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Subsurface Conditions Description of the C and A-AX Waste Management Area

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Abstract: This document discusses the subsurface conditions relevant to the occurrence and potential migration of contaminants in the groundwater underlying the C, A, and AX Tank Farms. It describes the available environmental contamination data and contains a limited, qualitative interpretation of the data as they apply to contaminant behavior.

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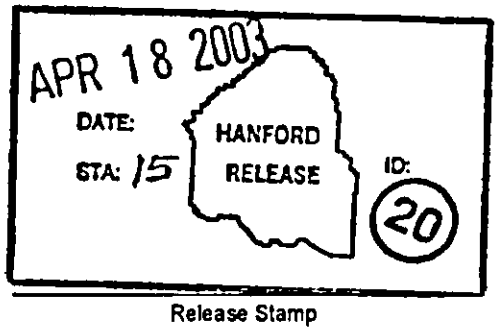

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SUBSURFACE CONDITIONS DESCRIPTION OF THE C AND A-AX WASTE MANAGEMENT AREA

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TABLE OF CONTENTS

1.0 INTRODUCTION 1-1
1.1 BACKGROUND 1-1
1.2 PURPOSE 1-5
1.3 SCOPE 1-5
2.0 PHYSICAL SETTING 2-1
2.1 C AND A-AX WMA INFRASTRUCTURE AND OPERATIONS HISTORY 2-1
2.1.1 C and A-AX WMA Infrastructure 2-1
2.1.2 Operations History 2-2
2.2 GEOLOGY 2-4
2.2.1 Geomorphology 2-11
2.2.2 General Stratigraphy 2-11
2.2.3 Methodology 2-12
2.2.4 Uncertainty 2-19
2.2.5 Columbia River Basalt Group 2-20
2.2.6 Undifferentiated Plio-Pleistocene Unit/Ringold Formation 2-21
2.2.7 Hanford Formation 2-25
2.2.8 Recent Deposits 2-28
2.2.9 Clastic Dikes 2-29
2.3 RECHARGE SOUCES AND EVENTS 2-29
2.3.1 Infiltration from Natural Sources 2-30
2.3.2 Subsurface Discharge 2-35
2.4 HYDROLOGIC PROPERTIES 2-36
2.4.1 Vadose Zone Properties 2-36
2.4.2 Aquifer Properties 2-38
2.5 GEOCHEMISTRY 2-49
3.0 SUBSURFACE CONTAMINATION CHARACTERISTICS AND ASSOCIATED TANK WASTE INFORMATION 3-1
3.1 GAMMA RAY LOGGING INFORMATION 3-1
3.1.1 Spectral Gamma Logging Data 3-1
3.1.2 Gross Gamma Logging Data and Synthesis with Spectral Gamma Logging Data 3-2
3.2 TANK WASTE CHEMISTRY AND LEAK CHARACTERISTICS OVERVIEW 3-3
3.3 C AND A-AX WMA TANK WASTE LOSSES EVENTS 3-5
3.3.1 C Tank Farm 3-5
3.3.2 A Tank Farm 3-10
3.3.3 AX Tank Farm 3-12
3.4 CURRENT ASSESSMENT OF SINGLE-SHELL LEAK INFORMATION 3-13
3.5 GROUNDWATER CONTAMINANT INFORMATION 3-15
3.5.1 Groundwater Monitoring Results Near the C WMA 3-18
3.5.2 Groundwater Monitoring Results Near the A-AX WMA 3-21
4.0 DATA INTEGRATION AND CONTAMINANT MIGRATION CONCEPTUALIZATION 4-1
4.1 GENERAL OBSERVATIONS 4-1

4.2 CONCEPTUALIZATION OF PRIMARY VADOSE ZONE CONTAMINATION EVENTS 4-2
4.2.1 Tank C-105 Data Integration and Interpretation 4-3
4.2.2 Tank A-105 and A-104 Data Integration and Interpretation 4-5
4.2.3 C and A-AX WMA Transfer Line Leak Data Integration and Interpretation 4-8
4.3 TANK LEAK AND TRANSFER LINE INVENTORY ESTIMATES 4-9
4.3.1 C Tank Farm 4-10
4.3.2 A-AX Waste Management Area 4-11
5.0 RECOMMENDATIONS FOR FURTHER CHARACTERIZATION OF THE C AND A-AX WMAS 5-1
5.1 DESCRIPTION OF CHARACTERIZATION ALTERNATIVES 5-1
5.2 RECOMMENDATIONS FOR ADDITIONAL CHARACTERIZATION IN THE C AND A-AX WMAS 5-3
5.2.1 Characterization of the Tank C-105 Leak 5-4
5.2.2 Characterization of Waste Transfer Line Leaks in the C WMA 5-5
5.2.3 Collection of Spectral Gamma Data from Lateral Underlying Tanks A-104 and A-105 5-5
6.0 REFERENCES 6-1

TABLE OF APPENDICES

A HISTORICAL BACKGROUND OF C, A, AND AX TANK FARMS OPERATIONS AND CONTAMINATION EVENTS

B ADDITIONAL TANK FARM INFRASTRUCTURE AND OPERATIONAL HISTORY INFORMATION

C SUPPORTING STRATIGRAPHIC INFORMATION

D SUPPORTING METEOROLOGICAL, HYDROLOGIC DATA

E SUPPORTING GAMMA LOGGING DATA

F ADDITIONAL CHARACTERIZATION DATA OF UNPLANNED RELEASES UPR-200-E-82 AND UPR-200-E-86

TABLE OF FIGURES

Figure 1-1 Location Map of the C and A-AX Waste Management Areas and Related Facilities. 1-2
Figure 1-2 Location Map of the C WMA (C Tank Farm and Surrounding Facilities) 1-3
Figure 1-3 Location Map of the A-AX WMA (A and AX Tank Farms and Surrounding Facilities 1-4
Figure 2-1 Well/Borehole Location Map 2-5
Figure 2-2 Stratigraphic Units 2-12
Figure 2-3 Quality Rating for 49 Boreholes within 1000 ft (300 m) of the C and A-AX WMAs. 2-15
Figure 2-4 Cross Section Location Map 2-16
Figure 2-5 Heterogencity within the Undifferentiated Plio-Plestocene Silt/Ringold Formation Mud? [PPlz/R(?)] Unit at Boreholes near the C and A-AX WMAs 2-24
Figure 2-6 Monthly Summaries of Rapid Snowmelt Events, 1981 Through 1997 2-31
Figure 2-7 Timeline of Hydrologic and C Tank Farms Operational Events 2-32
Figure 2-8 Timeline of Hydrologic and A and AX Tank Farms Operational Events 2-33
Figure 2-9 Historical Water Levels near the B-BX-BY WMA 2-36
Figure 2-10 Water Level Elevations in the 200 East Area in March 2002 2-40
Figure 2-11 Hydrographs for Wells in the WMA C Monitoring Network 2-41
Figure 2-12 Hydrographs for Two Wells in the WMA A-AX Monitoring Network 2-41
Figure 2-13 Flow Direction Map of Wells in the Vicinity of Waste Management Areas A-AX and C Base on Colloidal Borescope Measurements 2-46
Figure 2-14 Flow Direction Map of Wells around Waste Management Area C Based on Colloidal Borescope Measurements 2-47
Figure 2-15 Flow Direction Map of Wells around Waste Management Area A-AX Based on Colloidal Borescope Measurements 2-48
Figure 3-1 Distribution of Radionuclides in the Unconfined Aquifer in 200 East Area 3-16
Figure 3-2 Distribution of Chromium and Nitrate in the Unconfined Aquifer in 200 East Area 3-17
Figure 3-3 Trend Plots of Specific Conductance for C WMA 3-19
Figure 3-4 Trend Plots of Specific Conductance, Cations and Anions for Well 299-E27-14 3-19 3-19
Figure 3-5 Trend Plots of Technetium-99 for the C WMA 3-20
Figure 3-6 Trend Plots of Nitrate and Technetium-99 for the C WMA 3-21
Figure 3-7 Trend Plots of Specific Conductance for WMA A-AX 3-22
Figure 3-8 Trend Plots of Sulfate for WMA A-AX 3-23
Figure 3-9 Trend Plots of Nitrate for WMA A-AX 3-23
Figure 3-10 Trend Plots of Technetium-99 for WMA A-AX 3-24
Figure 3-11 Trend Plots for Filtered Chromium, Nickel, and Manganese, for Well 299-E24-19 3-25
Figure 3-12 Trend Plots for Filtered Chromium and Specific Conductance for Well 299-E24-19 3-25

TABLE OF TABLES

Table 2-1	Descriptive Characteristics of Boreholes within 1000 ft of the C and A-AX WMAs	2-7
Table 2-2	Stratigraphic Contacts for Boreholes within 1000 ft of WMA	2-17
Table 3-1	Tank Leak Information Summary	3-14
Table 4-1	Tank Leak Inventory Estimates for A, AX, and C Tank Farms	4-6
Table 5-1	Critical Factors Evaluations/Recommendations	5-2

LIST OF TERMS

ASTM	American Society for Testing and Materials
CRBG	Columbia River Basalt Group
CWP	PUREX Coating Waste
CWP2	PUREX cladding waste
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FIR	Field Investigation Report
HDW	Hanford defined waste
IP	intrusion prevention
IS	interim stabilized or isolated
ITS	in-tank solidification
OWW	organic wash waste
PAS	PUREX acidified sludge
PAW	PUREX acid waste
PI	partially interim isolation
PSN	PUREX supernate waste
PSPL	Preliminary Safety Analysis Report
PUREX	Plutonium-Uranium Extraction Plant
Qfg	Quarternary flood gravels
Qfs	Quarternary flood sands
RCRA	Resource conservation and Recovery Act of 1976
REDOX	reduction-oxidation
SST	single-shell tank
TBP	tributyl phosphate
WIDS	Waste Information Data Base System
W MA	Waste Management Area
UPR	unplanned release
UR	Uranium Recovery

1.0 INTRODUCTION

This document, *Subsurface Conditions Description of the C and A-AX Waste Management Areas*, discusses the subsurface conditions relevant to the occurrence and potential migration of contaminants in the groundwater underlying the C, A, and AX Tank Farms. These tank farms, located in the 200 East Area of the Hanford Site, make up the C and A-AX Waste Management Areas (WMAs). This document describes the available environmental contamination data and contains a limited, qualitative interpretation of the data as they apply to contaminant behavior.

1.1 BACKGROUND

Figure 1-1 shows the locations of the C and A-AX WMAs, and some other facilities in the 200 East Area. To facilitate *Resource Conservation and Recovery Act of 1976* (RCRA) groundwater monitoring programs, the A and AX Tank Farms were grouped into one WMA. Figures 1-2 and 1-3 provide more detail on the C and A-AX WMAs, respectively. Surrounding area facilities are also shown. In Figure 1-2 (C tank farm), other auxiliary tank farm structures are shown including the 244-CR vault, the C-301 catch tank and four small processing tanks, C-201 through C-204. In Figure 1-3 (A and AX Tank Farms), auxiliary structures (244-AR vault, A-350 Catch tank) and nearby liquid discharge facilities (cribs, trenches, retention basins and french drains) are shown.

Evaluation of vadose zone contamination under C and A-AX Tank Farms by tank waste is being evaluated as an extension of similar activities that have been completed for several other single shell tank farm WMAs including S-SX, B-BX-BY, T, and TX-TY WMAs. Subsurface Conditions Description Reports (SCDR) have been issued for these WMAs: *Subsurface Physical Conditions Description of the S-SX Waste Management Area* (Johnson et al. 1999), *Subsurface Conditions Description of the B-BX-BY Waste Management Area* (Wood et al. 2000), and *Subsurface Conditions Description of the T and TX-TY Waste management Areas* (Wood et al. 2001). The previous investigations were initiated because the source of some nearby groundwater contamination was attributed to a tank waste source in the vadose zone underlying these WMAs. Consequently, the Washington State Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) negotiated the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) *Change Control Form, Form No. Draft M-45-98-03* (Ecology et al. 1999). The proposed Tri-Party Agreement milestones mandated a series of activities addressing these WMAs. The goal of the activities was to determine the need for corrective action to mitigate the impact of contamination from single-shell tanks (SST) on the surrounding environment.

The C and A-AX WMAs were not included in this action because there has been no indication that vadose contamination in these WMAs is a source of current nearby groundwater contamination. However, it has become clear from previous investigations that if vadose zone contamination is present under a WMA, future groundwater contamination from these sources is plausible. In order to complete remediation of these WMAs and achieve final closure of the facility, the potential environmental impacts of these sources must be evaluated. Information

generated by these and future characterization activities will support waste management decisions for SST waste retrieval, and SST closure.

Figure 1–1. Location Map of the C and A-AX Waste Management Areas and Related Facilities.

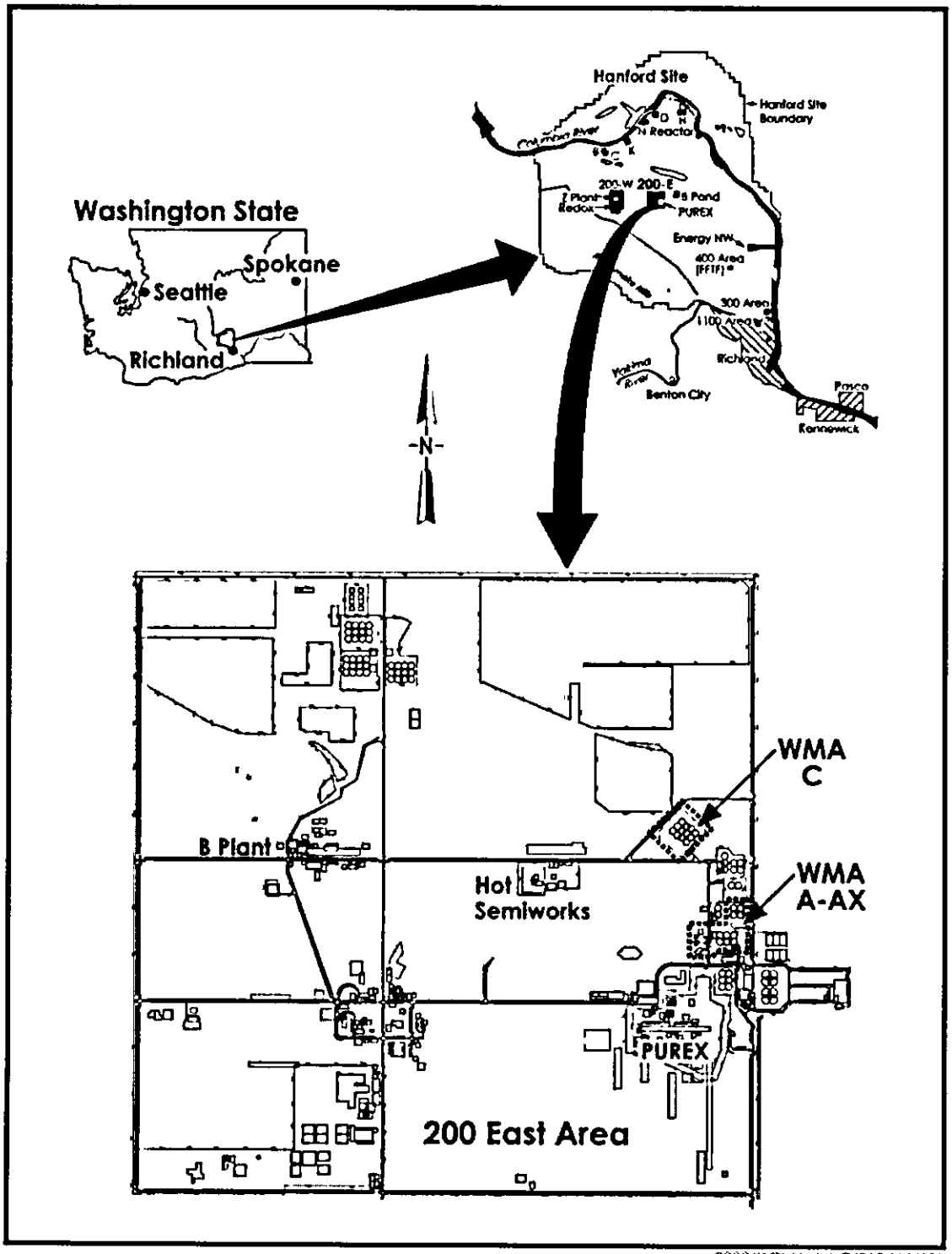

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Figure 1–2. Location Map of the C WMA (C Tank Farm and Surrounding Facilities).

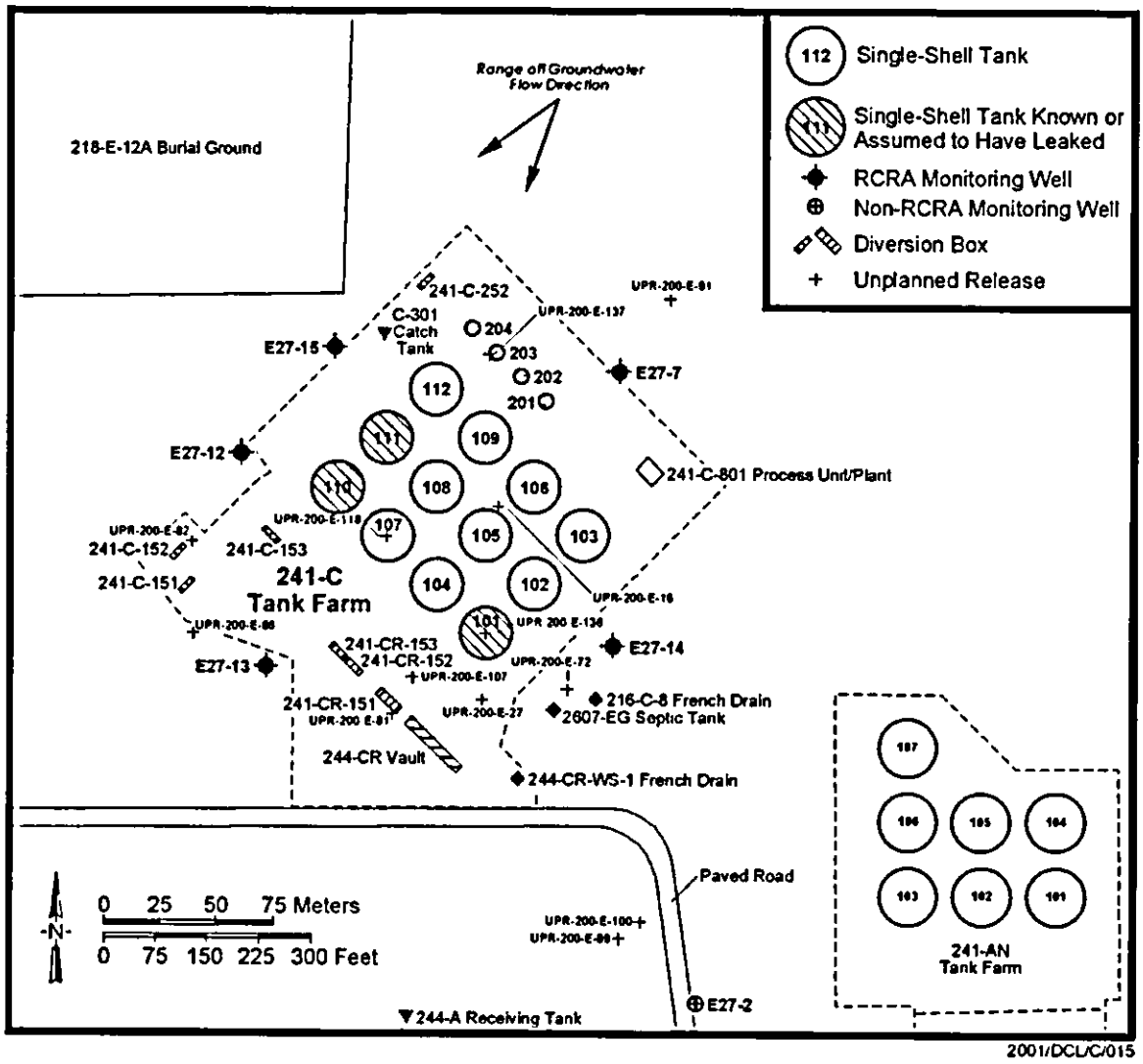
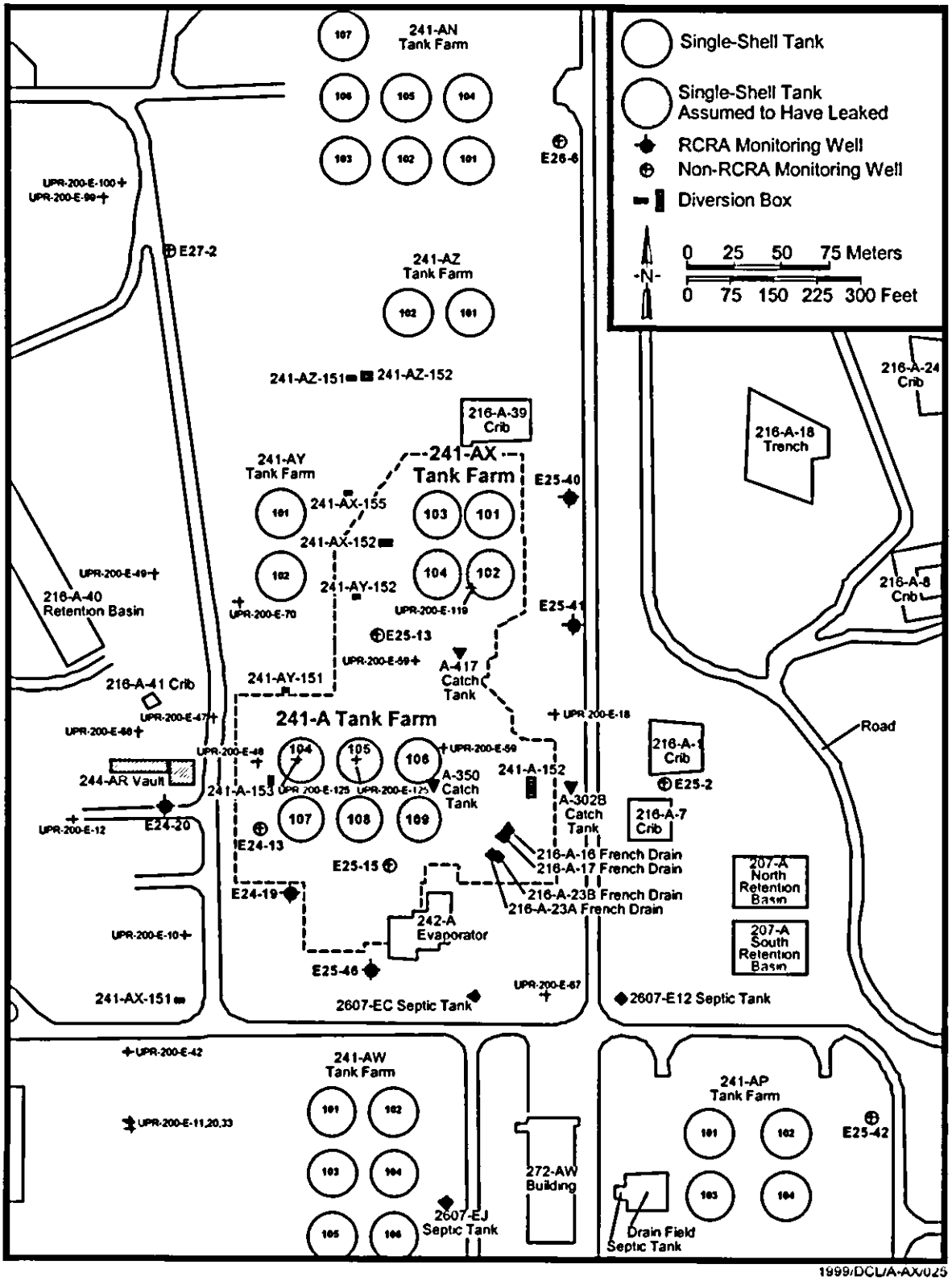


Figure 1–3. Location Map of the A-AX WMA (A and AX Tank Farms and Surrounding Facilities).



1.2 PURPOSE

Within the context of the characterization and evaluation program, this document fulfills several purposes. To aid in selecting a characterization approach, this document is focused on site-specific data that define the occurrence and migration of contaminants within the system to date. This document includes a concise description and limited interpretation of these critical data. A systematic description of the environmental conditions affecting contaminant migration still is needed to identify data gaps, recognize significant relationships among different data types, and organize data inputs to contaminant migration models. This document provides a framework for completing a systematic description as more data are collected, interpreted, and integrated with currently available information. This document supports the creation of a work plan addendum to the *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* (DOE/RL-99-36 1999).

1.3 SCOPE

The first part of this document describes the two primary components of the subsurface condition database: the physical setting of the C and A-AX WMAs and the contaminants contained within the WMAs. Chapter 2 describes the physical setting, which includes the tank farm infrastructure, geology, hydrology and infiltration mechanisms, and geochemistry. The tank farm infrastructure description emphasizes those parts of the system that allowed fluids to discharge into the soil column and the periods during which these parts were operational. The geology description emphasizes the impact of the geologic strata on fluid movement. The hydrology and infiltration discussion emphasizes infiltration mechanisms, infiltration history, and hydrologic properties of the geologic strata that control fluid movement. The geochemistry section emphasizes the characteristics that control contaminant movement, particularly in relation to fluids.

The second component of the subsurface characterization database is the description of contaminant occurrences and movement within the vadose zone. This is presented in Chapter 3. First, contamination events are summarized to orient the reader to the historical sequence. Second, the synthesis of the historical and spectral gamma database for the C, A and AX Tank Farms is summarized. These data are unique because of their extent, both temporally and spatially. The overview demonstrates the observed spatial variability of contaminant concentration and provides the most comprehensive indication of the diversity among various contaminating events. Distinct sources or similar types of sources within the vadose zone of the WMAs organize the remainder of the discussion in Chapter 3. The key data in this discussion include tank waste inventory and chemistry information derived from process history, the corroborating gamma data, and soil sample data where available.

Chapter 4 contains a brief qualitative integration of the data and relates the data to a conceptualization of the contamination events. Because the events are diverse, database interpretations are given for each specific contaminating occurrence or type of occurrence.

Key uncertainties and data gaps that are important to understanding potential future contamination of the unconfined aquifer are identified in Chapter 5. Chapter 5 also provides recommendations for resolving these uncertainties.

Six appendices also are provided. Appendix A contains the text of the C and A-AX WMA historical summary document *Historical Vadose Zone Contamination from A, AX, and C Tank Farm Operations* (Williams 2001). Appendix B provides additional tank infrastructure, operating history information and unplanned releases descriptions. Appendix C provides supporting geologic data. Appendix D provides supporting hydrologic data. Appendix D summarizes the analyses of spectral gamma logging data. Appendix E summarizes the analyses of gross gamma logging data. Appendix F summarizes field characterization work completed for two unplanned releases of tank waste from transfer lines in the southwest part of the C WMA.

2.0 PHYSICAL SETTING

2.1 C AND A-AX WMA INFRASTRUCTURE AND OPERATIONS HISTORY

This section discusses the infrastructure and briefly summarizes the C, A and AX Tank Farm operations history, including the use of ancillary equipment and nearby cribs, trenches and wells. A more detailed historical review is provided in Williams (2001), which is provided as Appendix A. This section identifies the infrastructure elements known or suspected to have discharged fluids to the vadose zone, along with elements that remain capable of future discharges.

2.1.1 C and A-AX WMA Infrastructure

The three tank farms, C, A and AX are divided into two WMAs, with the C Tank Farm in one and the A and AX Tank Farms in the other. Within the C Tank Farm, the primary structures through which tank waste was stored, transported and discharge are the 12 primary tanks (C-101 through C-112) and four secondary tanks (C-201 through C-204). The primary tanks are 23 m (75 ft) in diameter and 4.9 m (16 ft) deep with a capacity of 2 million liters (530,000 gal). Each ancillary tank is 6.1 m (20 ft) in diameter and 11 m (37 ft) deep with a capacity of 0.2 million liters (55,000 gal). Primary and secondary tank configurations and dimensions are provided in Appendix B, Figures B-1 and B-2. The 12 primary tanks were divided into 4 sets of 3 tanks each (e.g., tanks C-101, C-102, and C-103) with cascade lines attaching set so that waste would flow from southwest to northeast by gravity feed. The C Tank Farm also contains an assortment of ancillary equipment used to move tank waste during operations. These include seven diversion boxes, the 244-CR process vault and numerous waste transfer lines (see Figure 1-2).

Within the A-AX WMA, the primary structures are two tank farms containing a total of 10 tanks (tanks A-101 through A-106 and tanks AX-101 through AX-104). Each tank is 23 m (75 ft) in diameter and 9.1 m (30 ft) deep with a capacity of 3.8 million liters (1 million gal). Tank configurations and dimensions are provided in Appendix B, Figure B-3. The tanks were connected by overflow lines but did not cascade. The A Tank Farm was underlain by laterals connected to caissons as a leak detection system because the tank farm was designed to store boiling waste. The AX tanks included a grid of drain slots beneath the shell liner bottom and a leak detection well that could collect potential leakage. Ancillary equipment included diversion boxes and catch tanks inside the WMA and the 244-AR vault just west of A Tank Farm. Outside the A and AX Tank Farms are several liquid discharge facilities: retention basin 216-A-40 west of AX Tank Farm, crib 216-A-39 north of AX Tank Farm, crib 216-A-38 east of AX Tank Farm, crib 216-A-41 west of A Tank Farm, and cribs (216-A-1 and 216-A-7) and retention basins (207-A North and South) east of A Tank Farm (see Figure 1-3).

2.1.2 Operations History

The C, A and AX Tank Farm complexes received waste generated by essentially all of the major chemical processing operations that occurred at Hanford including bismuth phosphate fuel processing, uranium recovery, Plutonium-Uranium Extraction Plant (PUREX) fuel processing, fission product recovery and tank farm interim stabilization and isolation activities. Only C Tank Farm was operational during the bismuth phosphate and uranium recovery processes.

2.1.2.1 Bismuth Phosphate and Uranium Recovery Operations. The C Tank Farm was constructed between 1943 and 1944 and first received metal waste and first cycle waste from B Plant beginning in 1946. Ultimately, tanks C-101 through C-106 received metal waste and tanks C-107 through C-112 received first cycle waste. All tanks were filled with bismuth phosphate waste by the end of 1948. The 200 series tanks also received metal waste. To free up tank space, in 1952 first cycle waste was transferred to the 242-B evaporator.
Metal waste was also removed from C Tank Farm beginning in 1952 and transferred to U plant for uranium recovery. Ancillary equipment involved in the metal waste transfer included the 244-CR vault and diversion boxes 241-CR-151, -152 and –153. Subsequently, tributyl phosphate (TBP) waste, a byproduct of the uranium recovery process, was returned to C Tank Farm. The 244-CR vault was modified in 1955 to scavenge TBP waste (that is, to separate cesium-137 from the supernate by precipitation) that was present in tanks C-107 through C-112. The scavenged slurry was redeposited in tanks C-109 and C-112 to settle and the resultant supernate was discharged to the BC cribs.

2.1.2.2 PUREX Processing Operations. The A Tank Farm was constructed in 1955 to support the PUREX processing plant operations, which ultimately produced the greatest amount of plutonium during Hanford processing history. The PUREX process produced three major waste streams, PUREX Coating Waste (CWP), PUREX acid waste (PAW) which contained about 99% of the fission products, and organic wash waste (OWW). These wastes were neutralized, as needed, and stored in the C and A Tank Farms at various times. Beginning in 1956, neutralized PAW and OWW were sent to A Tank Farm and CWP was sent to C Tank Farm. Beginning in 1957 CWP in C Tank Farm was routed to the B-BX-BY Tank Farms. AX Tank Farm was constructed in 1963 and received PAW from 1965 through 1969. From 1962 until 1969 tank C-102 was designated as the receiver tank for CWP and all CWP from PUREX was sent there and in 1968, OWW was separated from PAW and also sent to tank C-102. The CWP and OWW wastes were routed to the in-tank solidification operations in the BY Tank Farm.

Both intentional and unintentional discharges to ground occurred during this time period. Tank condensate and cooling water were deliberately discharged to several cribs, ditches, french drains and ponds beginning in 1956. Several liquid discharge facilities received enough waste to reach their radiological capacity, released contaminants to groundwater and were decommissioned. Crib 216-A-8 was abandoned in 1958 but then reused from 1966 to 1976 when crib 216-A-24 reached its capacity and was abandoned in 1966. Crib 216-A-5 and ditch 216-A-10 received process condensate from 1956 until 1961 and from 1961 to 1978, respectively before groundwater contamination forced their abandonment.

Several unintentional PUREX waste releases to the environment occurred during this time period. In 1969, CWP leaked from a transfer line (V051) near diversion box 241-CR-151 to which it was connected. CWP also leaked from a transfer line between tanks C-105 and C-108 some time between 1956 and 1959. An estimated 190 L (50 gal) was lost. In early 1965, a violent steam discharge event occurred in tank A-105. A 30-minute steam release was associated with this event. The initial assessment was that up to 10 to 12 thousand gallons of waste might have been lost during the event. Subsequent investigation showed a bulge in the tank liner bottom providing an estimate void volume between the liner and the concrete shell of 19,000 to 57,000 L. Additional leakage was noted in 1967 (UPR-200-E-126).

2.1.2.3 Isotope Recovery Programs. By the late 1950s, it was clear that a number of SSTs had likely leaked and the long-term storage of large volumes of liquid radioactive wastes was untenable. Hanford Site contractors were directed to convert liquid radioactive waste to saltcake as soon as practicable. Conversion of the supernatant to saltcake required removal of much of the Cs-137 and Sr-90. As treatment processes were developed and implemented, PUREX waste streams depleted in strontium-90 and Cs-137 were stored at various times in some C farm tanks. Strontium-90 depleted PAW was stored in tanks C-107 through C-109 after Strontium Semiworks startup in 1961. In 1963, PUREX supernate waste (PSN) previously stored in tank C-103 was transferred to 241-C-801 facility for cesium-137 removal and subsequently returned to tank C-102. Eventually, this waste and commingled CWP in tank C-102 was transferred to BY Tank Farm. From 1963 to 1967 strontium-90 recovery processes were being developed at B Plant and the depleted wastes were stored in C Tank Farm and in tank AX-101.

The conversion of high-fission product radioactive waste supernatants into saltcake required both a 3 to 5 year cooling-off period to allow short-lived radionuclides to decay (thus, the need for boiling waste tanks in the S, SX, A, and AX Tank Farms) and removal of a significant amount of the longer-lived heat-generating radionuclides such as strontium-90 and cesium-137. In 1967, B Plant was reactivated to support an isotope recovery program. Beginning in 1967, PUREX current acid wastes were processed through B Plant for cesium-137 and strontium-90 recovery, prior to the 3 to 5 year cooling-off period. Aged PUREX supernatants and sludges were recovered from the tanks and processed through the B Plant for strontium-90 and cesium-137 recovery. The aged reduction-oxidation (REDOX) supernatants were transferred to 200 East Area tanks and processed through B Plant for cesium-137 recovery. Tank C-105 was the receiver tank for all supernatants going to B Plant for Cs-137 recovery. After cesium-137 removal, REDOX supernatants were transferred back to the 200 West Area for saltcake production in the T and S Evaporators.

After the cesium-137 was removed (or at least greatly reduced) in the aged PUREX supernatants, the wastes were transferred to various tanks in the B/BX/BY and C farms, leading to conversion of supernatants into saltcake using the BY farm in-tank solidification (ITS) process. In the ITS process, heater units were installed in three tanks in the BY Tank Farm. Waste supernatants were rotated through the ITS process tanks and out to the B-BX-BY tanks so as to produce saltcake. The available tank space in the B-BX-BY farms was filled with saltcake using the BY ITS process.

By 1967, all cesium-137 and strontium-90 removal from PSN was being done at B Plant and the primary transfer sequence was initial storage of PSN in AX Tank Farm followed by transfer through tank C-105. In the late 1960s, OWW was combined with CWP and stored in tank C-102 and subsequently transferred to BX Tank Farm for interim tank stabilization. PUREX sludges were also sluiced from A Farm tanks (A-101 in 1968, A-104 in 1969 and A-106 in 1970) and transferred to 244-AR vault for acidification, then to 244-CR vault as PUREX acidified sludge (PAS) and B Plant. Depleted wastes from B Plant were returned to AX Tank Farm for storage. This cycle ran until 1978 when the last of the PUREX waste in A and AX Tank Farm had been treated. Tanks deemed to be sound in C, A and AX Tank Farms (primarily tanks A-103, C-103 and C-104) stored all variety of wastes not segregated by waste type.

Intentional discharges during the waste fractionation period included slightly contaminated fluids from the 244-AR vault to crib 216-A-41 (1968 to 1974) and uncontaminated cooling water to Gable Mountain Pond. Unintentional releases included PSN losses from transfer lines V122 near diversion box 241-C-152 in 1970 (UPR-200-E-82) and line 812 near diversion box 241-C-151 in 1971 (UPR-200-E-86). In AX Tank Farm, three small releases occurred surface contamination around diversion box 241-AX-151 in 1972, (UPR-200-E-42), a pump pit leak at 241 AX-103 in 1974 (UPR-200-E-115), and a small spill created at 241-AX-104 in 1969 created by cable movement (UPR-200-E-119).

In the mid 1970s, a decision was made put all the single shell tanks out of service. At C, A and AX Tank Farms, saltwell jet pumping was employed to remove much of the liquid waste present in the tanks. Tanks C-103 and A-102 were designated as the receiver tanks for C farm and A-AX Tank Farms, respectively and pumping began in 1976. Currently, the majority of liquid wastes have been removed from these tanks. The most recent sluicing event occurred at tank C-106 in 1999.

2.2 GEOLOGY

This section summarizes the geologic setting and presents an updated conceptual geohydrologic model of the area in the vicinity of A-AX and C Waste Management Areas (WMAs), located in the east-central portion of Hanford's 200 East Area. This analysis is based on a total of 49 boreholes (Table 2-1) located within 1000 ft (300 m) of A-AX and C WMAs (Figure 2-1) and contains an update of previous geologic descriptions given for these areas (Caggiano and Goodwin 1991; Williams et al. 2000; Narbutovskih and Horton 2001; and Horton and Narbutovskih 2001). The resulting conceptual model was compared to regional studies to assure coherence within the larger framework of stratigraphic interpretations. The information in this section provides the framework for subsequent consideration of stratigraphic and structural controls on moisture and waste movement through the vadose zone to groundwater.

Figure 2-1. Well/Borehole Location Map.

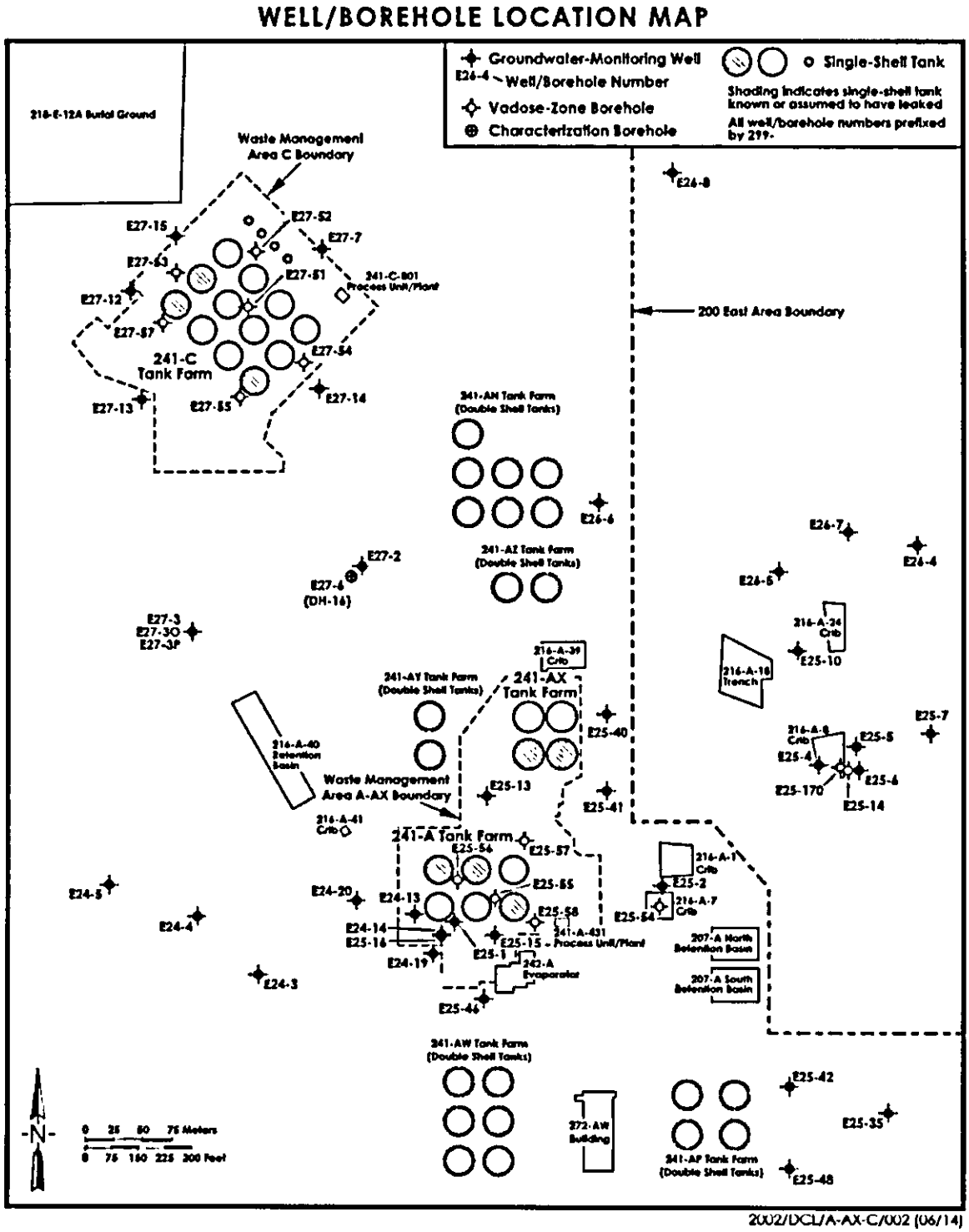


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Table 2-1. Descriptive Characteristics of Boreholes within 1000 ft of the C and A-AX WMAs. (3 sheets)

Borehole Name	Borehole ID	Quality Rating[1]	Included on Cross Section	Associated Facility	Drill Method[2]	Easting (m)	Northing (m)	Source	Casing Stick Up (ft ags)	Ground-Surface Elevation (ft)	Reference Point	Well Survey	Total Depth (ft)	Year Drilled	Open Interval (ft bgs)	Depth to Water (ft bgs)	Date of Water-Level Measurement	Lithologic Log[3]	Geophysical Log[4]	Moisture Data (Depth Interval in ft)	Particle-Size Distribution (Depth Interval in ft)	Calcium Carbonate (Depth Interval in ft)	Purpose of Borehole	Comments
299-E24-03	A5897	3		A Tank Farm	HT	575165 15	135983 20	USACE(JFCA)	1 67	700 35[b]	Top of Casing	NAVD88	333 0	1956	Perforated 0-135, 277-331			D	G, N, D		5-330	5-330	Groundwater well	
299-E24-04	A5898	3	B-B'	A Tank Farm	HT	575112 42	136035 20	USACE(JFCA)	1 43	700 38[b]	Top of Casing	NAVD88	330 0	1956	Perforated 0-135, 272-298	297 20	August-98	D	G, N, D, T		5-305	5-305	Groundwater well	
299-E24-05	A5899	3	B-B'	A Tank Farm	HT	575037 90	136063 46	USACE(JFCA)	1 76	698 55	Ground Surface	NAVD88	329 0	1956	Perforated 0-135, 274-327	298 20	April-02	D	G, N, D, T		5-329	5-329	Groundwater well	
299-E24-13	A4749	4	B-B'	A Tank Farm	HT	575300 61	136037 32	USACE(JFCA)	4 00	694 36	Brass Cap	NAVD88	340 0	1969	Perforated 0-20, 90-260, 270-338	289 10	July-93	D			5-340	5-340	Groundwater well	
299-E24-14	A4750	4		A Tank Farm	DB/HT	575323 85	136018 81	KFH	0 40	694 65	Brass Cap	Converted to NAVD88 from NGVD29	343 0	1969	Perforated: 270-338	289 30	July-93	D			15-300		Groundwater well	
299-E24-19	A4754	2		A Tank Farm	DB/HT	575316 95	136003 51	USACE(JFCA)	2 80	694 44	Brass Cap	NAVD88	303 0	1989	Well screen 279 6-300 7	295 80	March-02	G	G	5 - 265			Groundwater well	
299-E24-20	A4756	3	B-B'	A Tank Farm	DB/HT	575251 10	136049 40	KFH	3 44	689 37	Brass Cap	Converted to NAVD88 from NGVD29	304 0	1991	Well screen 279 2-299 7	291 10	March-02	G	G	5 - 25, 265 - 290			Groundwater well	
299-E25-01	A4759	3	A-A'	A Tank Farm	HT	575336 03	136030 88	USACE(JFCA)	0 33	693 80	Brass Cap	NAVD88	322 0	1955	Perforated 0-20, 90-270	288 50	July-93	D	G		30-322	30-322	Groundwater well	
299-E25-02	A4766	3	E-E'	A Tank Farm	HT	575513 76	136061 87	USACE(JFCA)	2 00	677 02[b]	Top of Casing	NAVD88	375 0	1955	Perforated 0-235, 276-316	277 70	March-02	D	G, T, N, D		5-360	5-330	Groundwater well	
299-E25-04	A4788	5		216-A-8 Crib	HT?	575648 83	136169 12	USACE(JFCA)	2 42	662 71[b]	Top of Casing	NAVD88	289 0	1956	Perforated 239-281	258 80	June-93	D	SG, G, T, N, D				Groundwater well	Two contradictory driller's logs
299-E25-05	A6025	4		216-A-8 Crib	HT?	575681 24	136184 94	USACE(JFCA)		661 5[b]	Top of Casing	NAVD88	293 0	1956	Perforated 235-291			D	G, N, D				Groundwater well	
299-E25-06	A4796	3	B-B'	216-A-8 Crib	HT	575683 76	136163 97	USACE(JFCA)	2 42	662 33	Brass Cap	NAVD88	290 0	1956	Perforated: 234-288	264 40	April-02	D	SG, G, N, D		5-290	5-290	Groundwater well	
299-E25-07	A6026	4	B-B'	AN Tank Farm	HT	575745 61	136197 87	USACE(JFCA)	2 50	660 38[b]	Top of Casing	NAVD88	290 0	1956	Perforated: 235-290			D	G, N, D				Groundwater well	
299-E25-10	A4760	2		A-29 Ditch	HT	575630 06	136267 59	USACE(JFCA)	1 90	657 73	Brass Cap	NAVD88	293 0	1958	Perforated: 226-291	254 90	June-96	D	SP, N, G, T				Groundwater well	
299-E25-13	A4762	3		AX Tank Farm	DB/HT	575362 87	136140 43	USACE(JFCA)	0 33	685 66[b]	Top of Casing	NAVD88	317 0	1963	Perforated: 0-20, 90-236, 256-315	280 30	July-93	D			5-305	5-305	Groundwater well	
299-E25-14	A6029	4			DB/HT	575673 69	136164 47	299E_local		681 52	Top of Casing	Converted to NAVD88 from NGVD29	208 0	1966				D	G, N, D				Vadose-zone monitoring	
299-E25-15	A4763	4		A Tank Farm	DB/HT	575368 82	136018 65	USACE(JFCA)	0 43	692 55[b]	Top of Casing	NAVD88	340 0	1969	Perforated: 0-20, 90-260, 270-338	287 70	June-93	D			5-300		Groundwater well	
299-E25-16	A6030	5		A Tank Farm	CT	575323 66	136018 54	USACE(JFCA)	4 00	694 51	Brass Cap	NAVD88	340 0	1969	Perforated: 270-338			D					Groundwater well	
299-E25-35	A4783	3	A-A'	Grout	DB/HT	575708 34	135864 69	USACE(JFCA)	3 38	674 57	Brass Cap	NAVD88	285 0	1988	Well screen: 260-281			G	G, N, D				Groundwater well	
299-E25-40	A4789	2		AX Tank Farm	DB	575464 68	136212 32	USACE(JFCA)	3 22	666 40	Brass Cap	NAVD88	274 0	1989	Well screen: 252-273	276 50	March-02	G	G	5 - 270			Groundwater well	
299-E25-41	A4790	2	B-B', E-E'	AX Tank Farm	DB/HT	575466 06	136145 93	USACE(JFCA)	3 15	671 72	Brass Cap	NAVD88	279 0	1989	Well screen: 255 3-276 3	267 80	March-02	G	G	5 - 220			Groundwater well	
299-E25-42	A4791	3	A-A', E-E'	AP Tank Farm	DB/HT	575622 80	135887 60	KFH	3 58	679 74	Brass Cap	NAVD88	294 7	1991	Well screen 267 6-288 9	273 30	March-02	G	G				Groundwater well	
299-E25-46	A4793	2	A-A'	A Tank Farm	DB	575359 73	135963 50	USACE(JFCA)	3 01	695 16	Brass Cap	NAVD88	310 3	1992	Well screen 286 0-306 3			G	G	5 - 300			Groundwater well	

Table 2-1. Descriptive Characteristics of Boreholes within 1000 ft of the C and A-AX WMAs. (3 sheets)

Borehole Name	Borehole ID	Quality Rating[1]	Included on Cross Section	Associated Facility	Drill Method[2]	Easting (m)	Northing (m)	Source	Casing Stick Up (ft agl)	Ground-Surface Elevation (ft)	Reference Point	Well Survey	Total Depth (ft)	Year Drilled	Open Interval (ft bgs)	Depth to Water (ft bgs)	Date of Water-Level Measurement	Lithologic Log[3]	Geophysical Log[4]	Moisture Data (Depth Interval in ft)	Particle-Size Distribution (Depth Interval in ft)	Calcium Carbonate (Depth Interval in ft)	Purpose of Borehole	Comments
299-E25-48	A4795	4	E-E'	Grout Treatment Facility	AR/DB	575623 85	135815 69	USACE(JFCA)	2 64	683 05	Brass Cap	NAVD88	287 5	1992	Well screen 274 3-294 6	296 60	March-02	G	SG, Mag				Groundwater well	
299-E25-54	A6043	3		216-A-7 Crib	CT	575512 44	136043 48	USACE(JFCA)	1 33	679 31[b]	Top of Casing	NAVD88	150 0	1955		284 00	March-02	D	SG, N, G				Vadose-zone monitoring	
299-E25-55	A6044	3		A Tank Farm	CT	575369 18	136050 83	USACE(JFCA)		692 14	Brass Cap	NAVD88	151 0	1955				D	G				Vadose-zone monitoring	
299-E25-56	A6045	4		A Tank Farm	CT	575337 65	136066 77	USACE(JFCA)		689 9[b]	Top of Casing	NAVD88	151 0	1955				D	G				Vadose-zone monitoring	
299-E25-57	A6046	3	B-B'	A Tank Farm	CT	575394 96	136101 62	USACE(JFCA)		688 7[b]	Top of Casing	NAVD88	150 0	1955				D	G				Vadose-zone monitoring	
299-E25-58	A6047	3		A Tank Farm	CT	575402 68	136029 42	USACE(JFCA)		691 17	Brass Cap	NAVD88	151 0	1958				D	G				Vadose-zone monitoring	
299-E25-170	A6585	5		A Tank Farm	CT	575667 76	136166 57	USACE(JFCA)					204 0	1966				NA					Vadose-zone monitoring	
299-E26-04	A4804	3	C-C'	216-A-24 Crib	HT	575733 96	136360 88	USACE(JFCA)	2 05	649 50	Brass Cap	NAVD88	283 0	1958	Perforated 225-281	250 20	March-02	D	SG		5-283	5-283	Groundwater well	
299-E26-05	A6641	4	C-C'	216-A-24 Crib	HT	575614 42	136337 77	USACE(JFCA)		651 70	Brass Cap	NAVD88	292 5	1958	Perforated 237-273, 277-290 5	243 50	June-88	D	SG, G, N, D		5-290	5-290	Groundwater well	
299-E26-06	A6642	4	C-C'	AN Tank Farm	HT	575459 84	136397 86	USACE(JFCA)		653 5[b]	Top of Casing	NAVD88	290 0	1960	Perforated 250-290			D			5-290	5-290	Groundwater well	
299-E26-07	A6643	4		216-A-24 Crib	DB/HT	575673 17	136373 30	CONVERTED					245 0	1965	None documented			D	G, N, D				Groundwater well?	
299-E26-08	A4805	3	D-D'	216-B-3-3 Ditch	HT/AR	575522 23	136687 23	USACE(JFCA)	2 70	620 79	Brass Cap	NAVD88	400 0	1982	Well screen. 326-396	222 00	March-02	D	SG, G, T, D, Mag, SP&R, Sonic, Cal				Groundwater well	Monitors Rattlesnake Ridge Interbed
299-E27-02	A6670	4		AN Tank Farm	HT	575254 18	136341 95	CONVERTED		666 30		Reported in as-built	312 0	1948	Perforated 262-313			D, G					Groundwater well	
299-E27-03	A6671	3	C-C'	North of PUREX	HT	575108 94	136284 23	USACE(JFCA)	1 40	684 54	Ground Surface	NAVD88	360 0	1958	Perforated 265-348			D	G, T, N		5-360	5-360	Groundwater well	
299-E27-06	A6673	2	A-A', C-C', E-E'	North of PUREX	DB/DC	575245 07	136332 48	CONVERTED		670 00	Ground Surface	Asbuilt	353 0	1977	Perforated 0-20			D			5-290	5-290	Ringold Characterization	Same as DH-16
299-E27-07	A4816	5		C Tank Farm	HT	575220 59	136619 40	USACE(JFCA)	0 50	636 93	Brass Cap	NAVD88	281 0	1982	Well screen 241-281	237 10	March-02	D					Groundwater well	
299-E27-12	A4810	2		C Tank Farm	DB	575054 14	136583 53	USACE(JFCA)	3 40	661 26	Brass Cap	NAVD88	270 0	1989	Well screen. 246 5-267 6	263 10	March-02	G	G	5 - 258			Groundwater well	
299-E27-13	A4811	2	D-D'	C Tank Farm	DB/HT	575064 92	136489 23	USACE(JFCA)	2 70	669 61	Brass Cap	NAVD88	275 6	1989	Well screen 253 6-274 7	270 90	March-02	G	G	5 - 240			Groundwater well	
299-E27-14	A4812	2	A-A', D-D'	C Tank Farm	DB/HT	575217 34	136498 24	USACE(JFCA)	3 00	658 95	Brass Cap	NAVD88	266 8	1989	Well screen. 245 8-266 8	260 50	March-02	G	G	5 - 240			Groundwater well	
299-E27-15	A4813	2	A-A'	C Tank Farm	DB/HT	575095 26	136630 36	USACE(JFCA)	2 83	653 45	Brass Cap	NAVD88	262 5	1989	Well screen 238-259	255 20	March-02	G	G	5 - 245			Groundwater well	

Table 2-1. Descriptive Characteristics of Boreholes within 1000 ft of the C and A-AX WMAs. (3 sheets)

Borehole Name	Borehole ID	Quality Rating[1]	Included on Cross Section	Associated Facility	Drill Method[2]	Easting (m)	Northing (m)	Source	Casing Stick Up (ft ags)	Ground-Surface Elevation (ft)	Reference Point	Well Survey	Total Depth (ft)	Year Drilled	Open Interval (ft bgs)	Depth to Water (ft bgs)	Date of Water-Level Measurement	Lithologic Log[3]	Geophysical Log[4]	Moisture Data (Depth Interval in ft)	Particle-Size Distribution (Depth Interval in ft)	Calcium Carbonate (Depth Interval in ft)	Purpose of Borehole	Comments
299-E27-51	A6676	4	A-A'	C Tank Farm	CT	575155 58	136568 87	USACE(JFCA)		647 5[a]	Top of Casing	NAVD88	150 0	1944	Perforated 48-148			D	G				Vadose-zone monitoring	
299-E27-52	A6677	4		C Tank Farm	CT	575162 73	136618 71	USACE(JFCA)		646 7[a]	Top of Casing	NAVD88	150 0	1944	Perforated 48-148			D	G				Vadose-zone monitoring	
299-F27-53	A6678	5		C Tank Farm	CT	575093 53	136598 34	USACE(JFCA)					150 0	1944	Perforated 48-148			D					Vadose-zone monitoring	
299-F27-54	A6679	4		C Tank Farm	CT	575204 73	136519 90	USACE(JFCA)					155 0	1944	Perforated 54-154			D	G				Vadose-zone monitoring	
299-F27-55	A6680	4		C Tank Farm	CT	575148 53	136491 34	USACE(JFCA)					154 0	1944	Perforated 53-153			D	G				Vadose-zone monitoring	
299-F27-57	A6682	5		C Tank Farm	CT	575083 31	136555 50	USACE(JFCA)					150 0	1944	Perforated 51-151			D	G				Vadose-zone monitoring	

[1] 1 = best, 5 = worst

[2] CT = cable tool; HT = hard tool; DB = drive barrel; AR = air rotary; DC = diamond core

[3] D = driller's log, G = geologist's log

[4] SP = spontaneous potential, G= natural gamma, N = neutron-neutron, D = density, T = temperature, SG = spectral gamma, mag = Magnetic, Cal = caliper

[a] Stick-up unknown, subtracted 2 ft from top of casing as estimate of ground surface

[b] Ground surface = casing elevation minus stick up

NA = not available **Bold** = hole to top of basalt

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2.2.1 Geomorphology

A-AX and C WMAs lie along Cold Creek bar, a large compound flood bar formed during Pleistocene Ice Age floods (DOE 1988, Wood et al. 2000). The upper surface of the bar in the 200 East Area forms a broad plain extending westward for several miles. The northern boundary of the bar is defined by a series of northwest-southeast trending flood channels. WMA A-AX is near the apex of the bar at an elevation of about 690 ft (210 m) whereas WMA C lies along the gently sloping, north flank of the bar at an elevation of about 650 ft (198 m).

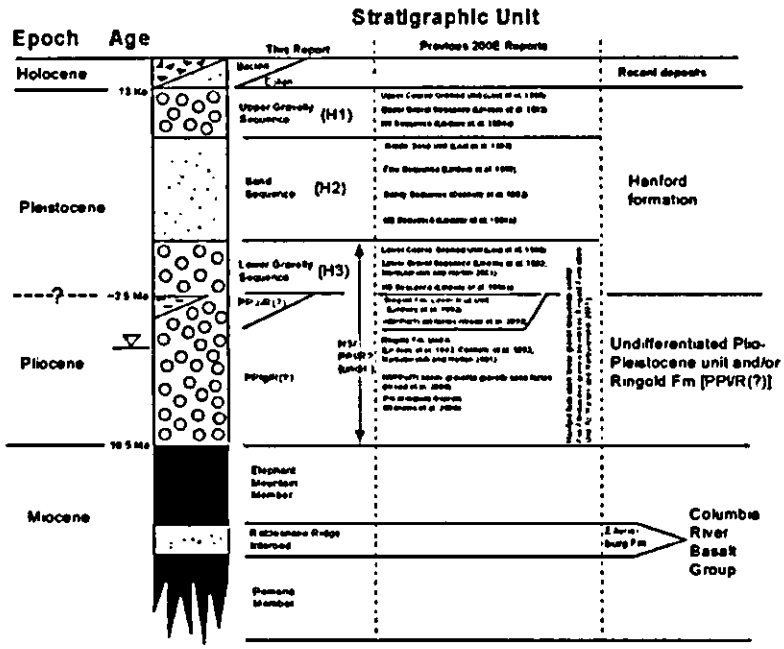
2.2.2 General Stratigraphy

The regional geologic setting of the Pasco Basin and the Hanford Site has been described by *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports* (Delaney et al. 1991), "Geohydrologic Setting of the Hanford Site, South-Central Washington" (Lindsey et al. 1994b), and DOE (1988). *Geology of the Separation Areas, Hanford Site, South-Central Washington* (Tallman et al. 1979) and more recently *Geologic Setting of the 200 East Area: An Update* (Lindsey et al. 1992), *Geologic Setting of the Low-Level Burial Grounds* (Lindsey et al. 1994a), Last et al. (1989), and Williams et al. (2000) described the geology of the 200 East Area. The geology specific to WMA A-AX was first described by Price and Fecht in *Geology of the 241-A Tank Farm* (1976a) and *Geology of the 241-AX Tank Farm* (1976b) followed by *Fate and Transport of Constituents Leaked from Tank 241-A-105* (Caggiano and Goodwin 1991). Most recently, the WMA A-AX geology was summarized in *A Summary and Evaluation of Hanford Site Subsurface Contamination* (Jones et al. 1998), and Narbutovskih and Horton (2001). The geology specific to WMA C was first described in *Geology of the 241-C Tank Farm* (Price and Fecht 1976c) followed by Caggiano and Goodwin (1991). Most recently the WMA C geology was summarized by Jones et al. (1998) and Horton and Narbutovskih (2001).

A total of seven stratigraphic units lie within the A-AX and C Waste Management Areas (Figure 2-2). These units are represented on hydrogeologic cross sections and isopach and structure-contour maps (Appendix C):

- Recent deposits
- Hanford formation - upper gravelly sequence (H1 unit)
- Hanford formation – sand sequence (H2 unit)
- Hanford formation - lower gravelly sequence (H3 unit)
- Undifferentiated Plio-Pleistocene silt (PPlz) and/or Ringold Formation mud? [PPlz/(R)?]
- Undifferentiated Plio-Pleistocene unit gravel (PPlg) and/or Ringold Formation UnitA? [PPlg/(R)?]
- Columbia River Basalt Group .

Figure 2-2. Stratigraphic Units.



A-AX and C WMAs were constructed in the near-surface sediments that overlie the Columbia River Basalt Group (i.e., bedrock) on the north limb of the Cold Creek syncline. The oldest suprabasalt sediments in the vicinity of A-AX and C WMAs include, (1) a gravelly sequence belonging to undifferentiated Ringold Formation member of Wooded Island (Unit A) and/or younger fluvial gravel facies of the Plio-Pleistocene unit (PPlg), referred to in this report as PPlg/R(?), overlain by (2) undifferentiated Ringold Formation mud and/or Plio-Pleistocene silt (PPlz), abbreviated here as PPlz/R(?). These deposits predate Pleistocene cataclysmic flooding, which blanketed the area with mostly coarse sand and gravel. Cataclysmic flood deposits, collectively referred to as the Hanford formation, include a lower and upper gravelly sequence, separated by a sand-dominated sequence in the study area. Recent deposits of eolian silty sand and man-made backfill locally overlie flood deposits.

The thickness of the vadose zone beneath the study area ranges from 235 ft (72 m) in the vicinity of WMA C to 295 ft (90 m) around WMA A-AX (Narbutovskih and Horton 2001; Horton and Narbutovskih 2001). The unconfined aquifer is relatively thin (60-90 ft [18-27 m]) and resides mostly within the undifferentiated Plio-Pleistocene gravels/Ringold Formation Unit A sequence (see Appendix C).

2.2.3 Methodology

The sources of available geologic data, the quality of these data, and how they are used to develop the conceptual geohydrologic model for C and A-AX WMAs are described in the following paragraphs. The quality of data available from the boreholes varies considerably depending on when the boreholes were drilled, the drill method(s) used, and intended purpose of the borehole.

2.2.3.1 Data Sources. Borehole data consisting of driller's logs, geologist's logs, archived samples, and geophysical logs, as well as limited laboratory characterization data (grain-size distribution, $CaCO_3$, and moisture content), are the principal data sets used to interpret subsurface geology. In addition, numerous reports describing the geology of the area create the foundation from which the model has evolved (e.g. Tallman et al. 1979; DOE 1988; Last et al. 1989; Lindsey et al. 1992, Connelly et al. 1992, Horton and Narbutovskih 2001, and Narbutovskih and Horton 2001). A summary of the types of data available for the 49 boreholes within 1000 ft (300 m) of A-AX and C WMAs is presented in Table 2-1. Interpretations in this report are biased in favor of the higher-quality boreholes, which have one or more of the following characteristics: 1) recent installation, 2) available geologist logs, 3) available geophysical logs, and 4) available moisture, grain-size, and other characterization data.

Initially, well-site geologists' logs or drillers' logs were examined and compared to geophysical logs from boreholes. The quality of drilling logs differs because many wells and boreholes were drilled without a geologist present at the site; this is generally true for all boreholes drilled prior to the mid-1980's. Up until that time, driller's would collect sediment samples every 5 ft (1.5 m) and provide general descriptions of the formation materials and problems encountered during drilling. Most of the archived sediment samples from these early (pre-1980) borings were subsequently analyzed in the laboratory for grain-size distribution and $CaCO_3$ content; these results reside in a database called ROCSAN, which is available but no longer maintained. For this study, grain-size distribution and wt% $CaCO_3$ plots were generated after manually reentering the data into EXCEL spreadsheets from ROCSAN printouts.

The quality of the grain-size distribution data largely depends on the drill method used. Most boreholes were drilled via the percussion cable-tool method, either with a hard tool or with a drive barrel. Those intervals drilled with a hard tool tend to produce more fines because of the pulverizing action of the solid hard-tool bit. The drive-barrel, on the other hand, better preserves the original grain-size distribution, but also can result in some pulverization. The suprabasalt sediments in only two boreholes within the study area were drilled by alternative methods (Table 2-1). Borehole 299-E25-48 was drilled using the air rotary method, which also has a pulverizing effect, and borehole 299-E27-6 (DH-16) was drilled via diamond core below the 100 ft depth (Webster 1977). Of all the methods, diamond core produces the best-quality samples from which to evaluate the subsurface geology.

Beginning in the mid-1980's, geologists were assigned the responsibility for providing lithologic descriptions during drilling and samples were no longer routinely analyzed in the laboratory. Therefore, most boreholes drilled after the mid-1980's were not analyzed quantitatively in the laboratory for grain-size distribution and wt% $CaCO_3$; qualitative estimates of these parameters were provided on geologists logs, however.

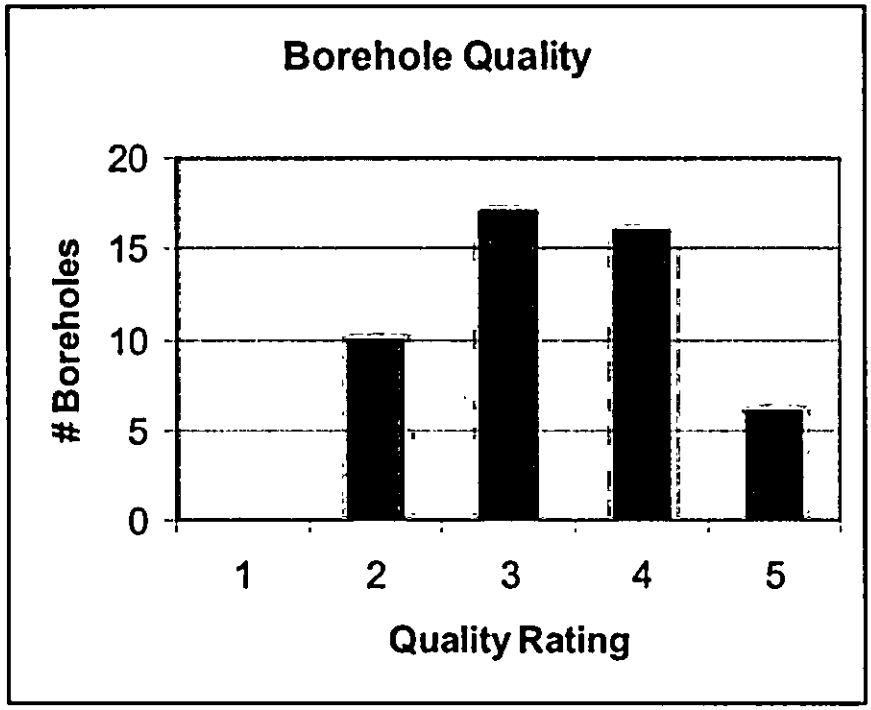
Geophysical logs (e.g., gross-gamma ray), available for most of the boreholes, differ in quality but are useful for identifying some, but not all, stratigraphic contacts. Geophysical logs sometimes show lithologic differences because of differing amounts of natural gamma-ray emitters (most commonly ^{40}K). The proportion of ^{40}K generally increases with decreasing grain size. The gross-gamma log is often more useful than physical samples for accurately determining

the depths of fine-grained layers, especially those more than about 3 ft (1 meter) thick. However, very thin clay and/or silt layers commonly go undetected on gross gamma logs.

When available, the neutron-moisture log is useful for identifying zones of higher moisture, which are often associated with capillary boundaries including fine-grained intervals. Within the vadose zone, moisture content frequently increases along sedimentary interfaces between materials with contrasting grain size or lithology. Other geophysical logs listed in Table 2-1 (e.g., density, temperature, magnetic, caliper) have not proven particularly useful for stratigraphic interpretation.

2.2.3.2 Development of Geohydrologic Model. The process of building the physical geohydrologic model followed a series of investigative steps that were designed to honor the data and give preferential treatment to the boreholes with the highest quality data available. Boreholes near the C and A-AX WMAs are rated in Table 2-1 according to the quality of data and degree of certainty in the interpretation of the geology of the borehole. The rating scale ranges 1 to 5 (Figure 2-3), with boreholes rated #1 having the highest confidence in the geologic interpretation. Those boreholes rated #5 (least confidence and highest uncertainty) are associated with those boreholes with only a driller's log available. None of the 49 boreholes within 1000 ft (300 m) of the C and A-AX WMAs (Table 2-1) are rated #1, as none of the holes have a complete set of high-quality characterization data. Boreholes rated #1 are those with a complete geologist's log accompanied by a gross-gamma and moisture logs, as well as grain-size, $CaCO_3$, and/or other characterization data. Only 10 boreholes are rated #2 (Figure 2-3). Number 2 rated boreholes have a geologists log, accompanied by a gamma log and either a neutron-moisture log, or laboratory measurements of moisture, grain size, and/or $CaCO_3$. The majority of the boreholes in the study area has limited data sets (drillers log only, perhaps with a gamma log and/or grain size/$CaCO_3$ data) and therefore has a quality rating of only 3 or 4. Six of the boreholes are rated #5 (no useful geologic information or questionable drillers log only) and thus of no use for geologic interpretation.

Figure 2-3. Quality Rating for 49 Boreholes within 1000 ft (300 m) of the C and A-AX WMAs. Boreholes rated #1 provide the highest quality geologic information while those rated #5 provide the lowest quality.



Five cross sections were constructed in the study area that included as many higher-quality boreholes (rating =2 or 3) that best represented the study area and especially the tank farms. These cross sections, located on Figure 2-4, are presented in Appendix C. Stratigraphic contacts for the various units and facies were identified on these cross sections. Elevations and thicknesses for the seven major stratigraphic units (Figure 2-2) were calculated and plotted onto structure-contour and isopach maps, as a way to determine if the contacts are realistic and make sense geologically. If the interpreted depths of contacts are chosen correctly, the data should plot as relatively smooth surfaces transitioning from one borehole to another. Isolated, large, steep-gradient "bull's eyes" on contour maps indicate that the contact may be mislocated; in those cases the interpreted stratigraphic contact would be reevaluated and adjusted as necessary. Final picks for stratigraphic units are presented in Table 2-2 and the final isopach and structure-contour maps are presented in Appendix C.

Figure 2-4. Cross Section Location Map.

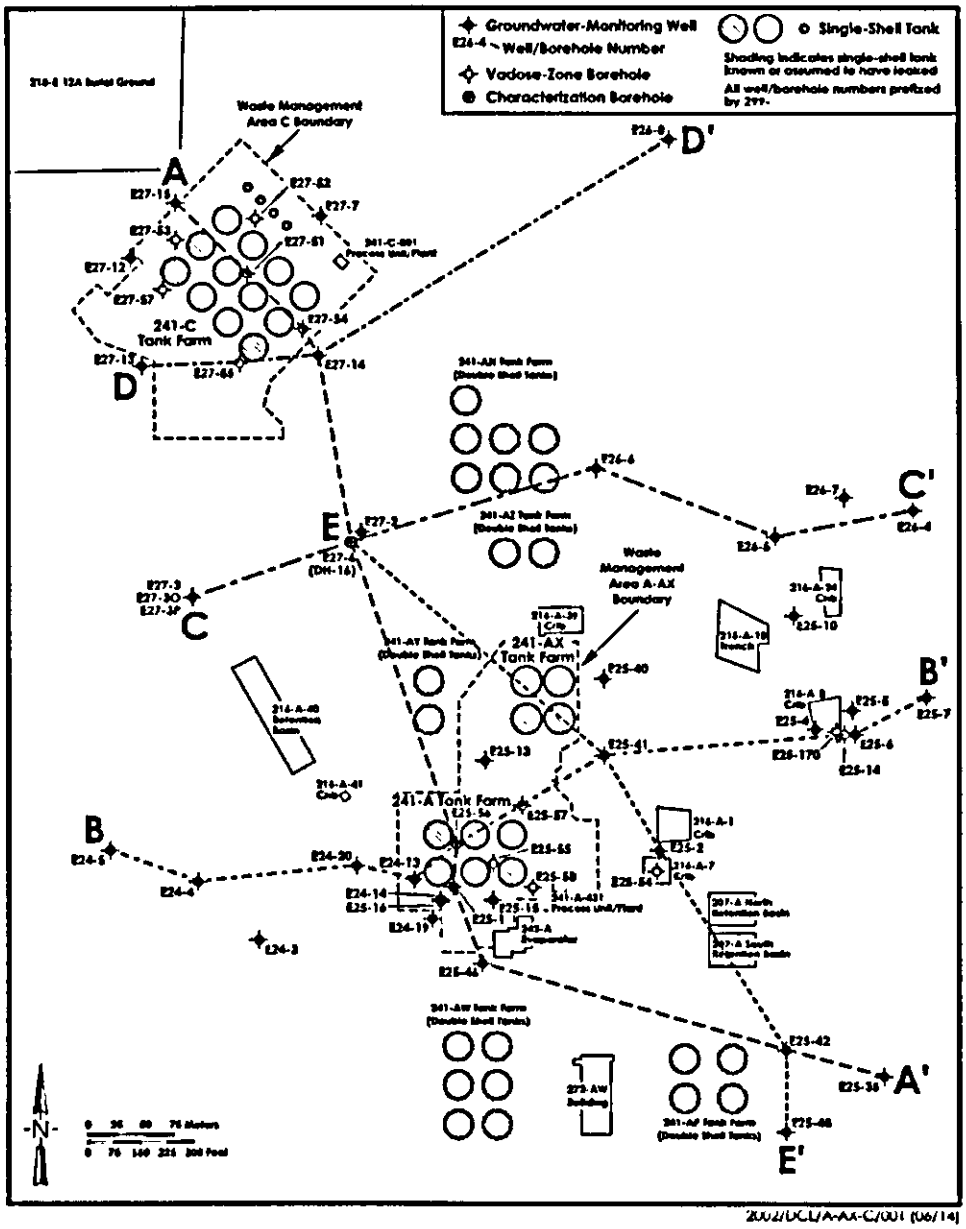


Table 2-2. Stratigraphic Contacts for Boreholes within 1000 ft of WMA (2 sheets).

