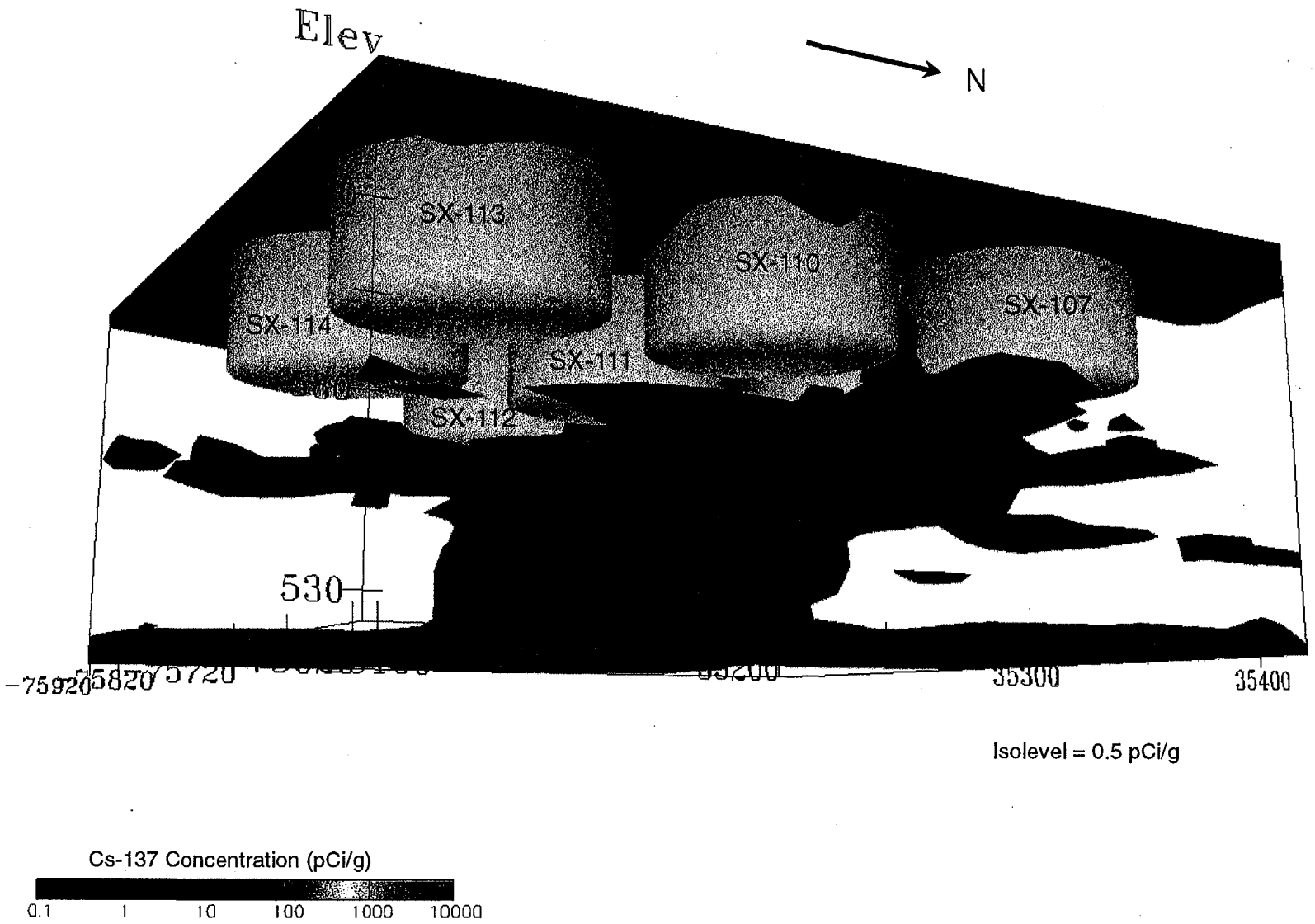


Figure 31. Visualization of Tank SX-110 ^{137}Cs Plume Viewed From the Southeast

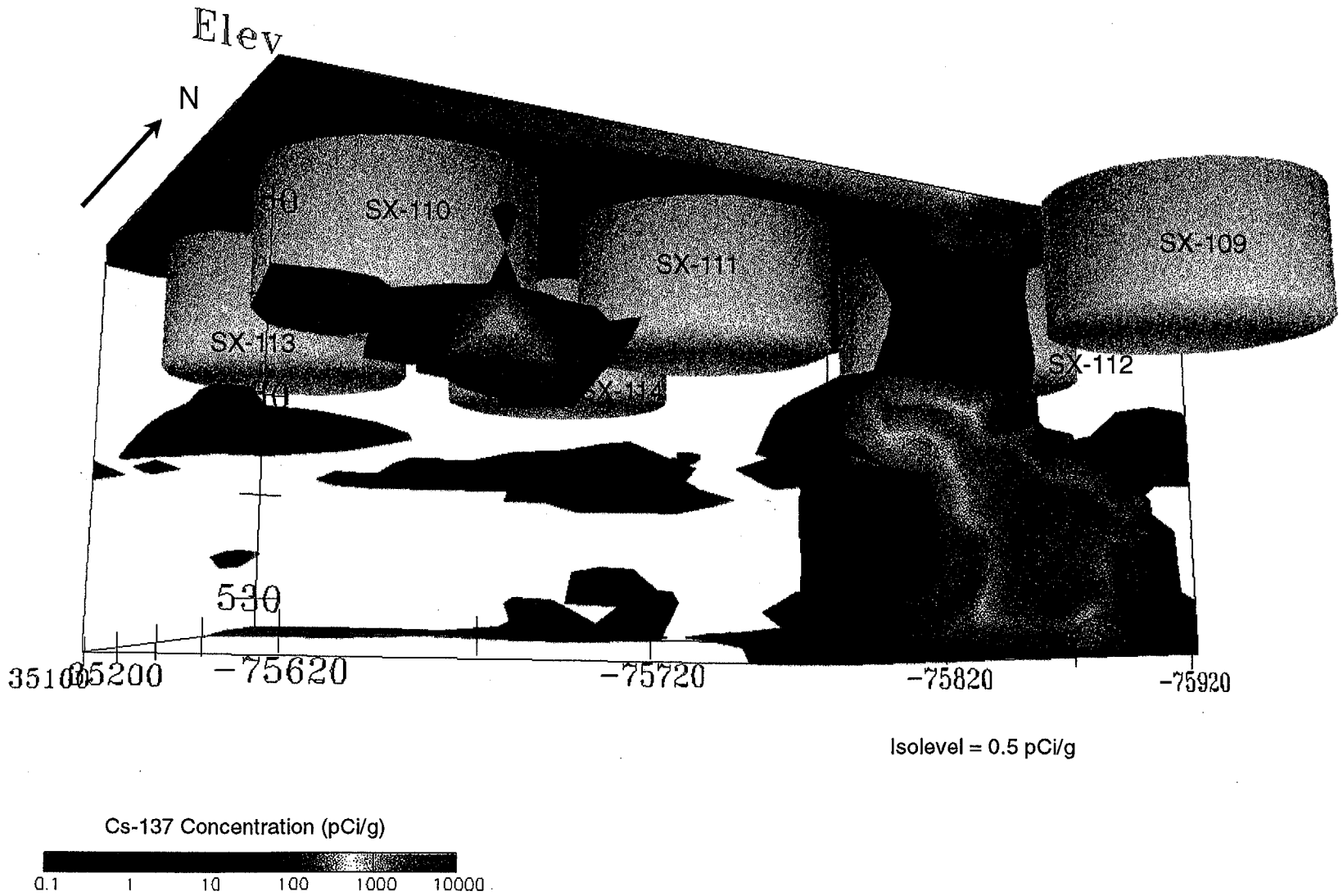


Figure 32. Visualization of Tank SX-111 ^{137}Cs Plume Viewed From the Northeast

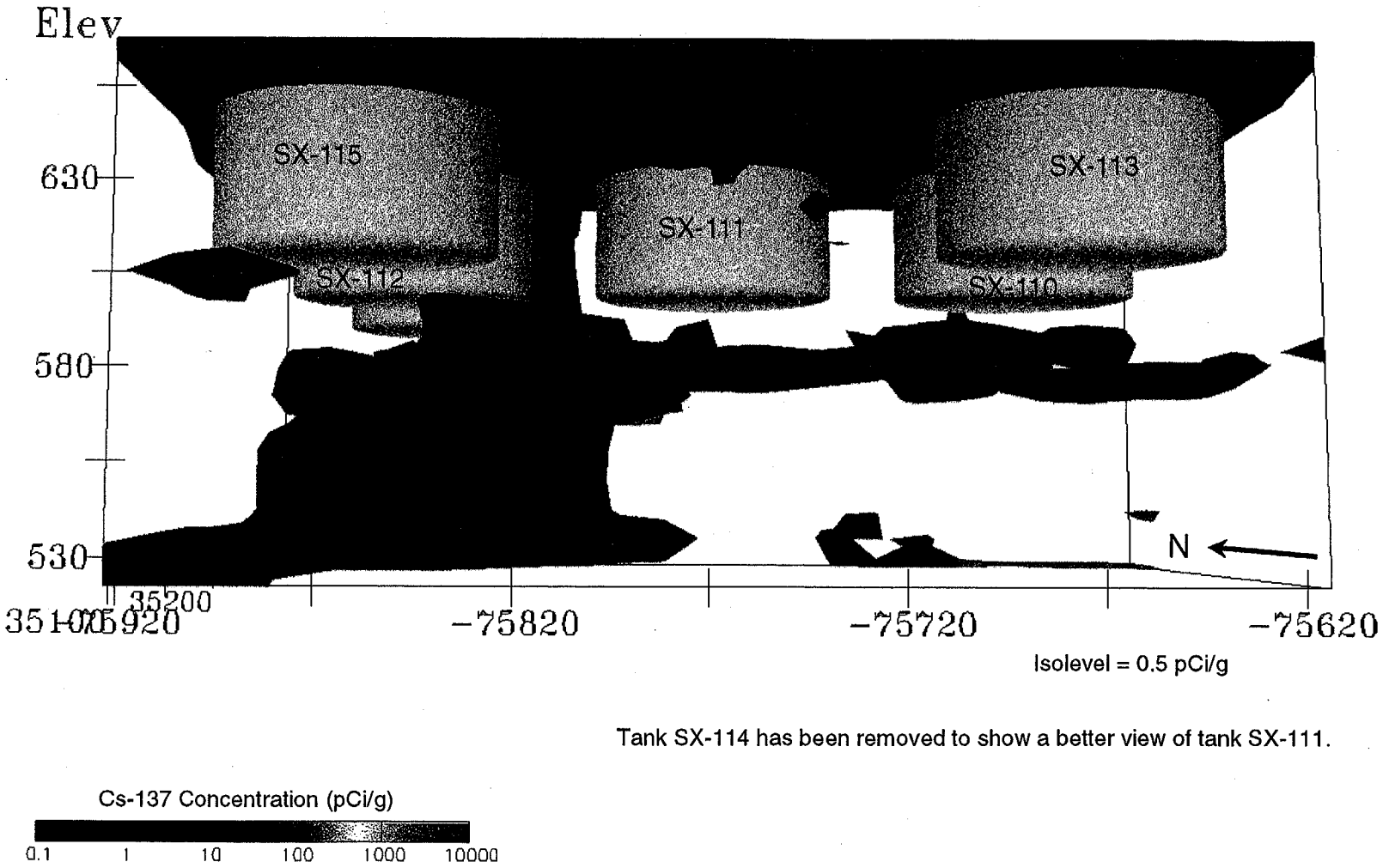


Figure 33. Visualization of Tank SX-111 ^{137}Cs Plume Viewed From the South

The contamination under the northwest side of the tank measured in borehole 41-11-10 and shown in Figure 32 probably originated from a combination of leaks from tanks SX-108 and SX-112.

The ^{137}Cs contamination detected under the south side of this tank in borehole 41-11-06 (Figure C-11) probably originated from tank SX-111. The ^{137}Cs concentration is too high (greater than 10 pCi/g) to be the result of contamination blown down the inside of the borehole.

Tank SX-111 presently contains about 7,000 gal of drainable liquid (Hanlon 1996). Because this is such a small amount of liquid, there is no way to detect any additional leakage from this tank from inside the tank.

10.2.12 Tank SX-112

Tank SX-112 had a liquid-level decrease in 1970, and increased activity was detected in the laterals beneath the tank several weeks later. In 1974, an in-tank photograph revealed a 3-in.-wide crack in the side of the tank at the 17-ft level. The records do not state where that crack is located along the circumference of the tank (azimuth) (Welty 1988). The bottom liner of the tank also had a large bulge. The leak-volume estimate for this tank is 30,000 gal. This estimate was based on the liquid-level decrease and is relatively accurate.

The contamination originating from this tank has created an extensive plume on the northeast side of the tank (Figure 32). Figure 32 is a view of the contamination plume around tank SX-112 from below the northeast corner of the farm, with a northeast-southwest vertical cut in the visualization located just north of the tank. The cut removed all contamination to the northeast to show the extensive, high contamination plume. Figure 34 is a view of the same plume from the southwest corner of the farm.

Figure 11 shows boreholes 41-12-02 and 41-12-03, which are located northeast and east of the tank, respectively. Data from these boreholes indicate high levels of ^{137}Cs contamination. The ^{137}Cs concentration in borehole 41-12-02 was high enough to saturate the 35-percent efficiency detectors used to log this borehole.

Borehole 41-12-02 was deepened from 75 to 125 ft in 1972, just after the contamination had leaked from the tank and before the contamination had reached a stable configuration in the vadose zone sediment, as indicated by the gross gamma logs. Contamination was detected to at least 95 ft in the sediment samples recovered during drilling. Gross gamma logging of the borehole about one year later indicated the presence of contamination down to TD in the borehole, which is the same situation encountered in borehole 41-09-04 (see Section 10.2.9). Some minor additional migration may have occurred later as the driving moisture continued to move before the contamination stabilized in the vadose zone, but the character of the gross gamma profile has not changed significantly since the borehole was deepened.

On the basis that contamination was detected in the sediment samples and that the contamination was detected after drilling with the gross gamma logs for this borehole, the contamination

detected around borehole 41-12-02 is present in the vadose zone sediment and did not migrate extensively down the outside of the borehole casing. The plume depicted by the ^{137}Cs contamination model provides what is probably the best representation of the actual vadose zone contamination.

The total vertical extent of the plume is not known. The maximum depth of the borehole is 125 ft, and the contamination extent has exceeded that depth.

Contamination is probably more extensive immediately beneath the tank than is shown on Figure 34, on the basis of gross gamma logs for the laterals under the tank. The gross gamma log data are not incorporated into the model.

The major plume appears to have commingled with contamination originating from tanks SX-108 and SX-109 to create a very large plume in this area. The cross-borehole correlation among the boreholes defining this plume is very good, and the statistics show that the correlation is statistically valid and the data correlate even with the minimum plume.

The large size and extent of this plume is consistent with the size and extent of other smaller plumes in the SX Tank Farm, considering that at least 30,000 gal have leaked from this tank. It is relatively important to define the vertical extent of this contamination plume, to determine what other radionuclides are present, and to determine how far the radionuclides have migrated. Tank SX-112 presently contains only about 3,000 gal of drainable liquid (Hanlon 1996).

10.2.13 Tank SX-113

Tank SX-113 was the first SST at Hanford to have laterals installed beneath it. When this tank was first used in 1958, the bottom steel liner of the tank bulged upward about 4 ft.

The tank was leak tested (Hanson et al. 1962), then reused while the tank was checked for a leak. The tank bottom bulged again, a liquid-level decrease subsequently indicated a leak, and measurements in the center lateral (see Figure 11) showed elevated activity. As a result, the tank was classified as a leaker.

At first it was thought that the bulge in the liner was the result of thermal expansion of the steel and that expansion of the bottom was prevented by the manner in which the walls are joined to the base of the tank (see Section 5.2, "SX Tank Farm History and Tank Contents"). Later investigation of the shape of the bulge revealed that it was asymmetric and the cause of the bulge was more than just thermal expansion (GE 1958; Brownell 1958). Vaporization of the water or organic compounds in the asphaltic membrane were suspected to cause enough vapor pressure to bulge the liner. The vapor was then released when the liner base or side buckled and the gas was released into the tank. It was suspected that the weld joint between the tank sides and bottom was the most likely location of liner failure (Brownell 1958).

The leak-volume estimate for tank SX-113 is 15,000 gal, which is probably relatively accurate because it was determined from the cumulative liquid lost during gauged pumping operations.

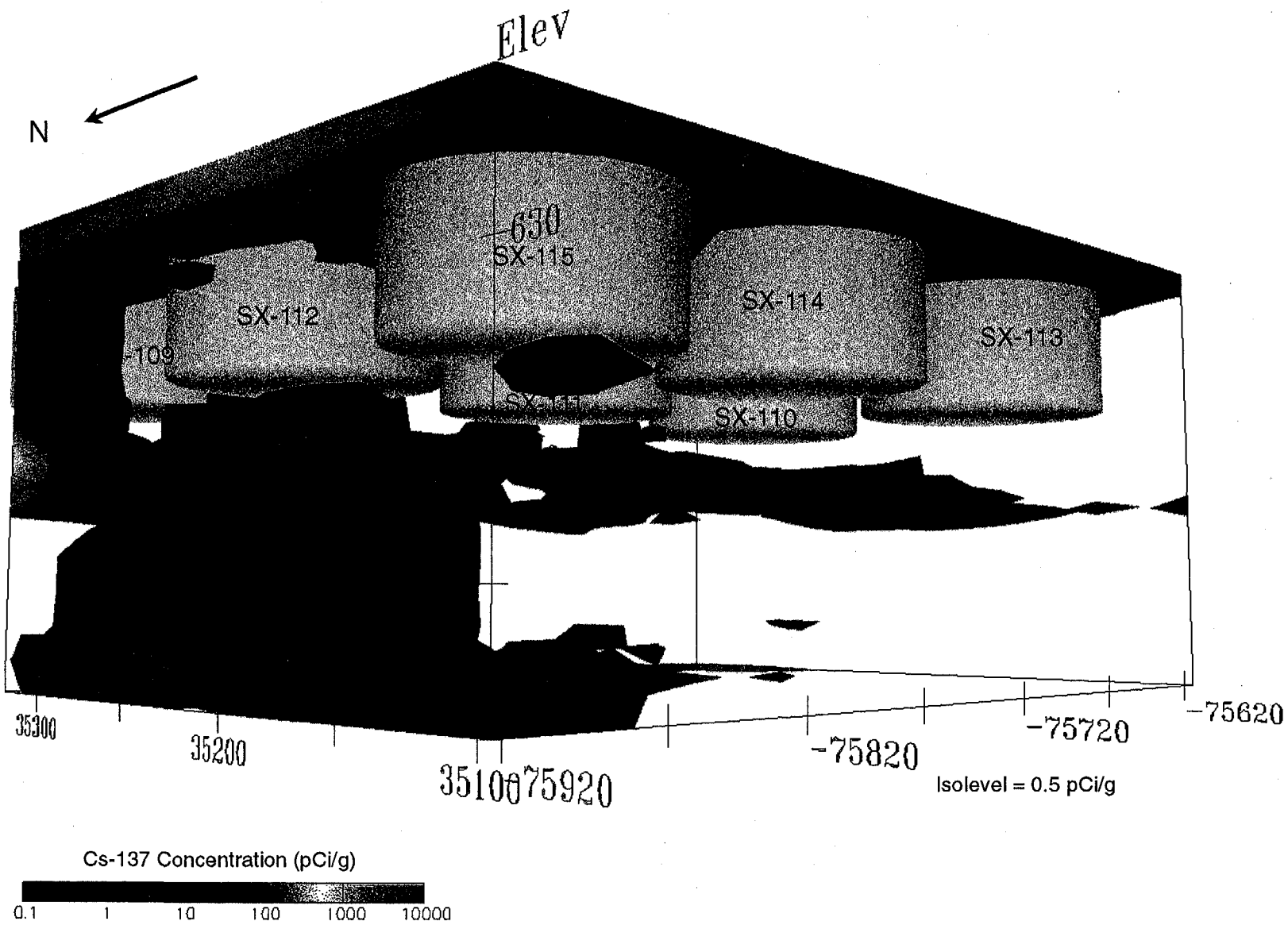


Figure 34. Visualization of Tank SX-112 ^{137}Cs Plume Viewed From the Southwest

Only three monitoring boreholes that can be used to obtain subsurface contamination data are located close to this tank (see Figure 11). Borehole 41-00-05 was not logged because the borehole is double-cased and grouted, making it impossible to obtain accurate radionuclide concentration data from this borehole. In addition, no gross gamma anomalies were detected in this borehole; therefore, no contamination zones greater than about 10 pCi/g are present.

The ^{137}Cs contamination visualization presented in Figure 33 shows a region of contamination under the west side of the tank that is defined by data from the two boreholes adjacent to tank SX-114.

Data from laterals that were not used in development of the visualization show a region of elevated gross gamma activity under most of the tank. If these data were incorporated into the model, the visualization would show that the contamination zone on the west side of the tank originated from this tank.

The ^{137}Cs plume beneath the west side of this tank is deeper than 75 ft, the greatest depth of the monitoring boreholes near tank SX-113. The total vertical extent of this plume has not been determined and deeper boreholes are needed.

This tank contains virtually no drainable liquid.

10.2.14 Tank SX-114

Tank SX-114 was declared a leaker in 1972 when contamination was detected in the laterals and perimeter monitoring boreholes with the gross gamma logging systems. The estimated leak volume of 8,000 gal is not accurate because it is based on an estimate of the postulated total volume of leaks from eight tanks and is not based on volumetric calculations.

The ^{137}Cs contamination that leaked from this tank is represented by the plume model shown on Figures 35 and 36. Figure 35 shows the tank viewed from above on the northeast with an east-west vertical cut face inserted just north of the last row of tanks. Figure 36 is a view of the same model, except it is viewed from below on the south side.

As with all the SX tanks, contamination directly beneath the tank is not shown because the laterals were not logged. Gross gamma logs of the laterals show little contamination, but accurate logs of the laterals would provide additional data for the contamination model.

The ^{137}Cs contamination model provides evidence that the tank leaked and that the contamination is present beneath the tank. No data are available for depths of more than about 75 ft, the greatest depth of the boreholes. Therefore, the contamination plume may be deeper than 75 ft. A deeper plume is expected, based on the shape of the contamination distribution seen in the ^{137}Cs logs shown on Figure C-14.

This tank contains about 14,000 gal of drainable liquid (Hanlon 1996) that probably cannot be pumped. No leak-detection method is used for this tank because of the low liquid level in the tank.

10.2.15 Tank SX-115

Tank SX-115 was identified as a leaker in 1965 on the basis of a liquid-level decrease of at least 1.5 ft and a liquid loss of about 50,000 gal. That leak volume is one of the highest estimated leaks of all the leaking SSTs; only tanks T-106, A-105, and U-104 are listed with leak estimates of a higher volume.

Contamination was detected under the tank by gross gamma logging of the laterals shortly after the leak was detected by a drop in liquid level. A special project was conducted in 1965 to characterize the distribution of the contamination from the leak. This investigation involved drilling small-diameter sampling boreholes and assaying the samples in the laboratory. The sample distribution is shown on Figure 2 of the Tank Summary Data Report (DOE 1996i); the Tank Summary Data Report or the original report on the work by Raymond and Shdo (1966) presents a more complete discussion of this project.

Figures 36 and 37 show visualizations of the ^{137}Cs contamination beneath tank SX-115. Figure 36 provides a view of the tank from below on the south side. Figure 37 shows the contamination from above on the west side.

A small zone of contamination on the southwest side of the tank (see Figure 36) is defined by the anomaly at 57 ft in borehole 41-15-07 (see Figure C-15). If the gross gamma data from the laterals were used in the visualization, this small plume would be shown to extend under the tank and commingle with two additional plumes under the tank.

The plume on the east side of the tank (see Figure 36) is known to have originated from tank SX-115, on the basis of information obtained from the borehole sampling project conducted in 1965 (Raymond and Shdo 1966). This plume may have commingled with contamination from tanks SX-114 and SX-112.

The deepest plume (see Figure 37) may be attributed to contamination that was blown into the bottom of borehole 41-15-10 that is creating a false plume. Contamination was detected at the bottom of this borehole at a level of about 2 pCi/g, and the model development program correlated that contamination with the major plume from tanks SX-109 and SX-112. This contamination may not exist in the vadose zone in this immediate region.

The ^{137}Cs distribution around this tank indicates that although a large volume of contamination leaked from the tank, it did not migrate extensively in the horizontal or vertical directions. A plume was detected only in borehole 41-15-07 that is located on the south side of the tank, indicating that the ^{137}Cs plumes in the vadose zone have high concentration gradients at the plume fronts. Three plumes are known to exist under the tanks, as determined by gross gamma

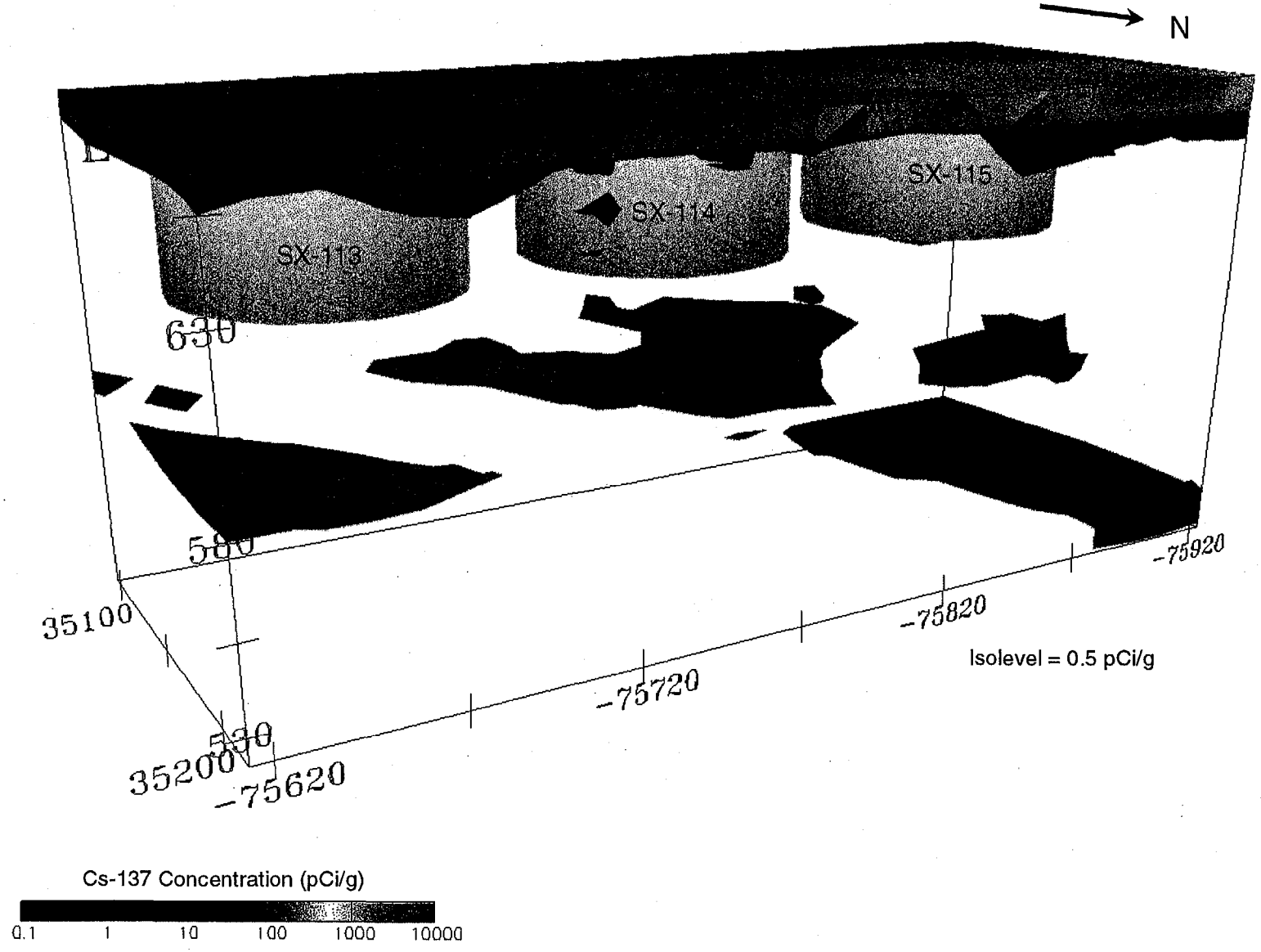


Figure 35. Visualization of Tank SX-114 ^{137}Cs Plume Viewed From the Northeast

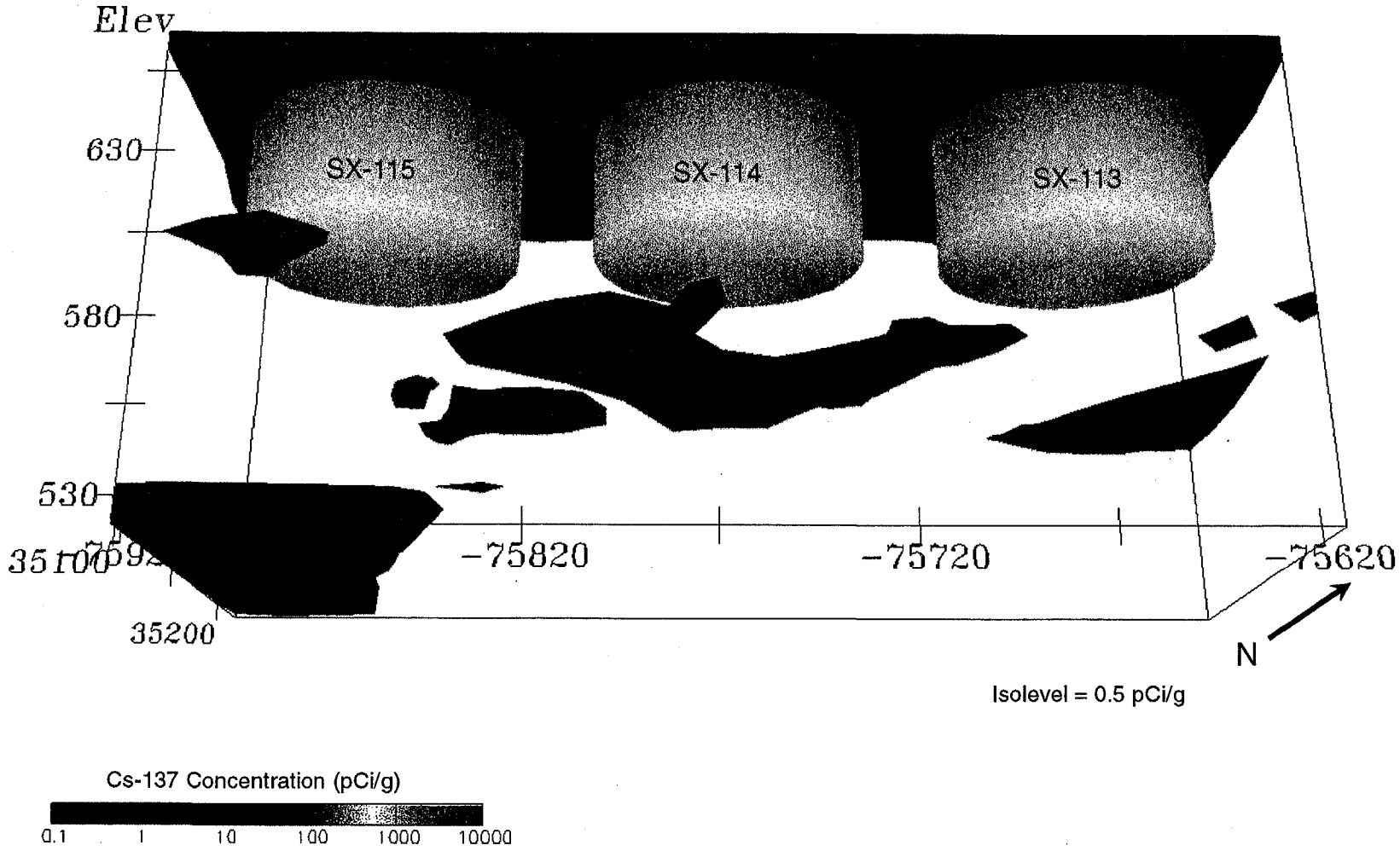


Figure 36. Visualization of Tank SX-114 ^{137}Cs Plume Viewed From the South and Below

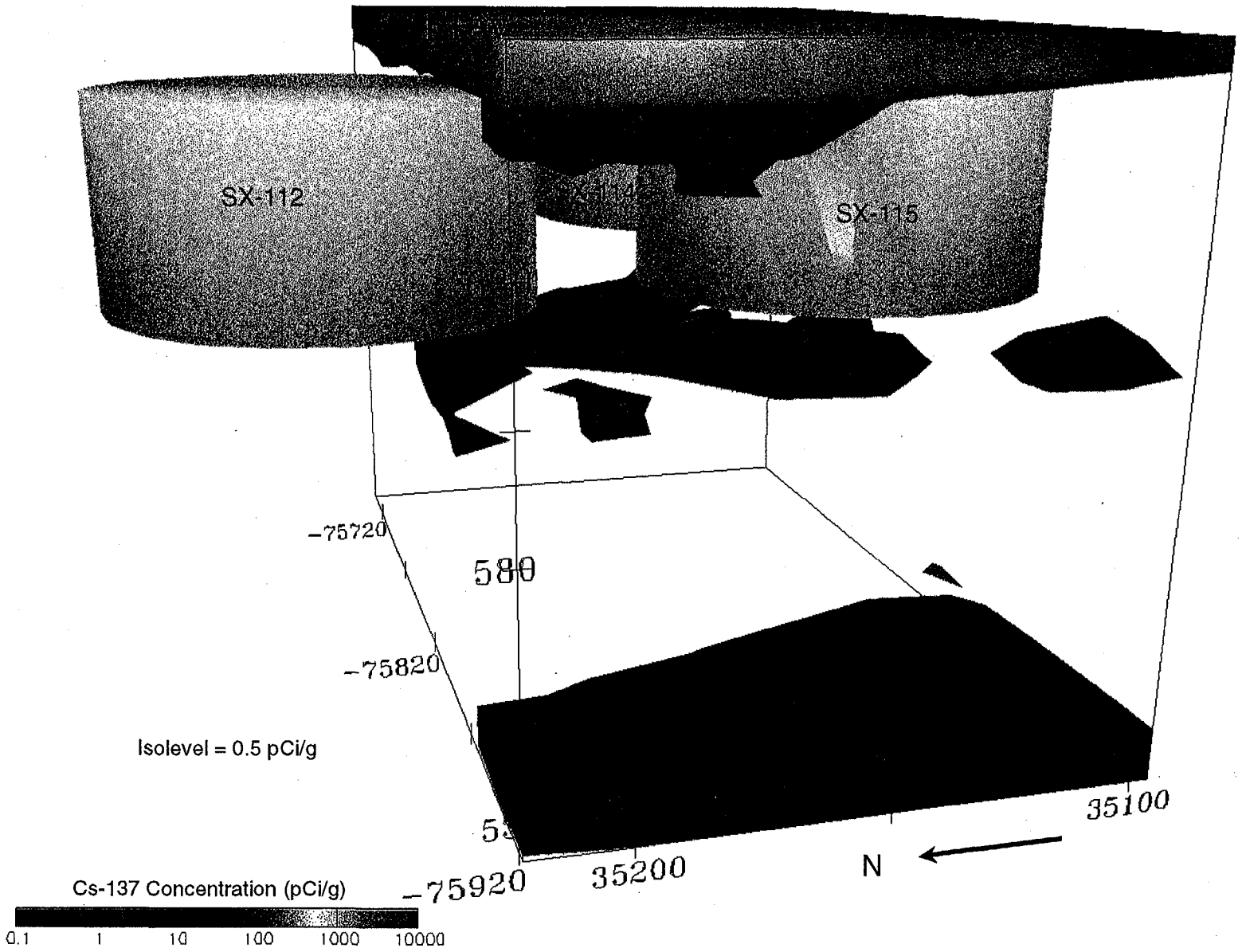


Figure 37. Visualization of Tank SX-115 ^{137}Cs Plume Viewed From Northwest

logs of the laterals, but those plumes were only detected in the one perimeter borehole (41-15-07).

Reasons for the minimal horizontal migration of the ^{137}Cs are discussed in the Tank Summary Data Report for SX-115 (DOE 1996i). A key reason may be that the liquid in the tank at the time of the leak may have been much lower in ^{137}Cs concentration or in total nitrate concentration, because an attempt was being made to recover sodium nitrate from the solids in the tank for reuse in the REDOX process. It is also possible that the leak-volume estimate is not accurate and that the leak volume is much less than what is reported.

There is clear evidence from all the information about the vadose zone contamination around and beneath tank SX-115 that this tank had leaked, but the contamination has remained beneath the tank. The depth of the ^{137}Cs contamination under this tank is unknown, but minimal horizontal migration of the contamination has occurred at this location.

This tank has no drainable liquid and is not monitored for additional leakage.

10.3 Major Subsurface Contamination Zones

Section 10.2 provides discussion of the various plumes depicted with the visualizations, and the sources of the plumes have been identified. Some plumes shown in the visualizations may be the result of contamination that was blown into the boreholes as particulate matter. Most boreholes were cut-off flush with the ground surface and some of them do not have borehole caps or the caps were left off of the borehole. This allows contaminated sediment to get into the holes where it appears at the borehole bottoms, creating an apparent "false" plume at a depth that is common to several boreholes. These apparent false plumes are not the result of contamination in the vadose zone sediment. It is sometimes difficult to distinguish the difference between such false plumes and contamination that actually originated from one of the tanks and is in the sediment around the borehole.

The most significant plumes and those that are clearly indicative of a subsurface source are the high-concentration plumes. Figures 38, 39, 40, and 41 show the differences in spatial distributions between the high- and low-concentration ^{137}Cs plumes. Figure 38 is a view of the SX Tank Farm from the northwest with an isolevel of 0.5 pCi/g. The isolevel is the lowest concentration of ^{137}Cs contamination that is visualized and shown as a solid surface.

Figure 39 is the same view angle as Figure 38, except the isolevel was increased to 10 pCi/g. Figure 40 is a visualization of the SX Tank Farm contamination viewed from the southeast with an isolevel of 0.5 pCi/g. Figure 41 is the same view angle as Figure 40 with an isolevel of 10 pCi/g.

The 0.5-pCi/g visualizations show many "false plumes" that may be caused by low-level contamination that appears to have blown down to the bottom of some of the boreholes. These false plumes disappear in the 10 pCi/g visualizations. However, some of the 0.5-pCi/g plumes are attributable to contamination that originated from tank leaks. One example is the

contamination directly beneath tank SX-115 that was determined from gross gamma logs of the laterals and from sediment sampling. The monitoring boreholes do not intersect this plume, except at the very edge, where the plume is of relatively low concentration and not shown in the 10-pCi/g visualizations.

This leads to the understanding that contamination levels of about 1 pCi/g or less can be significant in terms of identifying tank leaks and determining contamination sources. Even low-level ^{137}Cs contamination zones may be an indication of a subsurface source. Because ^{137}Cs is not a naturally occurring radionuclide, if the concentration is statistically above the MDA level and is present in a borehole, a deposition mechanism or pathway should be identified.

The reason the low-level concentrations are important as indicators of a source is that the gradients of the contamination fronts can be very sharp. These sharp gradients are seen in the vertical direction by borehole logs that traverse high-contamination zones. These gradients were just as sharp in the horizontal dimension in the tank SX-115 sediment sampling characterization project in 1965.

When ^{137}Cs is detected midway in the length of a borehole even at relatively low concentrations of several tenths of a picocurie per gram, it is a good indication of a subsurface source if there is no low-level contamination above or below the contaminated region. Identifying a low-level contamination zone as a subsurface source is more conclusive when that zone is spatially continuous. If there is a possibility that the contamination could have blown down the borehole, that possibility must be considered when interpreting the borehole log data.

In general, it is assumed that if contamination is transported from the surface down the outside of a borehole casing, a pattern of decreasing apparent concentration with depth will be observed in the borehole log. If that contamination were then to mix with contamination from a subsurface source, the contamination distribution pattern will be confusing.

Significant technical discussion is expected concerning the deep, high-concentration ^{137}Cs zone in the vicinity of tanks SX-108, SX-109, SX-111, and SX-112. The discussion revolves around the possibility that the boreholes caused the vertical migration of contaminants and that ^{137}Cs did not actually migrate through the vadose zone sediment to be deposited at such a great depth. Rather, it simply went down the inside or outside of the monitoring boreholes.

The hypothesis that ^{137}Cs migrated exclusively down the borehole casings is based on laboratory studies of contamination migration and on crib monitoring data. Because the tank waste is considerably different in terms of chemistry and radionuclide content and because the release mechanism at a tank is different from laboratory studies, preconceived assumptions about the behavior of ^{137}Cs in the vadose zone should not be applied summarily to the SX Tank Farm environment. Instead, until demonstrated otherwise, an assumption is adopted in this report that the contamination is in the vadose zone sediment.

The deep ^{137}Cs contamination could have originated from the surface and drained down the outside of the borehole casings by a flood or could have resulted directly from a surface spill.

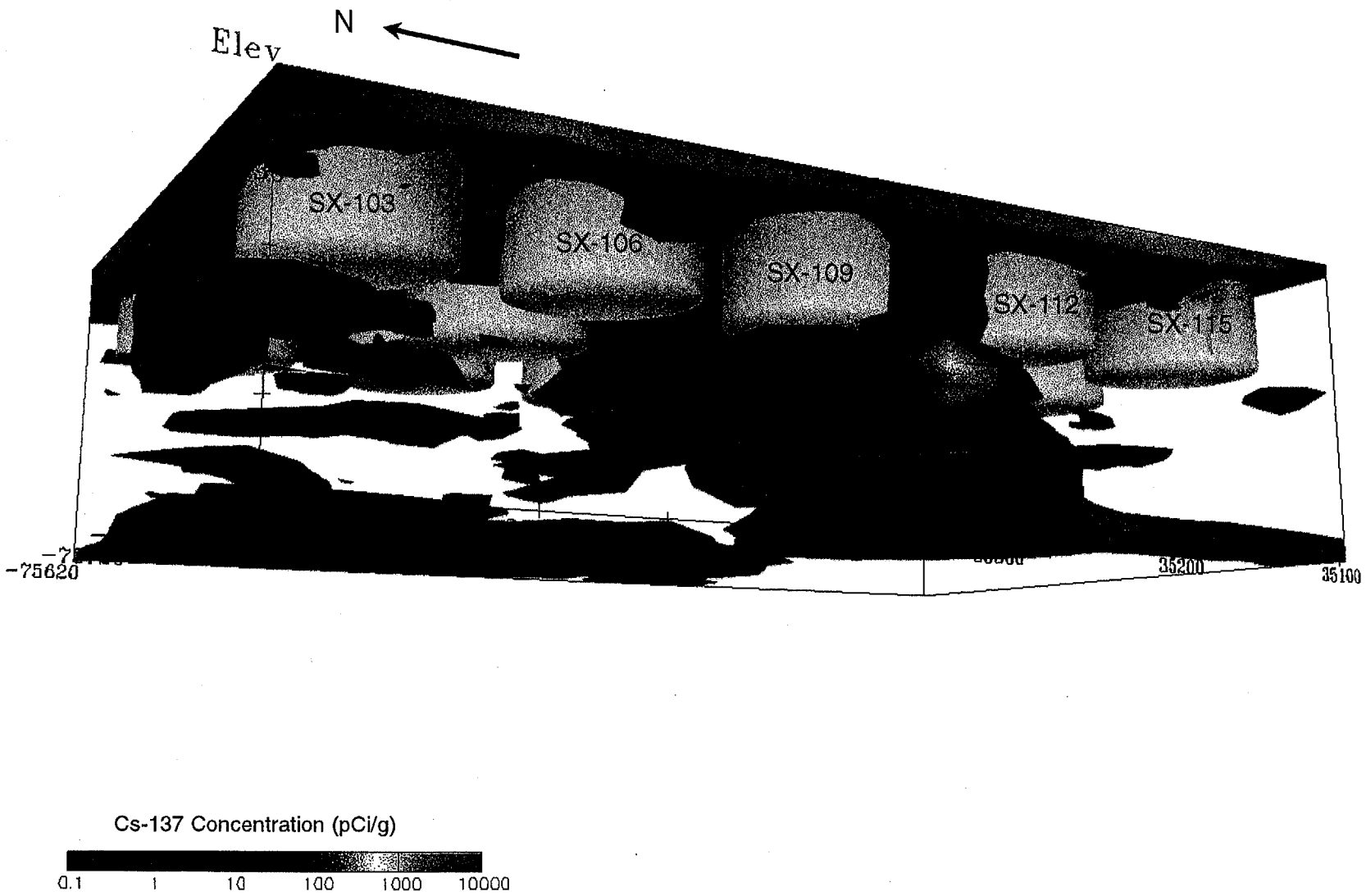


Figure 38. Visualization of the ^{137}Cs Contamination with an Isolevel of 0.5 pCi/g at the SX Tank Farm Viewed From the Northwest

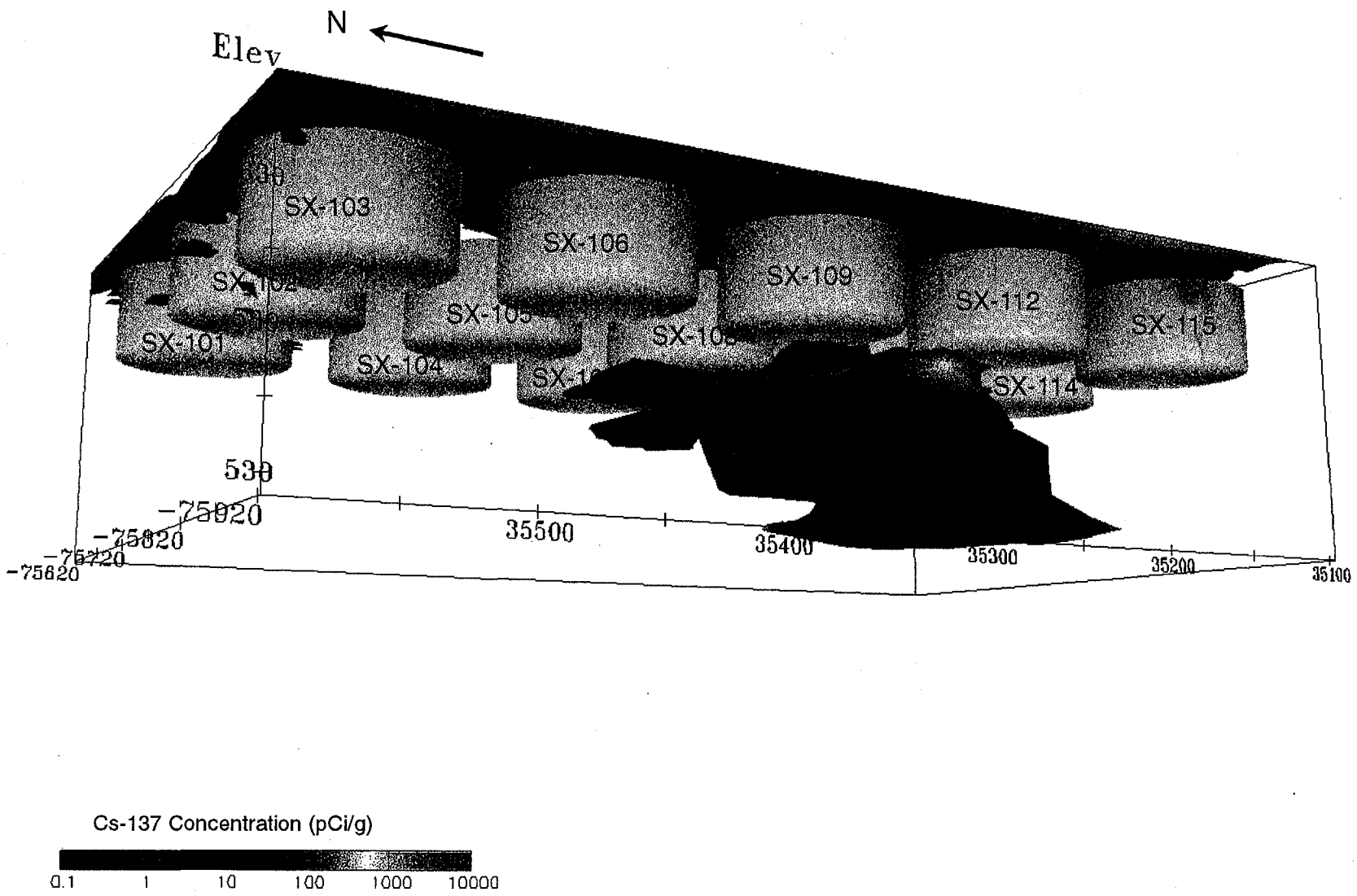


Figure 39. Visualization of the ^{137}Cs Contamination with an Isolevel of 10 pCi/g at the SX Tank Farm Viewed From the Northwest

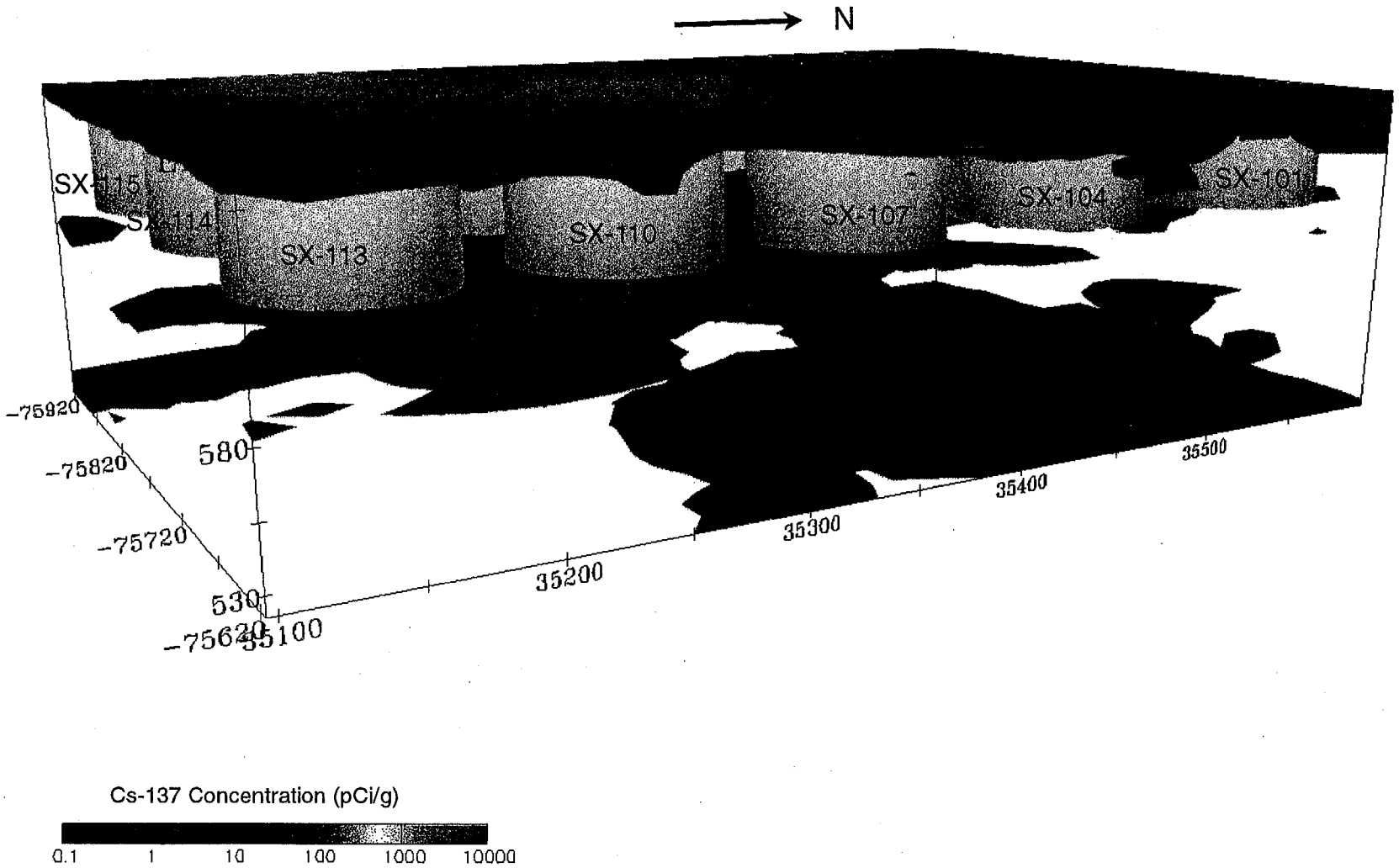


Figure 40. Visualization of the ^{137}Cs Contamination with an Isolevel of 0.5 pCi/g at the SX Tank Farm Viewed From the Southeast

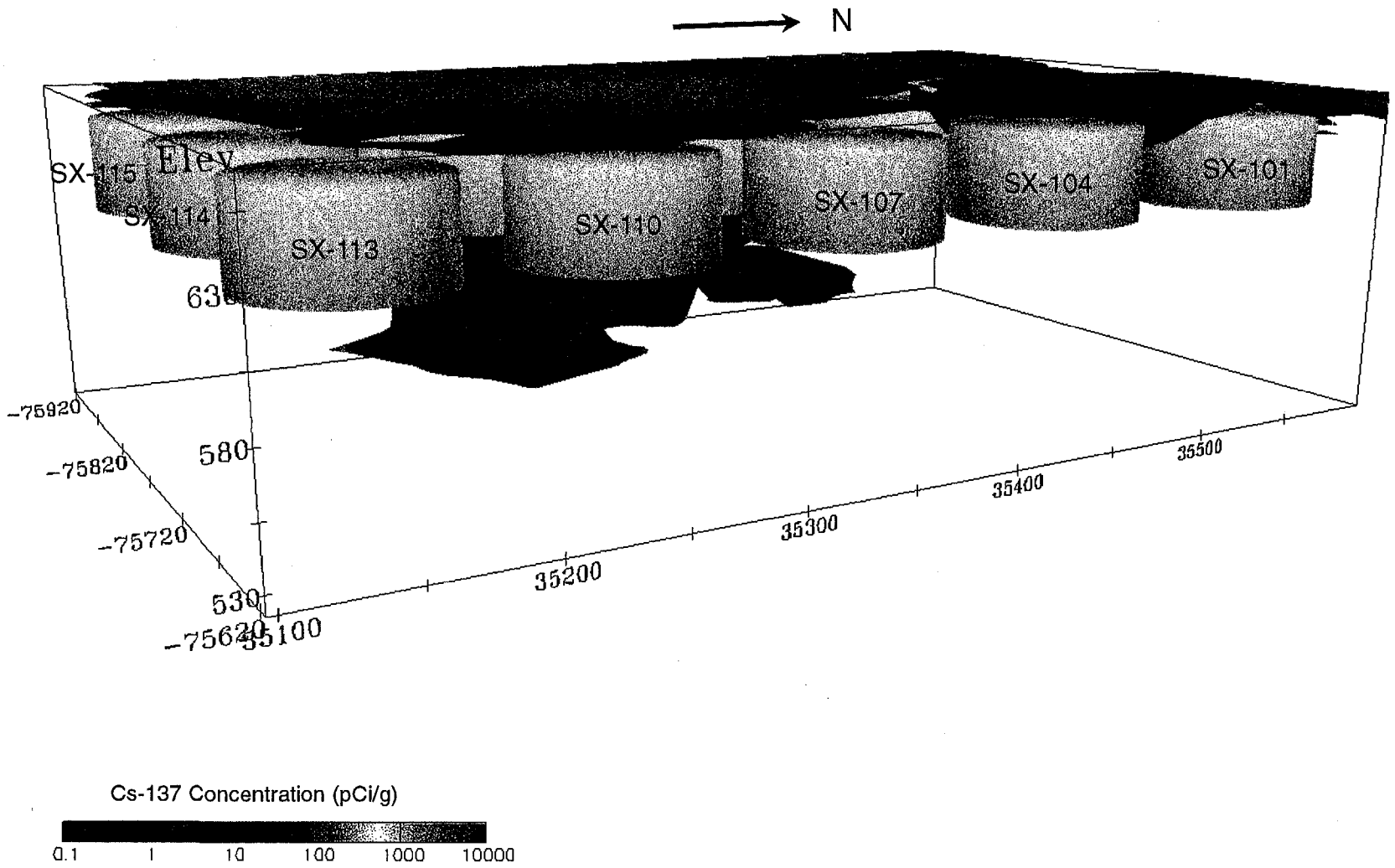


Figure 41. Visualization of the ^{137}Cs Contamination with an Isolevel of 10 pCi/g at the SX Tank Farm Viewed From the Southeast

Supporting this position is the fact that the surface contamination is highest in the vicinity of the deep ^{137}Cs contamination and the fact that at least one borehole (41-09-04) showed contamination inside the casing when it was swabbed before logging. The gamma-ray logs from some of the boreholes in the region, including boreholes 41-09-04 and 41-08-07, also show significant levels of contamination from the ground surface to TD at 75 ft, suggesting at least some continuity of contamination distribution. The distribution of ^{137}Cs contamination in borehole 41-08-07 is unlike any other contamination distribution. No explanation for this distribution can be postulated.