Borehole Name	Quality Rating[1]	Ground-Surface Elevation (ft amsl)	Total Depth (ft)	TOB	Top of PPlg/R?	Top of PPlz/R(?)	Top of H3	Top of H2	Top of H1	TOB	Top of PPlg/R?	Top of PPlz/R(?)	Top of H3	Top of H2	Top of H1	PPlg/R(?)	PPlz/R(?)	H3	H2	H1	Recent Deposits (Type[2])
299-E24-03	3	700 35	333 0		?	NP?	NP?	107	0		?	NP?	NP?	593	700		NP?	NP?	?	107	
299-E24-04	3	700 38	330 0		?	NP?	NP?	70	15		?	NP?	NP?	630	685		NP?	NP?	?	55	15 (BF)
299-E24-05	3	698 55	329 0		?	NP?	NP?	8	NP		?	NP?	NP?	691	NP		NP?	NP?	?	NP	8 (E)
299-E24-13	4	694 36	340 0		287	263	NP	120	10		407	431	NP	574	684		24	NP	143	110	10 (BF)
299-E24-14	4	694 65	343 0		290	275	NP	60	0		405	420	NP	635	695		15	NP	205	60	
299-E24-19	2	694 44	303 0		285	277	NP	125	10		409	417	NP	569	684		8	NP	152	115	10 (F)
299-E24-20	3	689 37	304 0		280	275	NP	115	0		409	414	NP	574	689		5	NP	160	115	
299-E25-01	3	693 80	322 0		280	265	NP	125	20		414	429	NP	569	674		15	NP	140	105	20 (BF)
299-E25-02	3	677 02	375 0	356	265	255	205	118	15	321	412	422	472	559	NP	91	10	50	137	103	15 (E)
299-E25-04	5	662.71	289 0																		
299-E25-05	4	661 50	293 0																		
299-E25-06	3	662.33	290 0		270	264	170	28	5		392	398	492	634	667		6	94	142	23	5 (E)
299-E25-07	4	660 38	290 0		?	?	180	0	NP		?	?	480	660	NP			?	180	NP	
299-E25-10	2	657.73	293 0																		
299-E25-13	3	685 66	317 0		280	256	NP	65	20		406	430	NP	621	666		24	NP	191	45	20 (E)
299-E25-14	4	683 52	208 0				205	120	0				479	564	684				145	120	
299-E25-15	4	692 55	340 0		284	275	NP	80	0		409	418	NP	613	693		9	NP	195	80	
299-E25-16	5	694 51	340 0		286	265	NP	60	0		409	430	NP	635	695		21	NP	205	60	
299-E25-35	3	674 57	285 0		270	257	210	75	8		405	418	465	600	667		13	47	135	67	8 (E)
299-E25-40	2	666 40	274 0		257	248	195	100	0		409	418	471	566	666		9	53	95	100	
299-E25-41	2	671.72	279 0		270	253	195	100	0		402	419	477	544	672		17	58	95	100	
299-E25-42	3	679.74	294 7		255	246	220	80	20		425	434	460	600	660		9	26	140	60	20 (BF)
299-E25-46	2	695 16	310 3		278 5	273	NP	80	7		417	422	NP	615	688		6	NP	193	73	7 (E)
299-E25-48	4	683 05	287 5		280	266 5	NP	86	20		403	417	NP	597	663		14	NP	181	66	20 (E)
299-E25-54	3	679 31	150 0																		
299-E25-55	3	692.14	151 0					100	20					592	672					80	20 (BF)
299-E25-56	4	689 90	151 0					85	50					605	640					35	50 (BF)
299-E25-57	3	688 70	150 0					120	50					569	639					70	50 (BF)

Table 2-2. Stratigraphic Contacts for Boreholes within 1000 ft of WMA (2 sheets).

Borehole Name	Quality Rating[1]	Ground-Surface Elevation (ft amsl)	Total Depth (ft)	TOB	Top of PPfg/R?	Top of PPfz/R(?)	Top of H3	Top of H2	Top of H1	TOB	Top of PPfg/R?	Top of PPfz/R(?)	Top of H3	Top of H2	Top of H1	PPfg/R(?)	PPfz/R(?)	H3	H2	H1	Recent Deposits (Type[2])
299-P25-58	3	691.17	151.0					122	30					569	661					92	30 (BF)
299-P25-170	5		204.0																		
299-P26-04	3	649.50	283.0		230	220	180	0	NP		420	430	470	650	NP		10	40	180	NP	
299-P26-05	4	651.70	292.5		?	?	190	8	NP		?	?	462	644	NP			?	182	NP	8 (E)
299-P26-06	4	653.50	290.0		247	243	NP	60	16		407	411	NP	594	638		4	NP	183	44	16 (E)
299-P26-07	4		245.0				176	14	0						0						
299-P26-08	3	620.79	400.0	250	NP	NP	136	10	NP	371	NP	NP	485	611	NP			?	126	NP	10 (E)
299-P27-02	4	666.30	312.0		263	255	NP	50	0		403	411	NP	616	666		8	NP	205	50	
299-P27-03	3	684.54	360.0	349	?	NP?	255	35	10	336	?	NP?	430	650	675			?	220	25	10 (E)
299-P27-06	2	670.00	353.0	343	266	257	NP	85	10	327	404	413	NP	585	660	77	9	NP	172	75	10 (E)
299-P27-07	5	636.93	281.0		?	?	210						427						?		
299-P27-12	2	661.26	270.0		?	NP	230	35	5		?	NP	431	626	656				195	30	5 (E)
299-P27-13	2	669.61	275.6		?	NP	240	40	0		?	NP	430	630	670				200	40	
299-P27-14	2	658.95	266.8		?	NP	230	40	10		?	NP	429	619	649				190	30	10 (E)
299-P27-15	2	653.45	262.5		?	NP	230	20	10		?	NP	423	613	643				190	30	10 (E)
299-P27-51	4	647.50	150.0																		
299-P27-52	4	646.70	150.0																		
299-P27-53	5		150.0																		
299-P27-54	4		155.0																		
299-P27-55	4		154.0																		
299-P27-57	5		150.0																		

[1] 1 = best, 5 = worst

[2] BF = backfill, E = eolian

NP = not present

2.2.4 Uncertainty

Sources of uncertainty for location of contacts between stratigraphic units in boreholes and correlations between boreholes include:

- Borehole-Related Uncertainty. This includes the drilling method, source and quality of the borehole and geophysical logs, and borehole spacing;

- Sampling-Related Uncertainty. This includes the method of drilling and sampling, sampling frequency, and bias induced by the sampling techniques;

- Geologic-Related Uncertainty. This includes the three-dimensional shape of the sedimentary features, lateral facies changes in relative proportion of sand, silt and gravel, and bed-form properties of the sediment layers.

2.2.4.1 Borehole-Related Uncertainty. Most boreholes near A-AX and C WMAs have been drilled using cable-tool percussion techniques. Cable tool drilling has been the standard technique from earliest drilling at Hanford because of its effectiveness at penetrating loose, gravelly sediments. Cable-tooled boreholes are advanced via a drive barrel or hard tool while driving a temporary string of welded casing. The technique generally provides good sample control and has proven successful, especially in the unconsolidated gravel-dominated facies of the Hanford formation. There are several disadvantages to cable tool technique, however. These include:

- Limited sample size;

- Samples can be difficult to retain in the drive barrel, in the vadose zone. Often, water must be added to give the sample cohesive strength so that it will stay in the drive barrel.

- Gravels are not easily retrieved because they are not easily retained in the drive barrel;

- The depth of the sample is difficult to control.

- Cemented units or zones with large gravel clasts must be drilled with a "hard tool" which pulverizes the material and alters the grain-size distribution of the recovered samples. Pulverization occurs to a lesser degree with the drive barrel.

Most boreholes drilled prior to the 1980s were drilled without a well-site geologist to log the samples. Thus, the only records of early drilling are driller's logs that vary in the quality of the sample description. The quality of the geologist's logs also varies from borehole to borehole because of different procedures being used as well as variable experience and expertise between geologists.

Many boreholes were completed without the benefit of being geophysically logged. Geophysical logging is sometimes a useful tool for determining the depth of lithologic changes. Finally,

borehole coverage is usually dictated by factors other than addressing geologic questions. Therefore, the spacing and distribution of boreholes is often inadequate to confidently address geologic problems.

2.2.4.2 Sampling-Related Uncertainty. The type and quantity of data collected varies substantially from one borehole to another, which adds uncertainty and complicates stratigraphic correlations based on different data sets of different data quality. Sample collection in the unconsolidated vadose-zone formations (i.e., Hanford formation) is often challenging because the samples are typically dry and are not easily retained in the drive barrel.

The most-important factor affecting quality of the geologic data is the borehole log. Prior to 1980 geologists were generally not present during drilling activities at the Hanford Site. Most often, drillers were the only personnel on site, which meant they were responsible for sample collection (one lithologic sample collected into a glass jar every 5 ft), completion of borehole log, and drilling of the hole. Because of widely different experience and backgrounds, and lack of training in geologic descriptions, the quality of drillers logs is variable and geologically inconsistent. The quality and consistency of borehole logs improved significantly in the 1980's when the responsibility for geologic logging and sampling of the boreholes shifted to geologists.

The quality of the geophysical logging (i.e., gross-gamma log) has also varied over the years. Earlier logs were often uncalibrated to a standard and/or run at rapid rates, which adversely affected data quality. However, the older logs are still useful for qualitative comparison and definition of lithologic contacts.

2.2.4.3 Geologic-Related Uncertainty. In addition to the uncertainty in borehole data, there is uncertainty in the geometric shape and distribution of sediment bodies. Because of the scale and dynamic nature of the cataclysmic flooding that produced the Hanford formation, very few analogs are available to compare the geologic model at the C and A-AX WMAs to an analog field locality. Nearby surface excavations, such the 218-E-12B Burial Ground, in the northeast 200 East Area provide valuable information on the types and scales of natural heterogeneity within the Hanford formation, which cannot be interpreted from boreholes alone (Wood et al. 2000).

2.2.5 Columbia River Basalt Group

The Columbia River Basalt Group (CRBG) forms the bedrock base of the unconfined aquifer under the C and A-AX WMAs. Sedimentary interbeds between CRBG flows belong to the Ellensburg Formation (Figure 2-2). The Elephant Mountain Member of the Saddle Mountains Basalt formation is a medium to fine-grained tholeiitic basalt with abundant microphenocrysts of plagioclase (DOE 1988). The Elephant Mountain Member has been dated by the K/Ar method at 10.5 Ma (McKee et al. 1977) and consists of two flows beneath the 200 East Area. The Elephant Mountain Member represents the youngest basalt flows in the study area; the top of the member lies at depths between 250-360 ft (75-110 m) bgs within the study area. The top of basalt dips south toward the axis of the Cold Creek syncline (Connelly et al. 1992). Up to 50 ft (15 m) of topographic relief (Figure C-6) exists on the basalt surface as a result of tectonic deformation

and/or erosion. In general, upper lava flows of the CRBG, as well as the Ellensburg Formation and overlying suprabasalt sediments, thicken to the south toward the axis of the Cold Creek syncline (DOE 1988).

Only four boreholes (299-E25-2, -E26-8, -E27-3, and -E27-6) within the study area extend to the top of basalt. One borehole (299-E26-8) fully penetrated the Elephant Mountain Member and advanced through the first sedimentary interbed (Rattlesnake Ridge) into the underlying Pomona Member of the CRBG (Figure C-4). In this borehole, the Elephant Mountain Member and the Rattlesnake Ridge Interbed were 90 ft (27 m) and 50 ft (15 m) thick, respectively.

2.2.6 Undifferentiated Plio-Pleistocene Unit/Ringold Formation

Where not eroded away, the Ringold Formation overlies Columbia River basalt in the central Pasco Basin (DOE 1988). The Ringold Formation in this area consists of multilithic, clast-supported to matrix-supported, variably cemented and/or limonitic-stained, sandy gravel sequences. Ringold Formation gravel sequences are occasionally separated by thinner sequences of horizontally laminated, ripple laminated and/or massive, locally calcareous sand, silt, and clay in various shades of blue, olive, gray, and brown (Lindsey 1995). Sands are generally well-sorted and predominantly quartzo-feldspathic (i.e., light colored). The gravels represent fluvial channel-fill and braidplain deposits while intervening, fine-grained deposits are interpreted as lacustrine and/or fluvial overbank-paleosol deposits.

At present it is uncertain how much, if any, of the Ringold Formation is present beneath the C and A-AX WMAs. This area lies at or near the axis of a paleochannel that removed most or all of the Ringold Formation from the northern half of the 200 East Area (Williams et al. 2000). Thus, most or all the Ringold Formation may have been removed from beneath the study area, either by fluvial processes that postdate the Ringold Formation and/or by Ice Age cataclysmic flooding. Some previous workers, however, include erosional remnants of the Ringold Formation beneath the A-AX and C WMAs (Lindsey et al. 1992, Connelly et al. 1992, Narbutovskih and Horton 2001).

The southeast-trending paleochannel underlying WMAs A-AX and C postdates regional incision of the Ringold Formation and marks the path of the ancestral Columbia River as it flowed through a topographic low at Gable Gap starting sometime after 3.4 Ma (Fecht et al. 1987). The shift of the Columbia River to its present path along the north side of Gable Mountain probably occurred at the onset of the Ice Age and associated cataclysmic flooding. These floods, which began about the beginning of the Pleistocene Epoch 1.5 to 2.5 million years ago as documented in "Long History of Pre-Wisconsin, Ice Age Cataclysmic Floods: Evidence from Southeastern Washington State (Bjornstad et al. 2001), led to further erosion as well as development and progradation of flood bars over the former course of the river. Prior to the Ice Age floods, however, there was a 1-2 million-year period where "normal" fluvial processes might have occurred within the central basin where the ancestral Columbia River continued to flow through Gable Gap and to the southeast. It is during this period that the Plio-Pleistocene unit deposits developed locally, either on the eroded Ringold Formation or directly on top of basalt bedrock within the study area.

Similar to the Ringold Formation, Plio-Pleistocene unit deposits in the central basin consist of multilithic, clast-supported sandy gravel. These deposits, previously referred to as Pre-Missoula Gravels in *Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report* (PSPL 1982) and Lindsey (1995), have more recently been included as a mainstream-alluvial facies of the Plio-Pleistocene unit (Lindsey et al. 1994b). Unlike the Ringold Formation, mainstream facies of the Plio-Pleistocene unit are generally unconsolidated, have a "whitish" or "bleached" appearance and lack limonitic staining, characteristic of the Ringold Formation. Because mainstream facies of the Plio-Pleistocene unit consists of essentially reworked fluvial sands and gravels of the Ringold Formation, it is often difficult to distinguish the two units from one another.

Another facies of the Plio-Pleistocene unit beneath the 200 East Area consists of a well-sorted silt to fine sand, which is locally up to 35 ft (10.5 m) thick beneath the B Tank Farm (Wood et al. 2000). The thickness of this unit, referred to as the Hf/PPu(?) silt by Wood et al. (2000), appears be too great for the Hanford formation and thus is probably entirely of Plio-Pleistocene age. A fine-grained layer, at about the same relative depth, is also present beneath most of WMA A-AX. The fine-grained layer is discontinuous, however, between this area and northern portion of the 200 East Area as it is missing beneath WMA C. Some of the sample descriptions of the fine-grained unit from WMA A-AX are more like those for the lacustrine/overbank/paleosol facies of the Ringold Formation (i.e., gray-, blue-, or green clay). In other boreholes, however, sample descriptions are more like those for the Plio-Pleistocene silty facies (brown silt to fine sand) (Figure 2-5). Therefore, it is uncertain at this time as to whether this fine-grained unit beneath WMA A-AX represents fine-grained facies of the Ringold Formation or Plio-Pleistocene unit, or both.

Where present, the top of the fine-grained unit, near the 250 ft (75 m) depth, defines the top of the undifferentiated Plio-Pleistocene silt/Ringold Formation mud unit (PPlz/R(?)) and the base of overlying flood deposits of the Hanford formation. Below the PPlz/R(?) unit is an undifferentiated sequence of Plio-Pleistocene gravel and/or Ringold Formation Unit A, designated PPlg/R(?). Where the fine-grained layer is missing, (e.g., beneath WMA C) it is not possible to differentiate between similar, coarse-grained facies of the Ringold Formation, Plio-Pleistocene unit, and flood gravels of the Hanford formation with the information available.

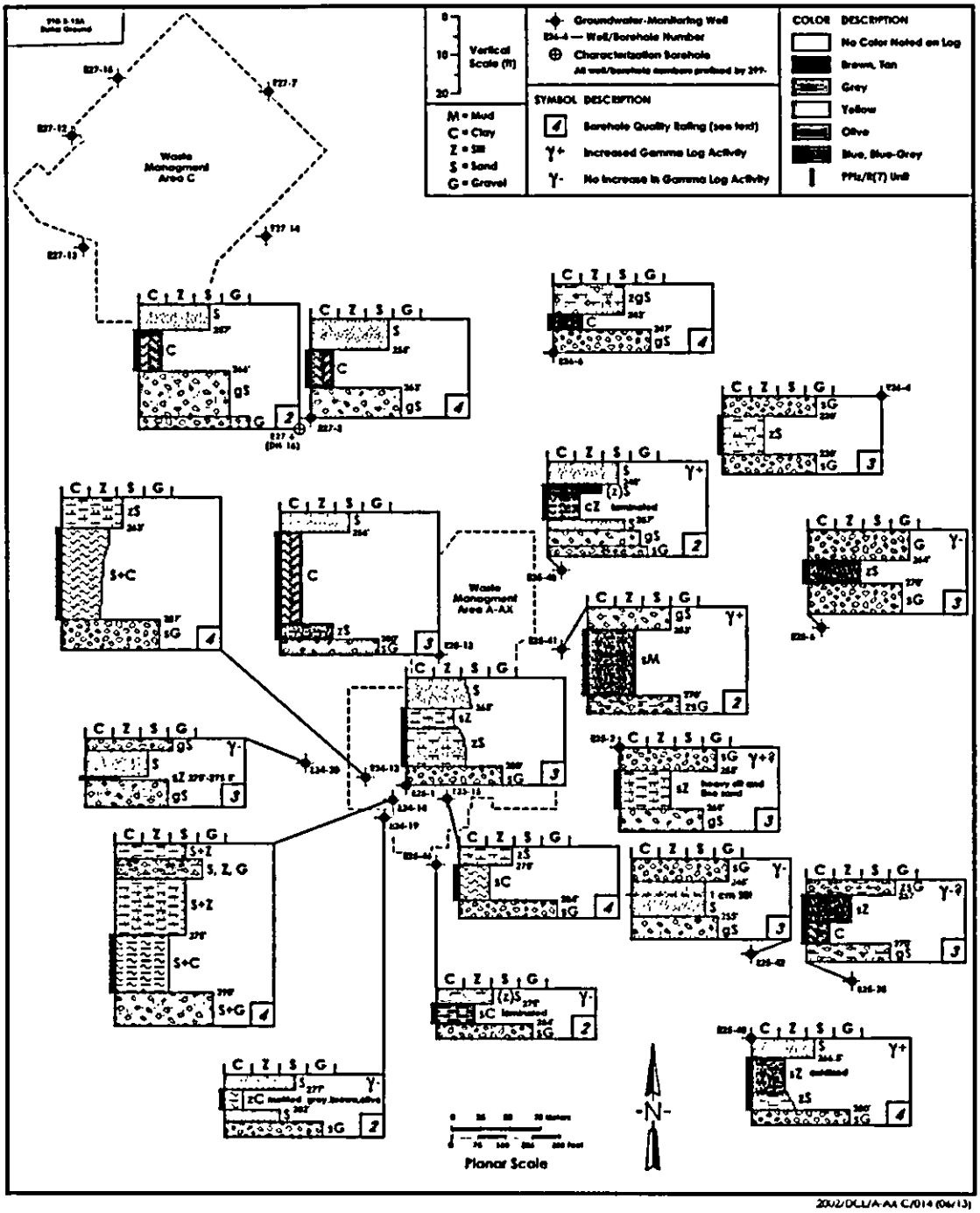
While these units have similar lithologic characteristics, their transport properties are believed to be very different. Whether this gravel sequence is Ringold, Plio-Pleistocene unit, and/or Hanford formation has important implications for the permeability and flow rate of groundwater in the unconfined aquifer. Overall, Hanford formation gravels are significantly (10 to 100 times) more permeable than gravel sequences in the Ringold Formation. Plio-Pleistocene-age gravels are probably intermediate between the Ringold and Hanford formations. The differences in permeability are attributed mainly to the higher degree weathering and matrix cementation and induration common in the Ringold sediments (Wurstner et al. 1995).

2.2.6.1 Undifferentiated Plio-Pleistocene Unit Gravel and/or Ringold Formation Unit A [PPlg/R(?)]. Gravelly facies immediately overlying basalt within the study area belong to either the Ringold Formation Unit A and/or the Plio-Pleistocene unit. An exception is to the northeast near borehole 299-E26-8 (Figure C-4), where the top of basalt rises above the depth of

post-Ringold-age scouring by Ice Age floods. It is probable that the PPLg/R(?) unit was completely removed during flooding so that flood deposits of the Hanford formation lie directly on top of basalt bedrock.

The PPLg/R(?) unit consists of predominantly sandy pebble- to cobble-sized gravel with occasional boulders. As a whole the unit shares characteristics of both coarse-grained facies of the Ringold Formation and the Plio-Pleistocene unit. In some boreholes the unit is described as tight, cemented, and brown colored with oxide coatings (characteristics of the Ringold Formation), whereas other boring logs describe the unit as loose, caving to heaving, losing water, gray colored, and clean/unweathered (more characteristic of the Plio-Pleistocene unit). Mineralogically, the sand fraction consists of 15-60% basalt grains with generally less than 1 wt% $CaCO_3$. The total thickness of this unit is $\leq$90 ft (27 m), based on a limited number of boreholes where the upper and lower boundaries are represented. The top of PPLg/R(?) unit ranges from about 390-425 ft (120-130 m) elevation amsl (Figure C-7).

Figure 2-5. Heterogeneity within the Undifferentiated Plio-Plestocene Silt/Ringold Formation Mud? [PPlz/R(?)] Unit at Boreholes near the C and A-AX WMAs.



2.2.6.2 Undifferentiated Plio-Pleistocene Silt and/or Ringold Formation Mud? [PPlz/R(?)]. A fine-grained unit, occurring at a depth of about 250 ft (75 m), is described for most boreholes beneath WMA A-AX (Figure 2-5). The fine-grained unit is described on borehole logs of cuttings and samples as clay, silt, sandy silt, and/or silty sand. Some gross gamma-ray logs show a reported increase in activity occasionally accompanied by an increase in moisture. No perched water was noted on top of the sequence (Caggiano and Goodwin 1991), but the water table was higher in the past. Thus, the increased moisture content may be a remnant of a higher water table.

The PPlz/R(?) unit is thickest (up to 24 ft [7.3 m]) near WMA A -AX (Figure C-8). This unit disappears to the north and is absent beneath the WMA C. Descriptions of this unit on drilling and geologic logs vary significantly (Figure 2-5), which may be due to: 1) different subjective descriptions/interpretations by different drillers and geologists, 2) heterogeneities within the unit, which may include multiple lithologic units (e.g., Plio-Pleistocene unit silts overlying Ringold Formation muds), or 3) a combination of these. Where present, this fine-grained unit is described in about half the boreholes as a blue-, gray- or olive-colored clay or mud; remaining boreholes describe the unit as a tan to brown sandy silt to "heavy" silt, which may display a laminated to mottled structure. The former description fits that of Ringold Formation paleosol facies (DOE 1988), whereas the latter fits descriptions for the Plio-Pleistocene silt facies (Wood et al. 2000), interpreted as eolian-overbank in origin. Unlike most other fine-grained units in the 200 Areas, the PPlz/R(?) unit is generally noncalcareous, containing only a few weight percent or less $CaCO_3$.

The top of the PPlz/R(?) unit ranges from about 400-435 ft elevation (Figure C-9). The top of the PPlz/R(?) unit was probably scoured and eroded during Ice Age flooding as suggested by a southeast-trending trough present at the top of this unit. The PPlz/R(?) unit may have extended further north prior to flooding but was subsequently removed during Ice Age flooding near WMA C.

2.2.7 Hanford Formation

The Hanford formation (informal name) overlies the Ringold Formation and consists of glaciofluvial sediments deposited by Ice Age cataclysmic floods from glacial Lake Missoula, pluvial Lake Bonneville, and perhaps other ice-margin lakes. Cataclysmic floods were released during major glacial events that occurred during the Pleistocene starting as early as 1.5 to 2.5 Ma (Bjornstad et al. 2001). The Hanford formation consists of pebble- to boulder-size gravel, fine- to coarse-grained sand, and silt (Baker et al. 1991). These deposits are generally divided into three facies associations: 1) gravel-dominated, 2) sand-dominated, and 3) interbedded sand and silt-dominated. The Hanford formation is present throughout the Hanford Site below elevations of about 1000 ft (300 m). The Hanford formation reaches its maximum thickness of 300 ft (100 m) between the 200 East and 200 West Areas beneath the Cold Creek flood bar.

1. GRAVEL-DOMINATED FACIES. This facies generally consists of poorly sorted mixtures of pebble to boulder gravel, fine- to coarse-grained basaltic sand, with variable amounts of silt. Gravel-dominated facies may display massive bedding, horizontal to low-angle bedding,

and/or large-scale, planar-tabular cross bedding in outcrop, as well as scour-and-fill channels. An open-framework fabric is also observed in outcrop, characterized by clast-supported basalt-rich gravel without little or no matrix-filling sand/silt. Discontinuous sand and silt beds may be interbedded throughout sequences of gravel-dominated facies. Gravel clasts are dominantly basalt with lesser amounts of reworked, Ringold Formation clasts such as granite, quartzite, and gneiss (Lindsey 1992). The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main cataclysmic flood channels (Baker et al. 1991).

2. SAND-DOMINATED FACIES. This facies consists of fine- to coarse-grained sand and pebbly gravel. The sands typically display a high basalt content (30-70%) with color commonly described as black, gray, or "salt-and-pepper" like. Sand-dominated facies may contain isolated matrix-supported pebbles and rip-up clasts, as well as discontinuous beds of pebble-gravel and/or silty interbeds generally less than 3 ft (1 m) meter thick. The silt content of the sands is variable, but when low, the sands are clean and well sorted. In outcrop this facies commonly displays horizontal to subhorizontal lamination and bedding. The sand-dominated facies was deposited adjacent to main flood channels during the waning stages of flooding (Baker et al. 1991). The facies is transitional between the gravel-dominated and the interbedded sand and silt-dominated facies associations.

3. INTERBEDDED SAND AND SILT-DOMINATED FACIES. This facies consists of thin-beds of interbedded, horizontal- to ripple cross-laminated fine- to coarse-grained sand and silt. Beds are typically a meter or less thick and commonly display normally graded-bedding. Unlike the other facies associations, in outcrop, individual "rhythmite" beds may be traced laterally for hundreds of meters or more. Sediments of this facies were deposited under slack-water conditions and in back-flooded areas during cataclysmic flooding (DOE 1988; Baker et al. 1991). This facies association is generally absent within the A-AX and C Waste Management Areas.

Coarser-grained sand and gravel fractions of the Hanford formation generally consist of about equal amounts of basaltic and quartzo-feldspathic material (Tallman et al. 1979). This mineral assemblage gives the Hanford formation its characteristic "salt and pepper" appearance, often noted in driller and geologist's logs. The non-basaltic component consists of predominantly quartz and feldspar with some samples containing greater than 10% pyroxene, amphibole, mica, chlorite, ilmenite and magnetite. The silt- and clay-sized fractions consist of mostly quartz, feldspar, mica and smectite.

The Hanford formation makes up the majority of the suprabasalt sedimentary sequence beneath the C and A-AX WMAs, ranging in thickness from 43 to 73 m (140 to 240 ft). The Hanford formation has been divided into three informal units (H1, H2, and H3) in the 200 East Area. The Hanford formation H1 and H3 units are gravelly units consisting of predominantly sandy gravel to gravelly sand. The H2 unit is predominantly sand, with occasional beds of slightly gravelly sand. The Hanford formation H1 and H3 units contain a higher percentage of flood gravel, associated with deposition within and along the main Ice Age flood channelways. The sand-dominated H2 unit was deposited under less-energetic currents, perhaps further away from

the main channelway. The third facies association of the Hanford formation, the interbedded sand and silt-dominated facies, are absent in C and A-AX WMAs.

2.2.7.1 Lower Gravelly Sequence (H3 Unit). The Hanford formation lower gravelly sequence (H3 unit) locally overlies undifferentiated Plio-Pleistocene/Ringold deposits (Figure 2-2). This sequence is equivalent to the lower coarse-grained unit of the Hanford formation of Last et al. (1989) and the lower gravel sequence of Lindsey et al. (1992), the Hanford formation H3 sequence of Lindsey et al. (1994a) and the Quarternary flood gravels (Qfg) deposits of *Geologic Map of the Pries Rapids 1:100,000 Quadrangle, Washington* (Reidel and Fecht 1994).

The H3 unit consists of predominantly gravelly facies of clast-supported, sandy, pebble to boulder gravel to matrix-supported pebbly sand. The maximum $CaCO_3$ measured is ~2.5 wt%. The sand fraction ranges from 15-70% basalt grains, but most often is reported as 40-50% basalt. This unit appears to be present everywhere except within the central and southwest portions of the study area; it is generally missing from beneath most of WMA A-AX (Figure B-5). The unit is probably absent from these areas because of lateral facies changes that take place between gravel-dominated facies to the north and sand-dominated facies to the south away from the primary flood channel that exists north and east of the study area. The greatest thickness [(94 ft 28.7 m)] occurs several hundred feet east of WMA A-AX. The exact thickness of the Hanford formation H3 unit beneath WMA C, on the other hand, is uncertain because the underlying PPLz/(R)? Unit, used to define the base of the unit, is missing.

A structure-contour map of the top of the Hanford formation H3 unit is shown in Figure C-11. The surface of this unit slopes to the south and west with the highest elevations occurring in the northeast and east portions of the study area. Coarser-grained facies are more common to the east and north along the axes of flood channels. About 20 m (70 ft) of relief (420-490 ft) exists on the surface of the H3 unit beneath WMAs A-AX and C.

2.2.7.2 Sand Sequence (H2 Unit). The Hanford formation sand sequence overlies the lower gravel sequence (H3 unit). This sand sequence is equivalent to the middle sand unit (Last et al. 1989), the fine sequence of Lindsey et al. (1992), the sandy sequence of Connelly et al. (1992), the Hanford formation H2 sequence of Lindsey et al. (1994a), and to Quaternary flood sands (Qfs) of Reidel and Fecht (1994).

The H2 unit consists of predominantly sand-dominated facies of the Hanford formation. Fine- to coarse-grained sand dominates with lenses of silty sand to slightly gravelly sand. Minor sandy gravel to gravelly sand beds occur sporadically. Consolidation ranges from loose to compact. Cementation is very minor or absent, and total $CaCO_3$ content is generally only a few weight percent or less. The sand fraction ranges from 10-70% basalt grains but most often a basalt content of 30-40% is reported. Silt lenses and thinly interbedded zones of silt and sand are common but are not abundant in the Hanford formation H2 unit. These thin (< 1 ft [0.3 m]) fine-grained zones generally cannot be correlated among boreholes and are not reflected in the gross gamma-ray logs or moisture data. This is probably because moisture samples are normally collected every 5 ft (1.5 m) during drilling; this sampling interval is too large to detect most thin zones. The fine structure observed in some older gross gamma-ray logs may reflect changes in the silt content that were not detected during drilling.

The Hanford formation sand sequence (H2 unit) underlies the entire area beneath WMAs A-AX and C. The base of the Hanford formation H2 unit is identified as the top of gravelly H3 unit or the top of the fine-grained PPlz/R(?) unit, if the H3 unit is missing. The H2 unit thickens to south and west (Figure C-12), except beneath WMA A-AX, where the upper portion may have been scoured by a southeast trending Ice Age flood channel, perhaps associated with deposition of the overlying gravelly sequence (HI unit). This is indicated by a south to southeast-trending trough present at the top of the H2 unit (Figure C-13). Furthermore, over 100 ft (30 m) of relief exists on top of the H2 unit along this trough.

2.2.7.3 Upper Gravelly Sequence (H1 unit). The Hanford formation upper gravel sequence overlies the Hanford formation sand sequence (H2 unit). This sequence is equivalent to the upper coarse-grained unit of Last et al. (1989), the upper gravel sequence of Lindsey et al. (1992), the Hanford formation H1 sequence of Lindsey et al. (1994a), and to Qfg of Reidel and Fecht (1994).

The Hanford formation H1 unit consists of predominantly loose, sandy gravel to gravelly sand, with minor beds of sand to silty sand. Coarser beds may contain boulder-sized materials. Only a few weight percent or less $CaCO_3$ has been measured in this unit. Sand fractions range from 10-80% basalt, although 40-50% basalt is most commonly reported. The Hanford formation H1 unit consists of mostly high-energy, coarse-grained gravel and sand deposits. Occasional thin, discontinuous lenses of fine sand and silt may also be present.

The isopach map of the Hanford formation H1 unit (Figure C-14) suggests the unit thickens along a northwest-southeast trending trough, which includes WMAs A-AX and C. The H1 unit appears to be missing in the northeast and extreme southwest portions of the study area. The maximum thickness (~100 ft[30 m]) of the H1 unit underlies WMA A-AX. The H1 unit is thinner in the immediate vicinity of the tanks because much of the Hanford formation H1 unit was removed and replaced with backfill during tank-farm operations.

2.2.8 Recent Deposits

Two types of recent deposits are present in the C and A-AX WMAs: 1) eolian sand and silt, and 2) backfill material. Fine to medium sand to silty sand naturally caps the sedimentary sequence in the C and A-AX WMAs. These relatively fine-grained deposits are derived from the reworking of uppermost flood deposits by winds since the last Ice Age flood (~13,000 years B.P.). These poorly sorted eolian deposits contain up to 10-wt% $CaCO_3$ associated with recent soil development.

Eolian sand and silt, forms a relatively thin [up 20 ft (6.1 m)] blanket over the study area (Figure C-15). The thickness of the eolian deposits appears greater along a northwest to southeast trend extending from the WMA AX toward the southeast (Figure C-15). Most or all of the eolian material has been removed and replaced with backfill in the immediate vicinity of tank-farm operations.

Backfill materials consist of unstructured, poorly sorted mixtures of gravel, sand, and silt removed during tank excavation, and then later used as fill around the tanks. Backfill materials extend to depths of 50 ft within the tank farms (Figure C-15).

2.2.9 Clastic Dikes

Clastic dikes are vertical to subvertical sedimentary structures that crosscut normal sedimentary layering. Clastic dikes are a common geologic feature of the Hanford formation in the 200 Areas, especially in the sand- and silt-dominated facies. Clastic dikes are much less common in the gravel-dominated facies of the Hanford formation.

Clastic dikes occur in swarms and form four types of networks (Fecht et al. 1999): 1) regular-shaped polygonal-patterns, 2) irregular-shaped, polygonal-patterns, 3) pre-existing fissure fillings, and 4) random occurrences. Clastic dikes in WMAs A-AX and C probably occur randomly in the gravel-dominated facies (Hanford formation Units H1 and H3) and as regular-shaped polygons in the sand sequence (Hanford formation unit H2). Regular polygonal networks resemble 4- to 8-sided polygons and the dikes defining the polygons typically range from 3 cm to 1 m in width, from 2 m to greater than 20 m in depth, and from 1.5 to 100 m along strike. Smaller dikelets, sills, and small-scale faults and shears are commonly associated with master dikes that form the polygons.

In general, a clastic dike has an outer skin of clay with coarser infilling material. Clay linings are commonly 0.03 mm to 1.0 mm in thickness, but linings up to about 10 mm are known. The width of individual infilling layers ranges from as little as 0.01 mm to more than 30 cm and their length can vary from about 0.2 m to more than 20 m. Infilling sediments are typically poor- to well-sorted sand, but may contain clay, silt, and gravel.

2.3 RECHARGE SOURCES AND EVENTS

The facility infrastructure, infiltration of water from natural and tank farm operation sources, and hydrologic properties of the stratigraphic units beneath the study area control the moisture and waste movement through the vadose zone to groundwater. This section summarizes available information on infiltration from natural resources; discharges caused by tank farm operations and observed spatial and temporal effects on subsurface hydrologic properties. Supporting data tables and figures are provided in Appendix D.

Fluid infiltration into the soil column from the natural and tank operation sources, which are discussed in Sections 2.3.1 and 2.3.2, respectively, had a substantial effect on current environmental contamination conditions in the A-AX and C WMAs at the Hanford Site (Figure 1-1). Temporal changes in vadose zone moisture distribution and water table elevation in response to historical variations in natural and artificial recharge (Section 2.3.3), combined with hydrologic properties (Section 2.4), account for the rate and direction of contaminant dispersal in the aquifer.

2.3.1 Infiltration from Natural Sources

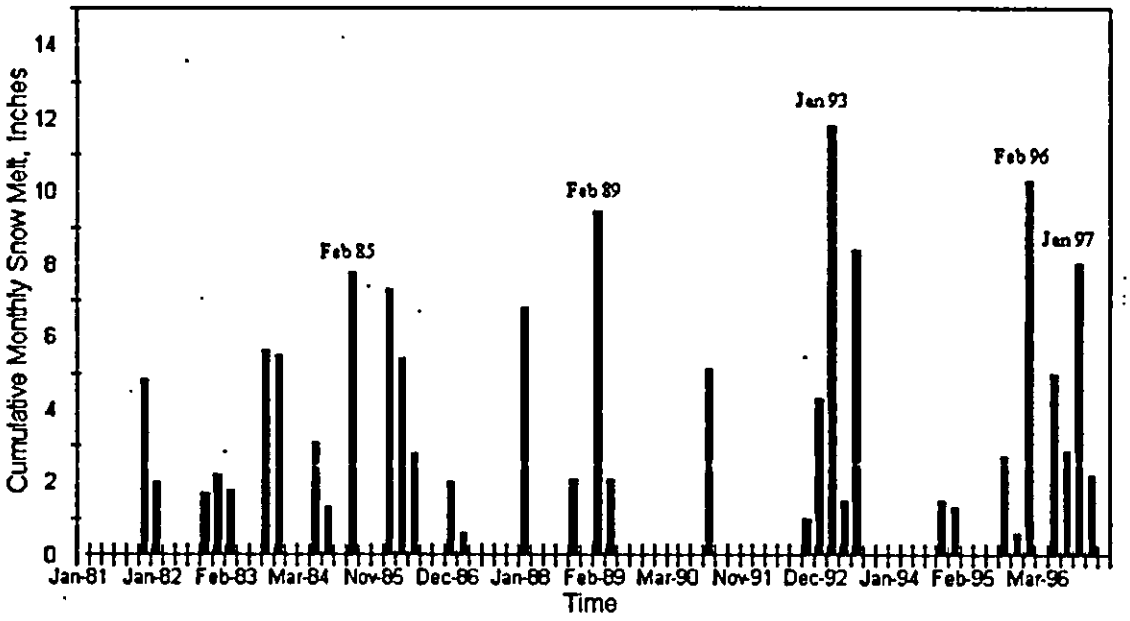
The tank farm surface characteristics and infrastructure create an environment conducive to enhanced general recharge and transient, high-intensity events. Natural infiltration, runoff events, and rapid snowmelt are discussed in Sections 2.3.1.1 through 2.3.1.3.

2.3.1.1 Infiltration. No direct measurements of the natural infiltration rate under the A-AX and C WMAs have been made. However, observations from similar, disturbed, gravel-covered areas at the Hanford Site indicate that as much as 10 cm/year (3.9 in./year) can infiltrate a vegetation-free coarse gravel surface (Gee et al. 1992; Fayer and Walters 1995; Fayer et al. 1996). This represents about 60 percent of the average annual precipitation (rainfall plus snowmelt). Fayer and Walters (1995) indicate that the C and A-AX WMAs are in an area estimated to have about of 5 cm/year to 10 cm/year (1.97 to 3.9 in./year) of infiltration. This estimate of infiltration is based on soil type, lack of vegetation, and land use. Actual recharge is significantly different and not uniform because of the presence of the tanks and the disturbed soil surrounding the tanks. Recharge is blocked and "shed" by the tank domes and flows into the disturbed soil near the tanks. Thus, infiltration rates near tank edges and between rows of tanks are likely manifold higher than average areal infiltration rates.

2.3.1.2 Runoff Events. Transient saturation from collection of runoff in low spots may be more significant as a driving force than average annual infiltration. For example, rapidly melting snow is one natural event that can lead to surface flooding. This type of occurrence has been documented at the T Tank Farm in *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and T-TX at the Hanford Site* (Hodges 1998), but no similar record is available for either C or A-AX WMAs. Runoff controls, berms and gutter sand diversions were installed around the C and A-AX WMAs in calendar year 2002.

2.3.1.3 Rapid Snowmelt. Records of snowmelt have been made since 1981 at the Hanford Meteorology Station, located between the 200 West and 200 East Areas. Figure 2-6 summarizes the total snowmelt per month for a 24-hour period. These records indicate likely periods when unusual accumulations or ponding of water may have resulted in transient saturation events, possibly leading to transport of contaminants through the vadose zone to groundwater. In addition to the February 1979 snowmelt ponding event mentioned in the previous runoff event section several additional events are likely to have occurred over the last 20 years as evidenced in Figure 2-6. The snowmelt events, as well as maximum monthly precipitation since 1946 (Appendix D, Table D-1), are shown on a time line with groundwater contamination occurrences, tank leaks and unplanned releases in Figures 2-7 and 2-8 for C and A-AX WMAs, respectively.

Figure 2-6. Monthly Summaries of Rapid Snowmelt Events, 1981 Through 1997.



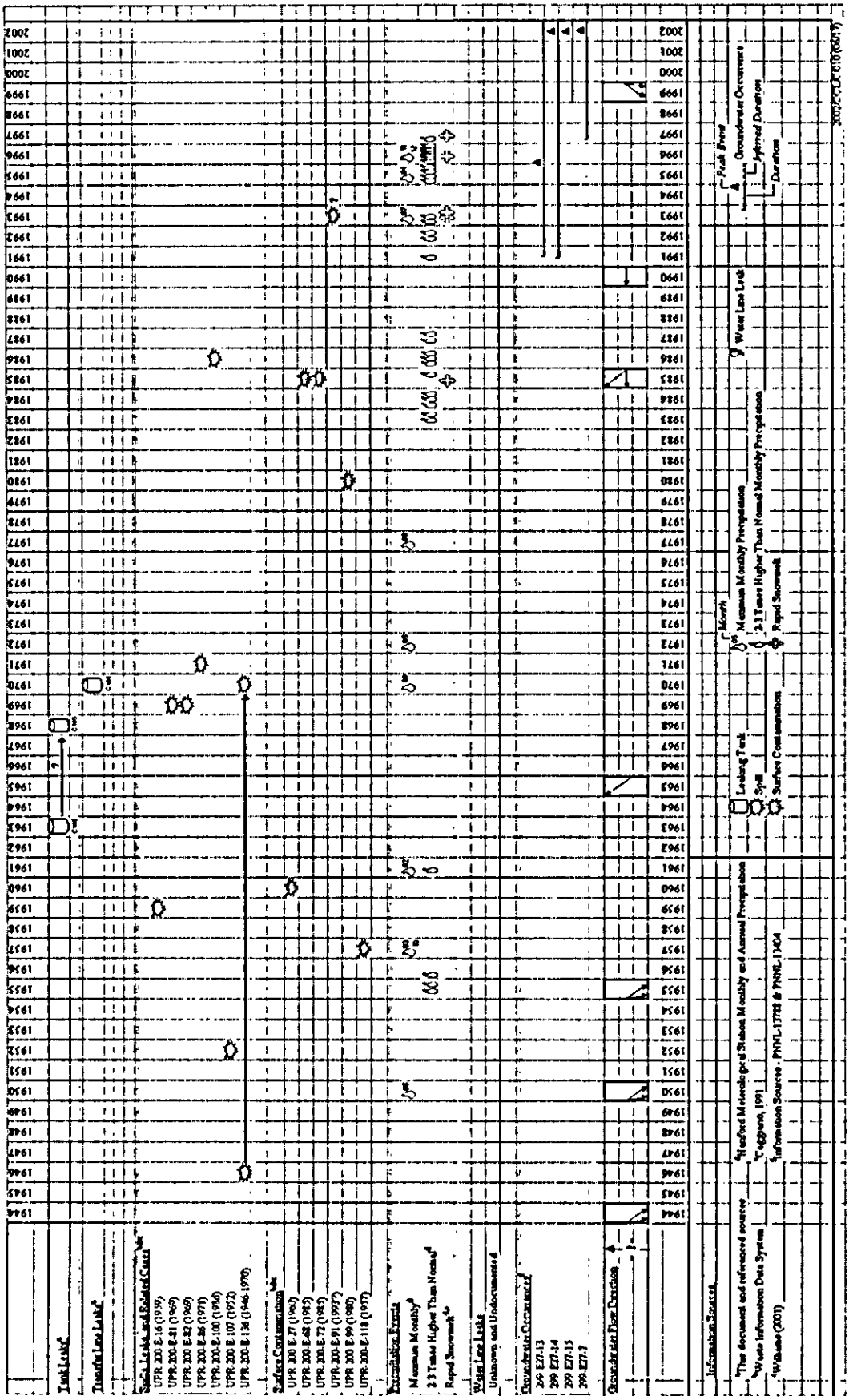
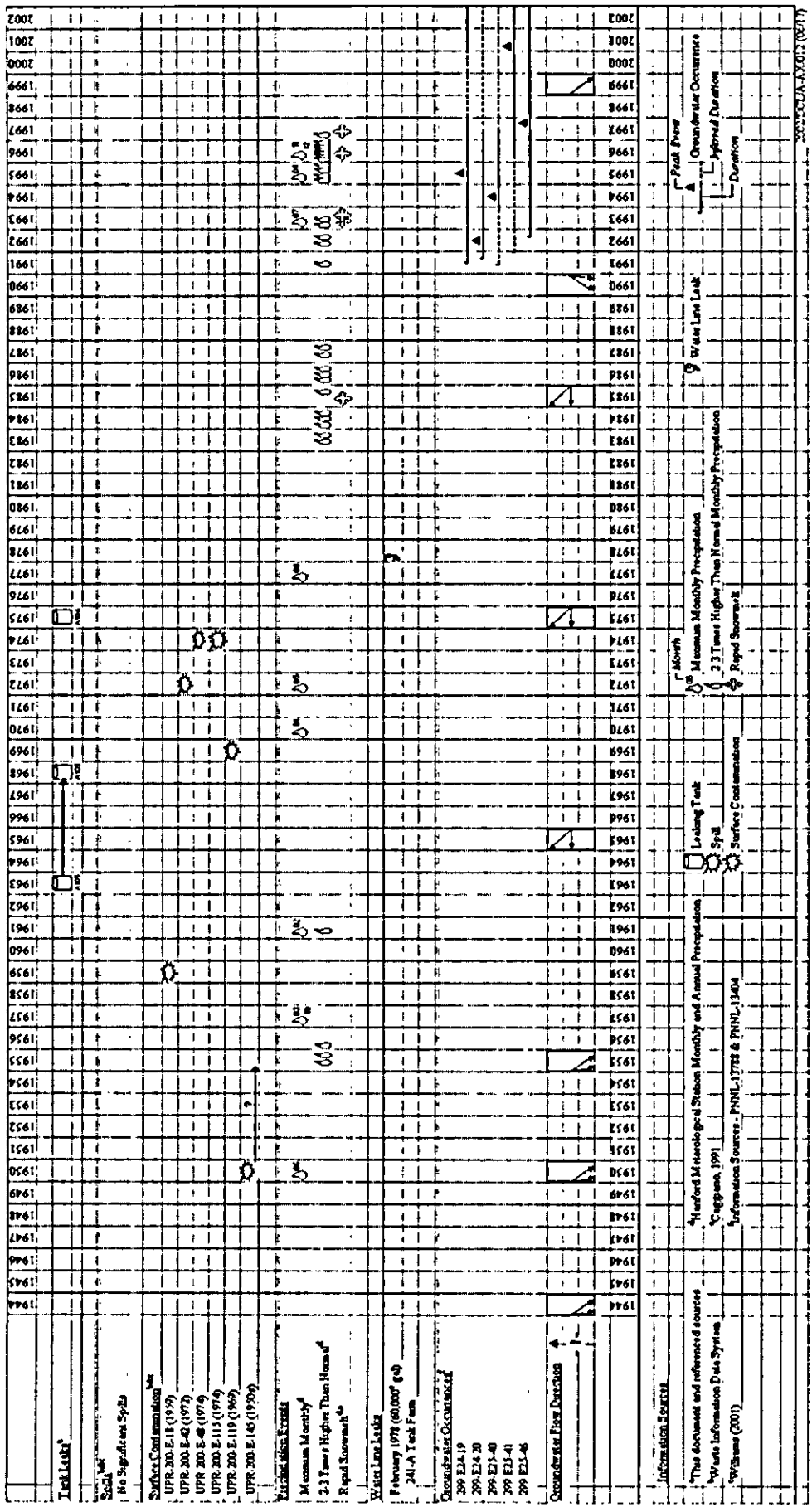


Figure 2-7. Timeline of Hydrologic and C Tank Farms Operational Events.

Figure 2-8. Timeline of Hydrologic and A and AX Tank Farms Operational Events



2.3.1.4 Fluid Discharges from Tank Farm Operations. During the operational history of the A-AX and C Tank Farms, fluids were discharged into the vadose zone, both deliberately and inadvertently. A list of intentional discharge sites and unplanned releases with descriptive information is provided in Appendix A from Williams (2001). Liquid discharge events are summarized by tank farm in the following paragraphs.

2.3.1.5 Intentional Releases. Unlike some tank farms at the Hanford Site, WMA C is not near many liquid waste disposal sites. At C farm the only intentional discharge facility was the 216-C-8 french drain, located about 75 ft (23 m) southeast of the 241-C Tank Farm. The drain is a 6-foot (1.8 m) diameter, 8-foot (2.4-m) long, gravel-filled concrete pipe placed vertically in the ground. It was used between June 1962 and June 1965 and received an unknown amount of ion-exchange regeneration waste from the 271-CR control house (DOE 1993b). The waste volume was not large compared to crib discharges. There is no indication that intentional releases had any significant impact on vadose zone contamination.

A greater number of intentional liquid discharge facilities were used around A and AX Tank Farm but the high discharge facilities were not adjacent to the tank farms. The high discharge facilities received condensate and cooling waters from PUREX operations and condensate generated in numerous tanks in A and AX Tank Farm because of high heat conditions. High discharge cribs that received waste from the tank ventilation systems included 216-A-8 and 216-A-24. Crib 216-A-8 lies about 500 ft (150 m) east of AX Tank Farm and received 1.15×10^9 L between 1955 and 1995. Crib 216-A-24 lies about 600 ft (180 m) northeast of AX Tank Farm and received about 8.2×10^8 L 1958 and 1966. Crib 216-A-9 about 300 ft (100 m) west of A Tank Farm operated intermittently with the largest discharges occurring from 1956 to 1958 when PUREX acid fractionator condensate and cooling water were released into the crib. A total of 9.8×10^8 L was discharged to this crib. Contaminants in these large discharge cribs did break through to groundwater. However, it is not likely that they impacted the vadose zone beneath the WMAs because they are located too far from the WMAs.

Numerous cribs and retention basins around and French drains in A and AX Tank Farm received PUREX cold startup waste, stack drainage and cooling water mostly from the mid 1950s through the 1970s. These facilities generally received between 10^4 and 10^6 L. As with the larger discharge facilities, there is no indication that discharge to these facilities had a significant impact on contaminant migration.

2.3.1.6 Unintentional Releases. Several unplanned release (UPR) incidents have been reported within and around C, A and AX Tank Farms over the course of tank farm operations history. These are shown in Appendix A (Table A-1 of Williams 2001) and briefly described in Appendix B, Section B.5. Those releases identified as tank leaks are discussed in more detail in Section 3.3. The following paragraphs discuss UPRs other than those identified as tank leaks.

Around C farm, the largest UPRs were transfer line leaks near diversion boxes 241-CR-151, 241-C-152 and 241-C-151 (UPR-200-E-86). All involved the transfer of PUREX waste around 1970. Estimated losses were 136,000 L of CWP (UPR-200-E-81), 10,000 L of PSN (UPR-200-E-82) and an unknown volume of PSN waste (UPR-200-E-86) that was reported to contain 25,000 Ci of cesium-137. The remaining 9 UPRs were primarily small surface spills and airborne contamination. With the exception of UPR-200-E-16 (an estimated 190 L leak from an

over ground transfer line between tanks C-105 and C-108) these events occurred outside the C Tank Farm.

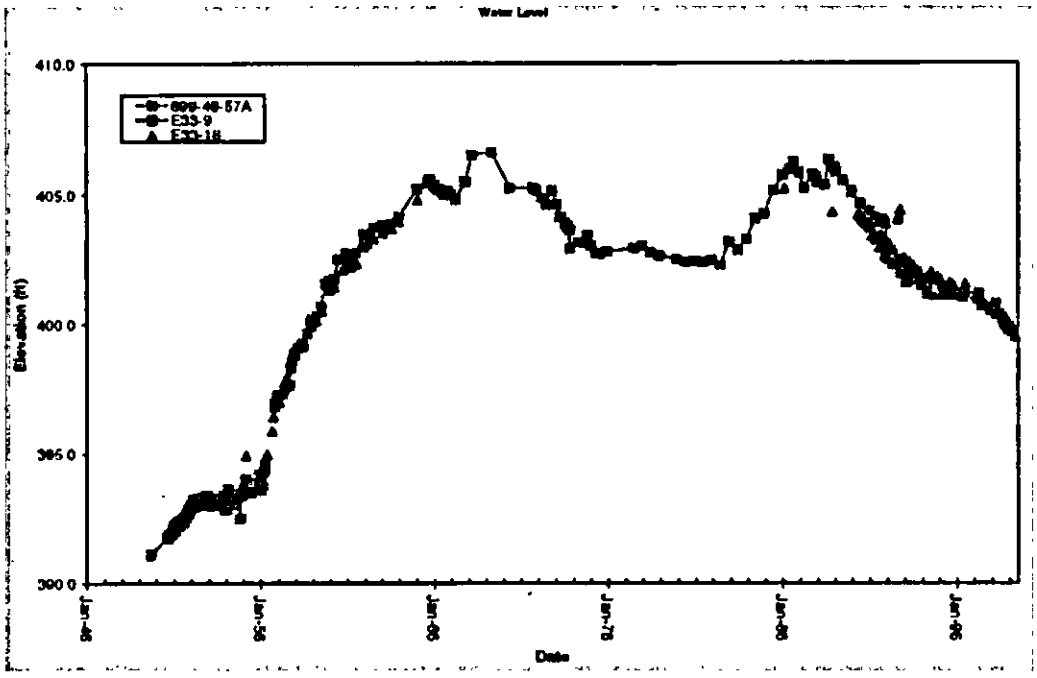
Around A Tank Farm two small UPRs occurred, a brief pump pit leak at tank A-106 (UPR-200-E-48) and leakage around transfer pipe near valve pit 241-A-08 east of the tank farm identified from contaminated soil (UPR-200-E-145). Around AX Tank Farm two small surface contamination events (UPR-200-E-42 and UPR-200-E-119) and an airborne event (UPR-200-E-155) occurred. None of these events apparently caused significant vadose zone contamination.

2.3.2 Subsurface Discharge

2.3.2.1 Vadose Zone Moisture Distribution. Fluids leaked from cribs and trenches could have migrated laterally into the vadose zone beneath the C and A-AX WMAs. However, no evidence exists to indicate that such lateral migration has occurred. Given that more than 20 years have passed since the discharges occurred and that the soils are highly permeable, any fluids of sufficient quantity from these sources have likely migrated from the cribs and trenches downward toward the water table. Vertical migration due to infiltration driven recharge from natural sources can be estimated by assuming an average recharge rate in the range of 5 to 10 cm/yr. If an average recharge rate of 7 cm/yr is assumed along with an average water content of about 10 percent by volume, , the pore water velocity will be 10 times the recharge rate or 0.7 m per year. Assuming no fast pathways (vertical channels, etc.) the expected limit of fluid migration is approximately 14 m below the original depth of the leak as documented in *A Comprehensive Analysis of Contaminant Transport in the Vadose Zone Beneath Tank SX-109* (Ward et al. 1997). It should be noted that the cribs and trenches received millions of gallons of discharge water. These large volumes would likely extend to groundwater, particularly in and near the cribs. During the past 20 years, discharge liquids would have been flushed about an additional 14 m downward to the water table by precipitation, not that the actual discharge liquids are only 14 m below the crib bottom.

2.3.2.2 Water Table Fluctuations and Artificial Recharge. The water table and general groundwater flow direction have changed significantly in the 200 East Area since large intentional discharges from processing plants and tank farm operations began in the early 1950s. In the 200 East Area, intentional discharges to B Pond located about 1.6 km (1 mi) east of the B-BX-BY WMA and 0.4 km (0.25 mi) east of A-AX and C WMAs have been particularly influential. Historical well data shown in Figure 2-9 around the B-BX-BY WMA show the water table rise that began in the early 1950s and continued until the mid 1980s. A similar profile would have occurred at the C and A-AX WMAs. In addition, the pre-Hanford operations flow directions (generally west to east) became more southerly and westerly as the B pond groundwater mound developed. When the B Pond discharges to B Pond and other liquid discharge sites were significantly reduced beginning in the 1980s, water table elevations began to drop toward pre-Hanford levels (see Table 2-10 showing relatively current levels) and general flow directions began to return to the more easterly pre-Hanford condition. In 5 to 8 years, some wells will contain little water as the water table is expected to decline in most parts of the 200 East Area an additional 4 to 5 m (13 to 16.4 ft). Given the transient hydrological conditions in this region, long-term water levels are difficult to predict.

Figure 2-9. Historical Water Levels Near the B-BX-BY WMA.



2.4 HYDROLOGIC PROPERTIES

2.4.1 Vadose Zone Properties

A summary of vadose zone hydrologic properties collected at the Hanford Site is provided in *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site* (Khaleel and Freeman 1995). A subset of this database is included in Appendix C, Table C-1. The most pertinent data were collected on Hanford formation soils underlying the BY cribs during the remedial investigation of the 200-BP-1 operable unit. Because of the distance between C, A and AX Tank Farms and most of the sampling sites, these data cannot be considered to be waste site-specific. However, there are sufficient similarities in their depositional environment to make the data potentially comparable. The database includes the location of the sample, the depth at which the sample was collected, particle size distribution, moisture retention curve data, and saturated hydraulic conductivity values. Generally, the soils are variable mixtures of sands and gravels. Well-defined horizontal strata with distinctly different hydraulic properties favoring lateral movement in the vadose zone (e.g., silty sands) are probably present locally, but are not widespread.

The water table is approximately 250 ft (75 m) below the surface at the C WMA and approximately 290 ft (83.4 m) below the surface at the A-AX WMA. Consequently, much of the migration pathway from the source to the groundwater monitoring well will be in the unsaturated zone. Liquid migration through this zone is influenced by soil grain size distribution heterogeneities and directional (lateral versus vertical) anisotropy in the soil permeability. The

bulk of the sediments are high-energy flood deposits with extreme variability in grain size over vertical and horizontal intervals on the order of tens of feet. Hydraulic conductivity values would be expected to change on at least the same scale if not less.

In the 200 East Area, unsaturated sediments are primarily gravelly coarse-grained sands and sandy gravels with a few thin intermittent silt-rich units, there are no low-permeability horizons that would cause appreciable lateral spreading of infiltrating liquid under the A-AX WMA. The detailed stratigraphic description provided in Section 2.2 shows a vertical column of predominantly coarse sands in the vadose zone. The slight doming effect seen at the top of the Ringold formation at the A-AX WMA appears to be carried through to the contact between the Hanford upper gravel and sand sequences. These subtle structures and changes in lithologies may control local flow directions for liquid migrating through the vadose zone. However, it is not possible to model or predict specific pathways. The C WMA does not appear to have such a feature that potentially could control flow in the vadose zone.

Studies of aqueous flow in sandboxes suggest that one common pattern of flow through unsaturated sediments is in relatively narrow, vertical fingers with some lateral spreading occurring at silty horizons. Once saturation of these horizons is reached, vertical flow commences again. Furthermore, once these vertical pathways are established with an initial infiltration event, liquids from later infiltration events will flow along these established channels (Stephens 1997). The cross-sections portray that the bulk of the sediments in the vadose zone should promote vertical transport of migrating fluids. The fine-grained sequence at the top of the Ringold may cause some lateral spreading at depth.

Evidence in support of this type of flow behavior in the 200 East Area comes from direct observation of infiltration tests performed at the 200E/105A Mock Tank Site (Narbutovskih et al. 1996). Electrical resistivity tomography was used to track leaking saline water from the surface to a depth of about 70 ft (21.3 m). Results indicate that this type of fingering does occur. Furthermore, analysis of the infiltration rate, the time to reach depth and the total volume of water leaked indicates that a point source leak of 0.13 gallons per minute (0.49 L/min) might reach groundwater in a few months (Hartman and Dresel 1997).

The sandbox studies and the infiltration tests suggest that relatively moderate volumes of liquid (~10,000 gals [37,854 L]) can travel rapidly through the vadose zone in the 200 East Area. Extrapolation of these data to the entire depth of the vadose zone suggests that a several thousand-gallon discharge could reach the aquifer in some time period less than a year. However, no field data demonstrate this occurrence and modeling studies have yet to predict such rapid migration through the vadose zone.

In several areas of the Hanford Site, clastic dikes exist in the subsurface. Clastic dikes may provide limited vertical pathways for rapid liquid migration from the surface to the groundwater. The observed clastic dike characteristics (Fecht et al 1999) suggest that these features do not extend as far as the vadose zone thickness and are oriented in a three-dimensional fashion, being neither strictly vertical nor horizontal. If clastic dikes do exist under the farms, a pathway might exist that allows local rapid vertical movement of fluids in the vadose zone but large-scale control of fluid migration is unlikely.

Other migration pathways that would allow local rapid vertical flow are the outer annulus of poorly sealed or unsealed drywells within the farm boundaries. Water may enter from the surface to flow downward along the outside of the well casing if the sealant material does not properly adjoin the casing. Contamination in the vadose zone may also enter an annular space via discontinuities in the seal column, such as a "bridge" caused by careless emplacement of sealant materials, and then flow downward between the flawed seal and well casing. These wells are used for vadose zone monitoring with gamma ray logging tools and extend to depths of approximately 100 to 150 ft (30.4 to 45.7 m) below the surface.

2.4.2 Aquifer Properties

This section provides information on the current nature of the unconfined aquifer in the immediate region of the C and A-AX WMAs. Aquifer properties were determined from lithographic and stratigraphic interpretations, current water elevations, and direct test methods. Aquifer properties described include: aquifer thickness, hydraulic gradients, hydraulic conductivity, and porosity. The estimated values for flow direction and velocity are also discussed in this section based substantially on the measurement and interpretation of the aquifer properties. Additional detailed data can be found in *Hanford Site Groundwater Monitoring for Fiscal Year 2000* and *Hanford Site Groundwater Monitoring for Fiscal Year 2001* (Hartman et al., 2001 and 2002).

Based on local hydrographs and colloidal boroscope measurements, it has been determined that the groundwater flow direction is generally to the southwest to south-southwest at C WMA and to the southeast at A-AX WMA. These flow direction directions are consistent with the regional water-table map (see Plate 1 Hartman et al., 2002). Using measurements from pumping tests results, hydraulic gradients, porosity estimates, and the colloidal borescope measurements the groundwater flow rate ranges between 2.4 and 4.8 ft (0.7 and 1.4 m) per day for C WMA and between 5.6 and 10.8 ft (1.7 to 3.3 m) per day for the A-AX WMA (Hartman et al. 2002 and Hartman et al. 2000).

2.4.2.1 Aquifer Thickness. Currently, the water table beneath the C WMA lies 400 ft (122 m) above sea level with about 255 ft (77 m) of vadose zone above. The aquifer thickness, based on the top of basalt at 355 ft (108 m), is approximately 44 ft (13.4 m). The aquifer materials consist dominantly of sandy gravel or silty sandy gravel. At the A-AX WMA the water table lies in basal gravels currently interpreted as Ringold Formation Unit A. As explained in Section 2.2, there is some ambiguity as to the location of the Hanford/Ringold contact in this area with respect to the water table. The aquifer thickness, based on data from well 299-E25-2, which extends to basalt, is approximately 89 ft (27.1 m). The lithology within the aquifer is dominantly a sandy gravel ranging from cobble to boulder-sized clasts.

2.4.2.2 Hydraulic Gradients. The water table is extremely flat across the 200 East Area (Figure 2-10), and in areas with flat water tables the choice of surveys may actually affect the relative position of the water elevation in a well with respect to other network wells. Because water elevations are the most common data set used at the DOE Hanford Site to determine flow

direction, a switch in the relative water elevations of wells used to determine direction could affect the interpretation of the flow direction.

The groundwater project recently switched the datum to which water levels are referenced in *Hanford Site Groundwater Monitoring for Fiscal Years 1998*, 1999, 2000, and 2001 (Hartman 1999; Hartman et al., 2000, 2001, 2002). In the past, water levels were referenced to the NGVD29 datum. The NGVD29 datum was chosen originally because the bulk of the wells used on site could be referenced not only to this datum but also to a specific survey called NGVD29-2. For areas the size of a WMA, there is no effect from switching to the NAVD88 datum. However with the datum change, there was also a switch in surveys. Many wells are now referenced to one of two surveys, with elevations referenced to NAVD88, both more recent surveys than NGVD29-2.

Figure 2-11 shows hydrographs for four of the five RCRA network wells that are currently used to monitor the water table at the C WMA. The water level data from well 299-E27-15 had been historically inconsistent with data from the other wells in the WMA C network and with the regional water table data (Hartman 1999). Corrections to water elevations based on the recent results of gyroscope surveys at the C WMA including this well provide a more consistent and thus interpretable water table surface (Hartman et al., 2002). Water table elevations across the C WMA vary from 402.3 to 402.8 ft (122.62 to 122.77 m). The local gradient between well 299-E27-7 and 299-E27-13 is 0.00021 based on June 2000 water levels.

Hydrographs of the two wells at the A-AX WMA gives a consistent picture of relative water elevations over time (Figure 2-12). The flow direction appears to be southeast. Based on these hydrographs, well 299-E24-20 is the upgradient well, while the other four are down gradient. Using NAVD88-1, water elevations across A-AX WMA vary from 402.9 to 403.1 ft (122.80 to 122.86 m) or 2.4 in. (6.1 cm). The local gradient between well 299-E25-41 and 299-E24-20 is 0.000078 based on March 1999 water levels.

Another well, 299 E24-19, was eliminated from the analysis because results from this well form a slight trough between E24-20 and E25-46. The water elevations in this well are low regardless of which survey is used, which has confused interpretation of the flow direction in the past. Based on recent findings with vertical borehole deviations, this well may be slightly out of plumb, explaining the abnormal trough. Consequently this well was eliminated from the network for flow direction determinations until gyroscope corrections are available.

2.4.2.3 Hydraulic Conductivity. Although there is some consolidation of the sediment within the unconfined aquifer at both WMAs, there is little evidence of significant compaction or cementing. Consequently, permeability is high within the aquifer. Currently, there is a discrepancy in reported hydraulic conductivity values in the area. Values are estimated between 24 and 110 ft (7.3 and 33 m) per day based on slug injection/withdrawal tests. Higher values of 6,500 ft (1981 m) per day are reported from pumping tests in the area (Newcomer et al 1990; Connelly et al 1992). Connelly (1992) reported hydraulic conductivity values for the C WMA between 3,500 and 6,800 ft (1,067 and 2072 m) per day and between 6,200 and 6,500 ft (1,890 and 1,982 m) per day at the A-AX WMA. Trent (1992) reported conductivities that range from 8,264 to 6,500 ft (2,519 to 1,890 m) per day for wells near the A-AX WMA. Finally, Hartman

(1999) reported hydraulic conductivities that range from 33,000 to 9,843 ft (10,000 to 3,000 m) per day for Hanford sediments.

Figure 2-10. Water Level Elevations in the 200 East Area in March 2002.

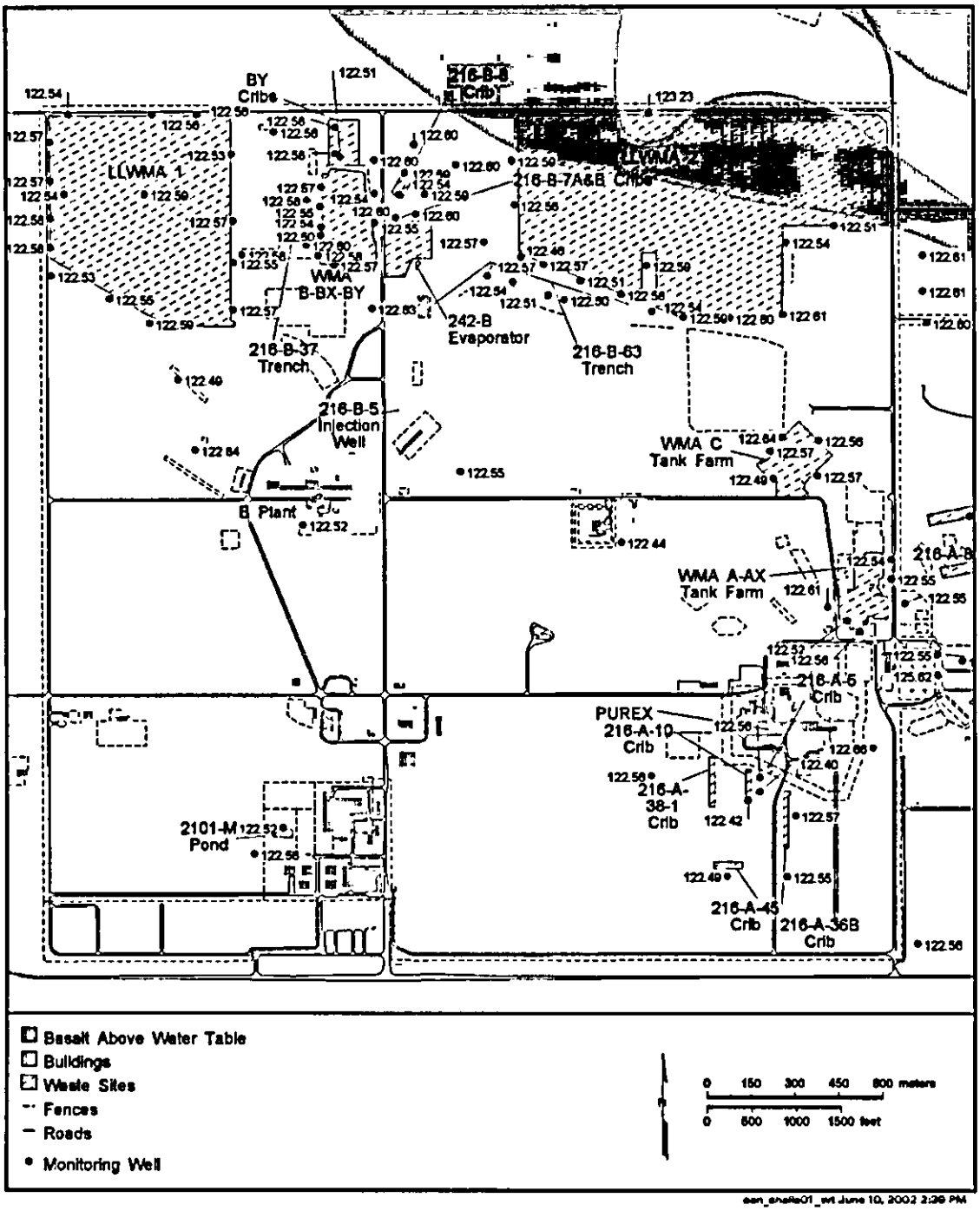


Figure 2-11. Hydrographs for Wells in the WMA C Monitoring Network. All data referenced to the NAVD88 datum. Spurious data have been removed.

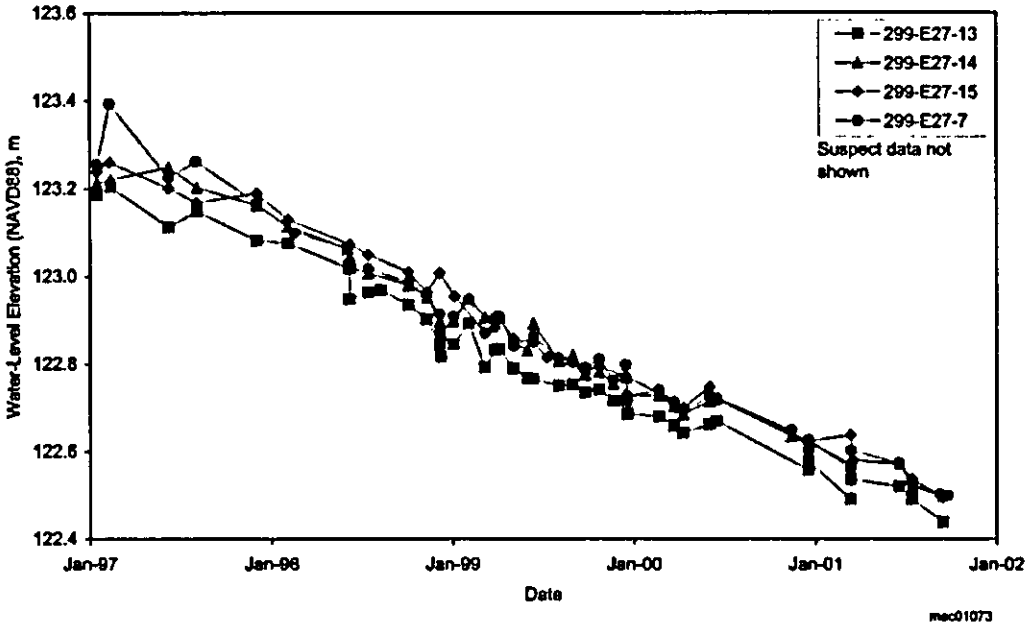
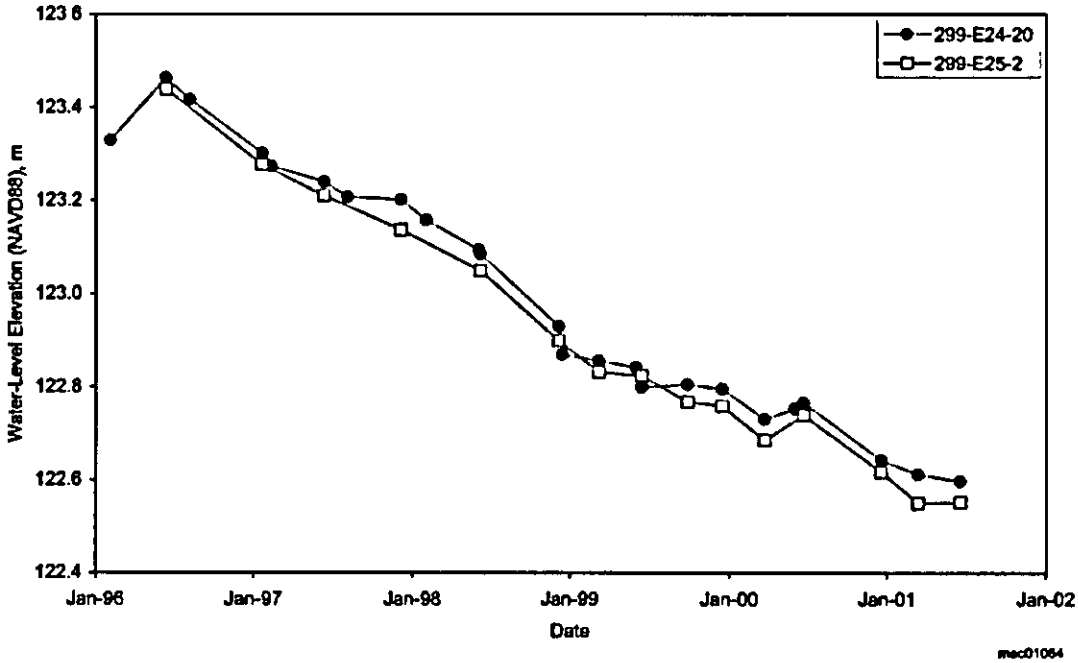


Figure 2-12. Hydrographs for Two Wells in the WMA A-AX Monitoring Network. All data referenced to the NAVD88 datum. Spurious data have been removed.



Two factors likely contribute to the measurement discrepancies. First, since the early 1990s the water table has dropped from the more permeable Hanford formation into the less permeable undifferentiated Plio-Pleistocene/Ringold Unit. The higher conductivity measurements were taken when the water table was elevated and reflected the influence of the Hanford formation on the overall permeability of the unconfined aquifer. Second, slug tests involve a more limited areal extent than pumping tests and tend to provide lower measurements. Slug tests apply a limited stress to the aquifer and are valid over a limited range of conductivities (Thorne and Newcomer 1992). Because the water table is expected to remain in the less permeable stratigraphic unit, an estimated hydraulic conductivity range of 15 to 150 ft (5 to 50 m) per day is estimated.

2.4.2.4 Porosity. Porosity is generally estimated to be about 30% for unconsolidated, coarse-grained sediments at the DOE Hanford Site (Hartman 1999). Because it has not been possible to collect intact core from the aquifer during past drilling, direct methods of determining porosity have not been used. The lack of direct measurements combined with the cobble to boulder grain size of the aquifer suggests 30% may be approximately correct or slightly high value for porosity. Where boulders and cobbles are present and mixed with sand and gravels in the interstices of the larger cobbles a value closer to 20% may be more appropriate for effective porosity (Eckis 1934, Evenson et al., 1962).

2.4.2.5 Flow Direction. The hydraulic gradient is relatively gentle across the 200 East Area. With about 6-in. (15 cm) across the C WMA and 2.4 in. (6 cm) of change across the A-AX WMA , the exclusive use of discrete water elevations to determine flow direction is not recommended. Although this low gradient is caused, in part, by the dissipating groundwater mound under B-Pond, it is primarily due to the high aquifer transmissivity in the 200 East Area with respect to upgradient regions farther west where transmissivity is considerably less. Before formation of the groundwater mound beneath B-Pond, the groundwater flowed regionally to the southeast towards the 300 Area. Recent interpretations of current flow direction show a southwesterly flow from the C WMA and turning more southeasterly at the A-AX WMA where the aquifer is more than twice as thick and the regional southeasterly flow pattern becomes dominant (Williams et al., 2000, Hartman et al., 2002). These patterns are consistent with regional flow directions.

Although the predominant flow directions at these two WMAs are consistent with the regional flow directions and plume trends, as evidenced over miles, they can be misleading when determining the local flow anomalies across these small sites that are 500 ft wide (152.4 m). Some suggestion of the complexity of flow patterns in the 200 East Area is shown by direct measurements shown in Figure 2-13. The large variation in flow directions may be somewhat exaggerated because the effects of well design and rapid changes in barometric pressure, which are not accounted for in Figure 2-13. It is known that wells south of PUREX can have large changes in flow direction in a single day because of their barometric efficiency.

Until this year, the flow direction at these two WMAs had been determined exclusively from gradient calculations based on local water elevations. Unfortunately, across the 200 East Area, the differences in water elevation between wells are small, on the order of a few inches. The combined errors from water level measurements, survey elevations and borehole deviations from

vertical are enough to cause uncertainties in local flow direction anywhere in the 200 East Area. As reported in Hartman et al. (2000), water level data alone are insufficient to determine flow direction in this area. Direct flow measurements were made in several wells at these tank farms to help determine flow direction and thereby minimize the uncertainty in flow direction. In addition, colloidal boroscope measurements have been added at site-specific wells to improve the database for interpreting local flow directions.

At the C WMA where barometric effects are usually minor and suspect data were intentionally avoided, the flow direction determined in well 299-E27-13 had a southwest flow direction, which was measured for more than two hours, and had no significant vertical component (Figure 2-13). The similar southwest flow direction determined in well 299-E27-14 had similar quality, but was recorded for only 36 minutes. Therefore, the value, which is shown in gray, is accepted as valid with caution. The flow directions of the other two arrows shown in gray for wells 299-E27-7, 299-E27-12 are very questionable because of their large vertical components.

Recent direct flow measurements with the colloidal borescope in wells 299-E27-14 (southeast of C Tank Farm), 299-E27-13 (southwest of C Tank Farm), and 299-E27-7 (northeast of C Tank Farm) indicate an average southwesterly flow direction of approximately 214 degrees from true north. Actual measurements in these three wells range from 200 to 235 degrees from true north. Only well 299-E27-12, which is located west of the C Tank Farm, indicates an easterly flow direction as shown in Figure 2-14. However, the two interpretable measured values in this well are suspect because they represent vertical flow, which may be related to their close proximity (i.e., less than 0.45 m) to the water table surface in the well.

According to water table elevations based on surveys referenced to NAVD88 and colloidal borescope data, the direction of flow at the C WMA appears to be predominantly southwest. The current monitoring network was designed for a flow direction to the west with two upgradient wells, 299-E27-7 and 299-E27-14, and three downgradient wells, 299-E27-12, 299-E27-13, and 299-E27-15. As seen on Figure 2-14, only well 299-E27-13 is downgradient if the flow direction is southwest or south-southwest while well 299-E27-12 and 299-E27-14 are cross gradient, providing little if any coverage of the WMA.

At the A-AX WMA where barometric effects can have a more significant impact on borescope results, periods of significant barometric changes were avoided as much as possible when selecting flow direction data. Four of the five wells surveyed with the colloidal borescope near this WMA suggest an eastward to southeastward flow direction (Figure 2-15). The fifth well is the upgradient well 299-E24-20 that shows a westerly flow direction, but it tends to show higher water-table elevations than those wells southeast of the site. The cause of this seemingly anomalous flow direction is unknown, but may be influenced by the presence of the Plio-Pleistocene silt/Ringold formation mud facies near the water table surface or possibly some barometric effect. A sixth well, 299-E24-19 is deviated significantly from vertical, and therefore, the colloidal borescope could not be used in this well.

According to water elevations based on surveys referenced to NAVD88, the direction of flow is southeasterly. The current network was designed for a southwesterly flow direction with two upgradient wells (then 299-E25-40 and 299-E25-41) and only 3 downgradient wells, 299-E24-19, 299-E24-20 and 299-E25-46. However, recent measurements with the colloidal

borescope in wells 299-E25-46, 299-E25-42 (both southeast of A Tank Farm) and 299-E25-41 (southeast of AX Tank Farm) indicate a southeasterly flow direction of approximately 125 degrees from true north (Figure 2-15). Data from well 299-E25-40, which is located northeast of the A-X Tank Farm, indicated easterly flow. The data from this well indicated primarily vertical flow, thus the flow in the well may be deviated with respect to the surrounding aquifer due to local borehole conditions. Results from well 299-E24-20 display a southwest direction, which, although southerly, does not agree as well with the either the water level data or the other borescope data. The results from this well may be due to borehole effects or other perturbations in flow due to local heterogeneities of permeability at this location. As shown in Figure 2-15 only well 299-E25-41 is down gradient. Well 299-E24-20 is marginally up gradient while wells 299-E25-19 and 299-E25-46 are marginally down gradient but only for the 241-A Tank Farm. This scenario results in a generally southeasterly flow direction across the site. This direction has been confirmed with the use of an alternative in situ method to determine flow direction. Recent direct measurements using the colloidal borescope in wells 299-E25-46 (southeast of A Tank Farm), 299-E25-41 (southeast of AX Tank Farm), and 299-E25-42 (southeast of A Tank Farm) indicate a southeasterly flow direction (Figure 2-15).

2.4.2.6 Flow Velocity. The rate of groundwater flow is calculated for a homogeneous, isotropic aquifer using the Darcy equation found in *Groundwater* (Freeze and Cherry 1979) incorporating the hydraulic conductivity, the gradient across the site and the effective porosity of the sediments in the aquifer. The current estimate is between 5.6 and 10.8 ft (1.7 to 3.3 m) per day for the A-AX WMA and 2.4 and 4.8 ft (0.7 and 1.4 m) per day for the C WMA (Hartman et al. 2002 and 2000).

At the C WMA values obtained from wells 299-E27-13 and 299-E27-14 using the colloidal borescope, after corrections for in well flow rates, indicate flow rates in the aquifer of 4 to 6.3 ft/day (1.2 to 1.9 m/day). These values for flow velocity, although higher than the current estimates of 2.4 to 4.8 ft (0.7 and 1.4 m) per day, are still within reasonable agreement with rates determined from the Darcy equation. However, in sharp contrast direct measurements of flow rates based on tracer tests and plume tracking suggest flow rates may be as high as 60 ft (18 m) per day in parts of the unconfined aquifer (Hartman 1999). The influence of the regional flow direction and velocity is demonstrated by the large tritium plume from PUREX waste disposed to the PUREX cribs, and the effective flow from the southeast corner of the 200 East to the east and southeast at rates from 14 to 18 ft (4.3 to 5.5 m) per day (Hartman 1999). However, these values are from an area where flow velocities are expected to be higher than in the C WMA because of slightly higher gradients and hydraulic conductivity southeast of the C WMA as evidenced by those at the A-AX WMA.

At A-AX WMA the flow rate may be in excess of the rate calculated from the ambiguous gradient data and the effective hydraulic conductivities and porosities. Direct measurements of flow rates based on tracer tests and plume tracking suggest flow rates in excess of 10 ft (3 m) per day (Hartman 1999). In-well flow rates, which are typically 1 to 4 times that of the rate in the natural sediments surrounding the well screen, were determined using the colloidal borescope. Values obtained from wells 299-E25-46 and 299-E25-41, corrected from in-well rates indicate aquifer flow rates of 1.5 to 7.5 ft/day (0.5 to 2.3 m/day), which span a similar, but slightly slower flow rate range than determined from the Darcy calculations.

It is known that rapid changes in barometric may effect flow direction and velocities in wells, particularly if a semi-confined condition exists. During use of the colloidal borescope in the wells near A-AX and C WMA barometric changes were usually small, however, this was not always true for wells south and southeast of PUREX (see Figure 2-13). Also, semi-confined conditions were created by Plio-Pleistocene silt /Ringold formation mud facies present from the north end of A-AX WMA to south of PUREX (see Figure 2-5). Water table surface is usually just below this cap silt unit or partially confined by it. The upper surface of the silt layer dips to the SW and the lower surface dip has not been defined but is believed to be similar, but more irregular. A small thickness to none of unsaturated permeable sand and gravel is just below the bottom of this layer. As the water table changes with the barometric pressure, air rushes either into or out of the wells that penetrate this unit, which distorts the predominant flow direction periodically by as much as 180 degrees. This silt layer continues south and may connect to the lower Ringold mud as discussed in Section 2.2.

Figure 2-13. Flow Direction Map of Wells in the Vicinity of Waste Management Areas A-AX and C Based on Colloidal Borescope Measurements.

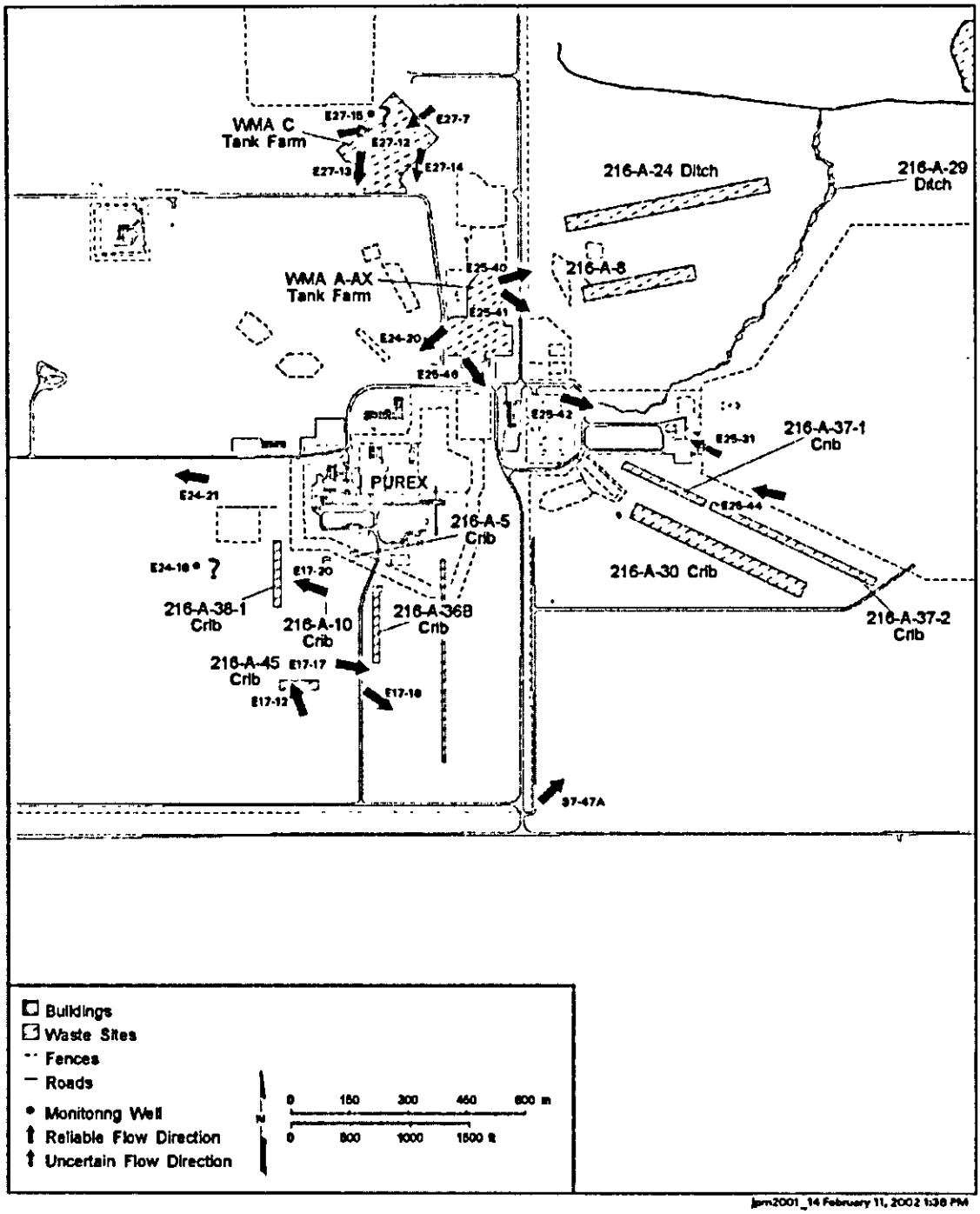


Figure 2-14. Flow Direction Map of Wells Around Waste Management Area C Based on Colloidal Borescope Measurements.

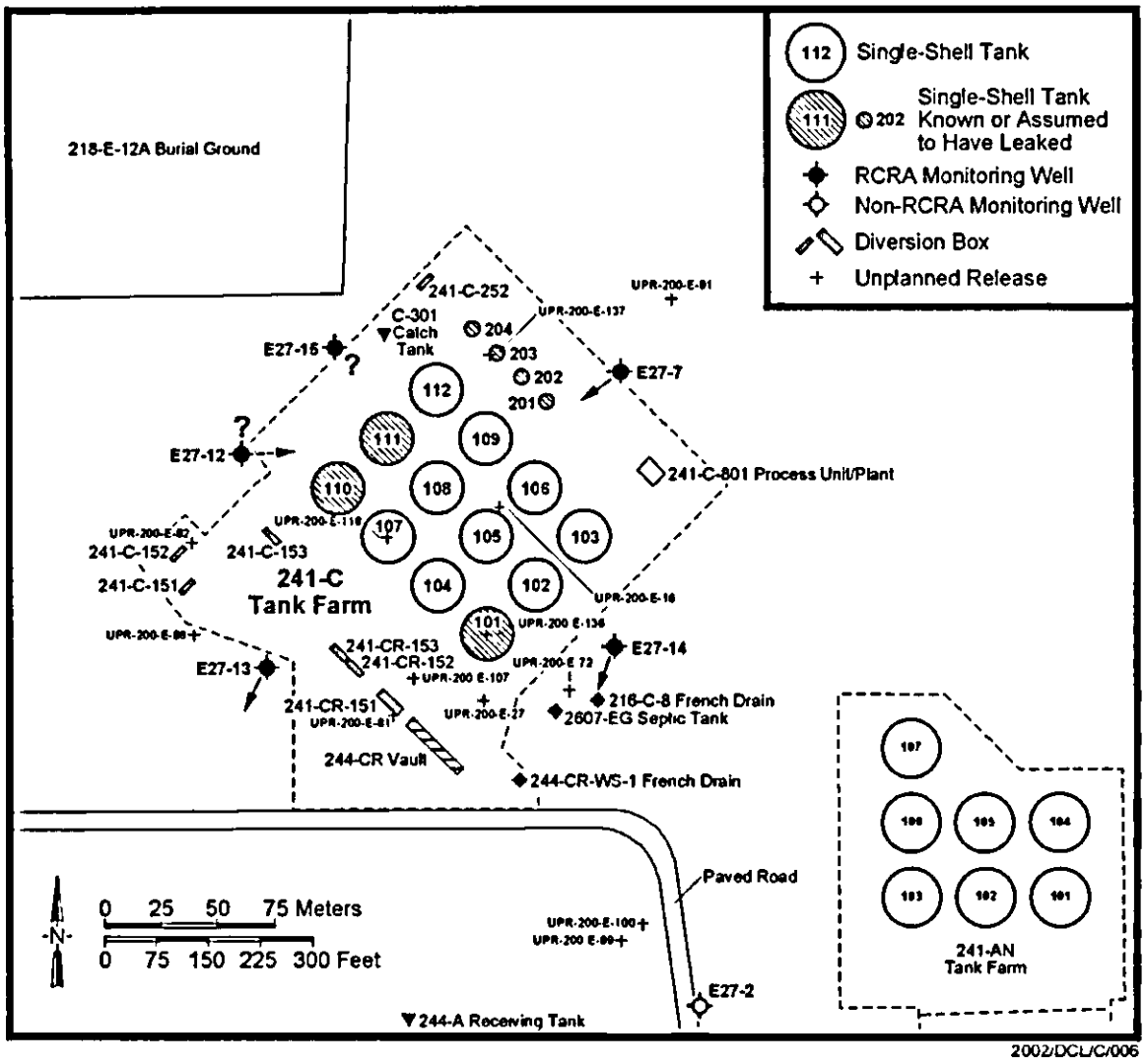
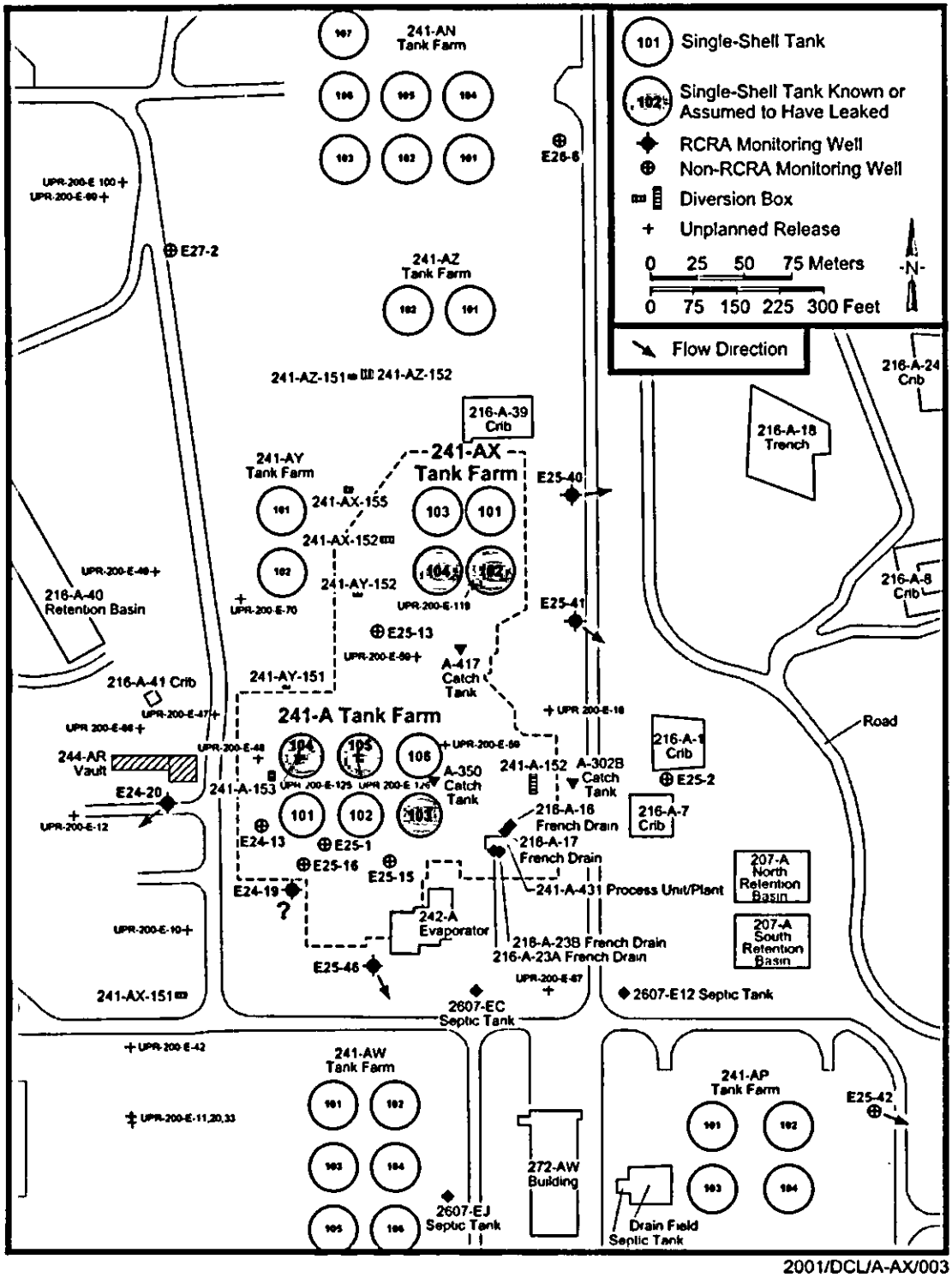


Figure 2-15 Flow Direction Map of Wells Around Waste Management Area A-AX Based on Colloidal Borescope Measurements.



2.5 GEOCHEMISTRY

This section covers geochemical factors and material properties of the vadose zone and unconfined aquifer underlying the C and A-AX WMAs. It addresses those factors that control contaminant mobility in the soil column. Radionuclide and hazardous-constituent mobility can be substantially different depending on the innate characteristics of the contaminant, the geochemistry of the natural soil-water system, and the changes in soil and water chemistry that occur from contact with tank fluid. In these soils, all factors are expected to be influential. Different contaminants present in the soils are variably mobile and, depending on interactions of tank fluids with the soil-water system, a given contaminant's mobility can be considerably different at different locations and times within the vadose zone and unconfined aquifer.

The geochemical characteristics and contaminant mobility are best considered in terms of behavior in relatively undisturbed soils versus soils that have interacted with tank waste fluids. In addition, tank fluid chemistry varies. Both types of soil conditions are expected in the vadose zone underlying the C and A-AX WMAs. For relatively undisturbed soils, a substantial Hanford Site-specific database is available that quantifies geochemical characteristics and contaminant behavior, particularly for radionuclides (e.g., Ames and Rai 1978; Serne and Wood 1990; Serne et al. 1993; Kaplan, Parker, and Kutynakov 1998, and Kaplan and Serne 1999). This database is not specific for the C and A-AX WMAs. Average soil properties are described in Section 2.2. Soil water in the vadose zone and groundwater in the unconfined aquifer have similar characteristics. They are moderately alkaline (pH about 8) and contain moderated concentrations of cations and anions. Dominant cations are calcium (about 50 mg/L), magnesium (about 14 mg/L), sodium (about 30 mg/L), and potassium (about 9 mg/L). Dominant anions are carbonate (about 70 mg/L) and sulfate (75 mg/L).

Within the C and A-AX WMAs, quantitative, site-specific radionuclide sorption/solubility data are not available. However, spectral gamma data from the drywell systems provide qualitative indications of the reactivity of detected tank waste constituents and some ability to compare radionuclide behavior known to occur in undisturbed Hanford Site soil environments. In contaminated regions containing several gamma-emitting radionuclides, spectral gamma data show that their spatial distributions relative to the expected source of leaks and to other radionuclides tend to be consistent. Given this database, the following observations are generally seen across the WMAs for the most commonly observed gamma-emitting radionuclides:

- Cesium-137 is concentrated in drywells near the potential sources of tank leaks. This suggests relatively rapid and complete sorption onto soil near the point of discharge. Vertical distribution in drywell 30-05-07 shows Cs-137 peaks coincident with the tank bottom and extending no more than 10 m deeper into the soil column. Several transfer line locations (e.g., between tanks C-104 and C-105, between tanks C-108 and C-109 and between tanks A-101 and A-102) are marked by sharp peak Cs-137 concentrations at transfer line depth. This behavior is consistent with measured K_d values in Hanford Site soil of more than 100 mL/g. For more detailed description of Cs mobility under tank farm conditions, see S/SX FIR.

- Cobalt-60 is highly mobile. When present in a drywell with Cs-137, it is routinely distributed below Cs-137 and the degree of separation between peaks can be tens of feet. The most obvious indication of Co-60 mobility occurs in the eastern portion of C Tank Farm where Co-60 occurs at and below 90 ft (27 m) bgs. In these instances, the chemistry of numerous tank fluids clearly plays an important role in providing complexing agents that cause ^{60}Co to be highly mobile, with a K_d value near 0 mL/g.

This data suggests that tank fluid chemistry in these WMAs has had little observable effect on ^{137}Cs mobility. In these tank farms, ^{137}Cs continues to be highly reactive and immobile in the soil column and is a good indicator of leak source location. Assigning a K_d value of 100 mL/g or more is a reasonable estimate. Tank fluid chemistry does have a significant effect on ^{60}Co and europium isotopes, reducing reactivity with the soil and enhancing mobility. Some small degree of sorption may occur, but assigning a K_d value of 0 mL/g is a reasonably conservative estimate. The particular fluid chemistry characteristics enhancing ^{60}Co mobility are unclear and no distinctly different effects on gamma radionuclide behavior caused by variability in tank fluid chemistry are apparent. The location of ^{60}Co also could show an approximate location of ^{99}Tc in the vadose zone underlying the C, A and AX Tank Farms.

3.0 SUBSURFACE CONTAMINATION CHARACTERISTICS AND ASSOCIATED TANK WASTE INFORMATION

Subsurface contamination has been generated by tank farm operations in the C and A-AX WMAs over the course of a long operating period from the mid-1940s until 1980. Tank farm operational histories have been described in Chapter 2 and Appendix A (narrative and tables from Williams [2001])). In this chapter, the available information about the nature and extent of subsurface contamination in specific locations within the WMAs is summarized. The primary data sources are gamma ray logging data, tank waste chemistry records and tank farm operations records. Because the gamma logging data are so important to this discussion, an overview of these data is provided in Section 3.1. A summary of characteristics for tank wastes that are the probable sources of subsurface contamination is provided in Section 3.2. In Section 3.3, data is described by specific area of contamination. Contamination discharged to the vadose zone from unplanned releases within the WMAs but located outside the tank farm is discussed in Appendix B. Available information on these releases is provided in Appendix B. A summary of tank leak determinations based on evaluations in this report is provided in Section 3.4. Finally, in Section 35, groundwater contamination around the C and A-AX WMAs is summarized. Although no C or A-AX WMA sources are known to have caused local groundwater contamination, groundwater characteristics are provided to complete the description of subsurface contaminant characteristics in and around the C or A-AX WMAs.

3.1 GAMMA RAY LOGGING INFORMATION

Two types of gamma ray logging data were collected in the C, A and AX Tank Farms. As part of a tank leak detection program (*A Scientific Basis for Establishing Dry Well-Monitoring Frequencies* [Isaacson and Gasper 1981]), gross gamma logging was conducted from the early 1960s through 1994. Recently, the gross gamma logging data from Tank Farms, C, A and AX were evaluated to assess potential movement of gamma-emitting radionuclides in the vadose zone (Randall and Price, 2001a, 2001b and Price 2001). More recently, spectral gamma logging data was collected for the C, A and AX Tank Farms (DOE-GJO 1998a, DOE-GJO 1999 and DOE-GJO 1997a, respectively).

3.1.1 Spectral Gamma Logging Data

The spectral gamma logging database is the most comprehensive database available that quantifies the nature and extent of subsurface contamination in the C and A-AX WMAs. Specific spectral gamma data that identify the most contaminated areas within in the C and A-AX WMAs are discussed in Section 3.3. In some cases, the spectral gamma data provide information that can be correlated with time-dependent waste transfer and storage records for specific tanks. This allows identification of specific waste types. The spectral gamma data also provide an independent means of evaluating the veracity of reported tank leaks. Drywell location maps in each tank farm and summary figures of the individual drywell spectral gamma logs are provided in Appendix E.

Some limitations are associated with the gamma logging methods.

- First, gamma logging interrogates only about 30 cm to 45 cm (12 to 18 in.) of the soil around the well.
- Second, uncertainties associated with distinguishing gamma contamination in the well or on the well casing from gamma activity originating in the soil may make data inaccurate.
- Finally, gamma activity monitored by these methods provides little information about the tank waste-related non-gamma-emitting radionuclides and chemicals.

These limitations must be considered in evaluating the referenced data reports.

The relationship between the leak status of single-shell tanks and spectral gamma logging data in nearby drywells is qualitative. However, both the depth of gamma activity and its intensity provide some ability to distinguish between failure of the tank and losses associated piping or tank overfills. Most easily distinguished are the cases where significant waste volumes engulf a section of the drywell. In these cases, Cs-137 activity is around 1E+08 pCi/g - depending on the waste type present; there are frequently other gamma emitters at much lower concentrations. This concentration of Cs-137 appears to represent the sorption capacity of the soil. If the high Cs-137 activity zones appear at or near the levels of the waste transfer lines or spare inlet ports then this is considered strong evidence for a piping leak or tank overfill event as being the origin of the contamination. High Cs-137 activity (>10,000 pCi/g) beginning near the base of the tank provides strong evidence for a leak from the tank. Other situations are much more difficult to interpret.

Low levels of Cs-137 contamination are ubiquitous in drywells around most single-shell tanks. It appears that open boreholes provided a pathway for contamination to enter the well casing and in some cases, the unsealed boreholes provided a pathway for contamination to move downward. In addition, the compacted base on the original tank farm excavation provided a region for liquids to pond and move laterally. The Cs-sorption chemistry predicts that the Cs-137 is held in a highly concentrated plume with sharp activity drops at the edge. Thus, when low Cs-137 activity is reported in one of the drywells it appears there are only two reasonable explanations. Either the drywell is sitting on the edge of a high-activity Cs-137 plume or the contamination was the result of a nuisance contamination spread. Distinguishing between the two options requires an assessment of other information such as waste transfer and waste level records, waste type in the tank, documented leak history, and data from nearby drywells.

3.1.2 Gross Gamma Logging Data and Synthesis with Spectral Gamma Logging Data

Because gross gamma logging was conducted over two decades, evaluating these data provides information on the time-dependent behavior of the gamma-emitting radionuclides in the subsurface. The concentrations of the individual gamma-emitting isotopes that contributed to the gross gamma curves over time were estimated using the recently collected spectral gamma data (concentrations of specific gamma-emitting radionuclides) from the drywells used to collect gross gamma data. By factoring in decay, these calculated curves were propagated over time and compared with the gross gamma curve histories. Using this process, changes in the curves

caused simply by decay can be distinguished from decay plus changes in gamma radionuclide concentrations at a given location over time.

Appendix E summarizes the results for the C, A, and AX Tank Farms. The summary figures (Figure 2-1 for each tank farm) indicate which drywells contain gamma-emitting radionuclides and which do not. Of particular interest are the drywells indicating a change in radionuclide concentrations at a given location over time that cannot be attributed solely to radioactive decay. These conditions are referred to as unstable events. For each location, the borehole number, the depth below the surface, the radionuclide present, the time over which changes in concentration were deduced, and the concentration increase or decrease over that period are listed.

Near-surface changes bgs are attributed to tank farm operations and are broken out separately from changes that occur at greater depths. Changes at depth are attributed to tank and transfer line leaks of tank waste. The changes in radionuclide concentration over time in the C, A and AX Tank Farms attributed to tank farm activity are listed in Table 3-1 in all three tank farm discussions. These changes occur within 30 ft (9 m) of the surface and generally occurred from 1975 to 1985 over most of the tank farm areas. This observation is consistent with a common drywell spectral gamma pattern in which a maximum radionuclide concentration (usually ^{137}Cs) of 10 pCi/g to 100 pCi/g or occasionally higher near the surface diminishes with depth to about 1 pCi/g with depth. We consider this pattern to be consistent with surface or near-surface leaks of contaminated fluid.

The remainder of the radionuclide migration events (e.g., referred to as unstable zones and listed in Appendix E, Table 6-1 in the C, A, and AX discussions) occurs at depths near the tank bottoms or lower. Over the time during which measurements were taken, unstable conditions are observed in 19 drywells in the C farm, 4 drywells in the A Tank Farm, and 7 drywells in the AX Tank Farm. The majority of unstable zones in the C Tank Farm are associated with the transfer line leaks between tanks C-104 and C-105 and between tanks C-108 and C-109. Most involve movement of Co-60 after leakage from the transfer lines. Four of the five unstable zones in the A farm are associated with the transfer line leaks between tanks A-101 and A-102. The fifth measured instability is probably associated with the tank A-105 leak. The unstable zones in the AX Farm appear to be associated with transfer line leaks.

3.2 TANK WASTE CHEMISTRY AND LEAK CHARACTERISTICS OVERVIEW

Environmental impacts of leaks from single-shell tanks or other waste loss events are closely linked to the type of waste lost to the soil column. Waste types stored in C farm tanks covered the complete range of waste types produced in the 200 Area chemical process facilities. The waste types stored in A and AX farm tanks tended to be less diverse, mainly PUREX high-level (boiling) wastes. The waste chemistry associated with the C farm is discussed first, then the A and AX farms.

As noted in Chapter 2.0, the C farm tanks began receiving wastes from the B Plant bismuth phosphate process in 1946. The high activity waste stream coming from the bismuth phosphate process contained essentially of the uranium by-product and the vast majority of the fission products (Serne et al 2003). This stream was called "metal waste". The first six tanks in the

C farm were filled with metal waste. The metal wastes were later recovered from the tanks and processed for uranium recovery in the U Plant in 200 West Area. The other six tanks in the C farm tanks were filled with so-called 1st Cycle waste, a much more dilute waste stream coming from the first plutonium dissolution/re-precipitation purification step. Cladding wastes were also added to these tanks. The cladding waste stream originated from the dissolution of the aluminum cladding from the fuel rods with a caustic nitrate solution and was a low activity stream. The 1st Cycle waste carried approximately 10% of the beta activity but a much lower fraction of fission products (Serne et al 2003). The cladding waste would have been a high aluminum, high hydroxide stream with low activity levels.

The uranium recovery process produced a waste stream at twice the volume of the metal waste recovery processed. This waste stream, called TBP or UR waste, was transferred back to a number of the C farm tanks. To free up tank space, the 1st Cycle wastes from C tanks were transferred to the B Evaporator. At a later date, the TBP wastes stored in C farm tanks was processed through for reduction of Cs-137 activity in the C Vaults. After allowing some time in C farm tanks for precipitation of resulting solids, the scavenged TBP waste was sent to the BC cribs and specific retention trenches. The 1st cycle wastes were later transferred to the B Evaporator. As C Farm tank space became available it was used to support pilot-plant studies at the Hot Semiworks and for low activity waste streams from PUREX. By the mid 1960s C Farm, tanks were being used to store aged PUREX high-level supernatants. As the B Plant isotope recovery process came online in 1968, several C farm tanks were used as feeder tanks supporting specific B Plant operations. Thus, many of the C farm tanks had very large volumes of wastes moved through them. The A Tank Farm, constructed in 1955, was used primarily to store PUREX high-level wastes. It was operated as a "boiling waste" tank farm with three laterals installed under each tank for leak detection. The four-tank AX farm was constructed in 1963 and 1964 and served the same purpose as the A farm tanks.

The high-level wastes coming from PUREX were very high-activity waste streams that were stored on the A and AX Tank Farms. After 3 to 5 years ageing, these wastes were transferred to other single-shell tanks to wait processing through B Plant. Waste streams coming from B Plant had reduced levels of Cs-137 and Sr-90 but also included additional organic completing agents.

The transfer of wastes through the C, A, and AX tanks are well documented in *Waste Status and Transfer Summary* (Agnew et al 1997) and *A History of the 200 Area Tank Farms* (Anderson 1990) and tank waste compositions are available from a number of sources, such as *Hanford Tank Chemical and Radio nuclide Inventories: HDW Model* (Agnew 1997), *Waste Management Technical Manual* (Buckingham 1967), and *B Plant Phase III Flow sheets* (Larson 1967). When tank waste loss events are well defined in terms of timing and volume, the inventory estimates for the lost materials are reasonability straightforward. However, the volumes of waste lost to the C and A-AX WMA vadose zone in various events are highly uncertain or unknown. Except for the tank A-105 leak no detailed analysis of known or suspected losses has been done in these tanks. Thus, inventory estimates for most waste loss events associated with the C and A-AX WMAs involve considerably uncertainty. Available information on specific leak events is provided in Section 3.3. Preliminary inventory estimates are provided in Section 4.3.

3.3 C AND A-AX WMA TANK WASTE LOSSES EVENTS

The *Waste Tank Summary for Month Ending December 31, 2002* (Hanlon 2003) lists three primary tanks and all four secondary tanks in the C Tank Farm, three tanks in the A Tank Farm, and two tanks in the AX Tank Farm as "confirmed or assumed leakers." Estimated leak volumes vary from 350 gal in secondary tank C-204 (1300 L) to a possible 277,000 gal (1,050,000 L) in tank A-105. None of estimated leak volume are well constrained. In addition to these a number of transfer line leaks have been reported as unplanned releases (see Section 2.1.2 and Appendices A and B). Each of the listed leaks is discussed below to determine the severity of the contamination. In addition, the validity of the leak designations was critically reviewed to determine if the observed contamination is significant enough to support the leaker designation and warrant further characterization. A number of tanks are listed as confirmed or suspected leakers by Hanlon (1999), but neither the waste transfer record nor the gamma logging data support the designation.

Some additional locations were also considered because spectral gamma logging data indicates sufficient contaminant concentrations to warrant evaluation. These sites have not been clearly identified in the past as vadose contamination zones.

3.3.1 C Tank Farm

Three of the twelve primary tanks in C Tank Farm (C-101, C-110 and C-111) and all four secondary tanks (C-201 through C-204) are listed in Hanlon (2003) as leakers. Of these, reliable leak estimates are available for none of the tanks. Evidence of tank waste losses to the vadose zone in these locations and other locations indicated by spectral gamma data are summarized below.

In addition to tank leaks, leaks from other infrastructure and tank farm activities occurred. An overall assessment of the spectral gamma logging data from C farm drywells indicates that most vadose zone contamination originated from surface or near surface sources. This is demonstrated by relatively high concentrations of Cs-137 near surface and a general decrease in Cs-137 activity with depth. Cobalt-60 is found near the bottom of many of the drywell with near surface Cs-137 contamination. This indicates that "mobile" Co-60 was driven down from recharge. These ubiquitous contamination events were not generally associated with particular recorded events and are not considered to be significant sources of vadose zone contamination. Those near surface contamination zones that are more concentrated are discussed in Section 3.3.1.2.

3.3.1.1 Tank Waste Losses from C Farm Tanks. Hanlon (2003) lists tank C-101 as a "known or suspected leaker" with a leak volume estimate of 20,000 gallons. Decreases in waste levels were documented in the late 1960s, a time when this tank contained aged PUREX high-level supernatant. A 20,000 gallon loss of this waste type would have released ~127,000 curies of Cs-137 (Simpson et al 2001), more than all of the Cs-137 projected to have been lost from all of the SX Tank Farm leaks (Jones et al 2000). The spectral gamma logging data from drywells around tank C-101 show little evidence of any leaks and certainly nothing of that order of magnitude. A far more likely scenario is the liquid level drops in the late 1960s were associated

with evaporation caused by the continuing high heat load of the aged PUREX high-level waste supernatants. The waste loss in the late 1970s appears to have been associated with saltwell pumping (Agnew et al 1997). Although the waste transfer records indicate that tank C-101 was filled above the 530 kgal fill limit from 1964 through 1969, there is no evidence of leaks from the spare inlet ports in this tank.

Spectral gamma data in two drywells around tank C-101 suggest small waste loss events may have occurred. In drywell 30-01-09, a Cs-137 peak (about 600 pCi/g) occurs about 28 ft bgs along with traces of Co-60, Eu-152 and Eu-154. The position of this peak suggests a small isolated leak from piping or a spare inlet port at this location. Tank waste chemistry suggests that Cs-137 in tank waste would be sorb readily on the soil and therefore, the leak location should be near the drywell. Because the peak value is low, it is concluded a substantial inventory was not associated with this leak. A second small tank leak may be indicated near drywell 30-01-06 where an apparent Cs-137 peak (about 50 pCi/g) around 40 ft bgs occurs, a depth that coincides with the tank bottom. Randall and Price (2001a) identified some instability in the gross gamma logs from 1979 to 1980 in this drywell at 30 to 41 ft bgs and interpreted the data as an indication of Cs-137 movement.

Hanlon (2002) lists tank C-110 as a known or suspected leaker. However, a detailed analysis of the history of the C Tank Farm (Agnew 1993) attributed liquid level decreases in 1969 to measurement errors and recommended the "leak status" of this tank be revisited. This analysis reaches similar conclusions. The spectral gamma logging data and historical waste transfer records provide no definitive evidence of leaks from this tank. The simplest explanation of spectral gamma logging in drywells around this tank is that the widespread surface contamination found its way down the inside or outside of well casings, likely from additions of water to suppress airborne transport of radionuclides.

At tank C-110 small concentrations of Cs-137 are found almost continuously in drywell 30-10-02 between the surface and 63 ft (19 m) bgs. The shallow contamination likely represents surface spills or shallow pipeline leaks (the cascade line between tanks C-110 and C-111 plugged in 1952 [Brevick 1994]), but the contamination between 44 and 63 ft (13 and 19 m) bgs may indicate the occurrence of a small leak. Cs-137 contamination was measured when the drywell was constructed in 1974, indicating the occurrence of a leak prior to this date. If a small leak did occur, the low Cs-137 concentration (maximum of 20 pCi/g) and the historical record of relatively dilute tank waste (first cycle waste, PUREX coating waste, organic wash waste) indicate that little contamination would have been released to the vadose zone. Very small concentrations of Cs-137 (< 1 pCi/g) were also measured on the west side of tank C-110 in drywell 30-10-09 between 17 and 38 ft (5 and 12 m) bgs. Contamination at this depth range may indicate a small transfer line leak. In addition, historical gross gamma records for 30-10-09 show a decrease of Ru-106 between 1975 and 1978 followed by an increase between 1978 and 1980 at tank bottom depth (40-60 ft (12 to 18 m) bgs). These data may be another indicator of this leak.

There are no spectral gamma data or well-documented historical record data suggesting leaks occurred at primary tank C-111 and secondary tanks C-201 through C-204. The *Waste Storage Tank Status and Leak Detection Criteria* document (Welty 1988) reported a liquid level drop in 1968 as the basis for questioning the integrity of tank C-111. However, the reliability of this

claim was not well-documented (DOE-GJO 1998b) and no spectral gamma data from drywells around the tank indicate loss of tank waste. No drywells are present near the secondary tanks and therefore no means of identifying leaked tank waste is available. In addition, no clear indication of tank leakage has been reported. However, given their small volume, it is concluded that no significant tank waste loss from this tanks has occurred.

Spectral gamma data strongly indicate that tank C-105 did leak, at least temporarily and the leak event is indicated by contamination observed at drywell 30-05-07 where two high Cs-137 concentration zones occur at and below the tank bottom. Between 34 and 44 ft (10 and 13 m) bgs and 48 and 62 ft (15 and 19 m), maximum Cs-137 values (10^7 pCi/g and 10^5 pCi/g, respectively) were recorded (DOE-GJO 2000a). The general location and profile of the spectral gamma logging data indicate that tank C-105 likely leaked near the bottom on the southwest side very near drywell 30-05-07. The gamma contamination was encountered when drywell 30-05-07 was drilled in 1974. The historical gross gamma data analysis indicates no changes in location or intensity of Cs-137 activity. Thus, if tank C-105 did leak then the leak occurred prior to 1974 and apparently self-sealed because tank C-105 was used as an active Cs-137 recovery feeder tank until 1978. The Cs-137 recovery wastes were aged PUREX and REDOX high-level wastes so any waste losses would have contributed radionuclides to the soil column.

Concerns about the integrity of tank C-105 are supported by the historical record of large liquid level drops (about 36 in) in tank C-105 between 1963 and 1967 (DOE-GJO 1997b). However, during the time tank C-105 stored aged PUREX high-level waste supernatant, liquid losses to evaporation are noted in the historical records (Agnew et al 1997). The contamination in the region between tanks C-104 and C-105 has been of interest (Brodeur 1993, Agnew 1993). Both cascade line and spare inlet port waste loss events have been suggested as sources of contamination in this region.

An alternate explanation for the high activity in drywell 30-05-07 has been given. It is suggested that Cs-137 in this drywell has origins in the cascade line between tanks C-104 and C-105 (Brodeur 1993). However, the likely waste, PUREX supernate, does not appear to have the appropriate chemical makeup to mobilize Cs-137 in the soil column. Therefore, a leak source at the tank wall two feet from the contaminated zone compared to the cascade line more than thirty feet away is much more plausible. The two high Cs-137 zones may indicate two leak events.

In addition to Cs-137 contamination at the tank bottom, isolated occurrences of Co-60, Eu-152 and Eu-154 are present. The true extent of these contaminants at this drywell location is difficult to determine. The very high Cs-137 concentrations may mask the occurrence of these isotopes at the same depth. In addition, the drywell ends at about 68 ft (21 m) bgs and additional contamination at greater depth cannot be determined.

Two other drywells may indicate the outer edges of the proposed tank C-105 leak. In drywell 30-05-05 just south of drywell 30-05-07, a Cs-137 peak (about 70 pCi/g) occurs between 60 and 65 ft (18 and 190 m) bgs and a Co-60 peak occurs at 70 ft (21 m) bgs. Proximity of the two drywells and consistent Cs-137 peaks with depth suggest the same leak source. Similarly, a Cs-137 peak (15 pCi/g) occurs at 47 ft (14 m) bgs in drywell 30-05-08. Co-60 is also present between 35 and 50 ft (11 and 15 m) bgs

3.3.1.2 Other Contamination Zones in the C WMA. Near surface contamination events are indicated at other locations within the C WMA by historical records, field investigations and drywell spectral gamma data. Unplanned releases in the C WMA, near surface transfer line leaks and generalized surface contamination are all indicated by this information. The most contaminated sources are discussed in greater detail below. Three significant unplanned releases that occurred to the west of C Tank Farm but still within the C WMA are described in this section. Within the C Tank Farm, spectral gamma measurements have been recorded at many drywells in the eastern half of C Tank Farm, particularly the southeastern segment. Cesium-137 and Co-60 are the most prominent contaminants and given the relative concentrations of these constituents, two locations appear to be the primary source of this contamination, these being the areas between tanks C-104 and C-105 and between tanks C-108 and C-109.

3.3.1.3 Unplanned Releases in the C WMA. Williams (2002) identifies a number of unintentional near-surface losses and windblown contamination events in the C Tank Farm. The Waste Information Data Base System (WIDS) summarized these events, also known as unplanned release events (UPRs). The *Handbook 200 Area Waste Sites* (Maxfield 1979) also discusses some events. Two of the UPRs (UPR-200-E-82, and UPR-200-E-86) involved PUREX high-level waste supernatant and contributed significant inventory to the soil column. A third UPR involved the loss of PUREX aluminum cladding waste. These three events occurred on the southwest side of the C Tank Farm and made relatively significant contributions to vadose zone contamination. The WIDS also identifies a number of other waste loss events but these involve either small (less than 100 gal) volume losses, airborne contamination spreads, or tank leak information mirroring the information in the monthly Hanlon report *Waste Tank Summary for Month Ending October 31, 2000* (Hanlon 2000). There is small overland piping leak (50 gal) involving the loss of PUREX cladding waste between tanks C-105 and C-108, documented in UPR-200-E-16. The spectral gamma logging data (DOE-GJO 1998a) for the C Tank Farm indicates widespread low-level Cs-137 contamination across much of this farm.

Report UPR-200-E-81 describes a 1969 waste loss event that occurred near the 241-CR-151 Diversion Box and involved the loss of 136,000 L (36 Kgal) of PUREX cladding waste (Williams 2001, Maxfield 1979). A puddle of contaminated liquid measuring 6 ft by 40 ft was formed. The puddle was backfilled with clean dirt in 1969. The PUREX cladding waste was a reasonably low activity waste stream produced from the caustic dissolution of the aluminum fuel rod cladding. The origin of the radioactive contamination in this waste stream was congruent dissolution of the uranium fuel during the de-cladding operation. It was estimated that 720 Ci of Cs-137 were lost to the soil.

Report UPR-200-E-82 describes the loss of Cs-137 Recovery Process feed solution being pumped from tank C-105 to the B Plant. The leak occurred near the 241-C-152 Diversion Box and involved the loss of approximately 2,600 gallons of liquids (Tanaka 1971). Approximately 100 gallons of this fluid surfaced. Surface contamination was covered with clean gravel in 1969. This waste loss event was thoroughly investigated and results are available in *B Plant Ion Exchange Feed Line Leak* (Tanaka 1971). It was estimated that 11,300 Ci of Cs-137 were lost to the soil. Additional inventory estimates of vadose contamination from this event are discussed in Chapter 4.

Report UPR-200-E-86 describes a waste loss event associated with a pipeline break near the southwest corner of the C Tank Farm. Fluids were being pumped from the 244-AR Vault to the C Tank Farm. Approximately 17,400 gal of fluid that contained approximately 25,000 Ci of Cs-137 were lost to the soil (Maxfield 1979). Based on the ratio of Tc-99 to Cs-137 in the irradiated fuel (~3x 10^{-4} Ci Tc-99/Ci Cs-137), approximately 7.5 Ci of Tc-99 were lost. This waste stream most likely originated from the water washing of PUREX sludge intended to remove Cs-137 (and other waste soluble components) from the sludge prior to acidification and Sr-90 recovery.

3.3.1.4 Near Surface Contamination in the C WMA. Generalized near-surface contamination occurs across the C Tank Farm and probably in other parts of the C WMA. About a dozen of the drywells in the farm have Cs-137 gamma activity that peaks at or above 100 pCi/g in the upper 15 feet of the vadose zone, however, most contaminated drywells are around 10 pCi/g. Two of these higher concentration zones, between tank C-104 and C105 and between C-108 and C-109, apparently are caused by small transfer leaks.

Between tank C-104 and C-105, a Cs-137 (531 pCi/g) peak at about 24 ft (7 m) bgs in drywell 30-04-03 indicates a transfer line leak. Apparently the Cs-137 was present before 1974 (Welty 1988). Below the Cs-137 peak, a Co-60 contamination zone (3–6 pCi/g) occurs from 26 ft (8 m) bgs to the bottom of the drywell (about 50 ft (15 m) bgs). Drywell 30-04-02 also includes Cs-137 and Co-60 contamination at similar depth ranges but the Cs-137 peak is not evident, suggesting that drywell 30-04-03 is closest to the source. In addition, Co-60 appears at a slightly greater depth interval between 40 and 60 ft (12 and 19 m) bgs in drywell 40-04-02. Historical gross gamma data indicate Co-60 movement for at least ten years beginning in 1975 when well-documented measurements were first taken. Drywell 30-04-01, which contains Cs-137 contamination almost continuously between the surface and the drywell bottom at 50 ft (15 m) bgs, may also have seen contaminant movement since 1975.

Third, a Cs-137 and Eu-154 peak (about 70 and 20 pCi/g, respectively) occurs in drywell 30-05-08 at 17 ft (5 m) bgs. This may or may not be the same transfer line that leaked near drywell 30-04-03. However, the fact that Eu-154 is present in this drywell and not in drywell 30-04-03 suggests somewhat different waste stream chemistry. No other contiguous drywells show this pattern.

Between tanks C-108 and C-109, a transfer line leak source is indicated by contamination in drywell 30-08-02. High Cs-137 concentrations occur between 20 and 22 ft (about 6 m) bgs and peak at 1,100 pCi/g in this zone. A Eu-154 peak (24 pCi/g) is coincident with Cs-137 and the more mobile Co-60 is present between 50 and 80 ft (15 and 24 m) bgs at concentrations up to 10 pCi/g. These contaminants were present when the drywell was installed in 1974. This contaminant plume appears to extend at least to drywell 30-06-10 where a similar Co-60 plume occurs between 86 and 115 ft (26 and 35 m) bgs at lesser concentrations (up to 1 pCi/g). Co-60 also occurs to a lesser degree in drywell 30-09-01 at 90 to 95 ft (27 to 29 m) bags. This location may represent the eastern extent of this contaminant plume. Other nearby drywells may also contain contamination that has migrated from this transfer line. These drywells (30-09-06, 30-09-07 and 30-09-02) along with drywells 30-08-02 and 30-06-10 contain mobile Co-60 that migrated in the 1980's between 40 and 115 ft (12 and 35 m) bgs according to the gross gamma record. The apparent lag time between initial discharge to the vadose zone before 1974 and the

observed Co-60 migration in the 1980s may indicate additional leakage or enhanced migration instigated by artificial discharge.

Numerous drywells in the east and southeast part of the tank farm other than those listed above contain Cs-137 primarily between the surface and tank bottom depth of about 40 ft (12 m) bgs and Co-60 that is located well below tank bottoms (80 ft [24 m] bgs and deeper) and has migrated during the course of the gross gamma logging program between 1975 and 1994. Generally speaking it appears that Co-60 migrates towards the east or southeast in the C WMA vadose zone, judging by the overall Co-60 distribution in the C Tank Farm drywells. The source of contaminants in the vadose zone may be related to the transfer line leaks, the proposed tank C-105 leak or unidentified leaks. However, when the transfer lines and tank C-105 are postulated as sources of the Co-60, contamination at specific drywells cannot be connected readily to these specific sources.

One other possible source is tank C-103. Two drywells (30-03-01 and 30-03-07) show small Cs-137 peaks around 50 ft (15 m) bgs that might indicate a tank leak. In addition, extended Co-60 contamination zones (20 ft (6 m)) occur in drywells 30-03-01 and 30-03-09 below 80 ft [24 m] bgs. However, these data do not clearly indicate a leak event. The Cs-137 data at drywell 30-03-01 is ambiguous because this drywell was completed in two stages and substantial Cs-137 contamination existed near the surface. During the second stage deepening of the drywell an opportunity presented itself for dragdown contamination in the depth range containing elevated Cs-137 concentrations. In drywell 30-03-07 the lack of a Co-60 contamination zone below the Cs-137 is unexpected if a tank leak occurred here and other surrounding drywells include Co-60 as a contaminant deeper in the vadose zone.

Finally, a small pipeline leak on the north side of tank C-112 is indicated by a thin high Cs-137 concentration zone at 8 ft (2 m) bgs in drywell 30-12-13. Lesser concentrations of Cs-137 (about 1 pCi/g), Co-60 and Eu-154 are found lower in the soil column (down to 50 ft (15 m) bgs).

3.3.2 A Tank Farm

Three of the six tanks in the A Tank Farm (A-103, A-104 and A-105) are listed in *Waste Tank Summary Report for Month Ending February 28, 1999* (Hanlon 1999) as leakers. Reliable leak estimates are available for none of the tanks. Evidence of tank waste losses to the vadose zone in these locations and other locations indicated by spectral gamma data are summarized below. Other areas of significant near surface contamination are discussed in Section 3.3.2.2.

3.3.2.1 Tank Waste Losses from A Farm Tanks. Spectral gamma measurements have been recorded in drywells around the A farm tanks and in laterals placed horizontally (about 10 ft [3 m] below the tank bottom) underneath each of the tanks. Historical reports (Welty 1988) identify an increase in radiation measured at the bottoms of drywells 10-03-01 and 10-03-07 (75 ft [23 m) bgs) in 1964 and in 1968 at drywell 10-03-07. Current spectral gamma data show little or no contamination at these locations. Spectral gamma data for several drywells (10-03-01, 10-03-0510-03-07, 10-02-03, and 10-03-11) around tank A-103 measure small amounts for Cs-137 (about 0.1 pCi/g) at 80 ft (24 m) bgs and below. All of these wells were drilled in two stages, first to 75 ft (23m) bgs and then further down. This history combined with

the very low measured values strongly indicates dragdown of any Cs-137 that might be present at depth. Given the lack of convincing evidence it is concluded that either tank A-103 did not leak or did not leak sufficiently to contaminate the vadose zone to any significant degree.

The primary evidence of tank waste leaks from tank A-104 is provided by measurements of increased radiation in two laterals underneath the tank in 1975, first in lateral 14-04-02 in the north central part of the tank and then in the southeast section in lateral 14-04-02. Eventually, radiation was measured in the third lateral as well. Evaluation of the gross gamma logs (Randall and Price 2001b) shows Ru-106 as a primary gamma emitter. The variable locations of radiation detection under the tank may indicate multiple leak locations. However, the extent of contamination that has actually entered into the vadose zone is quite limited given the lack of contamination in adjacent drywells. Spectral gamma data show no significant contamination at tank bottom depth.

Structural failure of tank A-105 is well documented (Caggiano 1991, WHC 1991, Beard et al. 1967). In January 1965, a sudden steam release occurred in tank A-105. Steam was released from a riser on an interconnected tank, A-103. The steam release event lasted for 30 minutes. Significant damage occurred to the bottom of the steel liner during the steam release event. It was estimated that, at most, 4 inches of liquids had been lost from tank A-105. Within a couple months, increased activity was measured in lateral 14-05-03 in two places on the east and north side of the tank. Subsequently, additional risers were drilled through the tank dome and the tank interior was inspected, revealing a significant section of the liner floor that had bubbled up and partially separated from the sidewall. Despite the obvious liner failure, it was determined that the tank was not leaking. No significant gamma activity was measured in the surrounding drywells suggesting that the concrete tank structure provided adequate containment for the tank fluids.

The tank was closely monitored until the tank contents had aged sufficiently to allow the supernatant to be sent to B Plant for Cs-137 recovery. Most of the PUREX sludge was sluiced from the tank, however, a high-heat hard heel was left in the tank. Consequently, water was added to the tank contents for cooling for the next eight years. Hanlon (2002) listed an estimated leak volume for tank A-105 as 10,000 to 277,00 gallons. The 10,000 gallons represents the upper limit of the volume of tank waste lost during the initial steam release event. The additional volume represents cooling water that may or may not have leaked from the tank during the eight years of water addition. The lack of significant gamma reading in nearby drywells strongly indicates the volume estimate of 10 kgal to be extremely conservative. Liquid volume lost associated with the 30-minute steam release event is unknown but could have accounted for all of the liquid loss from this tank.

Over time, additional lateral measurements of increased activity did occur in other laterals, which could have indicated additional leak locations or spreading from the initial leaks. The current spectral gamma database continues to show minimal tank waste contamination in the vadose zone (DOE-GJO 1998c). Cesium-137 concentrations have been measured at several drywells (10-05-02, 10-05-05, 10-05-07, 10-05-09, 10-06-09 and 10-05-12) at the tank bottom and lower depths. However, many of these drywells were constructed in two stages and dragdown contamination is likely in most of them. One drywell (10-05-10) may contain Cs-137 contamination from the A-105 tank leak (between 75 and 86 ft (23 and 26 m) bgs) but the

complicated drilling process may have shifted the Cs-137 from its original location. The historical gross gamma log shows a shift in Cs-137 contamination levels around 1978 but this is probably related to the second stage drilling that occurred then.

3.3.2.2 Additional A Tank Farm Contamination. The only other area of significant vadose zone contamination indicated by spectral gamma data in the A Tank Farm is a small area between tanks A-101 and A-102. In this area, subsurface contamination levels exceed those around the tanks that have leaked in the A Tank Farm. Historical records and the spectral and gross gamma data indicate a complicated tank waste release history. At least two leak sources appear to be indicated as well as enhanced recharge that occurred from leaking water lines in the vicinity. The first source appears to be leaking pipes at the 241-A-01B sluice pit at the southeast side of tank A-101. Occurrence Report 81-03 by Lindsay (1981) reports the drilling and sampling of several boreholes (not the current drywells) on top and at the periphery of the tank dome between the sluice pit and drywell 10-01-04. The boreholes near the sluice pit were reported to contain Cs-137 and those at the periphery contained C-60 and Ru-106. Two drywells 10-01-03 and 10-02-08 contain 2 ft (1m) zones of very high Cs-137 concentrations around 5 ft (2 m) bgs. Given the general reactivity of Cs-137, these sites are unlikely to contain Cs-137 that migrated from the sluice pit. The source of additional leaks is probably a shallow pipeline or multiple pipelines. Neither the time of the leaks nor the leak volumes are known.

Just south of these locations are a group of four drywells (10-01-28, 10-01-39, 10-01-16 and 10-01-04) that include Cs-137, Eu-154, and Co-60 and show a contaminant distribution pattern at 30 ft (10 m) bgs and below suggesting a common source to the north, either the postulated sources described above or an additional unidentified source (e.g., a cascade line leak). All of these drywells show Cs-137 contamination between 0 and 20 ft (6 m) bgs and then increasing contamination at greater depth. Peak concentrations occur at the shallowest depth in drywell 10-01-28 around 25 to 30 ft (8 to 10 m) bgs. As the drywell locations move south the peak concentration depths deepen slightly and more reactive contaminations drop out (e.g., all three isotopes are present in drywell 10-01-28 and 10-01-39, only Co-60 is present at drywell 10-01-04).

3.3.3 AX Tank Farm

Two of the four tanks in the AX Tank Farm (AX-102 and AX-104) are listed in Hanlon (2000) as leakers. Reliable leak estimates are available for neither of the tanks. The AX tanks had leak detection systems build into to the tank bases and no data have been found that indicate any positive hits in these systems. Evidence of tank waste losses to the vadose zone in these locations and other locations indicated by spectral gamma data are summarized below.

The conclusion that tank AX-102 leaked was based on several occurrence reports beginning in 1975 of slight liquid level drops, slight increases in borehole activity and an increase in the leak detection pit activity. None of these occurrences were clear indicators of leakage. The most likely real leak event associated with the occurrence reports was loss from a coupling to an exhaust vapor header attached to the tank. The highest gamma contamination among the boreholes surrounding tank AX-102 occurs at about 12 ft (4 m) bgs in drywell 11-02-12 and has been attributed to this event. In this zone Cs-137 concentrations exceeded the detection limit and

Eu-154, Co-60 and Sb-125 are also present. Co-60 and Sb-125, being apparently more mobile than Cs-137 and Eu-154 are measured below the high concentration zone between 12 and 30 (4 and 10 m) bgs. Very small Cs-137 concentrations (about 2 pCi/g or less) occur between 50 and 70 ft (15 and 21 m) bgs at drywell 11-02-01 and between 30 and 50 ft (10 and 15 m) bgs at drywell 11-02-02. While this contamination may be an indicator of a small tank leak, it seems more likely that dragdown is the cause.

The conclusion that tank AX-104 leaked was based on several occurrence reports describing increased activity in nearby drywells and one liquid level decrease event. The gross gamma activity records measured increased activity around tank bottom level but were brief in duration and of poor quality. The spectral gamma data from surrounding drywells show no levels of elevated activity (DOE-GJO 1997c). Thus, if any leakage did occur it was not significant.

Two other locations in AX Tank Farm contain elevated concentrations of gamma emitting radionuclides. Between tanks AX-103 and AX-101on the north side, a surface spill is indicated in drywells 11-01-10,11-03-02 and 11-03-12 (DOE-GJO 1997d, 1997e). Drywell 11-01-10 is located closest to the source of the spill. Between 3 and 5 ft (1 and 3 m) bgs, a high Cs-137 concentration zone occurs (up to 4,000 pCi/g) at drywell 11-01-10. Cobalt-60 and Eu-154 were also detected between 5 and 15 ft. At drywell 11-03-02 elevated Cs-137 concentrations (up to 1,000 pCi/g occur between the surface and 26 ft (8 m) bgs along with Co-60 and Sb-125. The edge of the spill may be indicated at drywell 11-03-12 where Cs-137, Co-60 and Sb-125 were measured between the surface and 10 ft (3 m) bgs.

The second location containing elevated gamma-emitting radionuclides occurs at the southwest side of tank AX-103 and northwest side of tank AX-104. Surface spills are again indicated by the intensity and distribution of gamma-emitting radionuclides at drywells 11-03-07 and 11-04-10 (DOE-GJO 1997c, 1997e). Elevated concentrations of Cs-137 (about 100 pCi/g), Co-60 (1 pCi/g) and Eu-154 (10 pCi/g) were measured between 5 and 8 ft (2 and 3 m) bgs at drywell 11-03-07. At drywell 11-04-10, Cs-137, (1450 pCi/g) Co-60 (5 pCi/g) and Eu-154 (22 pCi/g) peak about 5 ft (2 m) bgs. Contamination in these two holes may have resulted from the same discharge event or may indicate separate discharge events. Historical gross gamma data (Price 2001) indicate vertical migration of Ru-106 in boreholes 11-03-07 and nearby boreholes 11-03-09, 11-04-01 and 11-04-11 with all incidents occurring in the late 1970s.

3.4 CURRENT ASSESSMENT OF SINGLE-SHELL LEAK INFORMATION

The current status of tank leak information is summarized in Table 3-1 for the tanks in C, A and AX Tank Farms. All tanks listed as leakers in Hanlon (2002) and one additional tank, C-105, are listed Table 3.4-1. Concurrence or disagreement with the Hanlon report is indicated in the fourth column and reflects the evaluation provided in this report. Tank C-105 was added to the list because it was concluded to be a leaker in this evaluation.

The primary indicators of tank leakage are historical liquid level records for individual tanks and gamma logging data in drywells around tanks. Tank leaks are indicated by liquid level drops that clearly occurred and cannot be explained by liquid waste transfers and by the presence of gamma emitting radionuclides at appropriate depths and concentrations in the vadose zone near

tanks. A statement of no evidence for leaks indicates that the recorded liquid level drops, where available, were too uncertain to indicate tank leaks and gamma data showed little or no contamination that could be linked unequivocally to a leaking tank. In no case is the absolute integrity of any tank implied by this conclusion, but relative to further characterization and risk evaluation, these tanks are considered to be insignificant contributors to current vadose zone contamination.

Table 3–1. Tank Leak Information Summary

Tank	Listed in Hanlon Table-5	Hanlon Leak Volume (Gal)	Treated as Leaker Here	Volume Suggested
A-103	Yes	5,500	No evidence for leak	
A-104	Yes	500 to 2500	Yes	Inventory estimate assumes 2 Kgal
A-105	Yes	10K to277K	Yes, but likely very small	Inventory estimate assumes 1 Kgal
AX-102	Yes	3,000	No evidence for leak	
AX-104	Yes	Not Reported	No evidence for leak	
C-101	Yes	20,000	No evidence for leak	
C-105	No	-----	Early leak likely	Unknown but small Inventory estimate assumes 1 Kgal
C-110	Yes	2,000	No evidence for leak	
C-111	Yes	5,500	No evidence for leak	
C-201	Yes	550	No evidence for leak	
C-202	Yes	450	No evidence for leak	
C-203	Yes	400	No evidence for leak	
C-204	Yes	350	No evidence for leak	

3.5 GROUNDWATER CONTAMINANT INFORMATION

This section covers the current state of groundwater contamination surrounding the A-AX and C WMAs, including historic constituent trends that depict the temporal and spatial distribution of contaminants. Several distinct suites of contaminants are recognized, based on spatial relationships and on identifying associations of co-contaminants or aqueous chemical parameters. Given the complicated history of waste discharge to the subsurface in the last 50 years combined with artificial reversals in the natural flow direction and the ambiguities and dynamics in the current flow direction (see B/BX/BY Field Investigation Report (FIR) for further information), identifying sources at this time is not possible. The current regional distribution of radionuclides (i.e., tritium, strontium, uranium, technetium, and iodine) in the groundwater in the 200 East Area is shown in Figure 3-1, and the nitrate and chromium distribution is shown in Figure 3-2. Near the C and A-AX WMAs, contaminant concentrations are moderate and there is no clear indication of vadose contamination within the WMAs being a source.

Figure 3-1. Distribution of Radionuclides in the Unconfined Aquifer in 200 East Area.

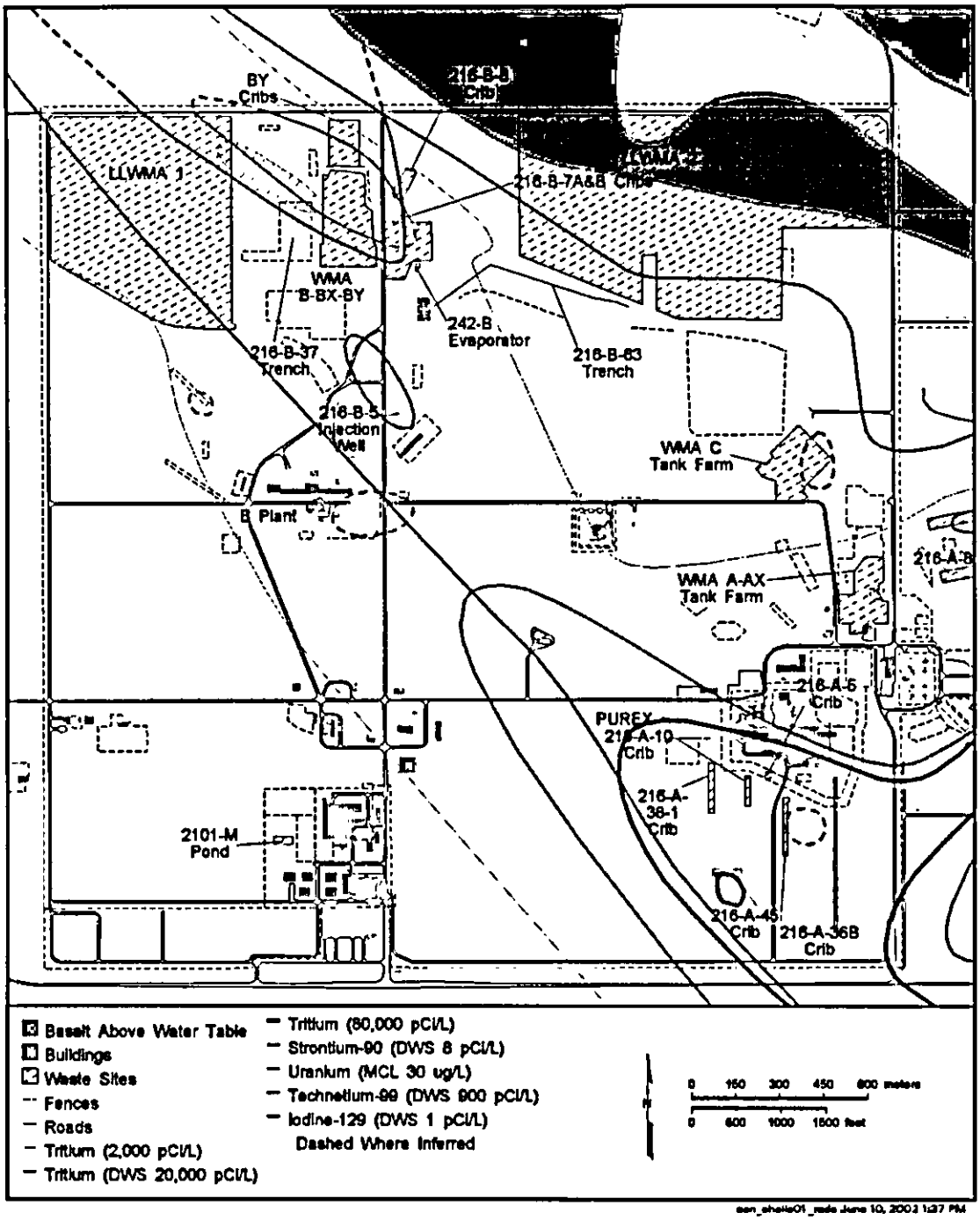
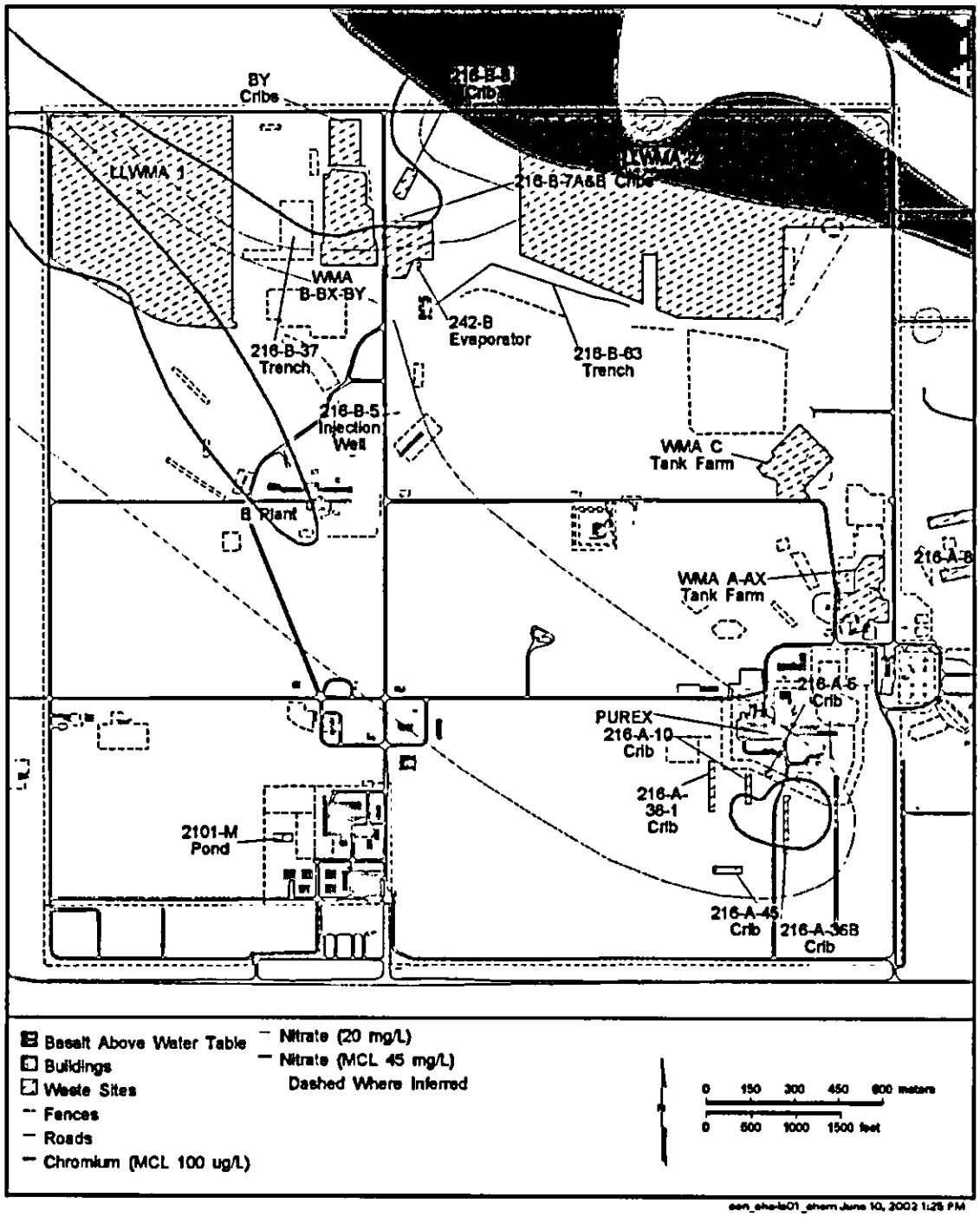


Figure 3-2. Distribution of Chromium and Nitrate in the Unconfined Aquifer in 200 East Area.