On the other hand, there is considerable evidence to suggest that the ^{137}Cs contamination deep in the vadose zone has migrated through the sediment to the 125-ft depth. Three tanks in this area leaked more waste into the vadose zone than any other tank-leak combinations. Possible leak volumes are up to 35,000 gal from tank SX-108, 250,000 gal from tank SX-109, and 30,000 gal from tank SX-112. A possible total volume of contamination in this area of 315,000 gal is three times the largest previously known leak volume (tank T-106). A comparison of the ^{137}Cs depth extent from the tank T-106 leak (100 ft) to the depth extent of the combined leak volume from the SX tanks (125 ft) provides a correlation demonstrating why the ^{137}Cs contamination is so deep at the SX Tank Farm.

Borehole 41-09-04 was deepened in 1972 from 75 to 105 ft, and the contaminated sediment was found by sampling and gross gamma logging. Likewise, borehole 41-12-02 was deepened from 75 to 125 ft, and some contaminated sediment was found, although the contamination assessment method is questionable and inconclusive. A subsequent gross gamma logging of the borehole showed high contamination levels down to the bottom of the hole. These gamma ray logs have retained the same basic shape over the years, suggesting no movement of contamination through time and no movement of contamination down the borehole after the logs were first run. It is possible that some contamination could have been driven down during the drilling operation, but it is not plausible that high levels of contamination would be found continuously from the bottom of the tanks to TD of the borehole.

Contamination was detected on the inside of the casing in borehole 41-09-04, but only near the bottom of the hole, indicating the contamination did not originate from the ground surface. If the high volume of contamination necessary to produce a large plume deep in the vadose zone had originated from the surface and moved down the borehole, the expectation would be that the entire length of the borehole would be contaminated.

Contamination in the SX Tank Farm is present in multiple boreholes, and this presence correlates well among the boreholes. Figure 42 shows the borehole logs for the region between tanks SX-108, -109, -111, and -112. A cursory review of the log data shows the ^{137}Cs contamination correlation among the boreholes.

The ^{137}Cs contamination model in the SX Tank Farm also shows good correlation, as shown statistically by the minimum and maximum extent plumes on Figure 43. This figure identifies the greatest and least extent of the statistical correlation according to the empirical geostatistical

model. In essence, the spatial correlation, which is based on and consistent with the behavior of ^{137}C in other plumes in the farm, shows that the boreholes correlate.

Data obtained under this baseline characterization work suggest that ^{137}Cs contamination may actually be in the formation at or below 125 ft in depth. Other data suggest the possibility that borehole communication could have occurred. However, an environmentally conservative approach is warranted in this case, and it is prudent to adopt the hypothesis that the ^{137}Cs contamination is deep and extensive in the vadose zone as suggested by the contamination visualizations. Contamination at this depth can then be considered in the operation of the tanks and in the development of remedial action plans. This hypothesis is adopted until further investigation confirms or denies it.

10.4 Geologic Correlations

Gamma-ray logs of naturally occurring ^{40}K, ^{238}U, and ^{232}Th were generated in an attempt to determine if there was any correlatable lithology in the upper vadose zone at the SX Tank Farm. Because all the boreholes in the SX Tank Farm are within the Hanford formation, only the natural gamma-ray character of the Hanford formation was determined.

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 that variations in lithology within the Hanford fine unit are mostly grain-size variations with little compositional variation and, thus, minimal changes in ^{238}U and ^{232}Th content.

At least one region within the Hanford fine unit appears to correlate among boreholes, as determined from similarities of the ^{40}K log. An attempt to create a model of the ^{40}K distribution was only partially successful, as shown by the crude model shown on Figure 44. This visualization shows a geostatistical correlation of the data in regions where the ^{40}K concentrations were above the calculated average. This model is of little use for cross-borehole correlations of the lithology.

An additional exercise to be accomplished would be to develop a model of the change in ^{40}K composition rather than the absolute ^{40}K concentration. The concentration spatial gradient may be indicative of orogenic processes that created the Hanford formation, and they may be correlatable.

10.5 Correlation of Nongamma-Emitting Radionuclides and Review of Tank T-106 Data

Because only spectral gamma-ray logging was performed at the SX Tank Farm, and essentially only ^{137}Cs was detected, this characterization is of limited value in determining the nature and extent of contamination and in assessing the impacts and implications of the contamination. Therefore, it is helpful to correlate the SX Tank Farm data with data from other tank farms and with drilling and sampling data.

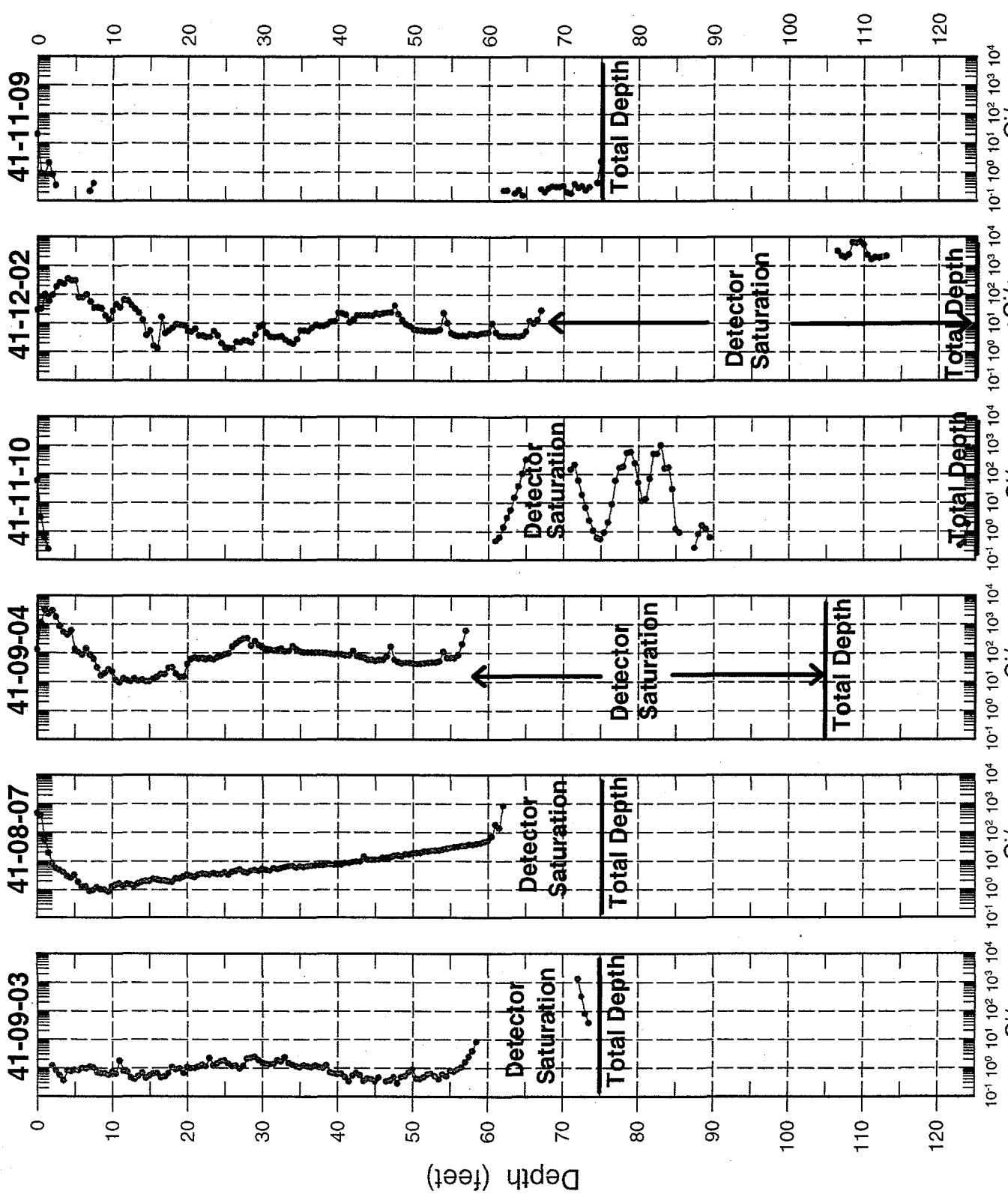
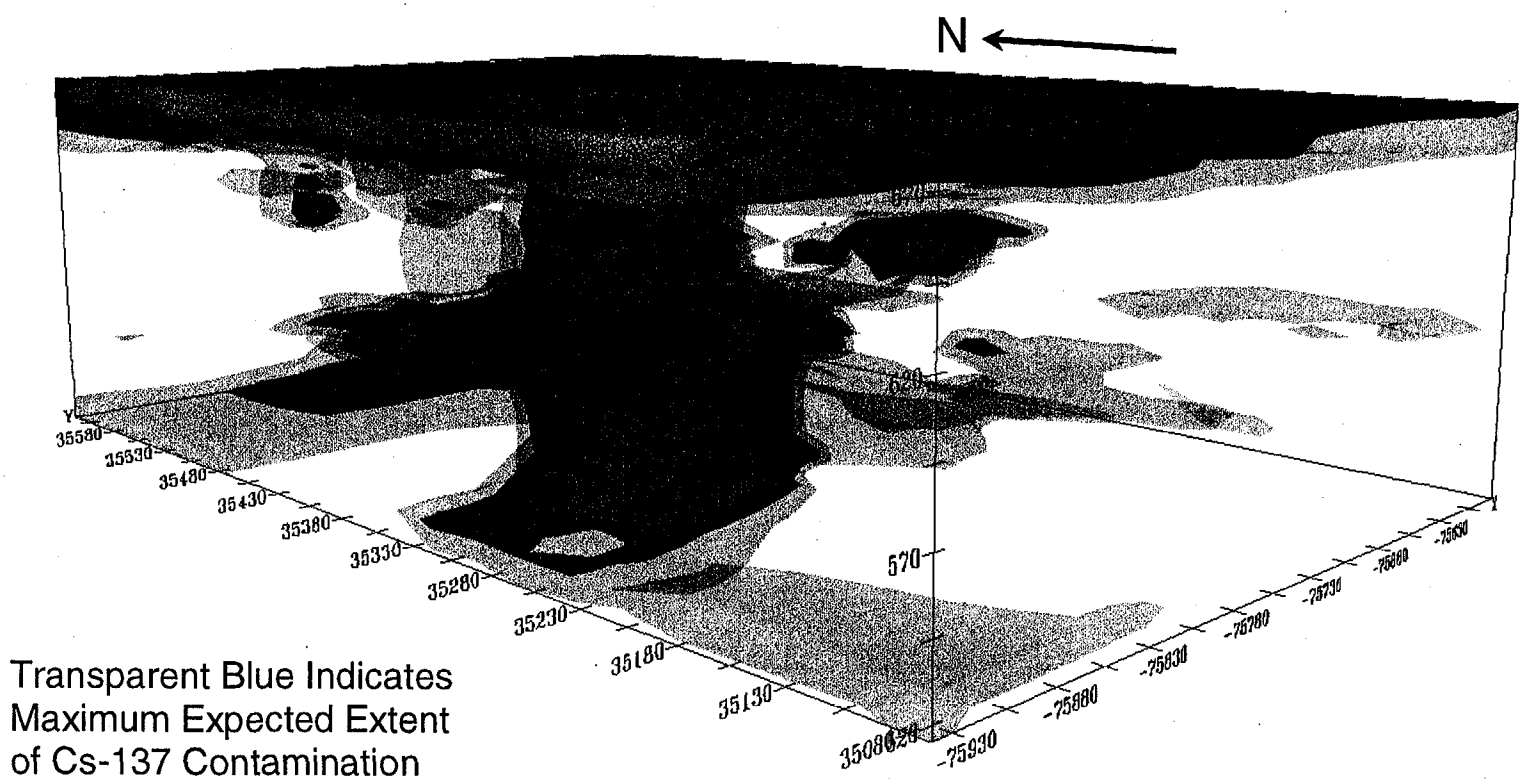


Figure 42. Borehole Log Data Correlation Plot for the Largest ^{137}Cs Plume in the SX Tank Farm



Transparent Blue Indicates
Maximum Expected Extent
of Cs-137 Contamination

Solid Blue Indicates
Minimum Expected Extent
of Cs-137 Contamination

Figure 43. Visualization of the Minimum and Maximum Extent of the 0.5 pCi/g ^{137}Cs Plume

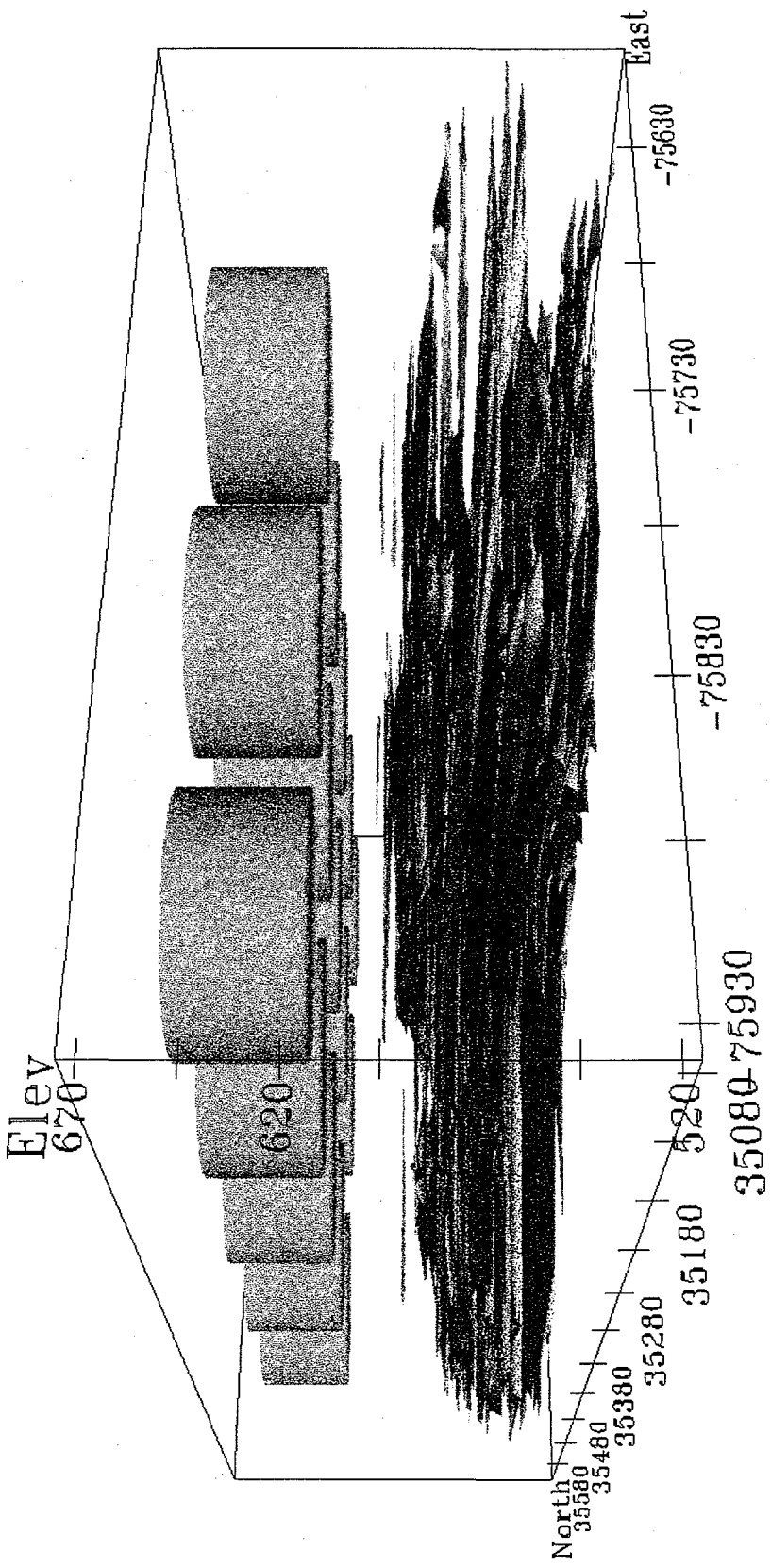


Figure 44. Visualization of the Above-Average ^{40}K Concentration at the SX Tank Farm

Few data are available from other tank farms and the only other characterization work that provides information is recent drilling of a borehole in the T Tank Farm in the region of the T-106 tank leak. A summary of those data in Freeman-Pollard (1994) shows several interesting correlations.

Data reported in Freeman-Pollard (1994) were obtained with careful drilling and sampling methods, and the laboratory analytical methods were subject to some of the highest levels of quality control. Because of the high levels of quality control, this information constitutes some of the best drilling and sampling data obtained at the Tank Farms to date. The boreholes were also logged with a spectra-gamma logging system, permitting direct correlation of the passive gamma data with drilling and sampling data.

Tank T-106 contained high-level waste that differed chemically and in radionuclide concentration from the high-level REDOX waste in the SX tanks. However, because the T-106 waste was lower in NO_3 molarity, it would be considered to have a lower radionuclide migration potential. The T-106 tank also contained other waste not present in the SX tanks, including bismuth phosphate waste from the T Plant and other miscellaneous waste.

The following general correlations are made from data reported in Freeman-Pollard (1994). These correlations are not conclusive because they are based on data from only a single borehole. As more data become available in the future, the correlations can be refined.

The concentration profiles of plutonium, americium, neptunium, strontium, and europium all show the same general character, although their concentrations differ and the vertical depth extent differs among the nuclides. The differences in the nuclide concentrations in the formation may be due to differences in the concentrations of the nuclides in the fluid that leaked from the tanks or differences in the mobility of the nuclides in the vadose zone. Nevertheless, the similarities in the shapes of the profiles suggest similarities in the chemical or transport properties of these elements in the vadose zone sediment. This similarity suggests that ^{154}Eu, ^{152}Eu, and ^{237}Np, which can be detected with gamma-ray logging, might be used to help locate the other elements.

Plutonium has migrated a surprisingly far distance, contrary to what was previously understood to be representative of its behavior in the vadose zone. Previously the belief was that plutonium would drop out of solution as soon as it came in contact with the vadose zone sediment. Plutonium was believed to have a high distribution coefficient, indicating it would remain fixed on the sediment at the release point. Because plutonium was measured as deep as 100 ft at a significant level relative to its health-and-safety risk (4.6 pCi/g), the previous theories about plutonium migration through the vadose zone may need to be revised.

The ^{137}Cs distribution at the tank T-106 plume warrants discussion. Characterization work accomplished in the early 1970s did not define the extent of the contamination plumes because only the high concentrations of ^{137}Cs were defined. The assay equipment used for that work was not calibrated to an activity per mass unit, and the sensitivity of the measurements (MDA) was not adequate to define the extent of the low-concentration plumes.

The most recent work came much closer to defining the extent of the low-concentration ^{137}Cs distribution. The in situ logging system was calibrated and had a low-level detection sensitivity of about 1 pCi/g. However, according to the contamination distribution observed at the SX Tank Farm, this sensitivity may not have been adequate. If ^{137}Cs contamination is detected at a particular depth location at a low-concentration level, it is significant because ^{137}Cs is man-made and there is no "background" level. The SX Tank Farm logging work shows that ^{137}Cs concentrations as low as 0.5 pCi/g or less are significant relative to identifying the migration of that contaminant.

^{137}Cs was detected at relatively high concentrations in the new borehole near tank T-106 down to about 70 ft, which is about 30 ft below the bottom of the tanks. ^{137}Cs was also detected in the new borehole at lower concentration with a single data point in the Plio-Pleistocene unit at 92.5 ft. This single data point indicates ^{137}Cs has migrated deeper into the vadose zone, reaching the Plio-Pleistocene unit, and it may be slightly more concentrated within the Plio-Pleistocene unit and have moved horizontally from the main plume to be intercepted by the new borehole.

There is some question about the validity of the single data point where the peak detection was above the statistical spectrum noise level and the possibility that contamination could have been carried down the borehole. However, the samples extracted from the borehole above and below the single positive detection location showed apparent ^{137}Cs peaks in the spectra, but the peaks were too low in intensity to assay.

The observed distribution of the higher ^{137}Cs concentrations leads to the conclusion that ^{137}Cs is immobile in the vadose zone. However, if the extent of the ^{137}Cs plume were to be defined by the lower concentrations around the T-106 leak, it may lead to the conclusion that ^{137}Cs is much more mobile than previously believed, explaining the occurrence of ^{137}Cs in the Plio-Pleistocene unit.

It is also useful to compare the depth of ^{137}Cs contamination resulting from the tank T-106 leak with the depth of ^{137}Cs contamination at the SX Tank Farm. The tank T-106 leak was 115,000 gal, while the combined leak volume from the four tanks that created the deep plume at the SX Tank Farm could be as high as 315,000 gal. (see Sections 10.2.8, 10.2.9, 10.2.11, and 10.2.12). If ^{137}Cs was detected at a depth of 92.5 ft at tank T-106, it is not unreasonable to detect ^{137}Cs at the SX Tank Farm at a depth of 125 ft. It is reasonable to assume that ^{137}Cs would be detected even deeper at the SX Tank Farm. Unfortunately, the deepest borehole in the region of the extensive plume is only 125 ft deep.

Uranium also appears not to correlate with other elements and radionuclides. This radionuclide has a high mobility relative to all other radionuclides, but it appears to be concentrated in different locations and sediment layers than the other elements.

Cobalt, technetium, and nitrate/nitrite concentration profiles appear to correlate. They show similar distributions in the vadose zone, and all three also appear to be highly mobile. If this correlation is accurate, then ^{60}Co, which is a high-intensity gamma emitter, might be used to locate the presence of technetium and nitrates in the vadose zone.

These assessments and postulated correlations create a starting point for designing future investigations and characterizations. No work of this type has been done at the Hanford SSTs. In the future when a better database is developed, such correlations may be developed to the point that they can be used to predict concentrations of contaminants that are difficult to measure.

Currently, there is no conclusive way to relate the observations from the tank T-106 study to the distribution of contaminants at the SX Tank Farm. These correlations should be investigated if sample data are obtained in the future from the SX Tank Farm.

10.6 Potential Effect of Adjacent Cribs

Based on the distribution of ^{137}Cs from leaks from the SX Farm tanks, it is apparent that ^{137}Cs does not migrate far from the leak source in the horizontal direction relative to the distance between the SX Tank Farm and the adjacent cribs, even at low concentrations. The sources of all significant ^{137}Cs contamination plumes detected in the upper vadose zone beneath the SX Tank Farm are identified and the plumes are explained. It is not possible for high concentrations of ^{137}Cs contamination detected in the vadose zone to have originated from those crib releases and migrated extensive lateral distances through the vadose zone to be deposited at the SX Tank Farm. If this had occurred, major plumes would have been intercepted and detected in monitoring wells between the crib sites and the SX Farm. Therefore, it must be concluded that the SX Farm is the source of the vadose zone contamination beneath the farm.

A possibility exists that some of the more mobile radionuclides may be detected on top of the Plio-Pleistocene unit and that this geologic unit could have acted to promote the horizontal migration of water and mobile radionuclides away from the cribs. The vadose zone was not characterized down to the Plio-Pleistocene unit because of limited borehole access to that depth.

The continuity of the Plio-Pleistocene unit has not been established at the SX Farm, but outcrops of this unit show that it is highly discontinuous in horizontal extent. Therefore, it is unlikely contamination could migrate along the Plio-Pleistocene unit to any significant degree from the cribs to the SX Tank Farm.

11.0 Impacts and Implications of the Vadose Zone Contamination

11.1 Nature of Contamination

The primary gamma-emitting contaminant detected in the vadose zone beneath the SX Tank Farm is ^{137}Cs. Only minor quantities of ^{60}Co and ^{154}Eu were detected near the surface in isolated occurrences that could not be correlated among boreholes (see DOE [1995n and 1996f]). The sources of the ^{60}Co and ^{154}Eu contaminants are small surface spills or near-surface pipeline leaks. 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.

^{90}Sr contamination was believed to be present in some regions on the basis of an observed elevated low-energy continuum in the spectra that is indicative of bremsstrahlung radiation. However, recent spectral-shape factor modeling indicates that some of the previous assessments may not be supported. The current monitoring program is not able to distinguish the occurrence of ^{90}Sr from high concentrations of ^{137}Cs located within the formation at a point that is remote from the borehole. Future monitoring program enhancements using spectral-shape factor analysis may provide a means to positively identify the presence of ^{90}Sr.

Radionuclides are present in the vadose zone beneath the SX 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 ^{137}Cs. 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

The distribution of ^{137}Cs beneath the leaking tanks at the SX Tank Farm shows that when a tank leak is on the order of 10,000 gal or less, the ^{137}Cs contamination can be expected to remain near the bottom of the tank, where it spreads more in the horizontal direction than the vertical direction. Essentially, the contamination does not appear to "break through" to lower lying stratigraphic layers.

The total horizontal extent of the small, high-concentration plumes also appears to be minimal, as evidenced mainly by the contamination distribution around tank SX-115. Comparison of the data from multiple small sampling boreholes, from the gross gamma logs of the laterals, and from the spectral gamma logs of the vadose zone monitoring boreholes shows it is unusual for a plume of high ^{137}Cs concentration to extend far beyond the perimeter of the leaking tank.

For the large leaks of high ^{137}Cs concentration effluent, such as what appears to have occurred to create the large contamination plume at the SX Tank Farm or which could occur from a large release in the future at tanks SX-101 through SX-106, the ^{137}Cs may have initially migrated a farther distance than with small leaks, especially in the vertical direction. The ^{137}Cs contamination distribution observed in the SX Tank Farm suggests that ^{137}Cs migrates much farther under a high leak-volume condition than it did under low leak-volume conditions.

In the case of the large ^{137}Cs contamination plume, ^{137}Cs was probably transported to the maximum vertical extent (greater than 125 ft) at the time of the release. Once it reached the current position within the vadose zone sediment, it appears to have stabilized and not moved any farther. A review of the old gross gamma-ray logs for each borehole in the region of the large plume shows the high-concentration zones to be relatively stable over several decades. It is

suggested that once the contamination has reached a stable condition after a leak, rapid migration does not occur. Rather, radionuclide migration times are measured in tens of years rather than weeks.

Regarding the nongamma emitters, data acquired with the current logging operation do not permit postulating the maximum extent of these radionuclides. The only data available for any of the tank farms are from one borehole from the tank T-106 study, and it would be inappropriate to postulate on the migration of these nuclides from one study.

11.3 Stability of Contamination

Only one region has been identified with short-term contamination migration. Gross gamma-ray logs of boreholes 41-09-09 and 41-00-08 in the region located on the west side of tank SX-109 show increasing trends in the spatial peaks. Figure 30 shows the change in the grade-thickness product from a spatial peak at 73.5 ft in borehole 41-09-09 from 1986 to mid-1989. The temporal curve is erratic because of depth-measurement problems with the logging system, but the trend in the data can be seen.

This is clearly a dynamic situation caused by the movement of ^{137}Cs that does not represent an example of the long-term stability of the contamination. Rather, this dynamic situation probably represents a continuation of a slow leak of the remaining liquid (48,000 gal) in tank SX-109. These data suggest a continued leak because this significant movement of contamination would not continue over such a long time period without some driving force. Other than a leak from the tank, there is no significant driving force for contaminant migration. Moisture infiltration probably would not produce a moisture flux adequate to cause the ^{137}Cs movement indicated by the gross gamma logs. More recent data from this borehole have not been made available for an assessment of current trends. If infiltrated moisture was the cause of the contamination migration, there is no explanation why it would occur only at the one location within the SX Tank Farm but not at other contamination plumes.

No data are available at this time to quantify or to determine the long-term stability of the contamination in the vadose zone beneath the SX Tank Farm. If the contamination is moving, that movement is so small that it cannot be quantified by the gross-gamma logging systems. The only baseline data available are from the gross gamma logging. Because of the low sensitivity of those systems and the poor spatial control, small changes in the contamination distribution cannot be quantified.

The spectral gamma logging work has now established the baseline of the current contaminant distribution. In several years, these boreholes could be relogged to determine if there are small changes in the distribution of the ^{137}Cs that may be indicative of diffusion described migration.

From a review of the gross gamma log data, the ^{137}Cs contamination appeared to move rapidly after each leak to its current location within the vadose zone sediment. Once a leak ceased, the ^{137}Cs contamination appeared to stabilize and adsorb or otherwise become relatively fixed in the sediment.

There is no evidence from the gross-gamma-logging historical data of contamination movement down the monitoring boreholes. This assessment is based on a limited database of gross gamma logs. Future review of all gross gamma logs for all boreholes may provide some conclusive evidence that this downhole movement did occur. Until that evidence is produced, the possibility of contamination moving down the outside of borehole casings will remain speculative.

A definitive statement cannot be made about the stability of radionuclides that do not emit gamma rays because they were not assessed in this project. Nongamma-emitting radionuclides must be studied by alternative sampling methods.

11.4 Impacts to Groundwater

The characterization of the ^{137}Cs contamination distribution in the vadose zone has not provided evidence that the SX Tank Farm has impacted the groundwater, because the monitoring boreholes do not extend down through the greatest vertical extent of the contamination and the deeper vadose zone was not characterized. In addition, the relationship between ^{137}Cs and other more highly mobile radionuclides has not yet been established. Consequently, there is no way to assess the potential for mobile radionuclides to impact the groundwater from the distribution of ^{137}Cs in the upper vadose zone.

As of this date, groundwater monitoring data provide the only evidence of groundwater contamination. Appendix B presents the groundwater contamination monitoring data provided by the WHC RCRA groundwater monitoring program. Those conclusions indicate that ^{99}Tc contamination in the groundwater may have originated from within the SX Tank Farm. A recently released RCRA groundwater assessment plan (Caggiano 1996) shows that element ratios of contamination constituents in the groundwater suggest two different contaminant populations are present. High ^{99}Tc/U and low $^{3}H/^{99}Tc$ ratios beneath the SX Tank Farm contrast with the contaminant populations beneath the surrounding cribs. This supports the hypothesis that the SX tanks have impacted the groundwater. Additionally, the detection of chromium in the groundwater provides conclusive evidence that the tanks have impacted the groundwater.

No cribs or subsurface effluent release sites are located within the SX Tank Farm. Contamination originating from surface spills does not appear to have migrated deep into the vadose zone sediment. Therefore, the only likely source of the groundwater contamination is leaks from the tanks.

The ^{99}Tc contamination detected in the groundwater is at concentrations below drinking water standards. Previous documents including DOE (1993) and Dresel et al. (1995) attribute the contamination to nearby waste sites. Now that chromium has been detected and a zone of high ^{137}Cs concentration has been detected near tanks SX-109 and SX-112, the SX Tank Farm is considered a source of groundwater contamination.

The exact origin of the ^{99}Tc in the groundwater at SX Tank Farm remains to be conclusively resolved under the RCRA groundwater assessment plan.

12.0 Use of Data/Interfaces

12.1 Operations

The vadose zone characterization of the SX Tank Farm was completed to support the interim operation, retrieval, and closure of the SSTs, and a baseline of some of the vadose zone contamination distribution is now established. That baseline will be used to compare future monitoring data to determine if changes have occurred and to evaluate the potential causes of the changes.

Most SSTs that contain any appreciable amount of liquid are presently monitored with in-tank leak detection equipment. In-tank leak detection is the best method of detecting leaks from the tanks because it provides the highest leak-detection precision.

However, if a leak occurs, it is useful to confirm the leak with other monitoring methods such as by detecting the contamination in the vadose zone sediment. Now that a baseline of the vadose zone contamination is established, new tank leaks can be detected or verified.

The DOE is also required by RCRA to determine the nature and extent of contamination that leaks or has leaked from the tanks. Those determinations have now been accomplished for past leaks, and the nature and extent of any new leaks can be determined by comparison with an established baseline.

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

Hard copies of the visualization of ^{137}Cs contamination model are published in this report, illustrating the contamination around the tanks (see Section 9.0, "^{137}Cs Contamination Model Development"). In addition, the ^{137}Cs contamination model is available with the visualization software so that a visualization of any area of the SX Tank Farm can be generated.

All log data are maintained in a database. Because the logging instruments are calibrated to an in situ radioelement concentration, the borehole log data are available for comparison with concentration data that could 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 are governed by RCRA. As required by RCRA, a 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 under NEPA include two that would likely

involve soil remediation ("clean closure" and "modified closure") and one that would not ("landfill closure").

This vadose zone contamination baseline characterization provides data needed to understand the scope of the vadose zone cleanup issues. Data provided in this document can also be used in feasibility studies to evaluate the cost and potential effectiveness of various closure options.

Additional data on the total vertical extent and on the distribution of nongamma-emitting radionuclides may also be required to satisfy the data needs of the SST closure process.

Some amount of contamination is expected to leak from the tanks during waste retrieval operations. Previous studies of the impacts of any waste retrieval operations have assumed that no tank leaks have impacted groundwater. Based on the groundwater monitoring data and on the apparent extent of migration of ^{137}Cs, this assumption will need to be re-evaluated. The current baseline of the vadose zone ^{137}Cs contamination distribution will provide a basis to determine those impacts.

12.3 Groundwater Protection and Remediation

Vadose zone contamination is the largest, most significant source of contamination reaching the groundwater at Hanford. Most of the groundwater contamination at Hanford resulted from releases to the vadose zone at the cribs and other waste sites. This characterization of the vadose zone at the SX 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 SX 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 1995b) 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 1995c) assumed that no groundwater contamination originated from vadose zone contamination from the SSTs. The vadose zone characterization data presented in this report can be used to revise the conceptual model of the groundwater.

12.4 Environmental Monitoring Reports

Since early 1943, radionuclide contamination was released at Hanford into the air, surface water, groundwater, surface sediment, and the vadose zone sediment. The risks associated with those releases varies 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 and groundwater, surface sediment, and subsurface sediment. For economic reasons, environmental monitoring programs justifiably place more emphasis on monitoring environmental media that compose pathways that are most likely to cause an exposure or those that have a higher exposure risk.

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

As work begins on remediation of the site and plans are prepared, more information will be 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 SX Tank Farm is the first such characterization report for the SSTs. It is necessary, therefore, to summarize and to report the results of this work in other Hanford characterization and monitoring reports so that the information is 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). That report 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 1994b). 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.

It is also necessary to report the results of this study in the *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities* (DOE 1995a). That report is required by RCRA and provides a summary of the results of each year's groundwater monitoring around the SSTs. Because the focus of that report is groundwater monitoring and because the source of groundwater contamination at the SSTs is the vadose zone contamination, it is important to report on those sources. Providing a review of the vadose zone contamination around the SX Tank Farm will be particularly important for the current year report, because pursuant to the RCRA, the Washington State Department of Ecology requires DOE to assess the source of groundwater contamination beneath the SX Tank Farm. Once placed in an assessment mode, the groundwater monitoring program must determine the full extent of the vadose zone

contamination to determine conclusively if this contamination has been or is contributing to the groundwater contamination.

The last environmental monitoring report in which the SX Tank Farm vadose zone characterization information should be reported is the Hanford sitewide groundwater monitoring report (Dresel et al. 1995). That document is not intended to provide a full report on the vadose zone contamination, but because it identifies groundwater contamination sources, the next annual report should identify the SX Tank Farm as a likely source of ^{99}Tc, and it should reference this SX Tank Farm vadose zone characterization work.

13.0 Conclusions

Ninety-five vadose zone boreholes in the SX Tank Farm were logged with a SGLS, and gamma-emitting radionuclide concentration data were generated at 0.5 ft-intervals, creating 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 context so it can be used for tank operations and remediation.

An empirical ^{137}Cs contamination distribution model was created with the geostatistical tools available in a commercial software package. That model was used to create the visualizations of the contamination distribution. Those visualizations were reviewed, interpreted, and discussed in this report.

The geostatistical software and the visualizations are powerful tools for use in the assessment and interpretation of borehole contamination data. Those tools made it possible to identify ^{137}Cs contamination zones and identify contamination sources. False plumes were segregated from actual vadose zone contamination and in some cases the contamination was related to the histories of the various tanks. The information on the contamination distribution beneath the SX Tank Farm can now be used by operations, various monitoring programs, and personnel responsible for tank closure.

Interpretation of the logging data was not easy or conclusive in some cases. Questions remain about the true nature and extent of the ^{137}Cs contamination. However, a high-quality database now exists for the ^{137}Cs distribution beneath the SX Tank Farm, and a baseline is established. Future monitoring can be conducted to determine if the contamination is moving, where the contamination is going, and if additional sources are present. The database will be made available to other Hanford programs in the near future.

In most cases, the assessment of the ^{137}Cs contamination model confirmed the leak status of the tanks. Adequate evidence from the vadose zone contamination distribution suggests that tank SX-102 also leaked. For tank SX-104, the data did not show that a leak had occurred. Tank SX-104 would not be listed as a leaker if the leak designation criteria were only based on the SGLS log data.

A review of the gross gamma log data suggests that tank SX-109 may still be leaking what liquid remains in the tank. The increase in ^{137}Cs concentration around the monitoring boreholes has been too much for too long to be attributed to redistribution of existing contamination.

In general, high-concentration ^{137}Cs contamination plumes have high-concentration gradients at the plume fronts. This high-concentration gradient is apparent in results from sediment sampling and assays and in the vertical SGLS log profiles. Regions of lower ^{137}Cs concentrations, however, do not have high gradients. In some ways, this distinction suggests more than one transport mechanism.

^{137}Cs was detected in the largest plume at high concentration at the bottom of several boreholes, the deepest of which is 125 ft. The conclusion is that this contamination was most likely transported to that depth through the vadose zone sediment; it could not reach that depth at those concentrations by moving down the borehole casing or by being driven down during drilling operations. Some minor redistribution of contamination may have occurred during or after the boreholes were drilled, but gross gamma logging showed it was not enough to appreciably change the contamination profile. Considering the collective volume of the leaks from the tanks in the region of the deep plume, the occurrence of ^{137}Cs at 125 ft is consistent with conditions found at the tank T-106 leak.

The total vertical extent of ^{137}Cs contamination is not known and was not established with this project because high concentrations of ^{137}Cs were detected at the bottom of the boreholes that define the largest contamination plume. The effect of the Plio-Pleistocene unit on the distribution of contamination at the SX Tank Farm also remains unknown. The horizontal extent of ^{137}Cs contamination at the SX Tank Farm is defined by the contamination model to the extent possible with the existing monitoring boreholes.

The nature and extent of nongamma-emitting radionuclides remains unknown. This project did not attempt to assay many of the radionuclides that may be important for risk assessments. On the basis of an initial correlation with the tank T-106 contamination distribution, the ^{137}Cs contamination distribution provides an indication of where the other contaminants might be located.

The impacts of the SX Tank Farm operation on the groundwater were not conclusively defined by this work. However, other reports have used groundwater monitoring data to establish that the groundwater beneath the SX Tank Farm is contaminated with ^{99}Tc, and the SX Tank Farm may be the source (Appendix B). Because the vadose zone boreholes do not extend into the deeper subsurface, the source of the groundwater contamination cannot be determined from the vadose zone contamination distribution. By identifying the significant vertical extent of ^{137}Cs, a relatively low-mobility radionuclide, the vadose zone characterization work indicates that the SX Tank Farm is a possible source of the mobile ^{99}Tc detected in the groundwater.

14.0 Recommendations

14.1 Tank and Farm Characterization Data

It is recommended that additional work be performed to collect, catalog, assess, and analyze historical documents, publications, and records about 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 data about the tanks have never been assessed. A good example is the Tank Farms gross gamma logs. Thousands of logs could be made available for use in the assessment of the vadose zone contamination. These data will help to define the movement of contamination and to identify sources.

Some good and significant work on collecting historical data was initiated with the publication of the multivolume data set referenced as 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 content information, including more of the previously classified records. 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. If the unplanned-release reporting system is intended to report all SST leaks, that reporting system should be updated, and the Environmental Sites Database (formerly called the WIDS database) should be expanded to include all SST leaks.

On the basis of the vadose zone ^{137}Cs contamination distribution, tank SX-102 should be reclassified as a leaker. In addition, the vadose zone characterization data do not indicate tank SX-104 has leaked; therefore, that tank's leak status should be reassessed.

It is recommended that the effects of the asphaltic layers on the SX tanks be evaluated to determine precisely how or if they caused the bottom liners to bulge. In addition, the asphaltic layers have been identified as a significant potential source of organic vapors or organic liquid in the tanks. Potential impacts of the organics on tank waste or tank safety should be evaluated.

14.2 Improvements to Spectral Gamma Logging

Implementation of improvements to the current spectral gamma-ray characterization project are recommended. Better characterization of the vadose zone would be possible if the high-gamma flux zones were assayed. The SGLS detectors have a relative efficiency of 35 percent and are saturated when the ^{137}Cs concentration is about 10,000 pCi/g. These high-efficiency detectors were originally selected to make the logging operations faster and more economical, and they have proven to be an excellent choice. However, it would be advantageous to implement a low-

efficiency detector system and to assay the high-concentration zones, thus, identifying the radionuclides in these zones and characterizing them for future comparisons. In this manner, it would be possible to quantify changes in the high-concentration zones caused by continuing leaks from the tanks, such as with tank SX-109.

It is recommended that a spectral-shape factor analysis method be implemented. This method is not a simple analytical technique that produces unequivocal interpretations, and it will produce mixed results in some cases. However, when the data are interpreted with an understanding of the inaccuracies and uncertainties of the theoretical basis of the method, it will help to explain some of the contamination distribution patterns, sometimes conclusively. The development of a spectral-shape factor analysis system has begun.

It is also recommended to log all the laterals beneath the SX Farm tanks. This logging can be accomplished using either a specially designed germanium logging tool or a sodium-iodide SGLS. For the most part, the primary gamma-emitting contaminant beneath the tanks has been identified as ^{137}Cs; therefore, a sodium-iodide characterization system may be adequate. The system must have the appropriate sensitivity and must be properly calibrated to provide the in situ radioelement concentration. This information will help fill in gaps in the data and further define the contamination plumes beneath the tanks. The data generated would fill in data gaps in the contamination model and help improve the accuracy of the visualizations.

14.3 Additional Logging Characterizations

Other borehole geophysical methods are recommended for development and implementation at the Tank Farms to provide better characterization data. Borehole geophysical methods are emphasized for characterization even though they do not provide all the required characterization data. These methods are used because they are cost effective 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 to implement a project to log all the boreholes with an effective moisture assay logging tool. Like the SGLS logging systems, a moisture logging tool 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 determined 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 tool must be designed to remove the effect of the near-hole variations in density. To date, no formation bulk-density tool 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 tool must be developed. It is recommended that such a tool be developed and used for the additional baseline characterizations of the SST farms.

It is also recommended to obtain carbon/oxygen logs of the SX Tank Farm boreholes. This type of log will show variations in the calcium carbonate content that change with changes in the lithology. This tool would be a useful tool for lithologic correlation. Great care must be taken to calibrate the tools for the unique borehole environment at Hanford and to operate, analyze, and interpret the data.

14.4 Additional Vadose Zone Characterizations

This report describes an initial vadose zone characterization at the SX 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. It is therefore recommended to perform additional characterization of the upper portion and the lower portion of the vadose zone.

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.

Characterization of the upper vadose zone should include a characterization of the sediment chemistry. Knowledge of sediment chemistry 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 if and to what extent contaminants have moved down the borehole casings in the SX Tank Farm. It is necessary to make a conclusive determination of the borehole effects for the largest, deepest plume in the SX Tank Farm.

To fully characterize the upper vadose zone, it is necessary to drill at least one borehole through the deep ^{137}Cs contamination plume. This drilling operation must permit acquisition of sediment samples that can be assayed to determine radionuclide content and basic sediment chemistry with the same procedures used to characterize the contamination plume from the T-106 tank leak. The drilling must be performed in such a manner to alleviate concern about contaminants being driven down the borehole during the drilling operation and to ensure the samples are not cross-contaminated. This borehole should also be logged with the SGLS to provide high spatial resolution data that will fill in the gaps between data points and provide new correlation data.

One borehole placed at the center of the contamination plume will provide much of the information needed to assess the quality of the geophysical logging characterization methodology presented in this report. This borehole should provide most of the data needed to begin developing correlations between the gamma-emitting radionuclides and other contaminants and

should conclusively determine the extent of contaminant migration down the boreholes in this region. An ideal location to drill a borehole would be close to borehole 41-12-02.

For the lower portion of the vadose zone, it is necessary to characterize the full vertical extent of the contamination at the SX Tank Farm to determine if and what contamination has reached the groundwater and to determine how the Plio-Pleistocene unit affected the migration of contaminants. It is possible and probable that this unit may have slowed the vertical migration of contaminants, causing the contaminants to move with the moisture along the top of the Plio-Pleistocene unit. The deeper vadose zone characterization must include assays of nongamma-emitting radionuclides and an assessment of the sediment chemistry.

Characterization of the deeper vadose zone can be accomplished by deepening some of the existing monitoring boreholes and by continuing the drilling of any new boreholes down into the Plio-Pleistocene unit. Samples of the sediment above the Plio-Pleistocene unit and samples of the water should be obtained and assayed in the laboratory to determine contaminant concentrations.

If an investigation of the top of the Plio-Pleistocene unit indicates contaminants have reached this unit, it is recommended to drill into the Ringold Formation unit below the Plio-Pleistocene unit to determine the vertical extent of mobile contaminants such as uranium, technetium, or nitrates. Once the vertical extent of the mobile contaminants is known, concerns regarding the source of groundwater contamination beneath the SX Tank Farm can be resolved. Again, all deepened boreholes or new drill holes should be constructed so they can be logged using high-quality borehole logging methods.

14.5 Future Vadose Zone Monitoring

It is recommended to implement a short-term vadose zone monitoring program at the SX Tank Farm. The purpose of the program would be to identify any contamination migration, to assist in the identification or verification of tank leaks, and to track the movement of contaminants over time.

A short-term monitoring system could use a suite of spectral gamma-ray detectors to cover a large range of gamma-ray flux encountered in the vadose zone. High efficiency sodium-iodide detectors would quickly produce logs of the low concentration areas, and low efficiency sodium-iodide detectors would be used to log the higher concentration zones. All the systems must be properly calibrated, data must be analyzed in a manner consistent with analysis of data for the baseline characterization project, and the data must be archived and made available to other Hanford personnel.

The highest monitoring frequency is recommended to monitor for verification of possible leaks from the tanks. Tanks that have an appreciable amount of drainable liquid in them should be monitored in this manner. Minimum monitoring frequency for leak verification purposes should be about once per month.

Longer period measurements are recommended for tracking the movement of contaminants in the vadose zone.

Tanks SX-101 through SX-106 all have more than 100,000 gal of drainable liquid remaining in the tanks. All the boreholes surrounding these tanks should be monitored, at least quarterly and possibly monthly. The in-tank liquid-level detection systems provide identification of catastrophic failure of liquid containment. However, a smaller, slower leak could occur and not be detected with the in-tank measurements. Such a leak might be detected by the presence of contamination in the vadose zone sediment.

Tank SX-107 currently contains only a minimal amount of drainable liquid, and quarterly monitoring is not necessary. However, because of the past dynamic conditions present in the vadose zone, it is recommended that this tank be monitored about once per year.

Tank SX-108 contains little drainable liquid, and there is no danger of extensive additions to the vadose zone contamination from this tank. Vadose zone monitoring for this tank over the longer term would enable tracking of any contamination movement.

A dynamic situation was encountered at tank SX-109, and this tank still contains about 10,000 gal of drainable liquid. Of all tanks in the SX Tank Farm, this tank should be monitored on a short-term basis. An appropriate monitoring frequency needs to be determined on the basis of quantified changes in concentration over time, but an initial monthly monitoring frequency is recommended.

Short-term vadose zone monitoring is probably not required for tank SX-110, because the tank does not contain any drainable liquid and there are no extensive contamination plumes beneath the tank.

Tanks SX-111, SX-112, and SX-113 contain little to no liquid, and short-term monitoring is not necessary. However, an annual monitoring frequency is recommended for the large contamination plume near tank SX-112 to detect any changing trends in the vadose zone contamination.

There still is a potential for the remaining liquid in the tank SX-114 to leak, so the vadose zone around this tank should be monitored on a quarterly basis.

Tank SX-115 has no drainable liquid left in it and short-term monitoring is not required.

It is also recommended that the characterization just completed at the SX Tank Farm be repeated in approximately five years to identify any changes in the contamination distribution and to determine the appropriate long-term monitoring frequency. Such monitoring could be appropriate as performance assessment monitoring because it would be conducted to demonstrate the validity of performance assessment models. It is important to prove the stability of any contamination that will be left in situ before feasibility studies are completed. Currently, performance of the leave-in-place option for the vadose zone contamination is not demonstrated.

It is recommended to seal and destroy all perforated boreholes in the SX Tank Farm. These boreholes may provide a pathway for movement of contamination down to the deeper vadose zone sediment. They were drilled when the farm was first constructed. Some of the drilling logs indicate these old boreholes were perforated, but some logs do not give any indication of borehole perforations. If necessary, a borehole television-camera inspection may be required to verify the perforations.

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Appendix A

Geology and Hydrology Data from Groundwater Monitoring Boreholes

DSI 2/26/96

To: Casey Ruud

From: Vern Johnsn

Subject: **REQUESTED INFORMATION ON Tc/U RATIOS IN GROUNDWATER, TANKS AND ADJACENT CRIBS AT AND IN THE VICINITY OF THE S-SX (TANK FARM) WASTE MANAGEMENT AREA (WMA)**

The Tc/U ratio plot that supports a statement I made in the WHC/Tank Farms occurrence report is attached. Please note that this figure was updated to include data for the most northerly monitoring well (2-W23-1) which was not included in the original plot. The anomalously high Tc/U ratio "core" seems to now extend into the S Farm and near the S-104 Tank (an assumed leaker).

As requested, I attempted to locate ratios for various adjacent cribs, but without much luck. I am attaching a "fact sheet" for Tank S-104 that includes ratios for leachate and wash solutions used to simulate the proposed sluicing process solutions. This data suggests that ratios over 300 would be expected for the wash and leachate from sludge. I am of the opinion that such solutions are more representative of the Tc/U ratios that would be present in liquid leaking from the tank than just the total or bulk ratio, as explained below.

The bulk composition of the sludge suggests a ratio of about 2.7. It should be noted, however, that most of the uranium in the sludge is probably bound as a relatively insoluble uranium phosphate phase. Thus the bulk ratio may not be very representative of the liquid waste assumed to have leaked to soil from S-104 (i.e., the uranium phosphate solid phase would have remained behind in the tank, thus significantly increasing the Tc/U ratio of the liquid leaving the tank as compared to the total or bulk composition ratio).

While it is difficult to state a precise expected Tc/U ratio for the liquid waste that is assumed to have leaked into the soil, it is more likely than not that it is fairly large and very likely is greater than 50.

The estimates for two of the adjacent cribs that could be past sources of technetium that may have migrated laterally under the tank farm are based on effluent records that Doug Hildebrand acquired. I am not sure of the data sources used but nevertheless, the apparent (average) ratios for the S-1/2 and S-3 cribs are 3.5 and 2.0, respectively.

Please note that the attached plot was based on some averaged data over a 4 yr period or so. I asked Bruce Ford to do an independent assessment of the ratio anomaly. His evaluation is attached and provides a time series view for each well. This supports the general conclusion that I originally made and also indicates some Tc/U ratios that are even as high as 750 (well 2-W23-15). The time series ratio data clearly illustrate that the wells near the S-25 Crib never had anomalously high ratios and thus could not be related to the technetium in wells near the SX tanks.

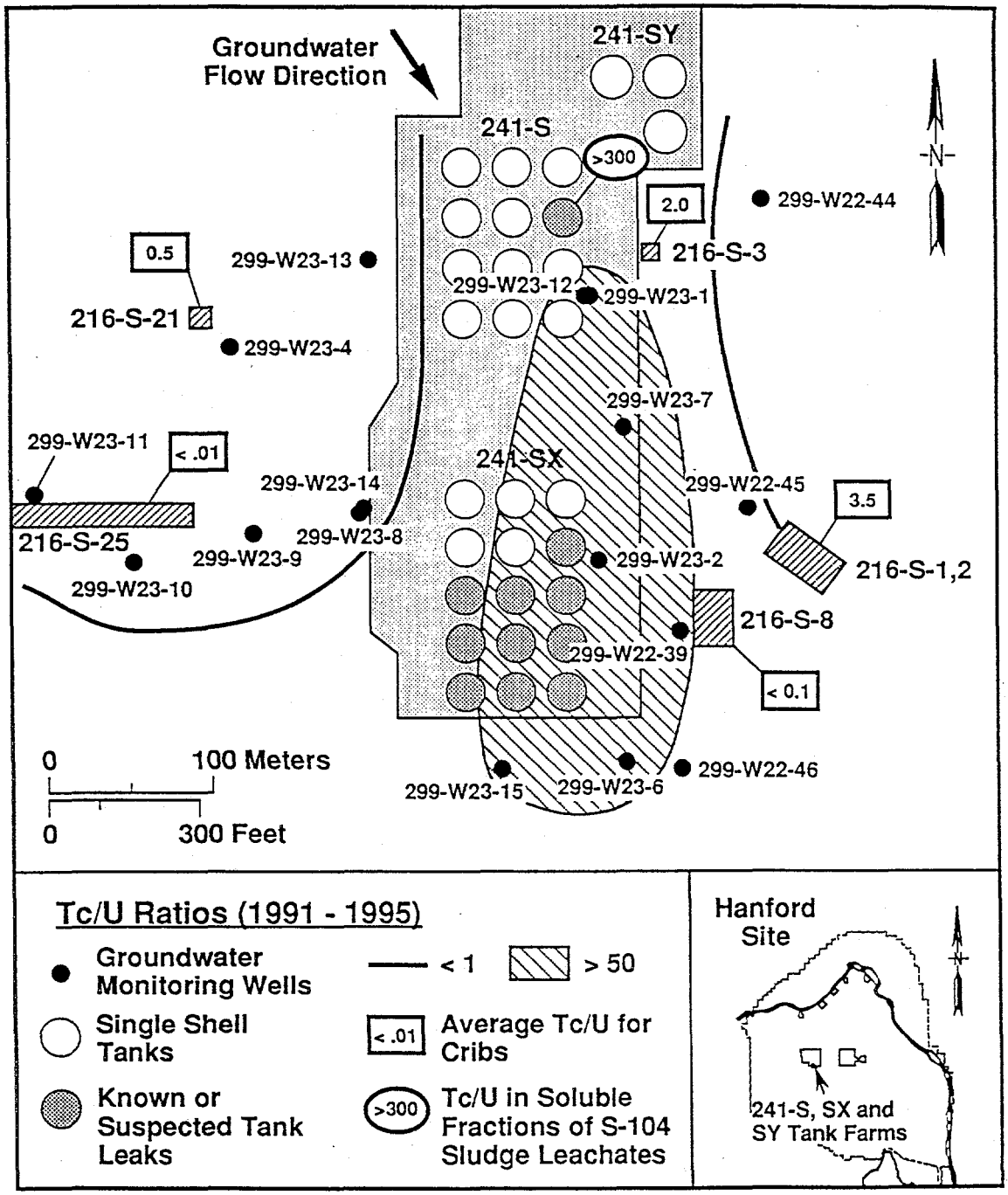
Finally, I need to emphasize that the bits and pieces of information we have assemblied at this time do not produce a solid picture of one source type standing out distinctly from alternate sources. Additional work will be needed to eliminate these uncertainties. Hopefully, a more definitive statement can be made at that time.

I hope the attached will be useful in your evalution of the tank farms.

Best regards,

Vernon G. Johnson, Ph.D.
Senior Principal Scientist
Environmental Sciences
Westinghouse Hanford Co.

Technetium/Uranium Ratio in Groundwater Near the S-SX Waste Management Area



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

WELL SUMMARY SHEET

Boring or Well No. 299-W23-14

Sheet 2 of 2

Location 200W/SST/299-SX Tank Farm
Project W-017
Elevation 661.00 Brass Cap (NGVD '29)
Drilling Contractor KEH
Driller L. Bultena
Drilling Method and Equipment Cable Tool
Prepared By Alan Pearson/Alan Pearson (Sign/Print Name) Date 2/5/91
Reviewed By [signature]/[signature] (Sign/Print Name) Date 8/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
8" Ø temporary carbon steel casing to 224.4' bls		170		SLIGHTLY GRAVELLY SAND
				" " "
		180		SLIGHTLY SILTY GRAVELLY SAND
				" " " "
Bentonite pellets 1/2"		187.0		" " " "
		190		
		192.4		
195.6		193.98		GRAVELLY SILTY SAND
4" Ø stainless steel, .010 slot (wire wound) screen		200		GRAVELLY SANDY MUD
				" " "
channel pak (Johnson)		210		" " "
		215.26		" " "
Sand Pack - Silica Sand 8-12		220		" " "
		223.7		" " "
		224.4		
		230		T.D. 224.4' bls

C-18

A-6000-384 (04/90

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

WELL SUMMARY SHEET

Boring or Well No. 299-W22-39

Sheet 1 of 2

Location 200W/SST SX Tank Fr. Project W017-SST

Elevation 665.26' Brass Cap N6W0'29 Drilling Contractor Kaiser Engineers Hanford

Driller DL Ludtke Drilling Method and Equipment BE22-14102 Cable Tool

Prepared By Stacey W. Callison (Sign/Print Name) Stacey W. Callison Date 2/14/91 Reviewed By DA Williams (Sign/Print Name) Date 8/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
				SAND
12" dia CS temporary casing (+0.9'-20.2')		10		GRAVELLY SAND
				SAND
Cement Grout		20		"
		20.2'		"
10" dia C.S. temporary casing (+1.1'-146.75')				"
		30		"
				"
8" dia CS temporary casing (2233')		40		"
				"
				"
		50		SILTY SANDY GRAVEL
				SAND
GRANULAR BENTONITE #8-20		60		SLIGHTLY GRAVELLY SAND
MESH				SAND
		70		"
				"
		80		"
				"
		90		"
4" ∅ STAINLESS STEEL CASING				"
				"
		100		"
				"
		110		"
				"
				"
		120		"
				"
		130		SILTY SAND
				"
		140		SLIGHTLY SILTY SAND
				SANDY SILT
		146.75'		SILTY SAND
		150		GRAVELLY SANDY SILT
				SLIGHTLY GRAVELLY SANDY SILT
		C-13 160		SILTY SAND

A-6000-384 (04/90)

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

WELL SUMMARY SHEET

Boring or Well No. 299-W22-39

Sheet 2 of 2

Location 200W | SST SX Tank Fr.
Project W017-SST
Elevation 665.26' Brass Cap NGVD'29
Drilling Contractor Kaiser Engineers Hanford
Driller DL Ludtke
Drilling Method and Equipment BE22-14102
Prepared By Stacey W. Callison (Sign/Print Name) Stacey W. Callison Date 2/14/91
Reviewed By DA Williams (Sign/Print Name) Date 8/21/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
Bentonite Crumbles 4-20 mesh		170		SILTY SAND
				SILTY GRAVELLY SAND
8" Temporary Carbon Steel casing to 224.3		180		" " "
				" " "
Top Bentonite Seal (1/4" Pellets) 192.6		190		" " "
Top Sand 196.3 (20-40 sand)				SLIGHTLY SILTY GRAVELLY SAND
Top Screen at 199.8'		200		" " " "
202.40 measured 2/21/91		205		SLIGHTLY SILTY SAND
Stain steel 4" 10 slot channel pack wire wrap		210		SLIGHTLY SILTY SANDY GRAVEL
				" " " "
		220		" " " "
Screen base set at 221.3'		225		SANDY GRAVEL
				TD 223.3'

C-14

A-6000-184 (04/90)

Westinghouse Hanford Company
Radionuclide Logging System Log Header

Project	RCRA (SX Tank Farm)	Log Types: HPGe Spectral Gamma-Ray
Borehole	299-W22-39 WID# A4970	

Borehole Environment Information

Borehole liquid depth none (ft) from Ground Level

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
12	0.36	0	20
10	0.32	0	147

RLS Passive Spectral Gamma Survey Information

Logging Engineer(s) R. V. Cram W. H. Ulbricht
Log depth reference at zero (0.0) depth is Ground Level

Log Date	Archive Disk Detector ID	Log mode	speed	Depth interval (ft) Top	Base	Incr
Jan 28, 1991	H2W22039\A019 RLSG1.0 (18%)	FIXED	0.4 fpm	0	92	0.5
Feb 3, 1991	H2W22039\A020 RLSG1.0 (18%)	FIXED	0.4 fpm	90	116.5	0.5
Feb 3, 1991	H2W22039\A021 RLSG1.0 (18%)	FIXED	0.4 fpm	116.5	156.5	0.5

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

Calibration and Analysis Information

RLS Calibration Date: Nov 28, 1990 (HPGe-18%)
Calibration Report: WHC-SD-EN-TI-292

Analyst Name(s): R. K. Price
Analysis Date: Feb 6, 1996

Analysis Notes: Well is by SX Tank Farm; and by 216-S-8 Crib.
Radionuclides Identified: No Man-made radionuclides detected.

RADIONUCLIDE LOGGING SYSTEM
Log Analysis Summary Report

Borehole: 299-W22-39 **Report Date:** Feb 6, 1996
Log Type: HPGe Spectral Gamma-Ray **Final Log Date:** Feb 3, 1991

General Notes:
The borehole was surveyed during drilling activities before the completion casing was installed. The well is by the SX Tank Farm and is about 75' from the 216-S-8 Crib.

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

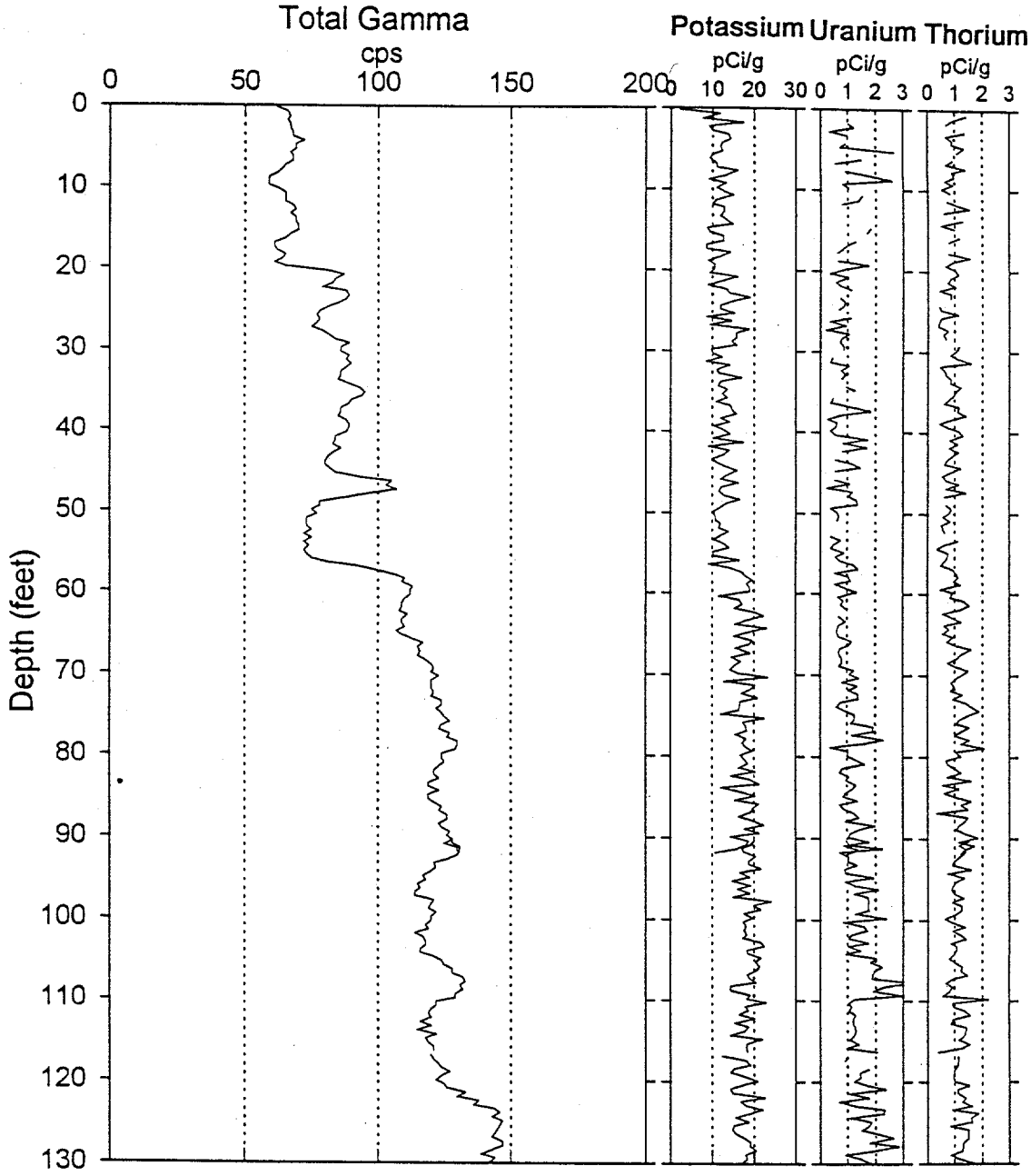
The 12-inch surface casing (to 20 ft) is identified on the Total-Gamma curve of the data plot by a depressed activity. Corrections to the potassium, uranium, and thorium concentrations have been applied. Field records indicate that the 10-inch casing drive shoe is located at 146-ft, it can be identified on the Total-Gamma curve plot as a decreased gamma activity.

No man-made radionuclides were detected in the high-resolution gamma-ray survey spectra.

RLS Spectral KUT Processed Data

Project: RCRA (W-017)
Borehole: 299-W22-39

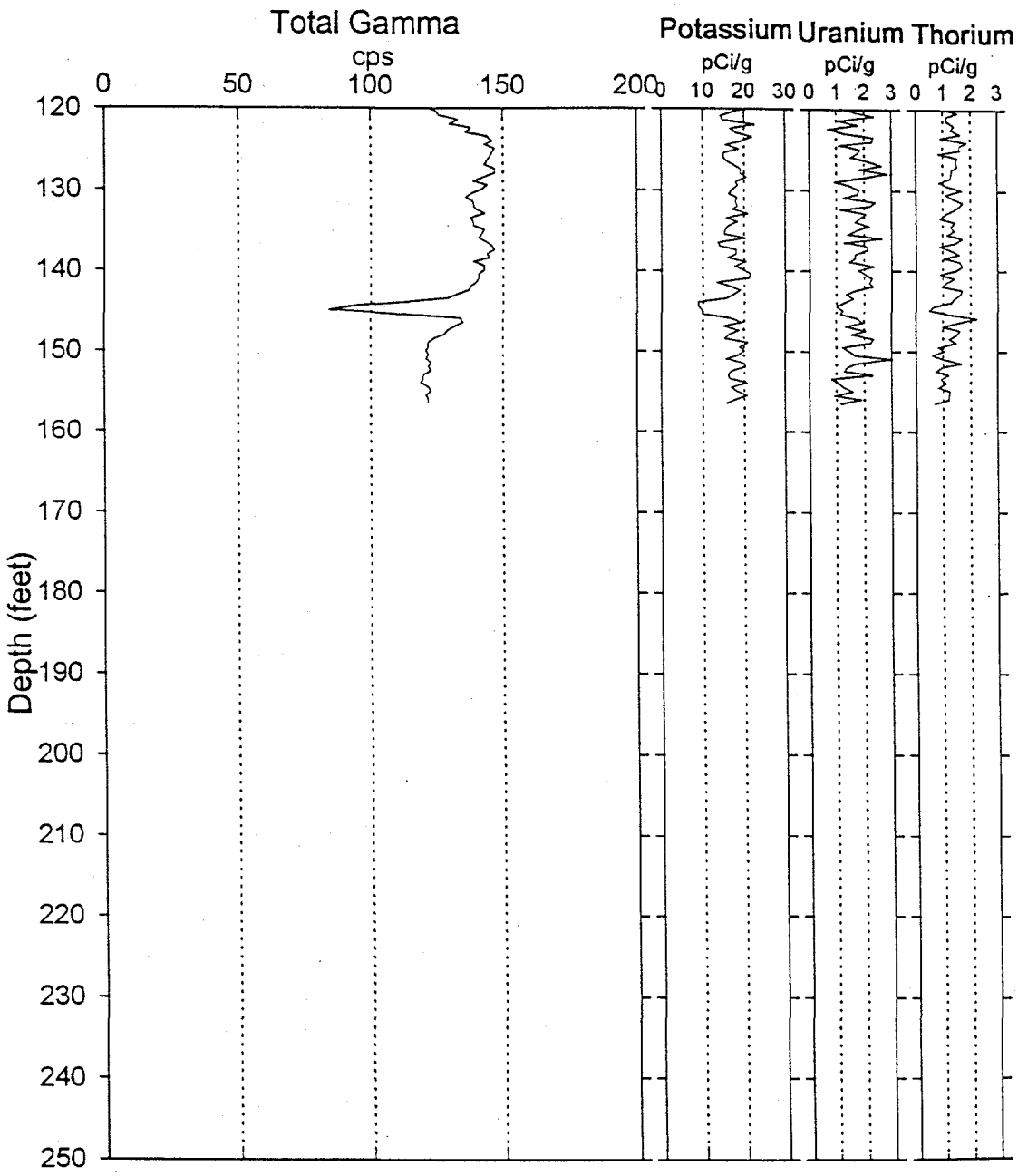
Last Log Date: Jan 30, 1991
Analysis Date: Feb 6, 1996
Westinghouse Hanford Company



RLS Spectral KUT Processed Data

Project: RCRA (W-017)
Borehole: 299-W22-39

Last Log Date: Jan 30, 1991
Analysis Date: Feb 6, 1996
Westinghouse Hanford Company



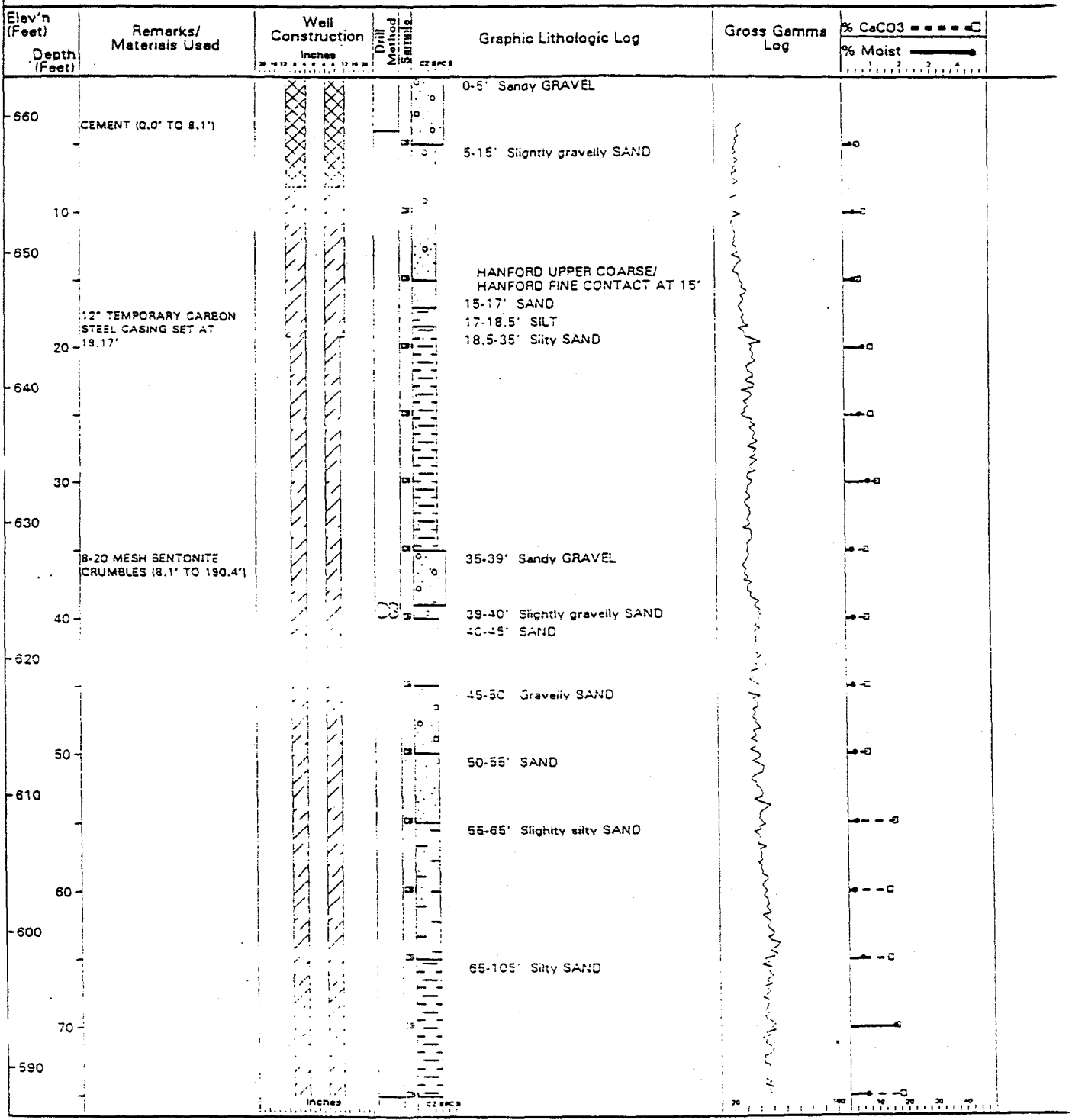
Project:	W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION	**Well No:**	299-W22-45		Page 1 of 3
		Total Depth:	240.00	Static Water Level:	201.30
Date Started:	7-15-92 Date Completed: 9-4-92	Surface Elevation:	662.97	Casing Elevation:	666.21
Location:	S-SX TANK FARM 200 WEST	Northing:	134293.51	Easting:	566945.16
Prepared By:	N BALLANTYNE, et al.	Hanford N:	35534.60	Hanford W:	75305.5
Drilling Co:	KEH Driller: K OLSON	Drill Meth:	CABLE TOOL	Drill Equip:	BE 22W

Screen: 35.79' OF 4" DIAMETER 20-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 198.11' TO 233.9'

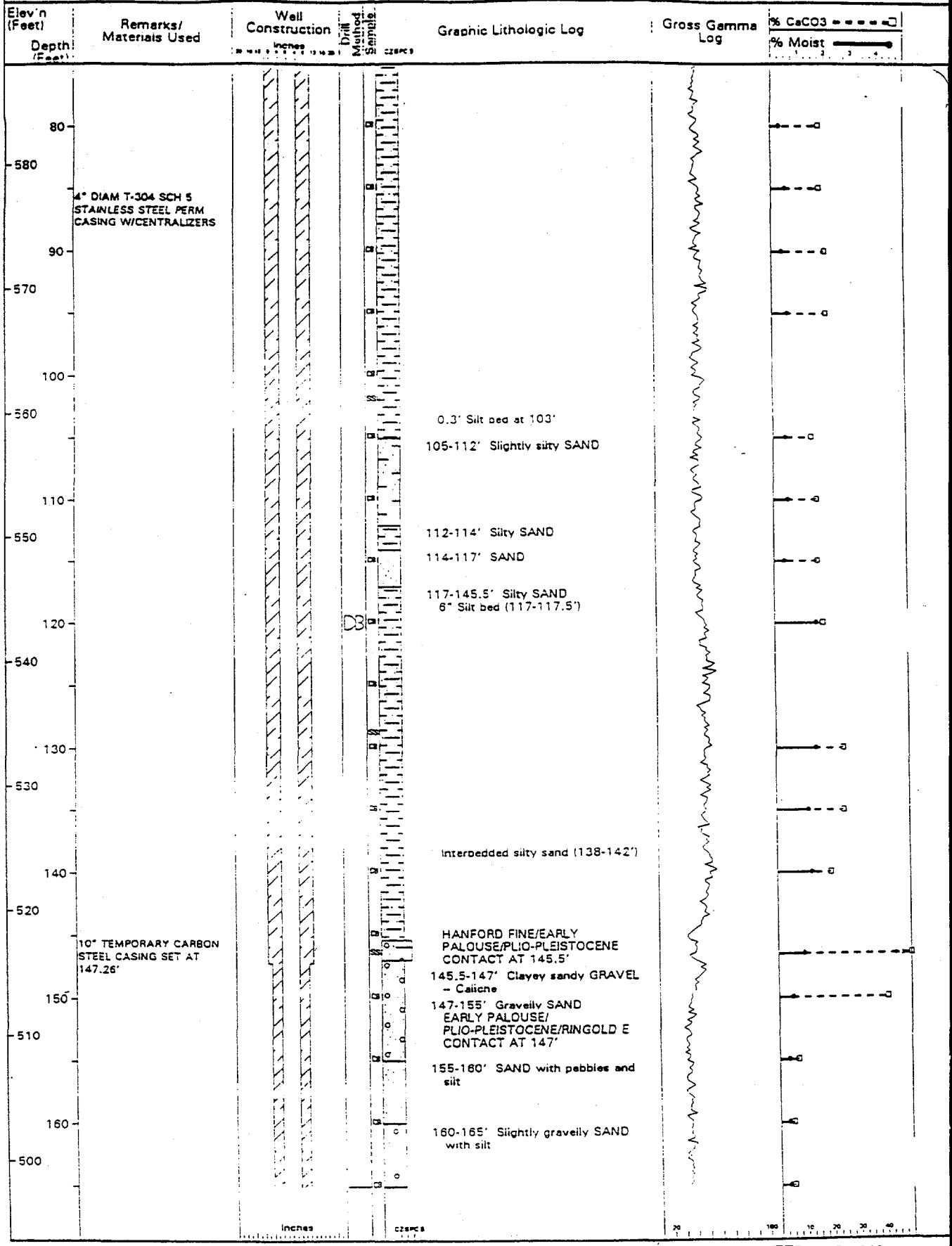
Filter Pack: 10-20 MESH SILICA SAND FROM 193.6' TO 239.0'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 198.11'

Comments: LITHOLOGY RENAMED ACCORDING TO PERCENTAGES LISTED ON BORE HOLE LOG FROM 155' TO 240'.



Reviewed By: KD Reynolds / KD Rey A-249 Date: FEB. 1 2 1999

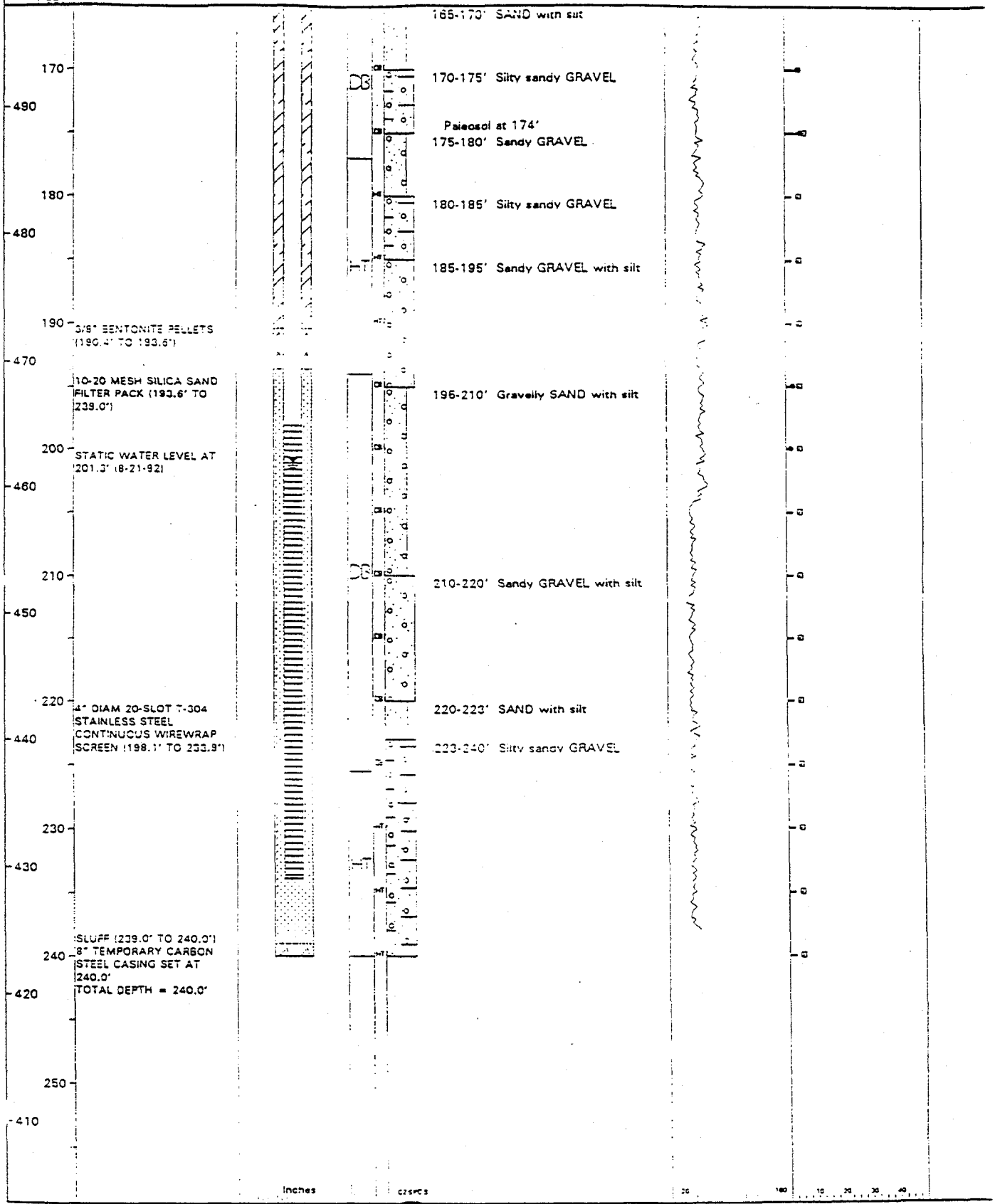


Reviewed By: KD Reynolds/ KD Rey Date: FEB. 12 1993

A-250

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

Well No: 299-W22-45



Reviewed By: KD Reynolds / KD Rue

Date: FEB. 12 1993

A-251

PROJECT NAME / # RCRA-W017-SST

WELL # 299-W22-45

LOCATION 200 WEST, S-SX TANK FARM

WELL DRILLING OPERATIONS	WELL COMPLETION OPERATIONS	WELL DEVELOPMENT ACTIVITIES
START DATE 7-15-92	START DATE 8-18-92	AQUIFER TEST DATE 9/2/92 9/4/92
FINISH DATE 8-14-92	FINISH DATE 8-21-92	
TOTAL DAYS 23	TOTAL DAYS 4	DEVELOPMENT DATE 9/12/92
TOTAL DEPTH 239.78'	COMPLETION DEPTH 239.0	
AVERAGE RATE 10.42 ft./Day	SCREENED INTERVAL 198.1'-233.9'	WATER REMOVED (gallons) 874
WATER ADDED (gallons) 217	WATER ADDED (gallons) 0	
DATE / DEPTH TO WATER 8-10-92 / 201.31' 8-12-92 / 202.70' 8-14-92 / 195.51 8-17-92 / 202.25	WATER REMOVED (gallons) 50	HYDROSTAR PLACEMENT DATE 9/4/92 - 9/12/92
	DATE/DEPTH TO WATER 8-19-92 / 201.94' 8-21-92 / 201.30'	DATE / DEPTH TO WATER 9/12/92 205.16' 9/4/92 205.12
OTHER	OTHER	OTHER

A-252

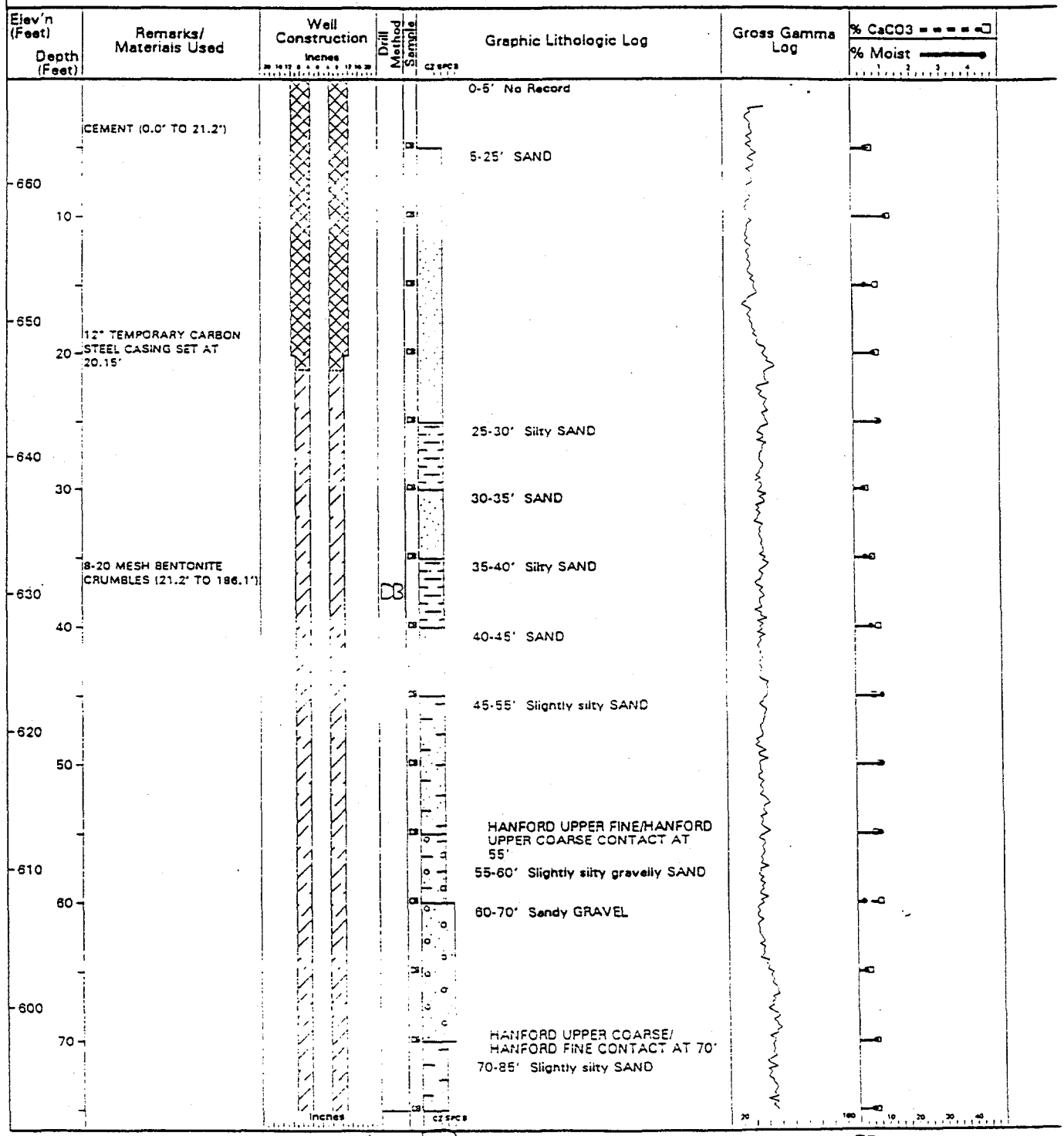
Project:	W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION	**Well No:**	299-W22-46
			Page 1 of 3
Total Depth:	241.00	Static Water Level:	205.90
Date Started: 9-24-91	Date Completed: 12-3-91	Surface Elevation:	667.60
Casing Elevation:	671.18		
Location: S TANK FARM, 200 WEST		Northing:	134127.84
Easting:	566903.85		
Prepared By: C WOLFE		Hanford N:	34994.20
Hanford W:	75442.60		
Drilling Co: KEH	Driller: M WRASPIR	Drill Meth:	CABLE TOOL
Drill Equip:			

Screen: 36' OF 4" DIAMETER 10-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 192.9' TO 228.9'

Filter Pack: 20-40 MESH SILICA SAND FROM 188.3' TO 238.7'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 192.9'

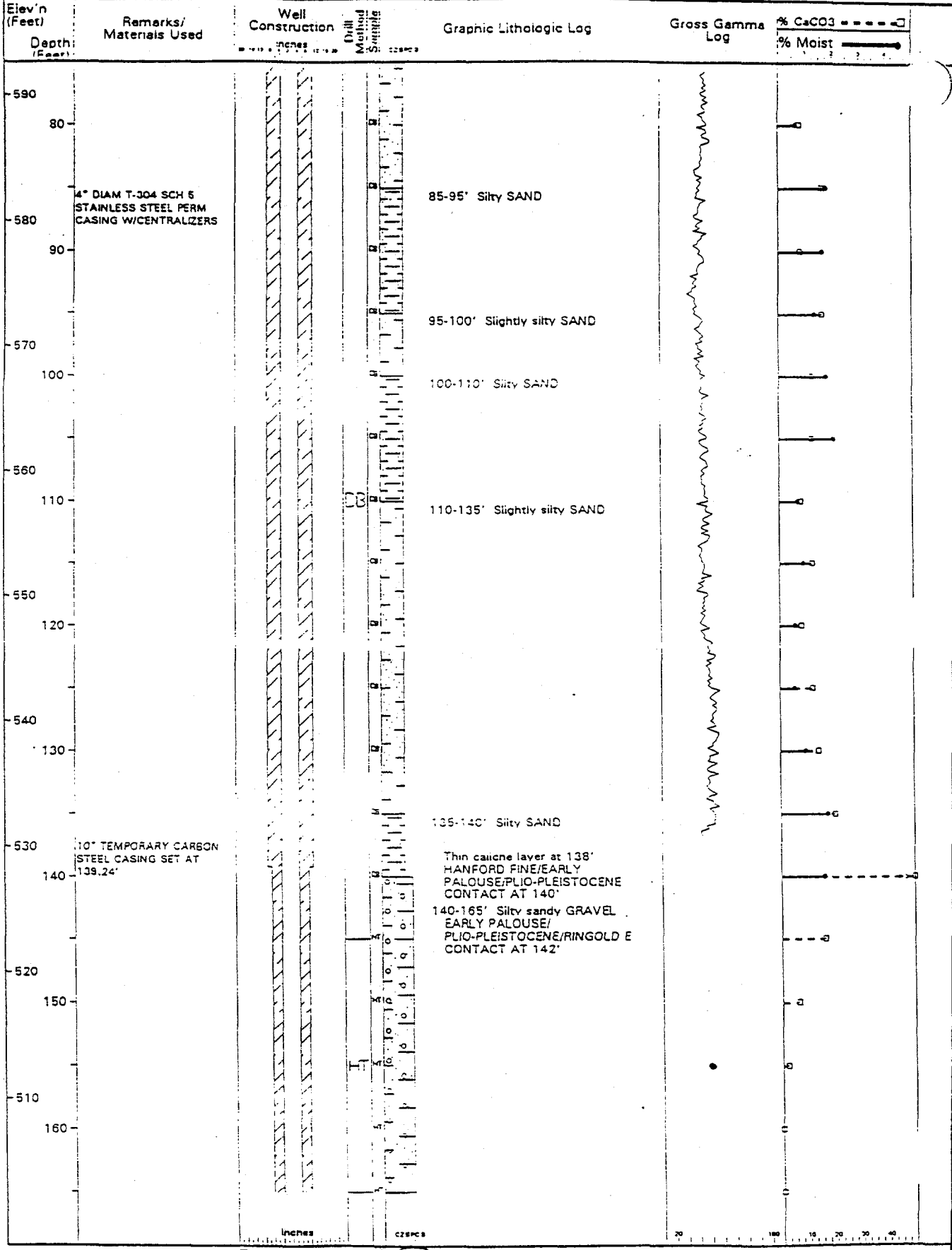
Comments:



Reviewed By: KD Reynolds / KD Reynolds Date: FEB. 12 1997

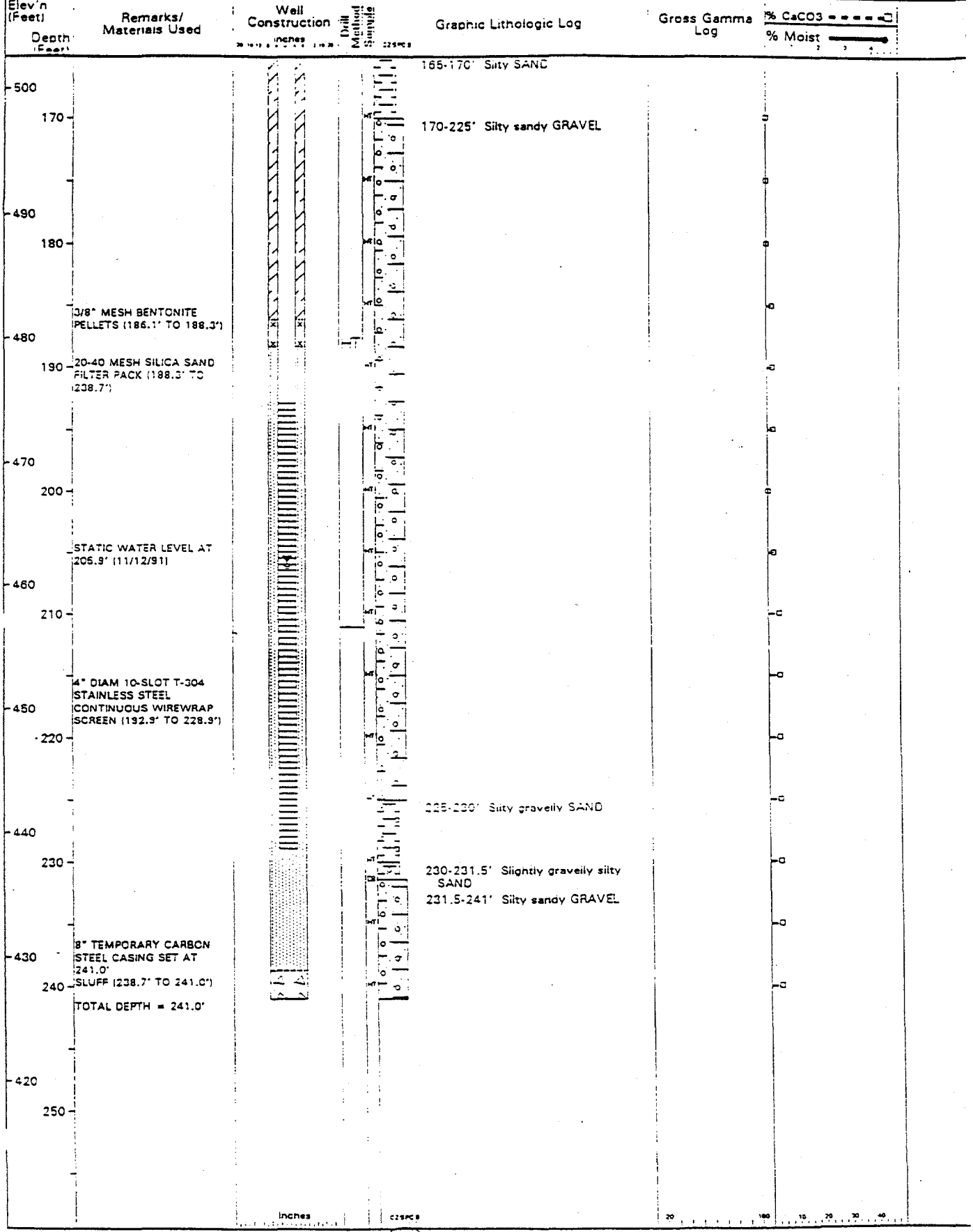
A-71

Project: W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION — WHC-SD-EN-DR-042 Rev 0 — Well No: 299-W22-46 — Page 2 of 3



Reviewed By: KD Reynolds / KD Ra — Date: FEB. 1 3 1998

A-72



Reviewed By: KD Reynolds / KD Rai Date: FEB 1 0 1998

A-73

W.O.# CR9582 (S TANK FARMS)

WELL 299-W22-46

DRILLING

START DATE	FINISH DATE	TOTAL DAYS	CURRENT DEPTH	FINAL DEPTH	DEPTH TO WATER		WATER ADDED(GAL)
9-24-91	10-18-91	19	N/A	241.0	10-15-91	205.4	610 GALLONS
					10-17-91	209.0	
					10-18-91	197.4	

DOWN HOLE COMPLETION

START DATE	FINISH DATE	TOTAL DAYS	DEPTH TO WATER		DEPTH TO BOTTOM	DEPTH OF SCREEN	WATER ADDED/ REMOVED (GAL)
11-4-91	11-12-91	7	11-4-91	198.1	238.7	192.9 - 228.9	30 GALLONS
			11-6-91	204.6			

DEVELOPMENT AND ASSOCIATED ACTIVITIES

TV CAMERA DATE	AQUIFER TEST DATE	DEVELOPMENT DATE	HYDROSTAR PLACEMENT DATE	WATER REMOVED(GAL)
N/A	12-2-91	12-2-91	12-3-91	321 GALLONS
	12-3-91	12-3-91		

COMMENTS:

Westinghouse Hanford Company
Radionuclide Logging System Log Header

Project	216-S-8 Crib Monitoring	Log Types:	HPGe Spectral Gamma-Ray
Borehole	299-W22-46 WID# A4977		

Borehole Environment Information

Borehole liquid depth 205.9 (ft) from Hanford Wells

Casing size (in.)	Casing thickness (in.)	Top depth (ft)	Base depth (ft)
6 (SS)	0.12	-3.6	10
4 (SS)	0.12	-1.1	241
4 (Screen)	0.12	192.9	228.9

RLS Passive Spectral Gamma Survey Information

Logging Engineer(s) R. V. Cram J. P Kiesler
Log depth reference at zero (0.0) depth is Ground Level

Log Date	Archive Disk Detector ID	Log mode	speed	Depth interval (ft) Top	Base	Incr
Mar 8, 1994	H2W22046	MSA	80 sec	0	100	0.5
	RLSG1.0 (18%)	"	"	97.5	105	0.5

MSA: Move-Stop-Acquire

Calibration and Analysis Information

RLS Calibration Date: Mar 30, 1993 (HPGe-18%)
Calibration Report: WHC-SD-EN-TI-292

Analyst Name(s): R. K. Price
Analysis Date: Feb 6, 1996

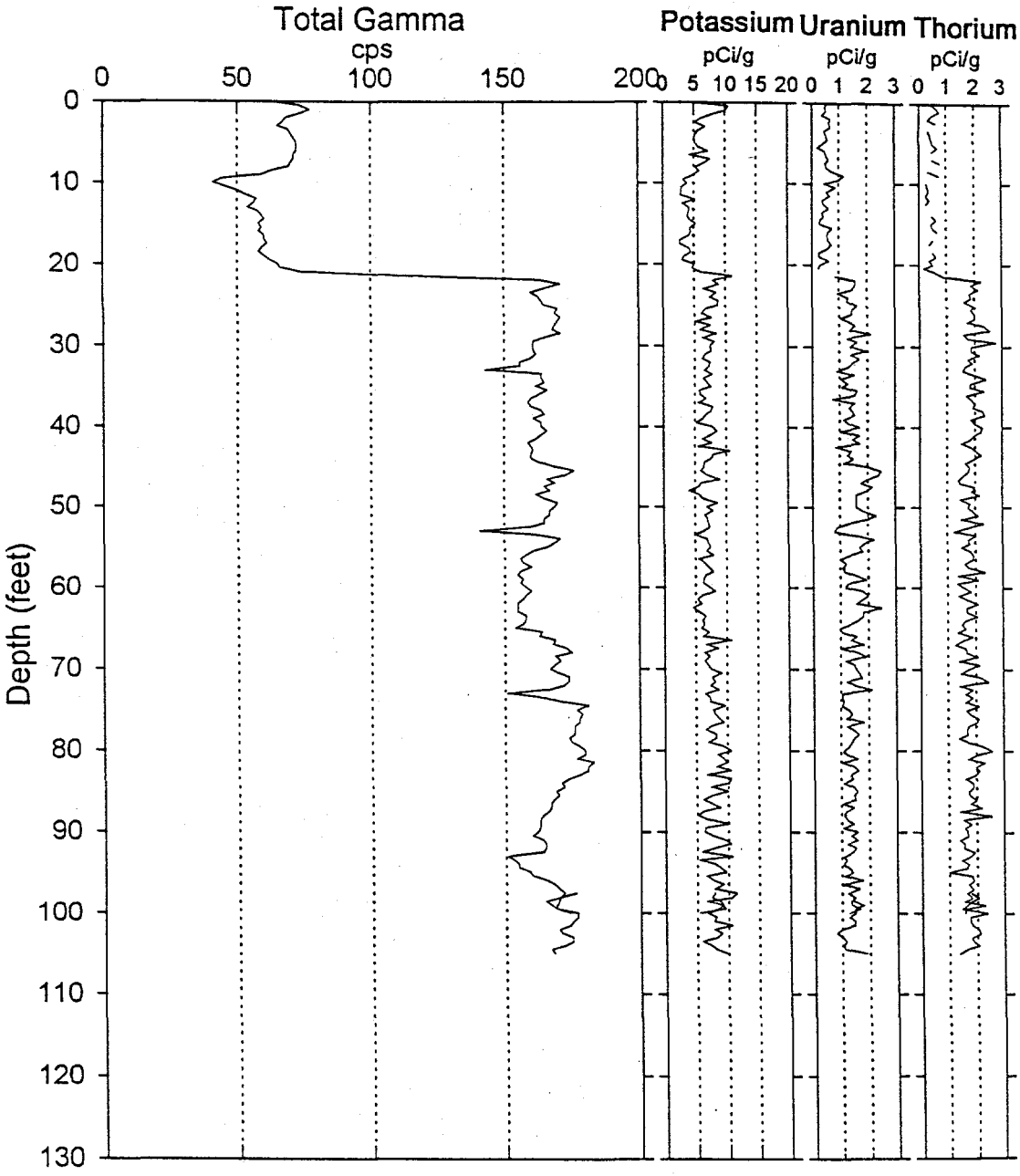
Analysis Notes: Well completed with Bentonite. Masked Natural Formation
Radionuclides Identified: No Man-made radionuclides detected.

RLS Spectral KUT Processed Data

Project: Crib Monitoring (S-8) Last Log Date: Mar 8, 1994

Borehole: 299-W22-46 Analysis Date: Feb 6, 1996

Westinghouse Hanford Company



RADIONUCLIDE LOGGING SYSTEM
Log Analysis Summary Report

Borehole: 299-W22-46 **Report Date:** Feb 6, 1996
Log Type: HPGe Spectral Gamma-Ray **Final Log Date:** Mar 8, 1994

General Notes:
The borehole was surveyed after ground-water monitoring well was completed (Nov 1991). The borehole was monitored for the inactive crib monitoring program to establish a baseline log. The borehole is about 250 ft from the south edge of the 216-S-8 Crib. The entire well depth was not surveyed.

The concentrations of the naturally occurring radionuclides potassium, uranium, and thorium are not characteristic of the natural formation materials, but are common for the bentonite well completion material used seal the stainless steel completion casing to the formation.

No man-made radionuclides were detected in the high-resolution gamma-ray spectra.

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

WELL SUMMARY SHEET

Boring or Well No. 299-W23-14

Sheet 1 of 2

Location 200W/SST/299-SX Tank Farm Project W-017

Elevation 661.00 ~~BENCH~~ CAP (NGVD'29) Drilling Contractor KEH

Driller L. Bultena Drilling Method and Equipment Cable Tool

Prepared By Alan Pearson/Alan Pearson (Sign/Print Name) Date 2/5/91 Reviewed By [signature]/BA Williams (Sign/Print Name) Date 2/25/91

CONSTRUCTION DATA		Depth in Feet	GEOLOGIC/HYDROLOGIC DATA	
Description	Diagram		Graphic Log	Lithologic Description
12" Ø temporary carbon steel casing to 19.33' bls		3.0'		SAND
		10		SLIGHTLY GRAVELLY SAND
Cement Grout				SAND
		19.33'		"
		20		
		20.4'		
10" Ø temporary carbon steel casing to 163.89' bls				SLIGHTLY GRAVELLY SAND
		30		SANDY GRAVEL
				SILTY SANDY GRAVEL
Granular Bentonite #8-20 Mesh				SLIGHTLY SILTY SAND
		40		SILTY SAND
8" Ø temporary carbon steel casing to 224.4' bls				SLIGHTLY SILTY SAND
		50		" " "
				" " "
		60		SILTY SAND
				" "
4" Ø stainless steel casing		70		SLIGHTLY SILTY SAND
				SILTY SAND w/ SILTY & CLAY LENSES
		80		SLIGHTLY GRAVELLY SLIGHTLY SILTY SAN
				SANDY GRAVEL
		90		" "
				SLIGHTLY SILTY SAND
		100		SILTY SAND to SANDY SILT
				SILTY SAND
		110		" "
				" "
		120		SILT
				"
		130		SILTY SAND
				SANDY SILT
		140		" "
				" "
		150		SLIGHTLY SILTY SAND
				SILTY SANDY GRAVEL
		160		SAND
		162.89'		

C-17

A-6000-384 (04/90)

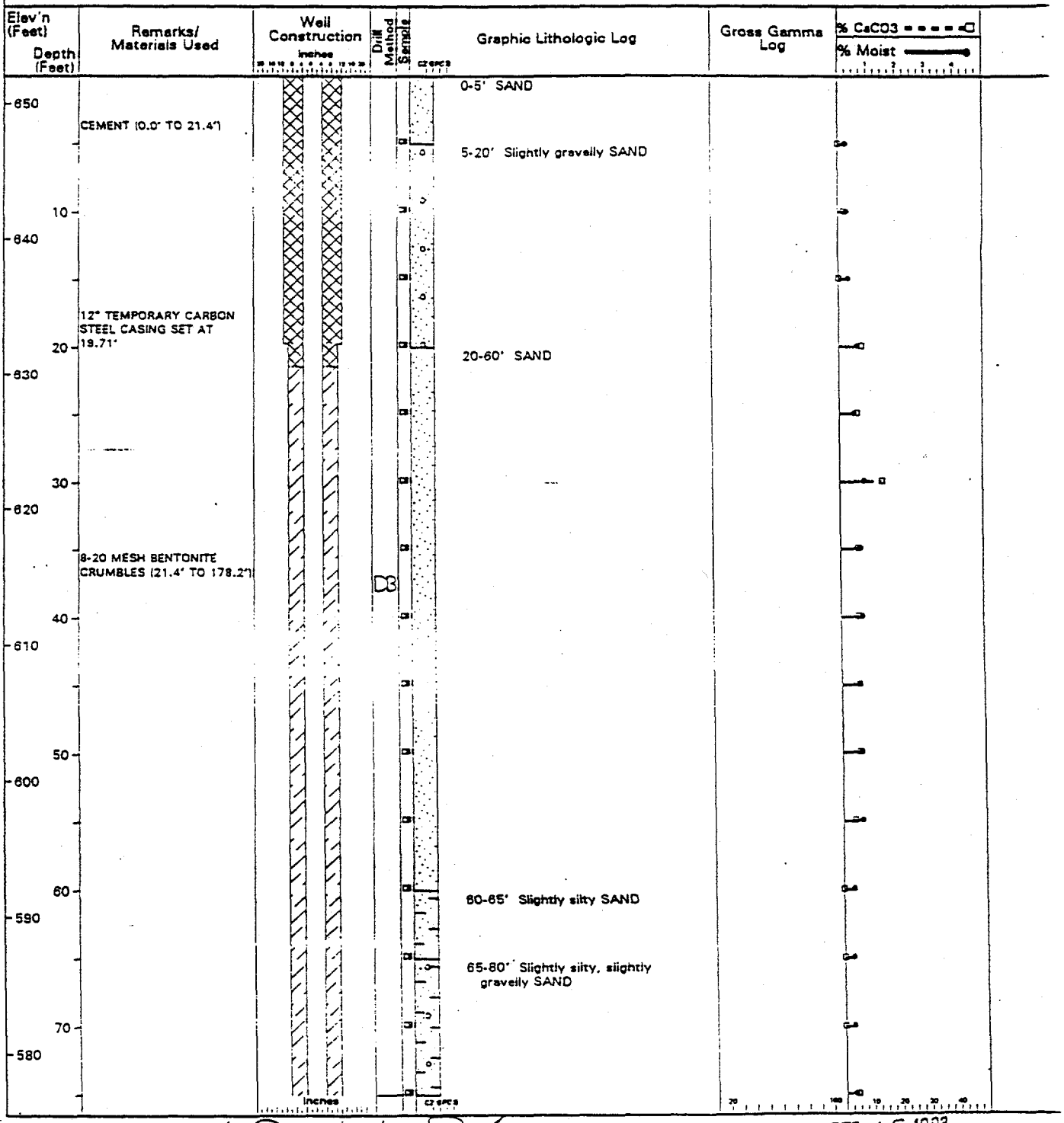
Project:	W-017H/WSST RCRA GROUNDWATER MONITORING WELL INSTALLATION		**Well No:** 299-W23-15		Page 1 of 3
			Total Depth: 225.00	Static Water Level:	189.70
Date Started:	9-17-91	Date Completed: 12-3-91	Surface Elevation: 652.01	Casing Elevation:	655.44
Location:	S-X TANK FARM, 200 WEST		Northing: 134127.23	Easting:	566794.00
Prepared By:	N BALLANTYNE, et al.		Hanford N: 34993.10	Hanford W:	75803.10
Drilling Co:	KEH	Driller: TJ OCKERT	Drill Meth: CABLE TOOL	Drill Equip:	BE 22W

Screen: 36.71' OF 4" DIAMETER 20-SLOT TYPE 304 STAINLESS STEEL CONTINUOUS WIREWRAP SET FROM 185.73' TO 222.44'

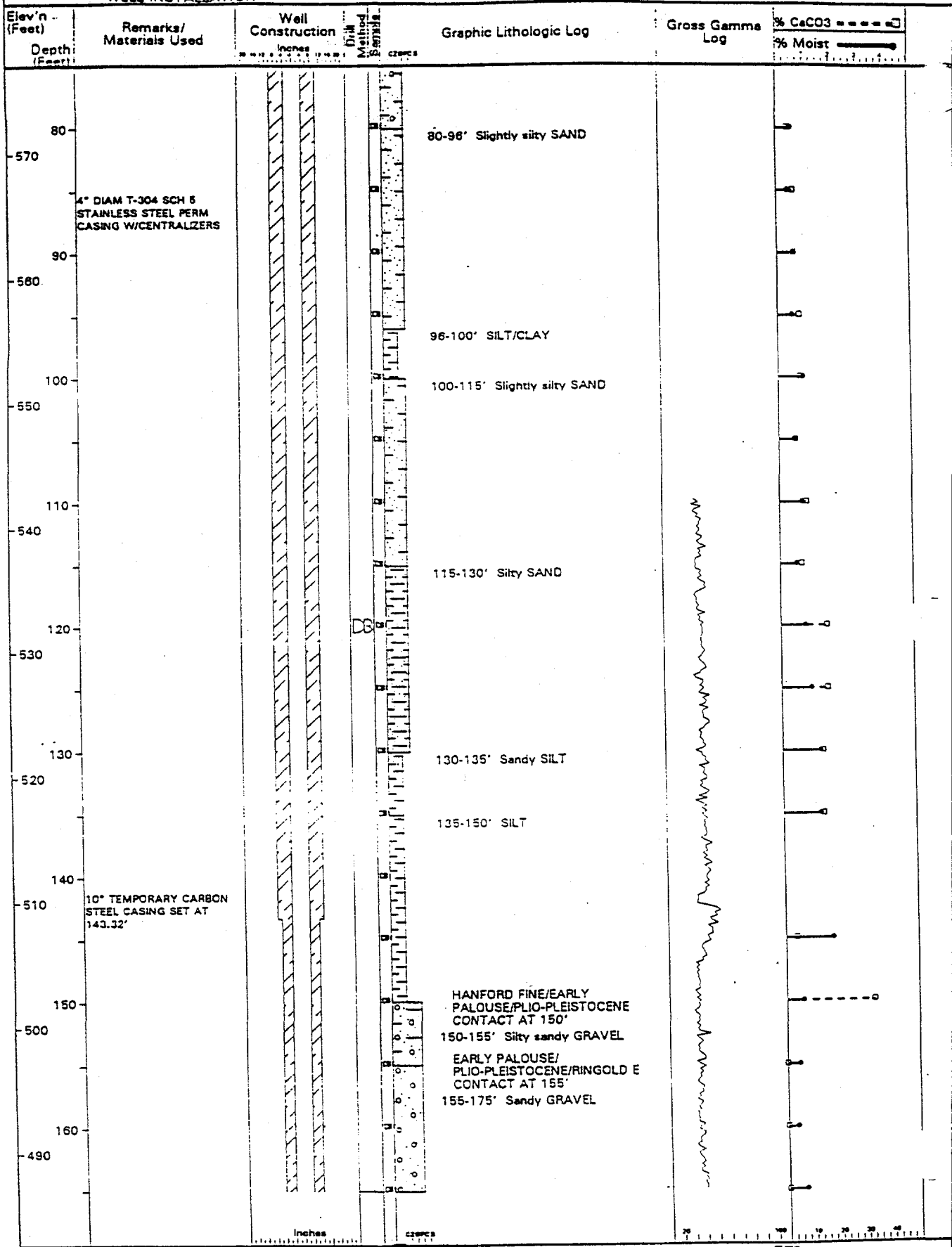
Filter Pack: 10-20 MESH SILICA SAND FROM 181.0' TO 223.4'

Permanent Casing: 4" DIAMETER TYPE 304 SCHEDULE 5 STAINLESS STEEL WITH CENTRALIZERS SET TO 185.73'

Comments: CHANGED DRILL RIGS ON 10/1/91.