3.5.1 Groundwater Monitoring Results Near the C WMA

Groundwater samples have been taken regularly from several groundwater monitoring wells around the C WMA since the early 1990s. These include monitoring wells299-E27-13. 299-E27-12, 299-E27-15, 299-E27-7, and 299-E27-14. Recent chronological changes in key constituent values (pH, specific conductance, and technetium-99, nitrate, sulfate and choride concentrations) are summarized below and illustrated in Figures 3-3 through 3-6.

Key constituent values remained essentially constant and at values below regulatory concern until the late 1990s, at which point some values began to increase. During fiscal year 2001, critical mean values from samples taken from groundwater wells monitoring the C WMA were not exceeded for the three indicator parameters of pH, total organic carbon, and total organic halides. However, the critical mean value for specific conductivity (553.3 uS/cm) was exceeded in well 299-E27-14 at the end of FY2001 (Figure 3-3). An averaged value of 614 uS/cm was reported for this cross gradient well for the September 2001 sampling event. The increase in conductivity is due primarily to rising sulfate and calcium along with nitrate and chlorine (Figure 3-4). Sulfate was 135 mg/L while nitrate was 29 mg/L for July 2001. The September 2001 sulfate data is abnormally low and is under review. The nitrate value for September 2001 is 43.8 mg/L, very close to the DWS of 45 mg/L.

Technetium-99 activities continue to increase in all wells at the C WMA(Figure 3-5). This technetium-99 contamination correlates to the rising anionic chemistry. Although downgradient well 299-E27-13 had a pulse of technetium-99 (487 pCi/L) seen in 1998, the recent technetium-99 contamination began to increase in the mid-1990s in well 299-E27-14, to a value of 1190 pCi/L in July FY2001. The greatest increase in FY2001 was detected in well 299-E27-7, which had a maximum value of 2190 pCi/L in July 2001 (DWS 900 pCi/L). The correlation of the nitrate to the technetium-99 is shown in Figure 3-6. As can be seen, nitrate is greater in well 299-E27-14 while technetium-99 is higher in well 299-E27-7. These reversals in concentration versus activity levels indicate contaminant contributions from multiple sources.

Figure 3-3. Trend Plots of Specific Conductance for C WMA.

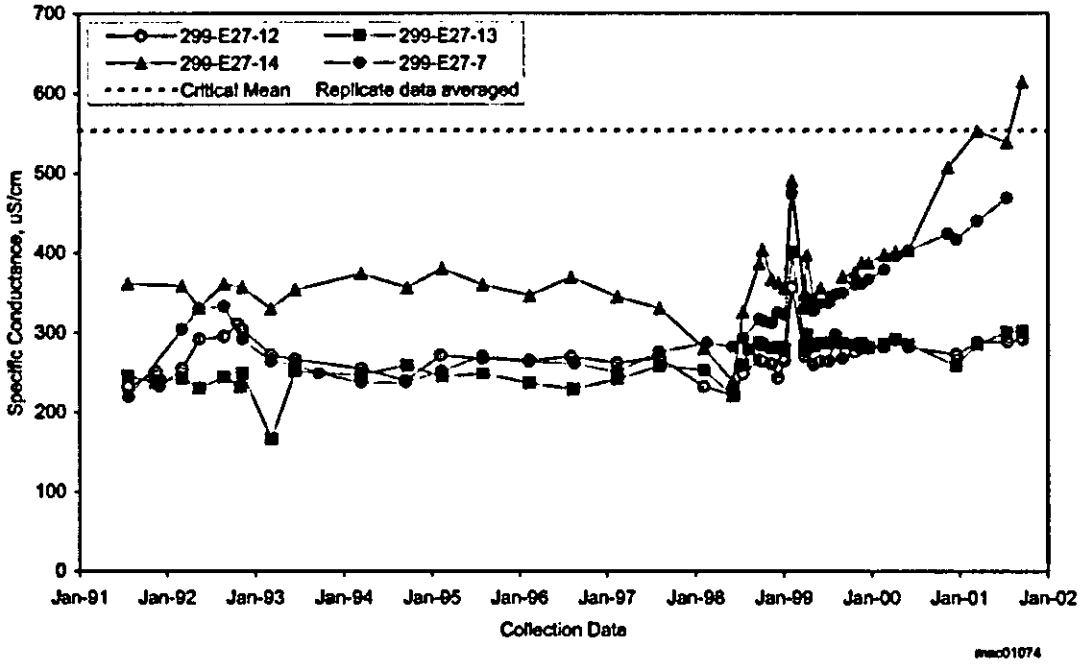
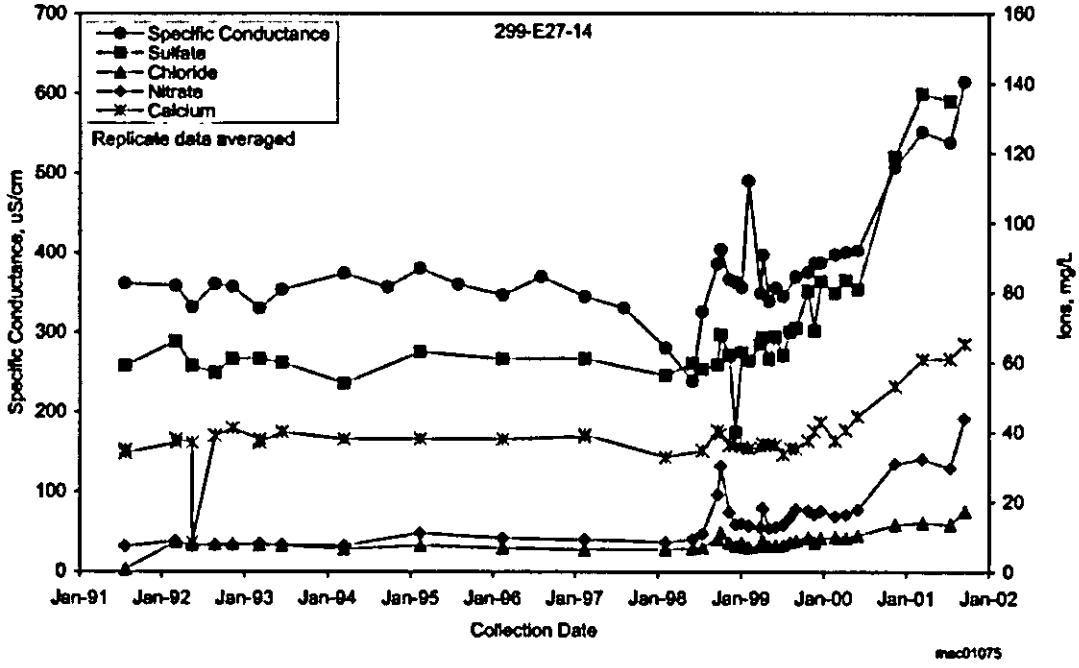


Figure 3-4. Trend Plots of Specific Conductance, Cations and Anions for Well 299-E27-14.



These increases in well 299-E27-14 are part of a contaminant plume that may be moving into the area from upgradient areas in recent years. Although the source of this contamination is presently unknown, it may be related to past discharges that moved through the area when the B Pond was in full operation or from the upgradient 216-B-3-1 ditch. As part of a continuous ditch system connected to the 216-B-63 Trench, this ditch was decommissioned in 1964 after an accidental release of mixed fission products from the PUREX Plant was discharged directly to the 216-B-3-1 Ditch (DOE 1993a).

The technetium-99 level in well 299-E27-7 rose quickly in 2001, which often indicates a nearby source. However, a plausible source is not readily identifiable. (e.g., the 216-B-3-1 ditch does not appear close enough to be the source of this groundwater contamination). Results from well 299-E27-7 have also shown low levels of cyanide with a maximum value of 17 µg/L in June 2000. Ferrocyanide scavenging was conducted in the 244-CR Vault with storage in selected tanks at Waste Management Area C (Kupfer et al 1997). Although well 299-E27-7 is the upgradient well for this WMA, the only known sources for cyanide are the 244-CR vault and the waste stored in the C Tank Farm. Again, a readily identifiable source is not known. Cyanide concentrations decreased during FY2001, and presently cyanide is not detected in this well or any other network monitoring well.

Figure 3-5. Trend Plots of Technetium-99 for the C WMA.

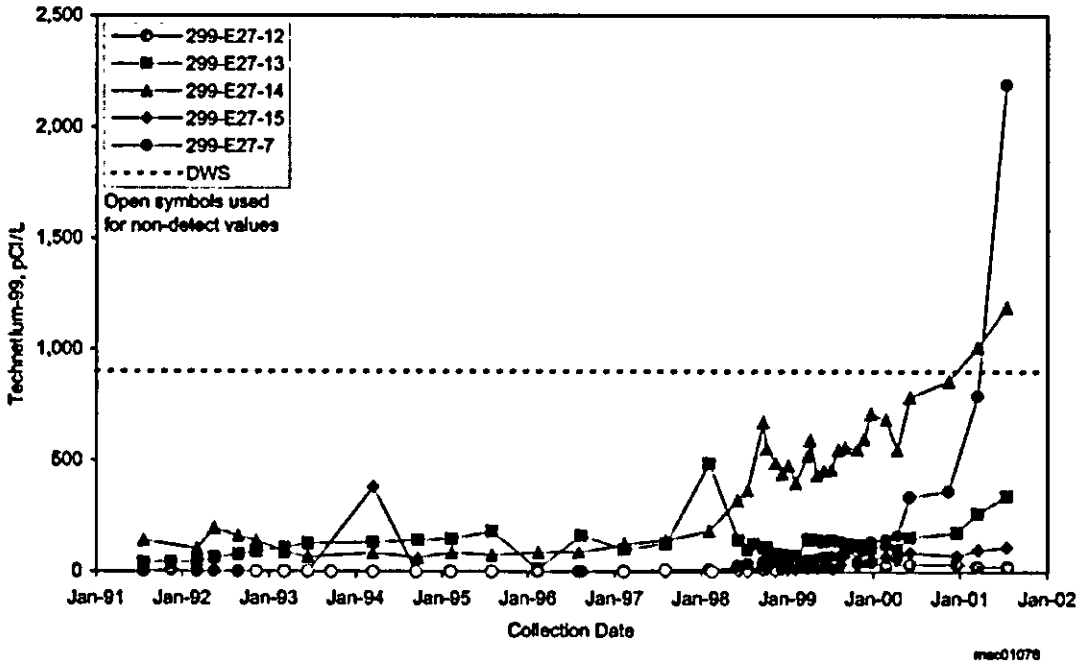
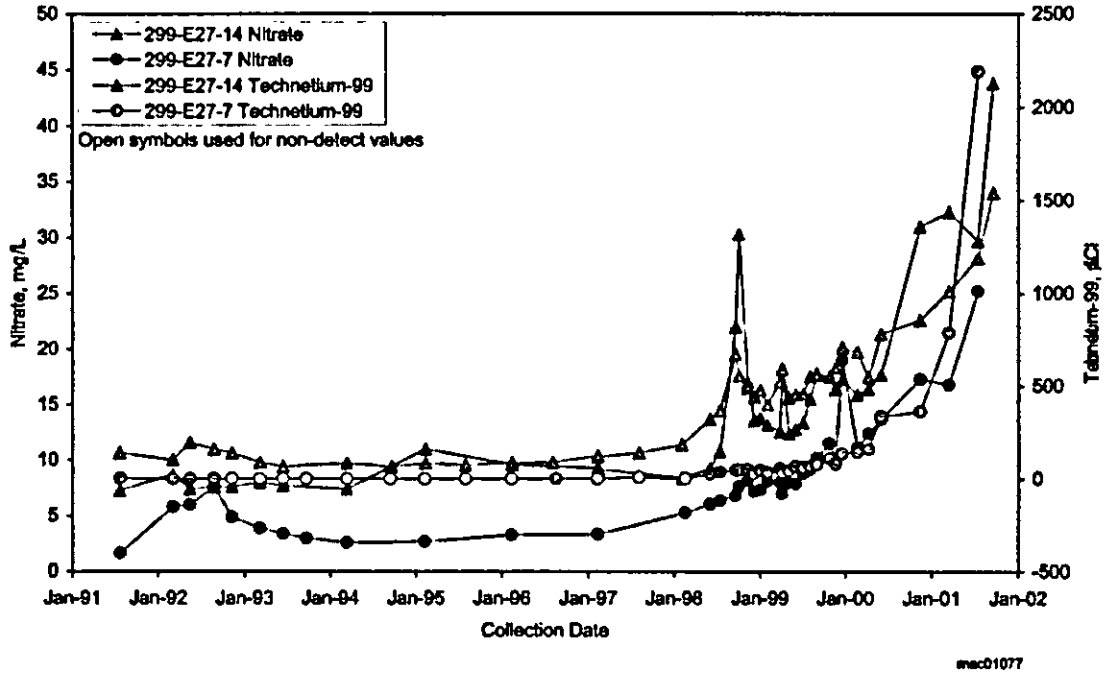


Figure 3-6. Trend Plots of Nitrate and Technetium-99 for the C WMA.



There does not appear to be other tank-related waste in the groundwater at Waste Management Area C. Tritium levels are low, generally less than 1,500 pCi/L, except at well 299-E27-7 where values rose from about 600 to 2,500 pCi/L during the late 1990s. Currently, the trend remains steady near 2,480 pCi/L. Based on these measurements, C WMA still is not considered to be under RCRA corrective actions.

3.5.2 Groundwater Monitoring Results Near the A-AX WMA

Groundwater samples have been taken regularly from several groundwater monitoring wells around the A-AX WMA since the early 1990s. These include monitoring wells299-E25-46, 299-E24-19, 299-E24-20, 299-E25-40, and 299-E25-41. Recent chronological changes in key constituent values (pH, specific conductance, and technetium-99, nitrate, sulfate and choride concentrations) are summarized below and illustrated in Figures 3-7 through 3-13. Overall, these data provide no indication that vadose zone contamination in the A-AX WMA contributes to local groundwater contamination and hence this WMA is not under RCRA corrective action.

Key indicator values (specific conductance, pH, technetium-99 activity and nitrate, sulfate and chloride concentrations) have generally remained below regulatory triggers. Although concentrations of indicator parameters, conductivity, TOC and TOX have not exceeded the critical means at Waste Management Area A-AX since 1992, the pH fell below the critical range (6.89 to 9.24) in well 299-E24-19 in July 2001. This well is, at best, cross gradient as it is located on the southwest side of the WMA (see Figure 1-3). Verification sampling was conducted in October 2001 resulting in a pH value of 7.13. Causes for the low pH are discussed

below in relation to the elevated chromium found in the groundwater at this location. Specific conductance values generally ranged from 261 to 374 µS/cm during fiscal year 2001 (Figure 3-7), reflecting changes in sulfate and nitrate concentrations. The primary cation is calcium. These specific conductance values are well below the critical mean of 534.9 µS/cm. Figures 3-8 and 3-9 show trend plots for sulfate and nitrate, comparing contaminant levels in the A-AX WMA network groundwater monitoring wells. The specific conductance changes that occurred at the A-AX WMA are generally dominated by sulfate except for well 299-E24-20 (maximum contaminant level 250 mg/L). Although sulfate appears to increasing in wells on the southwest side of the WMA, sulfate concentration ranges from 37 to 48 mg/L, which is within the Hanford Site background values reported in WHC-EP-0595 (~14 to 60 mg/L). Although in the past, sulfate concentrations above background values were identified in two wells, 299-E25-40 and 299-E25-41, the recent trend appears to be decreasing to values of 55 to 57 mg/L.

Nitrate values (Figure 3-9) have ranged from ~4 to 12 mg/L, which falls within the ranges of background values of 3 to 12 mg/L for the Hanford Site (Johnson et al 1993) except at well 299-E24-20 located west of the A Tank Farm and south of the 244-AR vault (see Figure 1-3) where anomalously high values have been measured. Nitrate concentrations about 45 mg/L occurred between 1992 and 1994 and then began to increase in 1996 and beyond to values above 30 mg/L.. This well is upgradient of the A-AX WMA, suggesting an upgradient source for higher nitrate concentrations in this well. There is a good correlation with anomalously high tritium activity at this well whose value remained the same from ~9,200 pCi/L in February 2000 to 9170 pCi/L in December 2000 (Hartman et al 2002). Tritium values at other nearby wells ranged from 3,530 to 5,000 pCi/L.

Figure 3-7. Trend Plots of Specific Conductance for WMA A-AX.

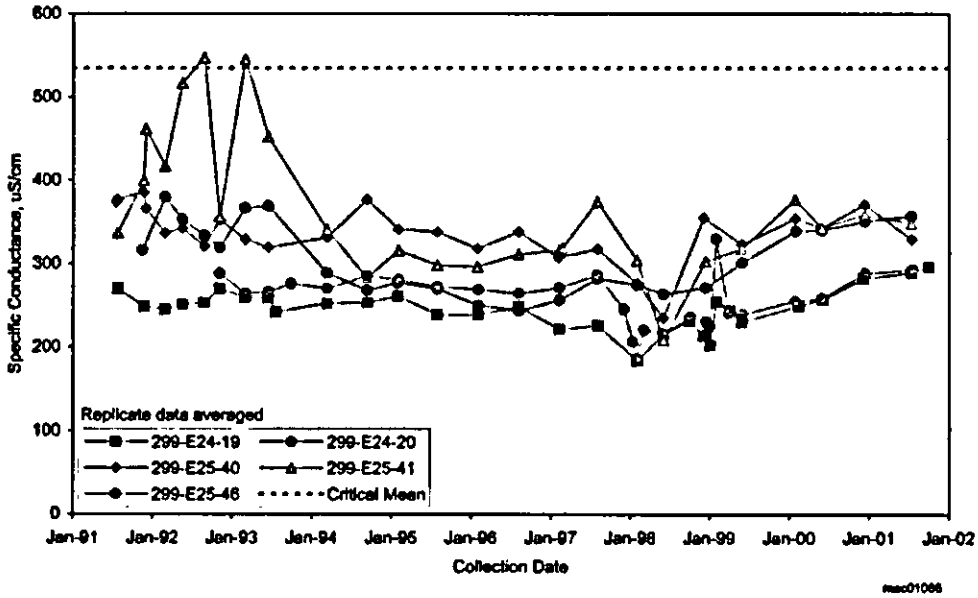


Figure 3-8 Trend Plots of Sulfate for WMA A-AX.

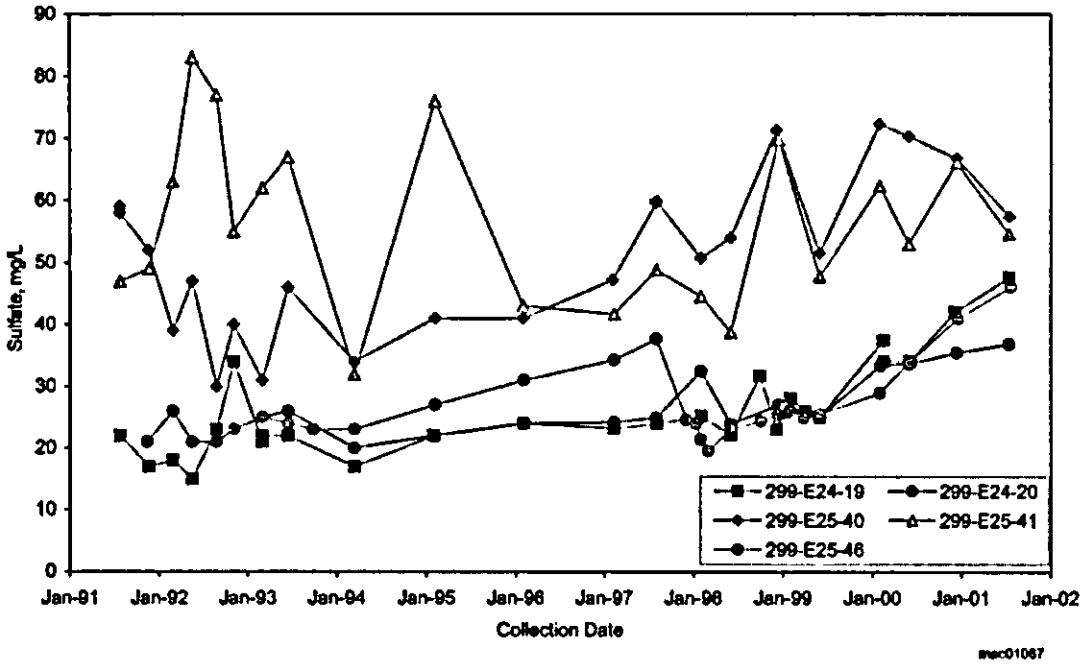
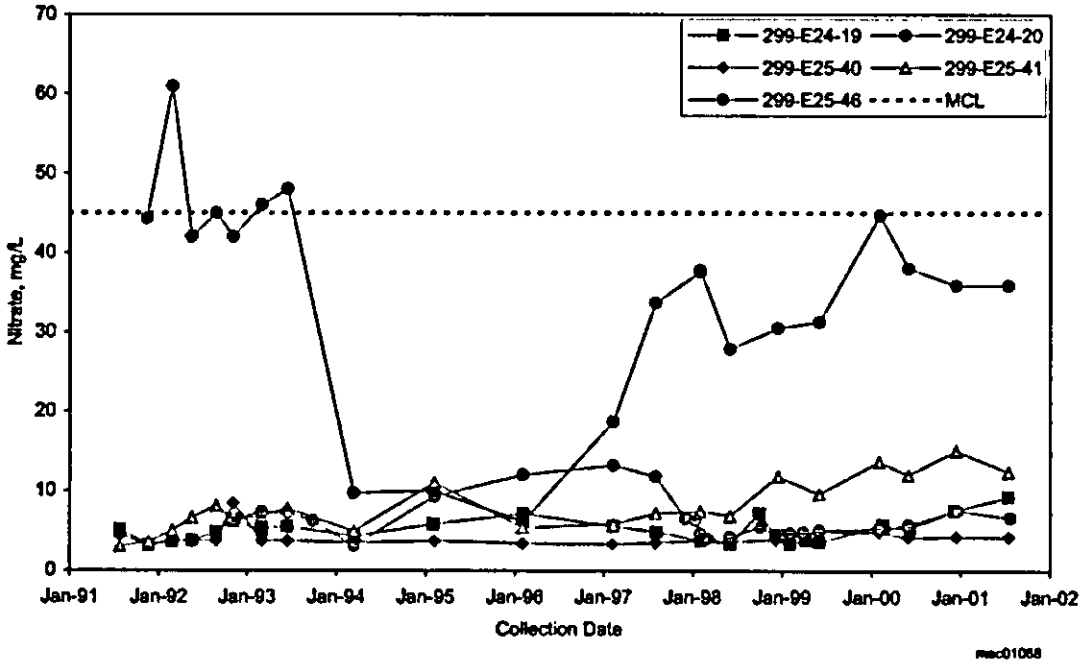


Figure 3-9. Trend Plots of Nitrate for WMA A-AX.



Technetium-99 concentrations for the same set of wells at this WMA are generally low (Figure 3-10), the one notable exception being in well 299-25-46 where a moderate increase in activity to about 400 pCi/L was measured in 1997. Comparison of nitrate and technetium-99 trends in these wells (figures 3-9 and 3-10) show no particular correlation, an observation that frequently is attributed to a vadose zone tank waste source..

In filtered samples from well 299-E24-19, chromium continues to be detected at values above the DWS of 100 ug/L. The last reported value in July 2001 is 1640 ug/L (Figure 3-11). The similarity of manganese and nickel concentration trends to chromium (Figure 3-11) indicate well screen corrosion effects rather than a tank waste source. To test this hypothesis, changes in well 299-E34-19 water chemistry were measured over a 40 minute period at a pumping rate of 3 gallons per minute in December 2000. During that time chromium concentrations dropped noticeably while specific conductance remained relatively constant (Figure 3-12). This suggests that chromium is only present near the borehole relative to those constituents prevalent in the groundwater and contributing to specific conductance measurements (e.g., nitrate, sulfate, sodium). Because chromium is a product of well casing corrosion, the supply is rapidly used up and concentrations fall quickly.

Figure 3-10. Trend Plots of Technetium-99 for WMA A-AX.

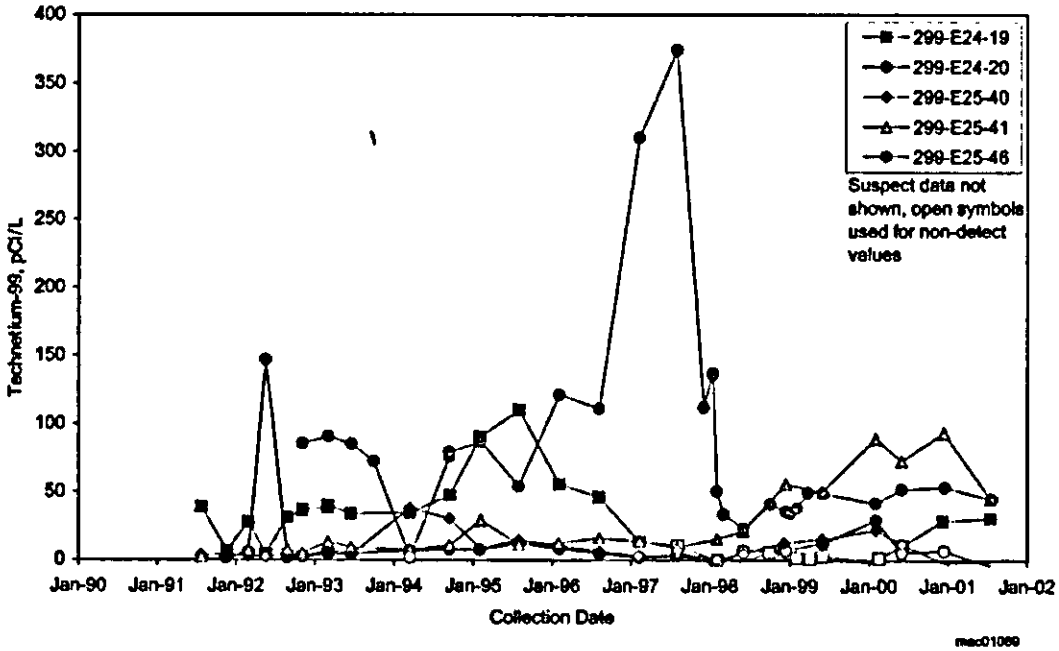


Figure 3-11 Trend Plots for Filtered Chromium, Nickel, and Manganese, for Well 299-E24-19. These data are from filtered samples.

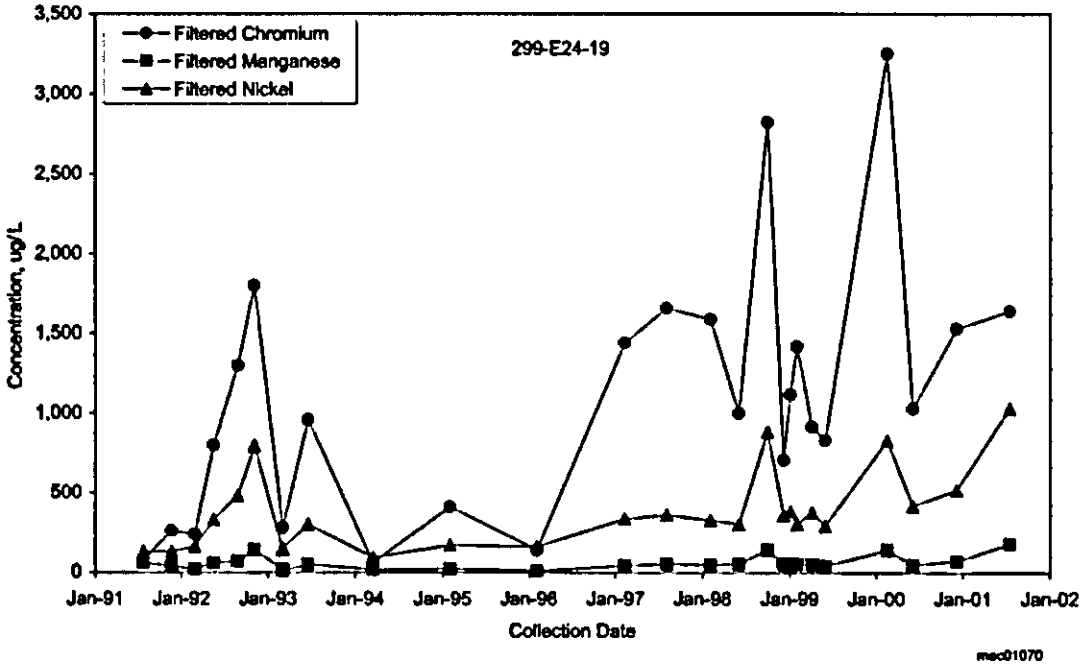
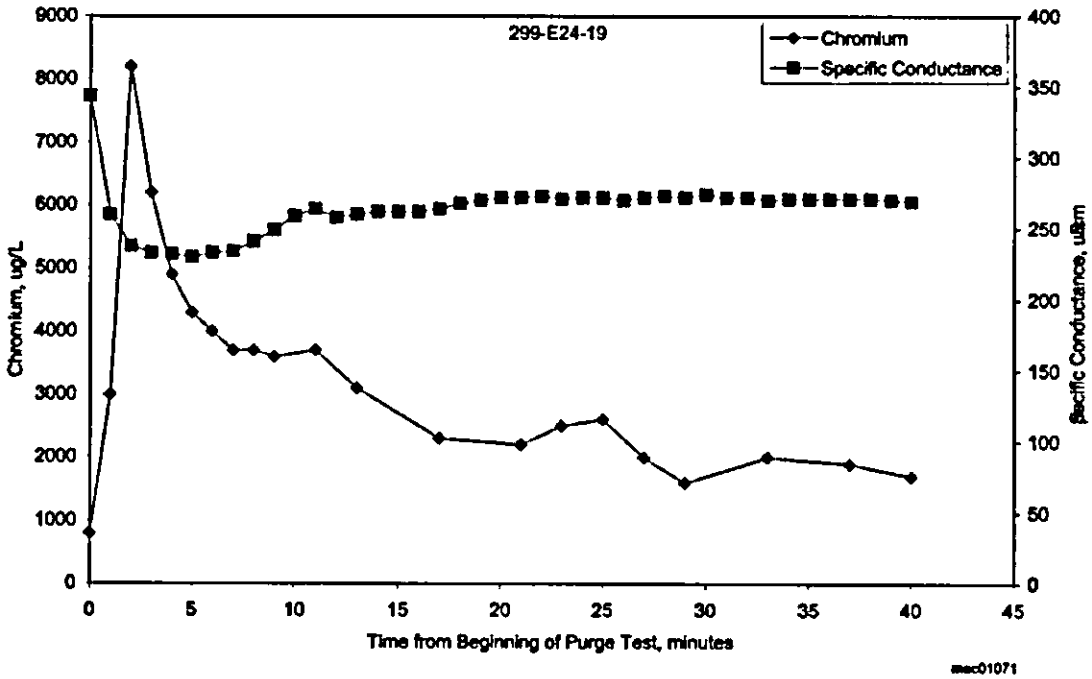


Figure 3-12. Trend Plots for Filtered Chromium and Specific Conductance for Well 299-E24-19.These data are from filtered samples.



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4.0 DATA INTEGRATION AND CONTAMINANT MIGRATION CONCEPTUALIZATION

This section provides qualitative hypotheses and conclusions about the nature and distribution of contamination present in the C and A-AX WMAs. The bases for these observations are the data described in Chapter 3 and the appendices.

4.1 GENERAL OBSERVATIONS

Multiple vadose zone contamination events have occurred in the C and A-AX WMAs. Evidence for these events is provided by the historical record, and historical gross gamma and spectral gamma data. Outstanding characteristics of contaminant occurrences in these WMAs include the following:

- The primary gamma emitting radionuclides measured in the C, A, and AX Tank Farms are Cs-137, Co-60, and Eu-154. Antimony (Sb)-125 is occasionally measured and historical gross gamma evaluations indicate the presence of Ru-106 in the 1970s, which has since decayed to negligible quantities.

- Cesium-137 contamination is found from the surface down to as much 30 ft (9 m) bgs in the majority of drywells in the C, A and AX Tank Farms. Typically, Cs-137 concentrations are < 10 pCi/g and are at maximum value just below the surface. This contamination is attributed to surface spills from tank farm activity. The most contaminated area apparently caused by a surface spill occurs in the AX Tank Farm between and on the north side of tanks AX-103 and AX-101. The drywell with the highest contamination, 11-01-10, contains up to 4,000 pCi/g between 3 and 5 ft (1 and 3 m) bgs. Co-60 and Eu-154 are also present in this borehole.

- Cesium-137 is most highly concentrated in drywell 30-05-07 next to the southwest part of tank C-105 where two zones at and just below the tank bottom (between 34 and 44 ft (10 and 13 m) bgs and 48 and 62 ft (15 and 19 m)) contain maximum concentrations of 10^7 and 10^5 pCi/g, respectively.

- Co-60 is concentrated in a few areas within these WMAs, including the eastern half of the C Tank Farm, between tanks A-101 and A-102 at the south end in the A Tank Farm, and in the northwestern quadrant of AX Tank Farm. Co-60 occurs most frequently and at greater depth (> 90 ft (27 m) bgs) in the eastern part of the C Tank Farm. Historical gross gamma data indicate Co-60 migration in the late 1970s and early 1980s in the C Tank Farm drywells near presumed transfer line leaks between tanks C-104 and C-105, between tanks C-108 and C-109 and around tank C-103. Co-60 is also tracked in drywells between tanks A-102 and A-102 at the south end between in the late 1970s and 1980s. The deepening progression of Co-60 over time is clearly illustrated at drywell 10-01-04.

- Gross gamma measurements in the 1960s in laterals underneath tanks A-104 and A-105 are the primary indicators of tank waste constituents leaked in the vadose zone from structural failure of these tanks.

- Unintentional releases of tank waste occurred sporadically during tank farm operations. From a vadose zone contamination perspective, the most significant losses occurred from two transfer lines at the west and southwest edge of the C WMA (UPR-200-E-82 and UPR-200-E-86). In both cases, high activity PUREX waste leaked into the vadose zone.

- Unintentional releases of raw water in the tank farms do not appear to have been common. One reported incident occurred on the east side of the A Tank Farm in 1978. A two-inch water line broke and released an estimated 60,000 gal (227,000 L) created a cave in at the surface between the tanks A-102 and A-105 (Caggiano 1991).

These observations clearly show that multiple contamination events have occurred and varying degrees of contamination in the vadose zone have resulted. Integration of the data and conceptualization of leak events associated with the larger contamination areas in the C and A-AX WMAs are described in greater detail in Section 4.2.

4.2 CONCEPTUALIZATION OF PRIMARY VADOSE ZONE CONTAMINATION EVENTS

Three types of vadose zone contamination events occurred in the C and A-AX WMAs. These include surface spills attributed to various unspecified tank farm activities, waste transfer line leaks, and tank leaks. Conceptual models are provided in the following sections for those leaks that have discharged the largest inventories into the vadose zone. Several assumed leaks are not discussed further because neither the historical record nor the field evidence supports a substantive tank waste loss to the vadose zone. These include assumed tank leaks from tanks C-110, C-111, A-103, AX-102 and AX-104. At tank C-101, two potential tank bottom leaks can be inferred from Cs-137 peaks at about 37 ft (11 m) bgs. One is on the west (drywell 20-01-09) and the other is on the south (drywell 30-01-06) side of tank C-101. In both cases, peak concentrations are less than 1000 pCi/g. The isolated contamination at this depth and the small peak concentrations could indicate a very small leak. Another possibility is the accumulation of activity at the compacted base of the tank farm excavation.

Several small transfer line discharges are indicated by peak concentrations of gamma emitting radionuclides in a single drywell that occur between 5 and 40 ft (2 and 12 m) bgs. Usually, the indicator radionuclide is Cs-137 and the high concentration depth interval is small, about 2 ft (1 m) thick. These factors lead to the conclusion that the areal extent of the discharge is small and the contaminant concentrations in the discharged fluid are low. Apparent transfer line leaks with these characteristics in the C and A-AX WMAs include the following:

- An apparent discharge on the north (drywell 30-07-11) side of tank C-107 indicated by an above detection concentration zone between 1 and 5 ft (1 and 2 m) bgs which is interpreted as contaminants contained in a nearby saltwell transfer line rather than a leak (DOE-GJO 1997b)

- A discharge on the north (drywell 30-12-13) of tank C-112 indicated by peaks of non identified radionuclides exceeding the detection limit at about 10 ft (3 m) bgs

- A discharge between tanks A-102 and A-103 (drywell 10-03-10) indicated by Cs-137, Co-60 and Eu-154 peaks (maximum values of 10, 0.5 and 8 pCi/g, respectively) between 5 and 10 (2 and 3 m) bgs

The remaining contamination areas that are considered to be the largest inventory contributors to the vadose zone in the C and A-AX WMAs are tank leaks from tanks C-105, A-105, A-104 and unplanned releases from transfer lines at the west and southwest edge of the C WMA. Smaller discharges also occurred from transfer lines between tanks C-104 and C-105, between tanks C-108 and C-109, between and south of tanks A-101 and 102, between and north of tanks AX-101 and AX-103, and between and west of tanks AX-103 and A-104.

4.2.1 Tank C-105 Data Integration and Interpretation

Tank C-105 has not been identified as a leaker in the past although it has been proposed as possible previously (Brodeur 1993). Two observations suggest that C-105 did leak. First, the spectral gamma data in drywell 30-05-07 on the southwest side of the tank contain two high Cs-137 zones near and just below the tank bottom, which indicates a past occurrence of a tank leak at the tank bottom. Second, a liquid level drop of 36 inches was noted between 1963 and 1967. During this time and into the early 1970s, C-105 was being used as a transfer tank for high activity PUREX waste being sent to B Plant for Cs-137 separation. This waste created high heat conditions in tank C-105 for several years. It is proposed that the high heat load in tank C-105 caused tank failure from rupture of the tank liner at a point of weakness (e.g., the weld between the sidewall and the bottom). Subsequently, a small loss of tank waste into the vadose zone occurred. This combination of tank history and environmental characteristics are similar to other tanks that are known to have leaked (e.g., tank T-106).

Alternative explanations for the causes of these observations other than a tank leak have been proposed. The Cs-137 source has been attributed to a nearby leaking transfer line between tanks C-104 and C-105, about 20 ft (6 m) from the tank bottom. This explanation seems unlikely because a temporary in situ chemical condition that enhanced Cs-137 mobility was needed to allow transport of Cs-137 at high concentrations a distance of more than 20 ft away from the source. Previous single-shell tank leak characterization studies indicate that enhanced mobility has only occurred during the tank SX-108 leak when extremely high sodium concentrations in the waste successfully competed with Cs-137 for sorption sites, allowing Cs-137 to be nonreactive with soils temporarily and migrate more than a few feet from the source location (Knepp 2002). The PUREX waste stream presumed lost from tank C-105 does not appear to have the correct chemistry to enhance Cs-137 mobility even temporarily (e.g., highly concentrated sodium or other competing cations). The observed liquid level drop is less convincing. The high waste heat load could certainly have induced evaporation and at least part of the liquid level drop. Nevertheless, some liquid loss due to tank failure is plausible.

The Cs-137 contamination was encountered when drywell 30-05-07 was drilled in the early 1970s. Therefore, the postulated leak would have occurred previously, probably in the late

1960s. It is hypothesized that the leak was small and self-sealed after a short time. Tank C-105 continued as a feeder tank to B Plant into the 1970s showing no obvious indication of leaking. An analysis of historical gross gamma logging data from this dry well indicates there have been no changes in the level or location of the Cs-137 contamination in the vadose zone since the drywell was installed. In addition, additional liquid level drops after 1967 were not observed. The waste volume released from tank C-105 is unknown and it is feasible that some areas underneath tank C-105 may be highly contaminated. Two distinctly separate high Cs-137 contamination zones with markedly different concentration levels (about 10^7 pCi/g in the upper zone at tank bottom depth versus 10^5 pCi/g in the lower zone) may indicate two leak events. Another option is that the lower zone indicates a dragdown effect because the contamination was in place at the time of drilling. The 36-inch liquid level drop in a 75 ft diameter tank corresponds to about 100,000 gallons, but evaporation because of high internal tank temperatures was likely responsible for most if not all of the liquid loss. The high Cs-137 vadose zone contamination area at tank T-106 (Wood et al 2001) can be used as a qualitative measuring stick for the size of the tank C-105 leak. At tank T-106, 115,000 gal of tank waste leaked into the vadose zone. During the T-106 leak approximately 40,000 Ci of Cs-137 was lost resulting in a high Cs-137 ($\sim 10^7$ pCi/g) plume extending over a 75 ft-diameter area. The area of the C-105 high Cs-137 concentration zone is much smaller as it is expressed by only one borehole. Given the uncertainty about contamination underneath the tank, a leak involving the loss of approximately 10,000 Ci of Cs-137 is feasible. The Cs-137 activity in the PUREX supernatant in tank C-105 at the time of the potential leak was in the range of 5 to 30 Ci/gal Ci-137. Thus, a leak volume could be could a small as several hundred gallons up to 2 kgal. A leak inventory estimate was developed for a nominal 1-kgal leak volume.

Since the timing of the waste loss event resulting in the Cs-137 activity in drywell 30-05-07 can only be constrained by the time of the drywell instillation (early 1970s), waste stream identification, and thus leak inventory, are somewhat problematic. Tank C-105 was first used to store bismuth phosphate metal waste. From 1954 through it was used to story uranium recovery waste. The spectral gamma logging data from drywell 30-05-07 are inconsistent with a leak from either of these two waste types. From 1956 until 1963 tank C-105 was used to store PUREX cladding waste. The concentrations of radionuclides in cladding waste were 3 to 4 orders of magnitude less than in the high-level waste supernatants passing through this tank from 1963 until 1978. Thus, if a PUREX cladding waste were the source of the Cs-137 found in drywell 30-05-07 then a much large leak volume would be required. However, the leak inventory would remain relatively constant.

Contaminant migration from drywell 30-05-07 to surrounding drywells is not clearly indicated by the spectral gamma data in these surrounding drywells. Two other nearby drywells, 30-5-08 and 30-05-05, show Cs-137 peaks at depths corresponding to the high concentration zones at drywell 30-05-07. In these drywells, maximum Cs-137 concentrations are < 100 pCi/g, much reduced relative to those at drywell 30-05-07. If this Cs-137 is from a tank C-105 leak, the rapid reduction in Cs-137 concentrations is consistent with the expected high Cs-137 reactivity with vadose zone soils. At drywell 30-05-05, Co-60 also appears to peak just below Cs-137 (at 70 ft (21 m) bgs versus 60 to 65 ft (18 to 20 m) bgs). If Cs-137 and Co-60 at this drywell location are both from the tank C-105 leak, Co-60 is nearly as reactive as Cs-137.

From this minimal data set, it is concluded that the proposed tank C-105 leak is largely constrained to the area southwest of tank C-105. However, a more mobile constituent such as Tc-99 probably migrated over a larger area that cannot be predicted with the available data.

4.2.2 Tank A-105 and A-104 Data Integration and Interpretation

Tanks A-105 and A-104 have been identified as leakers, a conclusion that is clearly supported by the available database. Of these, the tank A-105 leak event was the most serious (see Caggiano 1991, WHC 1991, and Beard et al 1967 for extensive reviews). Both tanks were used to store highly radioactive PUREX processing waste, and were designed to accommodate the high fission product waste and associated high thermal load. In 1963, the first indication of a leak at tank A-105 occurred with the measurement of elevated gamma activity in lateral 14-05-03 on the east side of the tank. This leak was thought to have self-sealed. The tank was then filled to capacity with PUREX high-level (boiling) waste in late 1964. However, the thermal conditions turned out to be too extreme. In January 1965, a steam eruption occurred at tank A-105. Steam was vented for 30 minutes and there was extensive damage to in-tank monitoring equipment. In addition, there was serious damage to the steel base of the tank. There were major safety concerns about the status of this tank at that time. Initial investigations identified a maximum 4-inch drop in the waste level in the tank. The tank was closely monitored for the next few years with no evidence of additional leakage even though the steel liner was severely damaged. After the heat load in the wastes in tank A-105 had decreased for 3 or 4 years the supernatant was transferred to B Plant for Cs-137 recovery. Most of the sludge was removed by sluicing. However, a hard heel was left in the tank when increasing activity was noted in nearby drywells. Because of the heat load of the remaining hard heel, water was periodically added to the tank for almost a decade. The volumes associated with the various leak events from tank A-105 are highly uncertain.

The current leak volume estimate for loss of PUREX high-level waste supernatant from tank A-105 vary from 10 to 45 kgal and estimates of losses of cooling water are between 0 and 232 kgal (Hanlon 2002). The volume of high-level waste supernatant lost controls leak inventory estimates. Impacts of cooling waste losses on leak inventory estimates are insignificant.

All of the available data suggest that the volume of high-level waste supernatant lost from tank A-105 is considerably less than the 10-kgal minimum listed in Hanlon (2002). Analytical data for the supernatant in tank A-105 at the time of the steam release event show the Cs-137 concentration was 8.1 Ci/L or 31 Ci/gal. Thus, the 10 kgal leak volume requires that 310,000 Ci of Cs-137 were lost to the soil column. Yet the drywells around tank A-105 have only very low levels of Cs-137 contamination (< 100 pCi/g). Since the PUREX high-level wastes contained the same array of gamma emitting radionuclides as those lost from tank T-106 in 1973, plumes similar to those found near tank T-106 would have been expected around tank A-105. The lack of significant activity in any of the drywells around tank A-105 (DOE-GJO 1999) provides a strong argument for minimum loss of gamma activity during the 1965 steam release event.

A 300,000 Ci Cs-137 loss would imply a loss of about ~90 Ci of Tc-99. The tank leak data in the monthly tank summary report (Hanlon 2002) implies that there was an additional loss of

about 230,000 gal of contaminated water from this tank – likely more than enough water to drive mobile constituents such as Tc-99 to the water table. Yet, the groundwater monitoring program has not detected groundwater contamination that can be associated with the A Tank Farm. Thus, a 10 kgal leak volume for tank A-105 is highly unrealistic. Thus, it is probable the volume of PUREX high-level supernatant lost from tank A-105 is less than 1 kgal. Table 4-1 reports an inventory for a nominal 1-kgal loss from tank A-105.

The tank A-104 leak occurred similarly to the tank A-105 leak. Enhanced gamma activity was note in lateral 14-04-02 in April 1975 followed by gamma hits at other locations under the tank. As with tank A-105 conditions, little or no contamination from the A-104 leak is found in the surrounding monitoring boreholes. In 1975, the waste stream in tank A-104 was PUREX sludge supernate (produced from PUREX sludge washing prior to acid dissolution for Sr-90 recovery). The Cs-137 activity in the PUREX sludge supernatant was about an order of magnitude lower than in the PUREX supernatants (Larson 1967). The estimated leak volume is very small (500 to 2,500 gallons according to Hanlon [1999]) and cannot be corroborated. Unlike the tank A-105 leak there was little opportunity for subsequent contaminant migration because water was not added to the tank after the leak.

The extent of subsequent migration of mobile constituents in waste leaked from tanks A-105 and A-104 in the vadose zone is not known. It is postulated that vertical migration has been limited by the fact that waste apparently was disposed directly underneath the tanks within the moisture shadow created by the tanks themselves. Without significant infiltration, migration beyond a few feet is unlikely.

Table 4-1. Tank Leak Inventory Estimates for A, AX, and C Tank Farms.
(3 sheets)

Tank	A-104	A-105	C-105	UPR-200-E-81	UPR-200-E-82	UPR-200-E-86
Leak Vol.	2.0 kgal	1 kgal	1 kgal	36 Kgal	2,600 gal	17,400 gal
Analyte	kg	kg	kg	kg	kg	kg
Na	2.44E+02	4.10E+02	4.49E+02	5.10E+03	1.17E+03	2.14E+03
Al	4.60E+00	7.14E-01	1.52E+01	2.32E+03	3.96E+01	3.93E+01
Fe	8.44E-01	1.80E+00	2.69E+00	1.53E+01	6.99E+00	7.41E+00
Cr	6.69E+00	6.71E+00	9.82E+00	2.18E+01	2.55E+01	5.88E+01
Bi	1.88E-02	4.42E-03	9.66E-02	0.00E+00	2.51E-01	1.60E-01
La	1.41E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hg	5.58E-04	9.06E-05	1.85E-03	2.75E-01	4.82E-03	4.84E-03
Zr	4.43E-05	1.06E-04	7.57E-04	0.00E+00	1.97E-03	4.27E-04
Pb	9.38E-02	1.34E-02	2.94E-01	4.54E+01	7.65E-01	8.14E-01
Ni	7.96E-01	1.70E+00	2.53E+00	1.23E+01	6.59E+00	6.99E+00
Sr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn	1.10E+00	3.40E-02	2.72E-01	0.00E+00	7.06E-01	9.67E+00
Ca	2.72E+00	5.80E+00	8.70E+00	4.93E+01	2.26E+01	2.38E+01
K	2.26E+00	2.99E+00	2.97E+00	1.34E+01	7.72E+00	1.98E+01
NO3	1.38E+02	1.51E+02	3.15E+02	5.79E+03	8.18E+02	1.21E+03

Table 4-1. Tank Leak Inventory Estimates for A, AX, and C Tank Farms.
(3 sheets)

Tank	A-104	A-105	C-105	UPR-200-E-81	UPR-200-E-82	UPR-200-E-86
Leak Vol.	2.0 kgal	1 kgal	1 kgal	36 Kgal	2,600 gal	17,400 gal
Analyte	kg	kg	kg	kg	kg	kg
NO2	1.65E+02	3.49E+02	2.69E+02	1.82E+03	6.98E+02	1.45E+03
CO3	6.62E+01	2.23E+01	6.46E+01	7.40E+01	1.68E+02	5.79E+02
PO4	1.67E+01	1.30E-01	1.64E+00	0.00E+00	4.25E+00	1.48E+02
SO4	5.90E+01	1.82E+02	8.64E+01	1.66E+02	2.25E+02	5.19E+02
Si	7.20E+00	1.43E+01	1.84E+01	0.00E+00	4.79E+01	1.71E+02
F	5.79E-02	1.76E-02	4.41E-01	0.00E+00	1.15E+00	4.89E-01
Cl	5.10E+00	1.23E+01	1.14E+01	5.59E+01	2.95E+01	4.46E+01
DBP	9.27E-02	1.29E+01	4.33E+01	0.00E+00	1.12E+02	0.00E+00
Butanol	3.27E-02	4.54E+00	1.52E+01	0.00E+00	3.96E+01	0.00E+00
TBP	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NPH	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-Total	4.26E+00	5.62E+00	7.06E+00	1.30E+02	1.83E+01	3.73E+01
Analyte	Ci	Ci	Ci	Ci	Ci	Ci
H-3	4.68E-02	1.83E+00	6.62E-01	9.95E-02	1.72E+00	3.89E-01
C-14	1.01E-01	3.77E-01	2.76E-01	1.40E-02	7.17E-01	8.86E-01
Ni-59	1.09E-02	4.67E-02	3.50E-02	3.93E-03	9.11E-02	9.59E-02
Ni-63	1.07E+00	4.66E+00	3.39E+00	3.96E-01	8.81E+00	9.39E+00
Co-60	1.02E-01	4.76E-01	1.95E-01	2.03E-02	5.08E-01	8.99E-01
Se-79	1.51E-02	3.00E-02	3.84E-02	3.10E-03	9.99E-02	1.32E-01
Sr-90	2.55E+02	5.10E+02	6.55E+02	3.29E+02	1.70E+03	2.25E+03
Y-90	2.56E+02	5.10E+02	6.53E+02	3.29E+02	1.70E+03	2.25E+03
Zr-93	7.54E-02	1.50E-01	1.91E-01	1.45E-02	4.97E-01	6.61E-01
Nb-93m	5.26E-02	1.05E-01	1.34E-01	1.06E-02	3.48E-01	4.63E-01
Tc-99	7.08E-01	2.67E+00	1.93E+00	1.02E-01	5.01E+00	6.22E+00
Ru-106	3.75E-05	5.45E-05	6.76E-06	3.36E-05	1.76E-05	3.31E-04
Cd-113m	4.52E-01	8.74E-01	1.05E+00	7.07E-02	2.74E+00	3.97E+00
Sb-125	3.84E-01	2.05E+00	4.94E-01	1.11E-01	1.28E+00	3.37E+00
Sn-126	2.26E-02	4.48E-02	5.76E-02	4.74E-03	1.50E-01	1.98E-01
I-129	1.37E-03	5.14E-03	3.73E-03	1.97E-04	9.69E-03	1.20E-02
Cs-134	1.74E-02	1.06E-01	1.54E-02	7.34E-03	3.99E-02	1.53E-01
Cs-137	2.37E+03	9.60E+03	6.33E+03	3.79E+02	1.65E+04	2.08E+04
Ba-137m	2.24E+03	9.12E+03	5.97E+03	3.58E+02	1.55E+04	1.96E+04
Sm-151	5.26E+01	1.05E+02	1.34E+02	1.12E+01	3.48E+02	4.63E+02
Eu-152	1.70E-02	5.84E-02	3.03E-02	2.56E-03	7.89E-02	1.49E-01
Eu-154	2.19E+00	6.26E+00	4.29E+00	4.01E-01	1.12E+01	1.92E+01
Eu-155	1.11E+00	4.21E+00	1.71E+00	1.84E-01	4.46E+00	9.79E+00

Table 4-1. Tank Leak Inventory Estimates for A, AX, and C Tank Farms.
(3 sheets)

Tank	A-104	A-105	C-105	UPR-200-E-81	UPR-200-E-82	UPR-200-E-86
Leak Vol.	2.0 kgal	1 kgal	1 kgal	36 Kgal	2,600 gal	17,400 gal
Analyte	kg	kg	kg	kg	kg	kg
Ra-226	4.67E-07	9.27E-07	1.19E-06	2.01E-07	3.10E-06	1.32E-06
Ra-228	4.24E-07	5.50E-08	1.34E-06	2.11E-04	3.48E-06	1.67E-06
Ac-227	2.71E-06	5.40E-06	7.22E-06	4.93E-05	1.88E-05	2.38E-05
Pa-231	1.51E-05	3.00E-05	4.00E-05	2.74E-04	1.04E-04	1.32E-04
Th-229	9.60E-08	3.02E-08	6.09E-07	9.51E-05	1.58E-06	7.74E-07
Th-232	8.50E-07	1.18E-07	2.87E-06	4.51E-04	7.46E-06	7.14E-06
U-232	4.77E-04	6.88E-06	9.18E-05	8.82E-03	2.39E-04	4.19E-03
U-233	1.84E-03	2.66E-05	3.59E-04	3.43E-02	9.33E-04	1.62E-02
U-234	1.48E-03	1.90E-03	2.33E-03	4.62E-02	6.06E-03	1.29E-02
U-235	6.07E-05	7.95E-05	9.90E-05	1.89E-03	2.57E-04	5.35E-04
U-236	4.05E-05	4.67E-05	4.55E-05	1.38E-03	1.18E-04	3.55E-04
U-238	1.42E-03	1.87E-03	2.36E-03	4.36E-02	6.13E-03	1.24E-02
Np-237	2.22E-03	6.50E-03	7.70E-03	7.63E-04	2.00E-02	1.94E-02
Pu-238	1.40E-02	4.18E-03	2.80E-03	2.88E-02	7.28E-03	1.24E-01
Pu-239	5.94E-01	1.31E-01	1.77E-01	1.20E+00	4.61E-01	5.24E+00
Pu-240	9.77E-02	2.35E-02	2.68E-02	2.14E-01	6.97E-02	8.60E-01
Pu-241	1.01E+00	3.00E-01	2.08E-01	2.30E+00	5.41E-01	8.93E+00
Pu-242	4.96E-06	1.64E-06	7.69E-07	6.49E-06	2.00E-06	4.37E-05
Am-241	2.26E-01	4.49E-01	5.75E-01	8.70E-02	1.50E+00	1.98E+00
Am-243	4.99E-06	1.11E-05	5.81E-06	9.18E-07	1.51E-05	4.36E-05
Cm-242	4.08E-04	1.56E-03	6.06E-04	3.70E-05	1.58E-03	3.56E-03
Cm-243	2.31E-05	1.12E-04	1.61E-05	1.02E-06	4.19E-05	2.00E-04
Cm-244	7.50E-04	1.18E-03	5.00E-04	3.49E-05	1.30E-03	6.61E-03

All radionuclides decayed to 1/1/1994

4.2.3 C and A-AX WMA Transfer Line Leak Data Integration and Interpretation

Numerous transfer line leaks have occurred in the C and A-AX WMAs. Among the tanks, spectral gamma data suggest that the most contaminating leaks occurred between tanks C-104 and C-105, between tanks C-108 and C-109, between A-101 and A-102, between AX-103 and AX-104, and between tanks AX-101 and AX-103. The data that characterize these events (primarily spectral gamma data) was summarized in Chapter 3. In addition, three transfer line leaks near three diversion boxes (241-CR-151, 241-C-151 and 241-C-152) have been reported as unplanned releases in the C WMA. Of these, the two near diversion boxes 241-C-152 (UPR-200-82) and 241-C-151 (UPR-200-86) are the most significant sources of contamination (see Section 4.3). Other unplanned releases were also reported, but their descriptions suggest a minimal vadose zone contamination outcome.

While there are individual differences in the occurrence, extent and waste type discharged to the vadose zone, the conceptual model for the various transfer line discharges of tank waste to the vadose zone and subsequent contaminant migration in the vadose zone is basically similar. Typically, waste leaks from transfer lines for some time before the leak is discovered, either through nearby drywell gamma data or observed collection of water at the near surface. At that point the transfer line was repaired or abandoned.

Contaminants proceed to migrate according to their reactivity with soils and natural infiltration rates. At the C, A and AX Tank Farms, the common gamma-emitting contaminants are Cs-137, Co-60, Eu-154 and Eu-152. Of these, the most reactive and therefore slowest moving contaminant is Cs-137. When drywell spectra gamma data are available the leak location is assumed to be near a drywell exhibiting a sharp high concentration Cs-137 peak at depths consistent with transfer line depths. Cobalt-60 tends to be the least reactive and fastest moving gamma-emitting radionuclide in the C and A-AX WMAs. Spectral gamma data suggest that contaminant migration generally has been limited to an area whose size is on the order of a tank diameter (75 ft [23 m]) or two. However, at C Tank Farm the extent of Co-60 migration may be greater because Co-60 is measured in numerous tanks as much as 250 ft (76 m) away from the two primary transfer line leaks between tanks C-104 and C-105 and between tanks C-108 and C-109. On the other hand when all the Co-60 spectral gamma data are considered in the C Tank Farm, logical patterns linking this Co-60 contamination to these two transfer line locations are not readily discernable. It is plausible that additional leak sources are involved that cannot be clearly identified by the available data (e.g., a tank C-103 leak).

Radionuclide migration may also have been accelerated because of additional artificial water discharge through the vadose zone area contaminated by transfer line leaks. This has rarely occurred at the C and A-AX WMAs or has rarely been identified. One possible occurrence was between tanks A-101 and A-102 on the south side where one or more transfer line leaks are indicated by drywells 10-01-28, 10-01-39, 10-01-16, and 10-01-04. The spectral gamma data show a progression of increased vertical migration of Co-60 in the vadose zone away from the apparent source, and gross gamma data interpretation at drywell 10-01-04 show a clear and rapid vertical migration of Co-60 from the late 1970s and through the 1980s. Just to the north of this area a raw water line break occurred in 1978, which was sufficient to cause soil cave in between tanks A-102 and A-105. At the same time increased activity in nearby laterals was also observed. It is therefore postulated that enhanced migration of transfer line leak waste occurred.

4.3 TANK LEAK AND TRANSFER LINE INVENTORY ESTIMATES

The approach used in developing quantitative leak inventory estimates is the same as that used in previous tank leak inventory estimates (Jones et al 2000a, Jones et al 2001b). The best estimates of actual leak volumes were combined with waste composition estimates at the suspected time of the waste loss events. The uncertainty of the inventory estimated depends mainly on the volume estimates and time of the leak. At least for the major constituents of the tank wastes, reasonable composition estimates are available as long as there has not been major commingling of waste types.

4.3.1 C Tank Farm

Except for tank C-105, there is essentially no evidence to support listing any of the C Farm tanks as known or suspected leakers. An inventory is provided in Table 4-1 for a nominal 1-kgal leak volume from tank C-105. If results for future investigations indicate a different leak volume the reported results can be scaled appropriately.

Outside the C Tank Farm, the most significant contamination comes from two transfer line leaks of PUREX high activity waste at the western edge of the C WMA, identified in the Waste Information Data Base System (WIDS) as UPR-200-E-82, and UPR-200-E-86. Report UPR-200-E-82 describes the loss of Cs-137 Recovery Process feed solution being pumped from tank C-105 to the B Plant. The leak occurred near the 241-C-152 Diversion Box and involved the loss of approximately 2,600 gallons of liquids (Tanaka 1971). The inventory estimate was developed assuming a PUREX high-level waste supernatant template. These results are listed in Table 4-1. Report UPR-200-E-86 describes a waste loss event associated with a pipeline break near the southwest corner of the C Tank Farm. Fluids were being pumped from the 244-AR Vault to the C Tank Farm. Approximately 17,400 gal of fluid that contained approximately 25,000 Ci of Cs-137 were lost to the soil (Maxfield 1979). The inventory estimate was developed using the "AR waste type" template (Agnew 1997). These results are listed in Table 4-1. The large estimated Tc-99 inventory from these events is a primary contributor in the C WMA to long-term risk estimates.

Two other transfer line leaks involved the loss of PUREX cladding waste. First, report UPR-200-E-81 describes a 1969 waste loss event that occurred near the 241-CR-151 Diversion Box and involved the loss of 136,000 L (36 Kgal) of PUREX cladding waste (Williams 2001, Maxfield 1979). The PUREX cladding waste was a reasonably low activity waste stream produced from the caustic dissolution of the aluminum fuel rod cladding. The origin of the radioactive contamination in this waste stream was congruent dissolution of the uranium fuel during the de-cladding operation. Inventory estimates for the waste loss event use the PUREX cladding waste composition used in the Hanford defined waste (HDW) Model for PUREX cladding waste (CWP2) (Agnew 1997). These inventory estimates are given in Table 4-1. Second, there is also a small overland piping leak (50 gal) involving the loss of PUREX cladding waste between tanks C-105 and C-108, documented in UPR-200-E-16. A negligible inventory is associated with this leak.

The final contamination source in the C WMA is generalized near-surface contamination across the C Tank Farm where Cs-137 contaminates the vadose zone between the surface and 15 ft (5 m) bgs to levels of about 10 pCi/g. About a dozen of the drywells in the farm have Cs-137 gamma activity that peaks at or above 100 pCi/g in the upper 15 feet of the vadose zone, with the most contaminated zones occurring between tanks C-104 and C-105 and between tanks C-108 and C-109. Inventory estimates of near surface contamination can be made for a generalized level of contamination and for transfer line 'hot spots'.

An inventory estimate based on the generalized level of Cs-137 (10 pCi/g) contamination is insignificant when compared to other Cs-137 inventory estimates in this tank farm. For example, if one assumes a surface area of 400 ft by 400 ft down to a depth of 15 ft with a soil density of 1.7 g/ml and a Cs-137 contamination level of 10 pCi/g, the estimated inventory of Cs-137 is

1.1 Ci. Assuming a PUREX high activity waste or B Plant isotope recovery source, other constituents can be scaled from the Cs-137 estimate. For example, a Tc-99 inventory estimate can be made assuming the Cs-137 is 1,000 to 10,000 times more abundant than Tc-99 in the discharged waste. Even if this Cs-137 inventory estimate increased by 2 or 3 orders of magnitude, both Cs-137 and other constituent inventories would still be insignificant compared to that from other losses in the C WMA.

A similar calculation can be done for smaller contamination zones affected by transfer line leaks with somewhat high Cs-137 concentrations distributed over a depth interval of a few feet. For example, at the transfer line leak between tanks C-104 and C-105, the maximum Cs-137 concentration approaches 1,000 pCi/g for a 1 ft depth interval. Assuming contamination in the area between four tanks (roughly a 25 ft (8 m) square down to about 20 ft (7m) bgs, a Cs-137 inventory of < 0.1 Ci Cs-137 is calculated. Based on these calculations it is clear that near-surface contamination inventories from small transfer line leaks are also insignificant compared to the high activity waste loss events from tank C-105, UPR-200-E-82 and UPR-200-E-86.

4.3.2 A-AX Waste Management Area

Inventory estimates are provided for a nominal 1-kgal leak for tank A-105 and a 2 kgal leak for tank A-104. The results reported in Table 4-1 were scaled from previously reported estimates (Simpson et al 2001). If results for future investigations indicate a different leak volume the reported results can be scaled appropriately.

As in C Tank Farm, low concentration near surface contamination is frequently observed in A and AX Tank Farms as well as occasional 'hot spot' higher contamination zones created by small transfer line leaks and other tank farm activities (e.g., between tanks A-101 and A-102, an apparent pump pit leak created a higher-level contamination zone). Simple calculations similar to those described for C tank indicate that currently existing vadose contamination is small (< 3 Ci of Cs-137 from these sources) and not significant as a potential source for future groundwater contamination. Additional inventory estimates are available for near-surface leaks in the AX Tank Farm (Hendrickson et al 1997).

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5.0 RECOMMENDATIONS FOR FURTHER CHARACTERIZATION OF THE C AND A-AX WMAS

Chapters 1 through 3 present information pertinent to the occurrence of contaminants in the vadose zone underlying the C and A-AX WMAs. Chapter 4 presents qualitative hypotheses of events leading to the observed vadose zone and aquifer contamination. From these observations and process knowledge, the primary locations of interest for additional aquifer contamination have been identified. For most of these areas, contamination extensive enough to warrant remediation is not expected. However, further characterization is recommended primarily because of the following three data gaps.

- The volumes of most leaks are not well documented because no clear means of measuring leaks was available.
- Analyses of leaked waste fluid chemistry are rare and incomplete.
- The spectral gamma data do not provide information about the nature and extent of non-gamma-producing contaminants. In particular, the distribution and inventory of technetium-99 is of interest.

5.1 DESCRIPTION OF CHARACTERIZATION ALTERNATIVES

The primary goal of additional characterization is to determine the nature and extent of tank waste contaminants near known or suspected leaks. This is to be done primarily through sampling soil in the regions of interest and analyzing the samples for expected contaminants of concern; soil water pH, electrical conductivity, moisture content, and, if feasible, hydrologic properties. Of particular interest are known mobile constituents, technetium-99 and nitrate. Other contaminants, particularly Cs-137 and Co-60, are of interest because they provide some indication of contaminant migration and distribution. Neither radionuclide is expected to contaminate groundwater to unacceptable levels in the future (see Field Investigative Reports for S-SX and B-BX-BY Waste Management Areas [Knepp 2002 and 2003]).

Table 5-1 lists the most highly contaminated vadose zone areas in the C and A-AX WMAs and the critical factors that influence future characterization decisions. These factors are primary indicators of the nature and extent of contamination underlying these WMAs in the vadose zone and are listed for separate, potentially significant contamination zones associated with the tanks listed in the top row of the table. The primary critical factors are leak volumes and contaminant inventory and distribution. Leak volume estimates are based on several sources where available, including historic liquid level measurements, waste transfer records, and gamma-emitting radionuclide distributions in the vadose zone. Contaminant distribution is indicated by the location and concentration of gamma–emitting radionuclides in drywells.

Table 5–1. Critical Factors Evaluations/Recommendations

Critical Factors	Vadose Zone Contamination Areas									
	Tank Leaks			Near Surface Leaks (Transfer Lines or Surface Spills)						
						AX Tank Farm				
	C-105	A-104	A-105	C-104 / C-105, C-108/ C-109	A-101/ A-102	drywell 11-01-10	drywell 11-02-12	UPR-200-E-81	UPR-200-E-82	UPR-200-E-86
[a]Discharge Volume Estimate (gal)	[b]1000	[b]2000	[b]1000	Unknown	Unknown	Unknown	Unknown	[c]36000	[d]2,640	[c]17400
Drywell/Lateral Coverage	Fair	Fair	Fair	Good	Good	Good	Good	None	None	None
Leak Boundary Controls	Fair	Good	Good	Good	Good	Good	Good	None	None	None
Gamma-Emitting Radionuclide Contamination Depth (ft below ground surface [bgs])	Tank bottom (50) to ?	Lateral Depth (60) to ?	50 to 70	25 to 70	25 to 70	3 to 30	10 to 30	Unknown	Unknown	Unknown
Relative Vadose Zone Contamination Level Among C, A and AX Sites	Medium	Low	Medium	Medium	Medium	Low	Low	Low	High	High
Maximum Cs-137 concentration in spectral gamma data (pCi/g)	~10,000,000	Unknown	Unknown	~1,000	~100	40,000	4,000	Unknown	Unknown	Unknown
[b]Estimated Cs-137 Inventory (Ci)	6,330	2,370	9,600	< 0.1	< 1	< 3	< 1	377	16,500	20,800
[b]Estimated Tc-99 Inventory (Ci)	1.9	0.7	2.7	< 0.001	< 0.1	< 0.001	< 0.001	0.1	[c]5.0	[c]6.2
Recommended Approach										
[e]Spectral Gamma Logging		X	X							
Borehole	Evaluate feasibility to deepen drywell 30-05-07; if feasible, drill to 250 ft bgs								Drill borehole near leak location to Plio-Pleistocene	

(a) Estimate of volume discharged to the vadose zone

(b) Estimates in this report

(c) Maxfield (1979)

(d) Tanaka (1971)

e) Logging recommended for laterals under these tanks

Estimates of key radionuclide inventories are based on process records of waste types present in the tank or transfer lines at the time of the leak, waste chemistry flow sheet records, the Hanford Defined Waste (HDW) Model (Agnew, 1997) and historic chemical analyses of supernatant, when available. The technetium-99 values shown in Table 5-1 were generated from a combination of these sources. Quantitative estimates of the critical factors are provided in Table 5-1 where available and appropriate. Other factors are qualitative and quantities are defined relatively. Finally, leak volume and contaminant information are evaluated for reliability and consistency.

The second part of Table 5-1 lists the primary additional characterization options that were chosen to improve the estimate of the nature and extent of contamination in the vadose zone underlying single shell tank farms. These were selected from a variety of characterization methods including the following:

- Direct push or cone penetrometer characterization allows limited downhole measurements (gamma and moisture measurements) and soil sampling. The primary limitation of the technique is that the feasible penetration depth is shallow under tank farm conditions, typically 30 to 40 ft (9 to 12 m), preventing exploration of contaminated soils beneath the tank bottom. Thus, this technique is potentially useful only if the contamination of interest exists above the tank bottom.

- Borehole drilling and sampling provide the greatest potential for collecting soil samples and indirect measurements. These techniques can be used anywhere in the soil column unoccupied by tanks and infrastructure. For the technique to be useful, sufficient evidence of contamination must be available to properly place the borehole in a location that intercepts the more highly concentrated portion of the contamination zone.

- Krieging is a mathematical technique for extrapolating or interpolating concentration data in a given region based on discrete data points within that region. This technique is useful only if data points of sufficient number and density are available. Given the present database, insufficient concentration data are available for the contaminated vadose zone areas in the C and A-AX WMAs.

- Additional spectral gamma logging provides updates to spectral gamma data collected previously. This technique can be used anywhere drywells or laterals underlying tanks in the WMA exist. Drywells exist in all three tank farms and laterals are present in the A Tank Farm.

5.2 RECOMMENDATIONS FOR ADDITIONAL CHARACTERIZATION IN THE C AND A-AX WMAS

Proposed characterization options are indicated in Table 5.1. Characterization is recommended for the contamination zones near the bottom of tank C-105, at the unplanned release location just southeast of the 241-C-152 and in the laterals underlying tanks A-104 and A-105. Collectively, this combination of characterization targets comprises all primary vadose zone contamination sites in the C and A-AX WMAs.

Further characterization is not recommended for the areas between tanks C-104 and C-106, between tanks C-108 and C-109, near diversion boxes on the west side of C Tank Farm, between tanks A-101 and A-102, and between tanks AX-101, AX-103 and AX-104. The primary reason is that conservative calculations of mobile radionuclide inventory in these areas indicate that inventory estimates of environmentally mobile constituents are too low to present a potentially significant long-term risk to the environment. Further characterization is also not recommended for various tanks listed as leakers in Hanlon (1999). These include tanks C-101, C-110, C-201 through C-204, A-103, AX-102 and AX-104. The vadose zone contamination resulting from these leaks is either fictitious or of insufficient contamination levels to be of concern.

5.2.1 Characterization of the Tank C-105 Leak

Two high concentration zones of cesium-137 (up to 10^7 pCi/g) are present in drywell 30-05-07 adjacent to the southwest side of the tank, concentration values that exceed gamma concentrations in all other contaminated areas in the C, A and AX WMAs by at least three orders of magnitude. This distribution strongly indicates the occurrence of a leak near the bottom of the tank. Tank C-105 has not been reported previously as a leaking tank but liquid level drops were recorded in the 1960s. The high cesium-137 concentration zones have been attributed to a leaking transfer line between tanks C-104 and C-105 but the probable waste chemistry and cesium-137 distribution patterns in the area do not support this hypothesis. This potential leak is of interest from a risk perspective because process records suggest that the waste is either high activity PUREX waste or cesium recovery waste, both of which are characterized by high technetium-99 concentrations.

Currently, neither the waste leak volume nor the real distribution of contaminants in the vadose zone is very well understood. Consequently, it is recommended that sampling and analysis of contaminated soils be completed if possible. Gaining access to the contaminated zone does present difficulties. The high contamination zone is only expressed in the one drywell very close to the tank sidewall and it is likely that some contamination exists underneath the tank.

Two approaches to sampling this zone are considered. The first is to drill a slant borehole underneath tank C-105. However, the area is congested with other drywells and piping systems. In addition, it is difficult to drill a slant hole at an angle that comes close to the bottom of the tank (e.g., within 10 ft [3 m]). Thus, there is a real possibility that the contamination zone would be missed. The second and recommended approach is to examine the feasibility of deepening the drywell in which high Cs-137 concentrations have been observed (30-05-07) and collecting soil samples down to the Plio-Pleistocene about 250 ft (76 m) bgs. If this approach is feasible then it should be implemented. The data to be collected are a complete set of chemical and radiological soil sample analyses with depth. The distribution and concentration of technetium-99 with depth are of particular interest. This database will increase substantially our understanding of the nature and extent of non-gamma-emitting constituents in this zone because no information exists presently.

5.2.2 Characterization of Waste Transfer Line Leaks in the C WMA

Historical records and previous field characterization efforts indicate that the largest contamination events in the C WMA were two unplanned releases of high activity derivatives of PUREX waste in waste transfer lines at the western edge of the C WMA, UPR-200-E-82 in 1969 and UPR-200-E-86 in 1971. Both transfer line leaks are estimated to have released collectively about 11 curies of Tc-99, the primary constituent of concern for future groundwater contamination. The contamination zone created by UPR-200-E-82 is the preferred alternative site even though a smaller volume, but more concentrated leak occurred here. The historical documentation of the leak is more complete at this site and locating the contamination zone should be more straightforward.

The primary characterization goal is to determine the extent of vertical migration of this and other mobile constituents (e.g., nitrate) over a thirty-year period and to provide a well-defined source location for estimates of future migration towards the unconfined aquifer. The recommended characterization approach is to complete a borehole down to the Plio-Pleistocene about 250 ft (76 m) bgs and collect a complete set of chemical and radiological soil sample analyses with depth. The combination of these data with the tank C-105 borehole data should also provide a useful indication of the effects of tank structures on infiltration rates.

5.2.3 Collection of Spectral Gamma Data from Lateral Underlying Tanks A-104 and A-105

Loss of tank integrity for tanks A-104 and A-105 were demonstrated in 1965 by the occurrence of gross gamma measurements in several laterals that underlie these two tanks. In this report it has been concluded that a relatively small loss of tank waste to the vadose zone has occurred in each tank, a conclusion that, in the case of tank A-105, is considerably smaller than the volume estimates provided in Hanlon (2002). The basis for the smaller volume estimate in this report is the lack of measured Cs-137 contamination in the drywells surrounding tank A-105. Given the estimated waste loading at the time of the leak, a large volume release should have distributed measurable Cs-137 over an area large enough to intersect the drywell locations.

The most direct means of measuring Cs-137 in the vadose zone is to relog the laterals underlying the tanks to collect spectral gamma data. The gamma emitting radionuclides that created the initial measured radiation were short-lived fission products (e.g., Ru-106). The data to be collected in the relogging effort will determine the concentrations of specific gamma-emitting radionuclides still present in the vadose zone near the laterals. By now, the primary gamma-emitting radionuclide should be Cs-137. If minimal concentrations of Cs-137 are found in laterals measurements about 10 ft (3 m) from the leak location, then the released tank waste volume will be constrained to a minimal value.

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APPENDIX A

HISTORICAL BACKGROUND OF C, A AND AX TANK FARMS OPERATIONS AND CONTAMINATION EVENTS

A.1.0 INTRODUCTION

This appendix includes narrative description from *Historical Vadose Zone Contamination from A, AX, and C Tank Farm Operations* (Williams 2001). Williams (2001) is a primary document supporting this report that describes tank farms operations history and provides the evolution of tank farm infrastructure. The narrative from Williams (2001) describing tank farm history and tables of liquid discharge events are provided in this appendix. Drawings of the tank farm infrastructure layout that existed with each of the major processing activities (e.g., bismuth phosphate processes and PUREX waste storage) are provided in the referenced document.

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HISTORICAL VADOSE ZONE CONTAMINATION FROM A, AX, AND C TANK FARM OPERATIONS

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Prepared by Fluor Federal Services

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CH2M HILL Hanford Group, Inc.

HISTORICAL VADOSE ZONE CONTAMINATION FROM A, AX, AND C TANK FARM OPERATIONS

TABLE OF CONTENTS

1.0 INTRODUCTION 1
2.0 SUMMARY AND CONCLUSIONS 2
3.0 FACILITIES HISTORICAL BACKGROUND 2
3.1 Construction and Bismuth Phosphate Operations (1944-1952) 3
3.2 Uranium Recovery Operations (1952-1957) 5
3.3 PUREX Operations 1956-1972 (1983-1988) 7
3.3.1 PUREX High-Level Waste Streams 8
3.3.2 Tank Farm Ventilation System 8
3.3.3 Other PUREX Low-Level Waste Streams 10
3.3.4 PUREX Cooling Water and Chemical Sewer 11
3.3.5 PUREX Waste in Tank 241-A-105 12
3.3.6 PUREX Shutdown and Restart 12
3.4 Fission Product Recovery (1961-1967) and Waste Fractionization Operations (1967-1978) 13
3.5 Stabilization and Isolation 1975-Present 16
4.0 MONITORING TEST WELLS 18
5.0 REFERENCES 21
5.1 Documents 21
5.2 Drawings 25
5.2.1 A and AX Tank Farm 25
5.2.2 C Tank Farm 27

Appendices
Appendix A Tables
Appendix B Timeline of Events
Appendix C Crib Discharge Histories
Appendix D Figures

ABBREVIATIONS/ACRONYMS

B	High-level waste generated by B Plant from 1967 to 1978
BL	Intermediate-level waste generated by B Plant from 1967 to 1978.
CWP	PUREX coating waste
DCRT	Double-contained receiver tank
DST	Double-shell tank
FP	Waste generated by B Plant from 1963 to 1967
HS	Waste generated by Strontium Semiworks from 1961 to 1967
ITS	In-tank solidification
LERF	Liquid Effluent Retention Facility
MW	Metal waste
OWW	Organic Wash Waste
PAW	PUREX acid waste (same as P, CAW, HAW, or IWW)
PSN	PUREX supernatant waste
PUREX	Plutonium-Uranium Extraction (Plant)
SNAP	Space Nuclear Applications Program
SST	Single-shell tank
TBP	Tri-butyl phosphate
UNH	Uranyl nitrate hexahydrate
UPR	Unplanned release
WESF	Waste Encapsulation and Storage Facility
WIDS	Waste information data system
1C	Bismuth Phosphate first-cycle waste
2C	Bismuth Phosphate second-cycle waste
224	Plutonium concentrator waste
5-6	B Plant cell drainage waste

GLOSSARY

Crib: An underground liquid waste disposal site filled with soil and/or crushed gravel utilizing the ion exchange properties to remove radioactive contamination. Typically, cribs were operated until contamination was observed in the groundwater beneath the crib.

Double-Contained Receiver Tank (DCRT): A reinforced concrete structure containing a receiver tank for radioactive liquid waste, a pump pit, and a filter pit.

French Drain: A buried horizontal pipe filled with rock, open-ended or perforated, for disposal of liquid waste by seepage into the ground.

Interim Isolation: The process of establishing at least one physical barrier to any credible source of liquid addition to a single-shell tank or other facility, such as a diversion box, and separating the tank atmosphere from the outside air by a filtered ventilation system.

Interim Stabilization: The process of pumping all supernatant waste and as much drainable interstitial liquid as possible from a single-shell tank, typically using a saltwell pump, to minimize the volume of liquid available to leak into the ground.

Reverse Well: A buried vertical pipe with the lower end open or perforated to allow seepage of liquid waste into the ground. Also called *dry well*.

Specific Retention Trench: An unlined excavation used for the disposal of a designated volume of low-level or intermediate-level radioactive waste. Liquid is retained in the trench soil and does not migrate to the groundwater.

Supernate: The supernatant liquid in a tank when all suspended solids have settled.

Tank Bump: A sudden release of a steam bubble from stratified waste in a tank, caused by radiolytic heating of the waste.

Vadose Zone: The portion of the soil below the surface but above the groundwater.

WIDS: The waste information data system (WIDS) comprises the official summary of the history and status of the Hanford waste sites. A general summary report is maintained for each site.

HISTORICAL VADOSE ZONE CONTAMINATION FROM A, AX, AND C TANK FARM OPERATIONS

1.0 INTRODUCTION

This document is a collection of historical information regarding radioactive contamination of the soil surface and vadose zone in the vicinity of the 241-A, 241-AX, and 241-C Tank Farms. Specifically, the information is compiled for the tank farms, all known liquid waste disposal sites (cribs), and all known unplanned releases (UPRs) in the vicinity. The area of interest is shown in Figure 1 (all figures are in Appendix D). Releases are included from initial construction in 1944 to the present. Tables showing disposal sites and UPRs are contained in Appendix A.

Four UPRs have been remediated and are not included in this report:

- On October 15, 1974, contaminated soil was discovered in 241-A Farm (UPR-200-E-47). The contaminated soil was removed and the area released for normal service.
- On November 22, 1974, the 241-A-106 pump pit contaminated the 241-A Farm parking lot (UPR-200-E-48). The area was cleaned and returned to normal service the same day.
- On May 23, 1979, contaminated mud was found in swallow nests at the 244-AR vault, and contaminated tumbleweeds and mud were found outside the containment bag in the 216-A-40 retention basin (UPR-200-E-59). The nests and tumbleweeds were removed, and the basin was decontaminated. The basin was backfilled and the surface stabilized in 1994.
- The soil around the 244-CR vault became contaminated from the numerous piping modifications (UPR-200-E-99). The site was decontaminated in 1981 and released from radiological controls.

Nonradioactive releases (such as fuel spills and septic tanks) and buried radioactive solid waste are excluded from this report. Water discharges to the soil, from precipitation, water line leaks, or decontamination activities, are addressed in Gaddis (1999).

A timeline of events is shown in Appendix B. Crib discharge histories are in Appendix C.

The primary focus of this report is on tank farm operations, which includes spills, tank leaks, and crib discharges. Crib discharges are the largest contributor of vadose zone contamination. Crib disposal outlets are typically located 3 to 10 meters below grade, while most spills occur above ground level and contaminate only the surface. Many spill sites were quickly cleaned up and decontaminated. Additionally, the sitewide volume of waste discharged to cribs is more than 100 times the volume of waste leaked from the tanks (Consort 1994).

The groundwater beneath the A/AX/C Tank Farm complex is approximately 80 meters under ground with a very small (2E-04) hydraulic gradient. The flatness makes it difficult to ascertain

the flow direction. Generally, groundwater under A/AX Farms moves to the east, and groundwater under C Farm moves to the southwest, at about 1 meter per day. The groundwater level beneath 200-East Area has been decreasing gradually since B pond was decommissioned in 1995 (Hartman 2001).

The topography of C Farm and of A and AX Farms is such that precipitation can run onto the farm and develop into standing water. Provisions for controlling run-on contamination are described in Gaddis (1999).

2.0 SUMMARY AND CONCLUSIONS

A number of significant discharges of radioactive contamination to the surface soil and vadose zone occurred throughout the operating history of the Hanford Site. The most significant discharges to the area of interest around the A/AX/C Farm complex are summarized as follows:

- Cribs 216-A-8 and 216-A-24 received a total of 1.97E+09 L of single-shell tank (SST) condensate.
- Crib 216-A-9 received 9.81E+08 L of PUREX acid fractionator condensate.
- Cribs 216-A-1, 216-A-18, 216-A-19, and 216-A-20 received a total of 2.65E+06 L of PUREX cold startup waste.
- The largest spill was UPR-200-E-81 (1.36E+05 L). The largest tank leaks were from 241-C-101 (9.10E+04 L) and 241-AX-104 (3.0E+04 L).

Other cribs in the 200-East Area are outside the scope of this report but are mentioned here for comparison. Cribs 216-A-6, 216-A-30, and 216-A-37-2 received 7.7E+09 L of PUREX plant steam condensate. Cribs 216-A-5, 216-A-10, and 216-A-45 received 5E+09 L of PUREX process condensate. Crib 216-A-37-1 received 3.8E+08 L of 242-A evaporator condensate. The BC cribs and trenches received 1.10E+08 L of scavenged tributyl phosphate (TBP) waste.

This report supports previous work on discharges to the cribs associated with the B/BX/BY and T/TX/TY Tank Farm complexes (Williams 1999; Williams 2000). Unlike the B/BX/BY and T/TX/TY Tank Farms, the A/AX/C Tank Farm complex is not completely deactivated. Interim stabilization operations will continue for several more years, and the possibility exists that future contamination events could occur.

3.0 FACILITIES HISTORICAL BACKGROUND

The 241-C Tank Farm contains 12 first-generation, reinforced concrete tanks with carbon steel liners covering the sides and bottoms. The tanks are 23 m (75 ft) in diameter and 4.9 m (16 ft) deep, with a capacity of 2 million liters (530,000 gallons). The tanks are arranged in four rows of three tanks. The tanks in each row are piped together so that when the first tank fills, it overflows (cascades) into the second tank, and the second into the third. Four diversion boxes were originally provided in C Farm; another three diversion boxes, the 244-CR process vault, the 271-CR control house, 271-CRL laboratory, and the 241-C-801 cesium loadout facility were built later. The farm also contains four smaller "200-series" tanks that are 6.1 m (20 ft) in

diameter and hold 0.2 million liters (55,000 gallons). These four tanks are piped to diversion box 241-C-252.

The 241-A Tank Farm contains six third-generation tanks similar to C Farm tanks but are 9.1 m (30 ft) deep with a 3.8 million liter (1 million gallon) capacity. The tanks are filled individually and do not cascade. Tanks were connected to each other by overflow lines (which had a water-filled seal loop to isolate individual tanks) and a common vapor header, also with water-filled seal loops. A Farm contains two diversion boxes and no 200-series tanks. A Farm also contains the 241-A-431 vent building, the 241-A-271 control building, and the 241-A-701 compressor building. The 241-A-401 condenser building, the 241-A-417 catch tank, the 241-A-702 filter building, and the 241-A-350 drainage lift station were constructed later. Since A Farm was designed to store boiling waste, it was equipped with leak detection caissons and laterals (see Section 4.0) (Anderson 1990).

The 241-AX Tank Farm contains four, fifth-generation tanks. These tanks are identical to the tanks in A Farm, but with a grid of drain slots beneath the steel liner bottom. The grids collect potential tank leakage, which is diverted to a leak detection well. The grids also provide an escape route for free water formed as it is released from the concrete grout during initial heating of the tank. AX Farm contains the 241-AX-152 diverter station and the 2707-AX change house, but no 200-series tanks. AX Farm has no leak detection caissons (Anderson 1990).

Other facilities located in and around the A/AX/C Farm complex are:

- 244-AR vault
- 241-AX-151 diverter station
- 204-AR unloading station
- 244-A lift station

The A/AX/C complex operations can be separated into six operational phases:

- Construction and bismuth phosphate operations, 1944-1952
- Uranium recovery operations, 1952-1957
- PUREX operations 1956-1972, 1983-1988
- Waste fractionation operations 1961-1978
- Tank farm interim stabilization and isolation began in 1975

Sanitary water was provided to the 271-CR control building in C Farm. Sanitary water was provided to the 241-A-271 control building in A Farm. Later, sanitary water was provided to the 2707-AX change house in AX Farm, the 244-AR vault, and the 242-A evaporator.

3.1 Construction and Bismuth Phosphate Operations (1944-1952)

The Hanford Site was constructed as part of the Manhattan Project to produce plutonium by chemical separation from irradiated fuel slugs using the bismuth phosphate process. Preliminary design (1943) called for four separations plants (B, C, T, and U) and their associated tank farms, but later development reduced that number to three. C Plant construction was cancelled, but by that time, 241-C Tank Farm had already been built. Figure 2 shows facilities constructed during that time.

The bismuth phosphate process produced five waste streams:

- Metal waste (MW) was the byproduct from the plutonium separation phase of the bismuth phosphate process. MW contained unfissioned uranium and approximately 90% of the fission products of the irradiated fuel.
- First-cycle waste (1C) was the byproduct from the first plutonium decontamination cycle of the bismuth phosphate process. This waste contained about 10% of the fission products of the irradiated fuel. This waste also contained coating-removal waste.
- Second-cycle waste (2C) was the byproduct from the second and last plutonium decontamination cycle of the bismuth phosphate process. This waste contained less than 0.1% of the fission products of the irradiated fuel. C Farm did not store 2C.
- The 224 waste was low-level liquid waste from the 224-B plutonium concentrator building. This waste stream was the primary contributor to plutonium contamination of the soil. This waste was discharged to the 216-B-5 reverse well, which is outside the scope of this report but is described in Williams (1995).
- The 5-6 waste was low-level liquid waste from floor drains in individual process cells in B Plant. Drainage from the cells was stored in the 5-6 tank before being discharged to the 216-B-5 reverse well.

During World War II, MW, 1C, and 2C were stored in tanks at B Farm, which is outside the scope of this report but is described in Williams (1999). In December 1946, underground lines were constructed from the 241-B-154 diversion box near B Plant to the 241-C-151 and 241-C-152 diversion boxes in C Farm (see Figure 3). MW from B Plant was stored in the 241-C-101/2/3 and 241-C-104/5/6 cascades, and 1C from B Plant was stored in the 241-C-107/8/9 and 241-C-110/1/2 cascades (Anderson 1990).

Ground disposal of aqueous industrial waste, relying on the ion exchange properties of the soil to decontaminate the water as it percolates to the aquifer, was a commonly accepted method in the 1940s. The ability of Hanford topsoil and substrate to adsorb radioactive material was tested at the Clinton Site in Tennessee (now the Oak Ridge National Laboratory) and at the University of California at Berkeley in 1944. Tests determined that ground disposal of 5-6 and 224 was acceptable, but ground disposal of 1C and 2C was not. Methods to treat 1C and 2C to facilitate ground disposal were investigated at the time, but were unsuccessful (Parker 1944; Patterson 1945; Leader 1945).

In September 1946, the Army Corps of Engineers Manhattan District selected General Electric Company to replace DuPont as the Hanford prime contractor. Pursuant to the McMahon Atomic Energy Act of 1946, control of the Hanford Site passed from the Army to the civilian Atomic Energy Commission (AEC) on January 1, 1947. The AEC opted to maintain Hanford as a permanent facility rather than dismantle it, as happened to many other wartime munitions plants. Wartime production had filled all available tank storage space, so plans were made to increase

high-level waste storage capacity and to recover some tank space. These plans included disposing of the relatively low-level 2C waste into the ground, and concentrating the intermediate-level 1C waste in an evaporator. Plans were also made to recover the unfissioned uranium in the MW (by 1947, most of the world's known supply of uranium was in the Hanford Site waste tanks) (Gerber 1991).

From 1947 to 1949, many new facilities were constructed at Hanford. The Hot Semi-Works complex, facilities for the planned uranium recovery mission (see Section 3.2), and other facilities beyond the scope of this report (BX, BY and TX Tank Farms, Z Plant, H Reactor, DR Reactor) were all built during this period (Gerber 1991). Figure 3 shows facilities constructed for post-war bismuth phosphate and uranium recovery operations.

The 242-B and 242-T evaporators were built in 1951 to reduce the volume of stored 1C. C Farm 1C was retrieved from January to March 1952 and evaporated in 242-B. A dedicated underground line (V121) was built for retrieval, and the waste was pumped from 241-C-152 to 241-B-154 to 241-B-152, which connected to evaporator feed tank 241-B-106. B Plant was shut down in 1952 (Anderson 1990; Williams 1999). The operations in 242-B are described in Williams (1999).

Conflicting information exists regarding the piping used for 1C retrieval. Line V121 is shown on drawing H-2-2021, but this drawing has no "as-built" note. The piping encasement from the 241-CR-151 diversion box to the 200-series tanks is shown in the same location as V121 on drawing H-2-41126, which gives an "as-built" date of October 14, 1952. Anderson (1990) says that 1C retrieval was finished on August 15, 1952, and MW retrieval in the 200-series tanks began no earlier than October 1953. This leaves over a year to remove V121 and build the encasement, however drawing H-2-41126 indicates it may have been only two months. Installation of a dedicated line for 1C retrieval was done for T, TX, and U Farms. Most likely, V121 was installed and used, then removed when the encasement was built in September 1952. It is possible that the "as-built" dates on some drawings may be wrong.

No UPRs occurred in C Farm during this time.

3.2 Uranium Recovery Operations (1952-1957)

U Plant was originally constructed during World War II as a bismuth phosphate plant, but was not needed for that purpose, and the facility was used as a simulator. It was modified in 1951 for uranium recovery operations using the TBP process. For this reason, U Plant was frequently referred to as the "TBP Plant." Beginning in October 1952, MW was sluiced from tanks in C Farm, treated in the 244-CR process vault, and transferred to U Plant via the cross-site transfer line. MW in the 200-series tanks was sluiced out in early 1954. MW from B, T and U Farms was also sent to U Plant for uranium recovery. Newly generated MW from T Plant was also sent to U Plant for uranium recovery, until T Plant shutdown in 1956. Uranium recovered by this method was in the form of uranyl nitrate hexahydrate (UNH), which was sent to the 224-U building for conversion to UO_3. 224-U was known as the "UO_3 Plant" (Rodenhizer 1987; Anderson 1990).

The uranium recovery facilities in C Farm include the 271-CR control house, the 244-CR vault, the 241-CR-151, -152, and -153 diversion boxes, and modifications to the underground piping system. Other facilities which are outside the scope of this report, but relevant, include the cross-site transfer line, the 241-ER-151 diversion box near B Plant, the BY cribs, and the BC cribs. Figure 3 shows facilities constructed for uranium recovery.

Uranium recovery operations produced two waste streams: TBP waste and low-level waste. TBP waste, concentrate from the waste concentrator, was returned to the tank farms, including C Farm (all tanks). The design called for the same volume of TBP waste to be produced as the volume of MW processed, but inefficiencies in the process resulted in approximately twice as much TBP waste produced as the MW processed. A total of 215 million liters of TBP waste was produced. Low-level waste included condensate from the feed concentrator, waste concentrator, and HNO_3 fractionator. This waste was sent to various cribs that are outside the scope of this report. Cooling water and cell drainage from the TBP Plant were discharged to U pond, also outside the scope of this report (Waite 1991; DiLorenzo 1994; GE 1951).

Despite additional tank farm construction and ongoing volume reduction efforts, tank space was not sufficient to support both the uranium recovery mission and plutonium production. To reduce the volume of stored waste, TBP waste was concentrated in the 242-T and 242-B evaporators beginning in July 1953 (very little C Farm waste was evaporated – some from 241-C-112 in the third quarter of 1953). Additionally, a ferrocyanide scavenging process was developed to remove the principal long-lived fission products, ^{137}Cs and ^{90}Sr, from the TBP waste to enable disposal of the waste supernate to the cribs. Beginning in September 1954, TBP waste was scavenged in U Plant, instead of being evaporated. The scavenged waste from U Plant was transferred to BY Farm only (see Williams 1999) (Anderson 1990).

The 244-CR vault was modified in 1955 to scavenge TBP waste that was stored in C Farm, and the 241-C-601 chemical makeup building was constructed. Nickel ferrocyanide was added to the TBP waste, which caused the ^{137}Cs to precipitate and join the ^{90}Sr in sludge settling at the bottom of the vault tank. The scavenged waste supernate could then be discharged to cribs. New piping was installed to facilitate TBP retrieval from the 241-C-107/8/9 and 241-C-110/1/2 cascades. TBP could be jetted out of these tanks to the 241-C-104 pump pit and transferred to the 244-CR vault via the existing encasements. Beginning November 1955, TBP waste was retrieved from the C Farm tanks and sent to 244-CR, using the encasements and pump pits. The 244-CR vault received TBP waste from only two tanks outside C Farm: 241-BX-108 and 241-BX-109.

Scavenged TBP waste was transferred from 244-CR via the 241-CR-151, 241-C-151, and 241-C-252 diversion boxes to 241-C-109 and 241-C-112 to settle, and from there to the BC cribs and trenches. Cribbing of scavenged TBP waste began in November 1954. Approximately 155 million liters (41 million gallons) of scavenged TBP waste was discharged into the ground. Of this, approximately 44 million liters (12 million gallons) resulted from in-farm scavenging in the 244-CR vault. The BC cribs and trenches are outside the scope of this report, and are over 2 kilometers from the nearest tank farm. The 241-C-601 building was torn down in August 1973 (Anderson 1990; Waite 1991).

The 241-CR steam cleaning pit was dug in 1954, northwest of 241-C-103. No further information is available about this facility (Baldridge 1959).

Two UPRs occurred in C Farm during this period. Installation of a transfer pump in the 244-CR vault on November 26, 1952, resulted in the spill of liquid waste to the ground (UPR-200-E-107). Airborne contamination spread from 241-C-107 to C Farm and the south bank of the parking lot on April 20, 1957 (UPR-200-E-118).

3.3 PUREX Operations 1956-1972 (1983-1988)

The PUREX process was the third and final plutonium separation process used at the Hanford Site, and the PUREX plant ultimately processed approximately 72% of the irradiated fuel produced at Hanford. The process recovered both plutonium (in the form of plutonium nitrate) and uranium (in the form of UNH) in a continuous solvent extraction process, and also recovered nitric acid and the TBP organic solvent for reuse. This innovation minimized waste generation and resulted in PUREX waste being more highly concentrated than other Hanford waste streams. The PUREX plant, the 241-A Tank Farm, and various and waste transfer lines and cribs were constructed for PUREX operations (Courtney and Clark 1954; Gerber 1993; Anderson 1990). Figure 4 shows the PUREX facilities constructed in the area of interest.

The use of TBP instead of the more flammable methyl isobutyl ketone (hexone) that had been used in the REDOX plant was also a safety improvement. Plutonium nitrate product generated by the PUREX plant was trucked to the Plutonium Finishing Plant (PFP), and UNH byproduct was trucked to the UO_3 Plant (Gerber 1993).

The PUREX plant produced various low-level waste streams and three high-level waste streams: PUREX coating waste (CWP), PUREX acid waste (PAW), and organic wash waste (OWW), also called "carbonate." PAW, which contained 99% of the fission products, was also known as P, HAW, CAW, and IWW. These waste streams are described in subsections below (Courtney and Clark 1954; Anderson 1990).

PUREX cold startup waste was discharged to 216-A-1 in November 1955 via an overground line from proportional sampler pit 3. When the specific retention capacity was reached, cold startup waste was then discharged to 216-A-18 in November 1955, 216-A-19 in November/December 1955, and 216-A-20, all via an overground line from proportional sampler pit 2 and the 216-A-34 ditch. It is believed that this was the only use of the 216-A-34 ditch (Heid 1956; Baldridge 1959; WIDS). The Hanford Engineer Works monthly report for December 1955 (GE 1956) states that AEC approval to crib the cold startup waste was obtained during that month. Analytical data for these discharges is presented in the following table:

PUREX Cold Startup Waste Disposal		
Crib No.	Waste Volume (L)	U (kg)
216-A-1	1.00E+05	152
216-A-18	8.02E+04	19
216-A-19	4.88E+05	2460
216-A-20	9.61E+05	N/A

3.3.1 PUREX High-Level Waste Streams

Self-boiling PAW and OWW from PUREX were stored in A Farm. The first waste discharges to 241-A-101 and 241-A-102 were not sufficiently concentrated to boil, so OWW was temporarily segregated and sent to 241-C-110. Subsequent waste discharges to A Farm did boil (see Section 3.3.2) (Anderson 1990).

Non-boiling CWP was sent to now-empty tanks in C Farm. Lines V050 from diversion box 241-A-152 to the 241-CR-151 diversion box, and V051 from 241-A-152 to the 244-CR vault, were built for this purpose. As the Uranium Recovery project provided space in B/BX/BY Farms (see Williams 1999), CWP was transferred there from C Farm beginning in 1957. In 1962, tank 241-C-102 was designated as the CWP receiver tank, and all CWP from PUREX went there. From 241-C-102, CWP was pumped to B/BX/BY Farms via the 241-CR-152, 241-CR-151, 241-C-151 and 241-B-154 diversion boxes (Anderson 1990).

New pump discharge line 8107 was built from 241-C-102 to 241-CR-152 in 1966 for CWP transfer to B/BX/BY. When the Waste Fractionization Program got underway in B Plant in 1968 (see Section 3.4), OWW was sent to 241-C-102 along with CWP. Line V843 was built in January 1969 and allowed CWP/OWW to be discharged from 241-CR-151 directly to 241-C-102, bypassing the 241-CR-152 diversion box (this simplified the routing to B/BX/BY). Line V844 was built at the same time, tying into 8107 and allowing 241-C-102 to discharge to 241-CR-151 instead of 241-CR-152. Additionally, line V051 from 241-A-152 to the 244-CR vault was rerouted to 241-CR-151 (Anderson 1990; H-2-33087, Rev 0, 3).

Several months later, in October 1969, CWP leaked from line V051 (UPR-200-E-81). Lines V050 and V051 from diversion box 241-A-152 were modified in November 1969 to bypass the 241-CR-151 diversion box and discharge CWP/OWW directly into 241-C-104 instead of 241-C-102. This waste was transferred from 241-C-104 to B/BX/BY Farms from 1969 to 1973, and from 241-C-104 to 200-West Area from 1973 to 1976 (Anderson 1990; H-2-33087, Rev 5).

There is a discrepancy between drawings H-2-33087 and H-2-44502, sh 7, regarding the piping from the 241-CR-151 and 152 diversion boxes to 241-C-102 and 104. Drawing H-2-44502 shows line 8107 discharging to tank 241-C-102 via a riser along with abandoned line V843, and line V844 connected to V843 and discharging to tank 241-C-104 via a riser. Drawing H-2-33087 shows line V843 discharging to 241-C-102 via a riser, and lines 8107 and V844 connected to the pump discharge line from 241-C-102. It is believed that drawing H-2-44502, sh 7, is wrong.

The overground transfer line from 241-C-105 to 241-C-108 broke sometime between January 1956 and July 1959 and spilled 190 L (50 gallons) of CWP to the ground (UPR-200-E-16). On November 1, 1960, during work in the 244-CR vault, wind spread contaminated particles eastward (UPR-200-E-27).

3.3.2 Tank Farm Ventilation System

PAW was sent to A Farm beginning in January 1956. The more efficient PUREX process was expected to produce highly concentrated waste that was expected to boil. This boiling was regarded as an efficient method of volume reduction. The A Farm tanks were designed to

accommodate self-boiling waste, based on experience gained in storage of Redox self-boiling waste in SX Farm. Four airlift circulators were installed in each tank, powered by two air compressors in the 241-A-701 building, and a vapor exhaust system exhausting through the 241-A-431 building (Anderson 1990).

The original tank farm ventilation system consisted of an underground vent header connected to all six A Farm tanks, the TK-401 deentrainment vessel, and direct buried contact condenser E-411 (E-412 was an installed spare condenser). TK-401 drained to 241-A-106, which was initially used only to collect condensate, not to store waste. Condensate/cooling water from the contact condensers drained to the 241-A-08 valve pit, and from there to the 216-A-8 crib. The condensers were vented to the 241-A-431 vent building, where the vapors were routed through another deentrainer to the 241-A-11 stack. Drainage from this stack went to the 216-A-16 and 216-A-17 French drains near the 241-A-431 building. Drainage from the deentrainer went to 216-A-23A and 216-A-23B French drains. A bypass line containing a water-filled seal pot connected the vent header (upstream of TK-401) directly to the 241-A-11 stack. If a tank bump occurred, headspace vapors would blow out the vapor header seal loop and the bypass seal pot and go directly to the stack (O'Neill 1956).

In May 1958, crib 216-A-8 reached its radionuclide capacity and the condensate/cooling water waste stream was diverted to crib 216-A-24 (WIDS).

There is a discrepancy in the description of the waste going to crib 216-A-8. Lundgren (1970) states that from November 1955 to December 1957, tank farm condenser cooling water went to 216-A-34 and condensate went to crib 216-A-8. In December 1957, the two streams both went to 216-A-8, and 216-A-34 was retired from service. This continued until May 1958, when crib 216-A-8 was retired from service and the condensate was rerouted to 216-A-24, and the cooling water rerouted to 216-A-25. However, the condensate and cooling water were commingled in the contact condensers and could not have been separated. Additionally, crib discharge records show little change in discharge volume to 216-A-8 around December 1957 (Bernard 1958 and Baldridge 1958). It is believed that the combined cooling water/condensate waste steam was discharged to 216-A-8 from PUREX startup until May 1958, and that 216-A-34 was used only for disposal of cold startup waste, as described above. This discrepancy is repeated in Maxfield (1979) and WIDS.

Dissatisfaction with the performance of the contact condensers led to their replacement in October 1959 by surface condensers in the 241-A-401 building (project CA-719). The new condensers still vented to the 241-A-431 building. Cooling water went to the newly built 216-A-25 Gable Mountain pond. Condensate drained to the 241-A-417 catch tank, and overflowed to the 216-A-24 crib. This modification reduced the condensate discharge volume to crib 216-A-24 by 95%. Cooling water was supplied by the raw water system. If raw water was unavailable, backup cooling was supplied by a closed-loop system with forced draft cooling towers and makeup water from a well (Wood 1957; GE 1960).

Crib 216-A-24 reached its radionuclide capacity in July 1966, and the condensate was diverted back to crib 216-A-8 until April 1976, when it was diverted to double-shell tanks (DSTs) instead of ground disposal. From 1973 to 1976, the 241-A-417 catch tank condensate was filtered by an

ion exchange column prior to discharge to 216-A-8. A small amount (600 L) of condensate was discharged to the crib in 1978 (McMurray 1967; Mirabella 1977; Anderson and Poremba 1979; Stickney and Lipke 1998; WIDS). The crib discharge history for 216-A-8 is shown in Table C-1, and the crib discharge history for 216-A-24 is shown in Table C-2 (see Appendix C).

The 241-AX Tank Farm and the 241-AX-151 and 241-AX-152 diverter stations were built in 1965. The AX Farm vapor header was tied into the 241-A Farm vapor header, upstream of the 241-A-401 condenser building (Doud et al 1962). Later, AY and AZ Farms tied into this system.

The 241-A-702 filter building was added in March 1969 to filter the headspace air. The 241-A-431 vent building was taken out of service at this time and the 216-A-16, 216-A-17, 216-A-23A, and 216-A-23B French drains were decommissioned. Discharge records were not kept for these drains, but estimates of the total discharges are included in Appendix A (WIDS).

In 1959, moisture dripping from a vent pipe bonnet at the 241-A-08 proportional sampler pit contaminated the ground near the 241-A-271 building (UPR-200-E-18).

3.3.3 Other PUREX Low-Level Waste Streams

PUREX process condensate was sent to crib 216-A-5 from startup until contamination broke through to the groundwater in November 1961, then to the 216-A-10 ditch until that broke through in May 1987, then finally to crib 216-A-45 until September 1991. Crib 216-A-38 was built to replace 216-A-10 but it was not used (Maxfield 1979). These cribs are outside the scope of this report.

PUREX steam condensate and drainage went to crib 216-A-6 from startup until January 1961, when 216-A-6 overflowed and caved in. From 1961 until 1992, it was sent to crib 216-A-30. In July 1964, 216-A-30 overflowed and 216-A-6 was reactivated until October 1966, when it overflowed again and was abandoned for good. From PUREX restart in 1983 until final shutdown in 1992, PUREX steam condensate and drainage was sent to the 216-A-37-2 ditch. Cribs 216-A-6 and 216-A-30 operated together from 1964 to 1966, and 216-A-30 and 216-A-37-2 operated together from 1983 to 1992 (Maxfield 1979; WIDS). These cribs are outside the scope of this report.

The 241-A-152 diversion box sump was originally equipped with an automatic siphon that discharged to the 216-A-7 crib in lieu of a catch tank. The crib received drainage from the diversion box sump from January 1956 until July 1959, when the 241-A-302B catch tank was built and piped to the sump drain. The catch tank was set up to overflow to the crib; however, no such overflow is documented. On November 22, 1966, 2.46E+05 L (65,000 gallons) of organic TBP-Soltrol waste was trucked from PUREX and discharged to the crib via the vent riser. In 1985, project B-231 isolated the 241-A-302B catch tank (H-2-57452; Eliason 1967). The crib discharge history for 216-A-7 is shown in Table C-3 in Appendix C.

There is a discrepancy regarding the discharges to crib 216-A-7. Lundgren (1970) states that the crib was still active at the time of publication (January 1970). Eliason (1967) states that the crib was abandoned in July 1959, when the catch tank was installed. Crib discharge records show no discharges after December 1956. It is possible that discharges continued from December 1956 to

July 1959 but were not recorded due to the low volumes involved. After July 1959, the crib was most likely not used, and any catch tank contents were pumped out to the tanks. (GE 1955, Courtney and Cox 1954).

Crib 216-A-9 received PUREX acid fractionator condensate and condenser cooling water from March 1956 to January 1958. This waste stream was then diverted to the 216-A-29 ditch via the PUREX chemical sewer (see Section 3.3.3). From April 1966 through October 1966, the crib received N Reactor decontamination waste via the manhole at the crib site. The crib was inactive but on standby from then until August 1969, when it was decided to discharge the acid fractionator condensate back to the crib. When this was tried, it was discovered that the effluent pipeline had failed, and so the waste was diverted back to ditch 216-A-29 (Lundgren 1970). The crib discharge history for 216-A-9 is shown in Table C-4 in Appendix C.

There is a discrepancy regarding the waste discharged to crib 216-A-9 in 1966-67. Anderson (1976) says that the crib received 1.82E+06 L in 1966 and 1.89E+05 L in 1967 (waste type not specified). McMurray (1967) says there was no discharge in 1966, and Uebelacker (1968) reports a discharge of 1.89E+06 L of N Reactor waste in 1967.

Numerous minor PUREX low-level waste streams went to various cribs around the plant that are outside the scope of this report.

3.3.4 PUREX Cooling Water and Chemical Sewer

PUREX cooling water was first discharged to the old A pond east of PUREX, which was a natural depression at the terminus of the original 200-East Area powerhouse drainage ditch. Powerhouse waste was diverted to the 216-B-2 ditch and B pond when PUREX was built, and the PUREX chemical sewer line was routed to the old drainage ditch outfall structure.

This discharge raised the water table under 200-East Area so much that crib 216-A-8 broke through to groundwater in December 1956. It was decided to send the cooling water elsewhere. Ditch 216-A-29 was built that connected the chemical sewer ditch and the cooling water line outfall. In December 1957, the old A pond was eliminated by tying the chemical sewer and the cooling water lines together at ditch 216-A-29, which emptied into the 216-B-3 pond.

A valve box was built in the cooling water discharge line to allow diversion to either the 216-A-29 ditch and B pond or to the newly built 216-A-25 Gable Mountain pond via an underground line. PUREX cooling water was diverted to the Gable Mountain pond (70%) and B pond (30%). The Gable Mountain pond was taken out of service in 1975 and decommissioned in 1987 (Gerber 1993).

After PUREX restart in 1983, cooling water went to B pond, which was modified for this purpose by the construction of three expansion lobes. B pond was decommissioned in 1995, when the 200-Area Liquid Effluent Retention Facility (LERF) opened. Although cooling water and chemical sewer waste were normally uncontaminated, occasional UPRs contaminated the 216-A-29 ditch. These UPRs are outside the scope of this report.

3.3.5 PUREX Waste in Tank 241-A-105

Tank 241-A-105 received PAW beginning in January 1963, and reached boiling on March 5. An apparent small leak was noticed in November 1963, when the tank was half full. The leak was thought to self-seal. Because experience had indicated that adding waste to a self-boiling tank that had been allowed to settle for a period of time could cause a temperature excursion, the filling continued. Tank 241-A-105 was filled to capacity in December 1964. On January 28, 1965, a sudden steam release occurred in 241-A-105. The earth in the immediate vicinity of the tank was reported to have trembled, and a temporary lead cover on a riser on tank 241-A-103 was dislodged allowing steam to vent from this opening for about 30 minutes. At the time of the bump, construction personnel were preparing to make a final weld in line 4105 connecting tank 241-A-105 with the 241-AX-151 diverter station. Several liters of liquid were ejected onto the ground in the excavation. Radiation dose rates of 4 Sv/hr (400 R/hr) were measured 30 cm (1 ft) from the spill. The 241-A-105 tank instrument enclosure had a dose rate of 5 Sv/hr (500 R/hr) at 30 cm (1 ft), and the liquid level electrode tape was broken. This event differed from previous tank bumps in that it occurred while the airlift circulators were operating (Beard et al. 1967).

An attempt to install an air sparger in a 10-cm (4-in) riser disclosed an obstruction 2.4 m above the normal position of the tank bottom. Additionally, airlift circulator dip tube static pressure readings indicated that either the piping was broken or the circulators had been physically elevated about 1.8 m. Nine holes were drilled through the tank dome and confirmed that the tank bottom was bulged upward by 2.6 m, providing a void volume of 3.03E+05 L underneath the bottom of the tank liner. A description of analyses of tank conditions following the bump is in Beard et al (1967). The tank would not be emptied until it was scheduled for sluicing or until further deterioration was detected. A third leak detection caisson was built near tank 241-A-105 in 1967 (see Section 4.0). The initial leakage amount was between 1.90E+04 L and 5.70E+04 L (Jansen 1965; Beard et al. 1967).

New leakage from the tank was noticed in October 1967 (UPR-200-E-126). The tank was sluiced to the 244-AR vault beginning in August 1968. The sluicing was stopped in November 1970 with a sludge heel remaining in the tank, because readings from the laterals indicated that the sluicing had aggravated the leak. At this time, another 1.90E+04 to 1.14E+05 L leaked from the tank. To cool the remaining sludge, cooling water was added to the tank weekly from November 1970 to December 1978. The total amount of cooling water added was 2.31E+06 L. Pursuant to Washington State law, all cooling water that was not evaporated is included in the leak volume estimate. Allen (1991) estimates the volume of evaporated cooling water at 1.43E+06 to 1.55E+06 L. The final leakage amount is therefore between 7.95E+05 L and 1.05E+06 L (WHC 1991; Hanlon 2001). The 1900-L waste volume given by WIDS for UPR-200-E-126 is incorrect.

3.3.6 PUREX Shutdown and Restart

PUREX was placed in standby in 1972 to allow accumulation of N Reactor spent fuel, and sluicing of A and AX Farms (see Section 3.4). The standby was intended to be 18 months, but various events prevented restart until 1983. PUREX steam condensate went to the 216-A-37-2 ditch. Process condensate went to crib 216-A-45 (Gerber 1993). These ditches are outside the scope of this report.

Crib 216-A-8 was reactivated for the restart, receiving steam condensate from the DSTs in AY and AZ Farms. Unfortunately, the Sr concentration in the tank condensate was too high, so the discharge was rerouted to the DSTs after only 3 days in 1983. This condensate was again discharged to 216-A-8 for a few months in 1984. This waste was rerouted to the DSTs in 1985, and the crib was deactivated permanently. The overflow line from catch tank 241-A-417 was capped at the tank in 1987, and the 216-A-508 distribution box was grouted in April 1995 (Aldrich 1984; Aldrich 1985; Aldrich 1986; WIDS).

Final PUREX shutdown was in 1988, and the closure order came in 1992. Following final PUREX shutdown, cribs 216-A-26, 216-A-30, 216-A-37-2, 216-A-45, and the 216-A-29 ditch received discharges until the 200 Area LERF opened in 1995. These cribs are outside the scope of this report (Gerber 1993; WIDS).

3.4 Fission Product Recovery (1961-1967) and Waste Fractionization Operations (1967-1978)

The concept of recovering fission products with industrial uses (primarily ^{137}Cs) began in the mid-1950s. The country's largest source of fission products was at Hanford. Removal of these isotopes from the PUREX waste stream would also make waste storage cheaper and waste disposal easier. Methods for scavenging Cs and Sr from liquid waste were developed during the Uranium Recovery Mission (see Section 3.2), and reduced storage costs so much that immediate research was begun in the mid-1950s on scavenging REDOX and PUREX waste for similar savings. There was also a growing commercial market for these isotopes. Since the isotope separation process involved precipitation and centrifugation, the first idea was to use B Plant to do this, since it had this equipment and was no longer needed. Plans were made to refurbish B Plant to remove Cs and Sr from PUREX waste (Tomlinson 1956).

An urgent need for ^{90}Sr by the Space Nuclear Applications Program (SNAP) resulted in an acceleration of the fission product recovery project in August 1960. An improvement in the PUREX process allowed modifications to the plant head-end that facilitated recovery. The 244-CR vault was reactivated for the program, and the Hot Semiworks complex would be a pilot plant until B Plant modifications were complete. Hot Semiworks was modified and renamed Strontium Semiworks and production began in July 1961. PAW was pumped via diversion box 241-A-152 and line V051 to 244-CR vault, allowed to age, then sent via line 8900 to Strontium Semiworks for purification. Sr product was loaded into shipping casks at 201-C for offsite shipment to customers (SNAP generators). Sr-depleted PAW waste from Strontium Semiworks (HS) was sent to tanks 241-C-107/8/9 in C Farm. The 271-CRL laboratory was built in C Farm in 1962 (Beard and Swift 1960; Judson 1960; GE 1961; Anderson 1990; Tomlinson 1963). Figure 5 shows facilities constructed in C Farm to support waste fractionization operations.

As well as ^{90}Sr, ^{137}Cs was recovered from PUREX waste during this time. Originally, in 1961, Cs was separated in 212-A. Beginning in 1963, stored PUREX supernate waste (PSN) from 241-C-103 was pumped to the 241-C-801 cesium loadout facility in C Farm and Cs product was loaded into shipping casks for offsite shipment. Newly constructed line V109 from 241-A-101 to 241-C-151 allowed PSN from A Farm to refill 241-C-103. Depleted PSN was returned to 241-C-102 and was eventually transferred (along with CWP) to BY Farm for in-tank

solidification (ITS). ITS is described in Williams (1999). Use of the 241-C-801 facility ended in 1969 (Michels 1961; Beard et.al 1964; Anderson 1990; Tomlinson 1963).

B Plant was used for partial Sr recovery work from 1963 to 1967. Beginning in August 1963, PAW was sent from the 244-CR vault to B Plant via line 8902 to 241-C-151, 241-B-154, and 241-BX-154. It was precipitated and concentrated, allowed to age, and later sent to Strontium Semiworks via line V743 for final purification. HS waste was sent to C Farm as before. Process condensate and other waste from B Plant (FP) was sent to B Farm, and was also sent (via tank 241-B-112) to 241-AX-101 in 1965 (Anderson 1990; Caudill and Zahn 1961; GE 1963). Figure 6 shows facilities constructed in A and AX Farms for waste fractionization operations.

Beginning in late 1967, B Plant went into full operation and began isolating Cs (by ion exchange) and Sr. Sr purification was also done in B Plant, and so Strontium Semiworks was no longer needed and was shut down (the facility was retired in 1967 and was decommissioned from 1983-87). Sr was now recovered by solvent extraction in B Plant instead of the previous precipitation method. PAW was now routed to B Plant via 241-AX-151 and the new 244-AR vault for Sr recovery, instead of via the 244-CR vault. In addition, B Plant received PSN from feed tank 241-C-105, via line V130, for Cs recovery by ion exchange. More than 95% of the Sr and Cs in PAW was removed in B Plant. Line V103 from 241-C-151 was modified in 1968 to bypass 241-C-104 and allow PSN transfer from AX Farm to 241-C-105. Redox supernate from SX Farm was also sent to B Plant for fractionization in 1970-'71. OWW was no longer mixed with PAW for storage; it was now mixed with CWP and sent to 241-C-102, and from there to BX Farm for ITS (see Section 3.3.1) (Buckingham 1967; Anderson 1990; Liverman 1975).

In between PAW transfers, sludge was sluiced out of the A/AX tanks for Sr recovery. Tank 241-A-101 was sluiced first in 1968, then 241-A-104 in 1969, and 241-A-106 in 1970. In the 244-AR vault, the sludge, called PUREX sludge waste (PSW), was dissolved in acid. The resulting PUREX acidified sludge (PAS) was pumped to the 244-CR vault via the 241-AX-151 diverter station and line 8656 for lag storage, and from there to B Plant via line 8653. Since PUREX was operating almost constantly, little sluicing was done until PUREX shutdown in 1972 (see Section 3.3.6). Following shutdown, the 244-AR vault was modified for full-time sludge processing and tank sluicing was accelerated. Sr and Cs were encapsulated and stored in the Waste Encapsulation and Storage Facility (WESF) beginning in 1974. Encapsulation was completed in 1985 (Anderson 1990; Rasmussen 1980).

B Plant produced four waste streams. High-level B, Sr-depleted PAW slurry similar to HS, went to AX Farm for storage. Intermediate-level BL (which was primarily ion-exchange waste, but also included waste concentrator concentrate), from PSW and PSN processing, went to B/BX/BY tanks for ITS (which ended in 1974). Process condensate went to the 216-B-12 crib, and organic waste to the 216-B-56 crib. Cooling water was discharged to B pond. Aside from the B waste, these waste streams are outside the scope of this report (Doud and Roddy 1964; Buckingham 1967; Agnew 1994).

Fractionization of stored waste continued until 1978, when the last of the stored waste in A and AX Farms was retrieved. Tank 241-A-102 was sluiced in 1973, 241-A-103 in 1974, 241-AX-101 in 1975, 241-AX-102 in 1976, 241-AX-103 in 1977, and 241-AX-104 in 1978. Following

sluicing, the sound tanks (241-A-101, -102, -103, 241-AX-101, and -102) were authorized for saltcake storage, and leakers were stabilized and isolated (see Section 3.5) (Anderson 1990; Rasmussen 1980).

As the tanks were sluiced, the sound tanks were refilled with CWP, OWW, B, and other Hanford waste types, all mixed together. By the mid-70s, every type of waste was being commingled in A/AX/C Farm, primarily in tanks 241-A-103, 241-C-103, and 241-C-104 (Anderson 1990).

In the sluicing operations that occurred from 1969 to 1971, the concentrated slurry layer in the 244-AR vault accumulation tank was washed with water prior to transfer to the acidification tank. After agitation and settling, the wash water was pumped to either tank 241-C-105 or 241-C-106. Some solids were transferred to these tanks. The solids in 241-C-106 contained several megacuries of Sr-90, which caused the waste to approach boiling temperatures. Tank 241-C-106 had not been designed as a boiling waste tank, and Section 3.5 describes efforts to deal with this situation (Walker 1977; Rodenhizer 1987).

The 244-AR vault stack drainage went to crib 216-A-41 from January 1968 to 1974. After that, it was rerouted to the vessel vent seal pot system. Cooling water, if uncontaminated, went to the Gable Mountain pond. Contaminated cooling water was diverted to the 216-A-40 lined retention basin and returned to 244-AR. The 244-AR vault has been inactive since 1978. It was upgraded in the mid-1980s in preparation for the PUREX restart, but by then B Plant was being refitted as a waste vitrification pilot plant, and PUREX waste that was generated after the restart was stored in DSTs and was not fractionized. The 244-AR vault is scheduled for interim stabilization (see Section 3.5) by September 30, 2003 (Maxfield 1979; Laney 2000).

The 216-C-8 French drain received an unknown amount of floor drain waste and ion exchange resin regeneration waste from experiments in the 271-CRL laboratory in C Farm beginning in June 1962. The ion exchange studies were terminated in June 1965 and the equipment removed (Lundgren 1970; H-2-31890). The total volume discharged to the crib is likely to be small, since crib discharge records do not mention 216-C-8.

In June 1966, a radioactive liquid line in the 241-AX-801B building pressurized and spilled 20 L of liquid onto the floor. Dose rates exceeded 50 mSv/hr (5 R/hr) at 3 m. The 216-A-39 crib was constructed to receive the waste. A hole was cut through the back side of 241-AX-801B, and a fire hose was used to flush the contamination out the door and into the crib (WIDS).

Line V122 from tank 241-C-105 to diversion box 241-C-152 (the PSN feed line to B Plant) began leaking in 1970 (UPR-200-E-82) and was replaced with line V115. A leak in line 812 from the 244-AR vault to diversion box 241-C-151 in 1971 contaminated a 36-m^2 area with PSN (UPR-200-E-86).

Three UPRs occurred in AX Farm during this period. Surface contamination occurred around 241-AX-151 in 1972, resulting from an inadvertent pressurization in the 244-AR vault (UPR-200-E-42). A spray leak in the 241-AX-103 pump pit occurred on February 12, 1974 (UPR-200-E-115). Removal of a contaminated electrode cable from 241-AX-104 in 1969 dripped a negligible amount of contamination onto the ground (UPR-200-E-119).

3.5 Stabilization and Isolation 1975-Present

Three tanks in A Farm, two tanks in AX Farm, and three tanks in C Farm have leaked. In accordance with Hanford operating policy at the time, liquid waste removal from a tank of questionable integrity was expedited and the tank was removed from service. Interstitial liquid was removed by saltwell jet pumping (Liverman 1975). Figure 7 shows facilities constructed in C Farm for saltwell pumping, and Figure 8 shows facilities constructed in A and AX Farms.

Tank 241-A-104 leaked 9500 L in May 1975 and was pumped down to a sludge heel (UPR-200-E-125). Tank 241-C-101 leaked 91 000 L in 1970 (UPR-200-E-136). Tank 241-C-203 leaked 1500 L in 1976 (UPR-200-E-137). Tank leaks which were not assigned UPR numbers occurred in 241-A-103, 241-AX-102, 241-AX-104, 241-C-110, 241-C-111, and the other three C Farm 200-series tanks. Volume estimates for these leaks are taken from Hanlon (2001). Leakage from tank 241-A-105 (UPR-200-E-126) is discussed in Section 3.3.5. Tank leaks are described in Table 2 of Appendix A.

There is a discrepancy in the reported volume of UPR-200-E-136. WIDS gives a range of 64 000 L to 91 000 L, while Hanlon (2001) reports the volume as 76 000 L. Information is not available to resolve this discrepancy.

Interim stabilization is the process of removing all supernatant liquid and as much drainable liquid as possible; this process began in 1972. The saltwell system for A/AX/C Farms included a pump pit for each tank, the saltwell and jet pump, piping from the pump pits to the receiver tank, and associated instrumentation and controls. Tank 241-C-103 was the receiver tank for C Farm, and 241-A-102 was the receiver tank for A and AX Farms. The 244-A lift station and new encased underground lines were constructed in 1975 that connected C Farm, A Farm, and the cross-site transfer line. The C Farm tanks were interim stabilized beginning in 1976, with the interstitial liquid pumped from 241-C-103 to the 242-S evaporator via line V228 from C Farm to the cross-site transfer line. Transfers to 242-S were discontinued when the 242-A evaporator started operations (Liverman 1975; Smith 1975; H-2-65052).

The 242-A evaporator began operating in March 1977 with saltwell receiver 241-A-102 as the feed tank and 241-AX-101 as the slurry receiver tank. C Farm saltwell waste was pumped from 241-C-103 to 241-A-102 via the 244-A lift station. The evaporator also receives waste from the 241-A-350 drainage lift station, which was built in 1976. Cooling water was discharged to the Gable Mountain pond and condensate went to 216-A-37-1 ditch. When AW Farm was built in 1980, DST 241-AW-102 replaced SST 241-A-102 as the feed tank. In April 1989, after final PUREX shutdown, the 242-A evaporator was shut down. Project B-534 renovated the evaporator, and project W-105 built the 200 Area LERF for evaporator condensate. The evaporator restarted in April 1994 and is still in use (Smith 1975; Maxfield 1979; Luen 1989; Wisness 1994).

Since 1968, all waste tanks constructed have been DSTs, and AEC policy in 1975 was to direct all liquid waste to DSTs. SSTs were removed from service in 1980, and DST 241-AN-101 replaced 241-A-102 as the saltwell waste receiver tank in 1981. Tank 244-CR-003 in the 244-CR vault has been used as a double-contained receiver tank (DCRT) for C Farm since 1979.

A new valve pit was built near tank 241-C-103 that tied into the existing saltwell piping and discharged to 244-CR-003. Waste was transferred from the 244-CR vault to AW Farm for evaporation via the 244-A lift station, the 241-A valve pits, and the 241-AW valve pits. The 244-CR vault has not been used since 1995. It is not yet scheduled for interim stabilization, but no future use has been identified (H-2-73799; Hanson 1980; Parkman 2000).

Following interim stabilization, SSTs were interim isolated by establishing at least one physical barrier between the tank contents and the environment, to preclude inadvertent addition of liquid. Cutting and blanking process piping to and from the tank, blanking all risers, and equipping the tank with a filtered ventilation system accomplished this. In A/AX Farms, the 241-AX-151 diverter station, the 241-A-152 diversion box, and the 241-A-302B catch tank were isolated by project B-231 in 1984-1985. In C Farm, all diversion boxes and the 241-C-301 catch tank were isolated by project B-231 (Liverman 1975; Hanlon 2001; WIDS).

Two leaking tanks in A Farm and two leakers in AX Farm were stabilized and isolated at the end of sluicing activities in 1978. Except for 241-A-101, 241-AX-101, 241-C-103, and 241-C-106, all tanks are interim stabilized. Tanks 241-A-101 and 241-AX-101 are still being saltwell pumped. Tank 241-C-103 has a layer of organic waste floating atop the aqueous supernate that will be removed prior to saltwell pumping. This removal will not use the 244-CR-003 DCRT. The stabilized tanks are also interim isolated, except that isolation is not complete on 241-A-102 and 241-C-105 (Hanlon 2001; Horner 2001).

Water additions to 241-A-105 (see Section 3.3.4) stopped in December 1978 and the 296-P-17 exhauster was installed in January 1979. The tank was interim stabilized in 1979 and interim isolated in 1985. The exhauster was removed from service in October 1991, and the tank is now on passive ventilation (Hanlon 2001; WIDS).

By 1982, the portion of the A Farm vapor header from AX Farm to the 241-A-401 condenser building was in danger of leaking, so project B-419 replaced that section of header. This project also isolated AX Farm from the A-702 ventilation system, and provided an isolation valve for A Farm (following this, the system served only AY and AZ Farms). This was intended to isolate the A Farm tanks; however, a ventilation path to the 241-A-401 condenser building via the old TK-401 deentrainment vessel was inadvertently left open. Project B-222 later isolated individual tanks in A Farm by filling the seal loops in the ventilation header with grout. The 296-P-17 exhauster on 241-A-105 provided ventilation to all A Farm tanks via the overflow lines between the tanks until it was removed (Braun 1982; Prosk and Smith 1986; H-2-62895).

When the waste in tank 241-C-106 reached boiling temperatures in mid-1971, it was connected to an exhauster to cool the waste. Cooling water was also added to the tank. BL waste was added to the tank from 1974 through 1976. The exhauster was replaced twice in 1976 due to excessive contamination. The 296-P-16 exhauster was installed in 1984 (project B-480). Because of continuing high temperature in the tank, the sludge was sluiced to 241-AY-102 in 1999 (project W-320). A special ventilation system, 296-C-006, and a new transfer line to 241-AY-102 were built for the sluicing operation. Following sluicing, the 296-C-006 ventilation system was abandoned in place. The 296-P-16 system will stay in use pending an interim isolation decision (Walker 1977; Anderson 1990; Wang 1994; H-2-93797).

Wind-borne contamination from 241-C-151 in January 1985 (UPR-200-E-68) was either decontaminated to background levels or covered for later decontamination. Following this incident, a radiation survey conducted on April 20, 1985, revealed a contaminated area south of C Farm that indicated the burial of previously undocumented contaminated material (UPR-200-E-72). The contamination was physically fixed in place with Turco Fabri-Film™ and the area posted as a Surface Contamination Area (WIDS).

On December 13, 1993, a project W-049H (200 Area Treated Effluent Disposal Facility) pipeline excavation resulted in the discovery of contaminated soil surrounding the vitrified clay pipeline from 241-A-08 to the 216-A-34 crib (UPR-200-E-145).

On March 23, 2001, the diverter station 241-AX-152 catch tank was declared an "assumed leaker." This leak has not yet been assigned a UPR number (Hanlon 2001).

4.0 MONITORING TEST WELLS

Monitoring test wells were drilled in each tank farm as part of original construction to check for tank leakage. To avoid groundwater contamination, these wells were drilled only to 46 m (150 ft) and did not extend to the upper aquifer (groundwater depth was 76 m [250 ft]). Wells were checked weekly. Test wells were also drilled near cribs as part of original construction to monitor vadose zone contamination. Typically, wells would be drilled to 46 m (150 ft), but major disposal sites had at least one 92 m (300 ft) well to check for nuclide migration to groundwater (Parker 1944; Brown and Ruppert 1950). The test wells are described in Table 4.1 and shown on the figures in Appendix D.

At the time of initial construction, knowledge of the groundwater hydrology of the Hanford area was limited to a few reports from the 1910's and 1920's. These reports were general in scope and limited in content. The continuing need to dispose of 1C and 2C waste into the ground led the AEC to contract with the U.S. Geological Survey to drill a series of test wells in the late 1940's to evaluate the 200 Area plateau soil for waste disposal suitability and for general groundwater research (Brown and Ruppert 1950).

Monitoring wells in other locations were drilled as needed. In the 1970's, additional wells were drilled in all three tank farms to monitor groundwater contamination (see Figure 6a). An extensive discussion of monitoring wells inside the tank farms is included in Gaddis (1999).

In addition to the monitoring wells, two 3.7-m (12-ft) diameter leak detector caissons, extending approximately 21 m below grade, were installed in A Farm during original constructions. Three horizontal leak detection wells (called "laterals") extend radially from each caisson, 2.4 m below the tank bottom. The laterals are approximately 3 m below the base pad elevation. Radiation probes are inserted into each lateral to provide information used to evaluate tank integrity and to determine changing conditions of the tank contents (Anderson 1990).

A third leak detector caisson was built for tank 241-A-105 in 1967 (see Section 3.3.4). This caisson had lateral wells located 0.6 m below the tank bottom, which were equipped with thermocouples to monitor sludge temperature (WHC 1991).

TABLE 4.1: TEST WELLS SURROUNDING A, AX, AND C FARMS

WELL IDENTIFICATION				COORDINATES				DIMENSIONS			NOTES
Location	Hanford Site No.	Washington State No.	Installed Date	Hanford		Lambert		Dia	Depth		
				North	West	North	East	in.	ft	m	
W of A Farm	299-E24-3	A5897	Jun 1956	41010.8	48310.4	135983.2	575165.1	8	333	101.5	1
W of A Farm	299-E24-4	A5898	Jun 1956	41182.9	48482.9	136035.2	575112.4	8	330	100.5	1
W of A Farm	299-E25-5	A5899	Jun 1956	41275.4	48727.2	136063.0	575038.0	8	329	100.3	1
S of A Farm	299-E24-19	A4754	Sep 1989	41075.8	47821.4	136003.8	575317.2	4	301	91.7	None
W of A Farm	299-E24-20	A4756	Mar 1991	41226.0	48038.0	136049.4	575251.1	4	304	92.6	None
W of A Farm	299-E24-63	A5818	Jun 1956	41335.0	48644.0	136081.7	575066.2	8	50	15.2	None
E of A Farm	299-E25-2	A4766	Mar 1955	41265.5	47175.1	136062.2	575514.0	8	375	114.3	1
E of AX Farm	299-E25-4	A4788	Apr 1956	41615.0	46739.0	136168.9	575646.5	8	289	88.1	1
E of AX Farm	299-E25-5	A6025	May 1956	41667.0	46632.0	136184.9	575681.2	8	293	89.3	1
E of AX Farm	299-E25-6	A4796	May 1956	41598.0	46619.0	136163.9	575683.7	8	290	88.4	1
NE of AX Farm	299-E25-10	A4760	Jul 1958	42000.0	46900.0	136268.0	575630.0	8	293	89.3	None
E of AX Farm	299-E25-40	A4789	Sep 1989	41759.6	47334.8	136212.3	575464.6	4	274	83.5	None
SE of AX Farm	299-E25-41	A4790	Sep 1989	41541.8	47330.9	136146.0	575466.3	4	279	85	None
S of A Farm	299-E25-46	A4793	Aug 1992	40944.2	47681.5	135964.0	575359.7	4	310	94.5	None
E of A Farm	299-E25-54	A6043	Mar 1955	41205.0	47169.0	136043.4	545512.4	8	452	46.3	None
E of AX Farm	299-E25-169	A6584	Jan 1966	41675.0	45550.0	136185.2	575696.5	6	85	25.9	1
E of AX Farm	299-E25-170	A6585	Jan 1966	41600.0	46650.0	136134.4	575673.6	6	208	63.3	1
E of AX Farm	299-E25-181	A6591	Jul 1981	41685.0	47040.0	136190.1	575554.8	6	12	3.6	None
S of A Farm	299-E25-184	A6594	Jun 1981	41085.0	47800.0	136006.4	575323.6	6	50	15.2	None

TABLE 4.1: TEST WELLS SURROUNDING A, AX, AND C FARMS

WELL IDENTIFICATION				COORDINATES				DIMENSIONS			NOTES
Location	Hanford Site No.	Washington State No.	Installed Date	Hanford		Lambert		Dia	Depth		
				North	West	North	East	in.	ft	m	
E of AX Farm	299-E25-205	A6609	Feb 1984	41490.0	46680.0	136130.9	575664.6	Unk	25	7.6	2
SE of A Farm	299-E25-209	A6613	Feb 1984	40800.0	46600.0	135920.7	575689.6	Unk	25	7.6	2
NE of C Farm	299-E27-7	A4816	Oct 1982	43097.6	48132.0	136619.6	575220.7	6	281	85.6	None
W of C Farm	299-E27-12	A4810	Oct 1989	42981.4	48678.4	136583.8	575054.3	4	270	82.3	None
SW of C Farm	299-E27-13	A4811	Oct 1989	42671.9	48644.0	136498.5	575065.1	4	275	83.8	None
SE of C Farm	299-E27-14	A4812	Oct 1989	42700.1	48143.6	136498.5	575217.6	4	266	81.1	None
NW of C Farm	299-E27-15	A4813	Oct 1989	43134.7	48543.0	136630.6	575095.5	4	262	79.8	None

Notes: 1 Grouted
2 Backfilled

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5.2 DRAWINGS

5.2.1 A and AX Tank Farm

Drawing No.	Rev.	Title
H-2-33295	3	216-A-39 Crib for Inst Enclosure 241-AX 801-B Plot Plan & Details
H-2-33981	5	Emergency Sluicing in TK-105-A - General Piping Arrangement
H-2-36645	4	Civil - Plan and Profile - Waste Transfer Lines

APPENDIX A

TABLES

Table 1. Intentional Release Quantities

Table 2. Unintentional Release Quantities

Table 1. Intentional Release Quantities

Crib	Location	Source	Waste Type	Date	Quantity (L)	Comments
216-A-1	Crib E of 241A	202A	Cold startup	11/55-12/55	98400	Capacity reached
216-A-7	Crib E of 241A	241-A-152	Overflow	1/56-11/66	3.26E+05	
216-A-8	Crib E of 241AX	SSTs	SST condensate	11/55-4/95	1.15E+09	
216-A-9	Crib W of 241A	202A	Condensate	3/56-2/58	9.81E+08	
		105N	Decon	4/66-10/66		
		202A	Acid fract con	8/69		
216-A-16	F. drain in 241A	241-A-431	Stack drainage	1/56-3/69	1.22E+05	
216-A-17	F. drain in 241A	241-A-431	Stack drainage	1/56-3/69	6E+05	
216-A-18	Pit E of 241AX	202A	Cold startup	11/55-12/55	4.88E+05	
216-A-19	Pit E of 241AX	202A	Cold startup	11/55-1/56	1.1E+06	
216-A-20	Pit E of 241AX	202A	Cold startup	11/55-1/56	9.6E+05	
216-A-23	2 F. drains in 241A	241-A-431	Deentrainer drainage	9/57-3/69	6000	
216-A-24	Crib NE of 241AX	SSTs	SST condensate	5/58-1/66	8.20E+08	Capacity reached
216-A-25	Gable Mt Pond	202A, 244AR	Cooling water	1957-1987	3E+12	Outside scope
216-A-29	Ditch to B pond	202A	Chem sewer, cond. Clg.wtr. Acid fract con	11/55-9/91		Outside scope
216-A-34	Ditch E of 241AX	202A	Cold startup	11/55-1/56	Unknown	
216-A-39	Pit in 241AX	AX-801B	Spill	6/66	20	
216-A-40	Retention basin W of 241AX	244-AR	Cooling water	1/68-1979	9.46E+05	Not used for disposal
216-A-41	Crib W of 241A	244-AR	Stack drainage	1/68-1974	1E+04	
216-C-8	Fr drain S of 241C	271-CR	IX regen	6/62-6/65	Unknown	

Table 2. Unintentional Release Quantities

UPR Number	Location	Date	Leak Type	Waste Type	Quantity (L)	Comments
UPR-200-E-16	C Farm	Unknown	Overground pipe break	CWP	190	
UPR-200-E-18	241-A-08	1959	Dripping vent	Condensate		
UPR-200-E-27	C Farm	11/1/60	Windblown contamination			
UPR-200-E-42	241-AX-151	11/6/72	Surface contamination			
UPR-200-E-68	241-C-151	1/11/85	Windblown contamination			
UPR-200-E-72	South of C Farm	4/20/85	Buried contamination			
UPR-200-E-81	241-CR-151	10/15/69	Line leak	CWP	136 000	
UPR-200-E-82	241-C-152	12/19/69	Line leak	PSN	10 000	
UPR-200-E-86	C Farm	1971	Line leak	PSN		25,000 Ci Cs
UPR-200-E-107	244-CR	11/26/52	Spill	TBP	18.90	
UPR-200-E-115	241-AX-103	2/12/74	Spray			
UPR-200-E-118	C Farm	4/20/57	Airborne contamination			
UPR-200-E-119	241-AX-104	12/22/69	Surface contamination		Negligible	
UPR-200-E-125	241-A-104	May 1975	Tank leak		9500	Pumped to heel
UPR-200-E-126	241-A-105	Jan 1965	Tank leak		1 049 000	Tank damage
UPR-200-E-136	241-C-101	1970	Tank leak		91000	
UPR-200-E-137	241-C-203	1976	Tank leak	PAW	1500	
UPR-200-E-145	A Farm	1993	Excavation	Uranium oxide		
None	241-A-103	1987	Tank leak		21000	Estimated
None	241-AX-102	1988	Tank leak		11000	Estimated
None	241-AX-104	1977	Tank leak		30000	Estimated
None	241-C-110	1984	Tank leak		7600	Estimated
None	241-C-111	1968	Tank leak		19000	Estimated
None	241-C-201	1988	Tank leak		2100	Estimated
None	241-C-202	1988	Tank leak		1700	Estimated
None	241-C-204	1988	Tank leak		1300	Estimated
None	241-AX-151	3/23/01	Catch tank leak		Unknown	

APPENDIX B

TIMELINE OF EVENTS

1943-44	Hanford construction. C Plant foundation excavated, but plant not built. C Farm constructed.
4/23/45	B Plant begins operations. 5-6 and 224 waste to 216-B-5 crib
8/14/45	World War II ends
3/46	B Plant MW sent to 241-C-101/2/3 tank cascade
4/46	B Plant 1C sent to 241-C-107/8/9 tank cascade
5/46	B Plant 1C sent to 241-C-110/1/2 tank cascade
10/46	B Plant MW sent to C-104/5/6 cascade
1/1/47	GE replaces DuPont as Hanford prime contractor
1/52	1C from C Farm sent to tank 241-B-106 (evaporator feed) via 241-C-152, 241-B-154 diversion boxes
10/52	MW from C Farm sent to U Plant via cross-site transfer line
11/26/52	UPR-200-E-107 (spill at 244-CR vault)
1954	241-CR steam cleaning pit
1955	PUREX and A Farm constructed
1955	244-CR vault modified for in-farm scavenging
11/55	In-farm scavenging begins
11/55	PUREX cold startup waste to cribs 216-A-1, 216-A-18, 216-A-19, 216-A-20 via 216-A-34 ditch
1/56	PUREX begins operations. PAW, OWW to A Farm; CWP to C Farm
1/56	A Farm tank condenser waste to 216-A-8 crib
1/56	Tank Farm stack drainage (241-A-431 to 216-A-16/17 wells)
3/56	PUREX acid fractionator condensate to 216-A-9 crib
12/56	216-A-8 crib waste hits groundwater
1957	244-CR vault scavenging completed
1957	PUREX cooling water to Gable Mountain pond
4/20/57	UPR-200-E-118 (C Farm airborne contamination)
9/57	241-A-431 deentrainer drainage to 216-A-23 drywells
12/57	Gable Mountain pond and 216-A-29 ditch built
1/58	Stop discharges to 216-A-9 crib
5/58	216-A-8 crib (tank condenser waste) replaced by 216-A-24 crib
1959	UPR-200-E-18 (drip at 241-A-08 valve pit)
7/59	241-A-302B catch tank replaces 216-A-7 crib
10/59	Surface condensers installed in A Farm; reduce 216-A-24 crib discharge by 95%
7/59	UPR-200-E-16 (overground CWP line break in C Farm)
11/1/60	UPR-200-E-27 (C Farm airborne contamination)
7/61	Hot Semiworks restarted as Strontium Semiworks
1962	271-CRL and 241-C-801 Cs loadout facility built in C Farm
6/62	271-CRL lab ion exchange regeneration waste to 216-C-8 French drain
1963	PUREX modified to process N Reactor fuel
1963	AX Farm built
1963	Cs recovery begins in 241-C-801
8/63	Sr recovery begins in B Plant
1965	241-AX-151 diverter station constructed
1/65	UPR-200-E-126 (damage to 241-A-105)
6/65	216-C-8 drain out of service

1966	244-AR vault constructed
4/66-10/66	N Reactor decon waste to 216-A-9
7/66	216-A-24 crib hits groundwater; waste diverted to 216-A-8
6/66	Spill in 241-AX-801B flushed to 216-A-39 crib (no UPR)
1967	Third leak detection caisson built in A Farm, near tank 241-A-105
1967	B Plant begins full operations. Strontium Semiworks shut down
1968	241-C-111 tank leak (no UPR)
1/68	244-AR vault stack drainage to 216-A-41 crib
2/22/69	UPR-200-E-119 (surface contamination in AX Farm)
3/69	216-A-23 drains (241-A-431 condensate) out of service
4Q/69	OWW from PUREX segregated from PAW, sent to tank 241-C-104
10/15/69	UPR-200-E-81 (underground CWP line leak near 241-C-151 diversion box)
12/19/69	UPR-200-E-82 (underground line leak near 241-C-152 diversion box)
1970	UPR-200-E-136 (241-C-101 tank leak)
11/70	Final heel removal from 241-A-105 tank; water additions begin
1970-71	REDOX supernate sent to B Plant for Cs recovery
1971	241-C-106 tank temperature reaches 100°C, put on forced ventilation
1971	UPR-200-E-86 (underground PSN line leak in C Farm)
1972	PUREX standby to allow for N Reactor spent fuel accumulation and A/AX Farm sluicing. 244-AR vault modified for full time sludge recovery
11/6/72	UPR-200-E-42 (contamination discovered at 241-AX-151 diverter station)
1973	PUREX restart delayed due to 241-T-106 tank leak
1975	241-ER-152, 241-ER-153 diversion boxes, 244-A lift station constructed
1975	Gable Mountain pond out of service
5/75	UPR-200-E-125 (241-A-104 tank leaks)
1976	UPR-200-E-137 (241-C-203 tank leaks)
1976	241-A-350 lift station built
4/76	Stop discharges to 216-A-8 crib
1977	241-AX-104 tank leaks (no UPR)
3/18/77	242-A Evaporator startup
1978	Sludge recovery complete
1/78-5/78	Resume discharges to 216-A-8 crib
12/78	241-A-105 tank water additions stop; 296-P-17 exhauster installed
1983	PUREX restart
1983-1987	Strontium Semiworks torn down
1984	241-C-110 tank leaks (no UPR)
1985	216-A-8 crib out of service
1/11/85	UPR-200-E-68 (airborne contamination in C Farm)
4/20/85	UPR-200-E-72 (buried contamination south of C Farm)
1987	Gable Mountain pond decommissioned
1987	241-A-103 tank leaks (no UPR)
1988	PUREX shutdown
1988	241-C-201, 202, and 204 tanks leak (no UPR)
1988	241-AX-102 tank leaks (no UPR)
4/12/89	242A shutdown
10/91	296-P-17 exhauster removed from 241-A-105