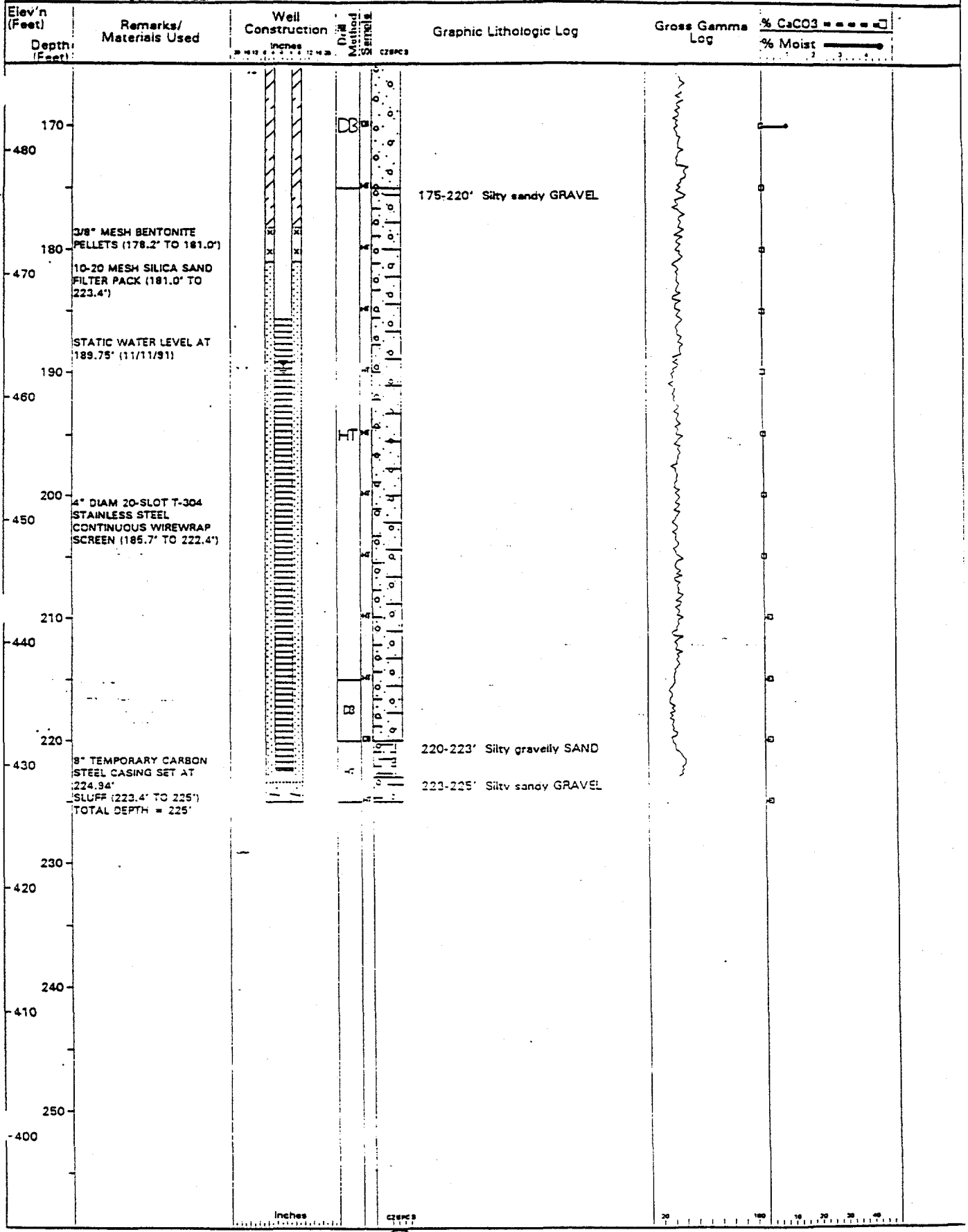


Reviewed By: KD Reynolds / KD Ry A-93 Date: FEB. 12 1993



Reviewed By: KD Reynolds / KD Rey Date: FEB. 1 2 1993

A-94



Reviewed By: KD Reynolds/ KD Rey Date: FEB. 1 2 1993

A-95

SINGLE SHELL TANKS

WELL 299-W23-15

DRILLING

START DATE	FINISH DATE	TOTAL DAYS	CURRENT DEPTH	FINAL DEPTH	DEPTH TO WATER		WATER ADDED(GAL)
9-17-91	10-25-91	29	N/A	225.0	10-19-91 PM	194.0 190.2	194 GALLONS
					10-21-91	188.6	
					10-22-91	194.5	
					10-23-91	190.1	
					10-24-91	189.7	
					10-25-91	193.9	

DOWN HOLE COMPLETION

START DATE	FINISH DATE	TOTAL DAYS	DEPTH TO WATER		DEPTH TO BOTTOM	DEPTH OF SCREEN	WATER ADDED/ REMOVED (GAL)
11-8-91	11-12-91	3	11-8-91 PM	212.4 190.1	223.4'	185.7'-222.4'	~30 GALLONS
			11-9-91	189.7			

DEVELOPMENT AND ASSOCIATED ACTIVITIES

TV CAMERA DATE	AQUIFER TEST DATE	DEVELOPMENT DATE	HYDROSTAR PLACEMENT DATE	WATER REMOVED(GAL)
N/A	12-3-91	12-3-91	12-3-91	525

COMMENTS:

Appendix B

Assessment of Groundwater Contamination Beneath the SX Tank Farm

1996

Prepared by Joseph A. Caggiano and Vernon G. Johnson, Westinghouse Hanford Company, Richland, Washington

A BRIEF REVIEW* OF HISTORICAL AND RCRA GROUNDWATER MONITORING AT THE 241-SX TANK FARM

J.A. Caggiano, Westinghouse Hanford Co.

SUMMARY AND ANALYSIS OF THE GROUNDWATER MONITORING DATA

1. Nitrate, tritium, gross beta, and ^{99}Tc are among the Hanford derived contaminants found in groundwater above natural background levels during RCRA sampling in the area of the 241-SX Tank Farm. Tritium, in wells 299-W23-14 and 299-W23-15, is the only constituent that currently exceeds Drinking Water Standards. These are among the constituents that leaked from tanks in the 241-SX Tank Farm and that were also discharged to soils (at lower concentration/activity) in the cribs surrounding the SX Tank Farm. A cumulative total of 145,400,000 gallons of liquid effluent were discharged to the 216-S-1, 216-S-2, 216-S-3, 216-S-4, 216-S-8, 216-S-21 and 216-S-25 facilities. As Table 1 illustrates, this total pales in comparison to the 43,593,100,000 gallons discharged to the now-decommissioned 216-U-10 Pond which is and has been upgradient of the 241-SX Tank Farm since SX farm began operating in 1954. The total estimated volume of leaked waste from the 10 leaking tanks in the 241-SX Tank Farm is 160,000 gallons (Hanlon, 1996), a small fraction of the total liquid discharged to surrounding liquid effluent facilities. The volume of liquid discharged to soil from the liquid effluent disposal facilities is more likely to have saturated the soil and infiltrated to groundwater than the volume discharged from even the cumulative total leakage known from leaking tanks in the 241-SX Tank Farm. It is not possible with available data to determine whether the spreading of liquid effluents added to soils in cribs, U Pond and the S-3 french drain has reached and mobilized wastes leaked from tanks to enhance infiltration deeper into the vadose zone or to groundwater.

2. Other RCRA groundwater monitoring results (1992 to present) in which there is more confidence (because of quality controled sampling and analytical techniques and frequent, periodic sampling) indicate some contamination of groundwater by other constituents. Gross beta has been elevated above natural background. The causative isotope appears to be ^{99}Tc which does not exceed the DWS of 900 pCi/L. As with the historical data, results can not be used to determine the source of the contaminants in groundwater beneath the 241-SX Tank Farm. Gross beta and ^{99}Tc are increasing in downgradient well 299-W22-39, but the 900 pCi/L DWS for ^{99}Tc has not been exceeded to date. RCRA wells are all located outside the perimeter fence of the 241-SX and 241-S Tank Farm (WMA S-SX). However, other nearby older wells (e.g., 299-W23-2, 299-W23-3) do exhibit elevated ^{99}Tc which, in well 299-W23-2, exceeds the 900 pCi/L DWS. *^{99}Tc, in RCRA well 299-W23-15, did reach nearly 8,000 pCi/L in 1993, but has declined below the DWS of 900 pCi/L since that time.*

3. Some trends are apparent in the RCRA groundwater monitoring data. Results for tritium are declining in RCRA wells 299-W23-14 and 299-W23-15. Nitrate in downgradient well 299-W23-15 reached a peak of about 77,000 ppb in 1993, but has declined to below 10,000 ppb (the DWS for nitrate is 45,000 ppb). These results appear to represent the transport, dilution and decay of liquid effluent discharged to the upgradient 216-S-25 crib in 1986 (the effluent from the ion-exchange operation at the 242-S Evaporator used to extract uranium from groundwater). The 216-S-25 crib is now inactive, but did receive liquid effluent through at least 1994.

* This was a cursory review completed during a two week period and should by no means be considered an exhaustive investigation or the final word on groundwater monitoring at the 241-SX Tank Farm. The report was submitted as a letter report to TWRS Engineering.

4. Results of analyses for ^{137}Cs during RCRA sampling have either been non-detects or been below 7 pCi/L--approaching the limit of detectable activity. The DWS for ^{137}Cs is 200 pCi/L. *However, ^{137}Cs has been detected in two samples in non-RCRA well 299-W23-7 (21.8 pCi/L in 9/94 and 18.5 pCi/L in 3/96).*

5. A qualitative assessment of historical groundwater monitoring data indicates that higher levels of contaminants were noted in groundwater in wells surrounding the liquid effluent facilities located east and west of the 241-SX Tank Farm than in the few wells within the tank farm. These surrounding facilities have certainly contributed to the degradation of groundwater quality in the area of 200 West where the 241-SX Tank Farm is located. If any waste leaked from any of the tanks in the 241-SX Tank Farm had infiltrated the entire vadose zone (about 160+ feet from the base of the tanks to groundwater), the contaminants would be masked by those that reached groundwater from the surrounding cribs. There are no known unique indicator constituents that can be used to trace contaminants in groundwater directly to an SST as a source. Without direct tracing of contaminants through the entire vadose zone to groundwater, it is not possible to confirm that any waste leaked from one of the 10 assumed leaking (of a total of 15 tanks) in SX farm has reached groundwater.

6. Several constituents in the historical groundwater monitoring data exhibit an upward trend in concentration/activity in the period 1986 - 1988. These increases are noted in monitoring results for wells within the tank farm as well as in those wells east and west of the 241-SX Tank Farm. A review of historical discharges to surrounding cribs revealed that a significant quantity of liquid effluent resulting from the ion-exchange process used to extract uranium from contaminated groundwater was discharged to the 216-S-25 crib beginning in 1986. The ion-exchange process at the 242-S evaporator was used to recover uranium extracted from a well near the old 216-U-1, 216-U-2 cribs. Uranium-bearing waste was discharged to these cribs from 1952 to 1967. Discharge of liquid effluent to the nearby 216-U-16 crib in 1985 remobilized the previously discharged uranium which then moved laterally and infiltrated to groundwater. Details of this occurrence may be found in Law and Schatz (1985) and Delegard et al (1986). The increases in activity in wells 299-W23-9 and 299-W23-4 in this period are attributed to the discharges of ion exchange residue to the 216-S-25 crib. Because the 216-S-25 crib is upgradient of the 241-SX Tank Farm, the increases in nitrate, tritium, gross alpha and beta in wells west of, within and east of the SX tank farm are likely to have been related to these discharges.

7. The aerial distribution of wells with historical groundwater monitoring data for any given period of time is too scant to contour to produce defensible plume maps of groundwater contamination. Some time-series plots show the variation of constituents with time. Plume maps for certain constituents using data from wells for the period 1991 - 1994 (Johnson, 1993; Dresel et al, 1995)) illustrate the aerial distribution of certain groundwater contaminants in the vicinity of the 241-SX Tank Farm. There is a plume of ^{99}Tc beneath the eastern portion of the 241-SX Tank Farm, with values rising above the 900 pCi/L DWS. The aerial distribution of wells exhibiting changes in ^{99}Tc with time in the last 10 years suggest the possibility that some of the leaking tanks within the 241-SX Tank Farm may be contributing to degradation of groundwater quality. However, the data require further analysis and investigation and would benefit from monitoring the deeper part of the vadose zone from the 125 foot maximum depth of dry wells to groundwater. Isotopic and/or constituent ratios might help determining whether all the contaminants are from one source (population).

8. The earliest recorded leak in the 241-SX Tank Farm is the 1962 leak of the 241-SX-108

tank (Hanlon, 1996). With the exception of the 216-S-25 crib, all the liquid effluent facilities in the vicinity of the 241-SX Tank Farm (Table 1) began operating in the early to mid 1950s and had received significant quantities of liquid effluent by the 1960s. The earliest indications of contaminants in groundwater in the area of the 241-SX Tank Farm are in the late 1950s to early 1960s. For example, there are four values for gross beta in well 299-W23-2 in 1956, but these values range from less than 1,000 pCi/L to 16,000 pCi/L. All these values suggest contamination (the natural background for gross beta in Hanford groundwater is in the range of 12 to 20 pCi/L [Johnson, 1993, Table A-1-2]), but the analyses are so highly variable that the validity of the results is in doubt. By 1961, nitrate in well 299-W23-3 had exceeded the present DWS of 45,000 ppb and was well above the natural background for nitrate in Hanford Site groundwater (a range of about 3,000 to 8,000 ppb [Johnson, 1993, Table A-1-2]). High variability typifies nitrate results for the period 1960 - 1962 (a range of 18,000 ppb to about 62,000 ppb for 10 analyses). The number and distribution of wells in the 1960s along with the infrequent sampling and the quality of the resultant analyses make it difficult to make any definitive conclusions. However, given the nature of the data, contamination of groundwater beneath the 241-SX Tank Farm area by the late 1950s to early 1960s is suggested. Results appear to be of higher concentration/activity for wells adjacent to cribs for the data from the late 1950s to early 1960s suggesting the cribs as the likely source of the contaminants. However, since the contaminants leaked to soils from tanks that reach groundwater are essentially identical, any contaminants leaked from a tank within the 241-SX Tank Farm that reached groundwater would have been masked by the discharges to nearby cribs and liquid effluent facilities.

9. Reported data for isotopic analyses suggest that the values are minimal detectable activities. For example, repeated values for ^{137}Cs of 750 pCi/L up to 1958 and 500 pCi/L for the period 1958 to 1963 appear to be minimal detectable activities. Without further investigation, it is difficult to determine whether these values should be considered as non-detects, or that some activity was found, but it was below the value in which any confidence could be placed in the results. Therefore, the minimal detectable activity was reported by the analyzing laboratory. This practice sometimes arises from contractual agreements between the laboratory and the customer. These available data do not allow any definitive conclusion as to whether these isotopes had contaminated groundwater in this era.

11. Results reported are for soluble species in groundwater. Sorption coefficients differ and lead to different rates of infiltration of different constituents to groundwater. For those radionuclides that reach groundwater, only the soluble species with very low sorptive coefficients are the ones that are likely to remain in solution and mobile. These are the constituents that pose the greatest risk. If ^{137}Cs were strongly sorbed to saturated sediments below the water table, little might be extracted in groundwater sampling. Soil washing experiments at the Hanford Site and at Idaho Falls have found that ^{137}Cs is difficult to dislodge from sediments on which it has sorbed. Furthermore, even when desorbed, it tends to quickly resorb. Considering the variable nature of Hanford soils and the chemistry of the infiltrating wastes in the vadose zone and the soil/waste interactions as well as groundwater/sediment/constituent interactions below water, it is recommended that further work be performed on geochemical aspects of waste transport. For example, spectral gamma logging of the saturated sediments in wells might demonstrate whether gamma-emitting isotopes like ^{137}Cs were present, but fixed on the sediments. Only with this information and appropriate characterization of the unsaturated and saturated sediments will a defensible risk assessment of groundwater transport of Hanford waste constituents be possible. These studies will also help in designing appropriate remedial measures that will function as intended. It is also important to understand the geochemistry of various isotopes and their

interaction with solid media when conducting pump and treat operations, especially if certain additives are used to enhance extraction of constituents from groundwater.

INTRODUCTION

241-SX TANK FARM

Fifteen single-shell tanks that are 75 feet in diameter and hold 1,000,000 gallons constitute the 241-SX Tank Farm. The tanks were constructed in 1953-54 of reinforced concrete with a single liner of carbon steel. Construction of previous SSTs used a dished bottom (i.e., a curving intersection of sidewall and floor), but the tanks in the 241-SX Farm were constructed with an orthogonal intersection of sidewall and bottom. Ten of the 15 tanks in the 241-SX Tank Farm are assumed leakers (Hanlon, 1995), having leaked a total of up to 160,000 gallons of waste [1]. The following tanks are listed as Assumed Leakers by Hanlon (1996):

107-SX	110-SX	112-SX	115-SX
104-SX	109-SX	113-SX	
108-SX	111-SX	114-SX	

A summary description of each of these leaking (and sound) tanks is included in Appendix 2B of the recently revised Single Shell Tank Closure/Work Plan (DOE, 1995). Table 2 lists the unplanned releases from the area of the 241-SX Tank Farm that may have released any significant quantity of liquid. There are other UPRs in the Environmental Database, but these mostly relate to the spread of contaminated soils by wind (or other solids dispersal).

HYDROGEOLOGY OF THE 241-SX TANK FARM AREA

Groundwater beneath the 241-SX Tank Farm occurs at a depth of 205 - 216 feet in unit E of the Miocene Ringold Formation, a matrix supported pebble and cobble gravel member of the suprabasalt (unconfined) aquifer. In places, unit E is heavily cemented and has a relatively low hydraulic conductivity compared with the overlying sand and gravel of the Hanford Formation. Elsewhere, there are poorly cemented lenses of fine to medium sand in the Ringold unit E, and these have posed problems to both drilling and maintaining wells with perforated casing. Drillers logs report "heaving sands" and as-built diagrams illustrate that sand has infilled many of these older wells with perforated casing. Between the Hanford Formation and the Ringold is some finer grained eolian silt and sand (the Early Palouse horizon) and the heavily calcareous, but discontinuous and fractured caliche of the Plio-Pleistocene unit. In places, some massive to thinly bedded fine sand and silt of the upper Ringold strata may be present. Strata of differing unsaturated hydraulic conductivity in the unsaturated (vadose) zone give rise to lateral spreading, and in places, perching of water (or liquid waste) as it infiltrates to groundwater. Additional information on the stratigraphy beneath the SX tank farm can be found in Caggiano and Goodwin (1991) or Lindsey (1991).

Wells (both RCRA and older carbon steel wells) in and around the 241-SX Tank Farm are shown on Figure 1. Older carbon steel wells used to monitor liquid effluent facilities are also shown on Figure 1. Note that numerous wells are present, but not all wells have monitoring data. Of those shown, some have only minimal data and were sampled infrequently.

Groundwater flow at present is generally to the south-southeast away from the water table mound that originated beneath the now-deccommissioned 216-U-10 Pond in the southwest corner of 200 West area. Hydrographs of the RCRA monitoring wells in WMA S-SX are included in the RCRA annual report (Figure 2). Hydrographs of some older wells with long term water level measurements are shown on Figure 3 to illustrate the changing hydraulic head beneath the 241-SX Tank Farm with time. Stratigraphy determined from drilling the dry wells is reported in Price and Fecht (1976).

Groundwater flow direction in the unconfined (suprabasalt) aquifer beneath the 241-SX Tank Farm has varied some with time. Regional groundwater flow in the unconfined aquifer is generally from west to east in this area, as shown on the pre-Hanford water table map for 1944 (Kipp and Mudd, 1974). At the time of startup of the 241-SX Tank Farm, groundwater flow in the unconfined aquifer beneath the SX Tank Farm was controlled by a water table mound that had developed beneath the 216-U-10 Pond in the southwest corner of the 200 West area (hereafter called the U Pond mound). The higher hydraulic head to the north and west from the U Pond mound resulted in groundwater in the unconfined aquifer flowing to the southeast beneath the SX Tank Farm. Groundwater flow has generally remained to the south to southeast in the southern 200 West area since the early 1950s before startup of the SX Tank Farm.

The water table beneath the SX Tank farm has varied in elevation with time. At the peak of Hanford operations, the water table elevation beneath the 216-U-10 pond increased up to 70 ft above pre-Hanford conditions. Water levels have been measured nearly continuously in well 299-W23-4. A hydrograph of this well (Figure 3) reveals fluctuations of about 10 feet between the mid-1960s and 1984 when U Pond was decommissioned. Since 1984, the water table has declined more than 20 feet in this well. Given the direction of groundwater flow beneath the SX Tank Farm, any contaminants in groundwater beneath this facility could come from the tank farm as well as any liquid effluent facility located upgradient from the tank farm. However, because of lateral spreading during infiltration through the vadose zone, liquid effluent from cribs east of the 241-SX Tank Farm could also have spread westward and infiltrated deeper into the vadose zone or to groundwater either interstitially, or along any preferential pathways (e.g., clastic dikes, unsealed wells).

Groundwater also occurs in various aquifers in the confined (basalt) aquifer system, but is not addressed further in this report. There are no documented routes of communication between the suprabasalt and basalt aquifer systms beneath or in the vicinity of the 241-SX Tank Farm. Therefore, the quality of groundwater in the basalt aquifers should be unaffected by any contaminant discharges from SSTs in the 241-SX Tank Farm or nearby cribs. There are no deep groundwater monitoring wells in the immediate vicinity of the 241-SX Tank Farm.

RCRA GROUNDWATER MONITORING

The 241-S and 241-SX Tank Farms are facilities that store radioactive and hazardous waste and are currently regulated as Treatment, Storage or Disposal (TSD) facilities under the Resource Conservation and Recovery Act (RCRA) and the Washington State Hazardous Waste Management Act. Groundwater is monitored for compliance with interim-status regulations under WAC 173-303-400 which references 40 CFR 265. The two facilities have been combined into one Waste Management Area (WMA S-SX) for groundwater monitoring purposes (Caggiano and Goodwin, 1991). There are seven RCRA wells that monitor WMA S-SX (Figure 1) and which are compliant with construction specifications in WAC 173-160 for resource protection wells. These wells are four inch diameter stainless steel wells with stainless steel screens and have been completed with filter pack and full annular seals (bentonite crumbles) and surface seals (concrete) as required. Each has four protective posts and a concrete pad. By

agreement with Ecology, these wells are located outside the perimeter fences of the tank farms and at least 100 feet from the nearest tank.

Groundwater sampling for RCRA compliance was begun in 1992 and has continued since then. Sampling and analyses are controlled by WHC procedures (e.g., WHC-7-8) that follow requirements/guidance in regulatory documents (e.g., EPA, 1986a; EPA 1986b). Data obtained from groundwater monitoring are input to the Hanford Environmental Information System (HEIS) and are reported regularly in quarterly reports (e.g., DOE/RL, 95-69-2) covering groundwater monitoring of RCRA facilities at the Hanford Site. Time-series plots of data in this report are from GeoDAT (Geologic Data Analysis Tool), a network Paradox database that obtains data from HEIS. An annual report (e.g., DOE/RL-94-136) is also prepared summarizing interpretations and changes that have occurred during the calendar year. Four quarters of background sampling data were used to calculate background statistics for upgradient well(s). Under RCRA interim-status monitoring, downgradient values for indicator parameters (pH, specific conductance, Total Organic Carbon [TOC] and Total Organic Halogens [TOX]) are compared with upgradient values during semi-annual sampling. If the value for one of these indicator parameters exceeds the background critical mean for specific conductance, TOC or TOX, or the critical range for pH is exceeded, then verification sampling is required to determine whether the change is an artifact of the sampling/analysis process or represents conditions in the aquifer and thus a potential effect of the facility on groundwater. There have been no exceedances of the critical mean or critical range for WMA S-SX and the site continues semi-annual groundwater monitoring for indicator parameter evaluation. There was one exceedance for specific conductance in downgradient well 299-W22-44 in December 1992, but resampling demonstrated that this value resulted from a faulty instrument and was not representative of aquifer conditions.

Constituents exceeding regulatory limits in all tank farms are reported annually (e.g., Caggiano, 1995; Table 4). At the 241-SX Tank Farm, tritium has exceeded the Drinking Water Standard (DWS) in upgradient well 299-W23-14 and downgradient well 299-W23-15 since the inception of RCRA monitoring in 1992. Tritium activity has steadily declined in well 299-W23-15 from about 350,000 pCi/L in 1992 to about 40,000 pCi/L in 1995. In well 299-W23-14, tritium has declined from over 200,000 pCi/L in 1992 to about 120,000 pCi/L in 1995, with a slight increase through 1994 and 1995. Limited historical data indicates that this is a continuation of a trend in this area of 200 West area. Gross beta is elevated in downgradient wells 299-W23-15, 299-W22-39 and 299-W22-46 reflecting elevated ^{99}Tc, but ^{99}Tc did not exceed the 900 pCi/L DWS in 1995. Gross beta and ^{99}Tc has been steadily increasing in downgradient well 299-W22-39 since the inception of RCRA monitoring in 1992 (Figure 5).

HISTORICAL GROUNDWATER MONITORING (PRE-RCRA)

Prior to constructing new wells, Ecology in 1990 requested that older wells within and around SST farms be reviewed to determine whether they were suitably located and constructed to comply with RCRA well construction specifications or whether they could be remediated to conform to RCRA requirements. Because the wells were not all suitably located to meet requirements in 40 CFR 265 and could not easily be converted to comply with required construction specifications without considerable risk, new monitoring wells were constructed. EPA and Ecology policy stipulates that sampling for hazardous waste constituents (dangerous and extremely hazardous waste) is restricted to wells that comply with construction specifications in WAC 173-160. Older wells can be used for supplemental data (e.g., radionuclides, water levels) per this joint Ecology/EPA policy.

There are six older carbon steel wells inside the perimeter fence of the 241-S and 241-SX

Tank Farms: 299-W23-1, 299-W23-2, 299-W23-3, 299-W23-5, 299-W23-7 and 299-W23-12. Two other carbon steel wells are located outside the perimeter fences: 299-W23-6 and 299-W23-8. These wells were all constructed with cable tool drilling methods and were unsealed for many years before a partial annular seal was constructed in the mid 1970s or early 1980s (Table 3). These partial annular seals were constructed by perforated the existing casing, installing a packer and smaller diameter liner within the old casing and placing grout under gravity feed. All eight wells but 299-W23-8 now have these partial annular seals. These wells are located farther from the tanks than the boreholes used for geophysical logging.

There is some historical groundwater monitoring data for some of these wells for some periods of time, but few have any continuous record of monitoring data and the constituents monitored are few (e.g., gross beta, tritium, nitrate, some radionuclides). Most have gaps of 10-20 years between sampling/analysis event(s). Many are no longer sampled and appear to be serving no useful purpose at this time. These wells represent greater potential pathways for contaminant migration to groundwater than the "dry wells" which surround the tanks. Some of older wells were used to monitor water levels for RCRA groundwater monitoring, but those inside the perimeter fences have not been used for water level measurements for over 2 years. Four of the wells inside the perimeter fences are used for annual sampling by the Environmental Surveillance Monitoring Program for conformance with DOE order 5400.1.

HISTORICAL SAMPLING RECORDS

Sampling conducted before 1992 (when RCRA sampling was initiated) is termed historical monitoring for this report. All historical groundwater monitoring data comes from carbon steel wells that are perforated over varying intervals (Table 3). Data for historical groundwater monitoring results were obtained from GeoDAT which contains all data in the Hanford Environmental Information System (including data from the now-defunct PNL Hanford Ground Water Monitoring Database). However, there are many gaps in the record for a particular constituent for a particular well. Wells were not sampled regularly, and generally for only a few "screening" parameters from which other information could be deduced. The sparcity of data for a particular constituent/parameter for a particular period of time does not provide a sufficient basis to contour the data so as to make plume maps. Furthermore, the location of the wells does not provide the best spatial coverage. Most of the wells were sited to monitor specific facilities, especially cribs and other liquid effluent facilities. The location of the wells allows some general conclusions about the quality of groundwater in the area of the 241-SX Tank Farm, but not necessarily specific to the tank farm. Because the constituents discharged to these cribs etc. were nearly identical in composition (but different in concentration/activity), there is no known way to trace the contaminants to a particular source. There is no particular constituent in groundwater that can be traced solely back to the SSTs as the only source.

Historical groundwater monitoring data provide useful information, but the data were obtained using an entirely different protocol than those obtained for RCRA compliance. All historical monitoring data were obtained from sampling older wells constructed of carbon steel casing that is perforated over varying intervals to communicate with the aquifer. The casing in these wells is corroded to varying degrees, and particles of rusted casing are not uncommon in water within these wells. The large openings in the casing also allow the infiltration of sediment into the well unless the well has been properly developed. Without adequate purging of water that may be more reflective of conditions in the well rather than those in the aquifer, the samples obtained may not be representative of groundwater in the aquifer. Hydrous iron oxides also are good sorbers of radionuclides, so it is possible that

some historical data on radionuclides may be skewed upward due to this preferential adherence of radionuclides to such particulate matter. It is difficult to estimate the significance of this effect, but it could lead to higher values for radionuclides in well water than are present in the aquifer. At least some of the historical samples were obtained using a bailer, with little or no purging of the standing water in the well. The database contains no information on the manner in which samples were collected, the volume collected, any preservatives that were added or the turbidity of the sample. Some historical data may have been obtained using submersible pumps which, because of the action of the pump, can cause samples to become aerated, and this in turn can affect the sample results. With casings perforated over long intervals, the depth below the water table from which the sample was obtained could also affect results. Samples obtained by bailer are likely obtained from just below the water table; samples obtained using submersible pumps may be obtained from deeper below the water table, depending on where the pump intake is set in the well. Previous work indicates that most groundwater contaminants at Hanford are in the upper part of the aquifer, with decreasing concentration/activity with depth. The exception is dense non-aqueous phase liquids (DNAPLs) which, because of a density greater than water, tend to sink deeper in an aquifer and occur at greater concentrations nearer the base of the aquifer. Carbon tetrachloride was a commonly used DNAPL at Hanford.

Furthermore, the methods used for analyses and the limits of detection or the minimal detectable activity are not recorded. Frequently repeated values during certain time periods do suggest these limits. However, it is not possible to determine whether the result is really a non-detect, or whether the activity was below the concentration/activity required to be reported under the laboratory contract. For example, there are numerous values of 17 pCi/L for gross alpha from the era of the late 1970s, suggesting that this was the minimal detectable activity. Similarly, numerous repeated values of 750 pCi/L and 500 pCi/L for the late 1950s and early 1960s, respectively, suggest a similar situation for ^{137}Cs. There are several other examples of this phenomenon which make it difficult to determine the actual level of a particular analyte/radionuclide in groundwater.

Background information given above is provided to indicate that historical groundwater monitoring data are *caveat emptor*. The results can be considered illustrative of general contaminants, their concentration/activity, and changes with time (if there are data over a sufficient period of time). Historical data should not be directly compared with RCRA groundwater monitoring data, nor should they be used to support any quantitative analyses without further investigation of the sampling and analytical methods used.

Wells and Facilities for the 241-SX Tank Farm Area

Table 3 lists wells, their construction, depth and dates of sampling. Note that some wells on Figure 1 in the vicinity of the 241-SX Tank Farm have very limited data, or no data at all. There are several groundwater monitoring wells inside the perimeter fence of the 241-SX Tank Farm: wells 299-W23-2,299-W23-3 and 299-W23-5. Wells 299-W23-6, 299-W23-7 and 299-W23-8 are located immediately adjacent to the 241-SX Tank Farm. Wells 299-W23-1 and 299-W23-12 are located nearby in and adjacent to the 241-S Tank Farm. While the wells are suitably located to provide results relevant to an assessment of groundwater quality beneath the SX Tank Farm, the lack of sampling precludes a better understanding of the contaminants present, any groundwater quality changes with time, and the areal distribution of contamination. They are not spatially distributed so as to determine conditions upgradient from those downgradient of the facility.

As with most tank farms, there are several cribs around the periphery of the 241-SX Tank Farm (Table 1). On the west side of the tank farm (groundwater upgradient side) are the 216-S-4, 216-S-21 and 216-S-25 cribs. On the east side (groundwater downgradient side) of the 241-SX Tank Farm are the 216-S-1, 216-S-2, and 216-S-8 cribs as well as the 216-S-3 French Drain. A summary of each of these facilities is given on Table 1. Groundwater monitoring wells surround several of these facilities (Table 3). Because operational decisions relating to waste management depended on data from groundwater monitoring at these facilities, there is generally more data available for the groundwater monitoring wells surrounding these cribs. Facilities on the downgradient side are listed because waste discharged from these facilities could spread laterally westward on strata of differing unsaturated hydraulic conductivity in the vadose zone. Westward spread of contaminants in the vadose zone could lead to vertical infiltration beneath the SX tank farm, or to penetration to greater depths in the vadose zone along some vertical pathways (e.g., clastic dikes, unsealed wells). Price and Fecht (1976), on geologic cross sections beneath the 241-SX Tank Farm, show several discontinuous lenses and strata of differing hydraulic conductivity. Furthermore, paleotoopography on several of these strata provide sloping surfaces along which fluids could spread westward in the vadose zone.

Probably the single biggest historical source of infiltrating liquid effluents in the 200 West area is the 216-U-10 Pond located less than a mile upgradient of the 241-SX Tank Farm. More than 99% of the liquid effluents discharged to ground within a few thousand feet of the 241-SX Tank Farm were discharged to U Pond, beneath which a significant water table mound developed. This water table mound has controlled the direction of groundwater flow beneath the 241-SX Tank Farm for more than 40 years and was a significant factor in the movement of groundwater and contaminants during much of the operational history of the 200 West area.

Historical Groundwater Monitoring Data

Groundwater monitoring in the early days of Hanford focused on the migration of radionuclides when these were the only recognized hazardous constituents of concern in groundwater. Because of differences in the sorption of various radionuclides as they passed through Hanford soils, only the more mobile radionuclides were likely to reach groundwater via interstitial infiltration. The only non-radionuclide regularly analyzed was nitrate because it was an inexpensive, easy to perform analysis for a constituent that served as a surrogate for non-sorbing or very poorly sorbing radionuclides (e.g., tritium, ^{99}Tc). The usual practice was to monitor screening parameters that indicate levels of activity reflective of the decay of alpha- and beta-emitting radionuclides. Gross alpha and gross beta data are among the more common analyses performed. Only if significant activity was revealed or there was special concern for some isotope were analyses for specific radionuclides performed. Monitoring wells were often located adjacent to cribs and served to determine when discharged liquid effluents "broke through" to groundwater (i.e., infiltrated the entire vadose zone to reach groundwater). At that point, discharge to that facility would cease and be routed to another facility. The general premise was that because of assumed travel time through the vadose zone to groundwater and thence to the Columbia River, any isotopes with a half life of less than three years would pose no significant threat to human health. Short-lived isotopes were assumed to decay to stable states prior to reaching the Columbia River. When ^{60}Co (half live of 5.3 yrs) was discovered in groundwater, some changes to liquid effluent practices were necessitated.

Wells Within the 241-SX Tank Farm

For the four wells within the 241-SX Tank Farm (Table 3), only gross beta was analyzed with any regularity. Frequent repetition of certain values (e.g., 150 and 75 pCi/L) suggest that the analyses were non-detects and the minimal detectable activity was reported. It is also possible that beta-emitting radionuclides were present, but the activity was below that which could be detected with contemporary analytical techniques. If radionuclide contamination were present in groundwater in any of these wells during the period of analyses, it was below these minimal detectable activities. There are a few, scattered values for tritium in well 299-W23-3 in 1976 that range up to 2,200,000 pCi/L, but reported values for gross beta for these analyses are what appear to be minimal detectable activities (i.e., 75 pCi/L). Isolated high values are difficult to interpret, for there are instances of gross beta values consistently being reported at apparent minimal detectable activity levels, with interspersed values of several thousand pCi/L. These values are suspect when analyses one week to one month before and one week to one month after in the same well report minimal detectable activities and there are no reasonable quality control data reported. Analyses for specific isotopes (other than tritium) were not performed until the mid-1980s. Values for gross beta and ^{99}Tc show an increasing trend beginning in the mid-1980s, with some decline in activity since then. In well 299-W23-2, ^{99}Tc is reported at about 5,500 pCi/L in 1988, with a rapid deline to about 100 pCi/L in early 1990, but then a sudden rise to over 5,000 pCi/L in late 1989 (Figure 6). The next reported analyses for ^{99}Tc for this well were in 1994 when results were about 2,200 pCi/L. A single value for ^{99}Tc in this well for 1995 is about 800 pCi/L. A few values for ^{99}Tc in well 299-W23-3 in 1994-95 range from about 520 to 330 pCi/L. The increase in ^{99}Tc in 1989 may be related to the mid-1980s increases in other isotopes reflecting discharges to the 216-S-25 crib (discussed later). A limited number of analyses for ^{137}Cs were performed on wells 299-W23-1, 299-W23-2 and 299-W23-3 in the period 1986 to 1990, with a couple of results in 1994-95. Reported results are either non-detects or values below 10 pCi/L. The DWS for ^{137}Cs is 200 pCi/L.

Wells West of the 241-SX Tank Farm

Several wells west of the 241-SX Tank Farm located adjacent to the 216-S-21 and 216-S-25 cribs were monitored more regularly. Values for most constituents monitored (gross beta, gross alpha, tritium and a few others) are generally higher than those from wells within the 241-SX Tank Farm, suggesting that these wells are closer to the contaminant source. The likely source(s) for such contaminants are the 216-S-21 or 216-S-25 cribs, or the 216-U-10 Pond. The data are highly variable and scattered on a time-series plot, so their significance is not readily apparent. The activities for these constituents generally decrease with time, but there is a common increase in activity in 1986 for gross alpha, gross beta and tritium which continues increasing through about 1988, and then begins a slow decline. Nitrate appears elevated in 1986, but there are no data for the period 1976 - 1986, so a trend is not seen. The significance of this pattern in the mid-1980s will be discussed later.

Well 299-W23-4 is northwest of the 241-SX Tank Farm, west of the 241-S Tank Farm and adjacent to the 216-S-21 crib. Data on water levels and constituent analyses are reasonably complete for this well (Figure 3). A hydrograph of 299-W23-4 reveals fluctuations of about 10 feet through the 1960s and 1970s. This hydrograph is probably reasonably representative of water table fluctuations with time. While it is possible that a small water table mound might have arisen beneath the 216-S-21 crib, the fluctuations in water level are likely common to the area of the SX tank farm in the 1960s, 1970s and 1980s. However, since decommissioning of U Pond in 1984, water levels have dropped from a high of 482 ft.above MSL to about 460 feet above MSL in this well.

Historical constituent data for well 299-W23-4 are more complete than for many in the vicinity of the 241-SX Tank Farm. Values for tritium reached 110,000,000 pCi/L in 1964. ^{137}Cs, another constituent exhibiting the mid-1980s upward spike in activity, was monitored intermittently in this well. Values in the early to mid 1970s ranged from about 8 pCi/L to about 50 pCi/L, with what appears to be an upward increase in the period 1972 - 1976. The most recent data (late 1980s) indicate activities ranging up to 8 pCi/L, but mostly below 5 pCi/L. Nitrate data for this well are highly variable, ranging from values in the 10,000 to 30,000 ppb range during the late 1950s to a high of 150,000 in 1962. Ten years later (no analyses in the period 1964 - 1972), nitrate results were in the 20,000 to 30,000 ppb range. Nitrate concentrations generally decrease to less than 1,000 ppb from the mid-1970s to the mid-1980s, when an increase to about 10,000 ppb was noted.

Gross beta in well 299-W23-4 has fluctuated with time. A few analyses performed in 1959 indicate activities of 100 - 1,000 pCi/L, with high variability. Frequent, periodic analyses for gross beta in this well began in 1968, with results ranging from 50 pCi/L to highs of about 250 pCi/L in 1972. Beginning about 1974, activities decline to minimal detectable levels through the early 1980s. An increase in gross beta is noted in the period 1987-88 in this well. No specific analyses were performed for the specific beta-emitting radionuclides typically in Hanford liquid effluents, so the causative isotope remains unidentified (but is likely ^{99}Tc or ^{90}Sr). No analyses were peformed for ^{99}Tc, but several analyses for ^{90}Sr indicate that it was a significant contributor to elevated gross beta. [In recent analyses for gross beta and ^{99}Tc (where ^{99}Tc is the principal radionuclide decaying by emission of beta energy), the values of gross beta are typically in the range of 20% to 30% of the value for ^{99}Tc. Since counters used to measure gross beta activity are usually calibrated to the activity of ^{90}Sr, there is likely a closer correspondence between gross beta and ^{90}Sr values.]

Gross alpha was also regularly analyzed in samples collected from well 299-W23-4 beginning in 1968 and this parameter displays a variability with time similar to that for gross beta. Late 1960s values increase from the 50 - 100 pCi/L, peak about 230 pCi/L in 1972, and appear to decline to minimal detectable levels by the mid 1970s. Values for gross alpha decline through the early 1980s, but rise again from the 10-20 pCi/L range in 1986 to about 80 pCi/L in 1988--the same mid-1980s spike that is common to several constituents (Figure 7). Gross alpha values appear to reflect uranium as the principal contributor. However, analyses for other isotopes decaying principally by emission of alpha particles were not performed, so this interpretation can not be confirmed.

Wells East of the 241-SX Tank Farm

Eleven older carbon steel (i.e., non-RCRA) wells are located east (downgradient) of the 241-SX Tank Farm and were likely constructed to monitor the 216-S-1, 216-S-2 and 216-S-8 cribs. These cribs received start-up waste and cell drainage waste from receiver tanks in the 202-S (REDOX) plant. Analyses were performed only on some of these wells, and with no regularity. Samples were collected and analyzed periodically, at times, for well 299-W22-1 which is located adjacent to the 216-S-1 and 216-S-2 cribs. Between 1957 and 1960, gross beta was generally in the range of a few hundred pCi/L. Analyses resumed in 1971, with gross beta ranging between 5,000 and 6,000 pCi/L. Although some ^{106}Ru was present in samples, most of this activity was due to ^{90}Sr which reached 5,000-6,000 pCi/L in the early 1970s (Figure 8). Values for ^{90}Sr activity have been declining since then and were below 1,000 pCi/L by the early 1980s, suggesting that not all of the activity was due to ^{90}Sr (with a 29.1 year half life). Gross alpha data are available for well 299-W22-1 for the period 1977 - 1989 and

decline from about 17 pCi/L in 1979-80 to a few pCi/L in 1989. No isotopes causing this activity were identified, as there were no analyses for specific alpha-decaying isotopes. A single value for tritium in 1966 reached 10,00,000 pCi/L. Periodic analyses were run for this isotope from 1971 through 1989, and exhibit a gradual decline from about 80,000 pCi/L to less than 2,000 pCi/L by 1982. Data for most other wells east of the 241-SX Tank Farm is infrequent, highly variable (and thus suspect) or reported at minimum detectable activities. These data are not amenable to analyses.

FOOTNOTE

1) Using the largest estimated value for each leaking tank from Table H-1 in Hanlon (1996).