1992	PUREX closed
12/13/93	UPR-200-E-145 (buried contamination in A Farm)
4/15/94	242A Evaporator restart
1995	All liquid low-level waste discharges to 200 Area TEDF
1999	Tank 241-C-106 sluiced to tank 241-AY-102
3/23/01	241-AX-152 catch tank leak

APPENDIX D

FIGURES

Figure 1: A, AX, and C Tank Farms, 200 East Area (present)

Figure 2: Facilities Constructed for the Manhattan Project (1943-1945)

Figure 3: Facilities Constructed for Postwar Bismuth Phosphate and Uranium Recovery Operations (1946-1957)

Figure 4: Facilities Constructed for PUREX Operations (1956-1964)

Figure 4a: Test Wells Constructed for PUREX Operations (1956-1964)

Figure 5: Facilities Constructed in C Farm for Waste Fractionization Operations (1961-1978)

Figure 6: Facilities Constructed in A/AX Farms for Waste Fractionization Operations (1965-1978)

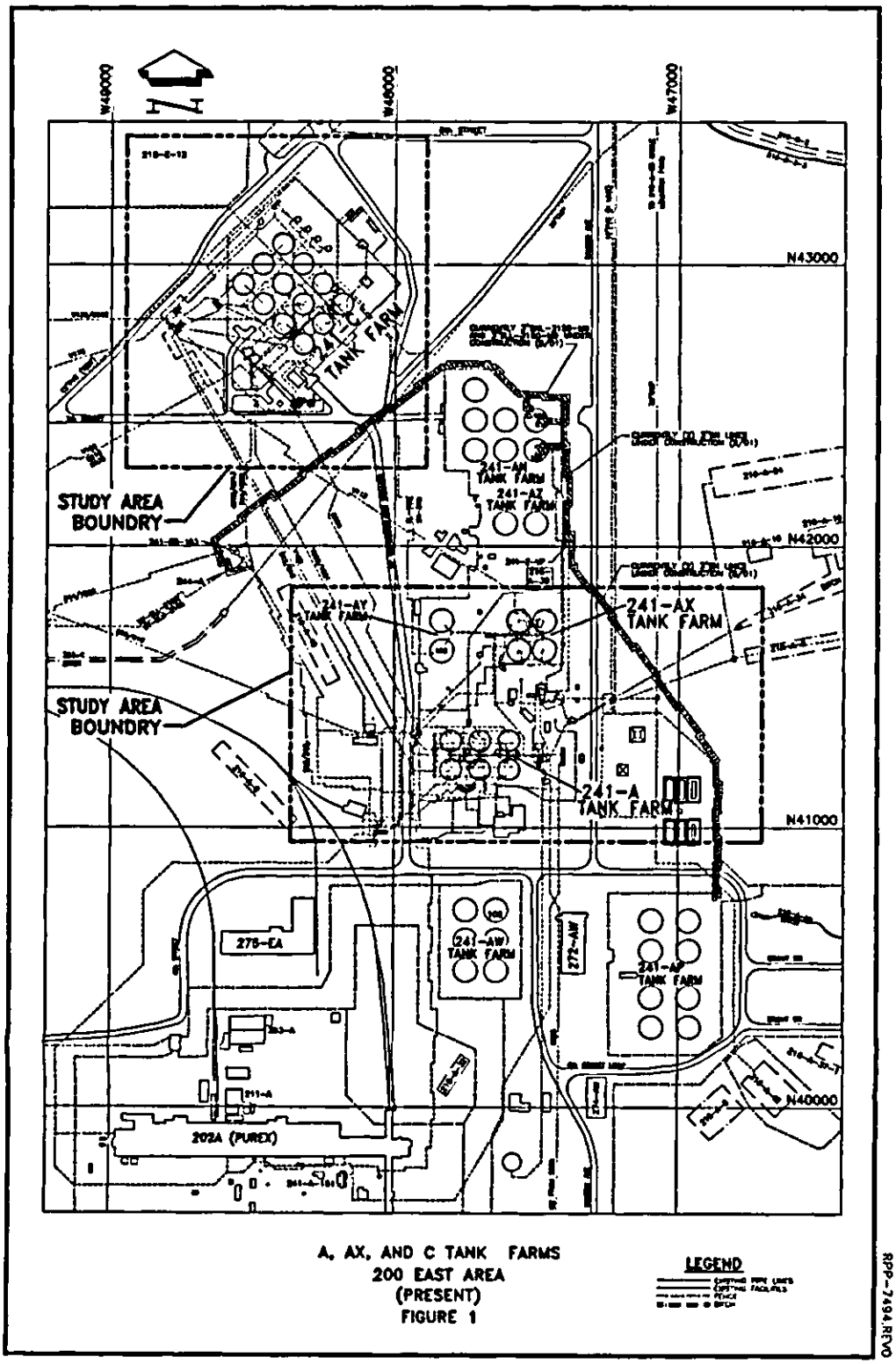
Figure 6a: Test Wells Constructed in A/AX Farms for Waste Fractionization Operations (1965-1978)

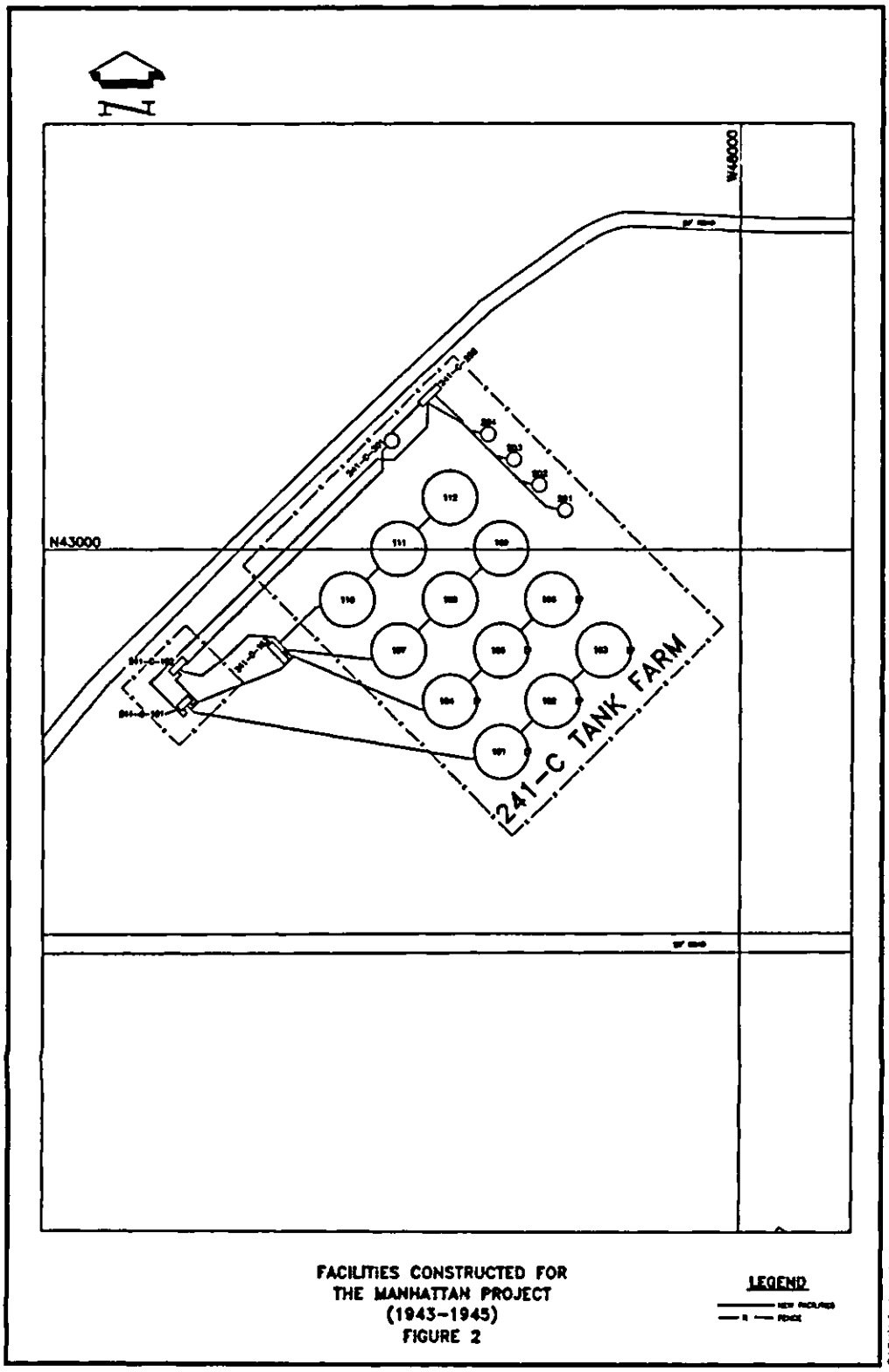
Figure 7: Facilities Constructed in C Farm for Interim Stabilization and Isolation (1975-2001)

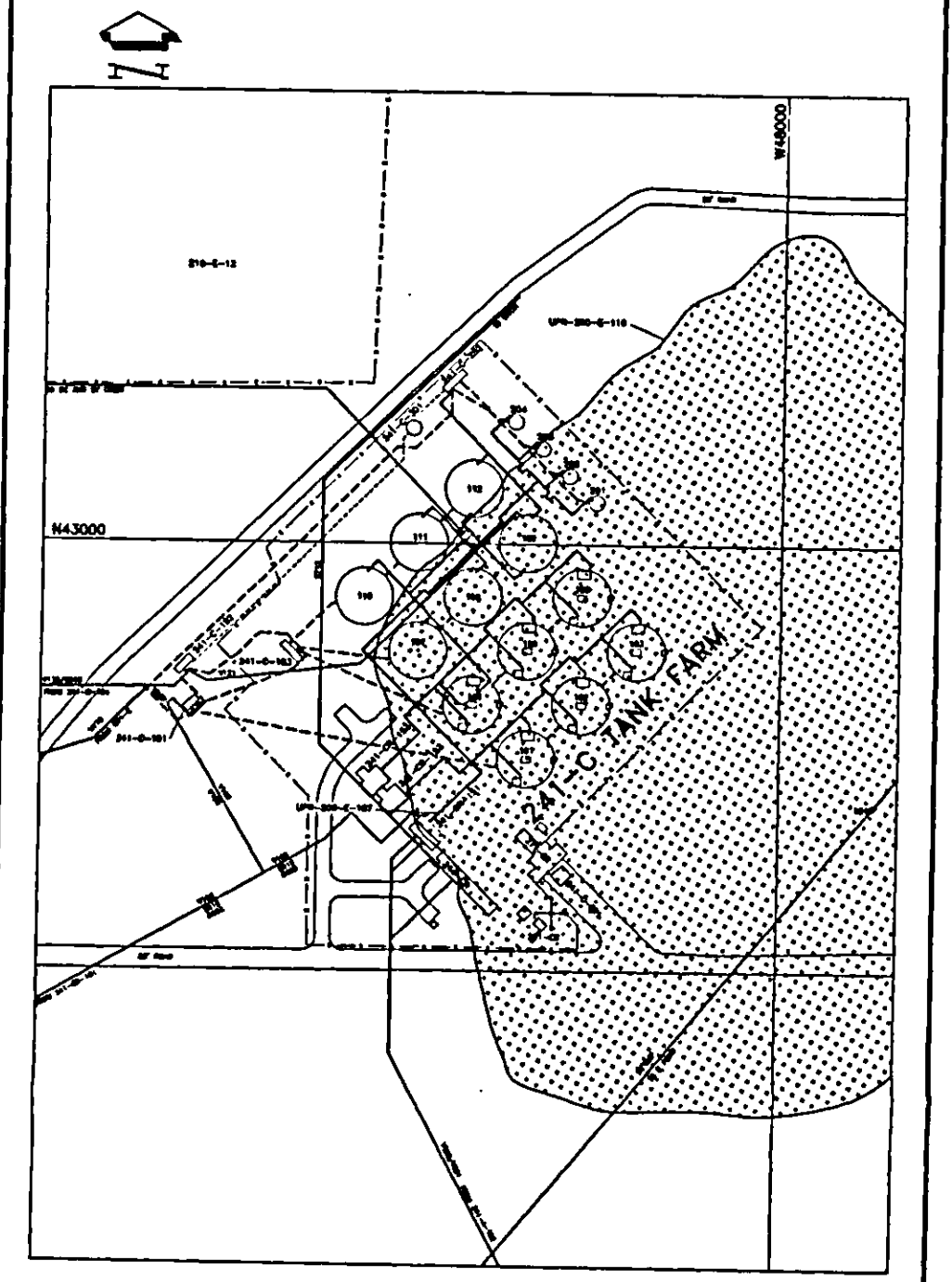
Figure 7a: Test Wells Constructed in C Farm for Interim Stabilization and Isolation, (1975-2001)

Figure 8: Facilities Constructed in A/AX Farms for Interim Stabilization and Isolation (1975-2001)

Figure 8a: Test Wells Constructed in A/AX Farms for Interim Stabilization and Isolation (1975-2001)


W48000
W48000
W47000
N43000
N42000
N41000
N40000
241-AY TANK FARM
241-AW TANK FARM
241-AZ TANK FARM
241-AX TANK FARM
241-A TANK FARM
241-AW TANK FARM
241-AP TANK FARM
STUDY AREA BOUNDRY
STUDY AREA BOUNDRY
275-EA
272-AW
202A (PUREX)
A, AX, AND C TANK FARMS
200 EAST AREA
(PRESENT)
FIGURE 1
LEGEND
RPP-7494.REV0


N
W49000
N43000
241-C TANK FARM
FACILITIES CONSTRUCTED FOR
THE MANHATTAN PROJECT
(1943-1945)
FIGURE 2
LEGEND
D-2
RPP-7494,REV0


N
W48000
N43000
241-C TANK FARM
241-C-151
241-C-152
241-C-153
241-C-154
241-C-155
241-C-156
241-C-157
241-C-158
241-C-159
241-C-160
241-C-161
241-C-162
241-C-163
241-C-164
241-C-165
241-C-166
241-C-167
241-C-168
241-C-169
241-C-170
241-C-171
241-C-172
241-C-173
241-C-174
241-C-175
241-C-176
241-C-177
241-C-178
241-C-179
241-C-180
241-C-181
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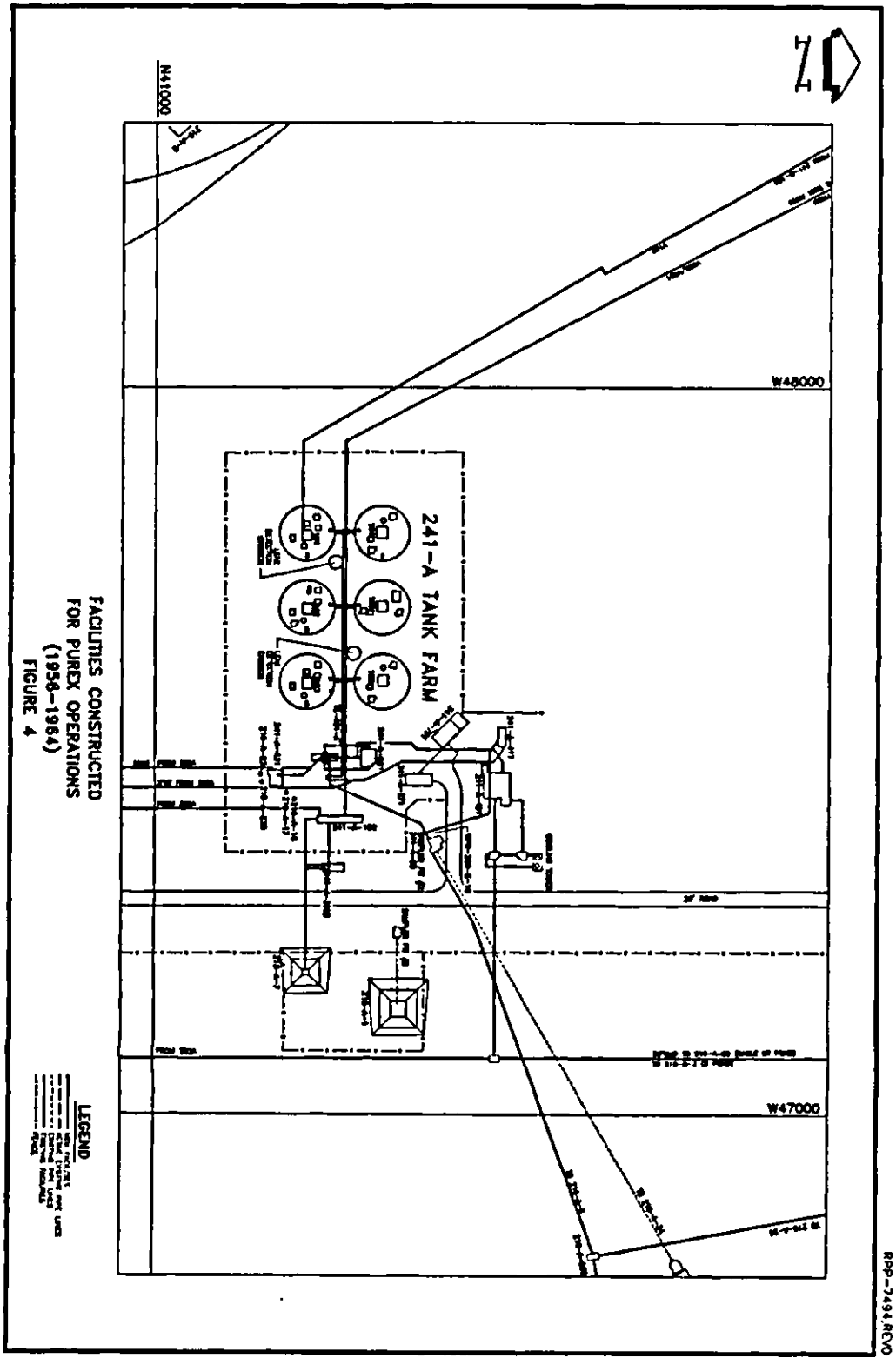
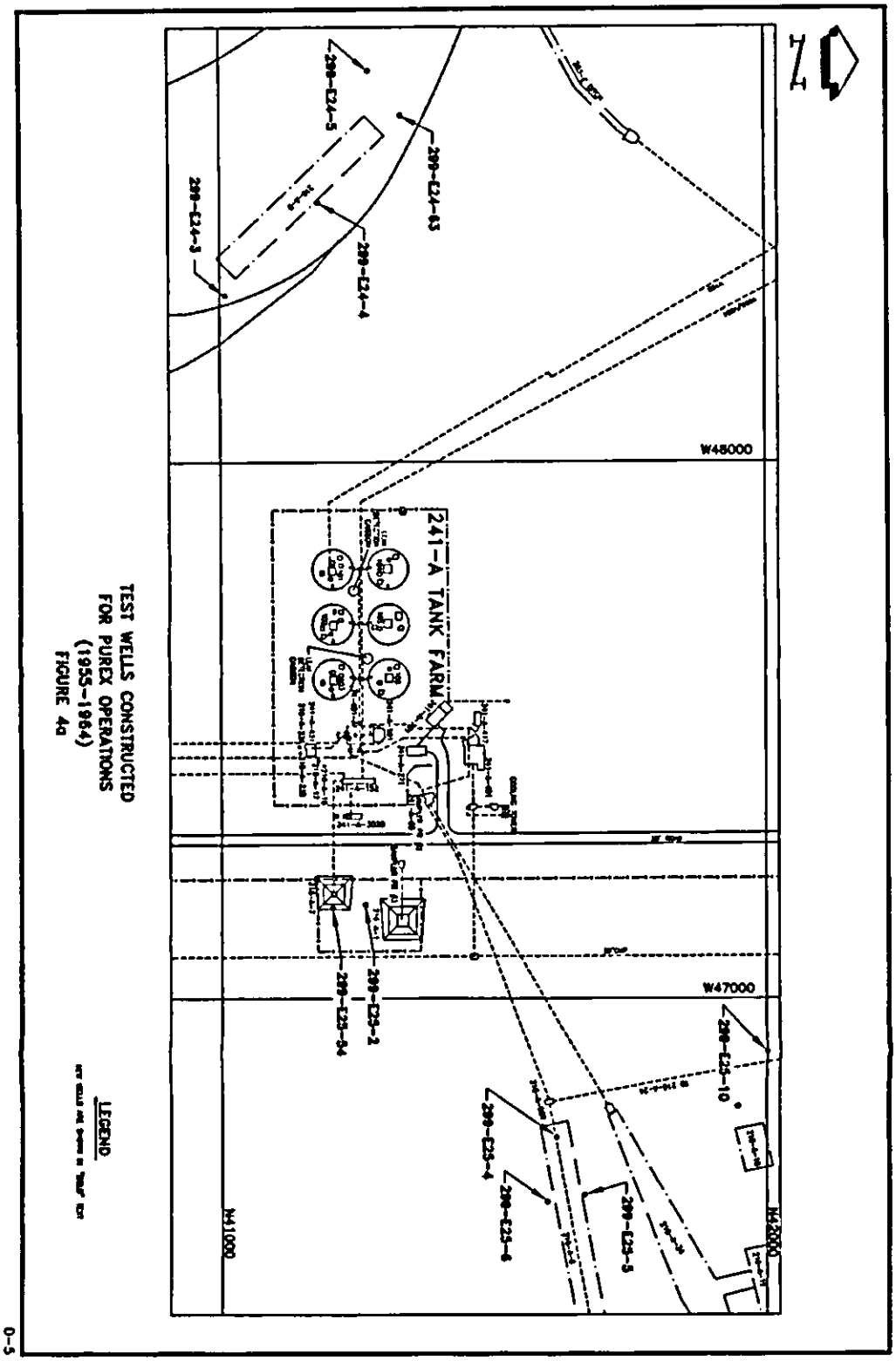
241-C-189
241-C-190

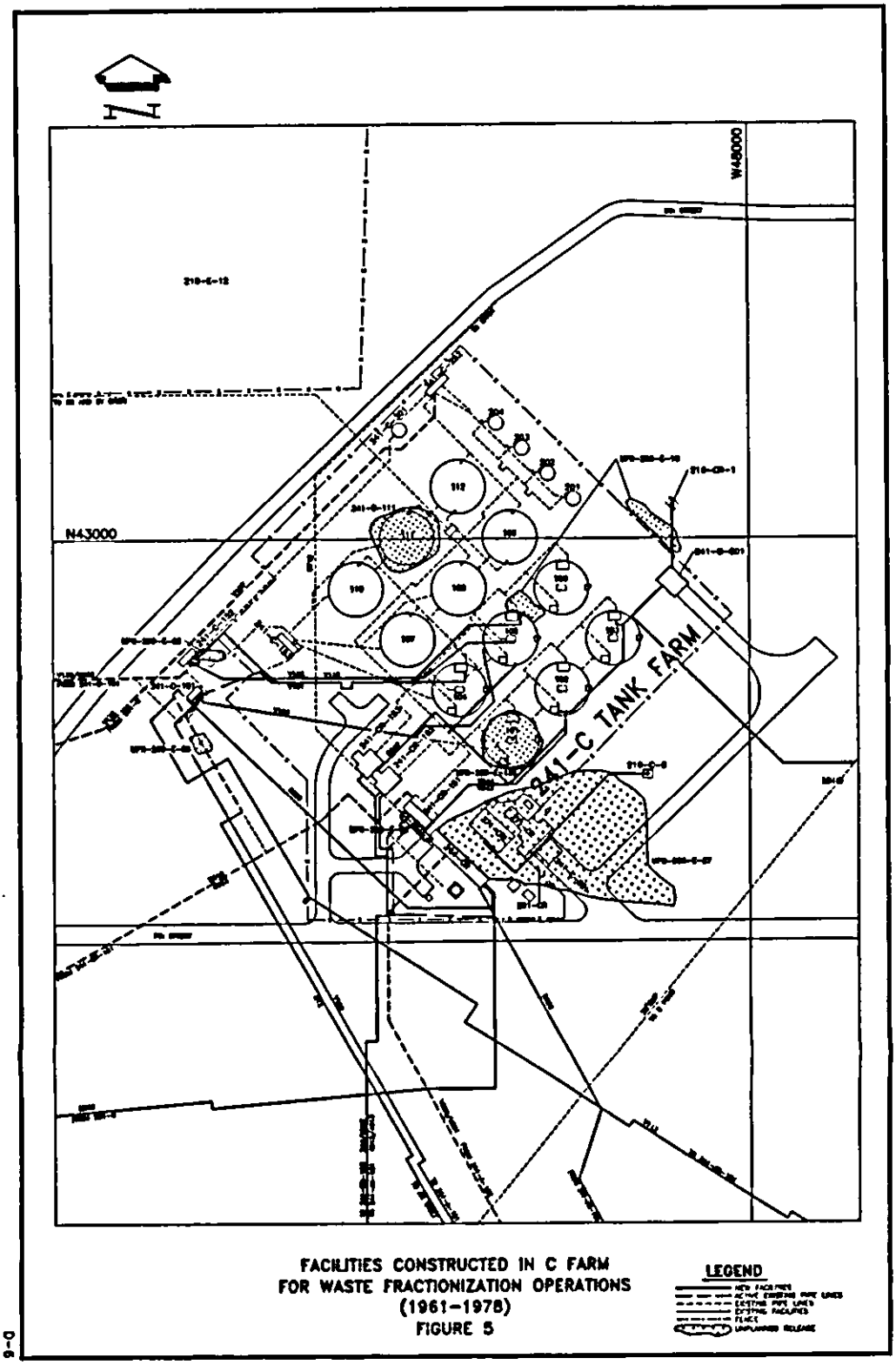

N
N41000
W48000
241-A TANK FARM
W47000
LEGEND
FACILITIES CONSTRUCTED
FOR PUREX OPERATIONS
(1956-1964)
FIGURE 4
D-4
RPP-7494,REV0



TEST WELLS CONSTRUCTED FOR PUREX OPERATIONS (1955-1964)
FIGURE 4a

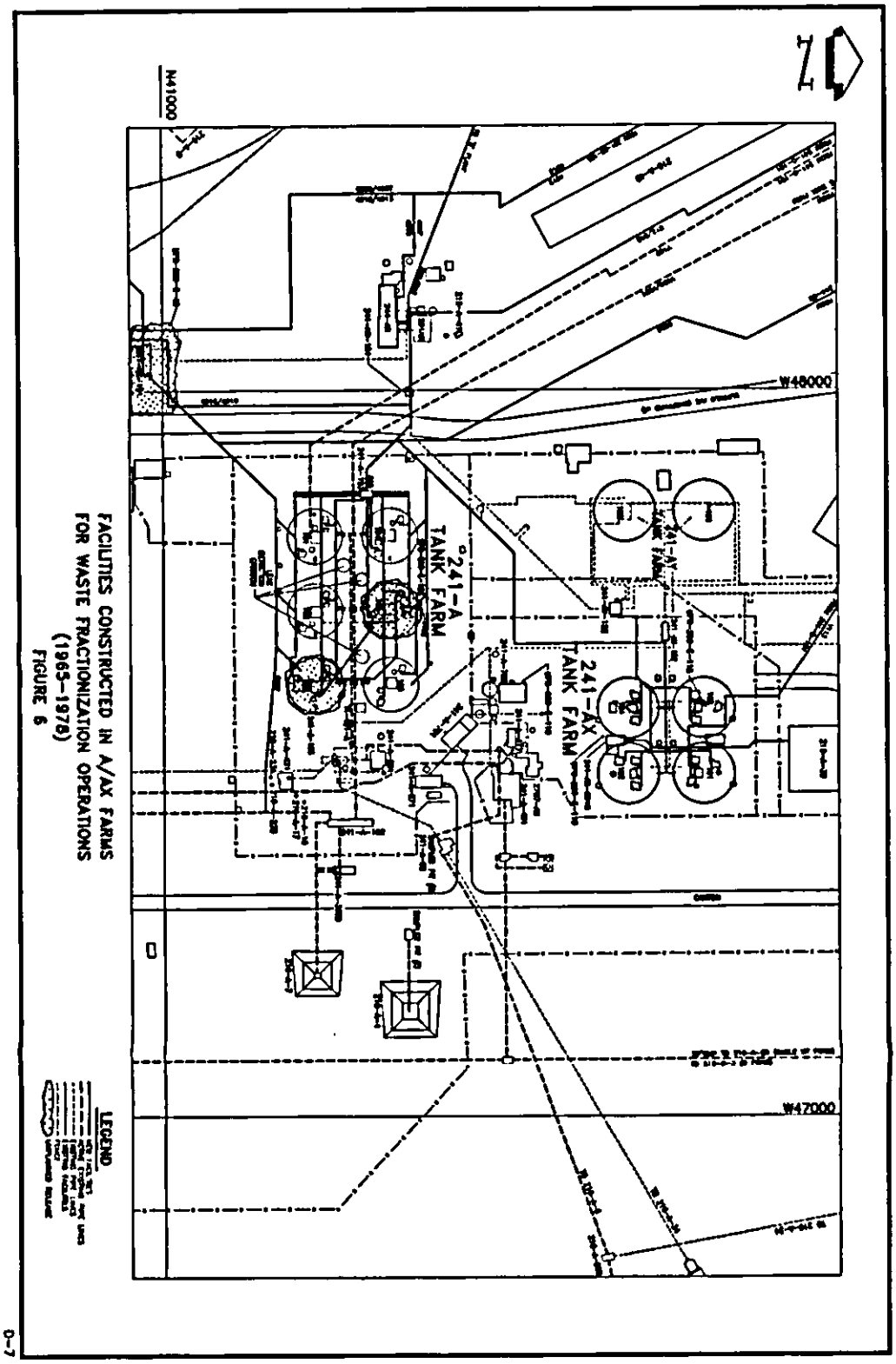
LEGEND

0-5

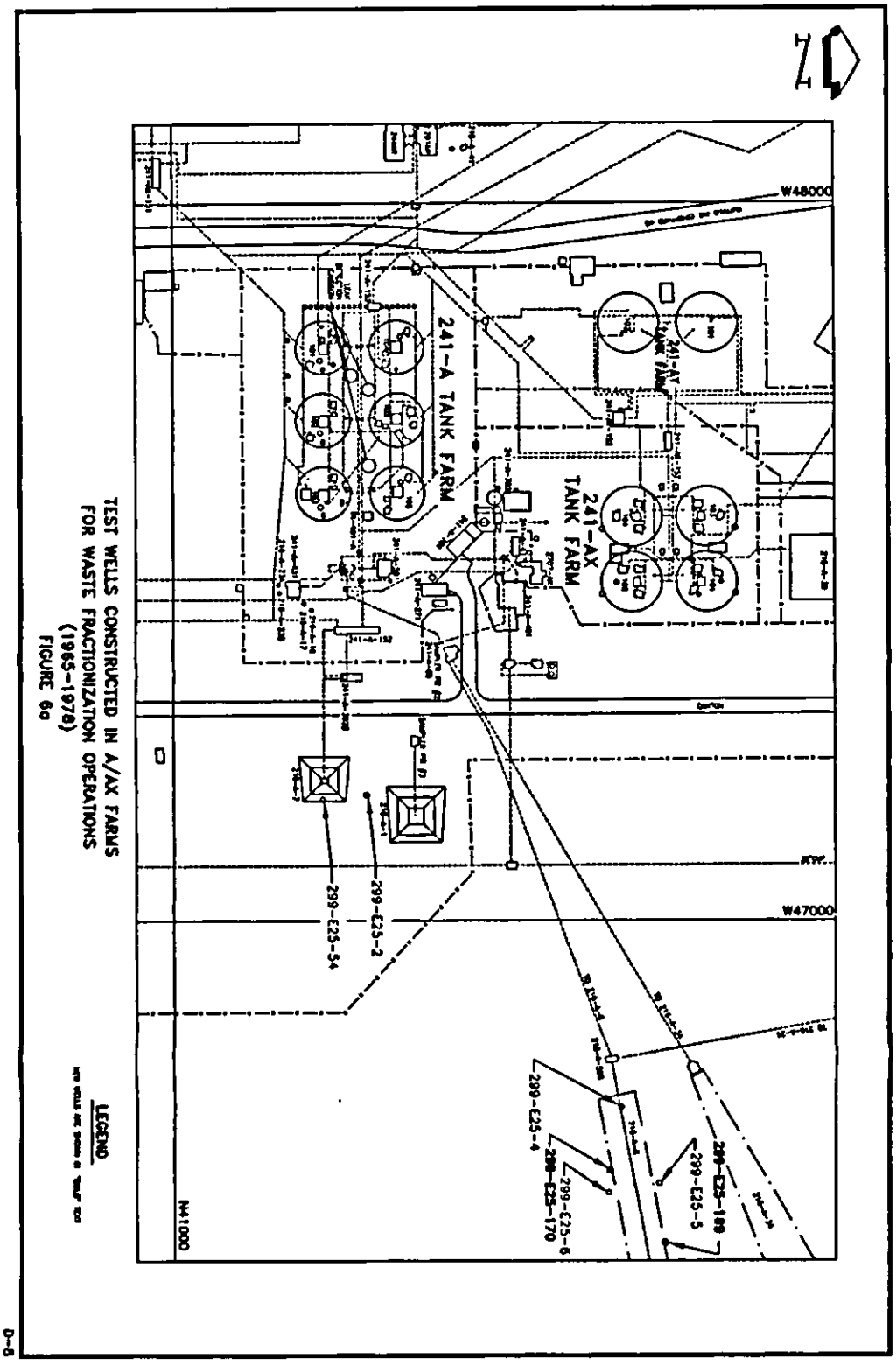


FACILITIES CONSTRUCTED IN C FARM
FOR WASTE FRACTIONIZATION OPERATIONS
(1961–1978)
FIGURE 5

RPP-7494.JCD



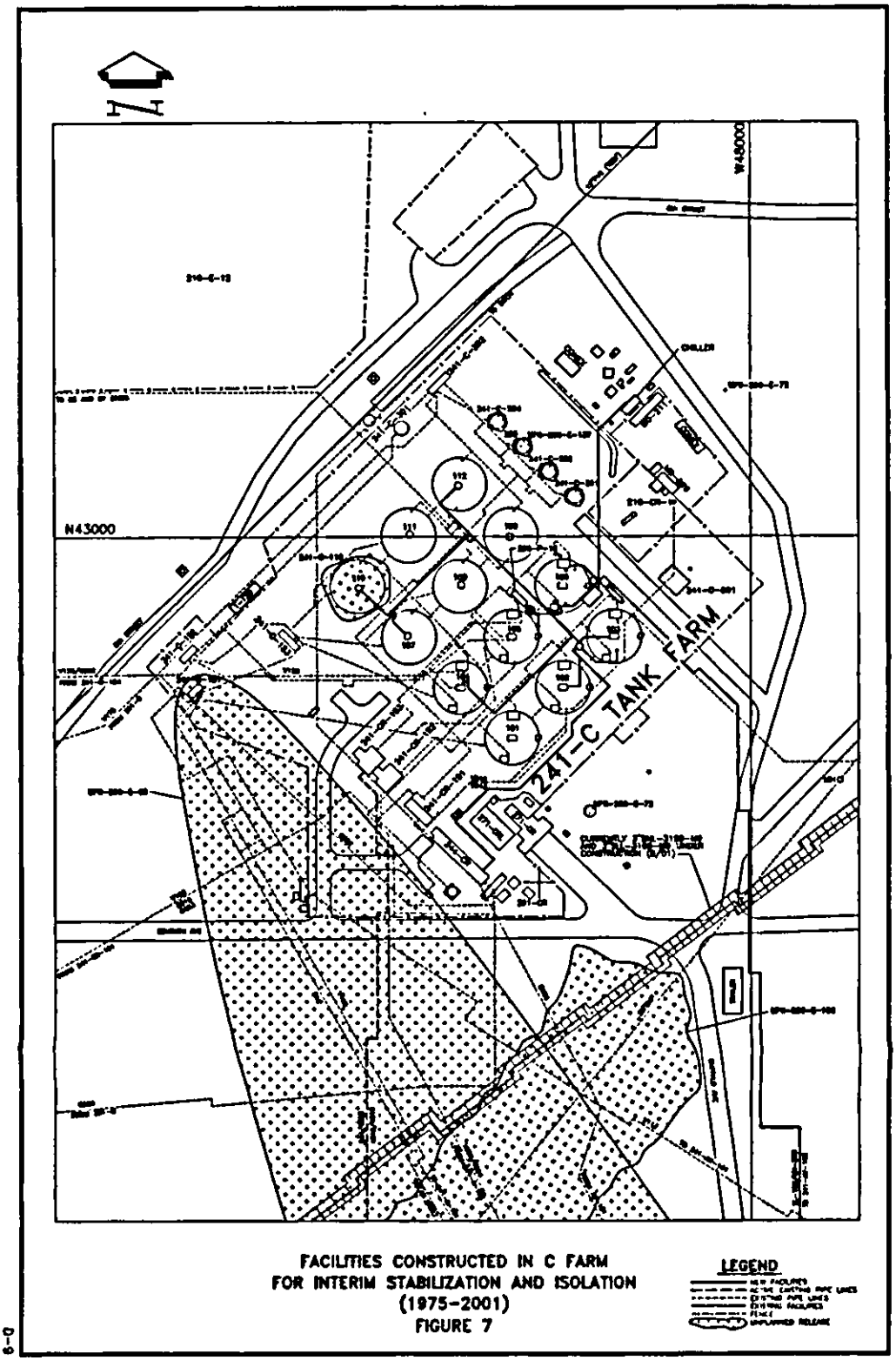
FACILITIES CONSTRUCTED IN A/AX FARMS
FOR WASTE FRACTIONIZATION OPERATIONS
(1965-1978)
FIGURE 6



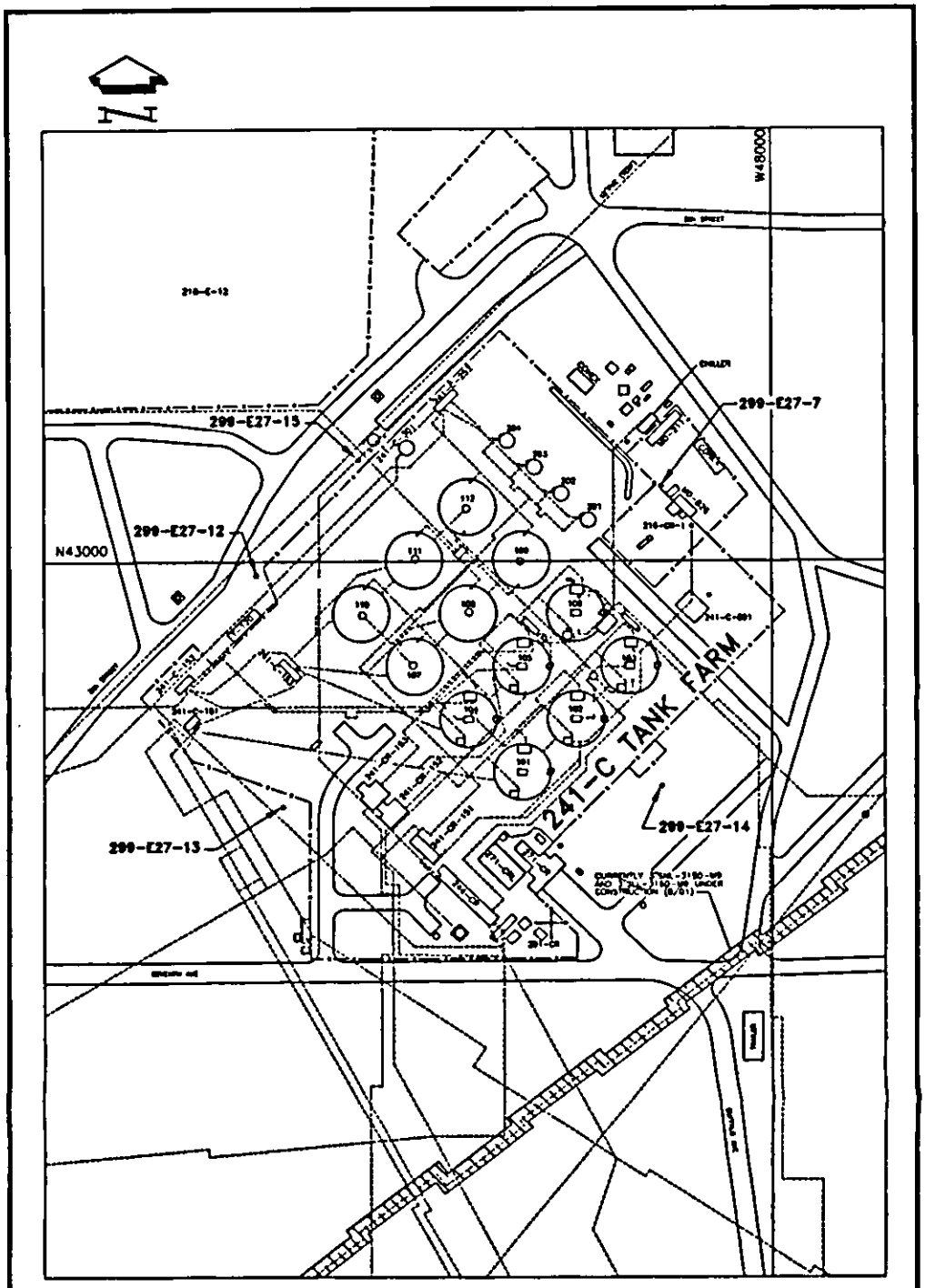
TEST WELLS CONSTRUCTED IN A/AX FARMS FOR WASTE FRACTIONIZATION OPERATIONS (1965-1978)
FIGURE 6a

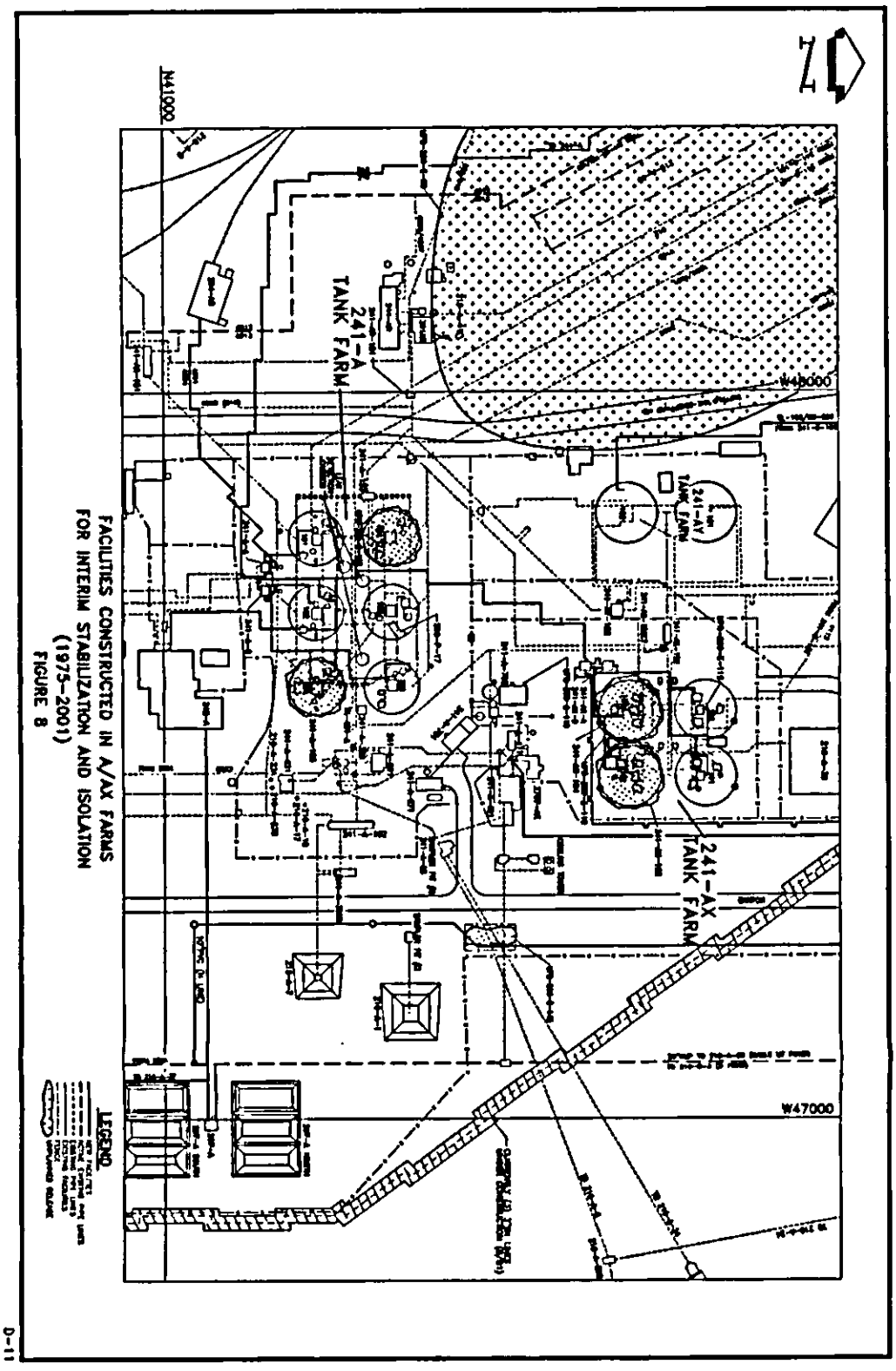
LEGEND

D-8

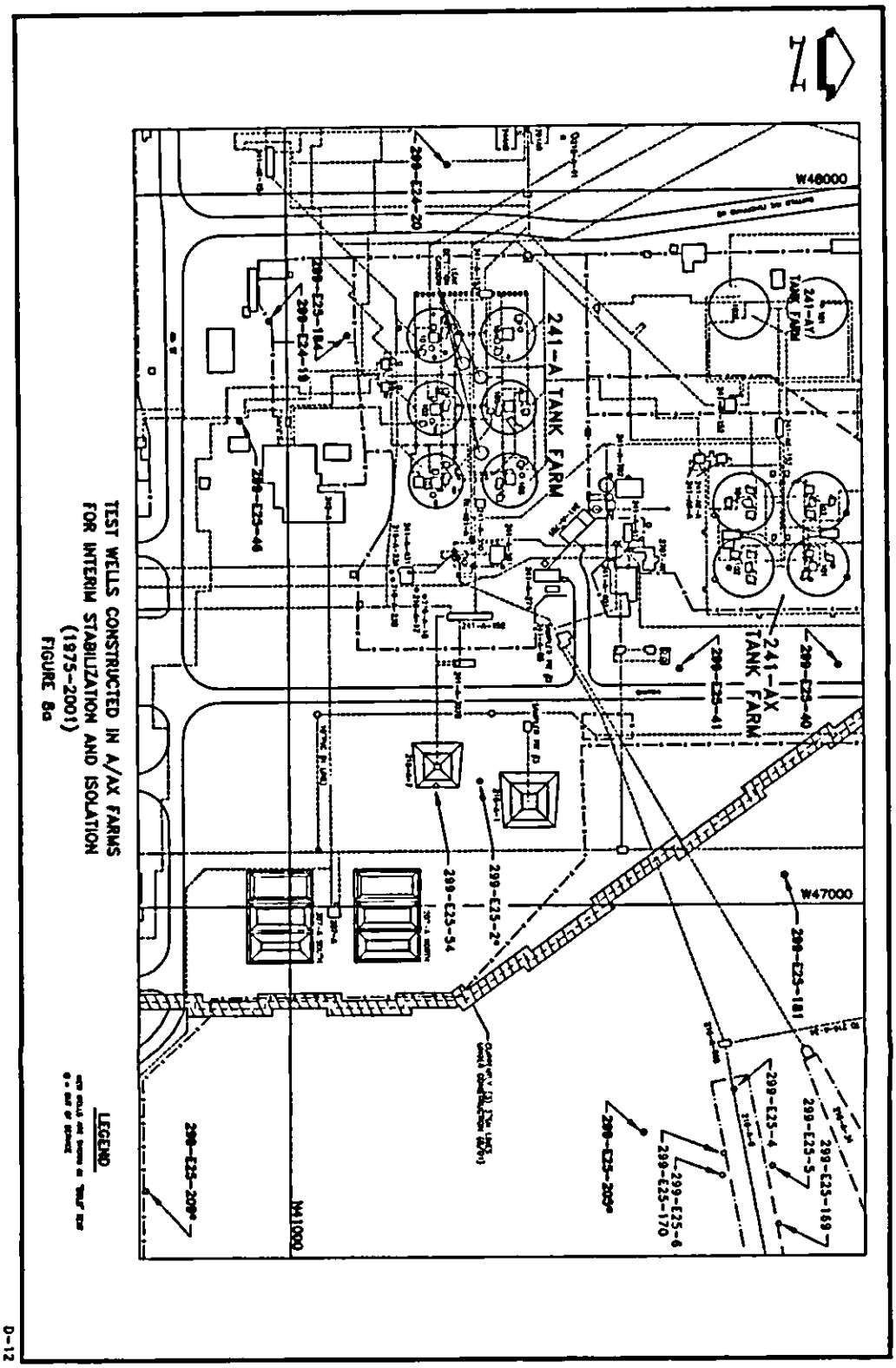


FACILITIES CONSTRUCTED IN C FARM
FOR INTERIM STABILIZATION AND ISOLATION
(1975-2001)
FIGURE 7


N
W48000
N43000
299-E27-15
299-E27-7
299-E27-12
241-C TANK FARM
299-E27-14
299-E27-13
TEST WELLS CONSTRUCTED IN C FARM
FOR INTERIM STABILIZATION AND ISOLATION
(1975-2001)
FIGURE 7a
LEGEND
0-10
RPP-7494.RDD



FACILITIES CONSTRUCTED IN A/AX FARMS FOR INTERIM STABILIZATION AND ISOLATION (1975-2001)
FIGURE 8



TEST WELLS CONSTRUCTED IN A/AX FARMS FOR INTERIM STABILIZATION AND ISOLATION (1975-2001)
FIGURE 8a

D-12

APPENDIX B

ADDITIONAL TANK FARM INFRASTRUCTURE AND OPERATIONAL HISTORY INFORMATION

CONTENTS

B.1.0 INTRODUCTION B-1
B.2.0 TANK FEATURES B-2
B.3.0 OTHER STRUCTURES B-5
B.4.0 SUMMARY TABLES OF OPERATIONAL HISTORY B-8
B.5.0 UNPLANNED RELEASES B-13
B.6.0 REFERENCES B-15

FIGURES

Figure B-1. Typical Configuration and Dimensions of Single-Shell Tanks in C WMA (Modified from Hanlon 1999). B-3

Figure B-2. Typical Single-Shell Tank Instrumentation Configuration at C WMA (From DOE 1993). B-4

Figure B-3. Schematic Showing the Construction of a Typical Single-Shell Tank at A-AX WMA with a 1 Mgal Capacity (after DOE/RL 1996). B-4

Figure B-4. Schematic of the 244-CR Vault in WMA C (from DOE/RL 1996) B-5

Figure B-5. Schematic of the 244-AR Vault, Which Consists of Four Smaller Tanks with Dimensions and Storage Capacities as Shown. B-6

Figure B-6. Schematic of a Typical Diversion Box Transfer System. B-7

TABLES

Table B-1. Operating Period and Capacities for WMA C Facilities[(a)] B-9

Table B-2. Tank Leak Volume Estimates (from Hanlon 2000) B-10

Table B-3. Inventory and Status by Tank (from Hanlon 2000) B-10

Table B-4. Summary Data for Facilities Comprising WMA A-AX B-11

Table B-5. Tank Leak Volume Estimates (After Hanlon 1999) B-12

Table B-6. Inventory and Status by Tank (After Hanlon 1999) B-12

B.1.0 INTRODUCTION

This appendix includes additional figures and descriptions of C, A and AX tank farm infrastructure and operational history summaries. A brief description of unplanned releases that have occurred around the tank farms is also provided.

B.2.0 TANK FEATURES

WMA C encompasses the 241-C Tank Farm and is located in the east central portion of the 200 East Area. The 241-C Tank Farm contains twelve single-shell 100 series and four single-shell 200 series tanks constructed in 1943 and 1944. The 100 series tanks are 75 ft (22.9 m) in diameter, have a 15 ft (4.6 m) operating depth, and have an operating capacity of 530,000 gal (1,892,500 L) each. The 200 series tanks are 20 ft (6.1 m) in diameter with a 17 ft (5.2 m) operating depth and a capacity of 55,000 gal (208,000 L) each. Tank configuration and dimensions are shown in Figure B-1. The tanks sit below grade with at least 7 ft (2.1 m) of soil cover to provide shielding from radiation exposure to operating personnel. The inlet and outlet lines are located near the top of the liners (Figure B-2). The tanks in WMA C were removed from service between 1970 and 1980 (Hanlon 1999). The SSTs in the 241-C Tank Farm were used to store waste primarily from the bismuth phosphate, the PUREX, and the uranium extraction processes.

The SSTs were constructed in place with carbon steel (ASTM A283 Grade C) lining the bottom and sides of a reinforced concrete shell. The tanks have slightly concave bottoms and a curving intersection of the sides and bottom. This curvature decreased the buildup of stress in the bottom corners of the tanks, reducing corrosive effects and thus reducing the chance of developing a leak in the tank bottom.

The 241-A Tank Farm contains six 100 series single-shell tanks (SST) constructed from 1954 to 1955. The 241-AX Tank Farm contains four 100 series SSTs constructed from 1963 to 1964. These tanks have an operating capacity of 1 Mgal (3,785,400 L) each. Tank configuration and dimensions are shown in Figure B-3. The tanks are below grade with at least six feet of soil cover to provide radiation shielding to protect operating personnel. The inlet and overflow lines are located near the top of the liners. The 241-AX Tank Farm is the only one in the 200 East Area to have a system of underground leak detection pipes located horizontally under the tanks. Access to these laterals is through vertical 12 ft (3.7 m) diameter caissons sunk approximately 70 ft (21.3 m) below grade (Figure B-3).

The SSTs were constructed in place with carbon steel (American Society for Testing and Materials [ASTM] A283 Grade C in 241-A Tank Farm and ASTM A201 Grade C in 241-AX Tank Farm) lining the bottom and sides of a reinforced concrete shell. Although they are essentially the same as 241-A Tank Farm, the tanks in the 241-AX Tank Farm have a grid of drain slots beneath the steel liner bottom to collect potential tank leakage. Any leaked liquid is then diverted to a leak detection well. The grids also served as an escape route for free water released from concrete grout during initial heating of the tank.

The 241-A and 241-AX Tank Farms, along with 241-SX Tank Farm, contain the only tanks with a right angle intersection of the sides and the bottom. Most of the other SST tanks have a dished intersection between sides and bottom. The configuration of the side-bottom intersections and the method of welding combine to create inherent weaknesses at these locations when they are subjected to heat stresses. In at least one case (tank A-105), these weaknesses may have contributed to tank failure and leaks to the subsurface.

Figure B-1. Typical Configuration and Dimensions of Single-Shell Tanks in C WMA (Modified from Hanlon 1999).

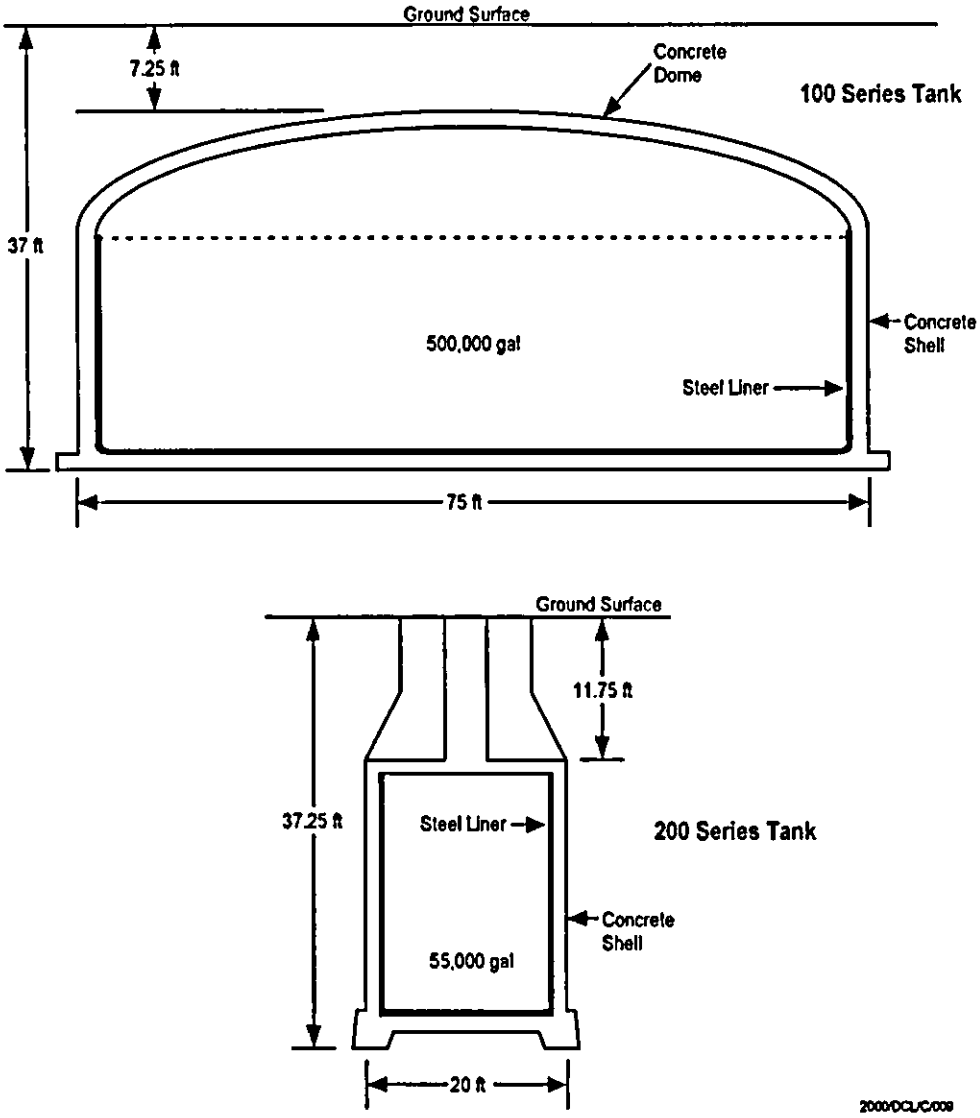


Figure B-2. Typical Single-Shell Tank Instrumentation Configuration at C WMA (from DOE 1993).

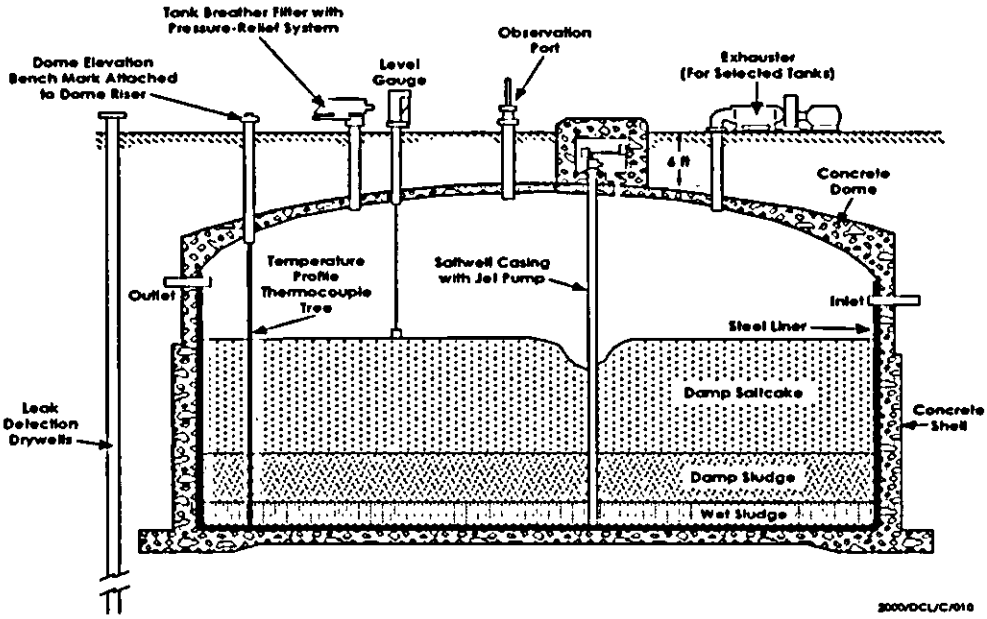
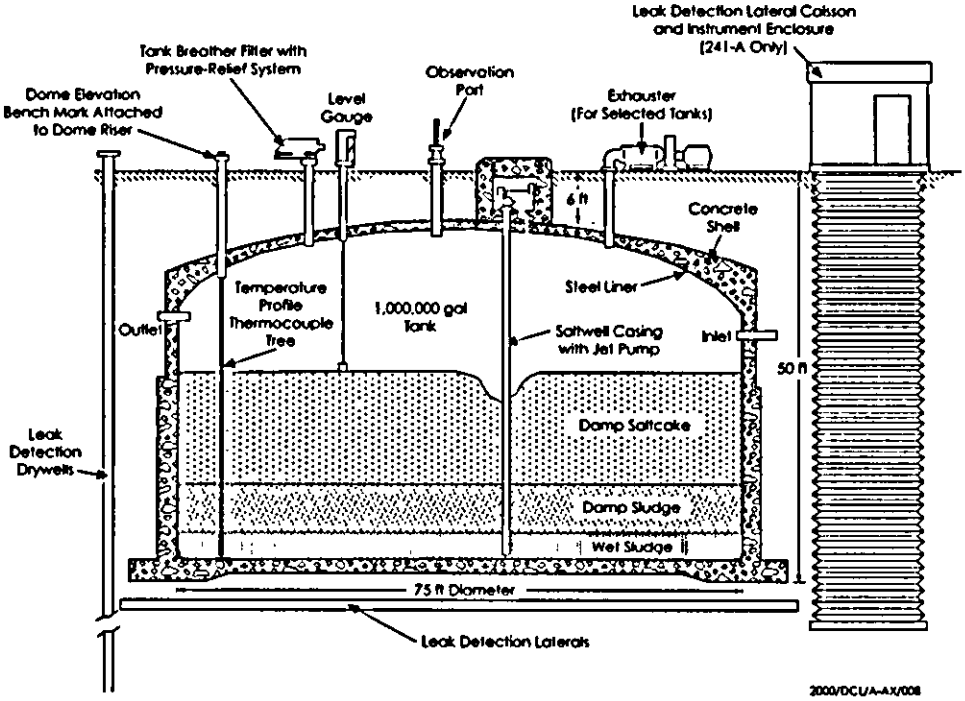


Figure B-3. Schematic Showing the Construction of a Typical Single-Shell Tank at A-AX WMA with a 1 Mgal Capacity (after DOE/RL 1996).

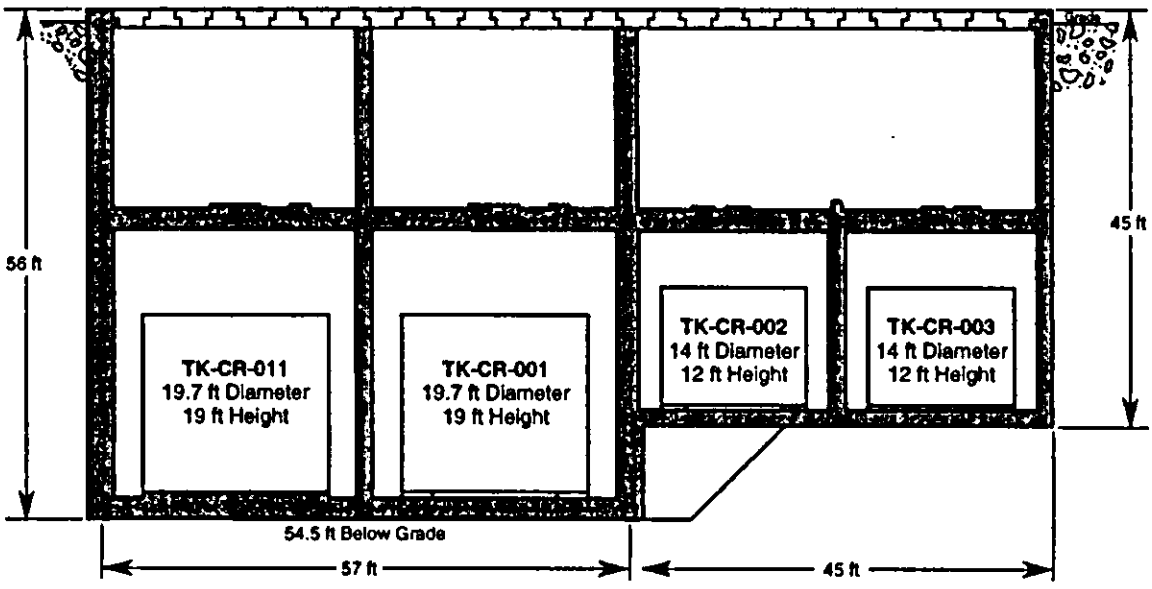


B.3.0 OTHER STRUCTURES

WMA C includes the 244-CR vault and eight diversion boxes. The 244-CR vault is located in the 241-C Tank Farm, south of the tanks. The vault is a two level, multi-cell, reinforced concrete structure constructed below grade (DOE 1993). The 244-CR vault (Figure B-4) contains four permitted underground tanks along with overhead piping and equipment. Two tanks (244-CR-001 and 244-CR-011) have diameters of 19.7 ft (6 m), are 19 ft (6 m) tall, and have a capacity of 45,000 gal (170,343 L) each. The other two tanks (244-CR-002 and 244-CR-003) are 14 ft (4 m) in diameter, 12 ft (3.7 m) tall, and have capacities of 14,700 gal (55,494 L) each. This vault was constructed in 1946 and ceased operating in 1988. It was used to transfer waste solutions from processing and decontamination operations (DOE 1993). Only tanks 244-CR-003 and 244-CR-011 are listed in DOE/RL-88-21, *Dangerous Waste Permit Application; Single-Shell Tank System,* as part of the WMA.

A similar structure, the 244-AR Vault (Figure B-5) is located next to the A tank farm and contains four permitted underground tanks along with overhead crane operations equipment. Constructed in 1976, the four underground units are stainless steel waste storage tanks. Also included are high-pressure pumps used to transfer water or tank supernate through specially designed nozzles to tanks being sluiced.

Figure B-4. Schematic of the 244-CR Vault in WMA C (from DOE/RL 1996).



Non-boiling liquid waste from the operations building was sent to the tank farms via underground lines and diversion boxes. Leaks occurred in the diversion boxes or into the surrounding line encasement drain and were collected by catch tanks. The leaked liquids were then pumped to the large SSTs. These transfer lines and diversion boxes are listed as part of the WMA in the Part A permit (DOE/RL-88-21). The catch tanks, however, are not listed as being part of the managed Resource Conservation and Recovery Act (RCRA) WMA.

In addition to the tanks and vaults seven inactive diversion boxes were constructed at A-AX WMA and eight at C WMA that are designated as waste piles along with the transfer pipes to the DST systems and associated equipment (DOE/RL-88-21) (Figure B-6). All diversion boxes used within the farms are inactive and presently isolated or covered from the weather. As used here, "isolated" means exterior water intrusion has been restricted. The diversion boxes are included in the RCRA permit application because they were an integral part of the waste transfer system. The boxes are important in the plan because some were the sites of contaminant releases to the subsurface. It is estimated that each box contains 50 lbs (23 kgm) of lead, and they are listed as waste piles (Hanlon 1999).

Figure B-5. Schematic of the 244-AR Vault, Which Consists of Four Smaller Tanks with Dimensions and Storage Capacities as Shown.

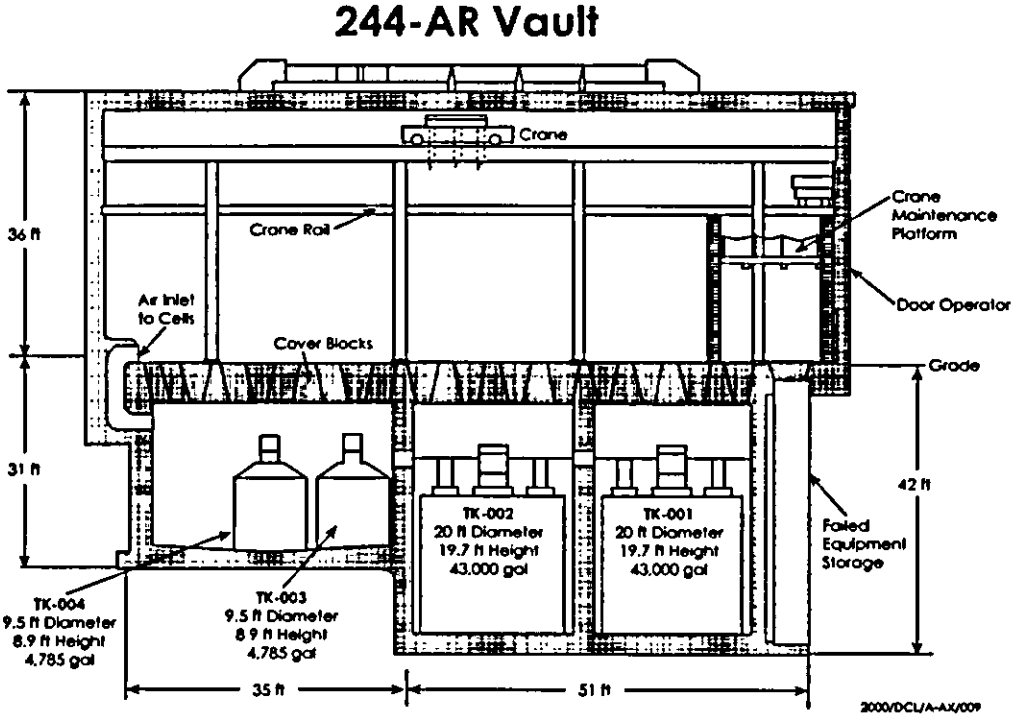
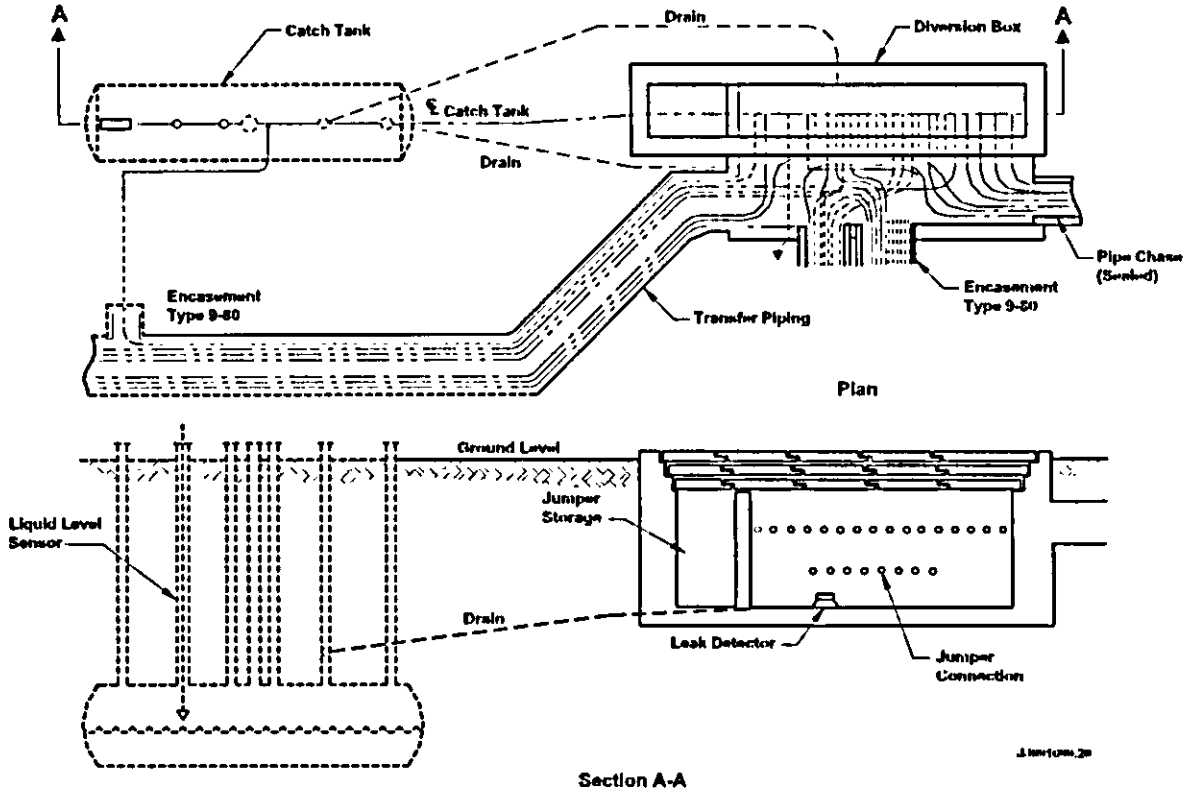


Figure B-6. Schematic of a Typical Diversion Box Transfer System.



B.4.0 SUMMARY TABLES OF OPERATIONAL HISTORY

Documented information on the operational history of the SSTs, the waste transfer vault, and the diversion boxes that are part of the C WMA is provided in three tables. Table B-1 lists the tank, vault and diversion box numbers, year of construction, year removed from service, and operating capacity or function. Tanks from which leaks that are officially considered as confirmed or assumed are listed in Table B-2 along with the estimated volume of leaked waste and the date that the tank was interim stabilized. Interim stabilized means that the tank now contains less than 50,000 gal (189,250 L) of drainable interstitial liquid and less than 5,000 gal (18,925 L) supernatant liquid (Hanlon 1999). Note that in the review of tank leaks in Chapter 3 of this document, the conclusions concerning tank status and leak volume estimates are not in agreement with Table B-2. None of the tanks listed appear to have leaked although infrastructure parts around some of the individual tanks (e.g., transfer lines) do seem to have leaked. Also, tank C-105, which does not appear in Table B-2, is proposed in this document to have leaked.

Table B-3 provides the current inventory and status of the SSTs in the C WMA. Most of the pumpable liquid has been removed and transferred to DSTs as part of the interim stabilization project. Interim stabilized means that the tank now contains less than 50,000 gal (189,250 L) of drainable interstitial liquid and less than 5,000 gal (18,925 L) of supernatant liquid. However, two tanks (241-C-103 and 241-C-106) are not yet interim stabilized, although tank 241-C-106 has been sluiced. As used in Table B-3, intrusion prevention (IP) is the administrative designation for the completion of the physical activities required to minimize the addition of liquids into an inactive storage tank. Electrical and other instrumentation devices are not disconnected during intrusion prevention. Partially interim isolation (PI) is the administrative designation for the completion of physical activities required for interim isolation except for isolation of risers and piping required for jet pumping or other stabilization methods (Hanlon 1999).

Pertinent information on the A-AX tanks, waste transfer vault, and the diversion boxes is provided in three tables. Table B-4 lists the tanks, vault, and diversion box numbers, year of construction, year removed from service, and operating capacity. The date a tank was declared a leaker, the volume of leaked waste and associated curies is provided in Table B-5. Table B-6 provides the current inventory and status of the 100 series tanks in A-AX WMA. Data on tank integrity, the total waste in the tank, total pump able liquid remaining in the tanks, total liquid pumped out of the tank during interim stabilization and the sludge/salt cake volumes for each tank are included in this table (Hanlon 1999). Note that in the review of tank leaks in Chapter 3 of this document, the conclusions concerning tank status are not in agreement with Table B-5. In Chapter 3, it was concluded that only tank A-105 itself leak. Some transfer line leaks around other tanks are likely.

Table B-1. Operating Period and Capacities for WMA C Facilities[a].

Facility	Constructed	Removed From Service	Operating Capacity (gal)
Single-Shell Tanks			
241-C-101	1943 - 1944	1970	530,000
241-C-102	1943 - 1944	1976	530,000
241-C-103	1943 - 1944	1979	530,000
241-C-104	1943 - 1944	1980	530,000
241-C-105	1943 - 1944	1979	530,000
241-C-106	1943 - 1944	1979	530,000
241-C-107	1943 - 1944	1978	530,000
241-C-108	1943 - 1944	1976	530,000
241-C-109	1943 - 1944	1976	530,000
241-C-110	1943 - 1944	1976	530,000
241-C-111	1943 - 1944	1978	530,000
241-C-112	1943 - 1944	1976	530,000
241-C-201	1943 - 1944	1977	55,000
241-C-202	1943 - 1944	1977	55,000
241-C-203	1943 - 1944	1977	55,000
241-C-204	1943 - 1944	1977	55,000
Diversion Boxes			**Function**
241-C-151	1946	1985	Interconnected 241-C-152, -153, and CR-151 diversion boxes
241-C-152	1946	1985	Interconnected 241-B-154 and -153 and 241-C Tank Farm, associated with the 241-C-301 Catch Tank
241-C-153	1946	1985	Interconnected 241-C-151 and -152 diversion boxes
241-C-154	1965	1985	Interconnected B-Plant to Hot Semi-Works locations. Box located at Hot Semi-Works
241-C-252	1946	1985	Interconnected 241-C-151 diversion box and 241-C Tank Farm
241-CR-151	1952	1985	Interconnected 241-C-151 and 241-C Tank Farms
241-CR-152	1946	1985	Interconnected 241-C-151 diversion box and 241-C Tank Farm
241-CR-153	1946	1985	Interconnected 241-CR-152 diversion box and 241-C Tank Farm
244-CR-Vault			
244-CR-011	1946	1988	Transfer of waste solutions from processes and decontamination operations.
244-CR-003	1946	1988	

[a] Data on SSTs is from Caggiano and Goodwin (1991) and Hanlon (1999). Data on diversion boxes and the 244-CR vault is from DOE (1993a) except for 241-C-154, which is from DOE (1993b).

Table B-2. Tank Leak Volume Estimates (from Hanlon 2000).

Tank Number	Date Declared Confirmed or Assumed Leaker	Volume Leaked (gal)	Interim Stabilized Date	Leak Estimate Updated
241-C-101	1980	20,000	11/83	1986
241-C-110	1984	2,000	5/95	1989
241-C-111	1968	5,500	03/84	1989
241-C-201	1988	550	03/82	1987
241-C-202	1988	450	08/81	1987
241-C-203	1984	400	03/82	1986
241-C-204	1988	350	09/82	1987

Table B-3. Inventory and Status by Tank (from Hanlon 2000).

Tank	Tank Integrity	Stabilization/ Isolation Status[a]	Total Waste (gal x 1000)	Total Pumped (gal x 1000)	Drainable Liquid Remaining (gal x 1000)	Pumpable Liquid Remaining (gal x 1000)	Sludge (gal x 1000)	Salt Cake (gal x 1000)
241-C-101	Assumed leaker	IS/IP	88	0.0	4	0	88	0
241-C-102	Sound	IS/IP	316	46.7	62	55	316	0
241-C-103	Sound	/PI	198	0.0	83	83	119	0
241-C-104	Sound	IS/IP	295	0.0	34	30	295	0
241-C-105	Sound	IS/PI	134	0.0	12	8	132	0
241-C-106	Sound	/PI	74	0.0	68	62	6	0
241-C-107	Sound	IS/IP	257	40.8	30	25	257	0
241-C-108	Sound	IS/IP	66	0.0	4	0	66	0
241-C-109	Sound	IS/IP	66	0.0	6	4	62	0
241-C-110	Assumed leaker	IS/IP	178	15.5	38	30	177	0
241-C-111	Assumed leaker	IS/IP	57	0.0	4	0	57	0
241-C-112	Sound	IS/IP	104	0.0	6	1	104	0
241-C-201	Assumed leaker	IS/IP	2	0.0	0	0	2	0
241-C-202	Assumed leaker	IS/IP	1	0.0	0	0	1	0
241-C-203	Assumed leaker	IS/IP	5	0.0	0	0	5	0
241-C-204	Assumed leaker	IS/IP	3	0.0	0	0	3	0

[a] IP = Intrusion Prevention; IS = Interim stabilized or isolated; and PI = Partially interim isolation.

Table B-4. Summary Data for Facilities Comprising WMA A-AX.

Tank Number	Year of Construction	Year Removed from Service	Operating Capacity (gal)
241-A-101	1954-1955	1980	1,000,000
241-A-102	1954-1955	1980	1,000,000
241-A-103	1954-1955	1980	1,000,000
241-A-104	1954-1955	1975	1,000,000
241-A-105	1954-1955	1963	1,000,000
241-A-106	1954-1955	1980	1,000,000
241-AX-101	1963-1964	1980	1,000,000
241-AX-102	1963-1964	1980	1,000,000
241-AX-103	1963-1964	1980	1,000,000
241-AX-104	1963-1964	1978	1,000,000
Diversion Box	**Year of Construction**	**Year Removed from Service[a]**	**Operating Capacity (lbs)**
241-A-152	1955	1985	NA
241-A-153	1966	1985 (?)	NA
241-AX-151	1963	1985	NA
241-AX-152	1962	NA	NA
241-AX-155	1983	1985 (?)	NA
241-AY-151	1975	1985 (?)	NA
241-AY-152	1970	1985 (?)	NA
Tank Number	**Year of Construction**	**Year Removed from Service**	**Operating Capacity (gal)**
244-AR-001	1976	NA	43,000
244-AR-002	1976	NA	43,000
244-AR-003	1976	NA	4,785
244-AR-004	1976	NA	4,785

NA = Not applicable.

[a] Isolation date.

Table B-5. Tank Leak Volume Estimates (After Hanlon 1999).

Tank Number	Date Declared Confirmed or Assumed Leaker	Volume Leaked (gal)	Associated Kilocuries ^{137}Cs	Interim Stabilized Date	Leak Estimate Updated
241-A-103	1987	5,500		06/88	1987
241-A-104	1975	500 to 2,500	0.8 to 1.8	09/78	1983
241-A-105	1963	10,000 to 277,000	85 to 760	07/79	1991
241-AX-102	1988	3,000		09/88	1989
241-AX-104	1977	8,000		08/81	1989

Table B-6. Inventory and Status by Tank (After Hanlon 1999).

Tank	Tank Integrity	Stabilization/ Isolation Status	Total Waste (Kgal)	Total Pumped (Kgal)	Drainable Liquid Remain (Kgal)	Pumpable Liquid Remain (Kgal)	Sludge (Kgal)	Salt Cake (Kgal)
A-101	Sound	PI	953	0.0	721	697	3	442
A-102	Sound	IS/PI	41	39.5	6	0	15	22
A-103	Assumed leaker	IS/IP	371	111.0	20	0	366	0
A-104	Assumed leaker	IS/IP	28	0.0	0	0	28	0
A-105	Assumed leaker	IS/IP	19	0.0	4	0	19	0
A-106	Sound	IS/IP	126	0.0	7	0	126	0
AX-101	Sound	PI	748	0.0	558	534	3	359
AX-102	Assumed leaker	IS/IP	39	13.0	17	3	7	28
AX-103	Sound	IS/IP	112	0.0	36	3	2	110
AX-104	Assumed leaker	IS/IP	7	0.0	0	0	7	0

IP = Intrusion prevention.

IS = Interim stabilized or isolated.

PI = Partially interim.

B.5.0 UNPLANNED RELEASES

In addition to leaks historically attributed to tanks, a total of seventeen unplanned releases have been reported in and around the tank farms (12 in C farm, 3 in A farm and 3 in AX tank farm). The following brief descriptions of these events is provided:

- Unplanned release UPR-200-E-16 is a surface spill that resulted from a leak in an over ground transfer pipeline between tanks 241-C-105 and 241-C-108. The surface spill associated with this release is located approximately 60 ft (18 m) northeast of tank 241-C-105 and occurred in 1959. The spilled liquid was classified as coating waste from the PUREX process.
- Unplanned release UPR-200-E-18 was moisture dripping from a vent pipe bonnet at the 241-A-08 valve pit near 241-A-271 building that contaminated the ground in 1959. Volume estimates and remediation efforts are not described.
- Unplanned release UPR-200-E-27 is located just east of the 244-CR vault and extends easterly beyond the tank farm fence line. DOE (1993) indicates the surface contamination was deposited in 1960, but does not specify the source or potential sources of the contamination.
- Unplanned release UPR-200-E-42 was surface contamination that resulted from inadvertent pressurization in the 244-AR vault in 1972. The area around diversion box 241-AX-151.
- Unplanned release UPR-200-E-48 occurred at the tank A-106 pump pit in 1974 and was confined to a small area within the pump pit (DOE-GJO 1999). Beta-gamma readings of 1,000 to 2,000 counts per minute were detected. The contaminated materials were removed immediately.
- Unplanned release UPR-200-E-68 was wind-borne surface contamination spread from the 241-C-151 diversion box. The release occurred in 1985 and was subsequently decontaminated or covered with clean sediment.
- Unplanned release UPR-200-E-72 is located south of the 241-C Tank Farm and occurred in 1985. The source of the contamination was buried contaminated waste. The waste posed little release potential because the contamination was fixed in place. The source of contamination was stabilized and the area posted as a radiologically controlled area. The volume of the contamination was not specified.
- Unplanned release UPR-200-E-81 is located near the 241-CR-151 diversion box and the 244-CR vault. It occurred as a result of a leak in an underground transfer pipeline in October 1969. The waste leaked from the pipeline consisted of PUREX coating waste. The site was covered with gravel.
- Unplanned release UPR-200-E-82 is located near the 241-C-152 diversion box and was the result of a leak from an underground pipeline from the 202-A building to the 241-C-102 tank by way of the 241-CR-151 diversion box. The release occurred in December 1969. The leak spilled an estimated 10,000 L of waste. The contaminated site was covered with clean gravel.

- Unplanned release UPR-200-E-86 was a spill that resulted from a leak in a pipeline used to transfer waste from the 244-AR vault to the 241-C Tank Farm. The release was approximately 8 ft (2.4 m) below the ground surface. It occurred in March 1971 and is located just outside the west corner of the tank farm. The spill was estimated to include 25,000 Ci of ^{137}Cs. The sediments surrounding the pipeline were sampled and it was determined the contamination had not penetrated below 20 ft. The contamination plume volume was estimated at 1,300 cubic feet.
- Unplanned release UPR-200-E-91 is located approximately 100 ft from the northeast side of C tank farm. It resulted from surface contamination that migrated from the 241-C Tank Farm. The date of the occurrence, its areal extent, and the nature of the contamination are not specified. DOE (1993) states that the contaminated sediment was removed and the area was released from radiological controls.
- Unplanned release UPR-200-E-99 was surface contamination that resulted from numerous piping changes associated with the 244-CR vault. It is located west of the 244-CR vault and was established as a release site in 1980 although the actual occurrence date is unknown. The site was decontaminated in 1981.
- Unplanned release UPR-200-E-100 was a surface spill of unknown proportions and constituents that occurred in 1986. It is located about 200 ft (60 m) south and east of the 241-C Tank Farm and surrounds the 244-A lift station.
- Unplanned release UPR-200-E-107 was a surface spill located north of the 244-CR vault, inside the 241-C Tank Farm. DOE (1993) states that a spill occurred on November 26, 1952 when a pump discharged liquid to the ground surface during a pump installation. The spilled waste was tributyl phosphate waste from 221-U building. The proportions of the spill and any cleanup actions were not documented.
- Unplanned release UPR-200-E-115 was a pipeline bleed from the tank AX-103 pump pit that occurred in 1974. The contaminated soil was removed and disposed.
- Unplanned release UPR-200-E-119 was moisture transferred from a contaminated electrode cable to soil when the cable that was briefly set on the ground. The cable had been retrieved from tank AX-104.
- Unplanned release UPR-200-E-118 was located in the northeast portion of C tank farm and extends north up to about 300 m beyond the fence line. It was the result of an airborne release from tank 241-C-107 that occurred in April 1957. The highest exposure rate was estimated at 50 mrem/hour at the ground surface (DOE 1993).
- Unplanned release UPR-200-E-145 was the discovery of contaminated soil around a shallow pipe running between valve pit 241-A-08 and crib 216-A-34 in 1993. The actual data of leakage and volume leaked is unknown.

B.6.0 REFERENCES

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APPENDIX C

SUPPORTING STRATIGRAPHIC INFORMATION

CONTENTS

C.1.0 INTRODUCTION C-1

FIGURES

Figure C–1. Cross Section A-A--Northwest to Southeast Section of Vadose Zone Underlying C and A Tank Farms. C-2

Figure C–2. Cross Section B-B--West to East Section of Vadose Zone Underlying A Tank Farm. C-3

Figure C–3. Cross Section C-C--West to East Section of Vadose Zone Between C and A-AX Tank Farms C-4

Figure C–4. Cross Section D-D--Southwest to Northeast Section of Vadose Zone Just South of C Tank Farm C-5

Figure C–5. Cross Section E-E--Northwest to Southeast Section of Vadose Zone Underlying AX Tank Farm C-6

Figure C–6. Structure Contour Map of the Top of Basalt. C-7

Figure C–7. Structure Contour Map of the Top of the Undifferentiated Plio-Pleistocene Gravels/Ringold Formation Unit A [Pplg/R(?)] Unit. C-8

Figure C–8. Isopach Map of the Undifferentiated Plio-Pleistocene Silt/Ringold Formation Mud? [Pplz/R(?)] Unit. C-9

Figure C–9. Structure Contour Map of the Top of the Undifferentiated Plio-Pleistocene Silt/Ringold Formation Mud? [Pplz/R(?)] Unit. C-10

Figure C–10. Isopach Map of the Hanford Formation H3 Unit. C-11

Figure C–11. Structure Contour Map of the Top of the Hanford Formation H3 Unit. C-12

Figure C–12. Isopach Map of the Hanford Formation H2 Unit. C-13

Figure C–13. Structure Contour Map of the Top of the Hanford Formation H2 Unit. C-14

Figure C–14. Isopach Map of the Hanford Formation H1 Unit. C-15

Figure C–15. Isopach Map of the Recent Deposits. C-16

C.1.0 INTRODUCTION

Appendix C provides the detailed stratigraphic cross sections used to construct the subsurface physical model of the C and A-AX Waste Management Areas. Figures C-1 through C-.5 show 5 cross sections of the C and A-AX WMAs. Figures C-6 through C-15 show thickness isopachs and elevations of stratigraphic units in the vadose zone.

Figure C–1. Cross Section A-A–Northwest to Southeast Section of Vadose Zone Underlying C and A Tank Farms.

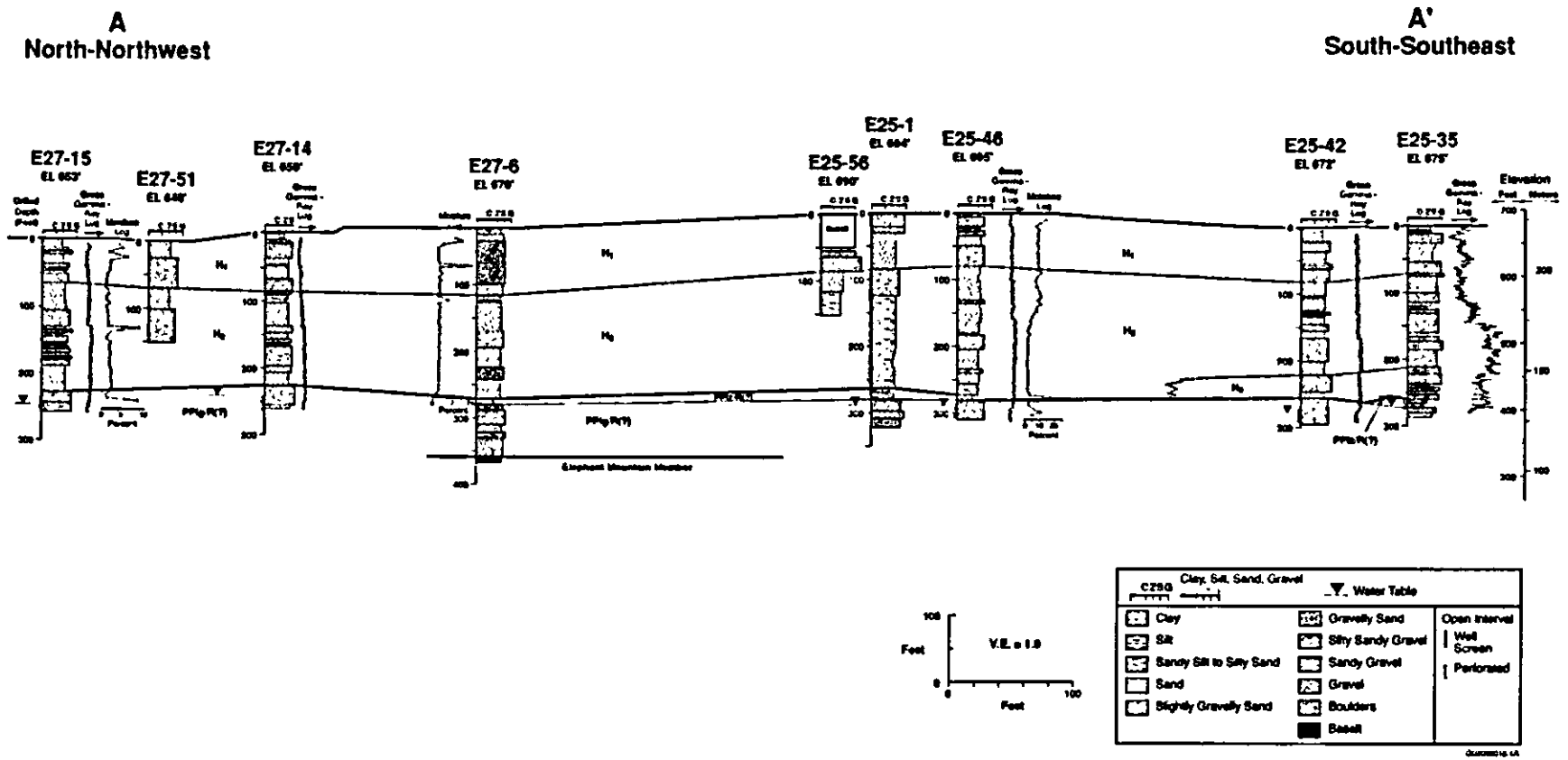


Figure C–2. Cross Section B-B–West to East Section of Vadose Zone Underlying A Tank Farm.

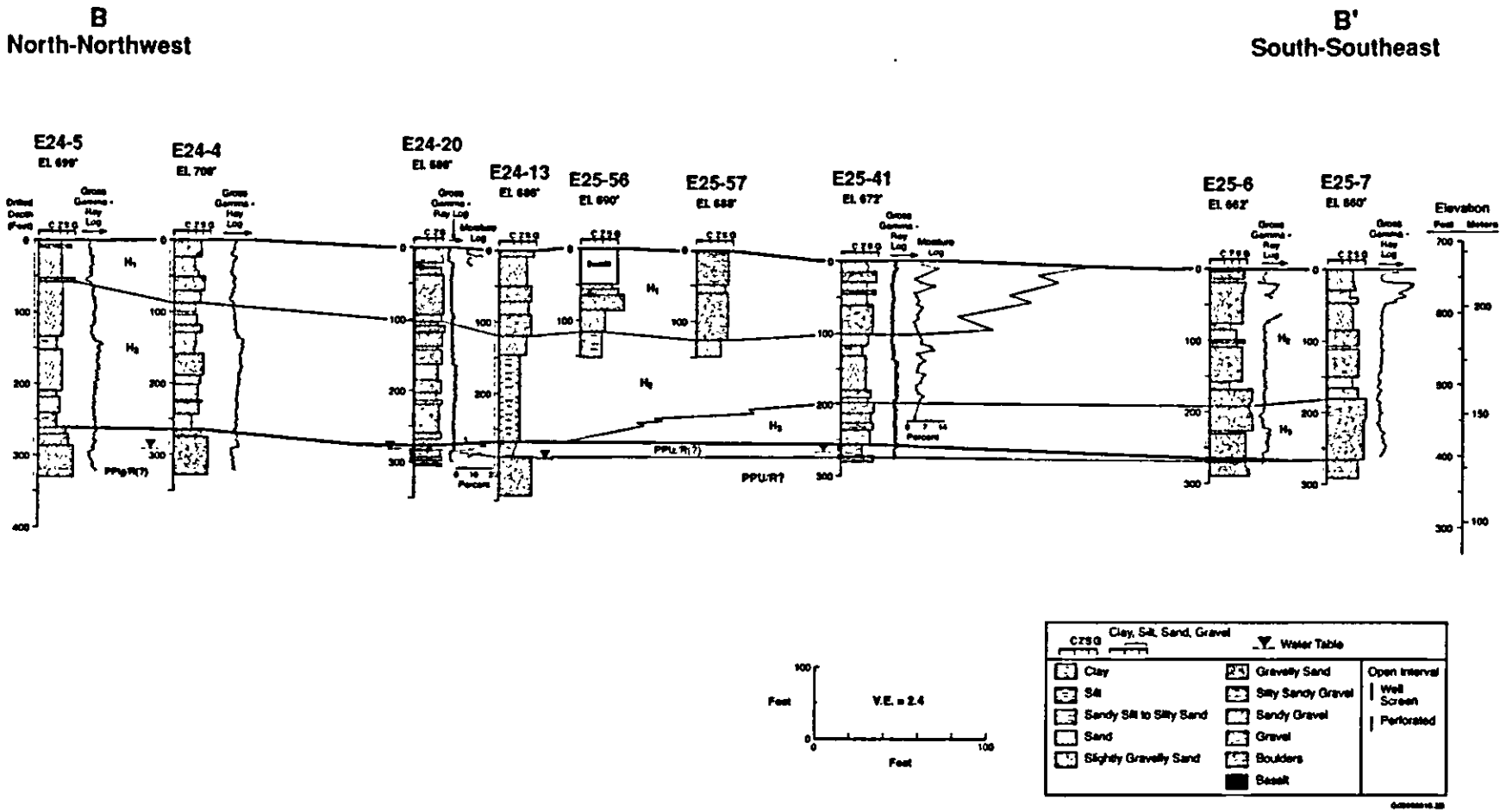


Figure C–3. Cross Section C-C'–West to East Section of Vadose Zone Between C and A-AX Tank Farms.

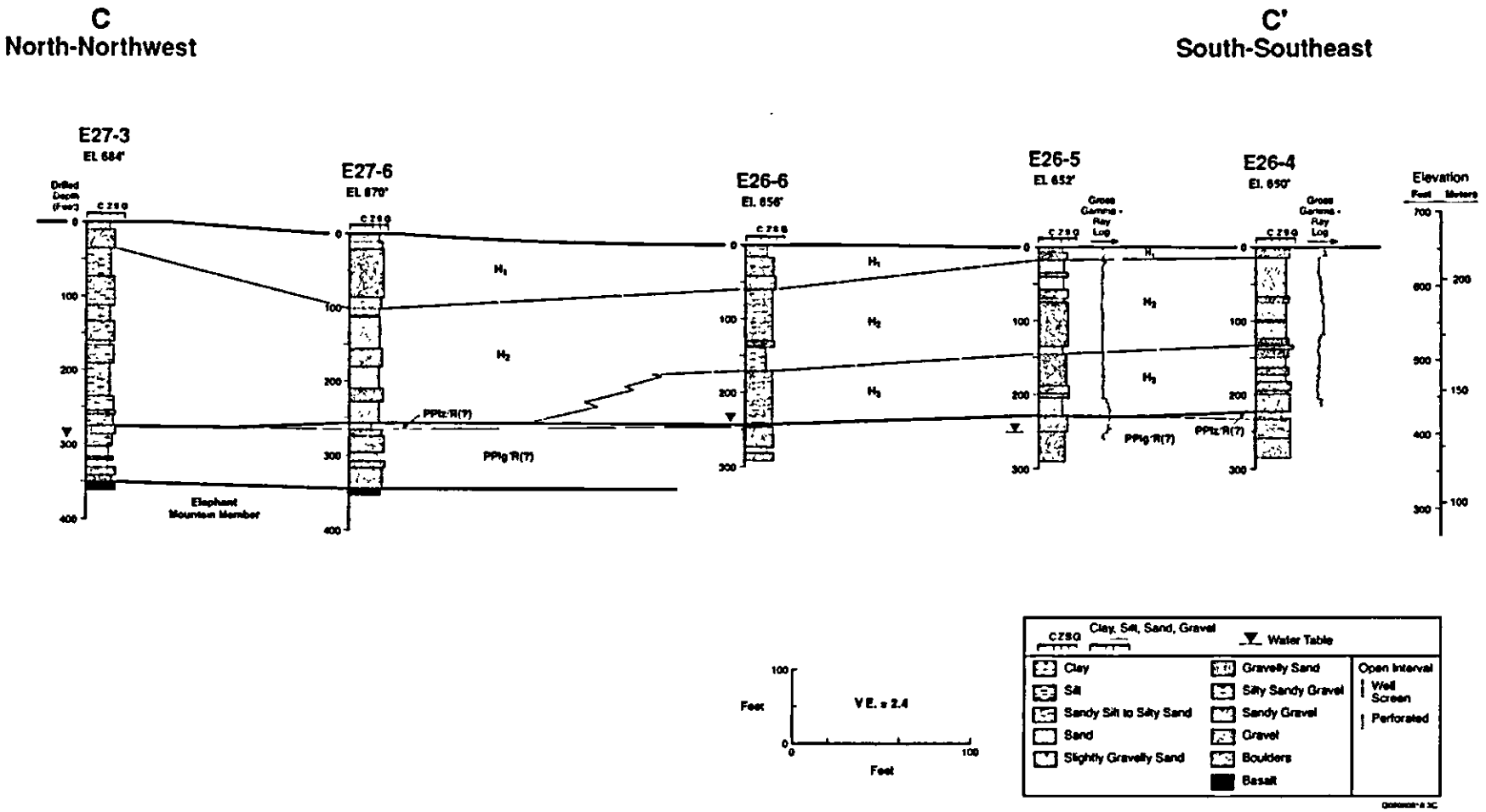


Figure C–4. Cross Section D-D--Southwest to Northeast Section of Vadose Zone Just South of C Tank Farm.

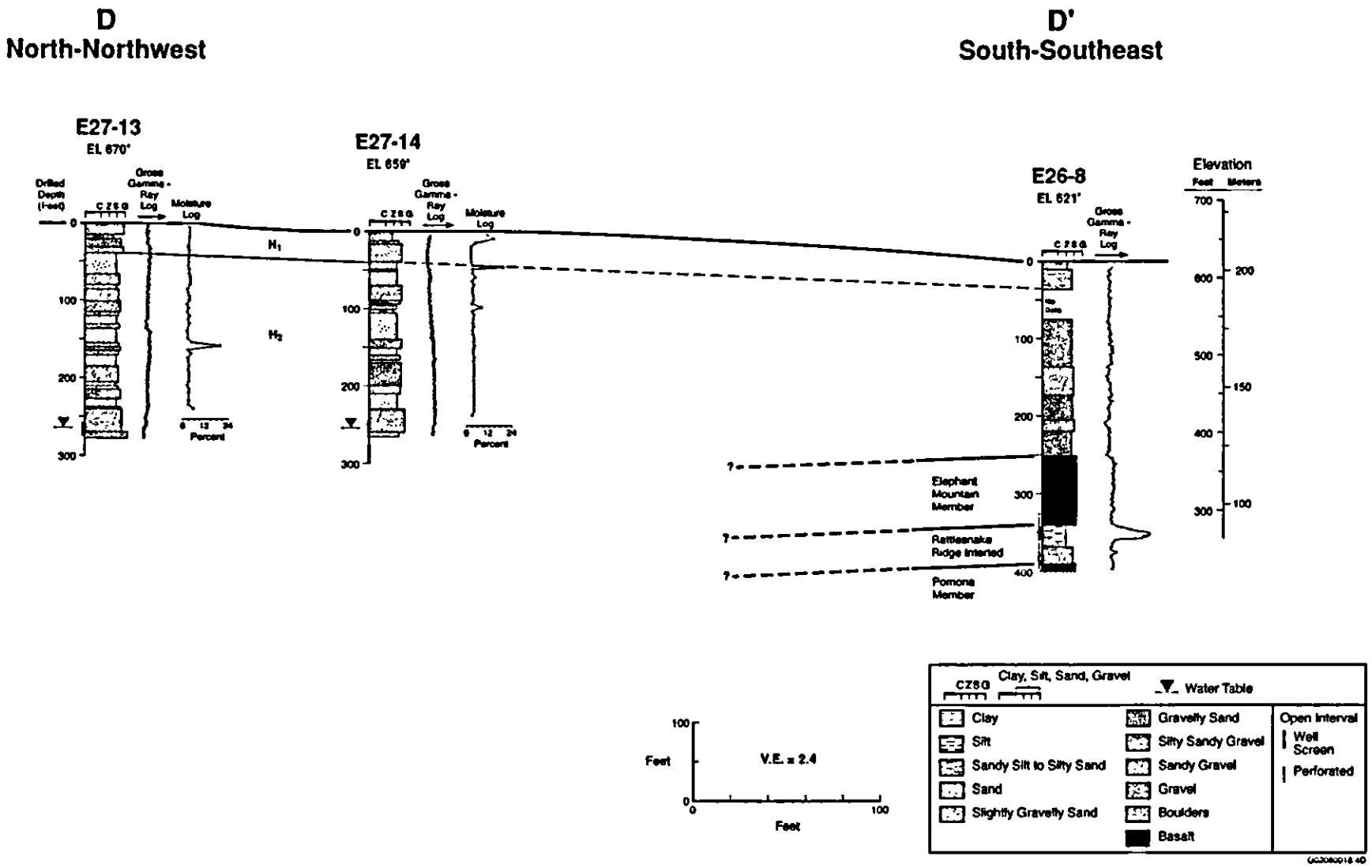


Figure C–5. Cross Section E-E--Northwest to Southeast Section of Vadose Zone Underlying AX Tank Farm

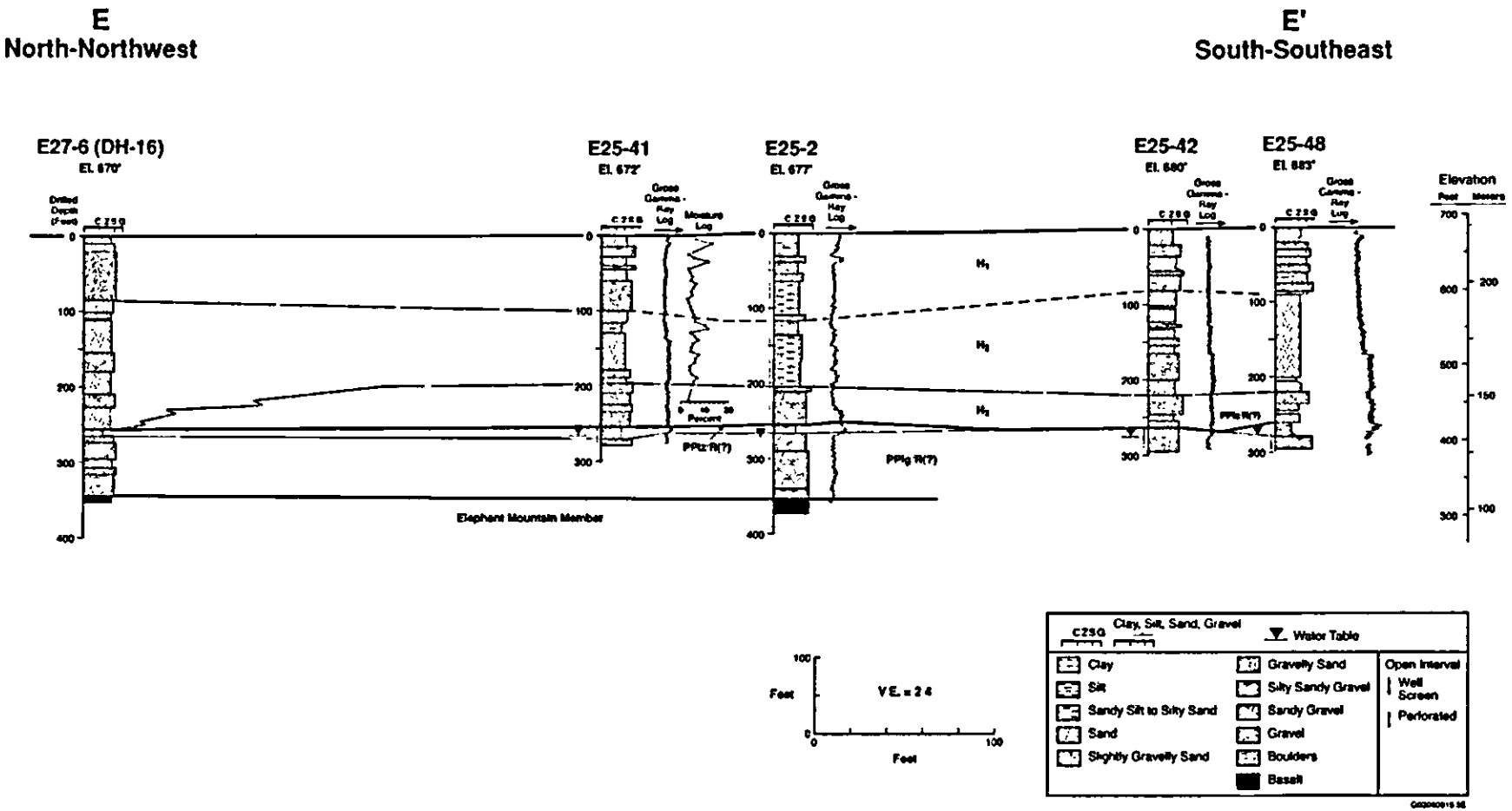


Figure C–6. Structure Contour Map of the Top of Basalt.

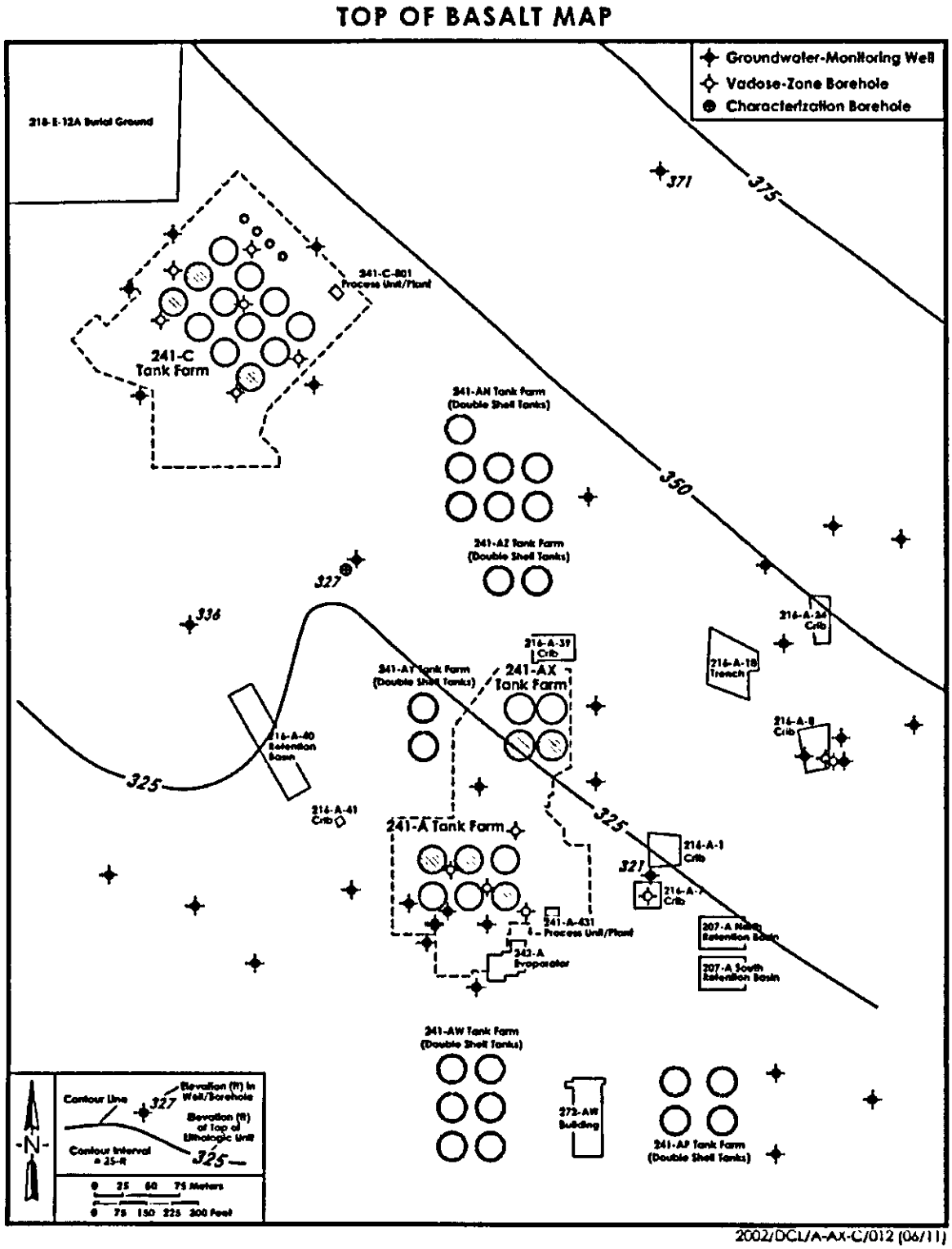


Figure C–7. Structure Contour Map of the Top of the Undifferentiated Plio-Pleistocene Gravels/Ringold Formation Unit A [Pplg/R(?)] Unit.

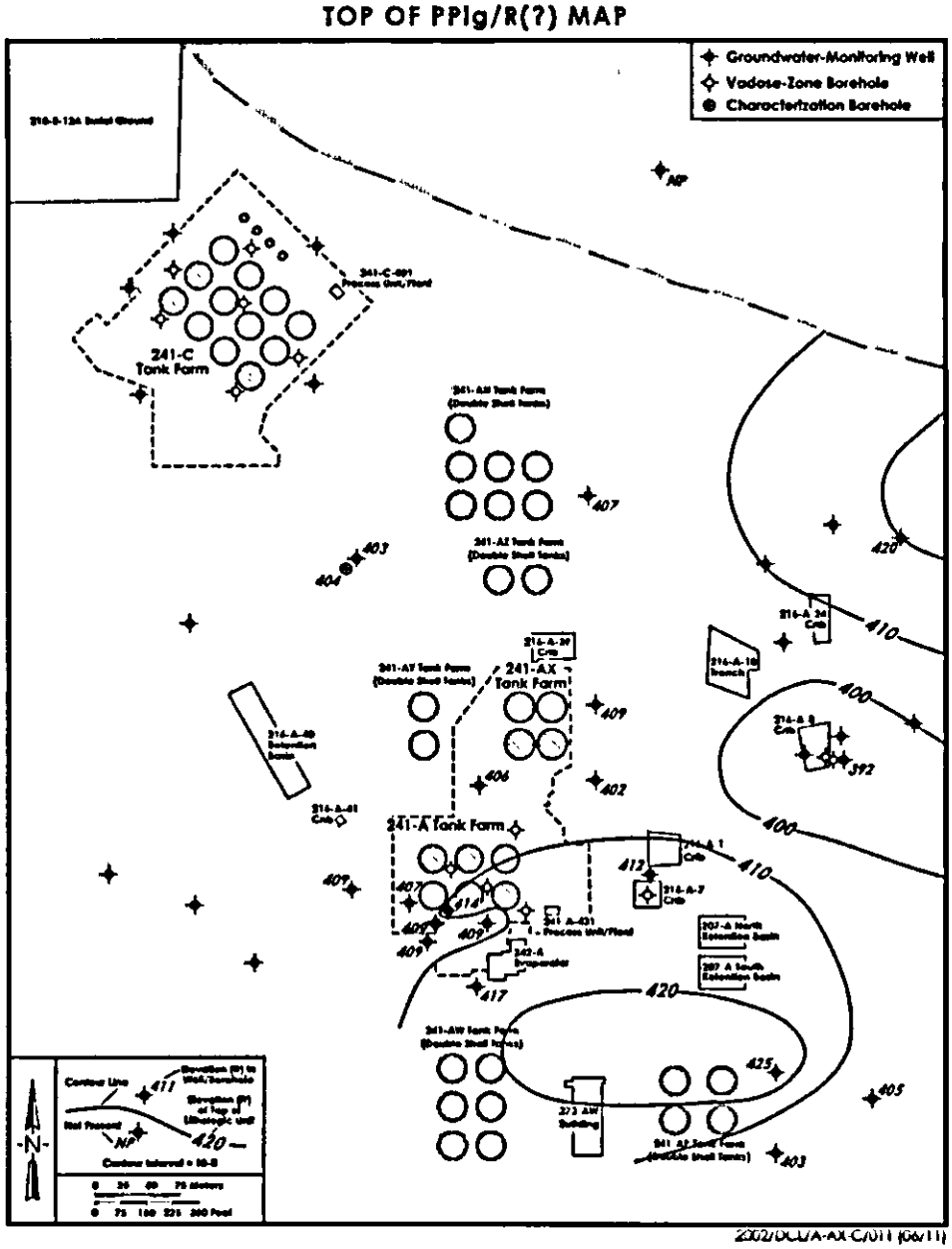


Figure C–8. Isopach Map of the Undifferentiated Plio-Pleistocene Silt/Ringold Formation Mud? [Pplz/R(?)] Unit.

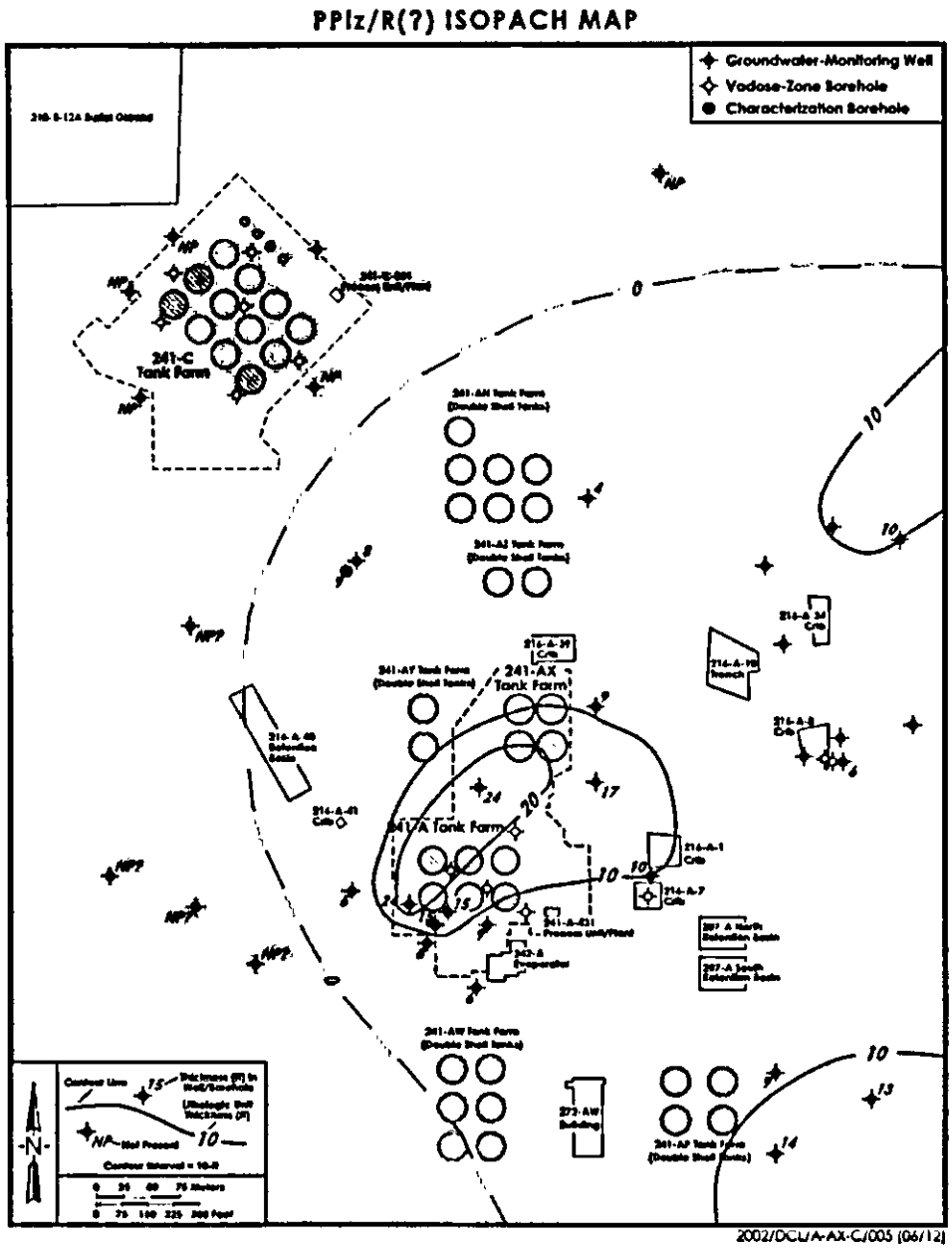


Figure C–9. Structure Contour Map of the Top of the Undifferentiated Plio-Pleistocene Silt/Ringold Formation Mud? [Pplz/R(?)] Unit.

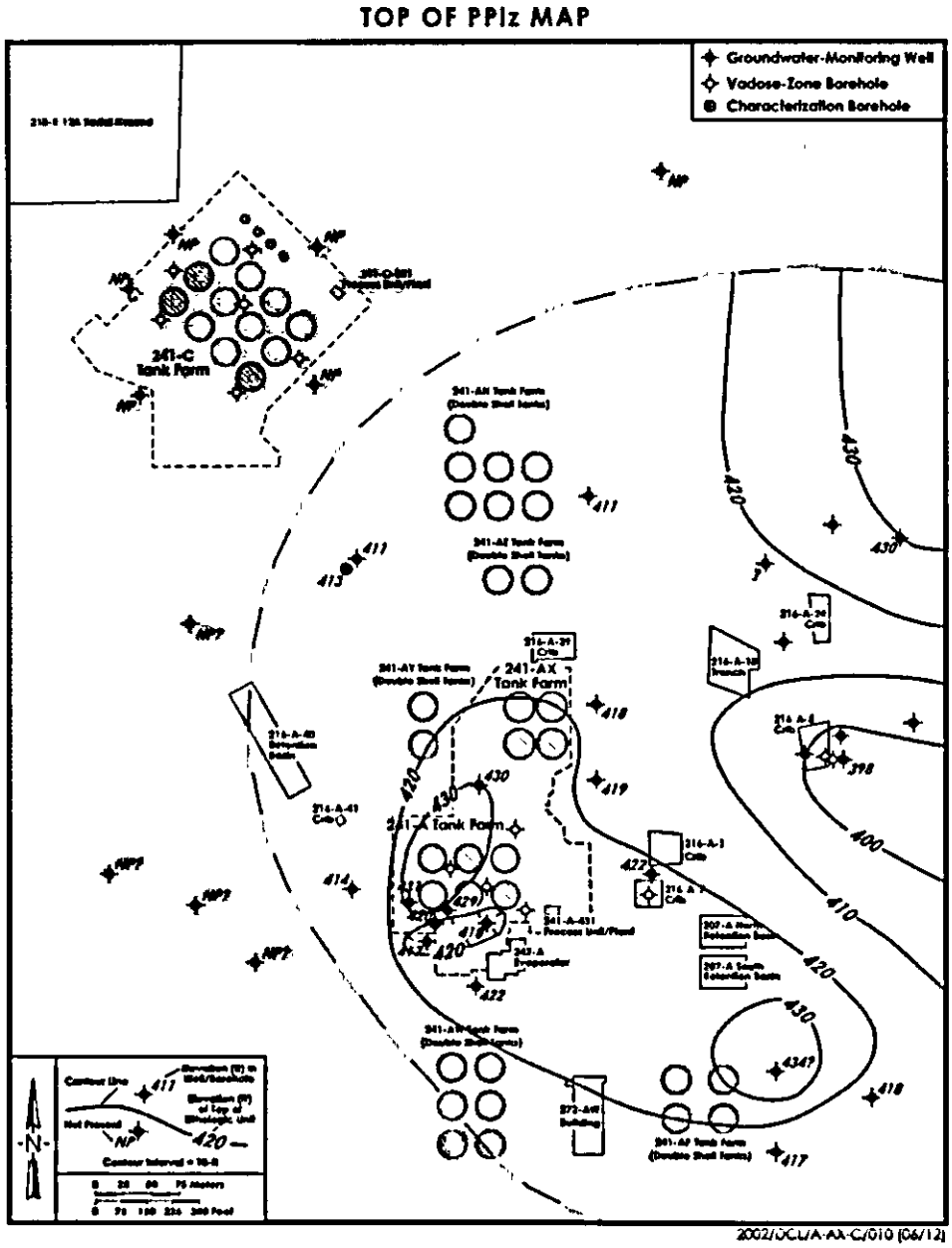


Figure C–10. Isopach Map of the Hanford Formation H3 Unit.

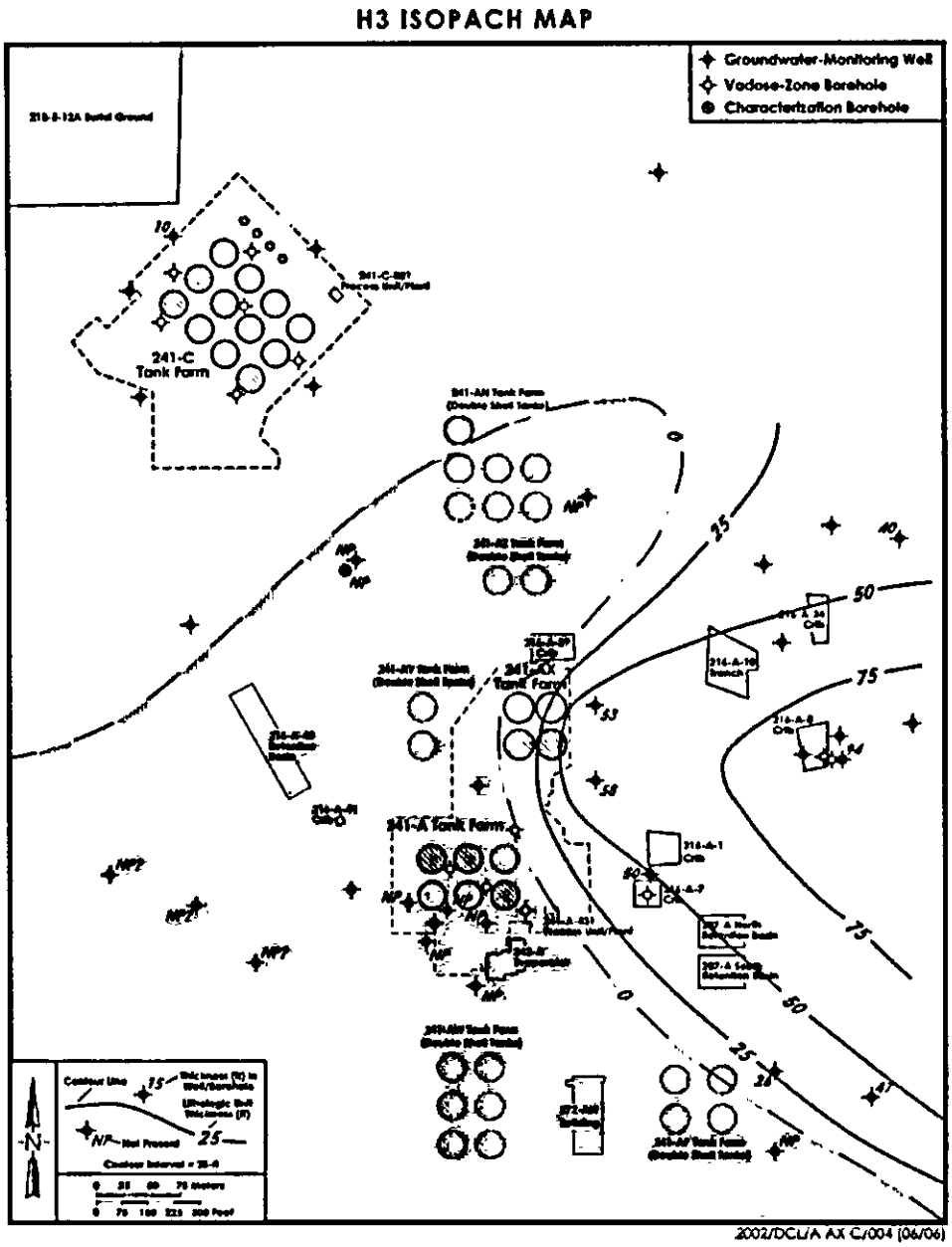


Figure C–11. Structure Contour Map of the Top of the Hanford Formation H3 Unit.

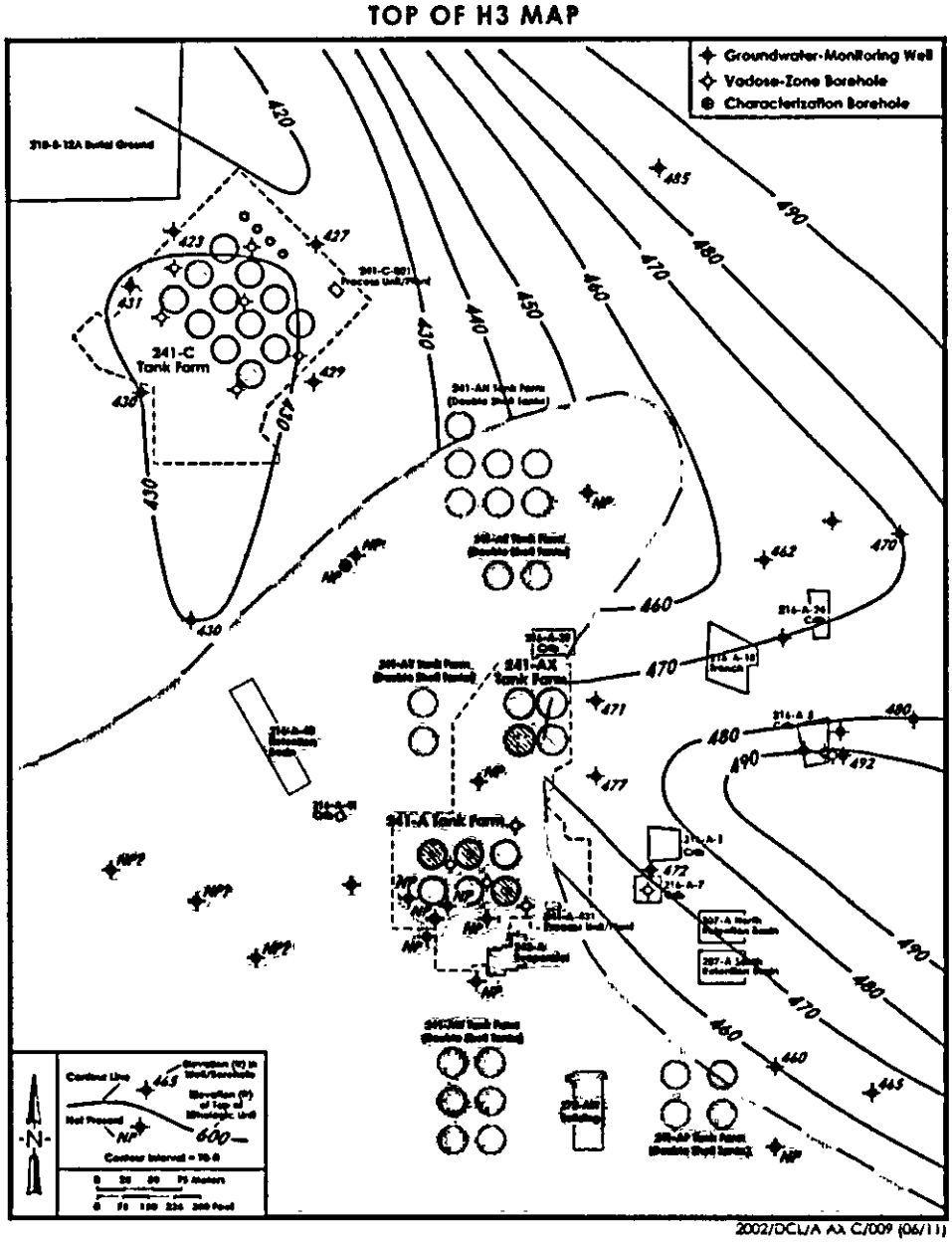


Figure C–12. Isopach Map of the Hanford Formation H2 Unit.

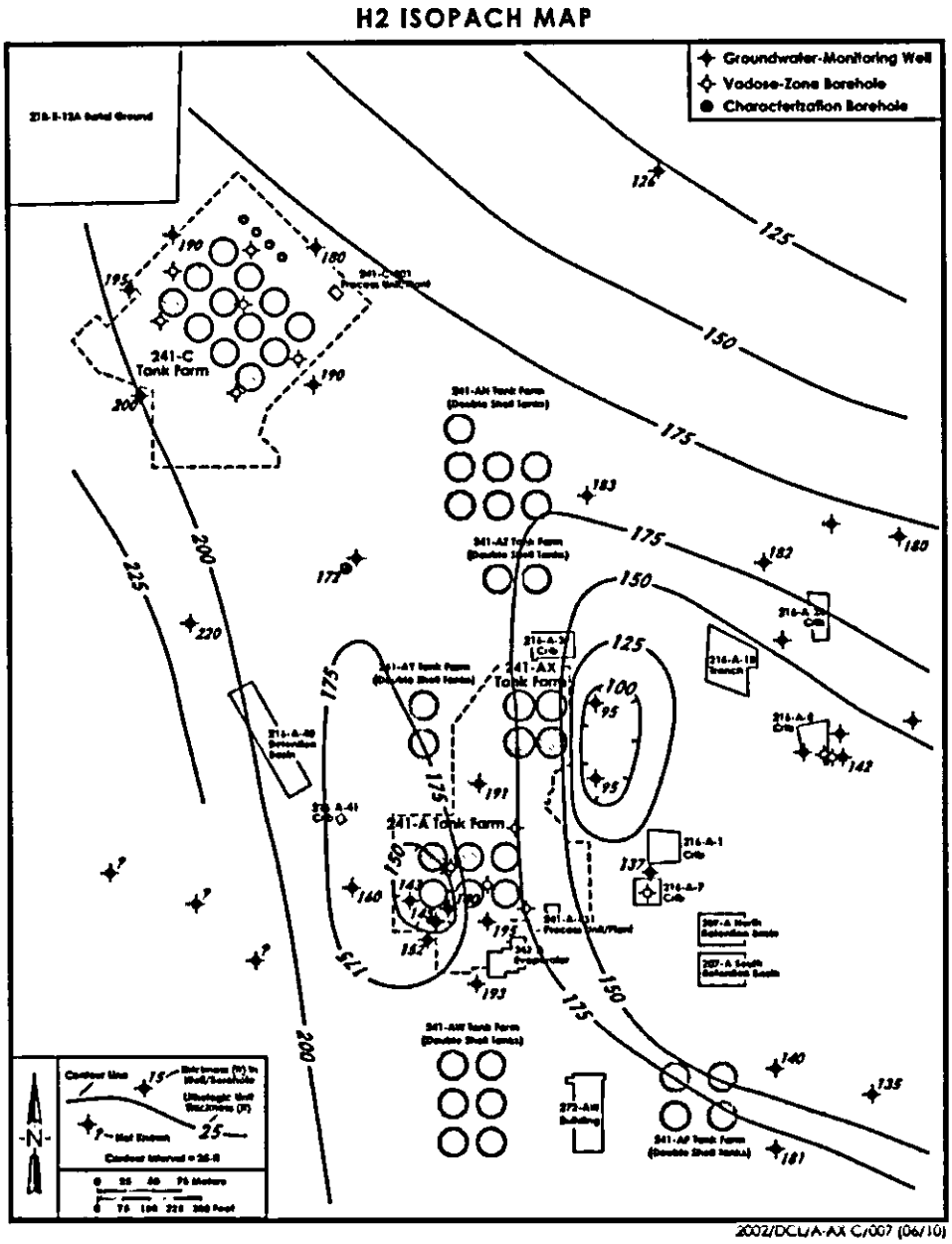


Figure C–13. Structure Contour Map of the Top of the Hanford Formation H2 Unit.

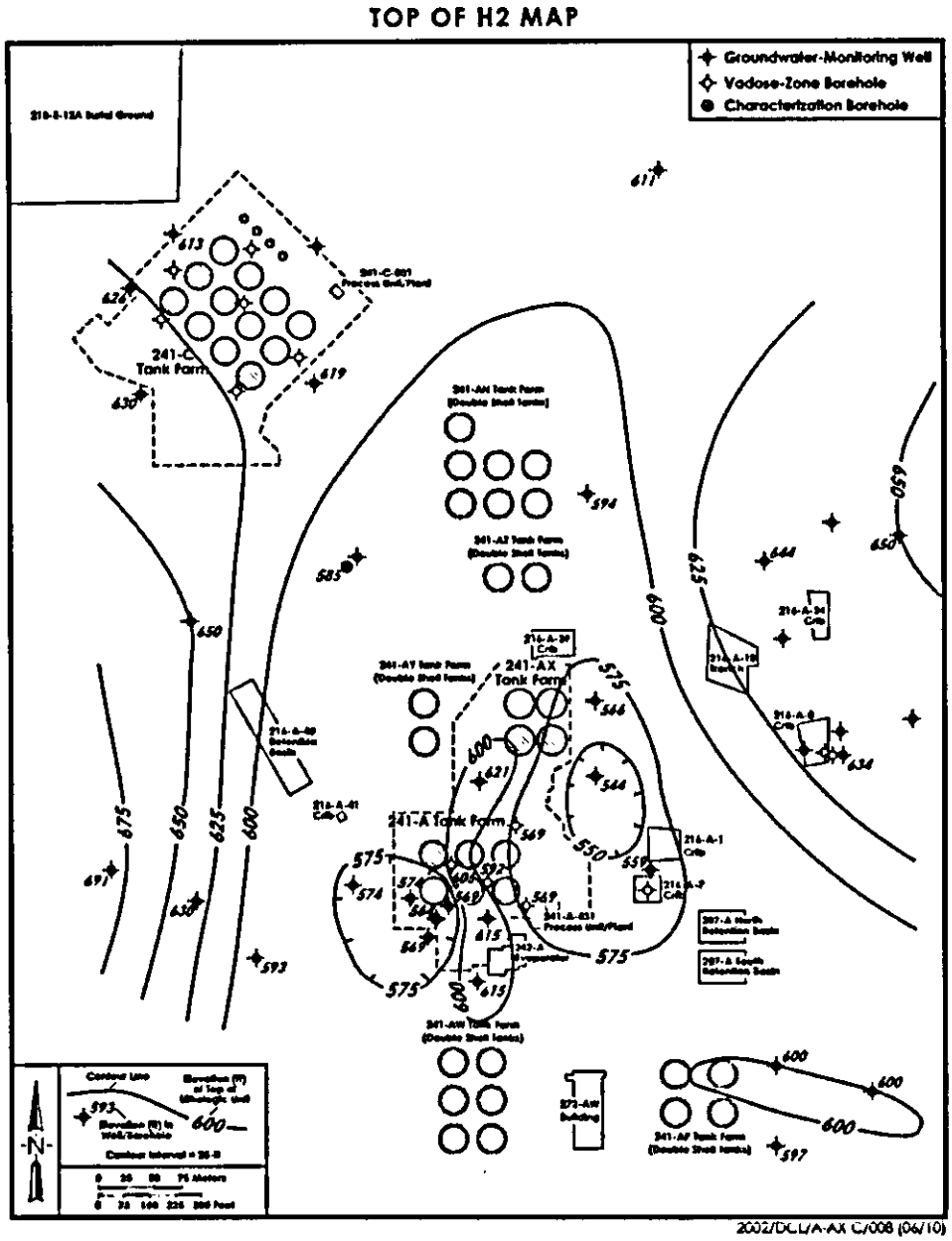


Figure C–14. Isopach Map of the Hanford Formation H1 Unit.

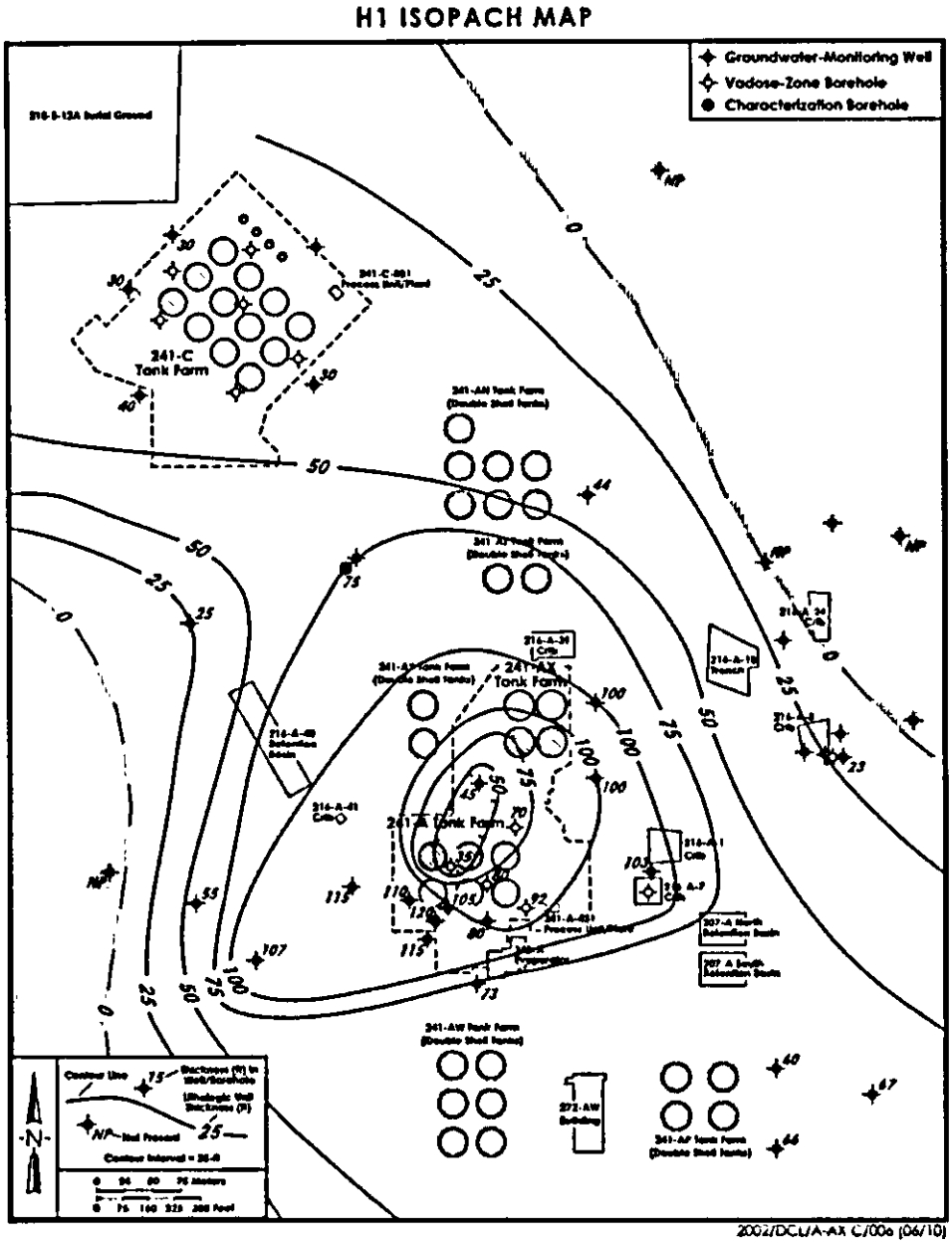
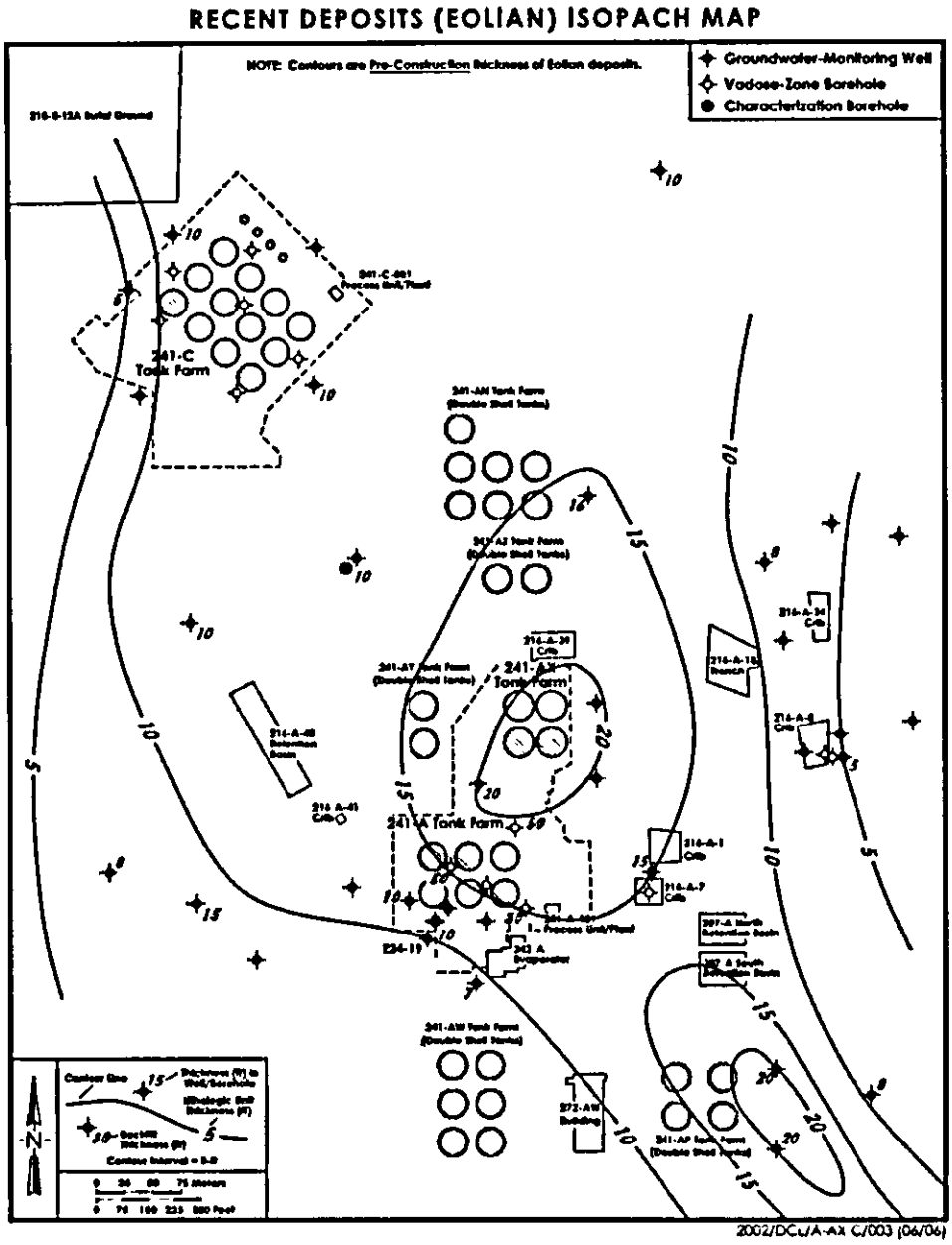


Figure C–15. Isopach Map of the Recent Deposits.



APPENDIX D

SUPPORTING METEOROLOGICAL, HYDROLOGIC DATA

CONTENTS

D.1.0 INTRODUCTION 1
D.2.0 REFERENCE 9

TABLES

Table D–1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998. 2

Table D–2. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the backfill (1) and Plio-Pleistocene/Ringold sandy gravel (5) sediments (Khaleel et al 2002). 4

Table D–3. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the sandy H2 (2) sequence (Khaleel et al 2002). 5

Table D–4. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the gravelly sand H3 (3) sequence (Khaleel et al 2002). 6

Table D–5. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the gravelly sand H1 (4) sediments (Khaleel et al 2002) 7

Table D–6. Composite van Genuchten-Mualem parameters for vadose zone strata (Khaleel et al 2002) 7

Table D–7. Macroscopic anisotropy parameters, based on Polmann (1990) equations for various strata (Khaleel et al 2002). 8

Table D–8. Non-reactive macrodispersivity estimates for non reactive species in vadose zone strata (Khaleel et al 2002). 8

D.1.0 INTRODUCTION

Table D-1 summarizes monthly and annual precipitation at the Hanford Site from 1946 to 1998. Tables D-2 through D-8 summarize the hydrologic soil property data and derived input parameter values used to model contaminant migration through the vadose zone underlying the C WMA (Khaleel et al 2002). These data are derived from soil hydrologic property measurements on Hanford soils collected from numerous sites across the Hanford Site (Khaleel and Freeman 1995). Similar property tables will be developed for the A and AX tank farms.