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LIST OF FIGURES

LIST OF TABLES

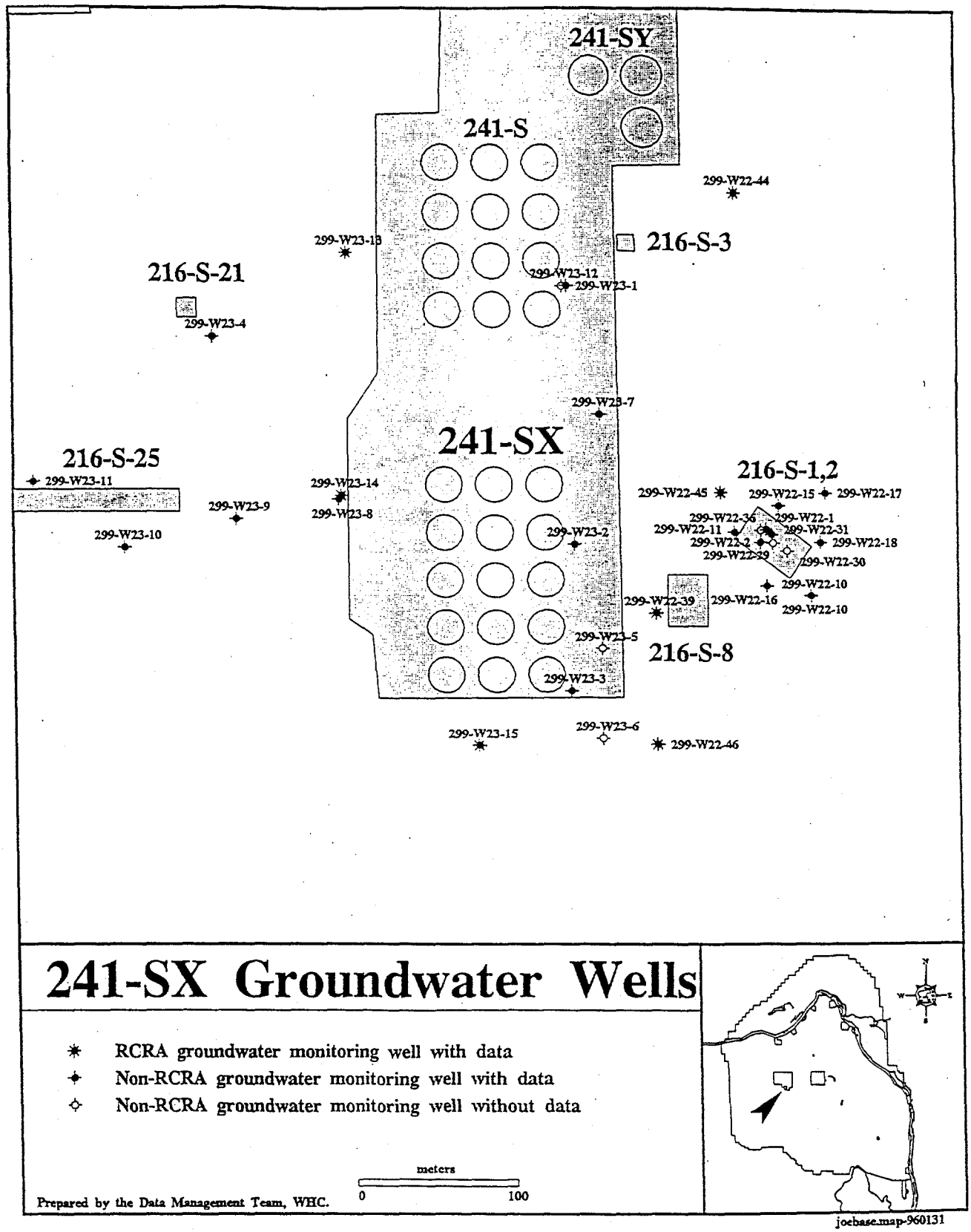

241-SY
241-S
299-W22-44
299-W23-18
216-S-3
216-S-21
299-W23-12
299-W23-1
299-W23-4
299-W23-7
241-SX
216-S-25
299-W23-11
299-W23-14
299-W23-8
299-W23-9
299-W23-10
299-W23-2
216-S-1,2
299-W22-45
299-W22-15
299-W22-17
299-W22-36
299-W22-1
299-W22-11
299-W22-31
299-W22-2
299-W22-18
299-W22-29
299-W22-30
299-W22-10
299-W22-39
299-W22-16
299-W22-10
299-W23-5
216-S-8
299-W23-3
299-W23-15
299-W23-6
299-W22-46
241-SX Groundwater Wells
RCRA groundwater monitoring well with data
Non-RCRA groundwater monitoring well with data
Non-RCRA groundwater monitoring well without data
meters
0
100
Prepared by the Data Management Team, WHC.
joebase.map-960131

FIGURE 1

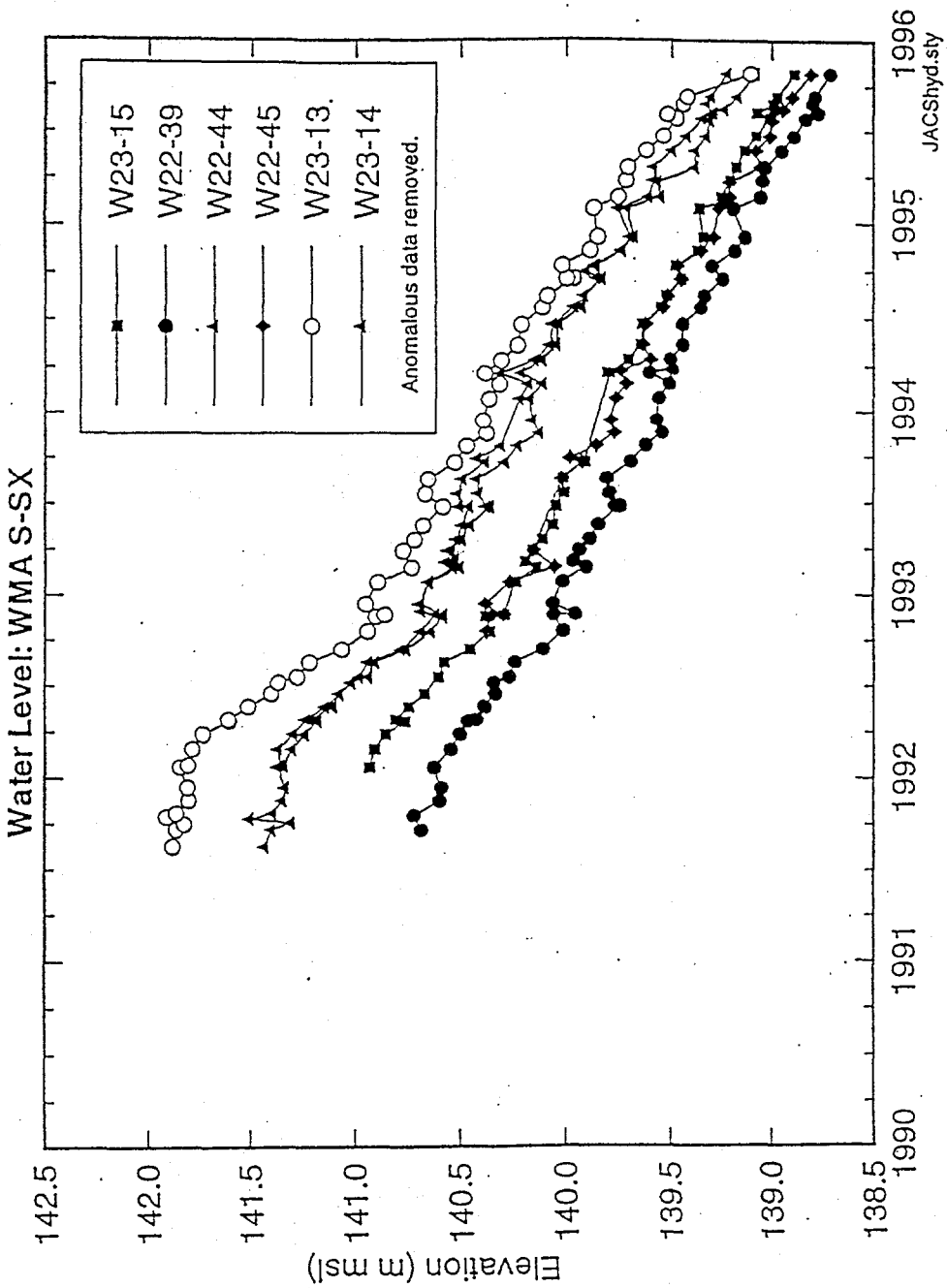

Water Level: WMA S-SX
W23-15
W22-39
W22-44
W22-45
W23-13
W23-14
Anomalous data removed.
Elevation (m msl)
142.5
142.0
141.5
141.0
140.5
140.0
139.5
139.0
138.5
1990
1991
1992
1993
1994
1995
1996
JACShyd.sty

FIGURE 2

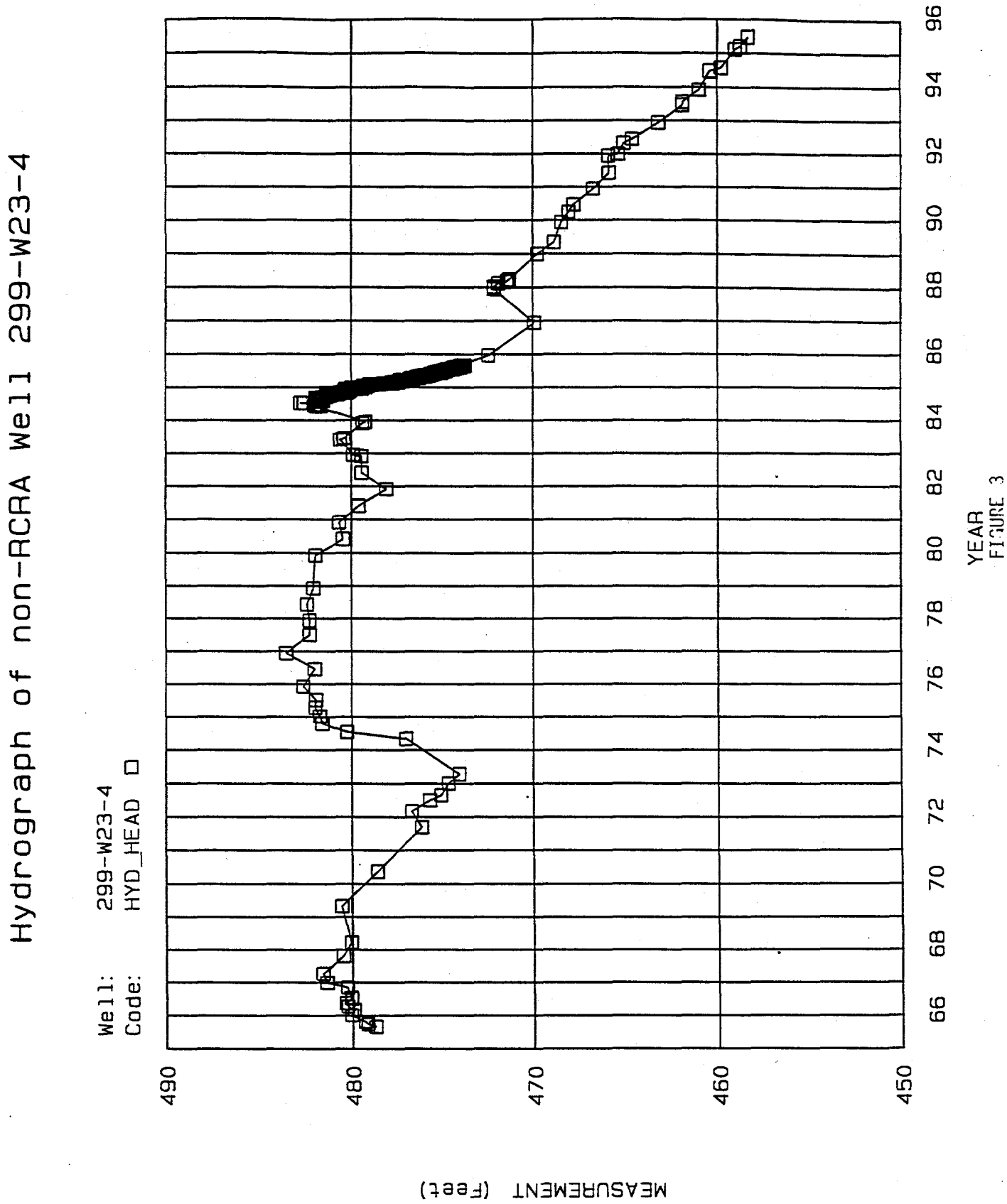

Hydrograph of non-RCRA Well 299-W23-4
Well: 299-W23-4
Code: HYD_HEAD □
490
480
470
460
450
MEASUREMENT (feet)
66
68
70
72
74
76
78
80
82
84
86
88
90
92
94
96
YEAR

FIGURE 3

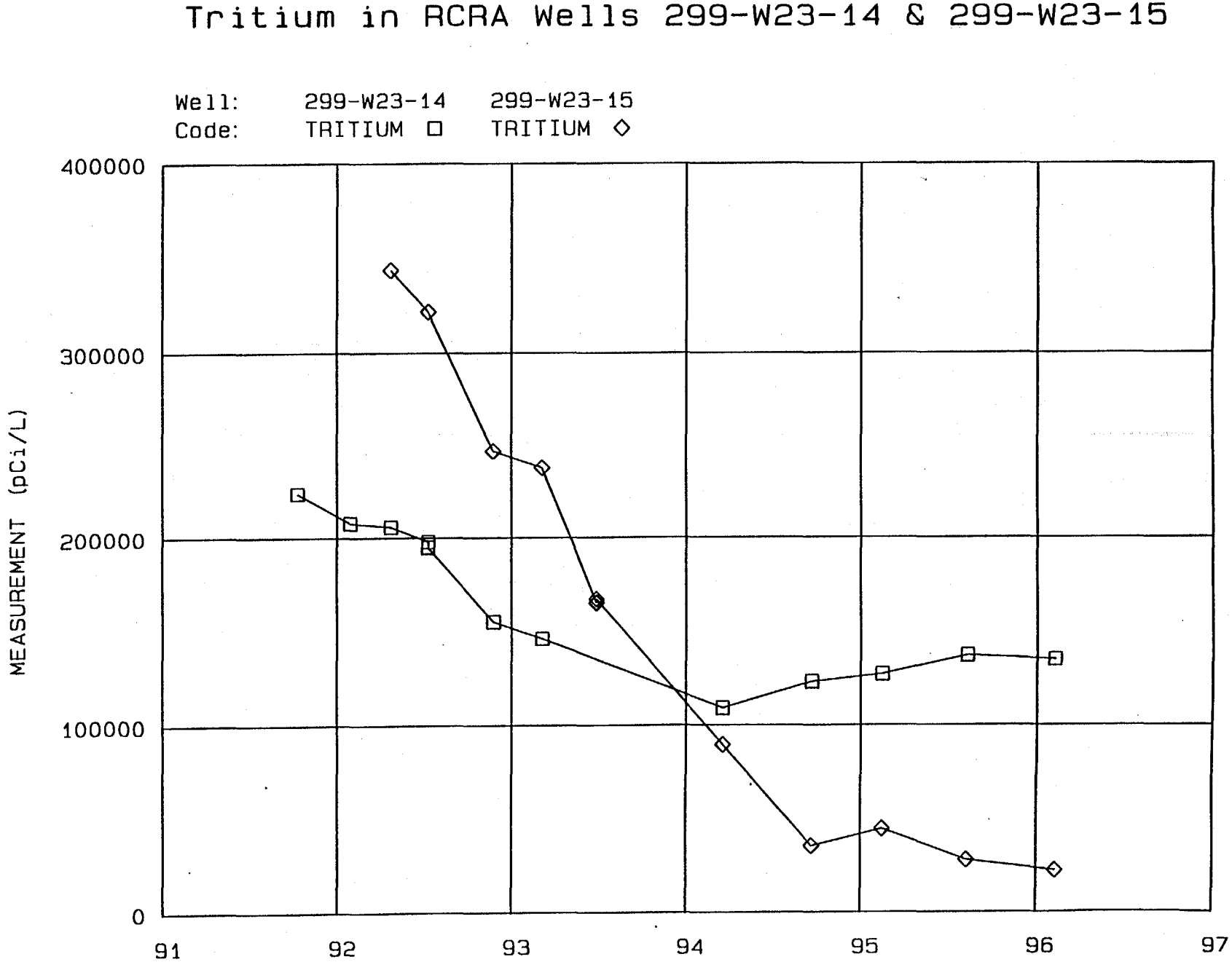

Tritium in RCRA Wells 299-W23-14 & 299-W23-15
Well: 299-W23-14 299-W23-15
Code: TRITIUM □ TRITIUM ◇
400000
300000
200000
100000
0
MEASUREMENT (pCi/L)
91
92
93
94
95
96
97
YEAR

FIGURE 4

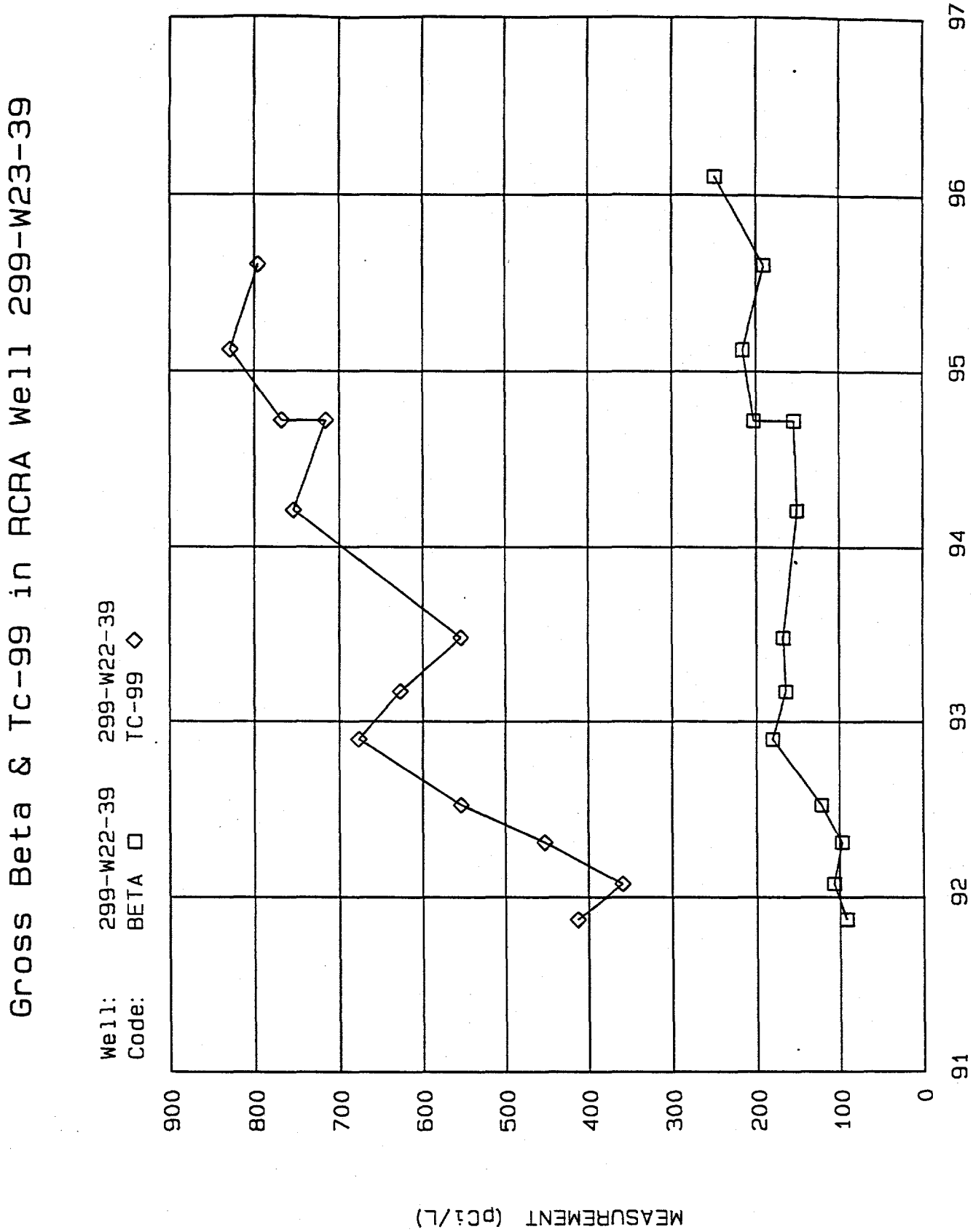

Gross Beta & Tc-99 in RCRA Well 299-W23-39
Well: 299-W22-39 299-W22-39
Code: BETA □ TC-99 ◇
MEASUREMENT (pCi/L)
900
800
700
600
500
400
300
200
100
0
91
92
93
94
95
96
97
YEAR

FIGURE 5

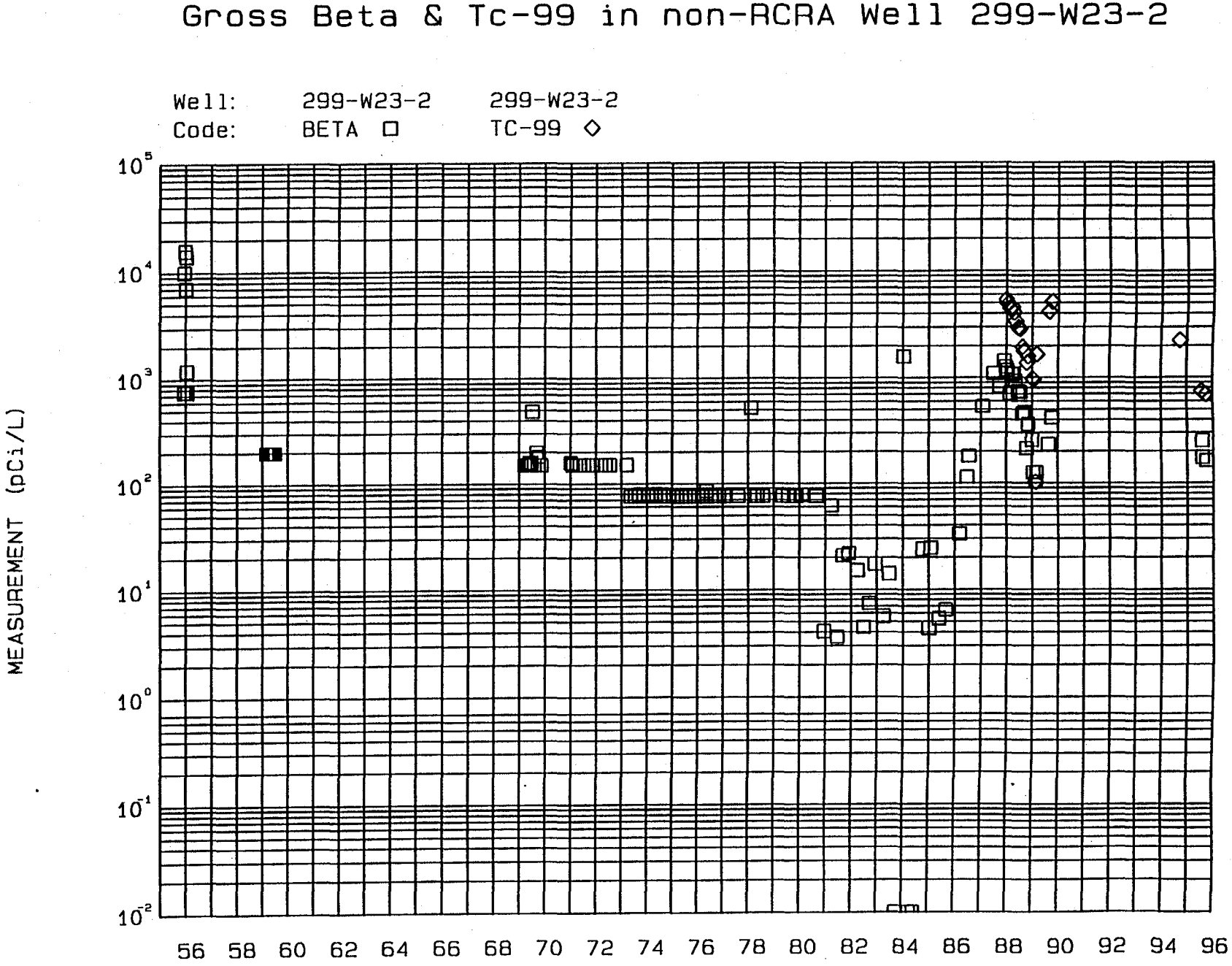

Gross Beta & Tc-99 in non-RCRA Well 299-W23-2
Well: 299-W23-2 299-W23-2
Code: BETA □ TC-99 ◇
MEASUREMENT (pCi/L)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96
YEAR

FIGURE 6

Gross Alpha & Uranium in non-RCRA Well 299-W23-4

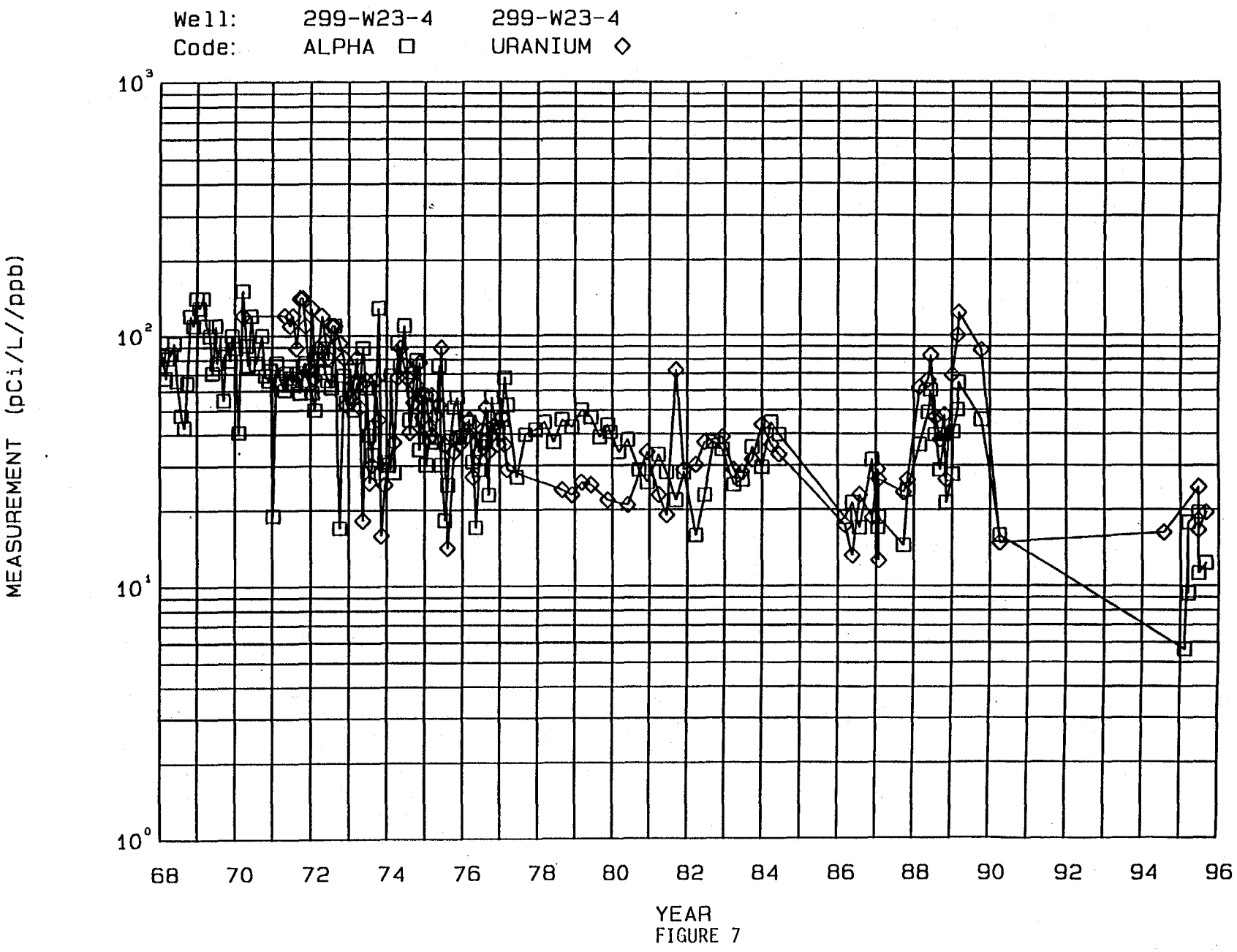


FIGURE 7

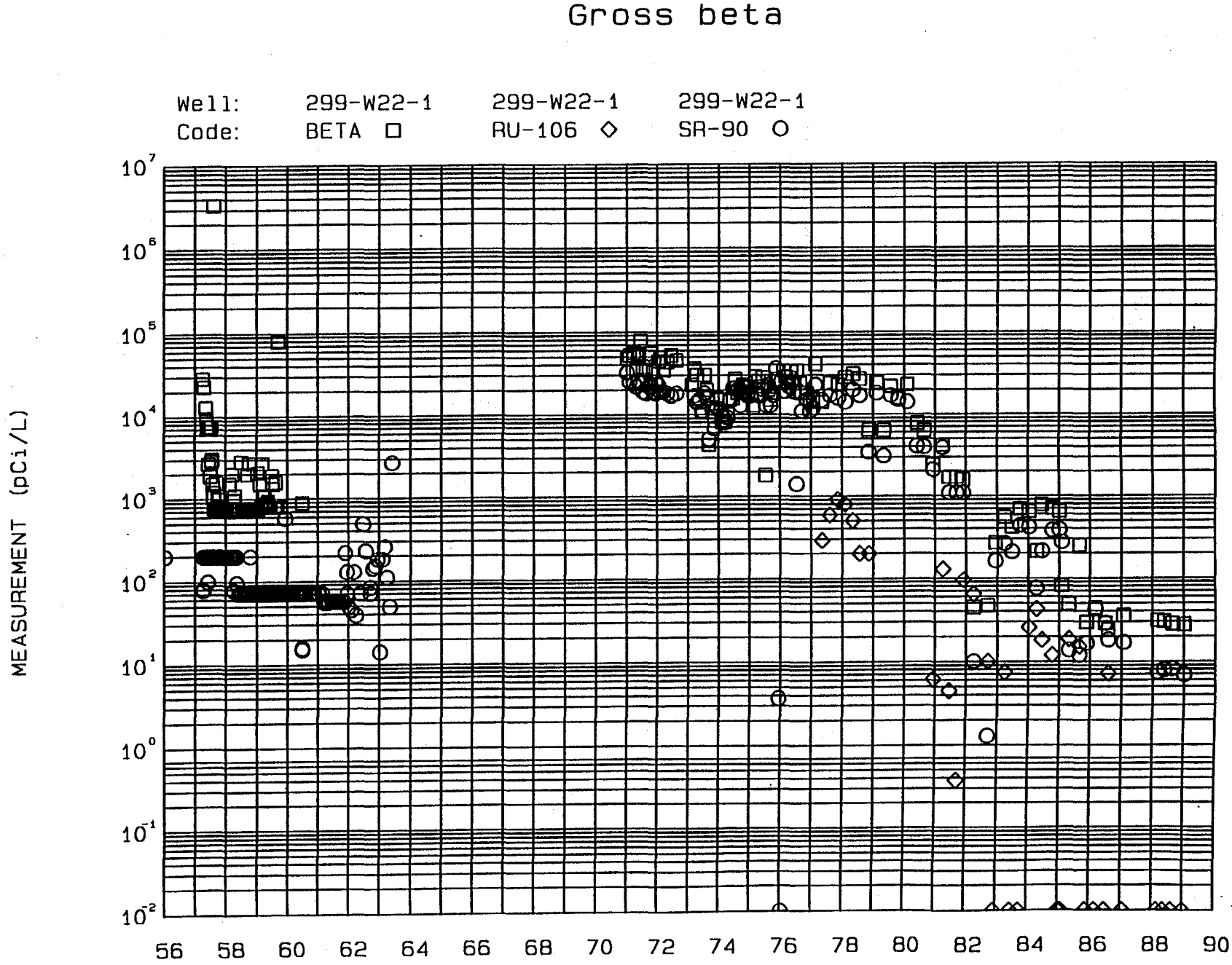

Gross beta
Well: 299-W22-1 299-W22-1 299-W22-1
Code: BETA □ RU-106 ◇ SR-90 ○
MEASUREMENT (pCi/L)
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90
YEAR

FIGURE 8

Table 1

Liquid Effluent Facilities in the Vicinity of the 241-SX Tank Farm				
Facility No.	Type	Operating Dates	Waste Volume (gals)	Waste Types
216-S-1&2	Cribs	1/52 - 1/56	42,272,100	202-S Cell Drainage/condensate
216-S-3	French Drain	9/53 - 8/56	1,109,640	Condensate from 101-S & 104-S Tanks
216-S-4	French Drain	8/53 - 8/56	264,201	Condensate/cooling from 101-S & 104-S Tanks
216-S-8	Trench	11/51 - 2/52	2,642,010	Non-irradiated startup waste from 202-S
216-S-21	Crib	11/54 - 2/69	23,011,900	241-SX condensate via 206-SX Tank
216-S-25	Crib	11/73 -	76,089,800*	242-S Evaporator Steam Condensate to 1980; S
216-U-10	Pond	7/44 - 8/85	43,593,100,000	Various waste streams, mostly cooling and proce
		TOTAL	43,738,500,000	
NOTES				
*Also received effluent from ion exchange process to remove U from 216-U-1, -U-2 cribs				

Table 2

Liquid Effluent Releases from the 241-SX Tank Farm Area					
Released From	Release Date*	Est. Leak Volume (gals)	Site Code	Operable Unit	Waste Type in Tank+
241-SX-104	1988	6,000			REDOX high-level, ion exchange, double-shell slurry, evaporator bottom
241-SX-107	1964	<5,000	UPR-200-W-140	200-RO-4	REDOX high-level, coating waste/supernatant
241-SX-108	1962	2,400 to 35,000	UPR-200-W-141	200-RO-4	REDOX high-level, concrete, supernatant from SX Tank Farm
241-SX-109	1965	<10,000	UPR-200-W-142	200-RO-4	REDOX high-level waste and high-level supernatant from SX Tank Farm
241-SX-110	1976	5,500			REDOX high-level and high-level supernatant, concrete,mB Plant low level/ion exchange, evap. bottoms, 224-U waste
241-SX-111	1974	500 to 2,000	UPR-200-W-143	200-RO-4	REDOX high-level waste and high-level supernatant/REDOX ion exchange from SX Tank Farm
241-SX-112	1969	30,000	UPR-200-W-144	200-RO-4	REDOX high-level and high-level supernatant from 241-SX Tanks
241-SX-113	1962	15,000	UPR-200-W-145	200-RO-4	REDOX high-level waste and diatomaceous earth
241-SX-114	1972	~8,000**			REDOX high-level waste/high-level supernatant. REDOX ion exchange/evaporator bottoms
241-SX-115	1965	50,000	UPR-200-W-146	200-RO-4	REDOX high-level waste and high-level supernatant
241-S-151 Div. Box	1958	NA	UPR-200-W-51	200-RO-2	
216-S-1, -S-2++	1955	NA	UPR-200-W-36	200-RO-2	
*Year tank was assigned an "Assumed Leaker" status or year of spill/release					
**Estimated average for each of 19 tanks (see Hanlon, 1995, Table H-1)					
+ From WIDS					
++Contamination spread from ruptured test well					

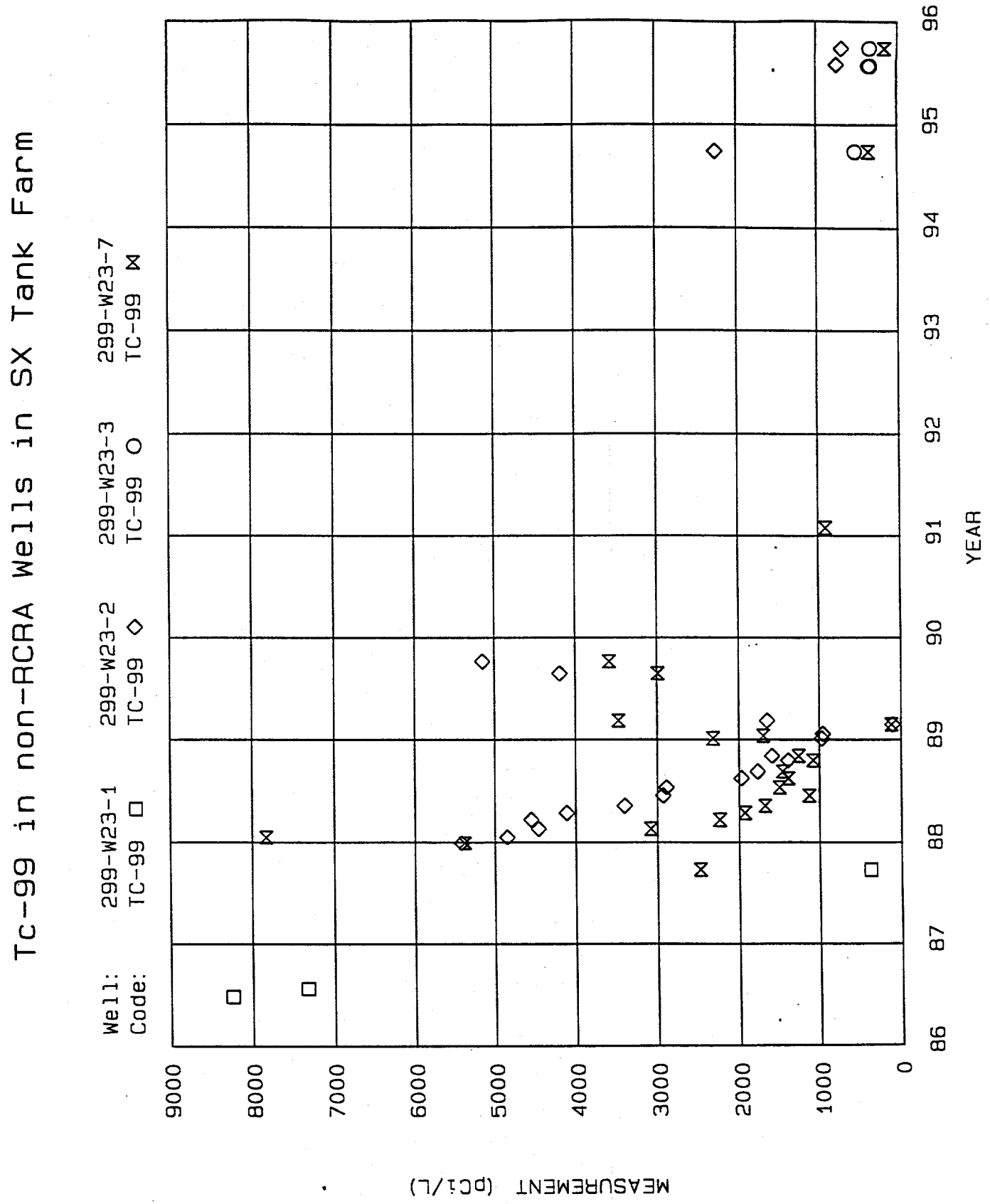
Table 3

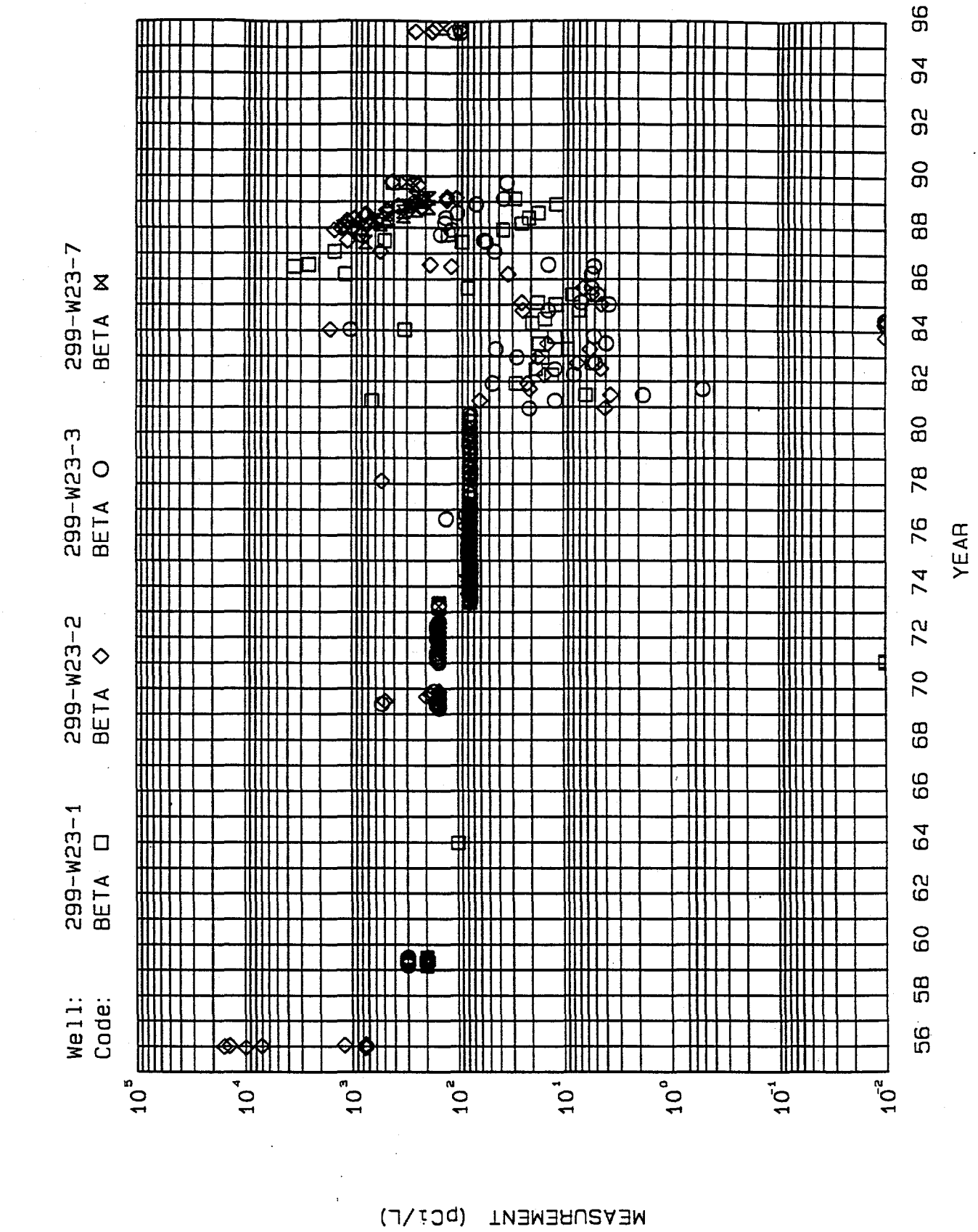
SX Tank Farm	Well No.	Nearest Facility	Const. Date	Depth (ft.)	Diameter (in.)	Annular Seal	Open Interval
	2-W23-2	SX-104, SX-107	1954	236	8, 4	Partial ('76)	P184 - 235
	2-W23-3	SX-112	1956	232	8, 4	Partial ('76)	P176 - 228
	2-W23-5	SX-112	1969	250	6, 4	Partial ('76)	P170 - 240; S205 - 238
	2-W23-7	SX-101	1969	250	6, 4	Partial ('76)	P170 - 248; S149 - 219
S Tank Farm	2-W23-1	S-107	1952	262	6, 4	Partial ('76)	P180 - 260; S178 - 235
	2-W23-12	S-107; 216-S-3 French Drains	1970	265	6, 4	Partial ('76)	P189 - 230
S-SX RCRA	2-W22-39	SX Tank Farm	1991	223.3	4	Full	S199.8 - 223.3
	2-W22-44	S/SY Tank Farms	1991	246	4	Full	S205.1 - 242.2
	2-W22-45	S Tank Farm	1992	240.0	4	Full	S198.1 - 233.9
	2-W22-46	SX Tank Farm	1991	241.0	4	Full	S192.9 - 228.9
	2-W23-13	S Tank Farm	1990	218.2	4	Full	S195.9 - 217.2
	2-W23-14	SX Tank Farm	1991	224.4	4	Full	S194.0 - 215.3
	2-W23-15	SX Tank Farm	1991	225.0	4	Full	S185.7 - 222.4
S-SX Tank Farm Area	2-W22-1	216-S-1, -S-2 Cribs	1952; 1956	306	8, 6	Partial ('80)	P190 - 280
	2-W22-2	216-S-1, -S-2, -S-8 Cribs	1951; 1956	307	8, 6	Partial ('80)	P195 - 285
	2-W22-6	SX Tk Fm; 216-S-8 Crib	1956	274	8, 6	Partial ('80)	P194 - 273; S170 - 229
	2-W22-10	216-S-1, -S-2 Cribs	1956	312	8, 6	Partial ('87)	P203 - 311
	2-W22-11	216-S-1, -S-2, -S-8 Cribs	1956	308	8, 6	Partial ('80)	P195 - 305
	2-W22-15	216-S-1, -S-2 Cribs	1956	268	8, 6	Partial ('80)	P190 - 263
	2-W22-16	216-S-1, -S-2 Cribs	1956	248	8, 4	Partial ('78)	P190 - 246
	2-W22-17	216-S-1, -S-2 Cribs	1956	261.5	8, 6	Partial ('80)	P209 - 260
	2-W22-18	216-S-1, -S-2 Cribs	1955, 1966	302	8, 6	Partial ('80)	P212 - 298
	2-W22-29	216-S-1, -S-2, -S-8 Cribs	1966	202	6, 4	Partial ('80)	NP#
	2-W22-30	216-S-1, -S-2, -S-8 Cribs	1966, 1980	231	6, 4	Partial ('80) *	NP*
	2-W22-31	216-S-1, -S-2, -S-8 Cribs	1966, 1980	250	6, 4	Partial ('80)	NP**
	2-W22-36	216-S-1, -S-2 Cribs	1966	206	6, 4	Partial ('80)	
	2-W23-4	216-S-21 Crib	1957	300	8	No	P180 - 295
	2-W23-6	SX Tank Farm	1969	250	6, 4	Partial ('80)	P172 - 248
	2-W23-8	SX Tank Farm	1972	235	6	No	P165 - 230
	2-W23-9	216-S-25 Crib	1972	235	6, 5	Partial ('83)	P164 - 230
	2-W23-10	216-S-25 Crib	1972	235	6, 5	Partial ('83)	P165 - 230
	2-W23-11	216-S-25 Crib	1972	235	6, 5	Partial ('83)	P165 - 230
		NOTES					
		#NP = Not perforated--hole abandoned because tools lost in well					
		*Contamination recorded in driller's log during construction					
		**Perforator contaminated in 1979-80 during deepening of well					

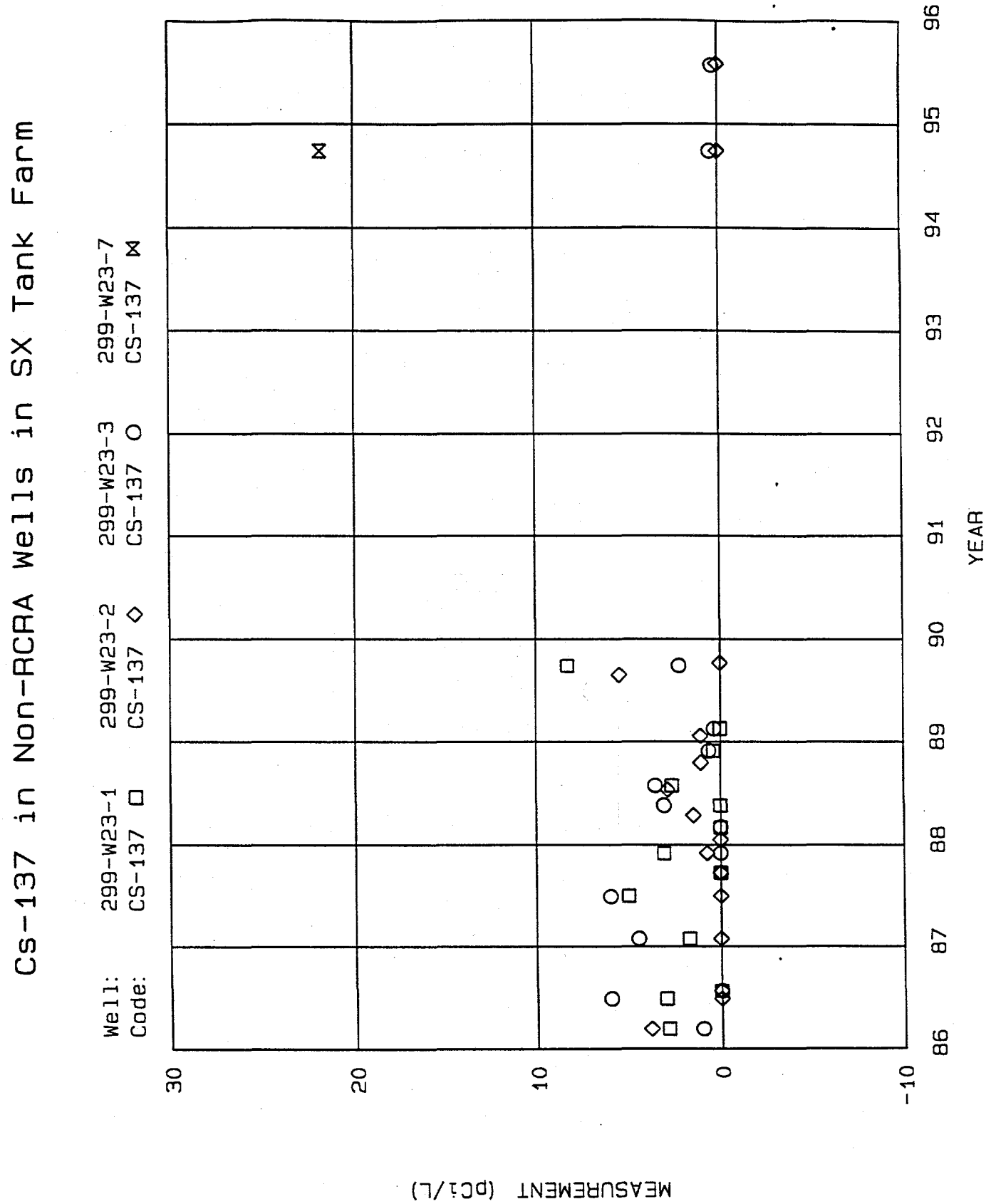
Table 4

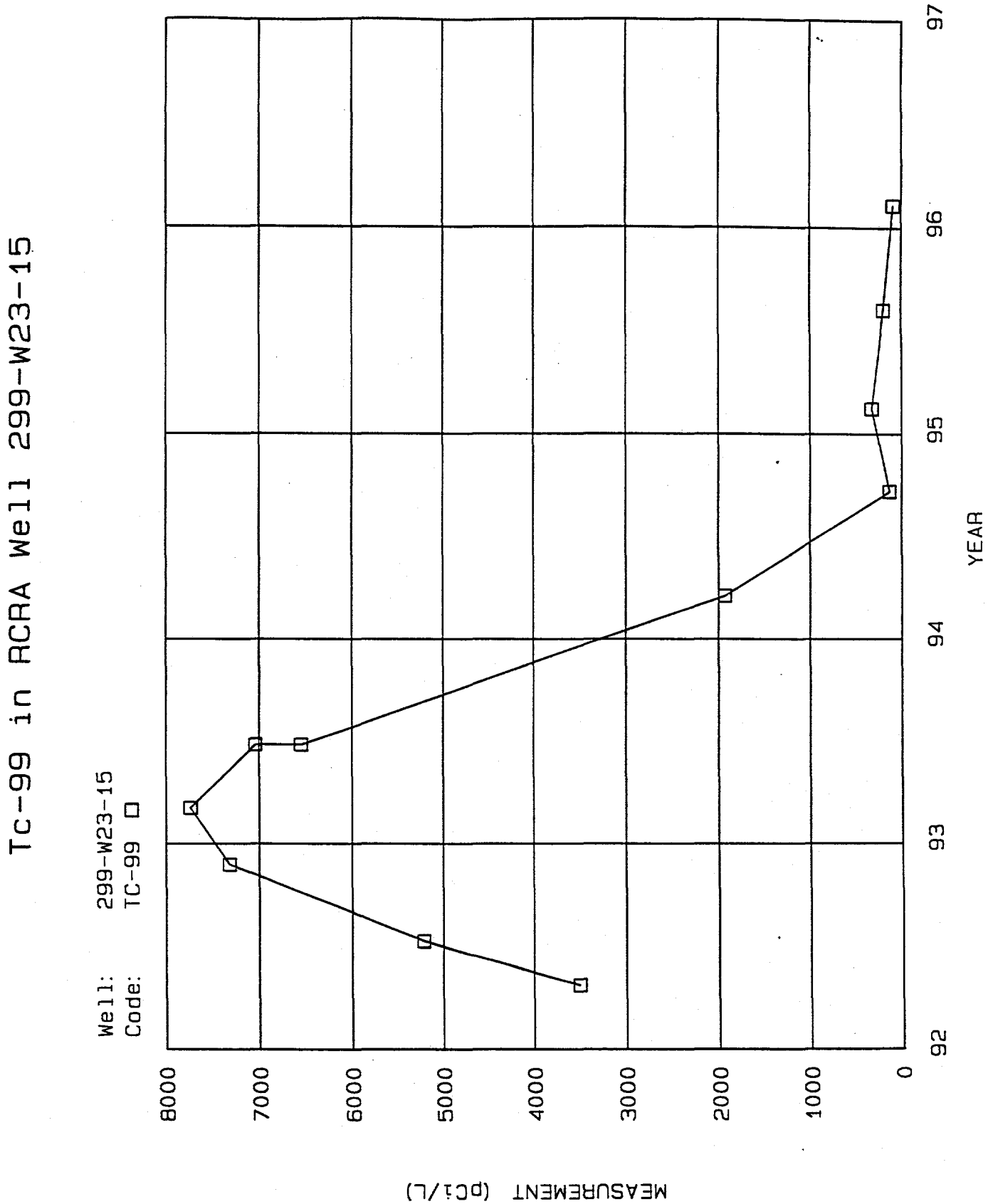
Constituents Exceeding Drinking Water Standards in the 241-SX Tank Farm (RCRA Wells)							
WMA	Well	Up/Downgradient	Constituent	Result	Units	DWStd.	Sample Date
S-SX	2-W23-14	Up	Tritium	127,000	pCi/L	20,000 pCi/L	2/14/95
				137,000	pCi/L	20,000 pCi/L	8/9/95
	2-W23-15	Down	Tritium	44,200	pCi/L	20,000 pCi/L	2/14/95
				27,700	pCi/L	20,000 pCi/L	8/9/95

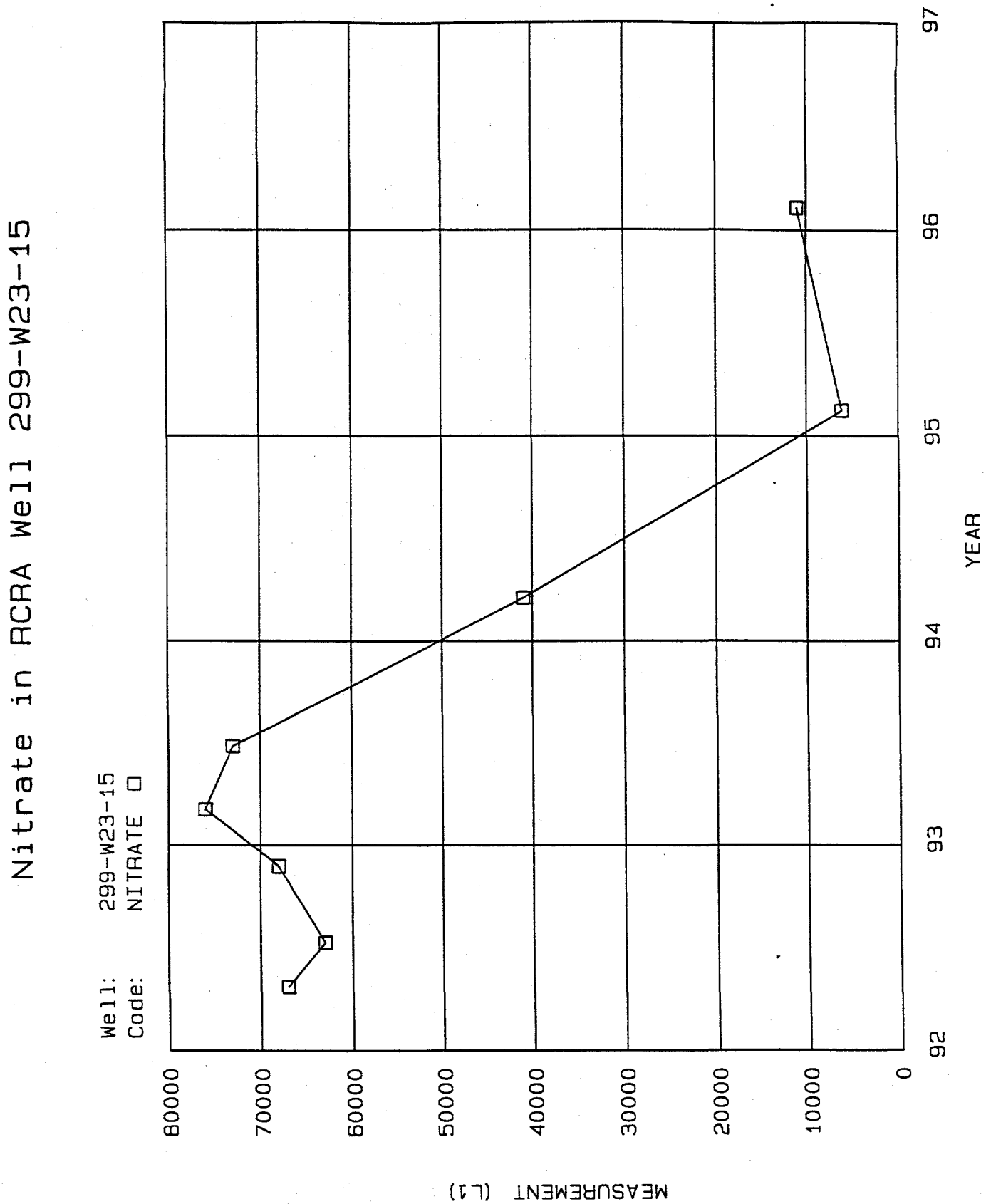
APPENDIX A

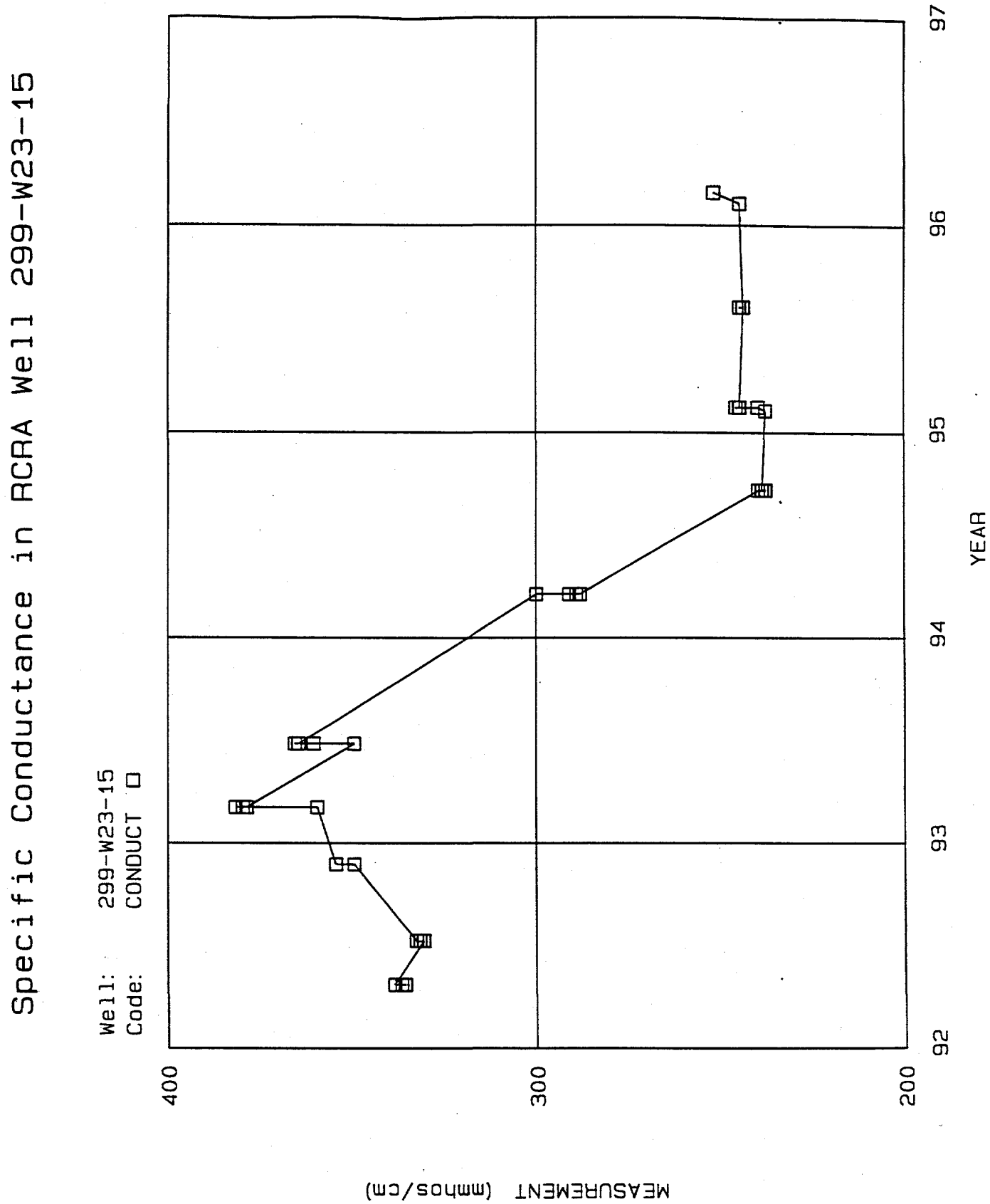

Tc-99 in non-RCRA Wells in SX Tank Farm
Well: 299-W23-1 299-W23-2 299-W23-3 299-W23-7
Code: TC-99 □ TC-99 ◇ TC-99 ○ TC-99 ⊠
MEASUREMENT (pCi/L)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
86
87
88
89
90
91
92
93
94
95
96
YEAR

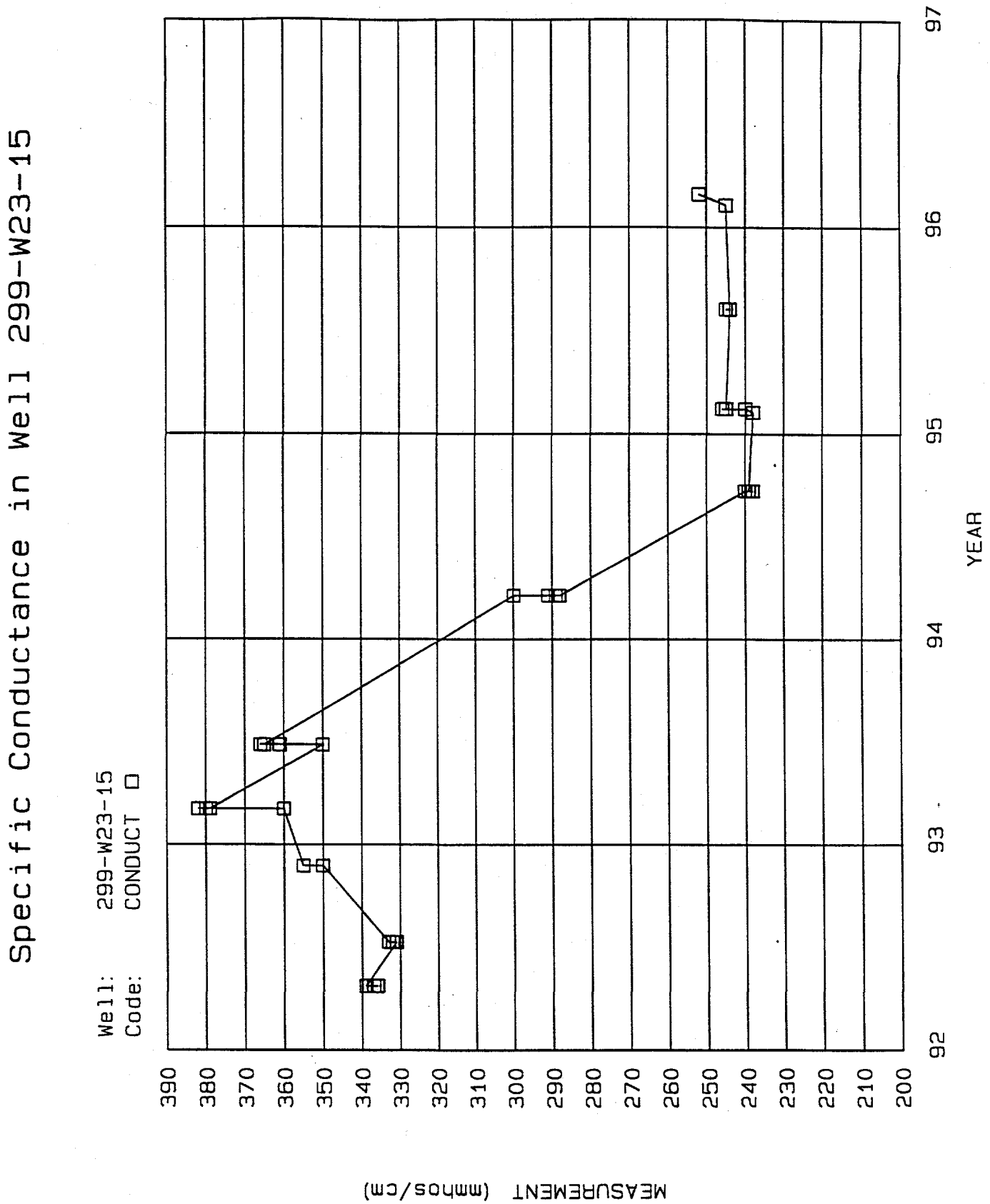

Gross Beta in non-RCRA Wells in SX Tank Farm
Well: 299-W23-1 299-W23-2 299-W23-3 299-W23-7
Code: BETA □ BETA ◇ BETA ○ BETA ⊠
MEASUREMENT (pCi/L)
YEAR
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96


Cs-137 in Non-RCRA Wells in SX Tank Farm
Well: 299-W23-1 299-W23-2 299-W23-3 299-W23-7
Code: CS-137 □ CS-137 ◇ CS-137 ○ CS-137 ⋈
MEASUREMENT (pCi/L)
30
20
10
0
-10
86
87
88
89
90
91
92
93
94
95
96
YEAR

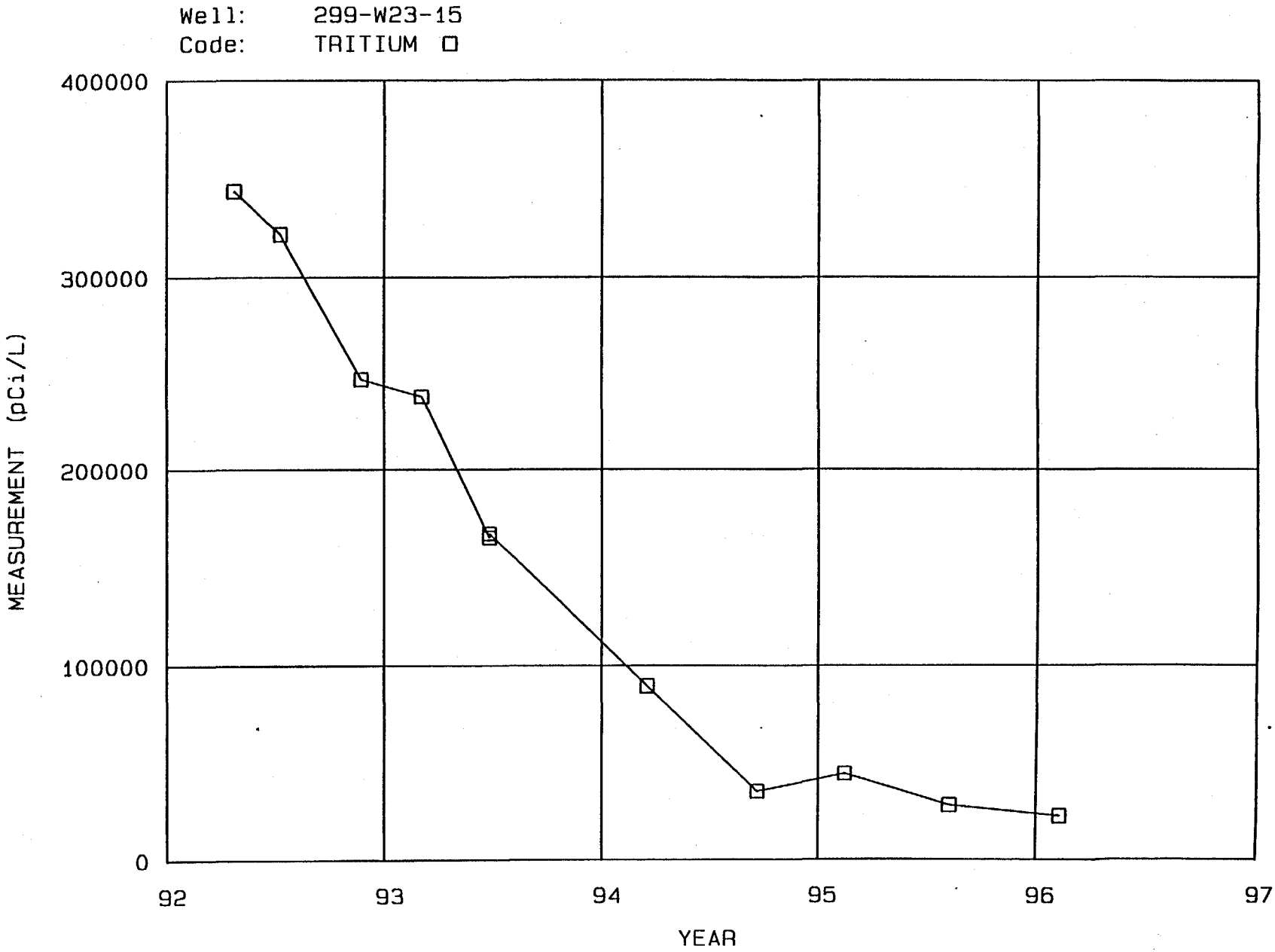

Tc-99 in RCRA Well 299-W23-15
Well: 299-W23-15
Code: TC-99 □
MEASUREMENT (pCi/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
92
93
94
95
96
97
YEAR


Nitrate in RCRA Well 299-W23-15
Well: 299-W23-15
Code: NITRATE □
MEASUREMENT (L1)
80000
70000
60000
50000
40000
30000
20000
10000
0
92
93
94
95
96
97
YEAR

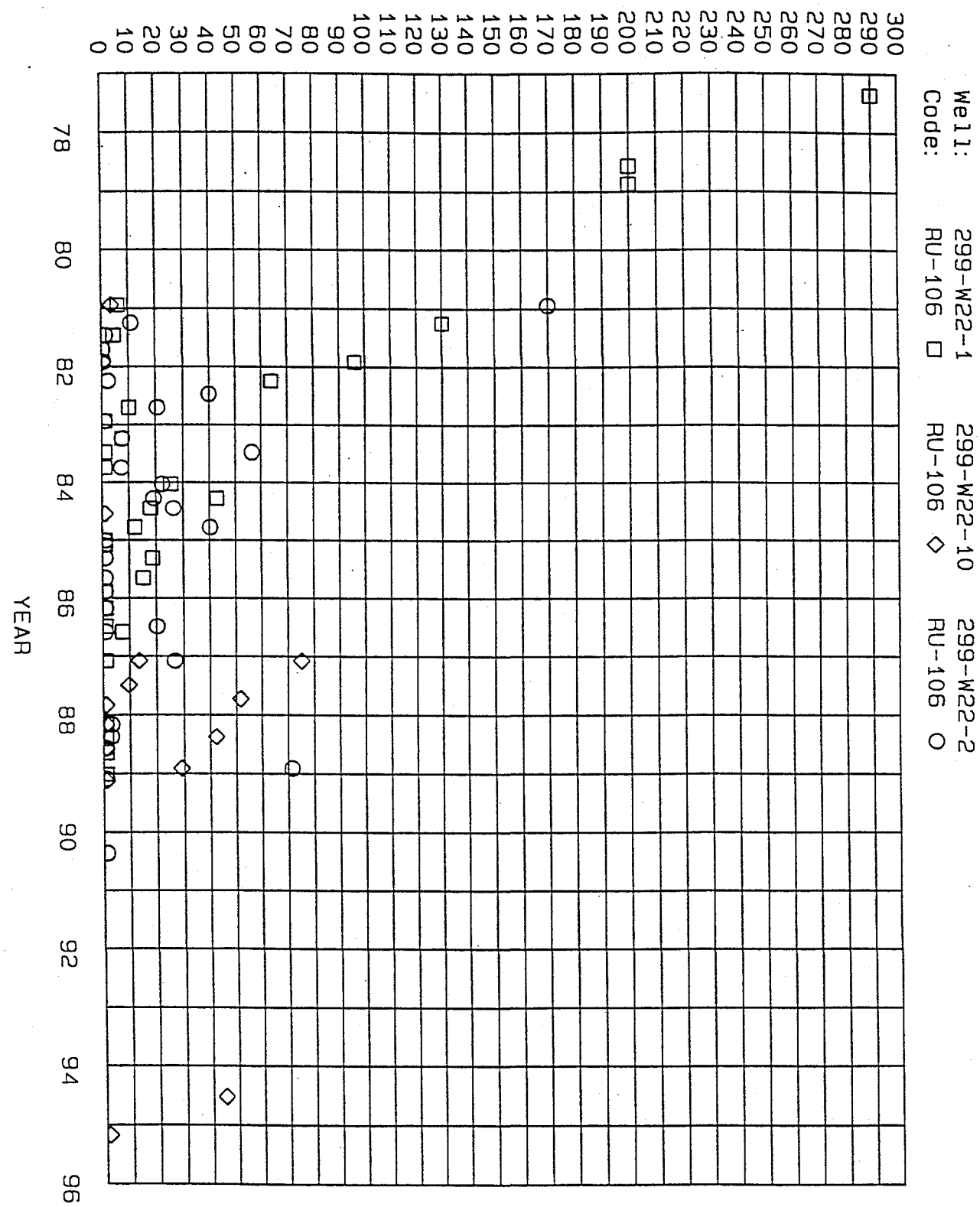

Specific Conductance in RCRA Well 299-W23-15
Well: 299-W23-15
Code: CONDUCT □
400
300
200
92
93
94
95
96
97
YEAR
MEASUREMENT (mmhos/cm)

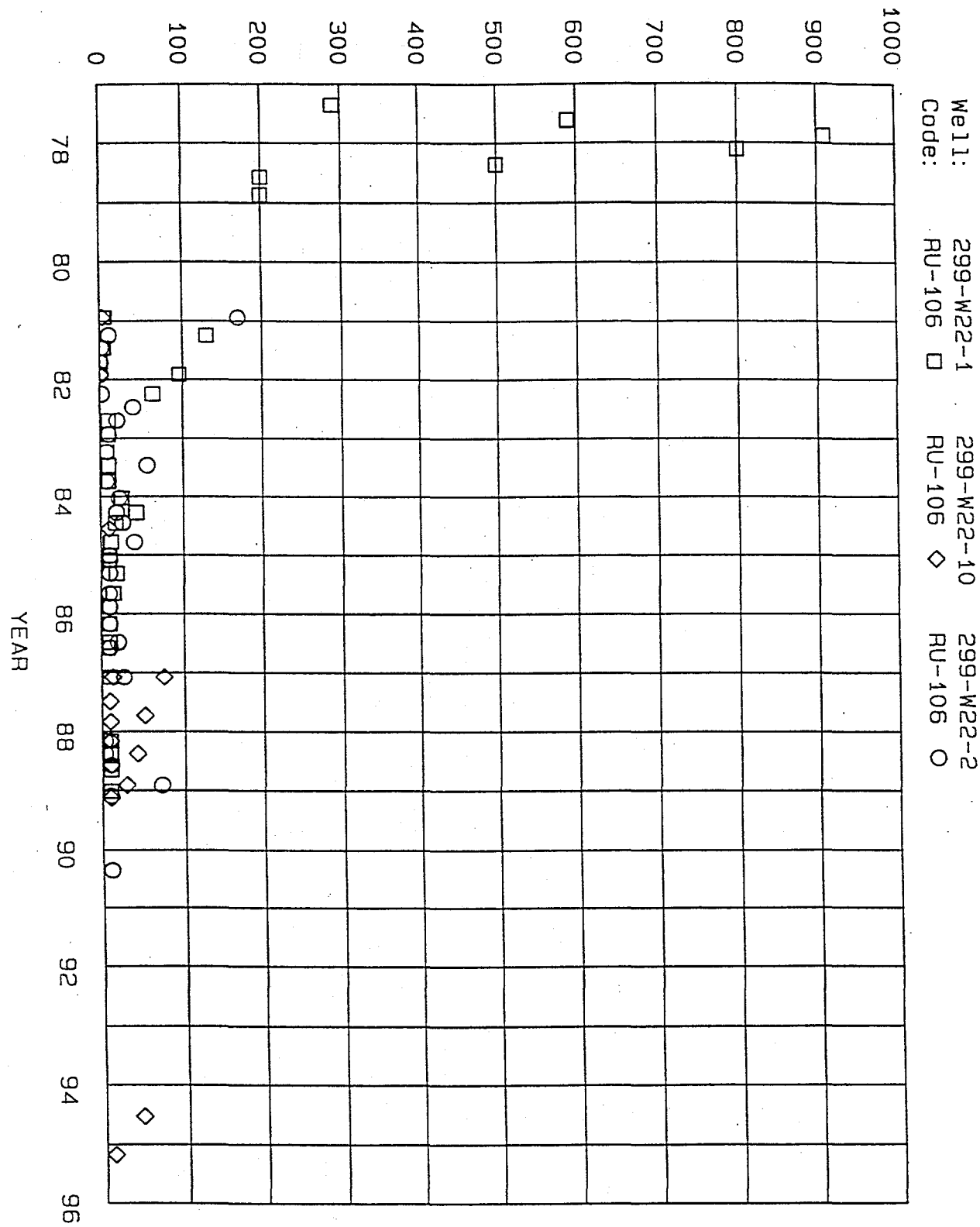

Specific Conductance in Well 299-W23-15
Well: 299-W23-15
Code: CONDUCT □
MEASUREMENT (mmhos/cm)
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
92
93
94
95
96
97
YEAR

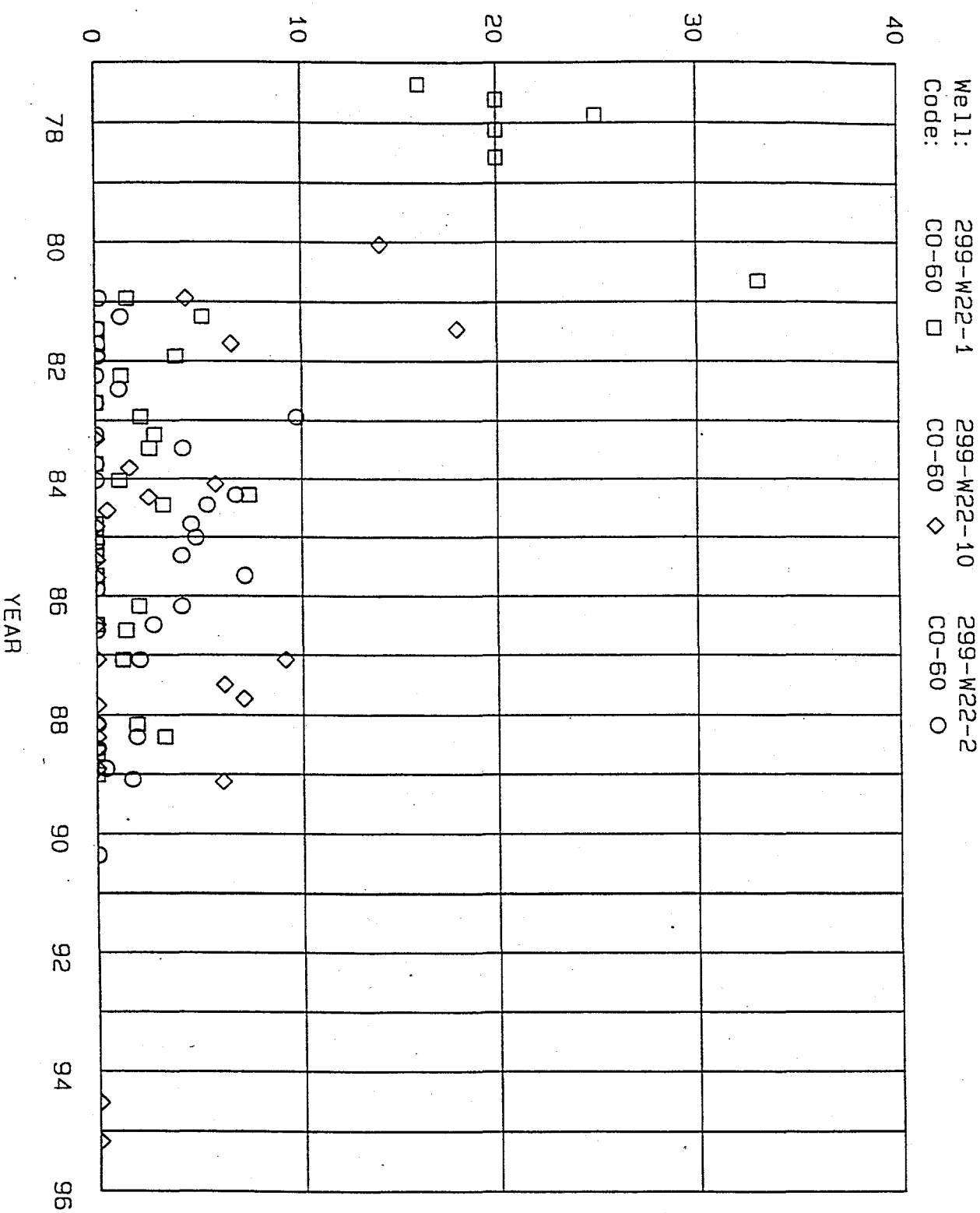
Tritium in RCRA Well 299-W23-15

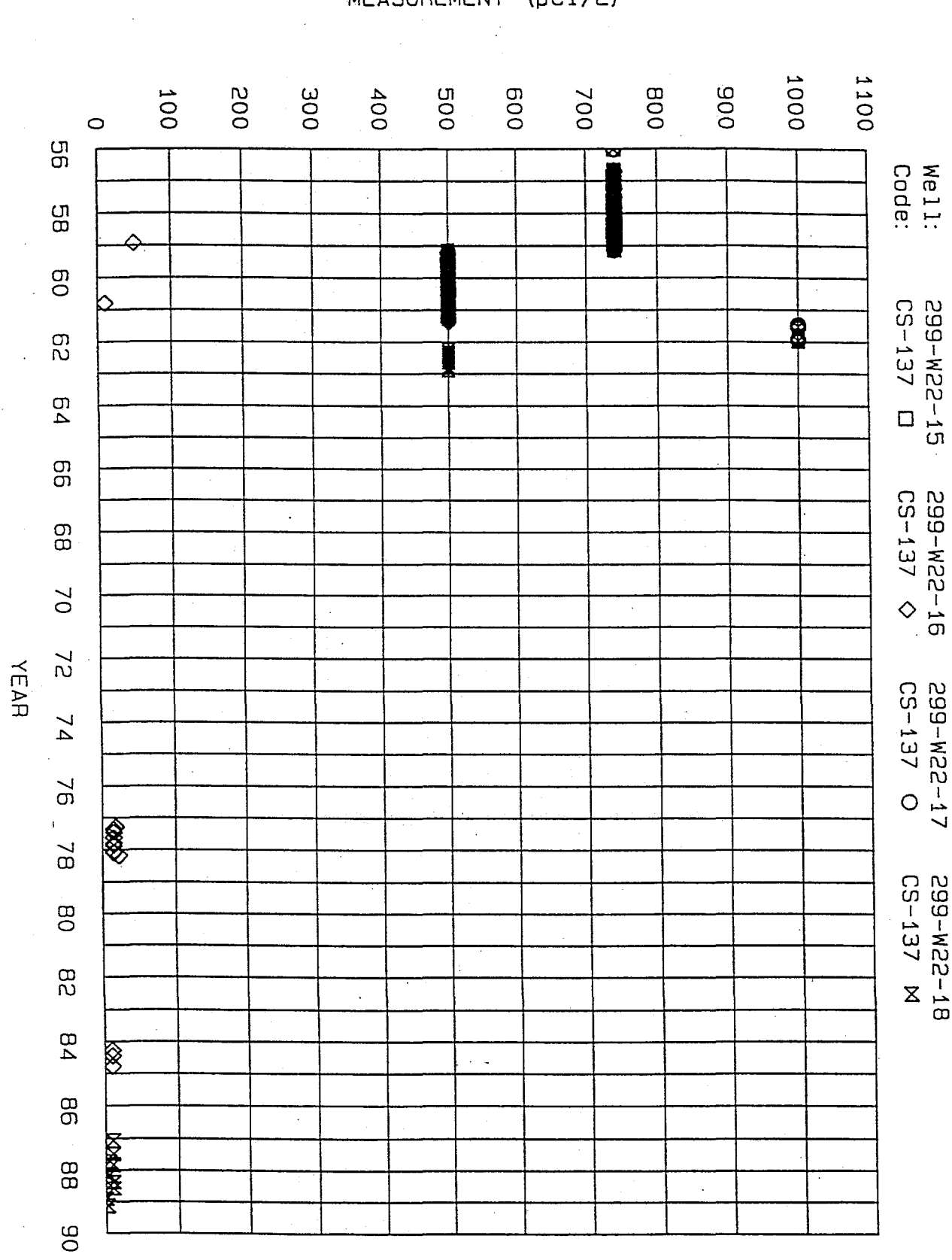


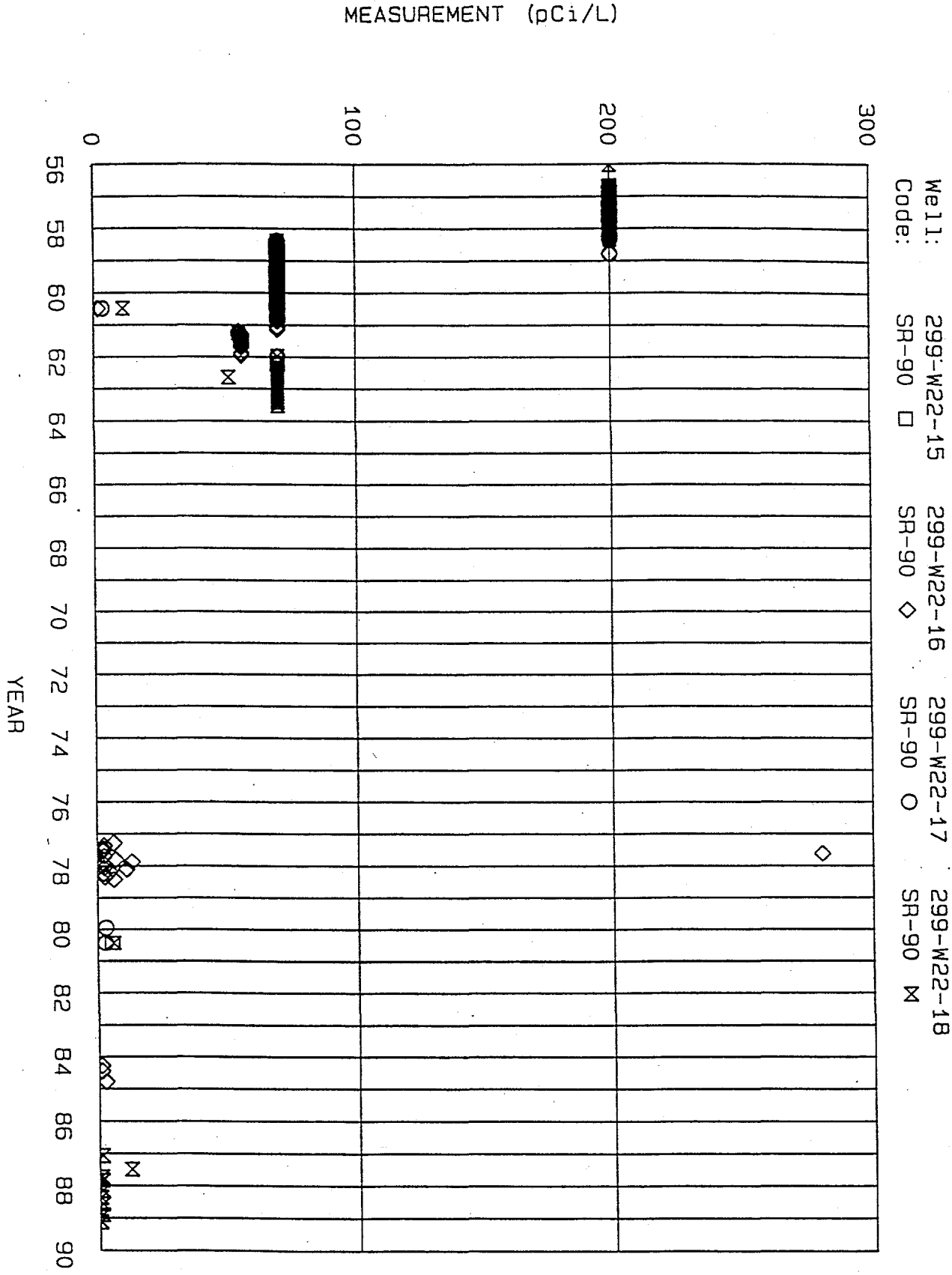
APPENDIX A

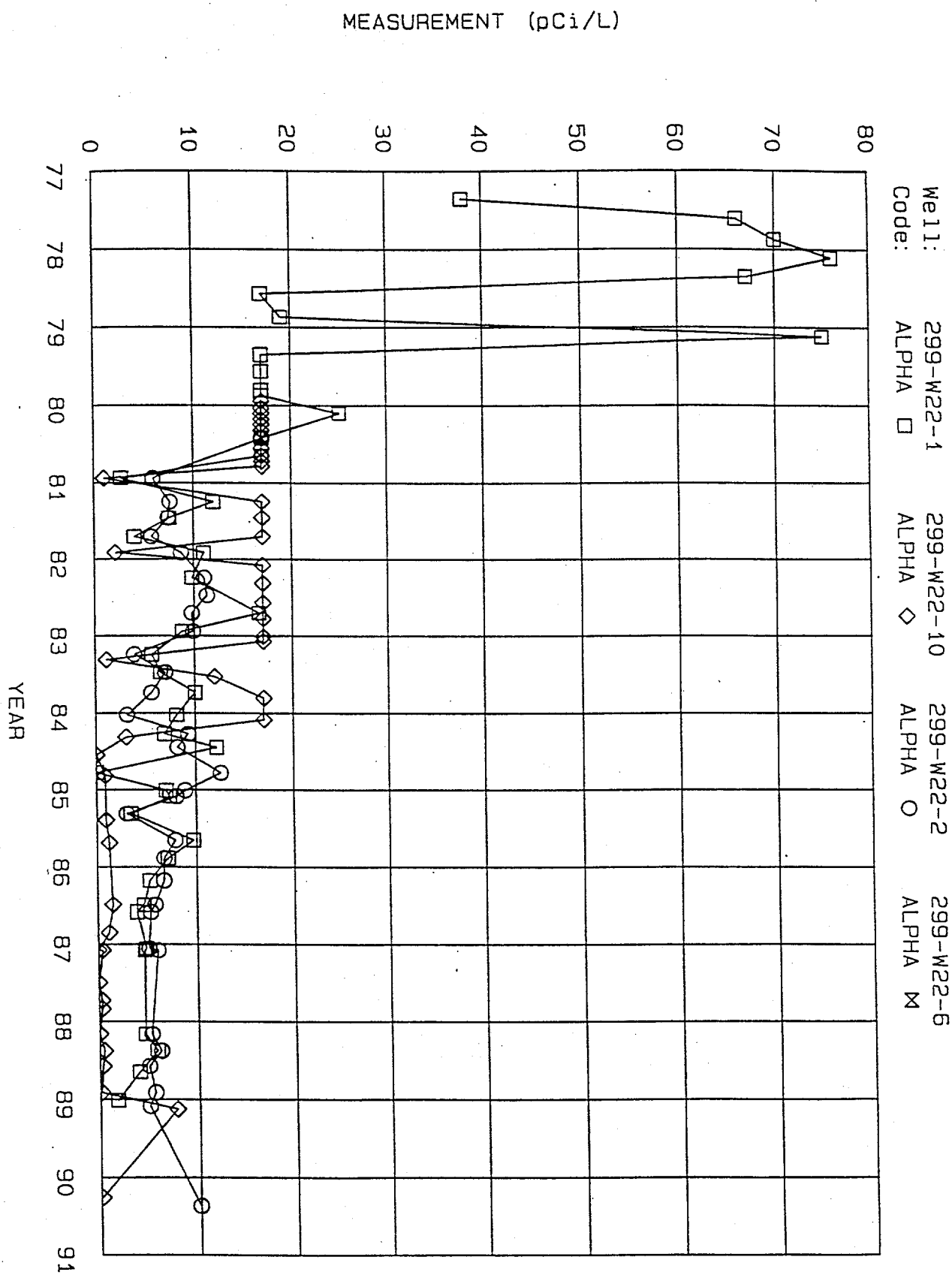

MEASUREMENT (pCi/L)
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W22-1 299-W22-10 299-W22-2
Code: RU-106 □ RU-106 ◇ RU-106 ○

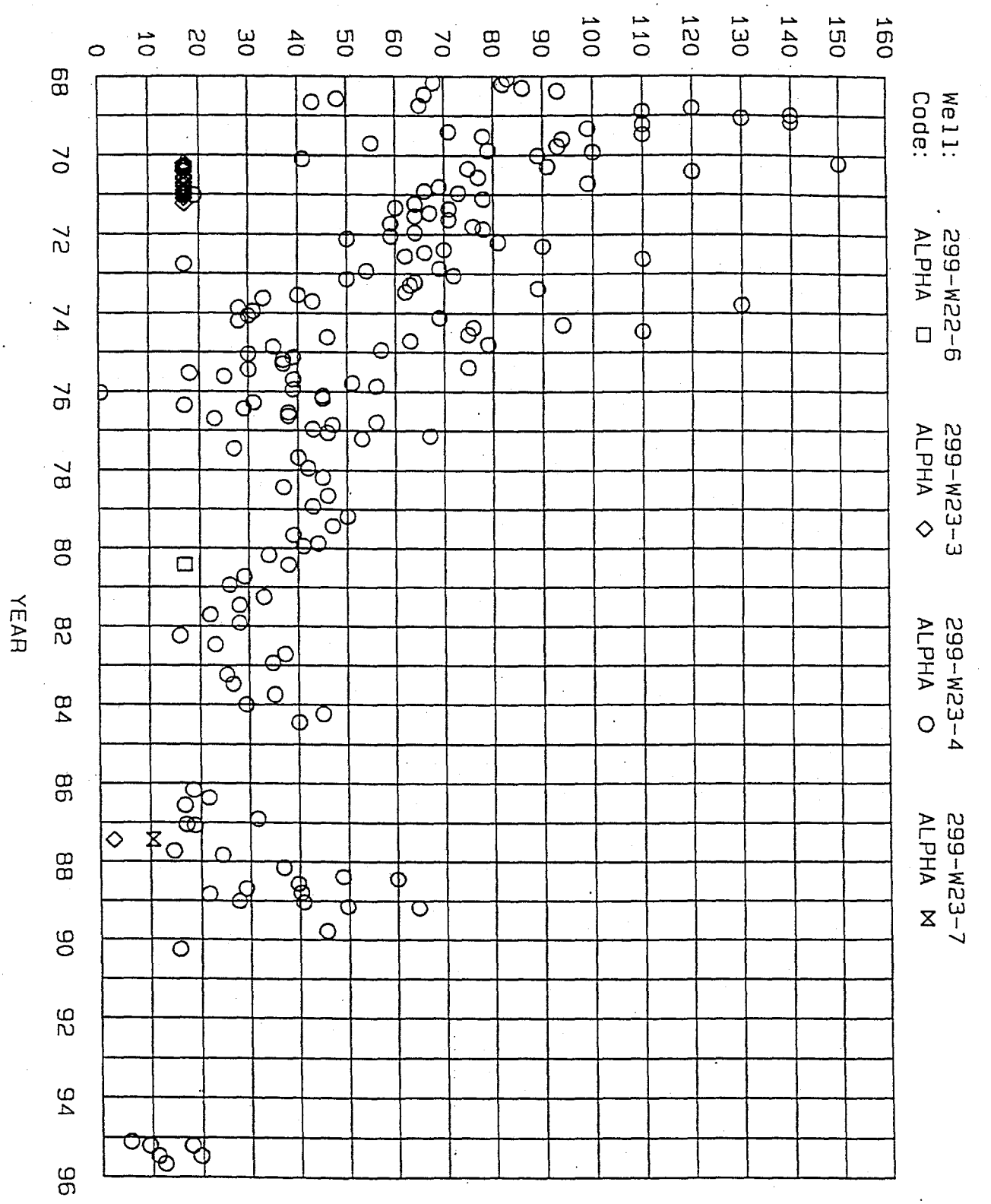

MEASUREMENT (pCi/L)
0
100
200
300
400
500
600
700
800
900
1000
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W22-1 299-W22-10 299-W22-2
Code: RU-106 □ RU-106 ◇ RU-106 ○

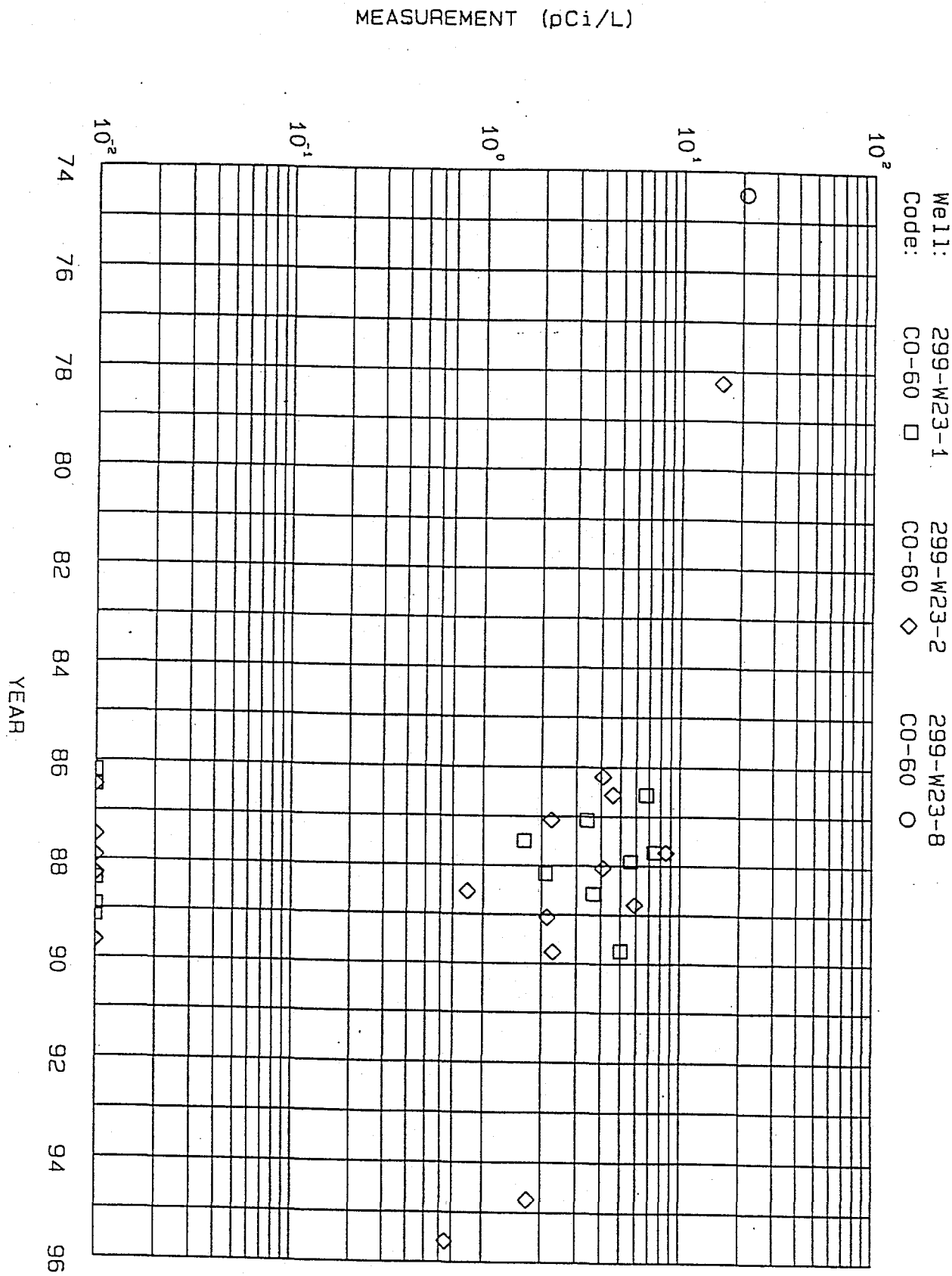

MEASUREMENT (pCi/L)
0
10
20
30
40
78
80
82
84
86
88
90
92
94
96
YEAR
Well:
Code:
299-W22-1
CO-60
299-W22-10
CO-60
299-W22-2
CO-60

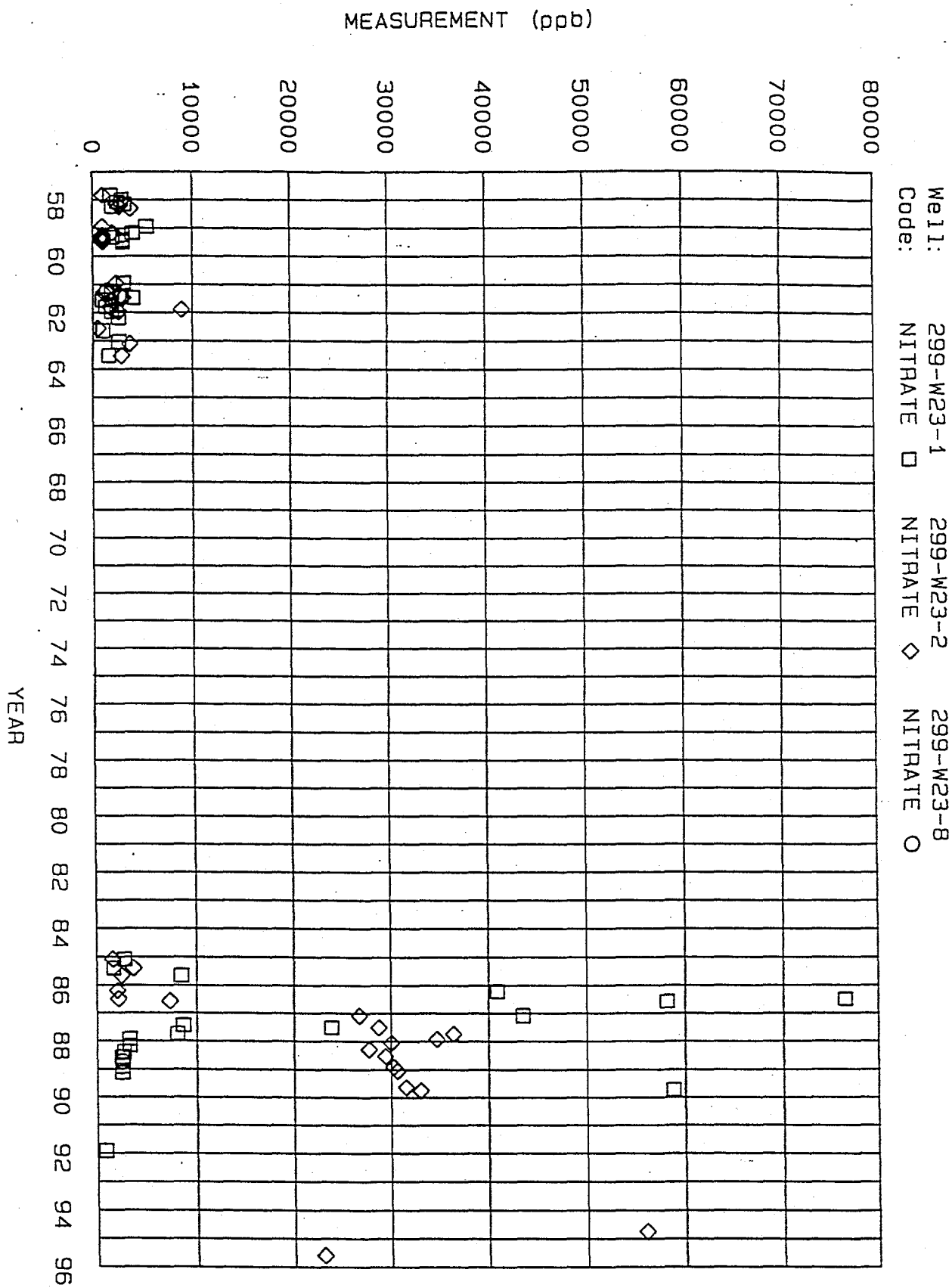

MEASUREMENT (pCi/L)
0
100
200
300
400
500
600
700
800
900
1000
1100
YEAR
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
Well:
Code:
299-W22-15
CS-137 □
299-W22-16
CS-137 ◇
299-W22-17
CS-137 ○
299-W22-18
CS-137 ⊠

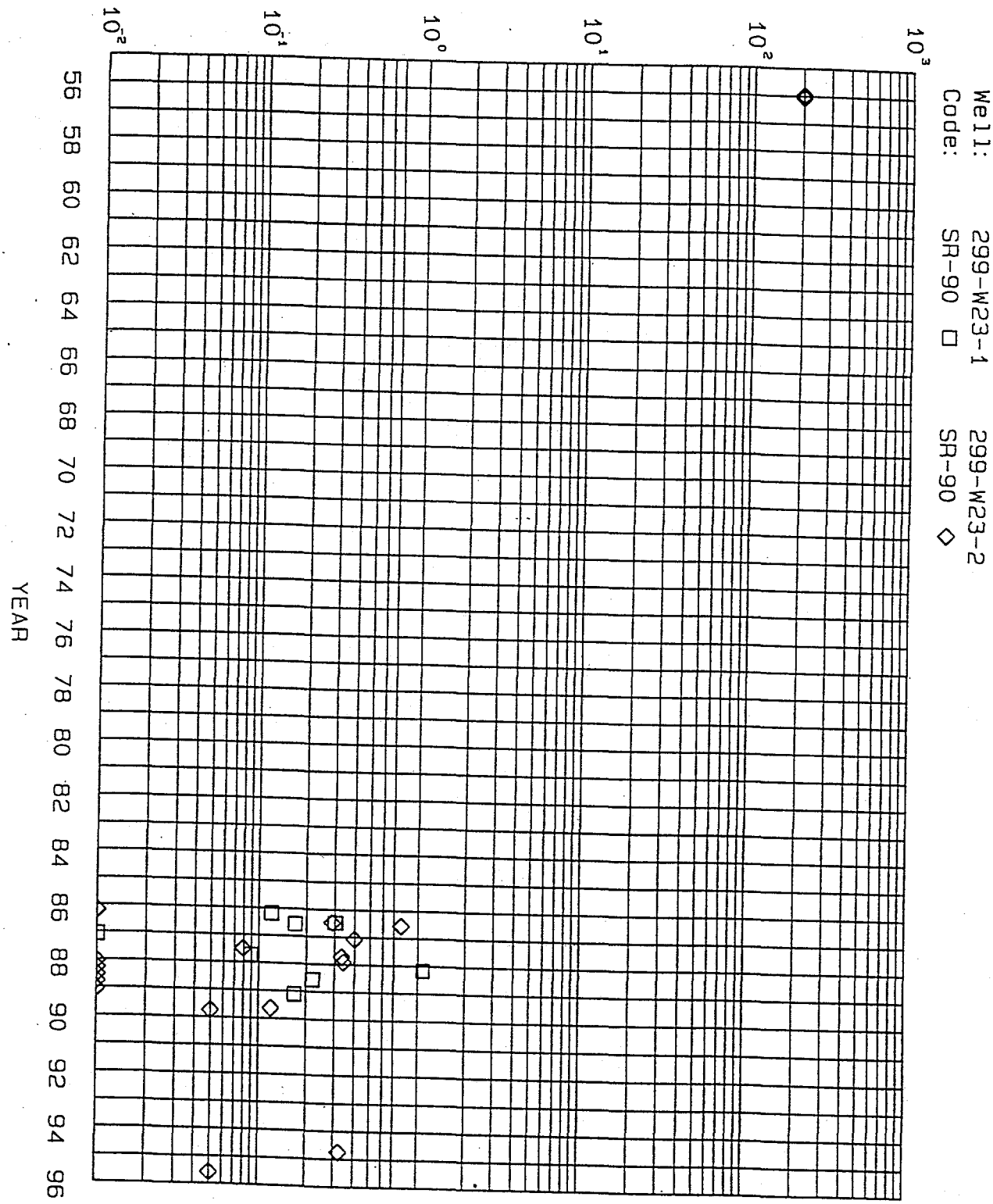

MEASUREMENT (pCi/L)
0
100
200
300
YEAR
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
Well: 299-W22-15 299-W22-16 299-W22-17 299-W22-18
Code: SR-90 □ SR-90 ◇ SR-90 ○ SR-90 ⊠

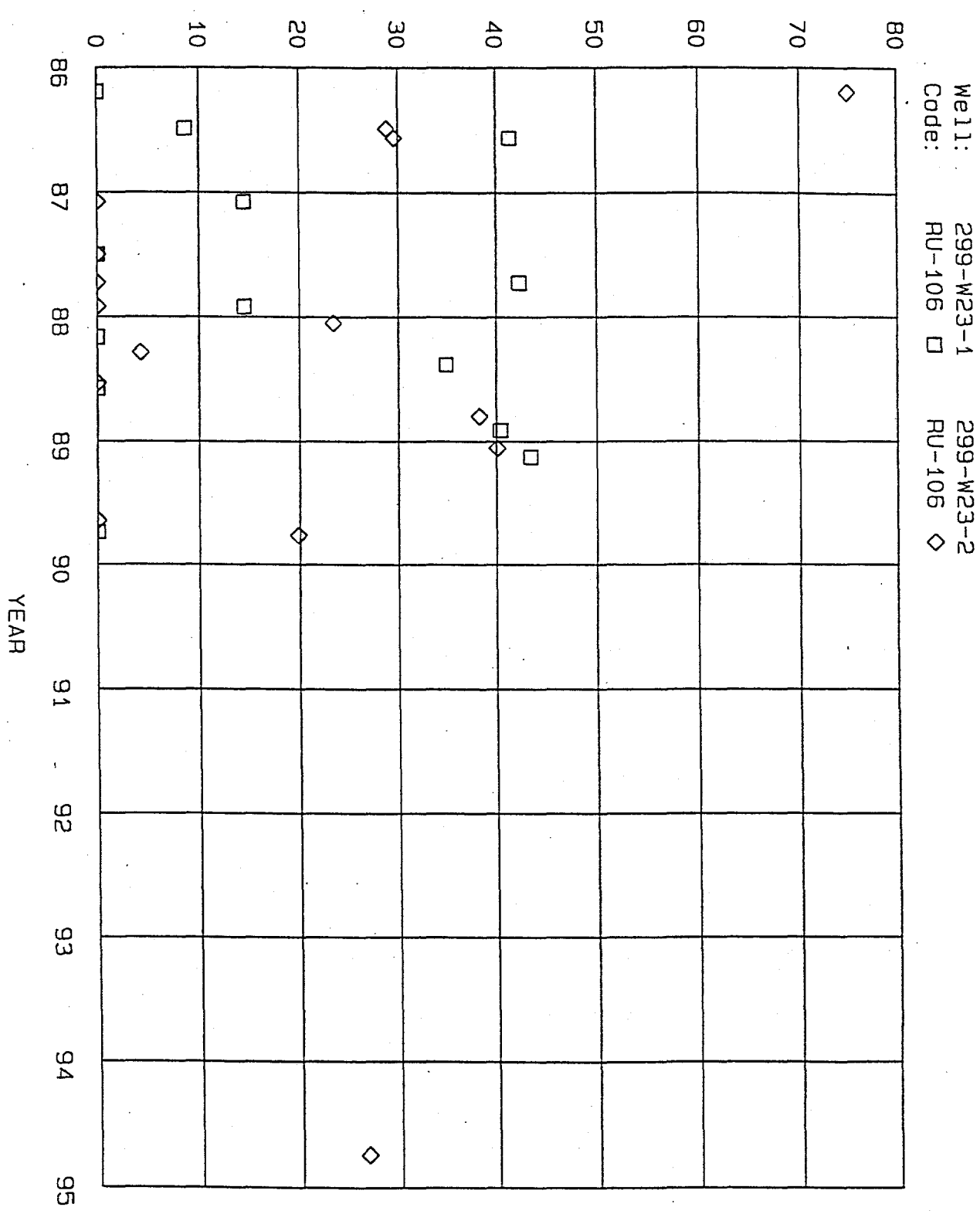

MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
YEAR
Well: 299-W22-1 299-W22-10 299-W22-2 299-W22-6
Code: ALPHA □ ALPHA ◇ ALPHA ○ ALPHA ⊠

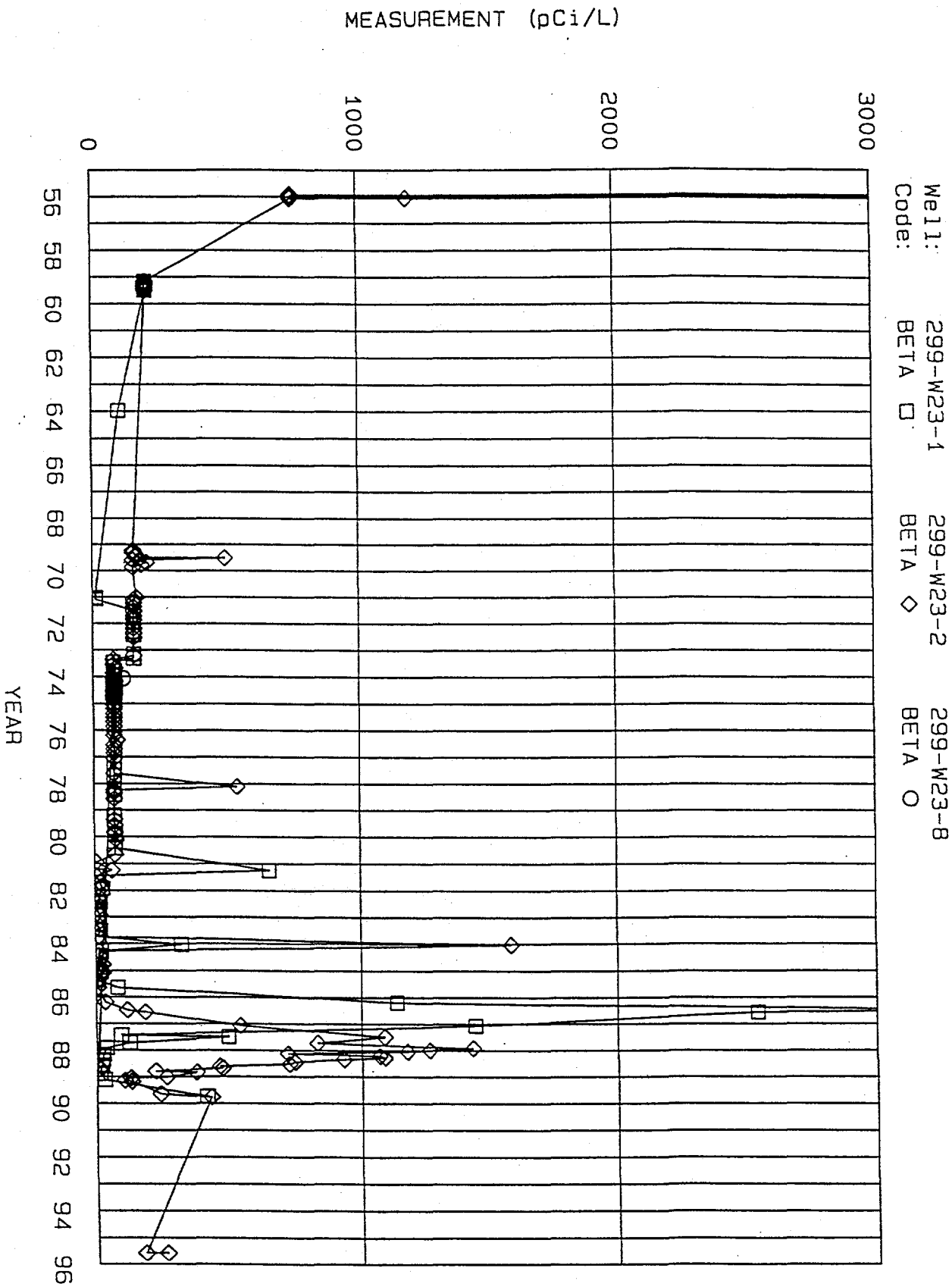

MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
68
70
72
74
76
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W22-6 299-W23-3 299-W23-4 299-W23-7
Code: ALPHA □ ALPHA ◇ ALPHA ○ ALPHA ⊠

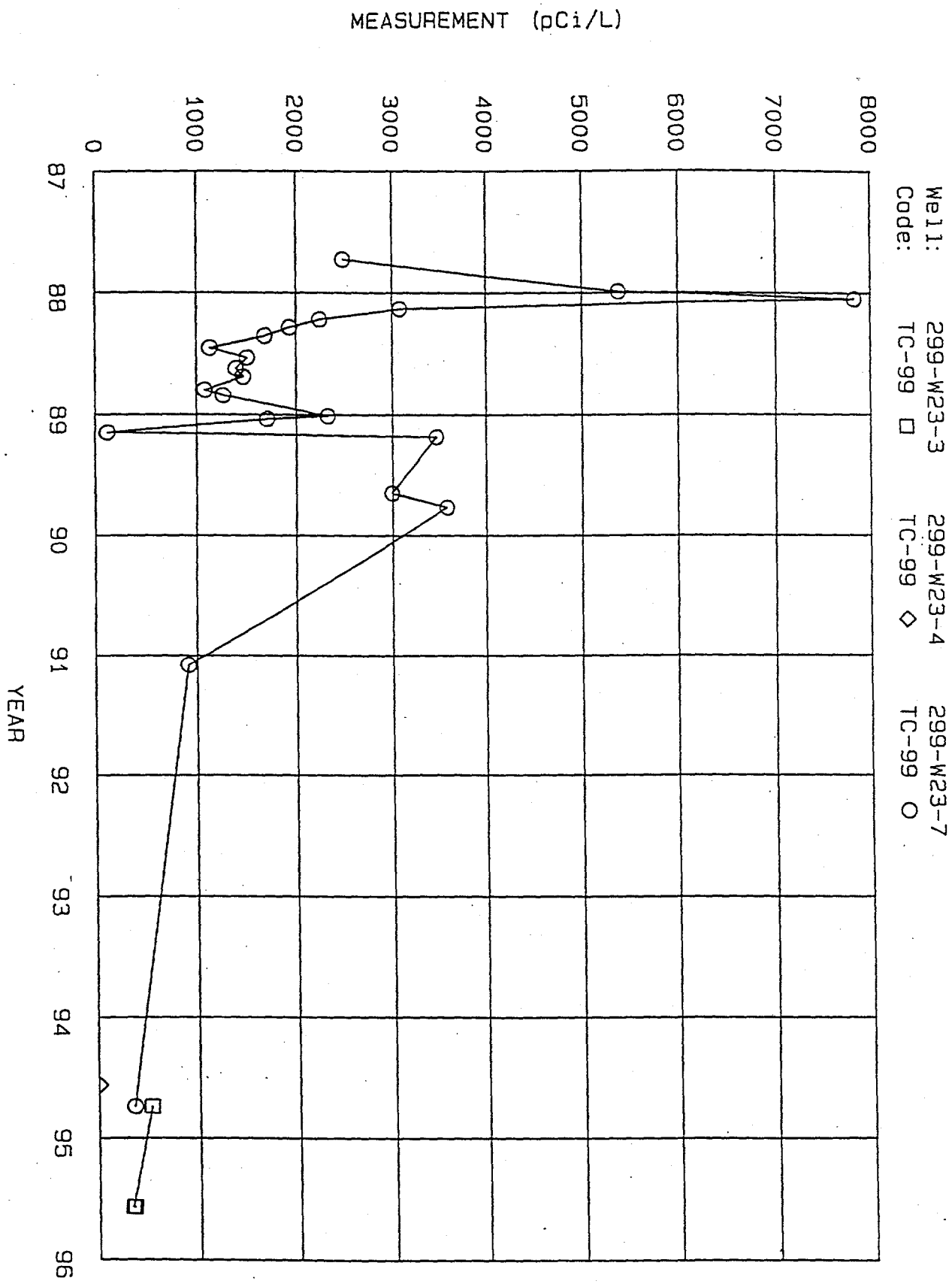

MEASUREMENT (pCi/L)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
74
76
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W23-1 299-W23-2 299-W23-8
Code: Co-60 □ Co-60 ◇ Co-60 ○

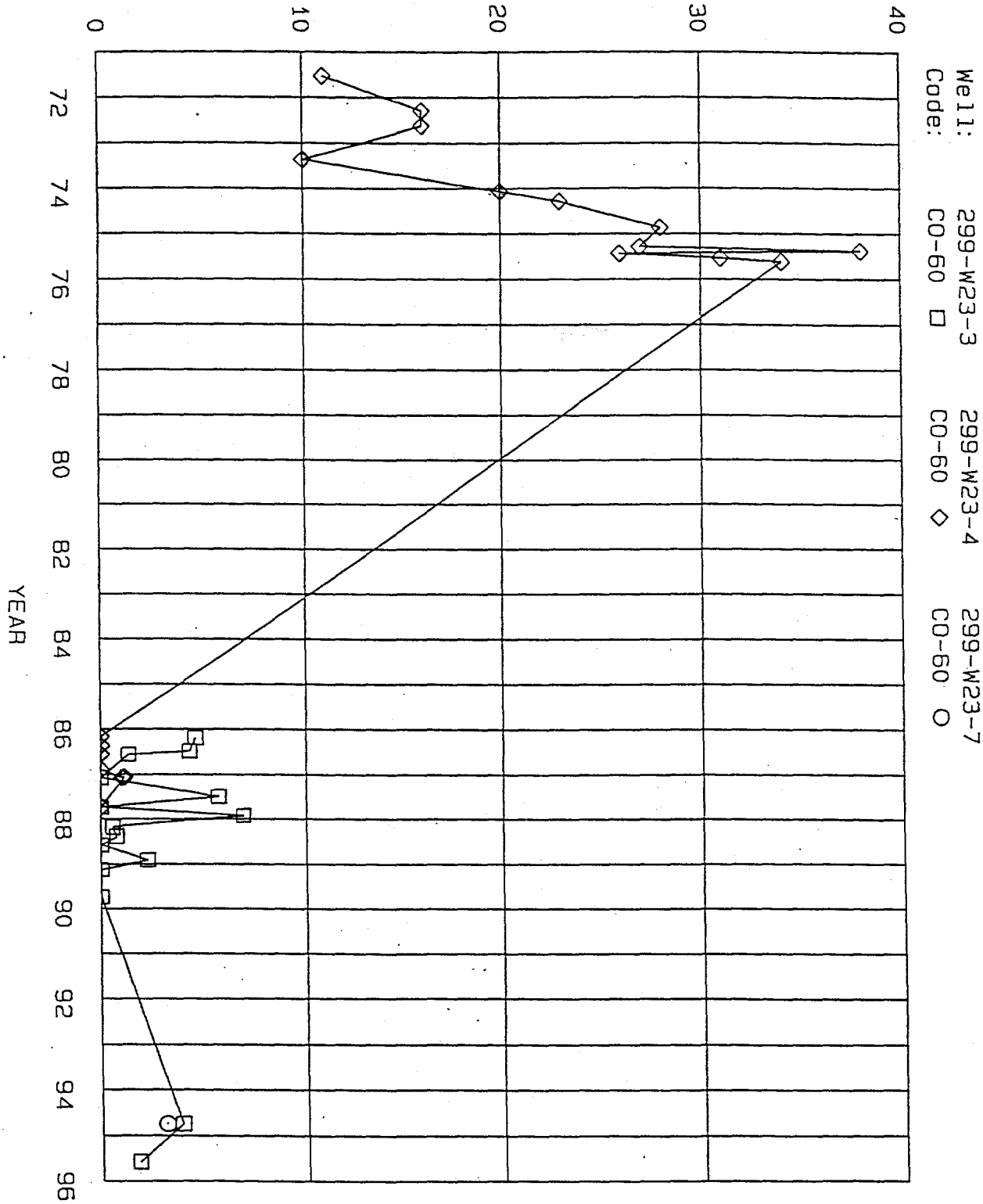

MEASUREMENT (ppb)
0
10000
20000
30000
40000
50000
60000
70000
80000
YEAR
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
92
94
96
Well: 299-W23-1 299-W23-2 299-W23-8
Code: NITRATE □ NITRATE ◇ NITRATE ○

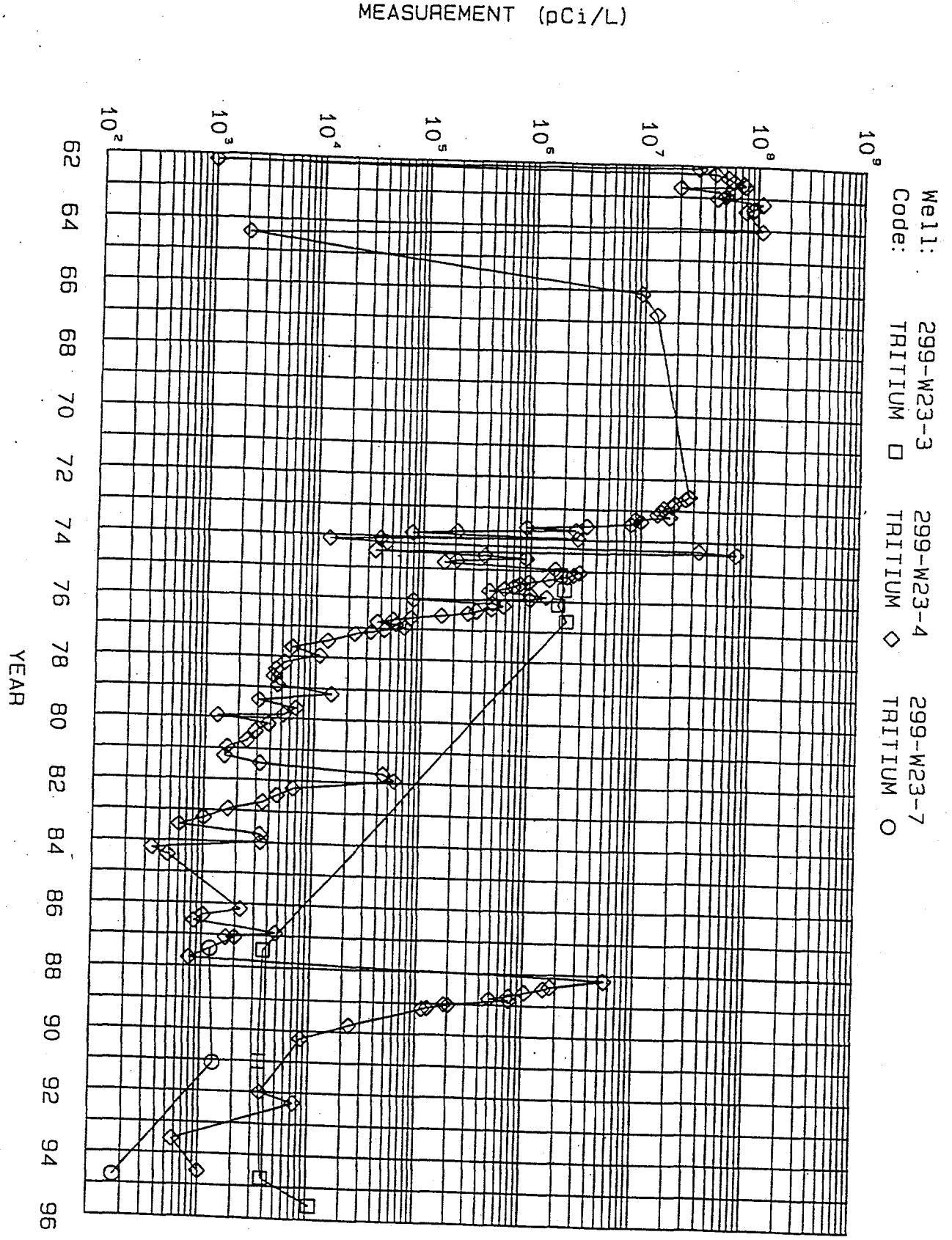

MEASUREMENT (pCi/L)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96
YEAR
Well: 299-W23-1
Code: SR-90 □
299-W23-2
SR-90 ◇

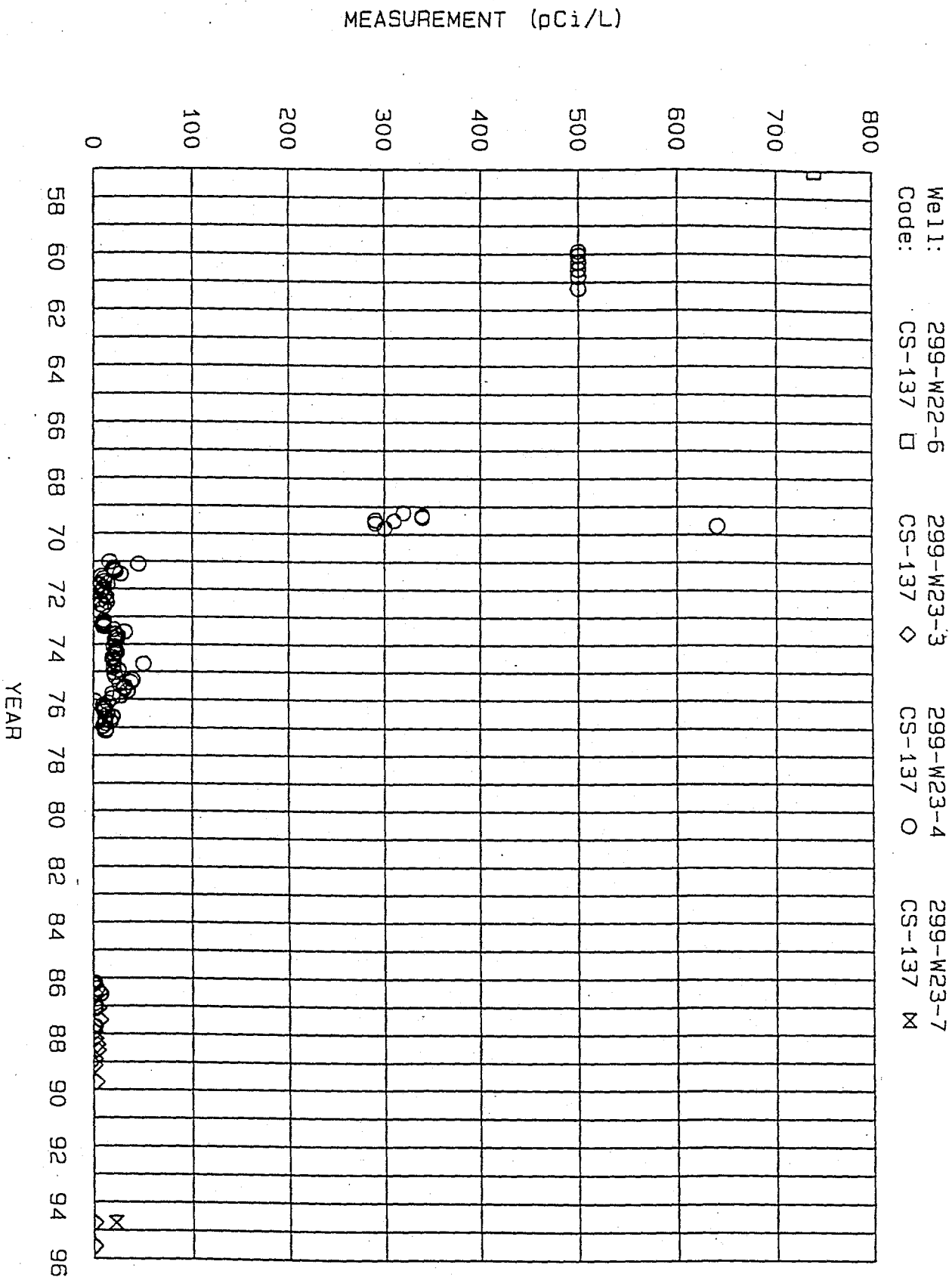

MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
86
87
88
89
90
91
92
93
94
95
YEAR
Well: 299-W23-1 299-W23-2
Code: RU-106 □ RU-106 ◇

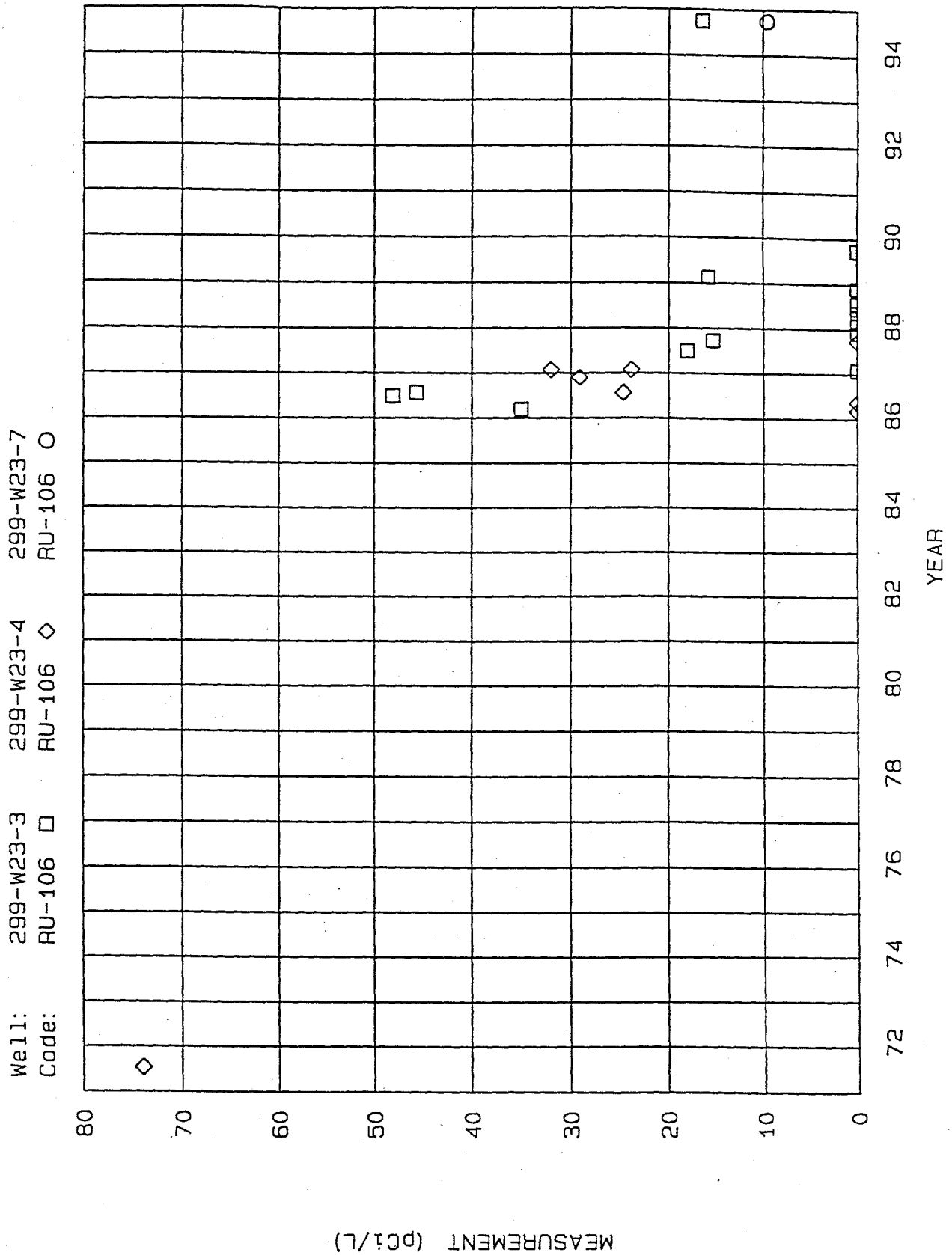

MEASUREMENT (pCi/L)
0
1000
2000
3000
YEAR
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96
Well: 299-W23-1 299-W23-2 299-W23-8
Code: BETA □ BETA ◇ BETA ○

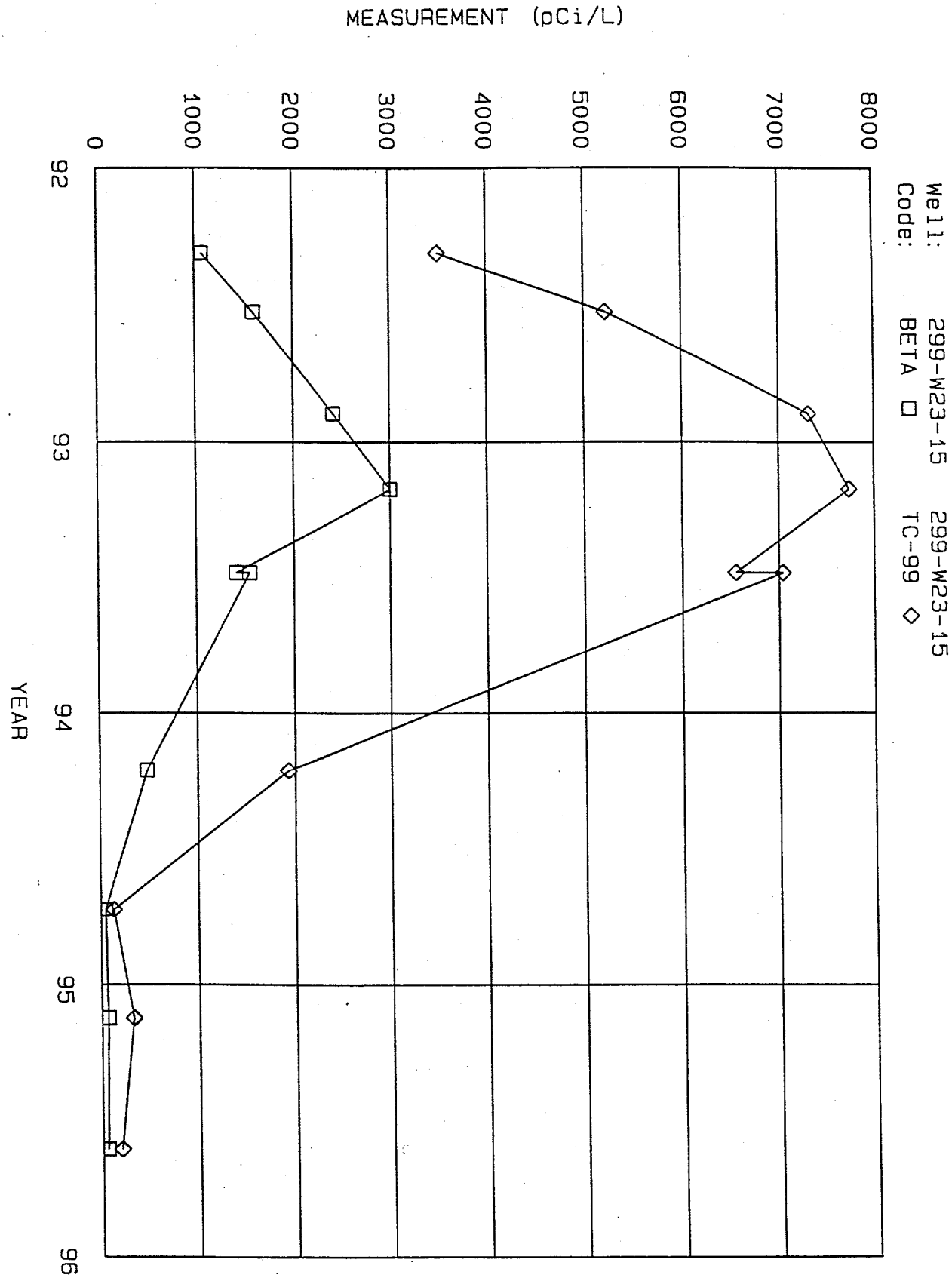

MEASUREMENT (pCi/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
87
88
89
90
91
92
93
94
95
96
YEAR
Well: 299-W23-3
Code: TC-99 □
299-W23-4
TC-99 ◇
299-W23-7
TC-99 ○

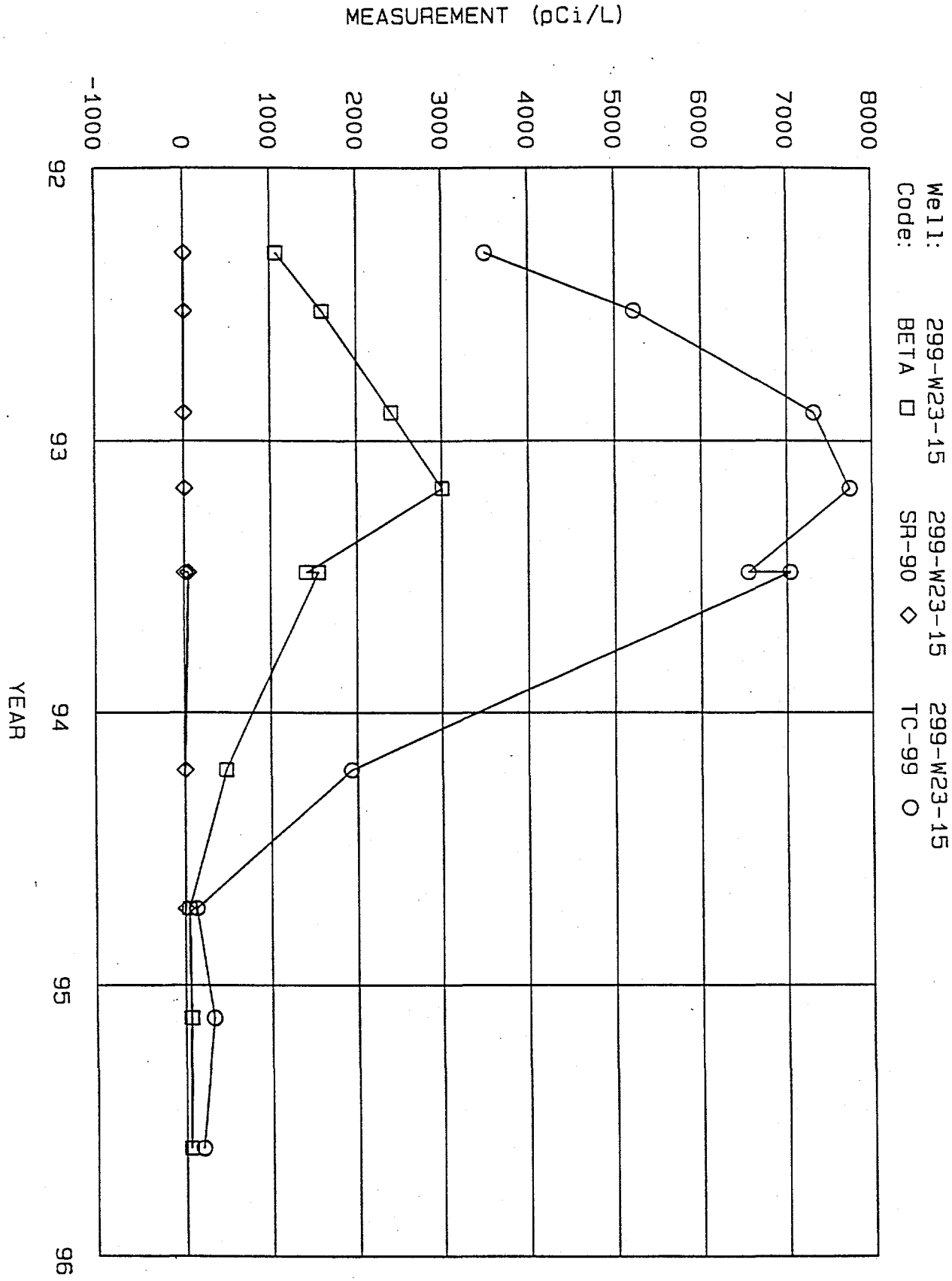

MEASUREMENT (pCi/L)
0
10
20
30
40
72
74
76
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W23-3
Code: Co-60 □
299-W23-4
Co-60 ◇
299-W23-7
Co-60 ○

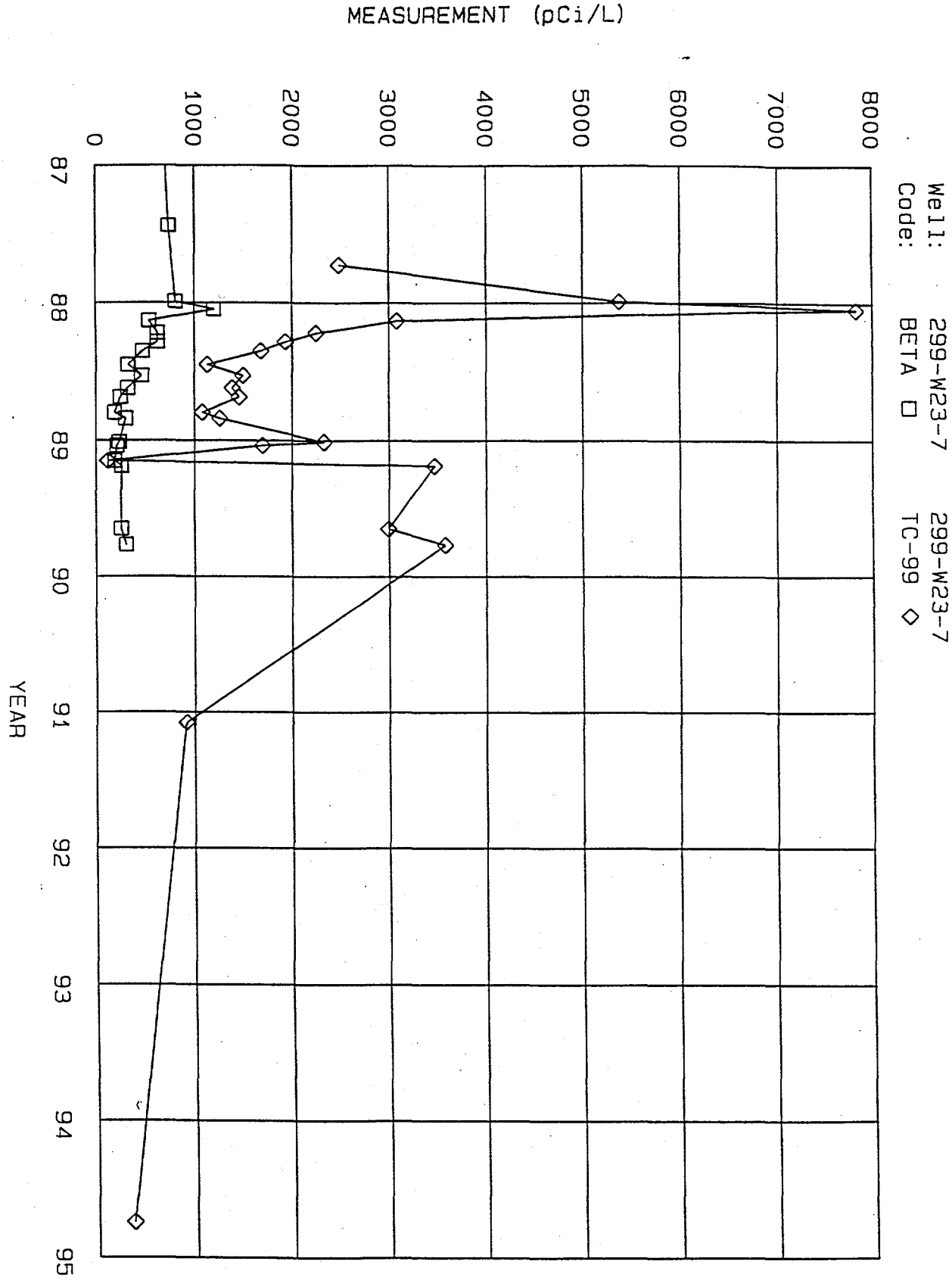

MEASUREMENT (pCi/L)
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96
YEAR
Well: 299-W23-3 299-W23-4 299-W23-7
Code: TRITIUM □ TRITIUM ◇ TRITIUM ○


MEASUREMENT (pCi/L)
0
100
200
300
400
500
600
700
800
58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96
YEAR
Well: 299-W22-6 299-W23-3 299-W23-4 299-W23-7
Code: CS-137 □ CS-137 ◇ CS-137 ○ CS-137 ⊠


Well: 299-W23-3 299-W23-4 299-W23-7
Code: RU-106 □ RU-106 ◇ RU-106 ○
MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
72
74
76
78
80
82
84
86
88
90
92
94
YEAR


MEASUREMENT (pCi/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
92
93
94
95
96
YEAR
Well: 299-W23-15
Code: BETA □
299-W23-15
TC-99 ◇


MEASUREMENT (pCi/L)
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
92
93
94
95
96
YEAR
Well: 299-W23-15
Code: BETA □
299-W23-15
SR-90 ◇
299-W23-15
TC-99 ○


MEASUREMENT (pCi/L)
0
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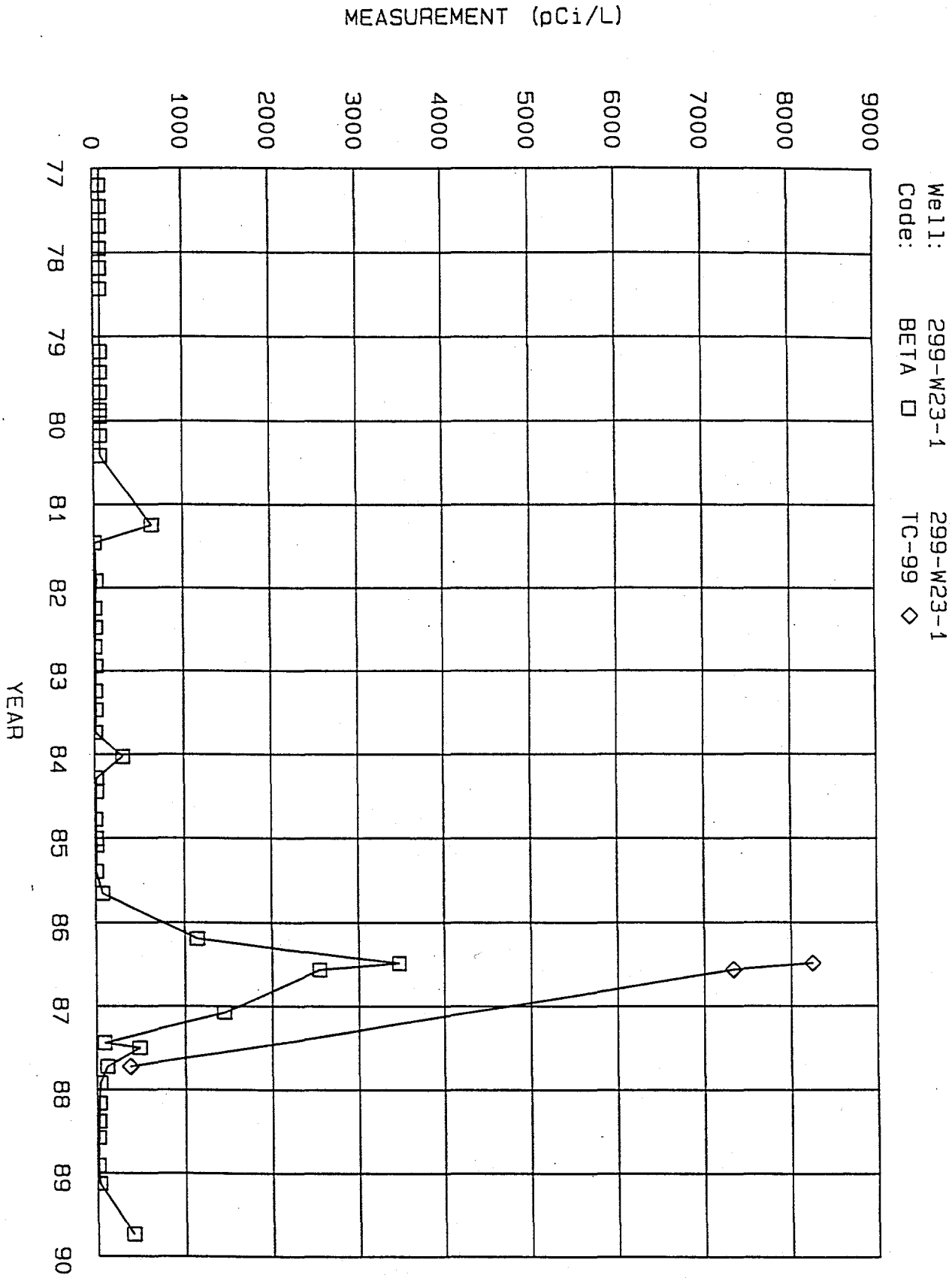
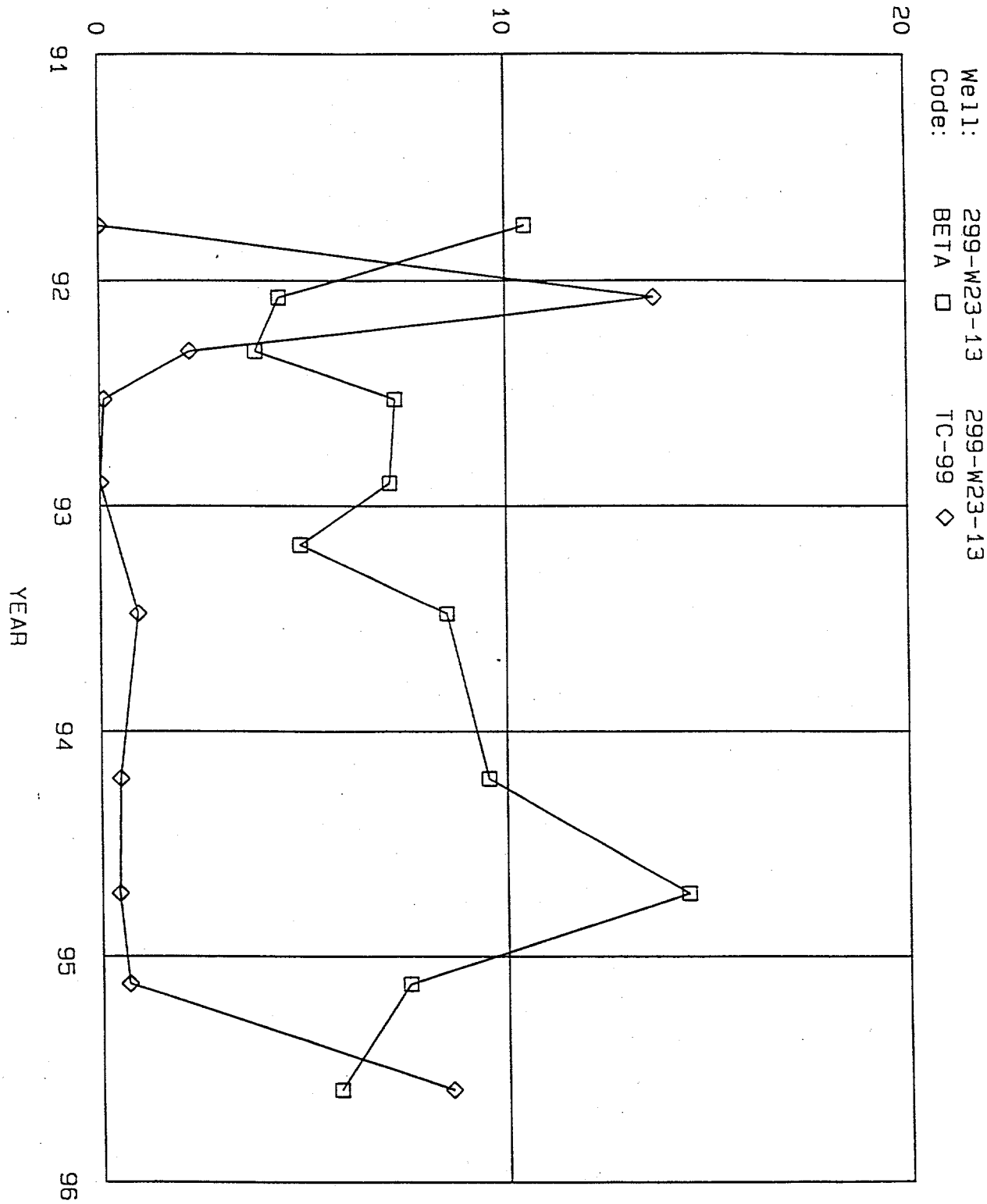
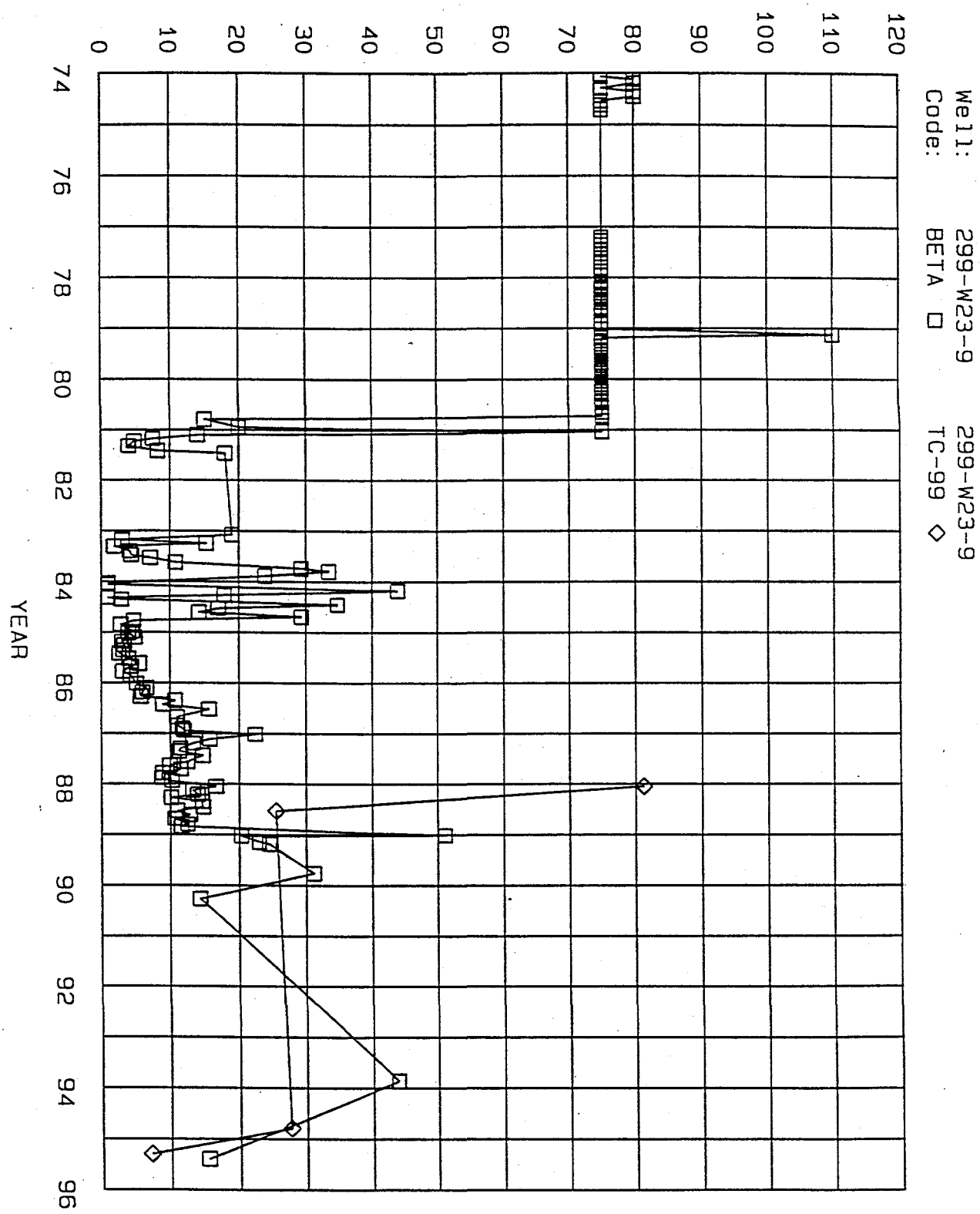
2000
3000
4000
5000
6000
7000
8000
87
88
89
90
91
92
93
94
95
YEAR
Well: 299-W23-7
Code: BETA □
299-W23-7
TC-99 ◇


MEASUREMENT (pCi/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
77
78
79
80
81
82
83
84
85
86
87
88
89
90
YEAR
Well: 299-W23-1
Code: BETA □
299-W23-1
TC-99 ◇


MEASUREMENT (pCi/L)
0
10
20
91
92
93
94
95
96
YEAR
Well: 299-W23-13
Code: BETA □
299-W23-13
TC-99 ◇


MEASUREMENT (pCi/L)
0
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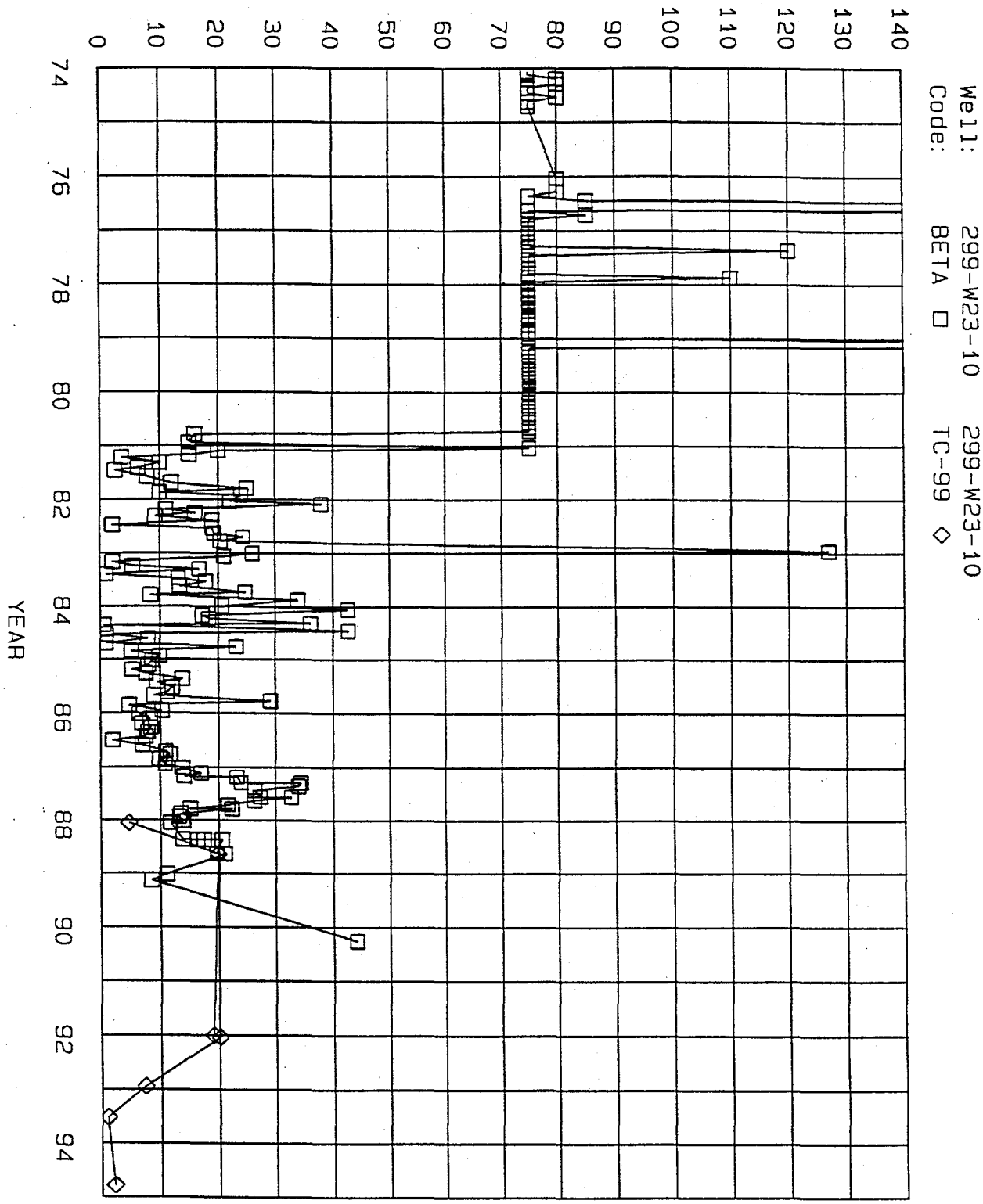
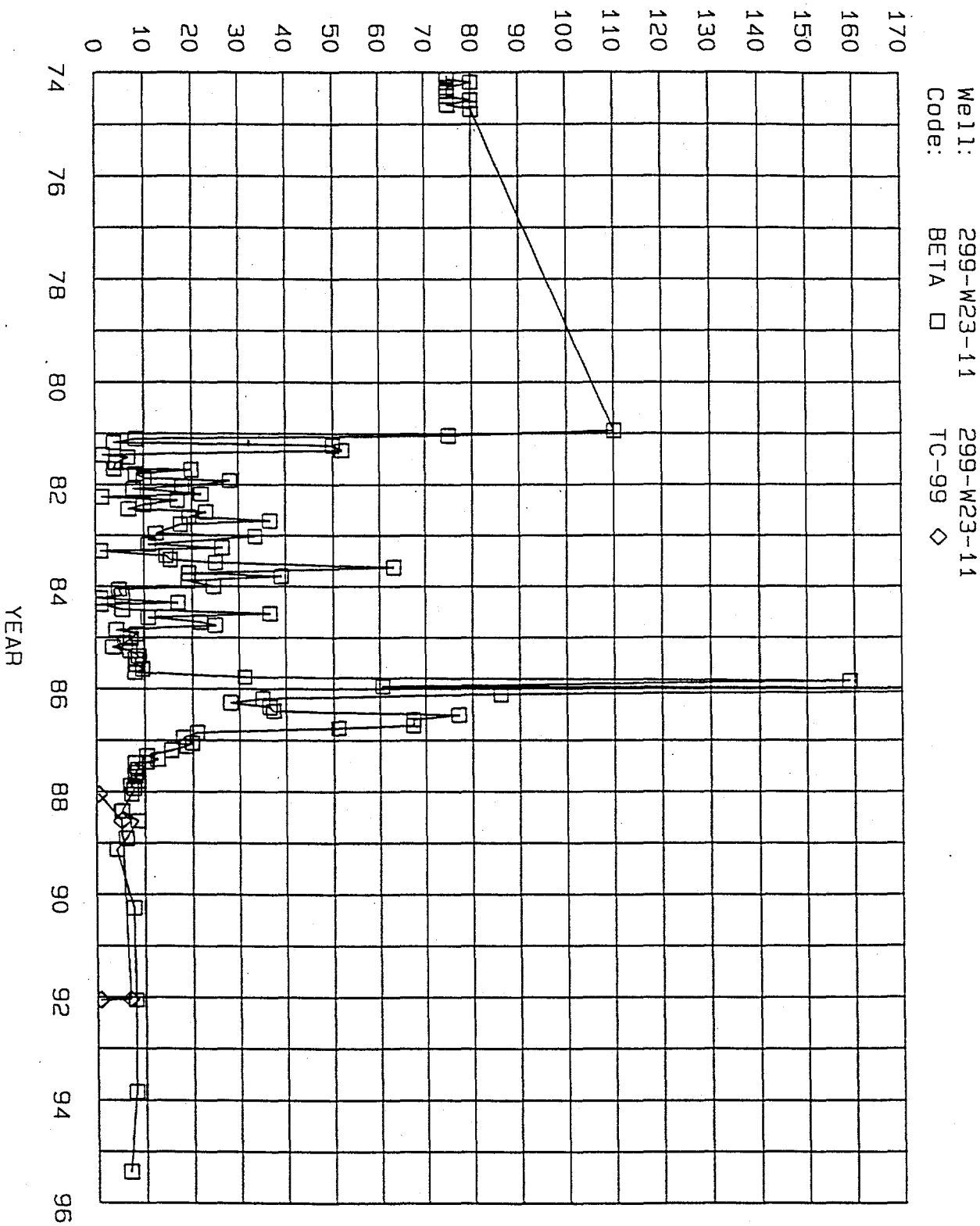
20
30
40
50
60
70
80
90
100
110
120
74
76
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W23-9
Code: BETA □
299-W23-9
TC-99 ◇


MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
YEAR
74
76
78
80
82
84
86
88
90
92
94
Well: 299-W23-10
Code: BETA □
299-W23-10
TC-99 ◇


MEASUREMENT (pCi/L)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
74
76
78
80
82
84
86
88
90
92
94
96
YEAR
Well: 299-W23-11
Code: BETA □
299-W23-11
TC-99 ◇

Appendix C

SX Tank Farm Correlation Plots

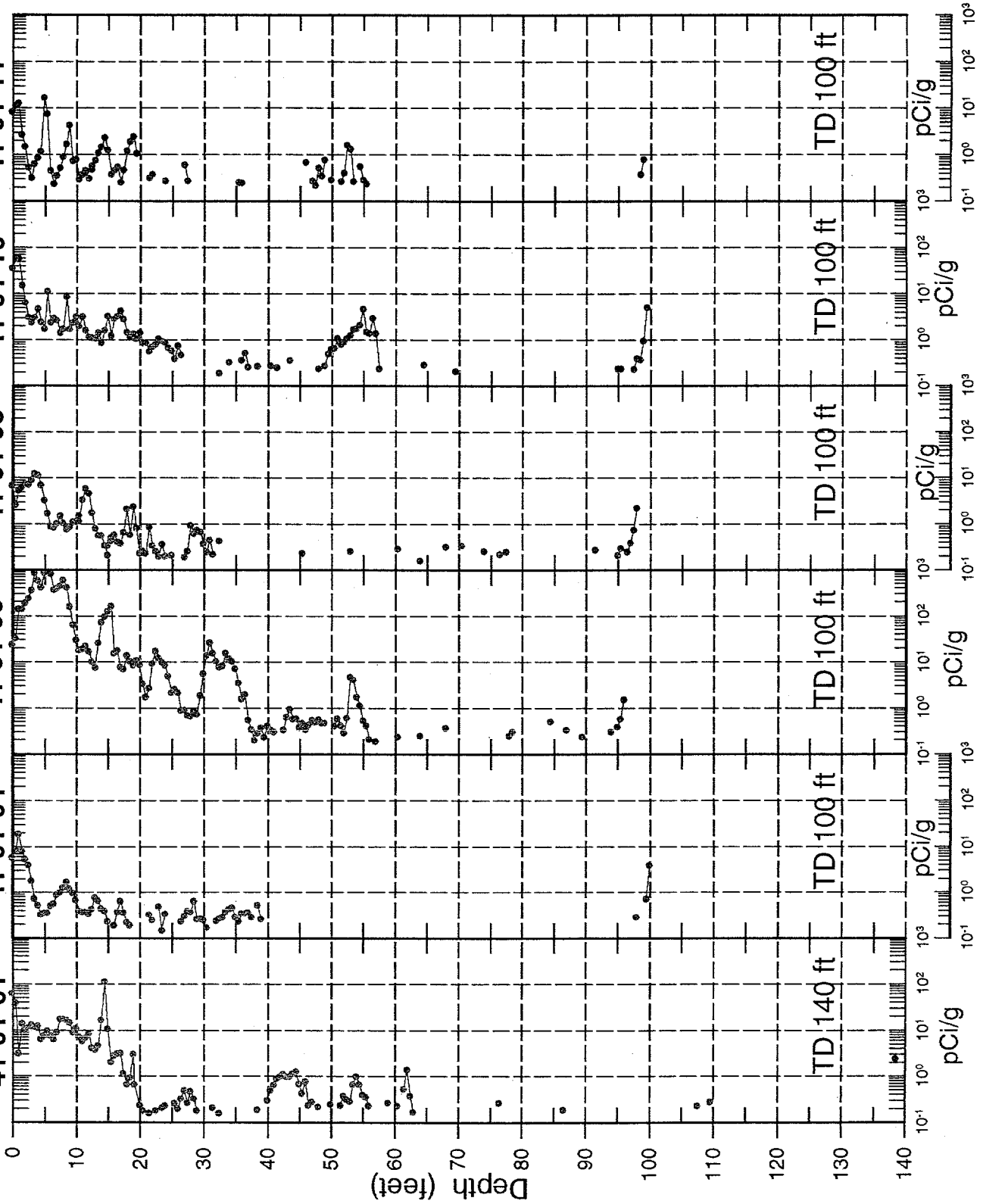


Figure C-1. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-101

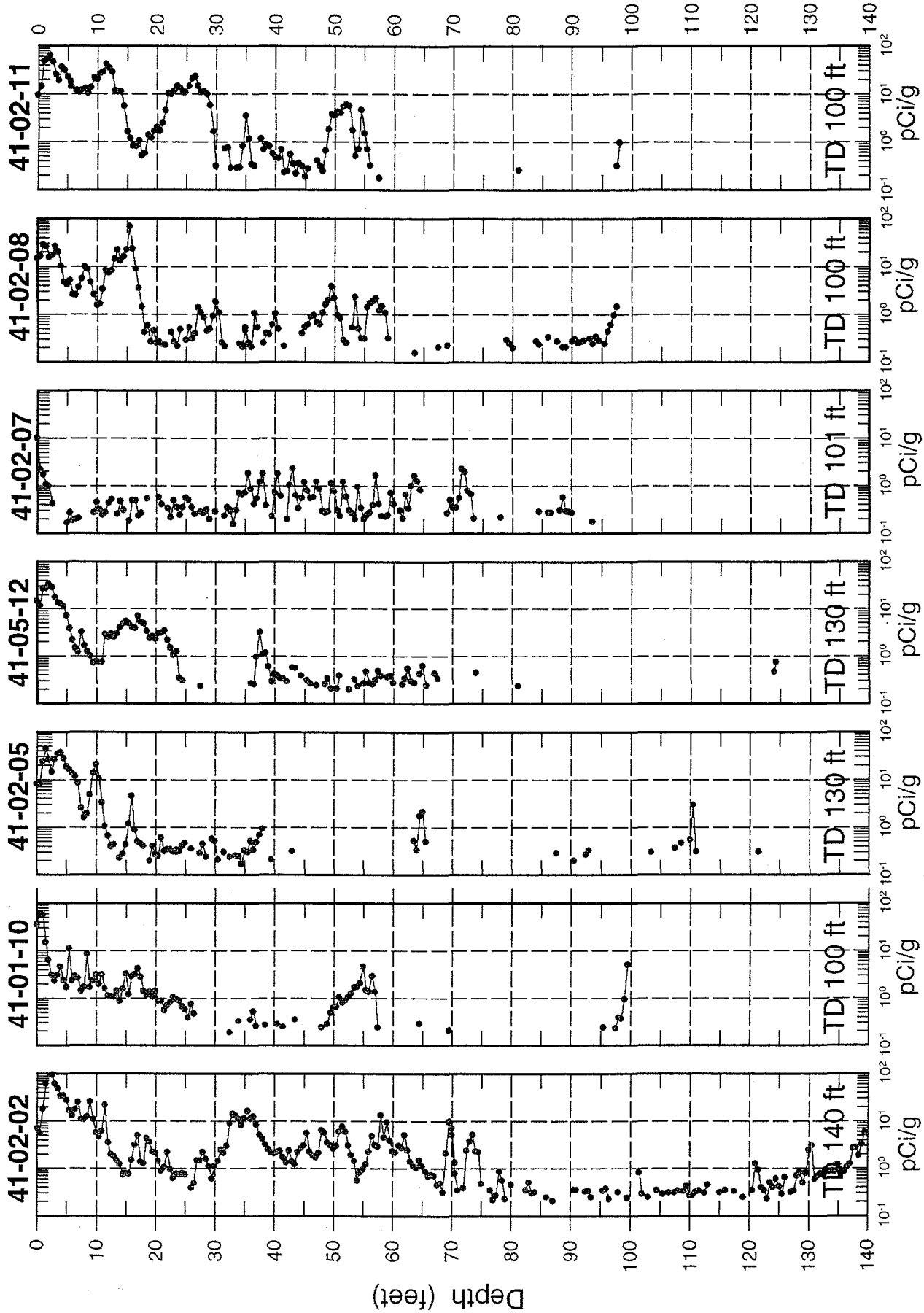


Figure C-2. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-102

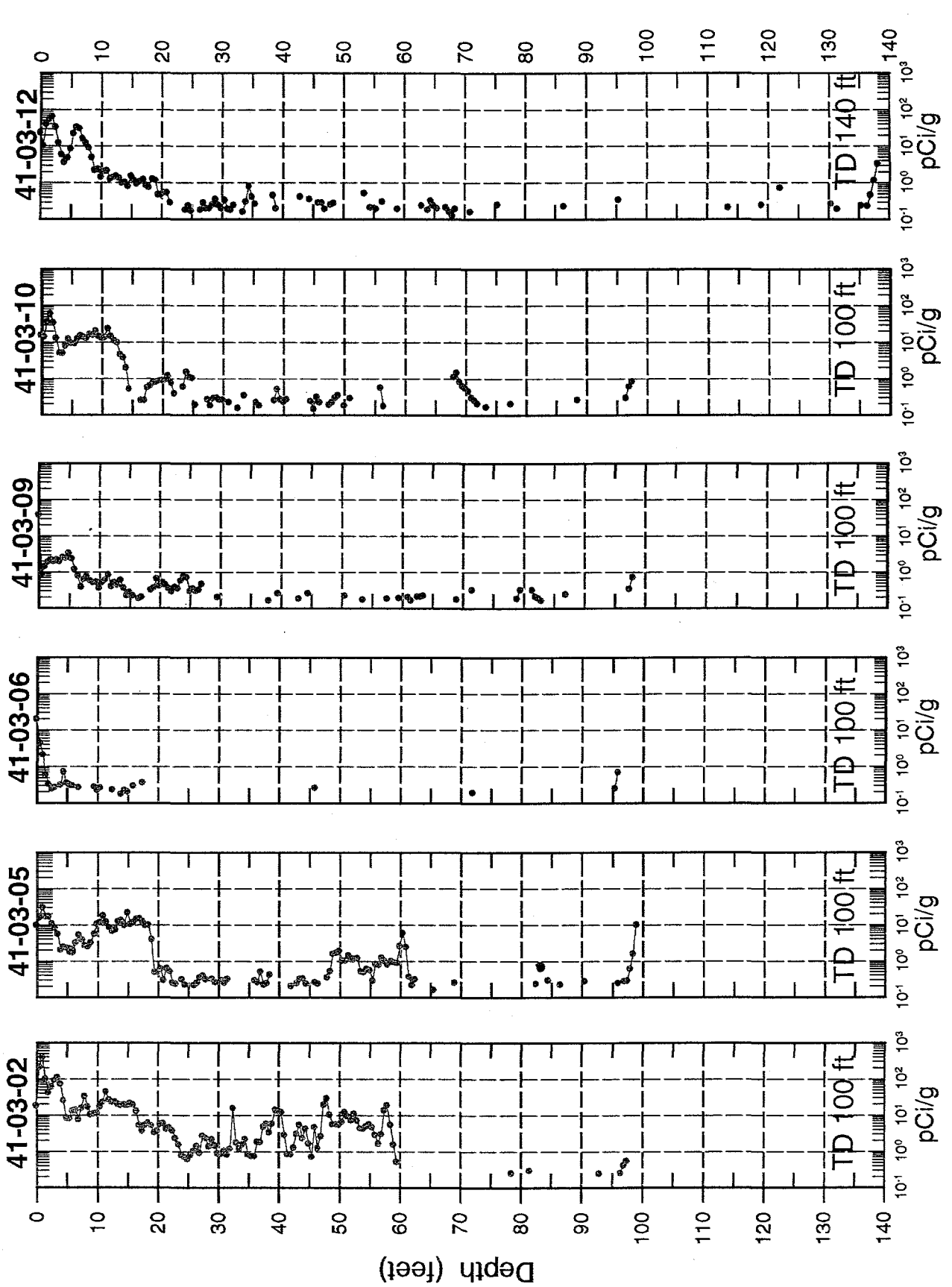


Figure C-3. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-103

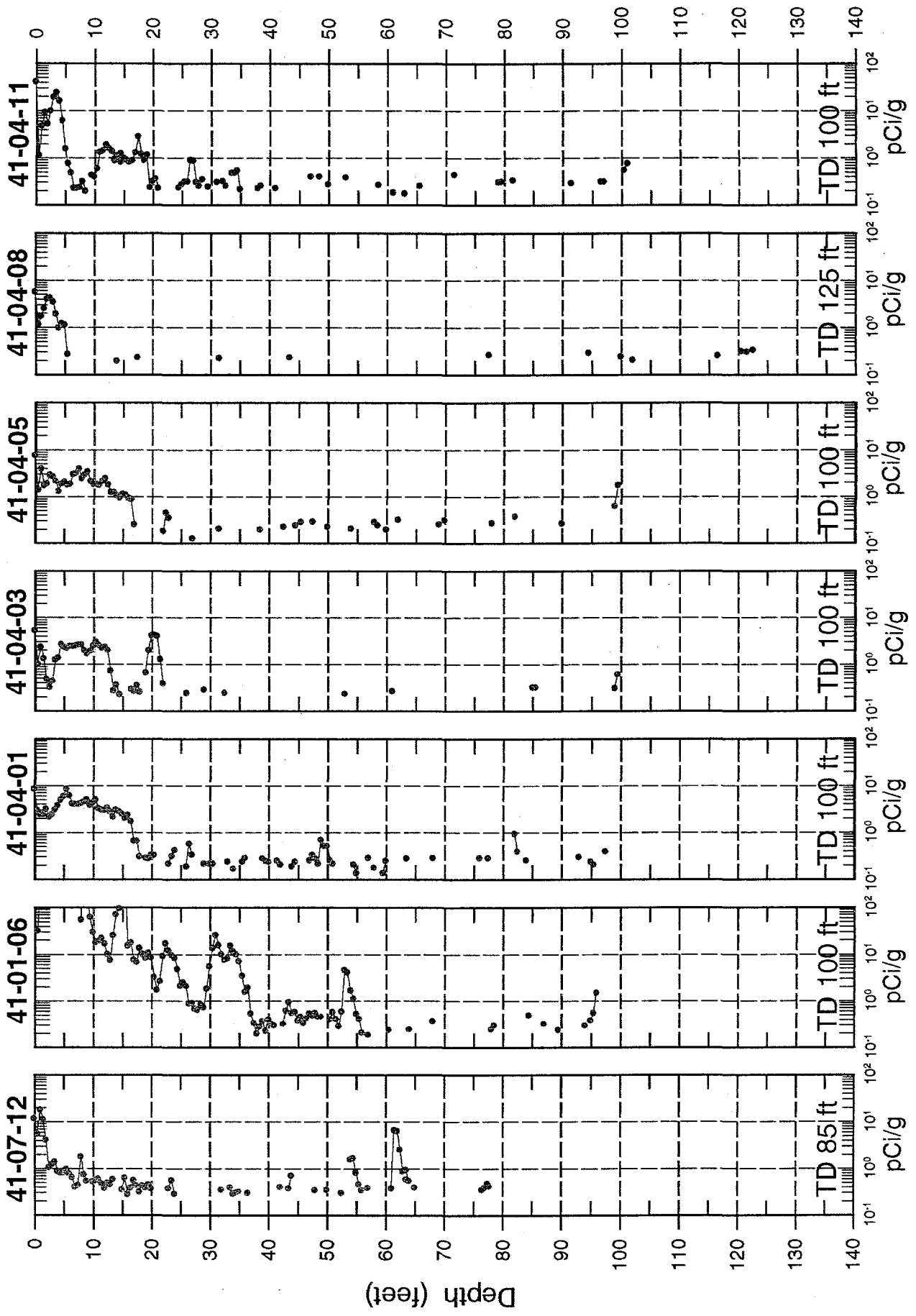


Figure C-4. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-104

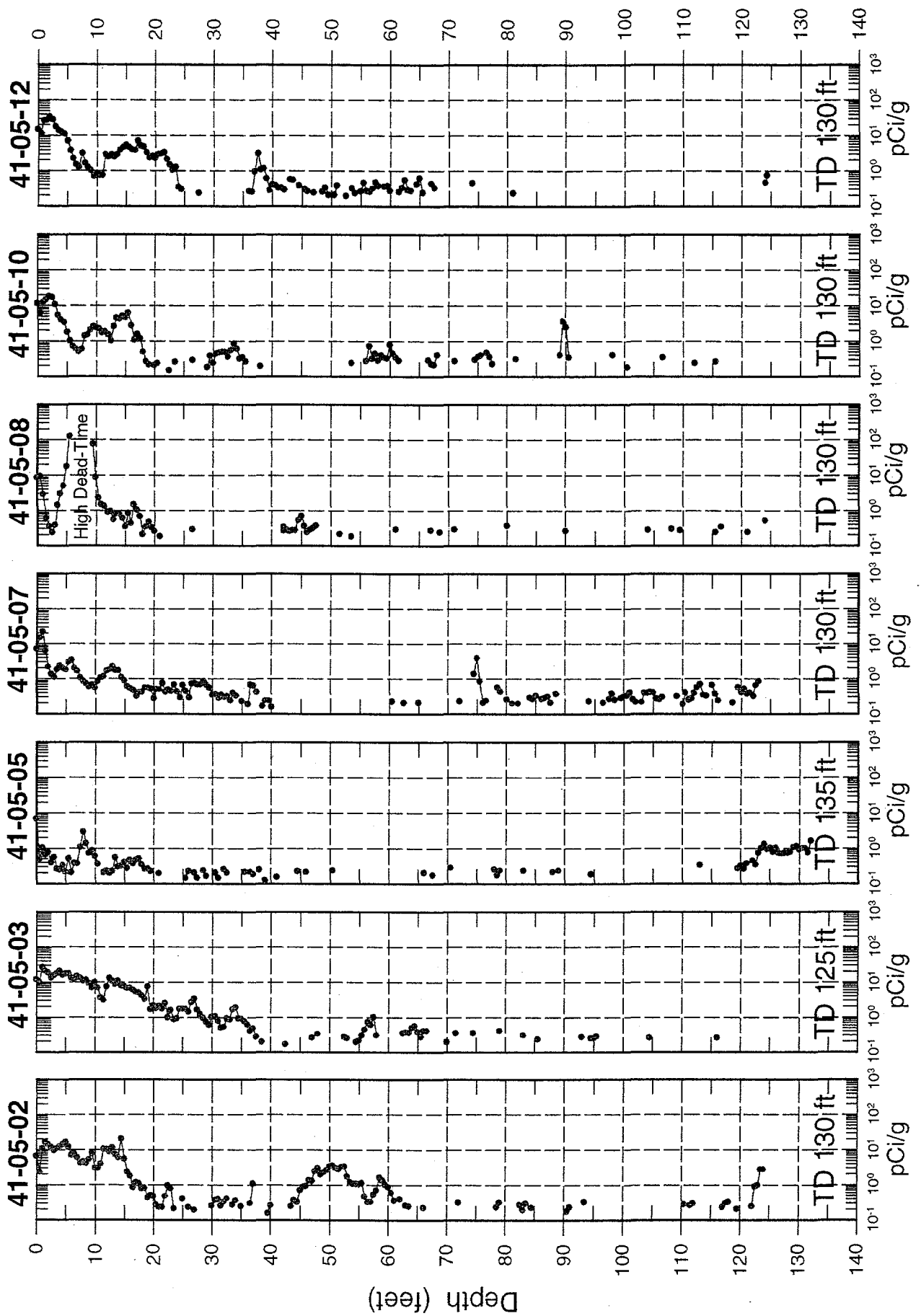


Figure C-5. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-105

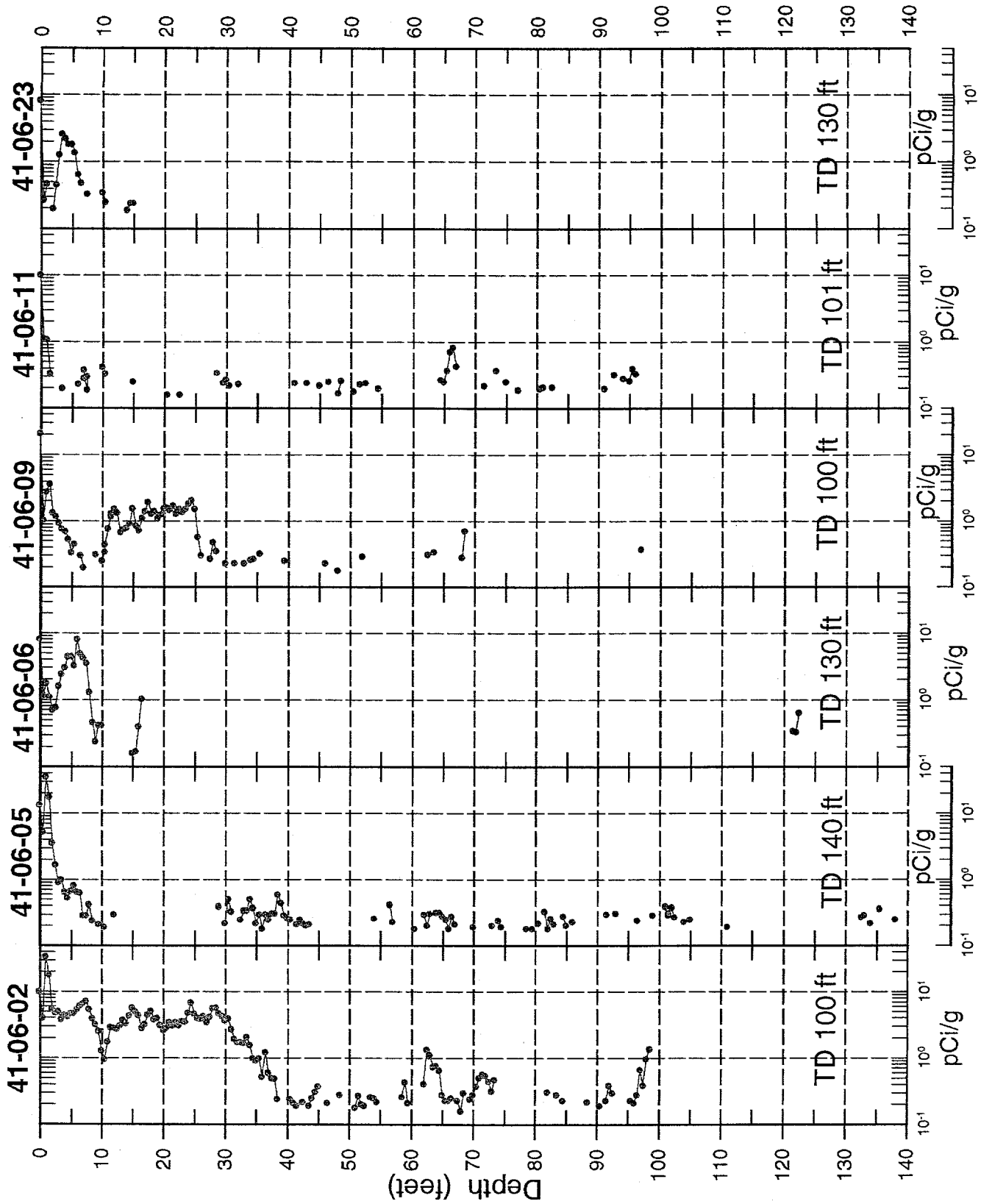


Figure C-6. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-106

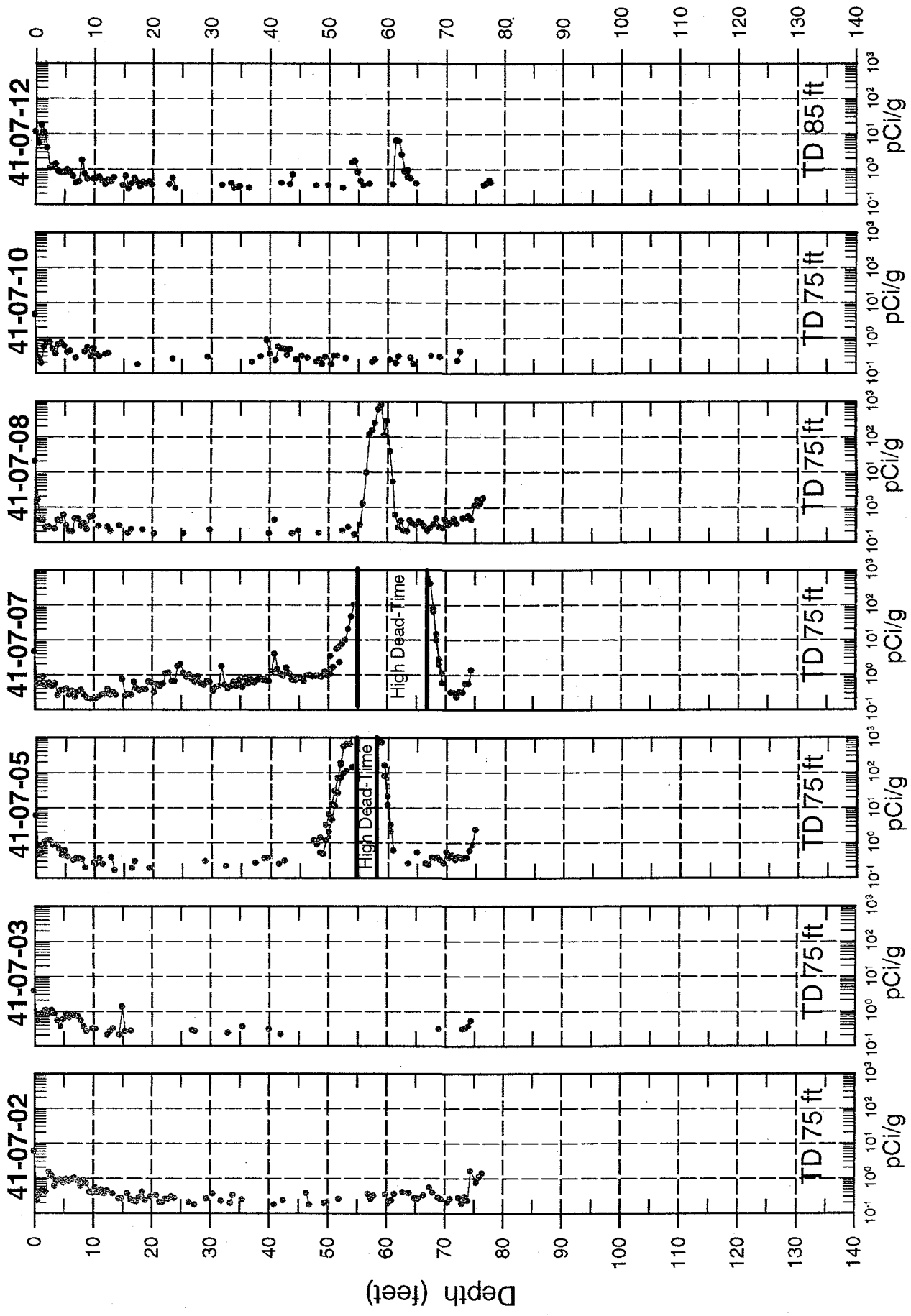


Figure C-7. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-107

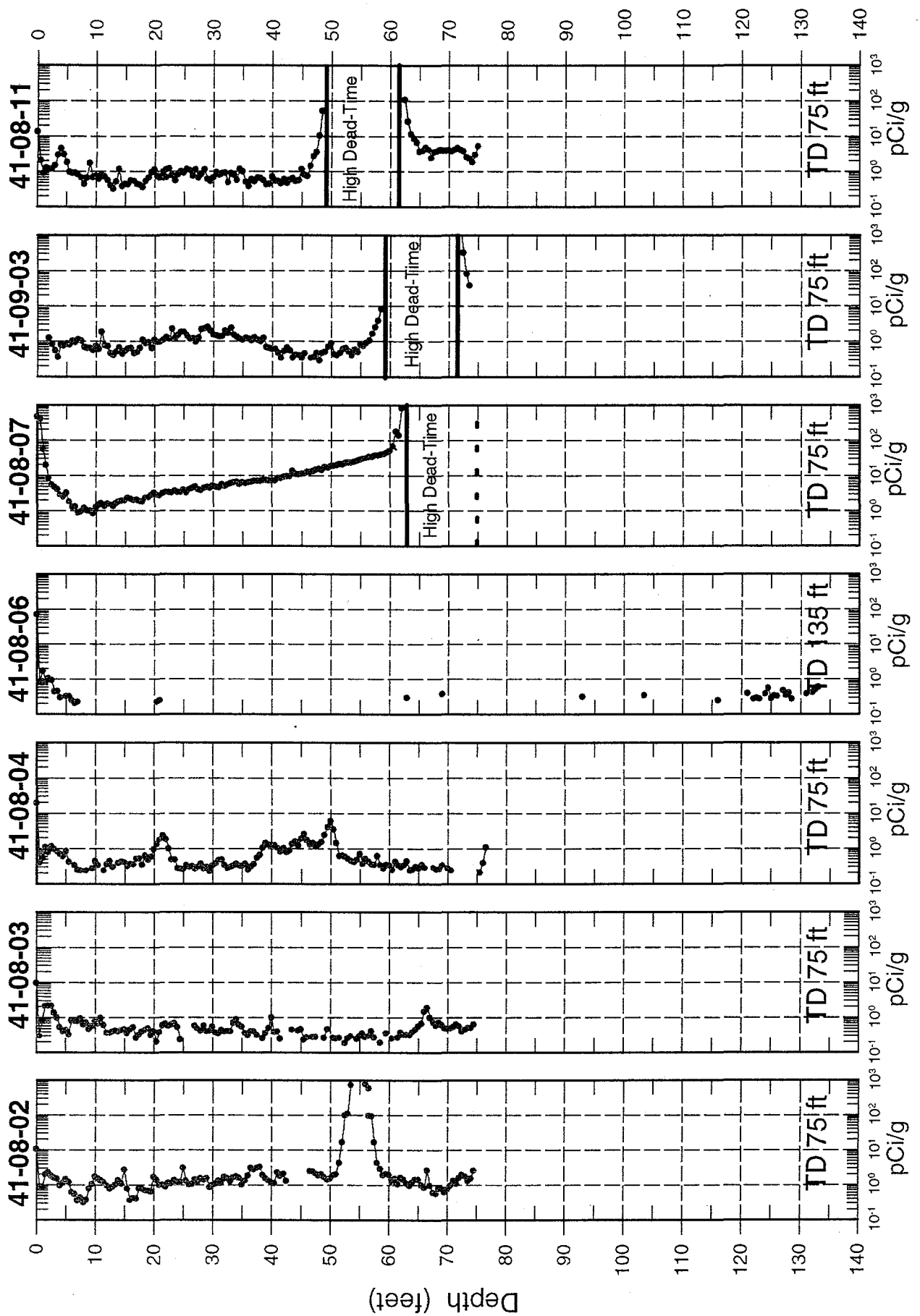


Figure C-8. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-108

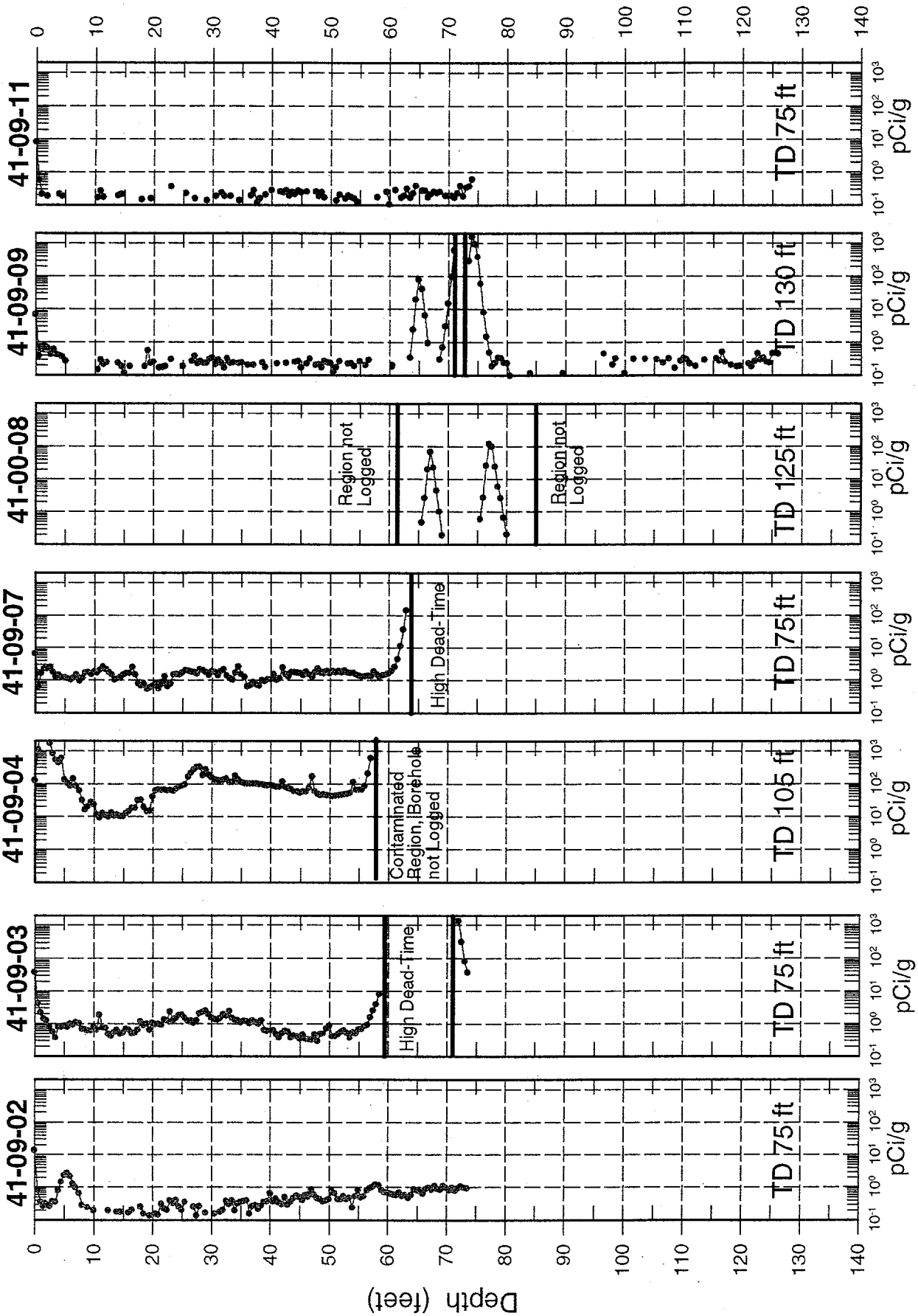


Figure C-9. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-109

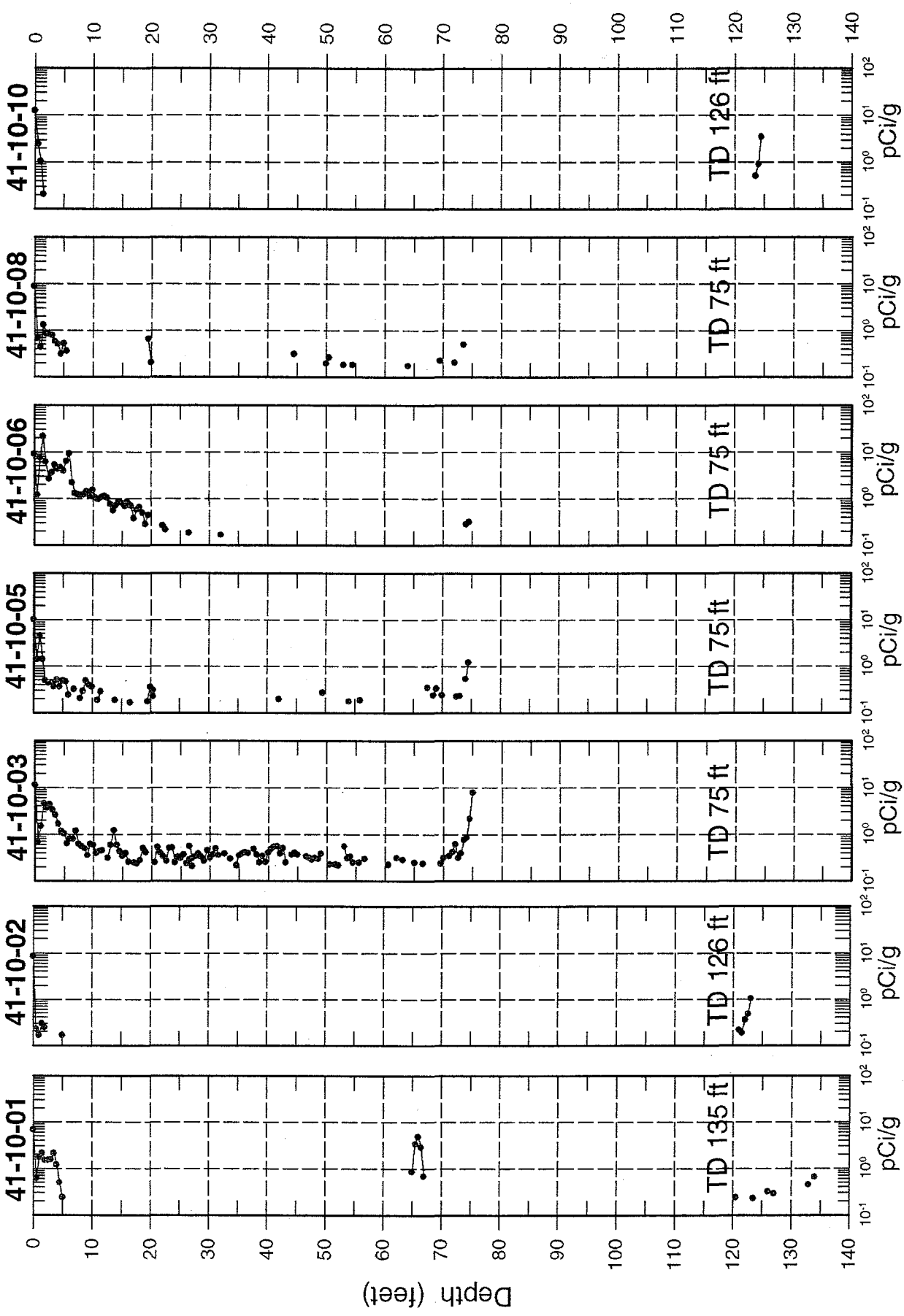


Figure C-10. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-110

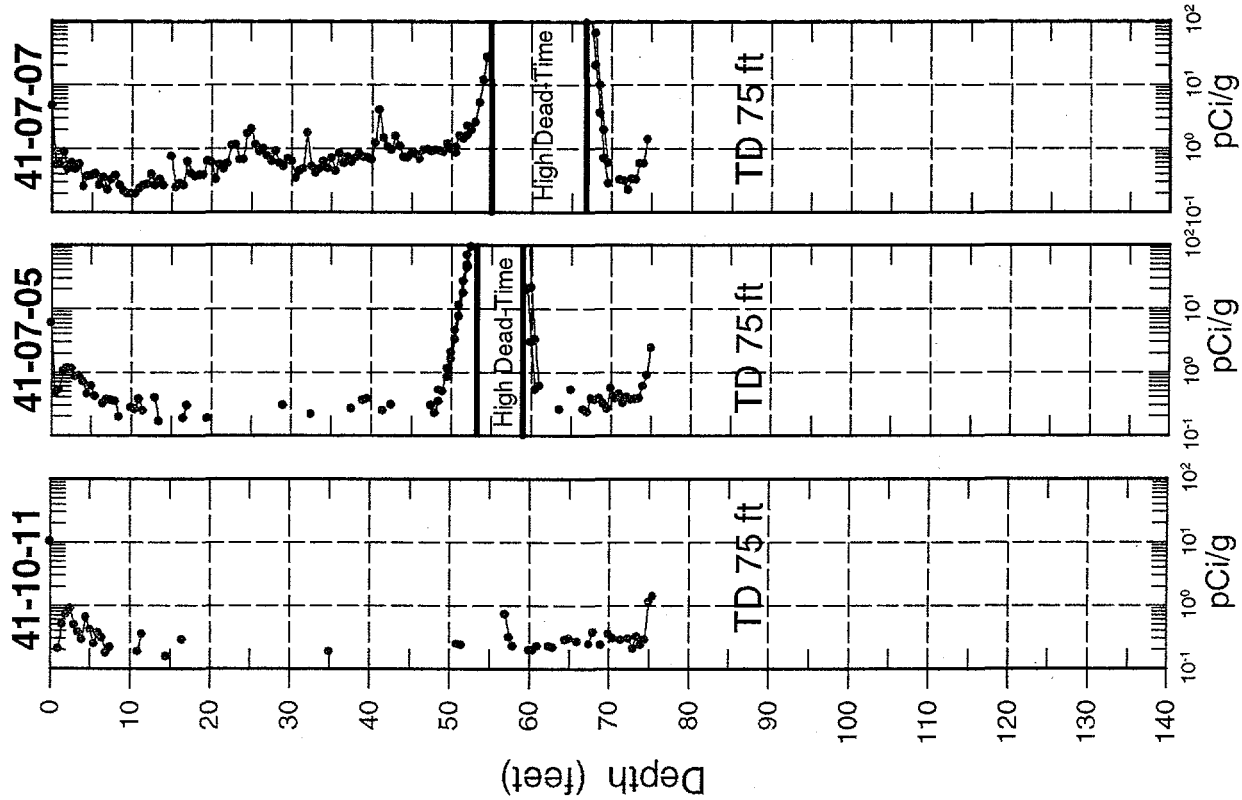


Figure C-10 (continued). Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-110

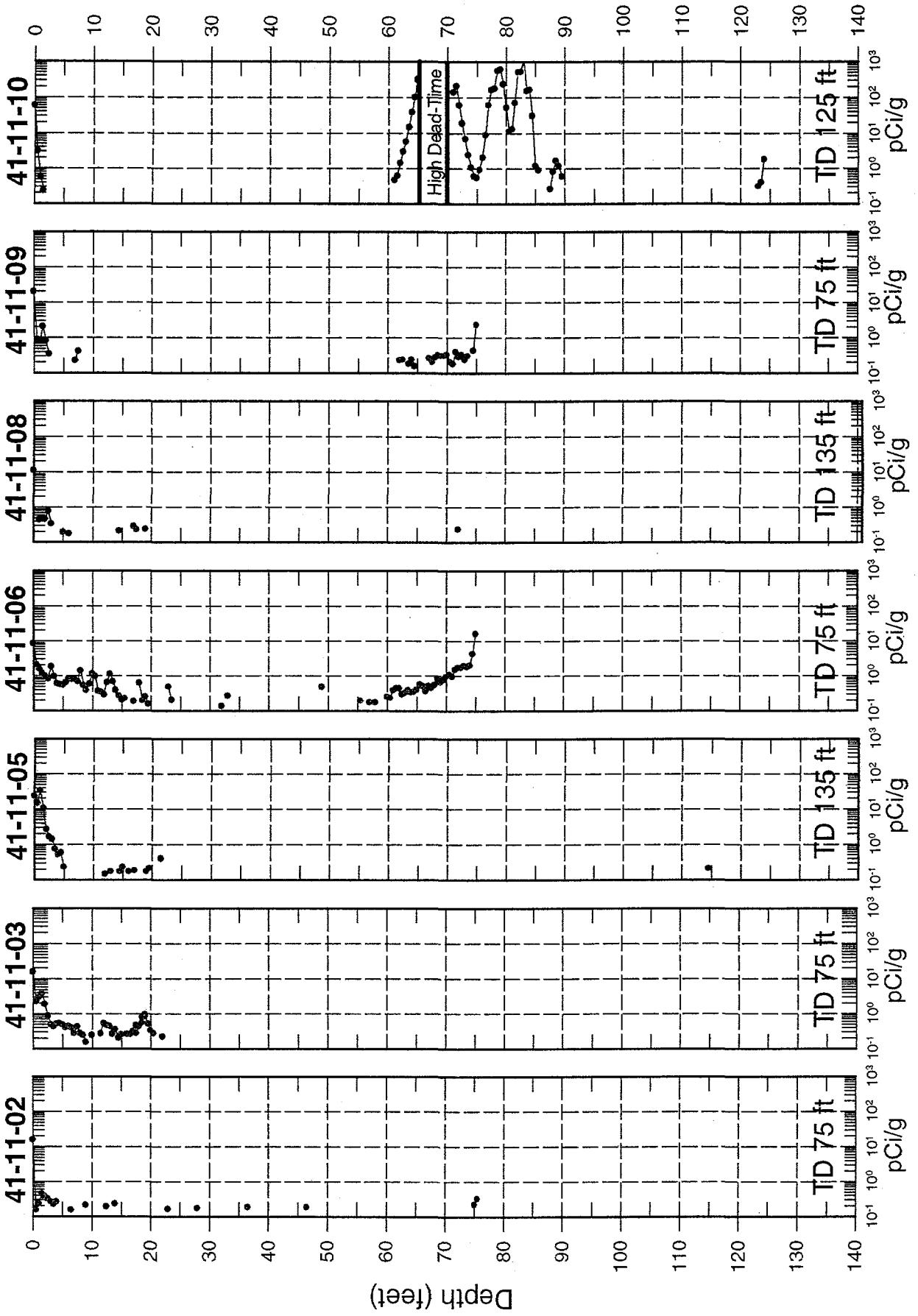


Figure C-11. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-111

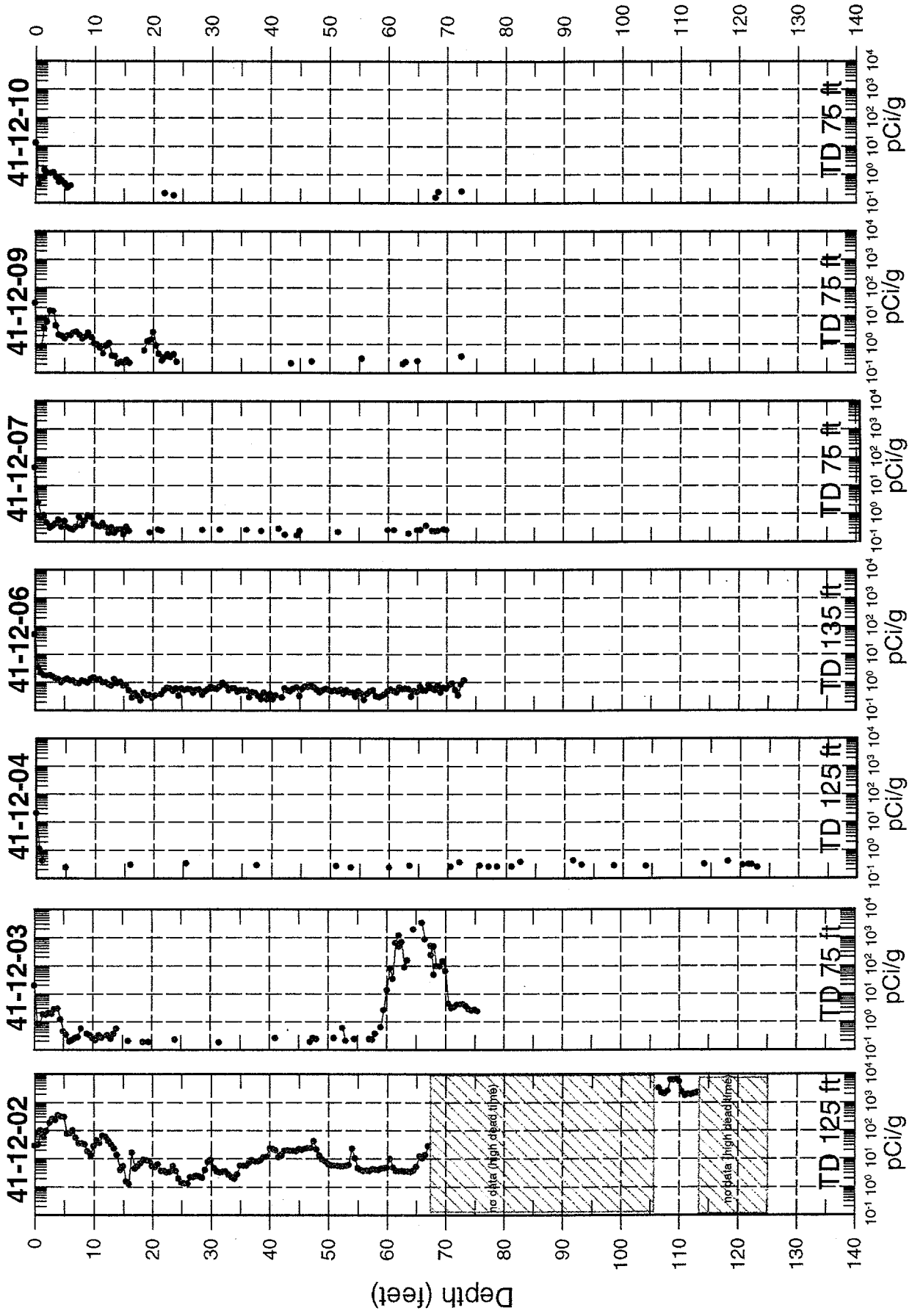


Figure C-12. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-112

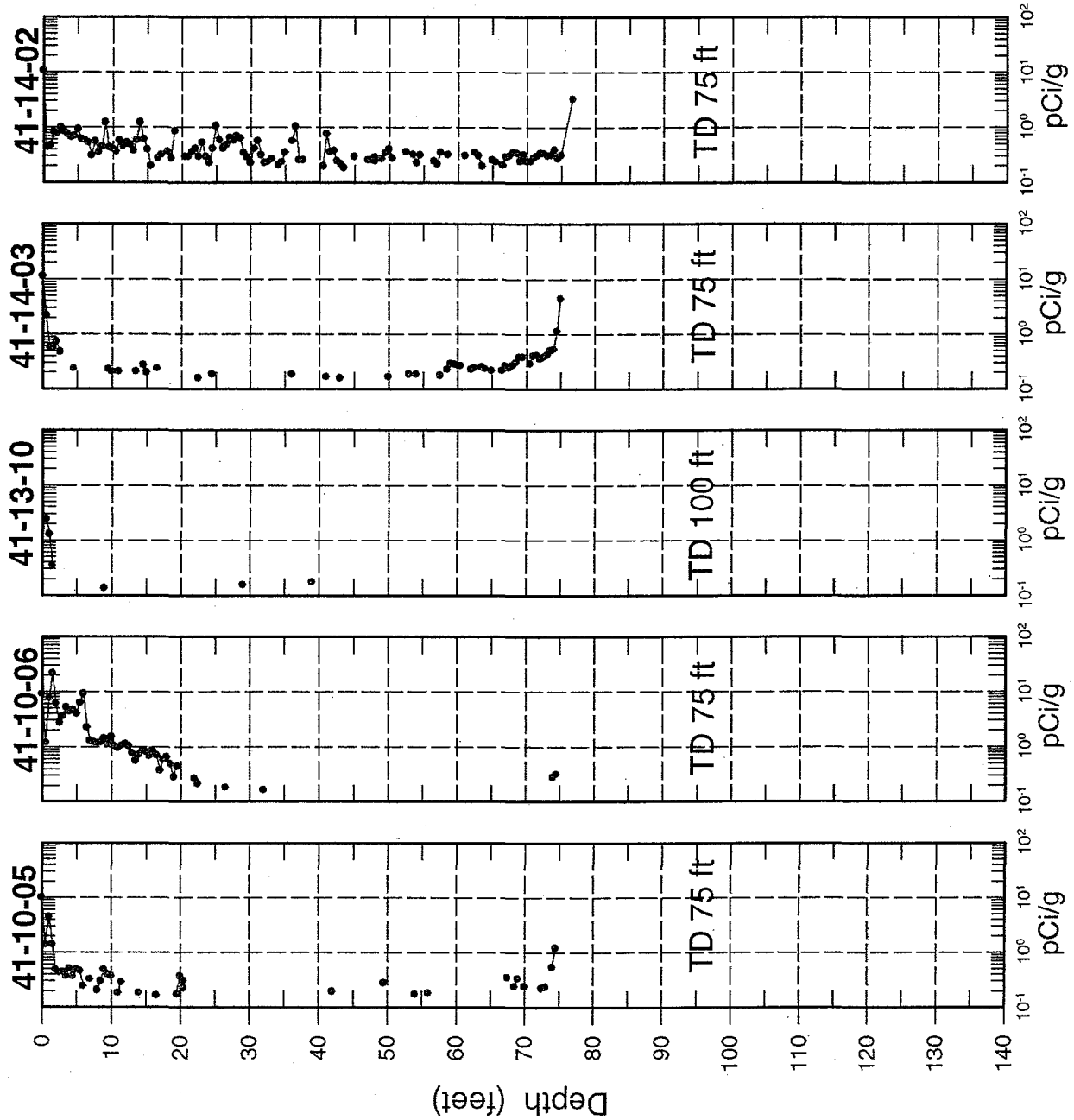


Figure C-13. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-113

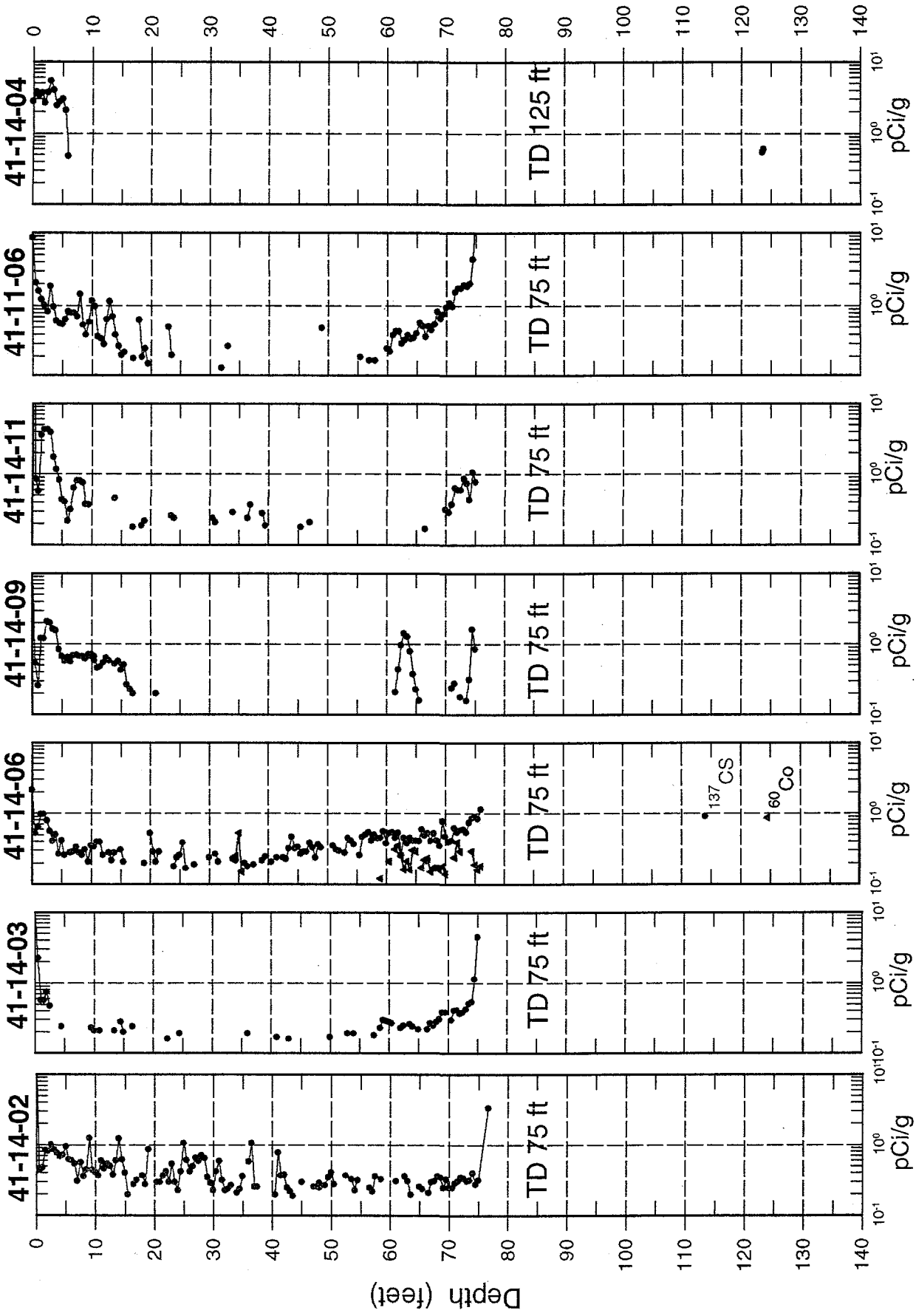


Figure C-14. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-114

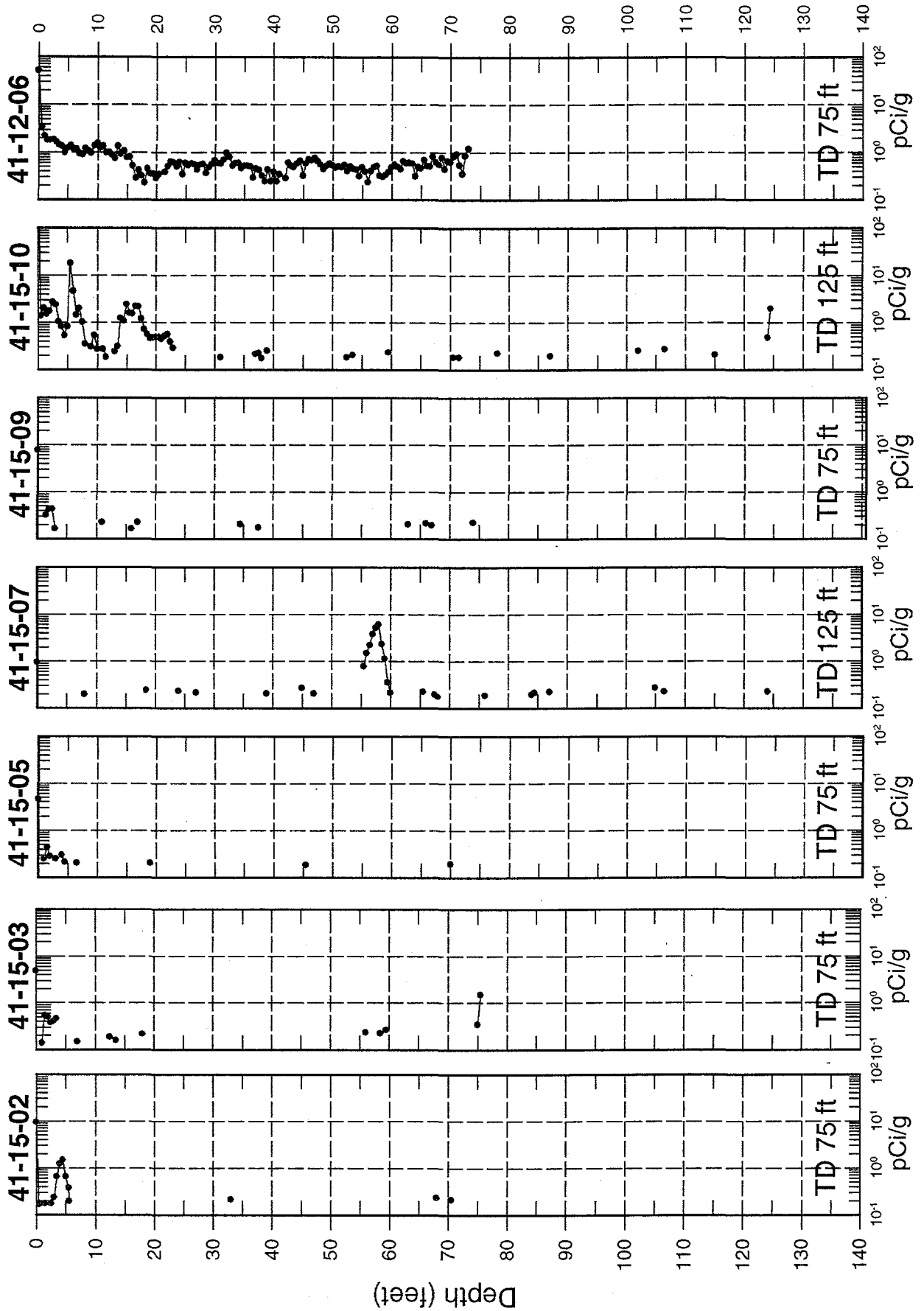


Figure C-15. Correlation Plot of ^{137}Cs Concentrations in Boreholes Surrounding Tank SX-115