Table D–1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1946	—	—	—	—	—	—	0.15	0.35	0.52	0.65	0.66	0.11	—
1947	0.32	0.27	0.42	0.70	0.02	1.07	0.71	0.68	1.34	2.20	0.81	0.75	9.29
1948	1.36	0.69	0.07	0.95	1.71	1.47	0.40	0.39	0.16	0.45	0.95	1.11	9.71
1949	0.13	0.68	1.12	0.02	0.16	0.01	0.01	0.03	0.23	0.10	1.47	0.16	4.12
1950	1.80	1.06	0.87	0.47	0.27	2.92	0.07	T	0.01	2.46	0.55	0.97	11.45
1951	0.84	0.51	0.46	0.53	0.43	1.38	0.37	0.15	0.10	0.71	0.82	0.70	7.00
1952	0.65	0.50	0.06	0.13	0.58	1.07	T	0.08	0.08	0.04	0.20	0.77	4.16
1953	2.16	0.25	0.17	0.77	0.28	0.55	T	0.96	0.13	0.20	0.96	0.49	6.92
1954	1.48	0.28	0.59	0.07	0.41	0.10	0.22	0.42	0.51	0.42	0.86	0.35	5.71
1955	0.56	0.22	0.17	0.40	0.59	0.28	0.57	0	0.77	0.40	1.54	2.03	7.53
1956	1.71	0.56	0.10	T	0.22	0.86	T	0.38	0.01	1.03	0.15	0.58	5.60
1957	0.48	0.23	1.86	0.38	0.82	0.47	0.05	0.02	0.34	2.72	0.39	0.53	8.29
1958	1.74	1.48	0.46	0.64	0.74	0.81	0.02	T	0.05	0.19	0.77	1.84	8.74
1959	2.05	1.17	0.40	0.20	0.50	0.23	T	0.03	1.26	0.56	0.41	0.26	7.07
1960	0.51	0.58	0.67	0.53	0.71	0.14	T	0.26	0.23	0.23	0.92	0.64	5.42
1961	0.33	2.10	1.02	0.48	0.80	0.42	0.15	0.09	T	0.07	0.49	0.89	6.84
1962	0.13	0.90	0.14	0.34	1.35	0.12	T	0.50	0.38	0.95	0.65	0.60	6.06
1963	0.95	0.69	0.53	1.17	0.43	0.28	0.31	0.01	0.02	0.04	0.74	1.14	6.31
1964	0.37	0.01	0.03	0.11	0.04	0.90	0.04	0.24	0.09	0.28	0.94	2.34	5.39
1965	0.93	0.14	0.03	0.09	0.15	0.49	0.11	0.03	0.11	0.01	1.17	0.39	3.65
1966	0.68	0.03	0.39	0.03	0.05	0.43	0.81	T	0.27	0.39	2.25	0.60	5.93
1967	0.32	T	0.14	0.90	0.56	0.57	T	T	0.05	0.13	0.16	0.43	3.26
1968	0.88	0.58	0.02	0.01	0.06	0.19	0.04	0.51	0.25	0.93	1.23	1.25	5.95
1969	1.24	0.54	0.10	1.22	0.51	0.75	T	T	0.48	0.10	0.13	1.29	6.36
1970	2.47	0.75	0.27	0.45	0.54	0.25	0.01	T	0.03	0.24	0.71	0.61	6.33
1971	0.78	0.10	1.02	0.07	0.56	0.71	0.13	0.09	1.13	0.18	0.46	1.07	6.30
1972	0.19	0.27	0.58	0.10	2.03	0.66	0.16	0.56	0.02	T	0.55	1.27	6.39
1973	0.90	0.21	0.08	T	0.24	0.01	T	0.02	0.43	1.72	2.64	2.02	8.27
1974	0.90	0.41	0.52	0.46	0.28	0.12	0.71	T	0.01	0.21	0.71	0.97	5.30
1975	1.43	0.98	0.33	0.42	0.38	0.24	0.32	1.16	0.03	0.87	0.60	0.70	7.46
1976	0.56	0.33	0.23	0.41	0.08	0.11	0.13	0.96	T	0.04	T	0.11	2.99
1977	0.08	0.57	0.41	T	0.65	0.37	0.06	1.36	0.66	0.15	0.63	1.47	6.41
1978	1.72	0.92	0.30	0.46	0.41	0.09	0.52	0.57	0.11	T	1.21	0.26	6.57
1979	0.54	0.17	0.54	0.52	0.10	T	0.09	0.38	0.20	0.67	1.36	0.99	5.56
1980	1.32	1.30	0.30	0.86	1.41	0.96	T	0.02	0.85	0.33	0.44	1.89	9.68
1981	0.56	0.60	0.70	0.02	0.99	0.43	0.19	0.03	0.60	0.39	1.08	1.45	7.04
1982	0.33	0.57	0.30	0.75	0.28	0.75	0.22	0.20	0.55	1.33	0.91	1.79	7.98

Table D–1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1983	1.44	1.36	1.00	0.42	0.52	0.68	0.31	0.12	0.46	0.52	2.12	2.12	11.07
1984	0.23	0.94	1.01	0.60	0.55	0.99	0.06	T	0.42	0.07	1.83	0.57	7.27
1985	0.34	0.82	0.36	0.01	0.12	0.15	0.12	0.01	0.63	0.46	1.24	0.84	5.10
1986	1.76	1.37	0.76	T	0.30	T	0.21	0.02	0.96	0.29	0.65	0.77	7.09
1987	0.80	0.19	1.05	0.14	0.17	0.11	0.50	0.07	0.01	T	0.40	1.63	5.07
1988	0.48	T	0.39	1.12	0.33	0.11	0.13	0	0.39	0.01	0.82	0.40	4.18
1989	0.21	1.67	1.56	0.84	0.59	0.01	0.01	0.26	0.02	0.42	1.04	0.29	6.92
1990	0.77	0.09	0.10	0.40	0.86	0.36	0.14	0.83	T	0.78	0.02	0.72	5.07
1991	0.33	0.19	1.12	0.45	0.49	1.44	0.29	0.07	0	0.53	1.44	0.40	6.75
1992	0.44	0.94	0.09	0.94	T	1.14	0.39	0.20	0.27	0.61	1.07	1.82	7.90
1993	1.30	1.17	0.67	0.71	0.60	0.12	1.76	0.24	0.04	0.09	0.19	0.94	7.83
1994	0.44	0.11	0.03	0.61	1.27	0.38	0.15	0.08	0.08	0.93	0.68	1.36	6.12
1995	2.14	0.69	0.95	1.54	0.79	0.77	0.34	0.07	0.79	0.87	1.04	2.32	12.31
1996	1.42	1.22	0.83	0.43	0.62	0.05	0.14	0.02	0.22	0.88	2.67	3.69	12.19
1997	1.51	0.25	0.70	0.33	0.33	0.46	0.19	0.06	0.32	0.92	1.01	0.31	6.39
1998	1.24	1.15	0.50	0.07	0.52	0.48	0.34	0.04	0.10	0.28	1.29	0.44	6.45
Average													
	0.93	0.63	0.51	0.45	0.53	0.53	0.22	0.24	0.32	0.55	0.91	1.01	6.82
Norm													
	0.79	0.62	0.47	0.41	0.51	0.38	0.18	0.27	0.31	0.39	0.91	1.03	6.26

Table D–2. Van Genuchten Parameters, Fitted Saturated Hydraulic Conductivity, and Measured Bulk Density Data for the Backfill (1) and Plio-Pleistocene/Ringold Sandy Gravel (5) Sediments (Khaleel Et Al 2002).

Sample	Site/ Operable Unit	Borehole Number	Depth (m)	Percent Gravel	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm^3)
4-0792	ERDF	699-35-65A	75.4	71	0.100	0.0084	0.03	1.5858	3.42E-04	2.32
4-1012	ERDF	699-35-69A	73.9	55	0.147	0	0.0076	1.5109	4.50E-05	2.19
4-1013	ERDF	699-35-69A	77.9	65	0.139	0.0127	0.0065	1.5656	1.06E-06	2.20
4-1079	ERDF	699-35-61A	90.9	61	0.163	0	0.014	1.3079	1.18E-04	2.06
4-1080	ERDF	699-35-61A	93.5	43	0.178	0	0.0074	1.3819	8.11E-06	2.00
3-0668	241-T-106	299-W10-196	38.9	62	0.175	0	0.0192	1.6124	1.63E-04	2.13
3-0682	241-T-106	299-W10-196	46.1	51	0.224	0	0.0166	1.6577	2.37E-04	2.14
3-0688	241-T-106	299-W10-196	48.5	49	0.199	0	0.0043	1.5321	2.60E-05	2.17
3-0689	241-T-106	299-W10-196	52.2	28	0.236	0	0.0025	1.4747	4.58E-05	1.93
3-0690	241-T-106	299-W10-196	53.7	53	0.1819	0.0177	0.0046	1.541	4.19E-05	2.19

Table D–3. Van Genuchten Parameters, Fitted Saturated Hydraulic Conductivity,and Measured Bulk Density Data for the Sandy H2 (2) Sequence (Khaleel Et Al 2002).

Sample	Site/ Operable Unit	Borehole Number	Depth (m)	Percent Gravel	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm^3)
3-0589	241-T-106	299-W10-196	25.5	1	0.429	0.0268	0.0057	1.7173	4.73E-05	1.86
3-1707	200-UP-2	299-W19-95	9.5	15	0.364	0.0742	0.0082	2.0349	1.55E-05	1.86
3-1712	200-UP-2	299-W19-95	43.1	0	0.290	0.0362	0.0156	2.021	2.05E-04	1.71
3-1713	200-UP-2	299-W19-95	46.3	0	0.5026	0	0.0077	1.6087	2.51E-05	1.72
3-1714	200-UP-2	299-W19-95	50.8	2	0.394	0.1301	0.0061	1.535	1.05E-04	1.68
4-0637	ERDF	699-36-63A	74.9	0	0.378	0	0.0153	1.7309	6.89E-05	1.62
4-0642	ERDF	699-35-69A	25.7	0	0.353	0.0286	0.014	1.4821	6.81E-04	1.98
4-0644	ERDF	699-35-69A	49.8	0	0.394	0.0557	0.0076	1.8353	3.24E-05	1.89
4-0791	ERDF	699-35-65A	63.2	0	0.338	0.0256	0.0226	2.2565	6.81E-04	1.60
4-1076	ERDF	699-35-61A	76.4	0	0.357	0	0.0293	1.7015	1.23E-03	1.74
4-1111	200-UP-1	699-38-68A	56.9	1	0.394	0.0497	0.0093	1.4342	5.80E-05	1.69
4-1112	200-UP-1	699-38-68A	66.0	0	0.4346	0	0.0054	1.4985	2.49E-05	1.73

Table D–4. Van Genuchten Parameters, Fitted Saturated Hydraulic Conductivity, and Measured Bulk Density Data for the Gravelly Sand H3 (3) Sequence (Khaleel Et Al 2002).

Sample	Site/ Operable Unit	Well Number	Depth (m)	Percent Gravel	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm^3)
3-0210	241-T-106	299-W10-196	3.1	48	0.186	0.029	0.014	1.7674	1.96E-04	2.11
3-0572-2	100-FR-3	199-F5-48	8.1	27	0.179	0	0.0031	1.4306	2.38E-05	2.03
3-0576	100-FR-3	199-F5-43B	5.4	20	0.244	0.0166	0.0167	1.5428	3.96E-04	1.95
3-0668	241-T-106	299-W10-196	38.9	62	0.175	0	0.0192	1.6124	1.63E-04	2.13
3-0682	241-T-106	299-W10-196	46.1	51	0.224	0	0.0166	1.6577	2.37E-04	2.14
3-0688	241-T-106	299-W10-196	48.5	49	0.199	0	0.0043	1.5321	2.60E-05	2.17
3-0689	241-T-106	299-W10-196	52.2	28	0.236	0	0.0025	1.4747	4.58E-05	1.93
3-0690	241-T-106	299-W10-196	53.7	53	0.1819	0.0177	0.0046	1.541	4.19E-05	2.19
5-0152	218-E-12B	299-E34-1	65.5	26	0.280	0.0252	0.0438	1.3253	2.43E-03	1.85
5-0153	218-E-10	299-E32-4	10.7	47	0.214	0.0092	0.0099	1.3829	1.41E-04	2.08
5-0158	218-E-10	299-E32-4	71.6	44	0.217	0	0.0104	1.3369	4.47E-04	2.15

Table D–5. Van Genuchten Parameters, Fitted Saturated Hydraulic Conductivity, and Measured Bulk Density Data for the Gravelly Sand H1 (4) Sediments (Khaleel Et Al 2002).

Sample	Site/ Operable Unit	Borehole Number	Depth (m)	Percent Gravel	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm^3)
3-0572-2	100-FR-3	199-F5-48	8.1	27	0.179	0	0.0031	1.4306	2.38E-05	2.03
3-0576	100-FR-3	199-F5-43B	5.4	20	0.244	0.0166	0.0167	1.5428	3.96E-04	1.95
3-1707	200-UP-2	299-W19-95	9.5	15	0.364	0.0742	0.0082	2.0349	1.55E-05	1.86
5-0149	218-E-12B	299-E34-1	24.4	16	0.260	0	0.0082	1.4422	1.80E-04	2.07
5-0150	218-E-12B	299-E34-1	24.84	17	0.240	0.0227	0.0295	1.7077	1.47E-03	1.95
5-0151	218-E-12B	299-E34-1	21.49	17	0.275	0	0.0049	1.4621	6.85E-05	1.95
5-0152	218-E-12B	299-E34-1	65.5	26	0.280	0.0252	0.0438	1.3253	2.43E-03	1.85
5-0157	218-E-10	299-E32-4	3.50	13	0.293	0.033	0.0273	2.1675	7.77E-03	1.88

Table D–6. Composite van Genuchten-Mualem parameters for vadose zone strata (Khaleel et al 2002).

Strata	Number of samples	0s	0r	α (1/cm)	n	ℓ	Fitted K_s (cm/s)
Backfill (1)	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04
Sand H2 (2)	12	0.3819	0.0443	0.0117	1.6162	0.5	9.88E-05
Gravelly Sand H3 (3)	11	0.2126	0.0032	0.0141	1.3730	0.5	2.62E-04
Gravelly Sand H1 (4)	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04
Plio-Pleistocene/ Ringold Sandy Gravel (5)	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04

Table D–7. Macroscopic Anisotropy Parameters, Based on Polmann (1990) Equations for Various Strata (Khaleel Et Al 2002).

Strata	Number of samples	$\langle LnK_s \rangle$	$\sigma^2_{LnK_s}$	p	ζ	λ (cm)	A
Backfill (1)	10	-15.76	3.56	-1.1E-4	1.84E-4	30	0.00371
Sandy H2 (2)	12	-14.59	1.50	-7.2E-4	6.55E-4	50	0.00620
Gravelly Sand H3 (3)	11	-14.85	1.94	-2.6E-4	2.50E-4	30	0.00368
Gravelly Sand H1 (4)	8	-15.3	1.83	-5.6E-4	5.16E-4	50	0.00415
Plio-Pleistocene/ Ringold Sandy Gravel (5)	10	-15.76	3.56	-1.1E-4	1.84E-4	30	0.00371

Table D–8. Non-reactive macrodispersivity estimates for non reactive species in vadose zone strata (Khaleel et al 2002).

Strata	σ^2_{LnK}	Correlation length, λ (cm)	A_L (cm)	A_T (cm)
Backfill (1) and Plio-Pleistocene/ Ringold Sandy Gravel (5)	4.54	30	~150	15
Sandy H2 (2)	4.60	30	~150	15
Gravelly sand H3 (3)	3.19	30	~100	10
Gravelly sand H1 (4)	4.95	30	~100	10

D.2.0 REFERENCE

Hartman, M.J., L.F. Morasch, and W.D. Webber, eds., 2000, *Hanford Site Groundwater Monitoring for Fiscal Year 1999*, PNNL-13116, Pacific Northwest National Laboratory, Richland, Washington.

R. Khaleel, M. P. Connelly, D. Crumpler, T. E. Jones, A.J. Knepp, F. M. Mann, W.J. McMahon,A.W. Miller and M. I. Wood, 2002, *Modeling Data Package For An Initial Assessment Of Closure For C Tank Farm,* RPP-13310, CH2M Hill Hanford Group, Inc., Richland, Washington.

Khaleel, R. and E. J. Freeman, 1995, *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site,* WHC-EP-0883, Westinghouse Hanford Company, Richland, Washington

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APPENDIX E

SUPPORTING GAMMA LOGGING DATA

CONTENTS

E.1.0 INTRODUCTION 1

E.2.0 REFERENCES 73

FIGURES

Figure E-1. Plan View of the C Tank Farm Showing Borehole Locations from DOE-GJO 1998a. 3

Figure E-2. 30-01-06 Man-Made Radionuclide Concentrations from DOE-GJO 1997h..... 4

Figure E-3. 30-01-09 Man-Made Radionuclide Concentrations from DOE-GJO 1997h..... 5

Figure E-4. 30-03-01 Man-Made Radionuclide Concentrations from DOE-GJO 1997e..... 6

Figure E-5. 30-03-01 Man-Made Radionuclide Concentrations from DOE-GJO 1997e..... 7

Figure E-6. 30-03-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997e..... 8

Figure E-7. 30-03-09 Man-Made Radionuclide Concentrations from DOE-GJO 1997e..... 9

Figure E-8. 30-04-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997j..... 10

Figure E-9. 30-04-03 Man-Made Radionuclide Concentrations from DOE-GJO 1997j..... 11

Figure E-10. 30-05-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 12

Figure E-11. 30-05-03 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 13

Figure E-12. 30-05-04 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 14

Figure E-13. 30-05-05 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 15

Figure E-14. 30-05-07 Summary of High Rate Logging Results for the C Tank Farm from DOE GJO 2000b. 16

Figure E-15. 30-05-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 17

Figure E-16. 30-05-08 Man-Made Radionuclide Concentrations from DOE-GJO 1997f. 18

Figure E-17. 30-06-04 Man-Made Radionuclide Concentrations from DOE-GJO 1997g..... 19

Figure E-18. 30-06-10 Summary of Repeat Logging Results for the C Tank Farm from DOE-GJO 2000b..... 20

Figure E-19. 30-06-12 Man-Made Radionuclide Concentrations from DOE-GJO 1997g..... 21

Figure E-20. 30-07-11 Summary of High Rate Logging Results for the C Tank Farm from DOE-GJO 2000b..... 22

Figure E-21. 30-08-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997l..... 23

Figure E-22. 30-09-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997m..... 24

Figure E-23. 30-09-06 Man-Made Radionuclide Concentrations from DOE-GJO 1997m..... 25

Figure E-24. 30-09-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997m..... 26

Figure E-25. 30-09-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997m..... 27

Figure E-26. 30-10-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997n..... 28

Figure E-27. 30-12-13 Man-Made Radionuclide Concentrations from DOE-GJO 1998b..... 29

Figure E-28. 30-12-13 Summary of High Rate Logging Results for the C Tank Farm from DOE-GJO 2000b..... 30

Figure E-29. Plan Map of the A Tank Farm Showing the Location of the Tank Monitoring Boreholes and Leak Detection Laterals from DOE-GJO 1999. 32

Figure E-30. 10-01-03 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 33

Figure E-31. 10-01-03 Summary of High Rate Logging Results for the A Tank Farm from DOE-GJO 2000c..... 34

Figure E-32. 10-01-28 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 35

Figure E-33. 10-01-39 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 36

Figure E-34. 10-01-16 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 37

Figure E-35. 10-01-04 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 38

Figure E-36. 10-01-04 Man-Made Radionuclide Concentrations from DOE-GJO 1998c..... 39

Figure E-37. 10-02-08 Man-Made Radionuclide Concentrations from DOE-GJO 1998d..... 40

Figure E-38. Plan view of Tanks and Boreholes in the A Tank Farm from DOE-GJO 1998e.. 41

Figure E-39. A-104 Laterals – Historical Gamma-Ray Correlations from DOE-GJO 1998e..... 42

Figure E-40. 14-04-02 Lateral – Historical Gamma-Ray Correlations from DOE-GJO 1998e..... 43

Figure E-41. Plan View of Tanks and Boreholes in the A Tank Farm from DOE-GJO 1998f. 44

Figure E-42. Lateral 14-05-01 Selected Historical Gamma-Ray Plots – Horizontal Segments from DOE-GJO 1998f..... 45

Figure E-43. Lateral 14-05-02 Selected Historical Gamma-Ray Log – Historical Segments from DOE-GJO 1998f. 46

Figure E-44. Lateral 14-05-03 Selected Historical Gamma-Ray Log - Horizontal Segment from DOE-GJO 1998f. 47

Figure E-45. Plan Map of the Hanford Site AX Tank Farm Showing the Tank Monitoring Boreholes from DOE-GJO 2000a. 49

Figure E-46. 11-01-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997a. 50

Figure E-47. 11-01-10 Summary of High Rate Logging Results for the AX Tank Farm from DOE-GJO 2000a. 51

Figure E-48. 11-02-12 Man-Made Radionuclide Concentrations from DOE-GJO 1997b..... 52

Figure E-49. 11-02-12 Summary of High Rate Logging Results for the AX Tank Farm from DOE-GJO 2000a. 53

Figure E-50. 11-03-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997c. 54

Figure E-51. 11-04-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997d..... 55

E.1.0 INTRODUCTION

Appendix E contains the drywell spectral gamma logging profiles generated in the 1990s for the C, A and AX tank farms. These profiles are a subset of a comprehensive database generated to measure vadose zone contamination in the single shell tank farms. Spectral gamma data are provided only from those drywells that plausibly indicate the presence of tank waste in the vadose zone. Almost all drywells show surface contamination linked with tank farm operations, but individual drywells are not shown if minimal surface contamination is the only gamma data measured. This appendix also includes summaries of historical gamma logging that was collected between 1974 and 1995 for the drywells in each of the tank farms. These data provide some indication of gamma-emitting radionuclide migration during the data collection time frame.

C TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-1. Plan View of the C Tank Farm Showing Borehole Locations from DOE-GJO 1998a.

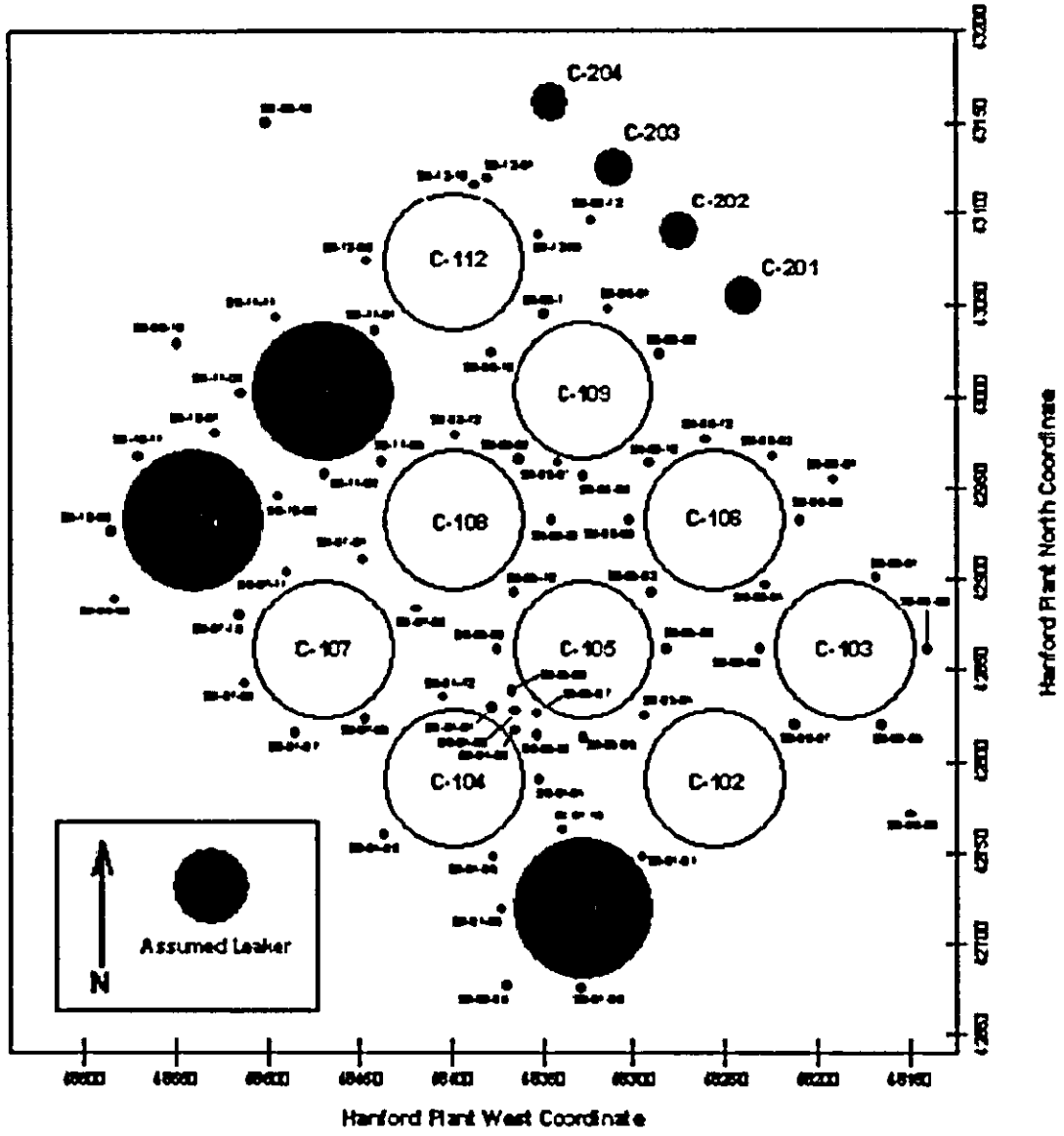


Figure 14-11. Plan View of the C Tank Farm Showing Borehole Locations

Figure E-2. 30-01-06 Man-Made Radionuclide Concentrations from DOE-GJO 1997h.

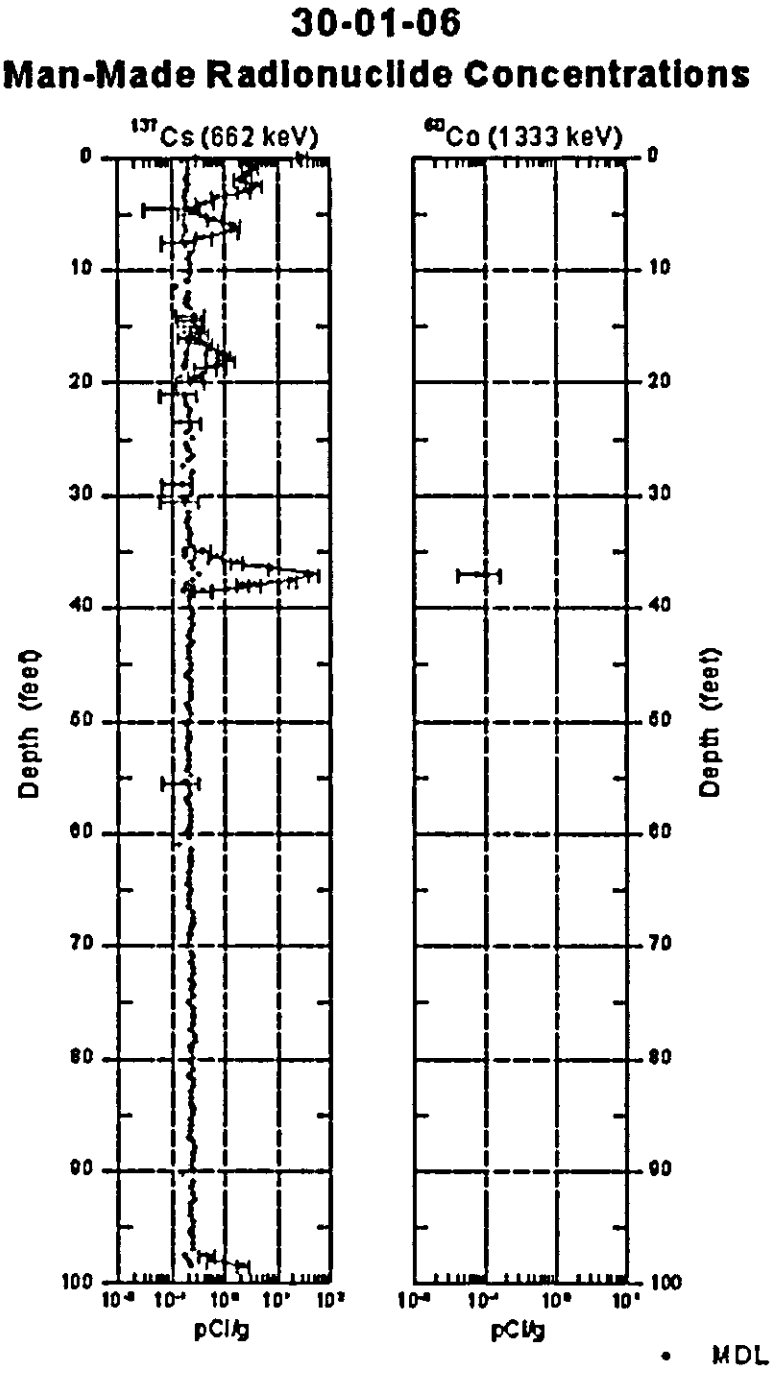


Figure E-3. 30-01-09 Man-Made Radionuclide Concentrations from DOE-GJO 1997h.

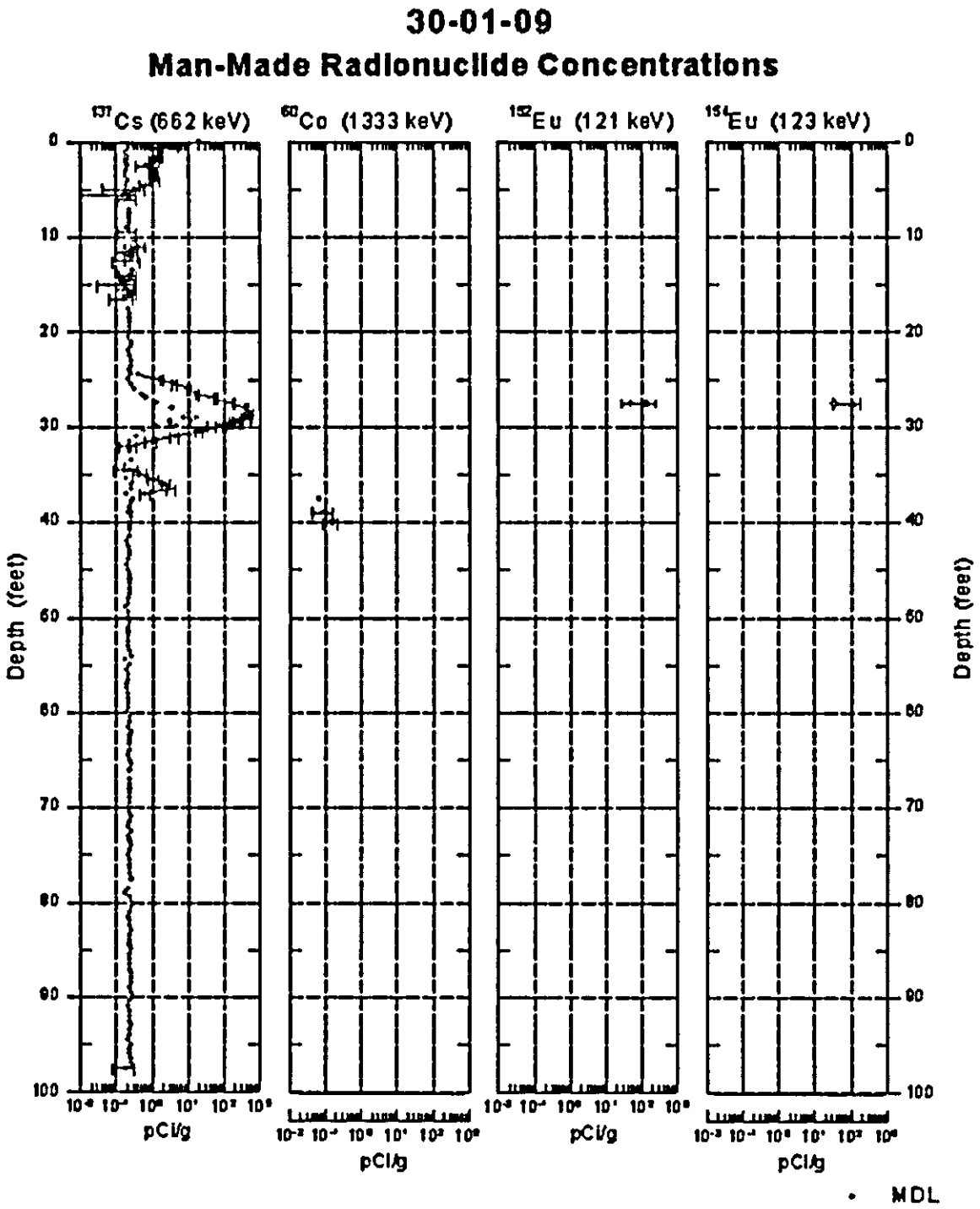
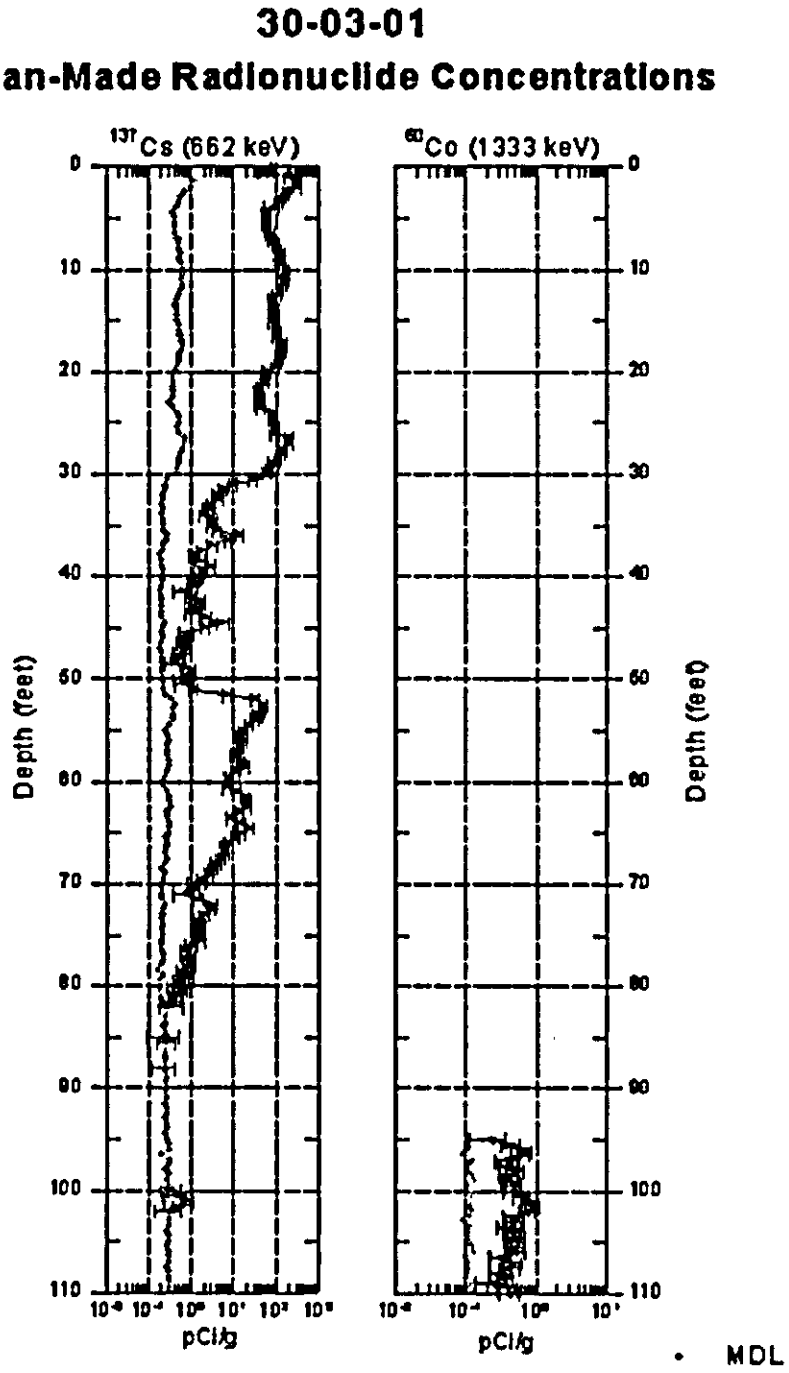


Figure E-4. 30-03-01 Man-Made Radionuclide Concentrations from DOE-GJO 1997e.



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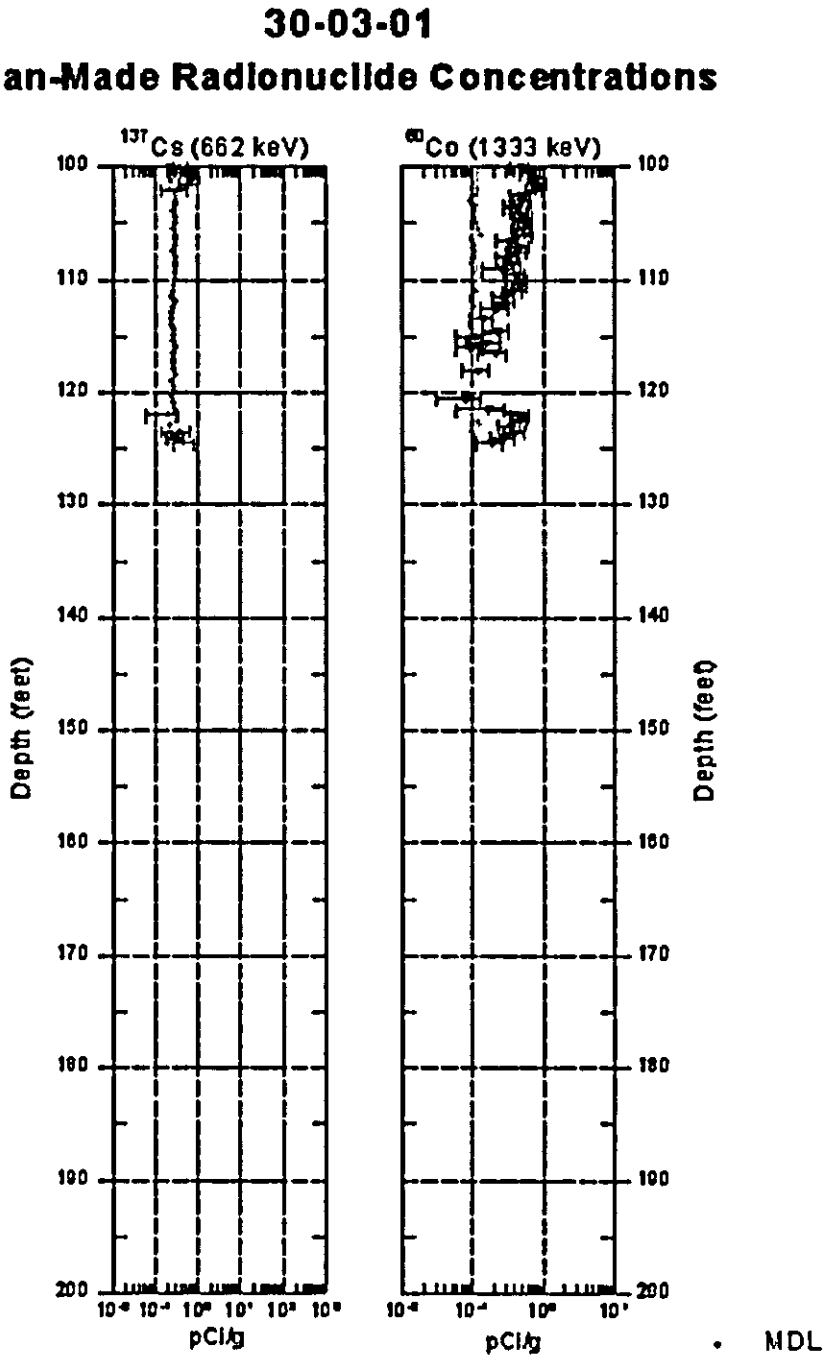


Figure E-6. 30-03-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997e.

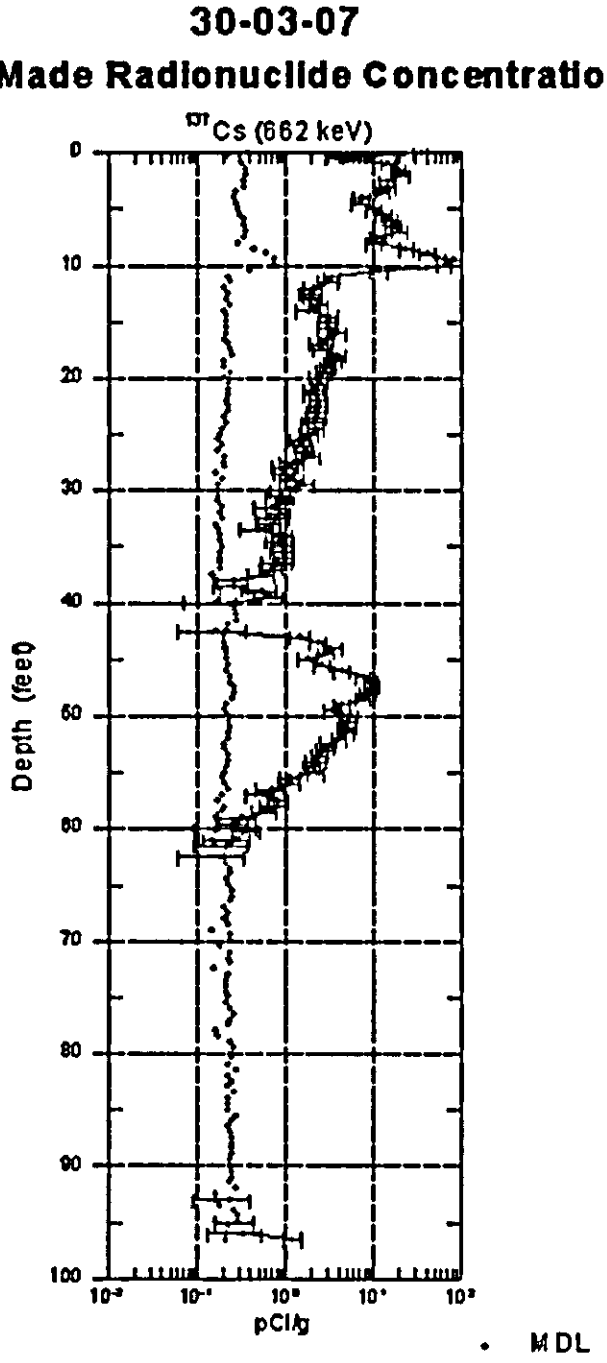


Figure E-7. 30-03-09 Man-Made Radionuclide Concentrations from DOE-GJO 1997e.

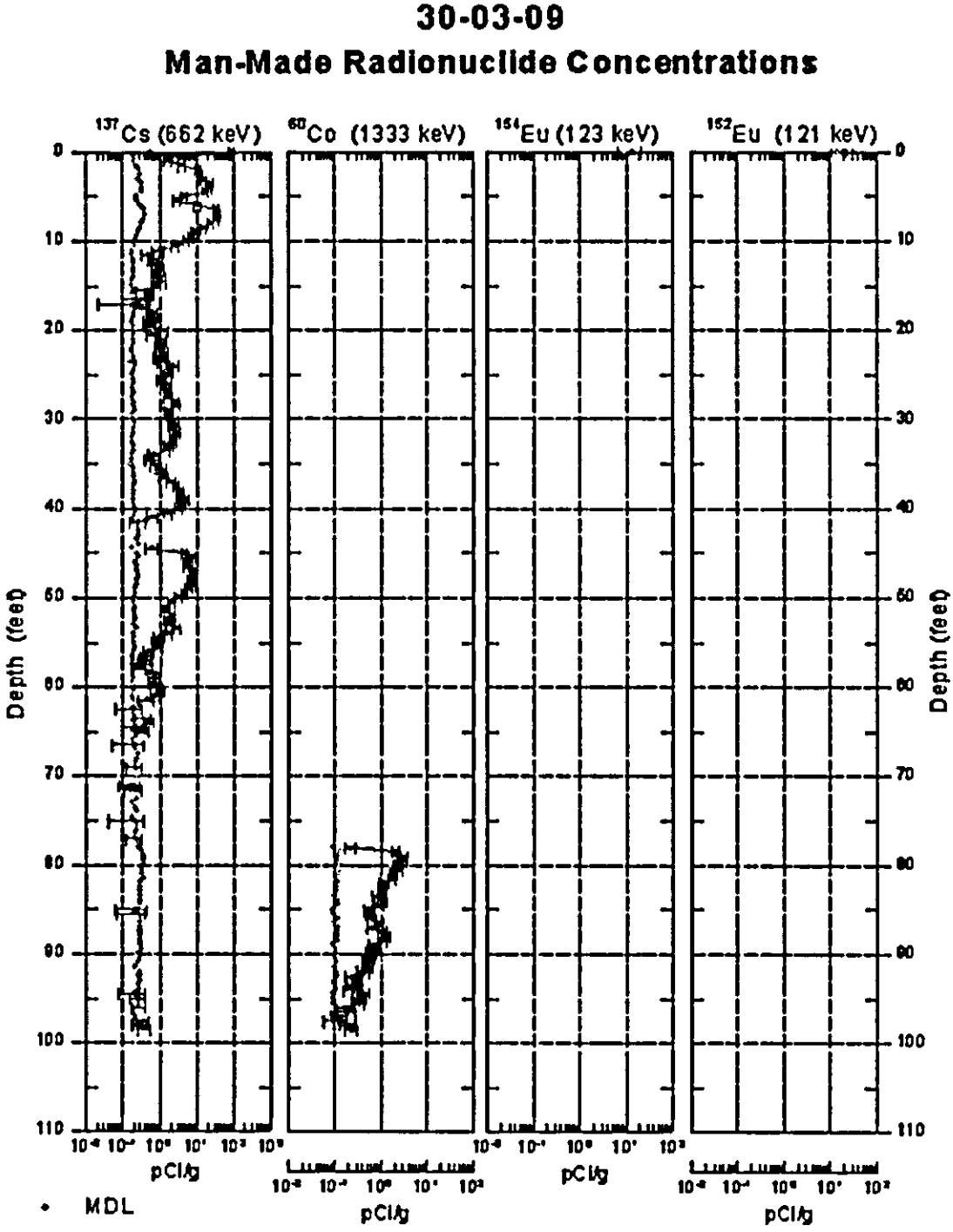


Figure E-8. 30-04-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997j.

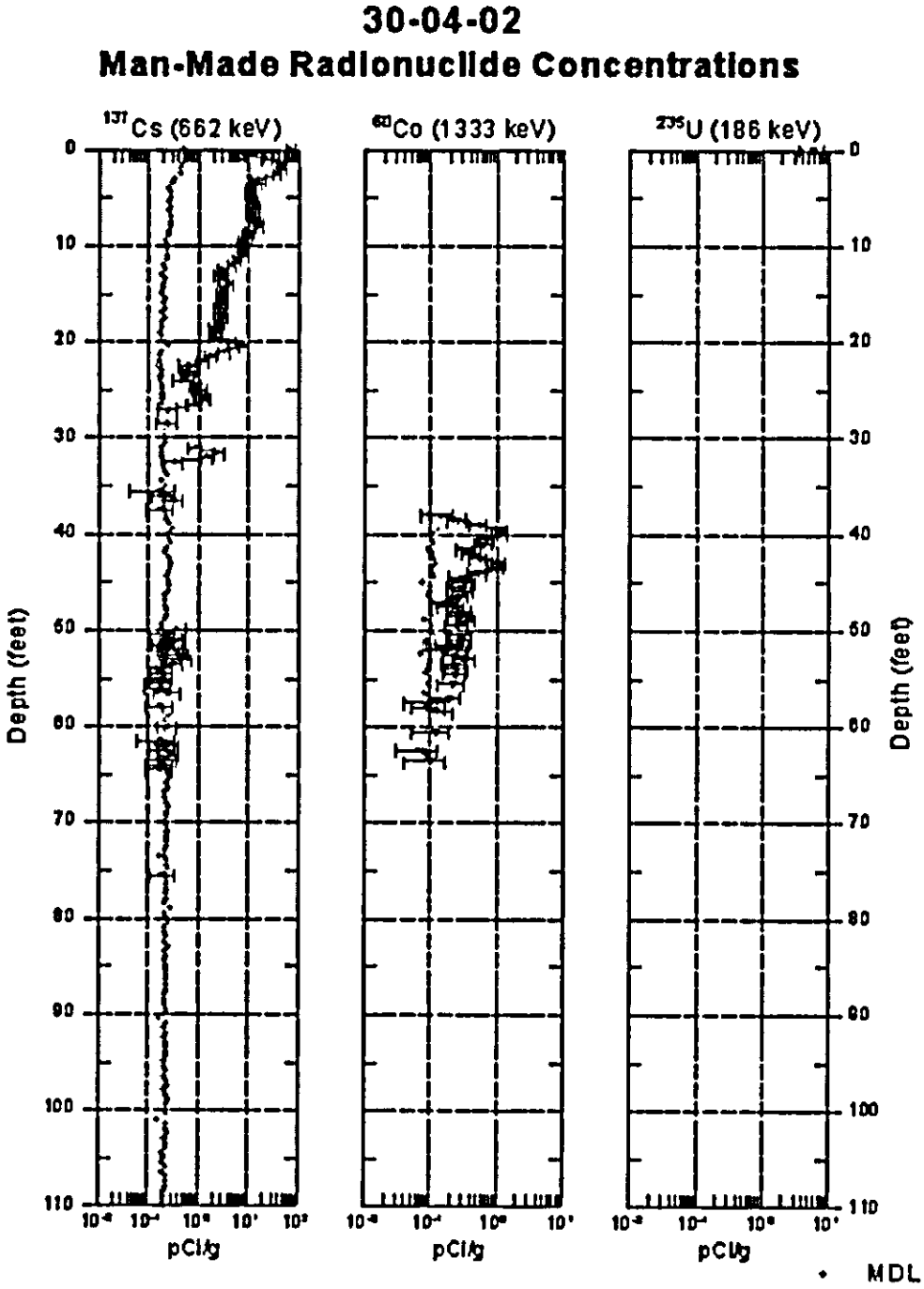


Figure E-9. 30-04-03 Man-Made Radionuclide Concentrations from DOE-GJO 1997j.

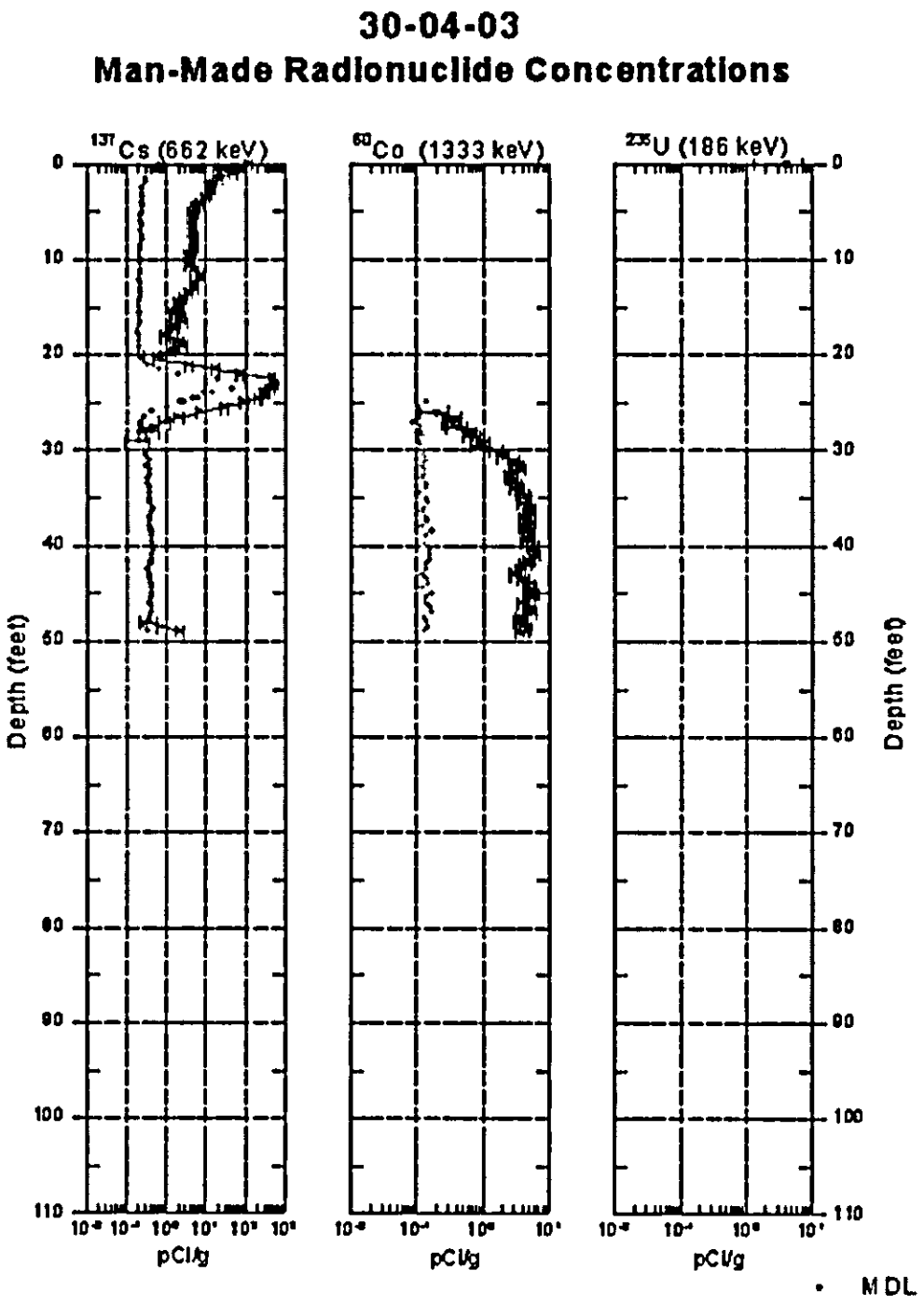
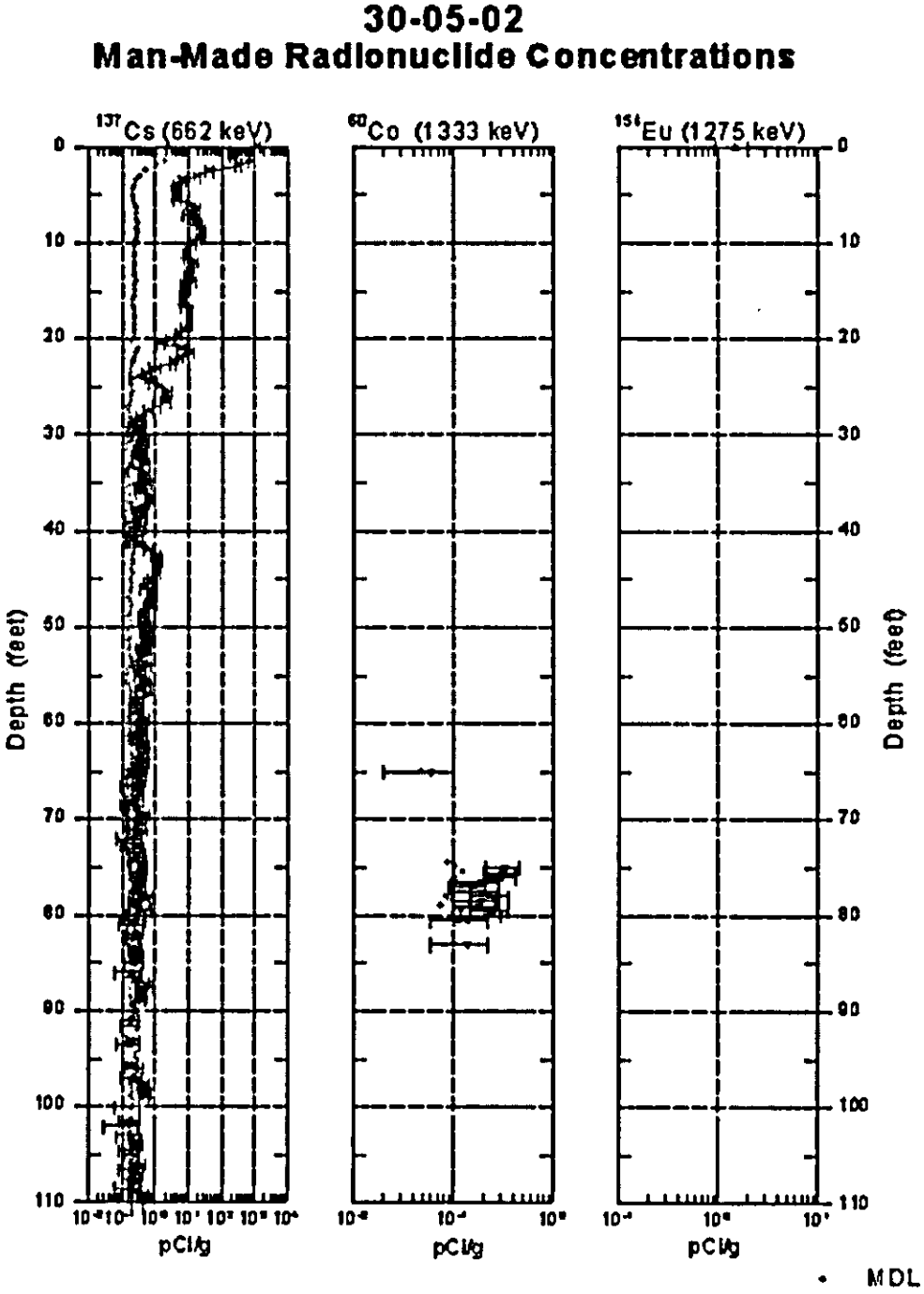


Figure E-10. 30-05-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997f.



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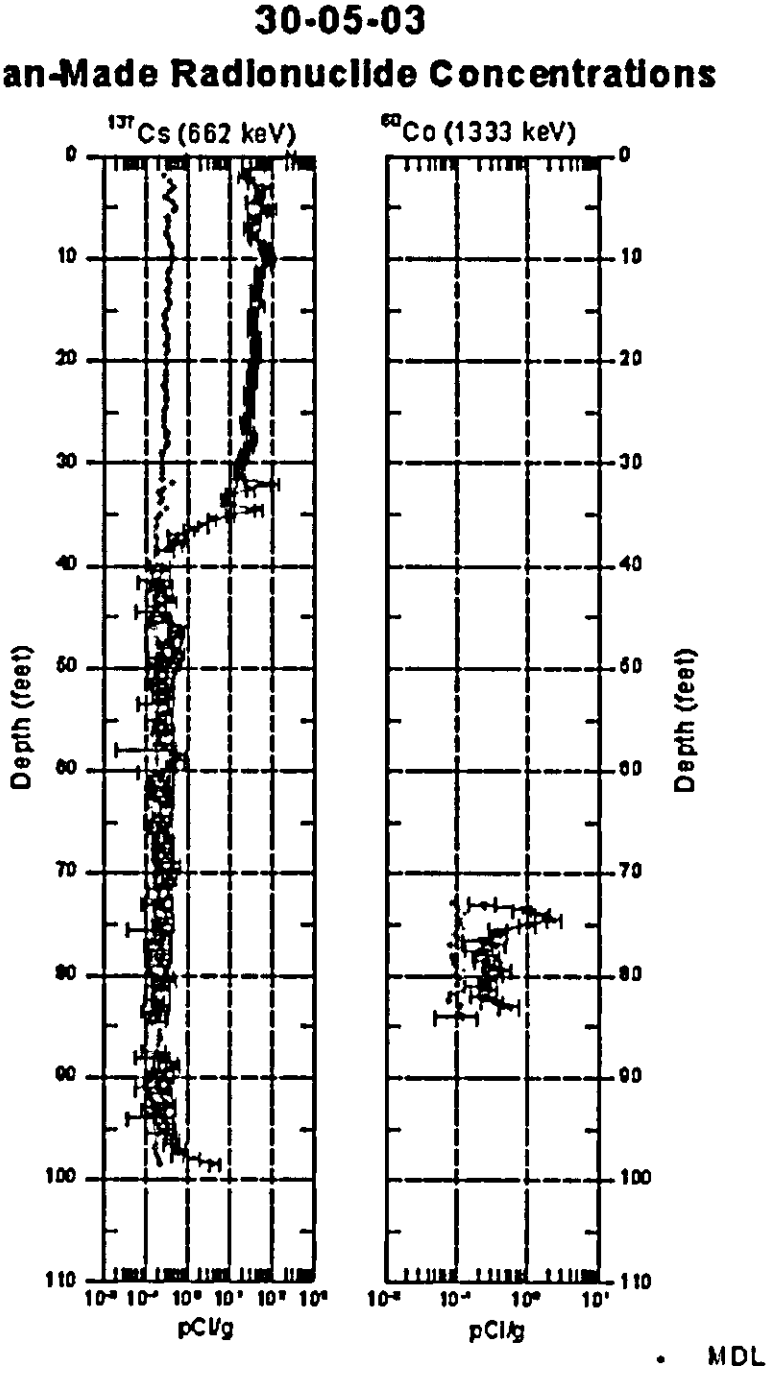


Figure E-12. 30-05-04 Man-Made Radionuclide Concentrations from DOE-GJO 1997f.

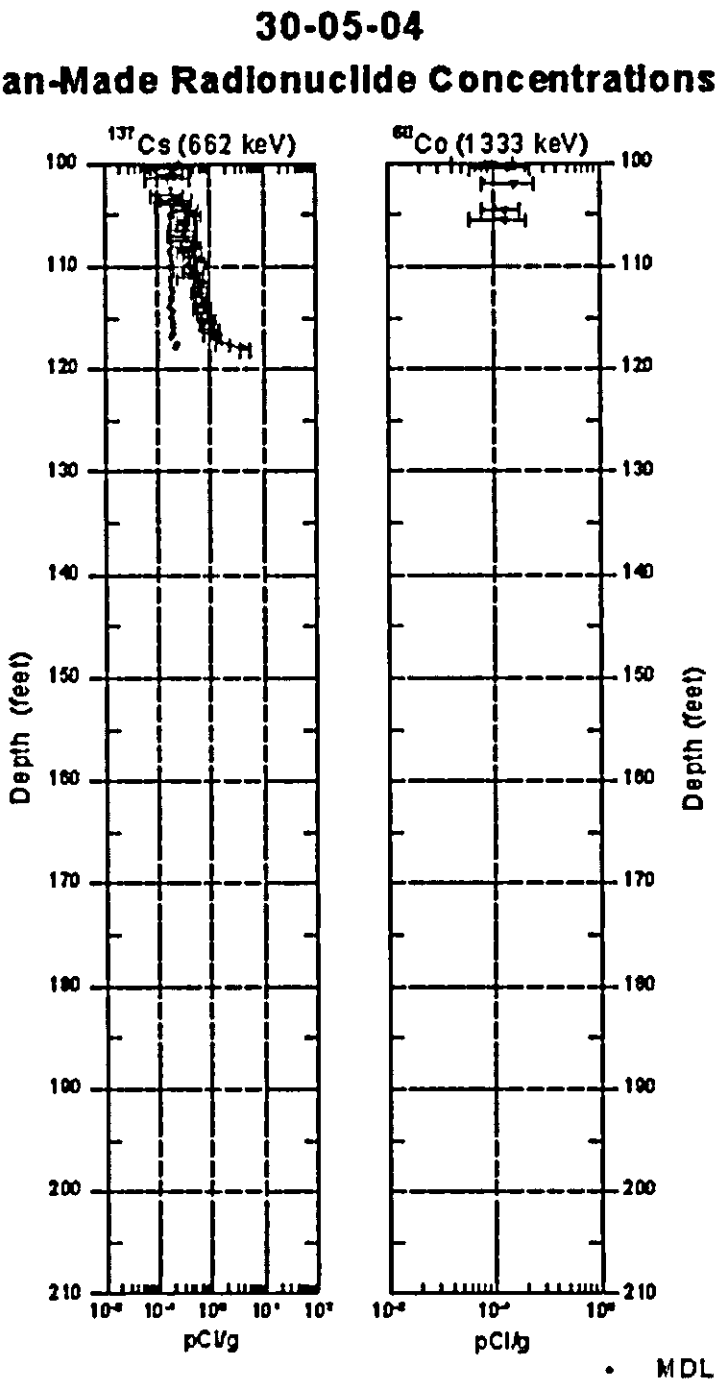


Figure E-13. 30-05-05 Man-Made Radionuclide Concentrations from DOE-GJO 1997f.

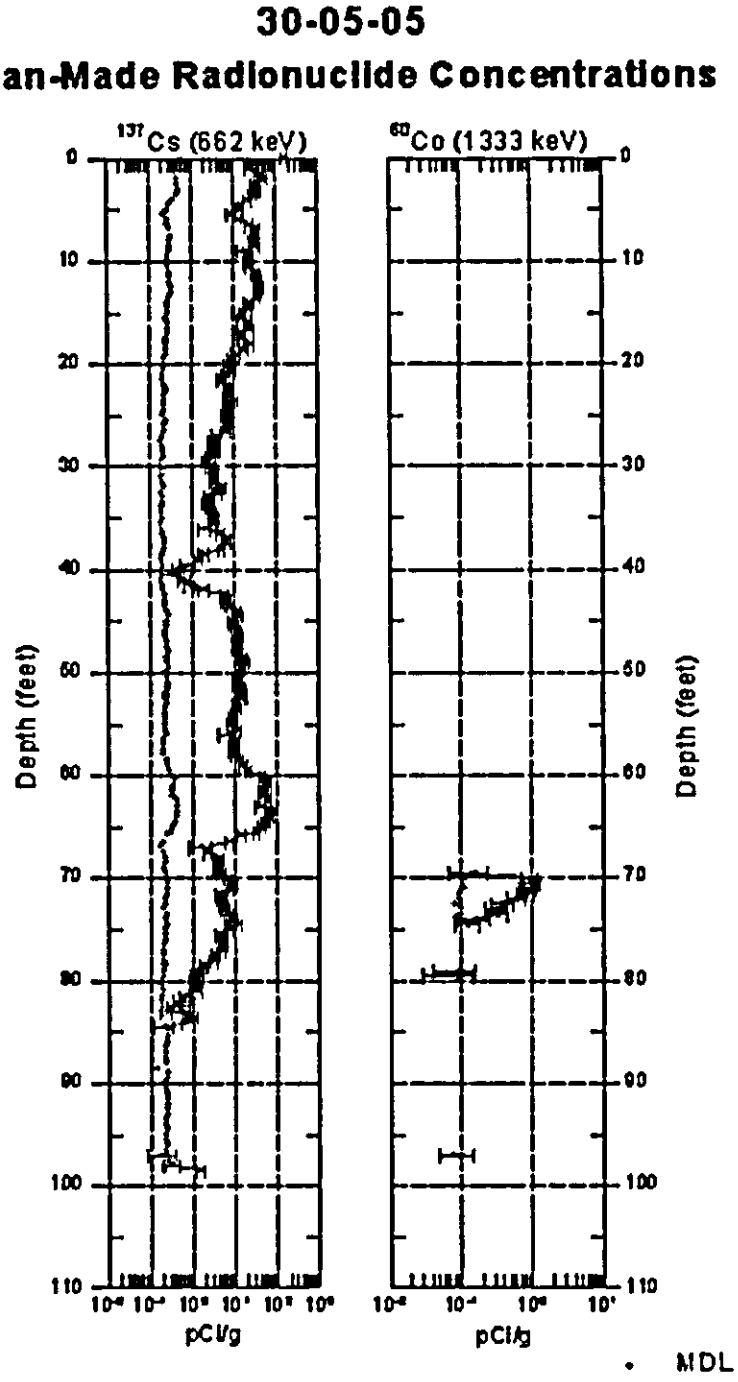


Figure E-14. 30-05-07 Summary of High Rate Logging Results for the C Tank Farm from DOE GJO 2000b.

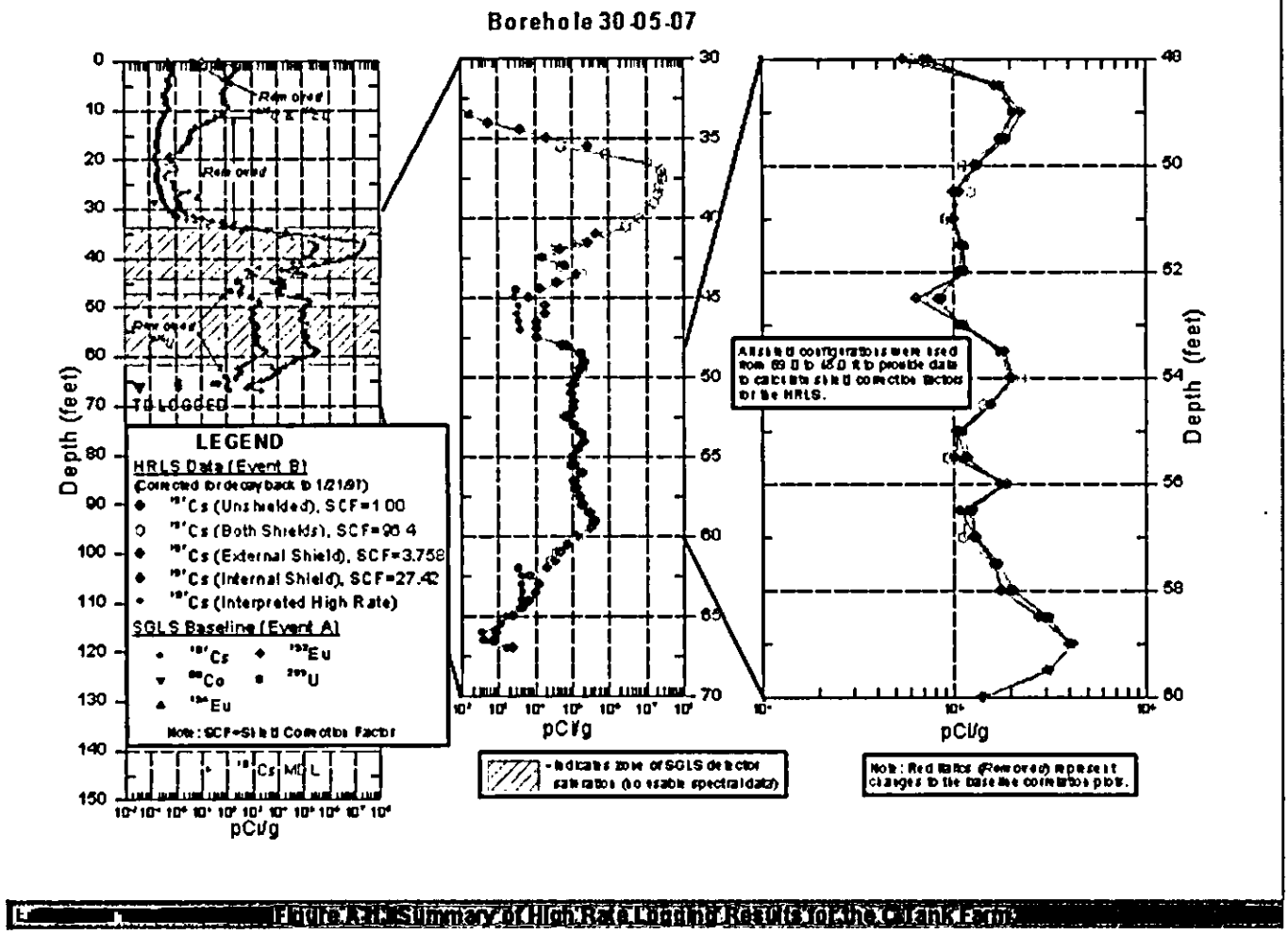


Figure E-15. 30-05-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997f.

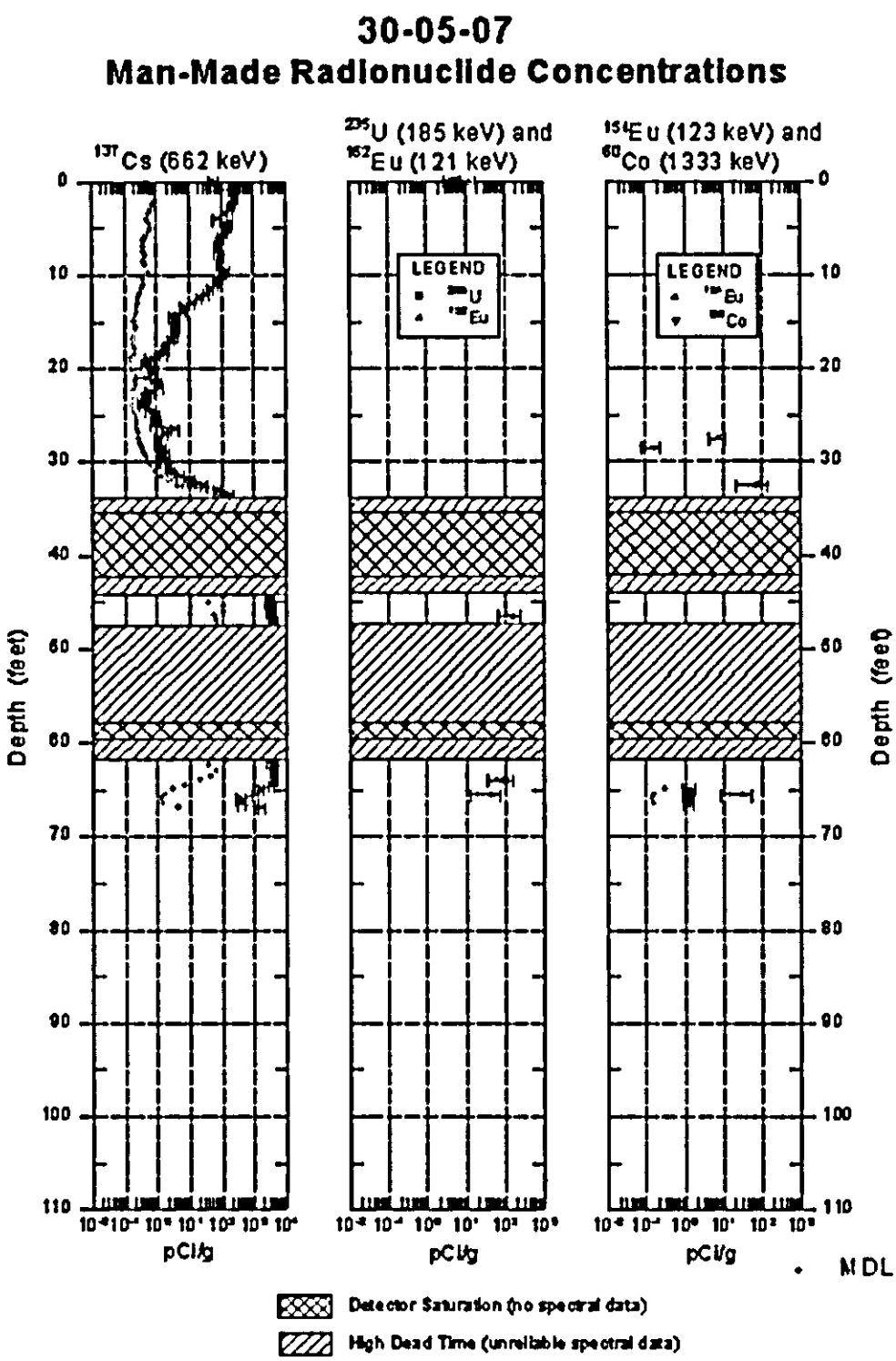


Figure E-16. 30-05-08 Man-Made Radionuclide Concentrations from DOE-GJO 1997f.

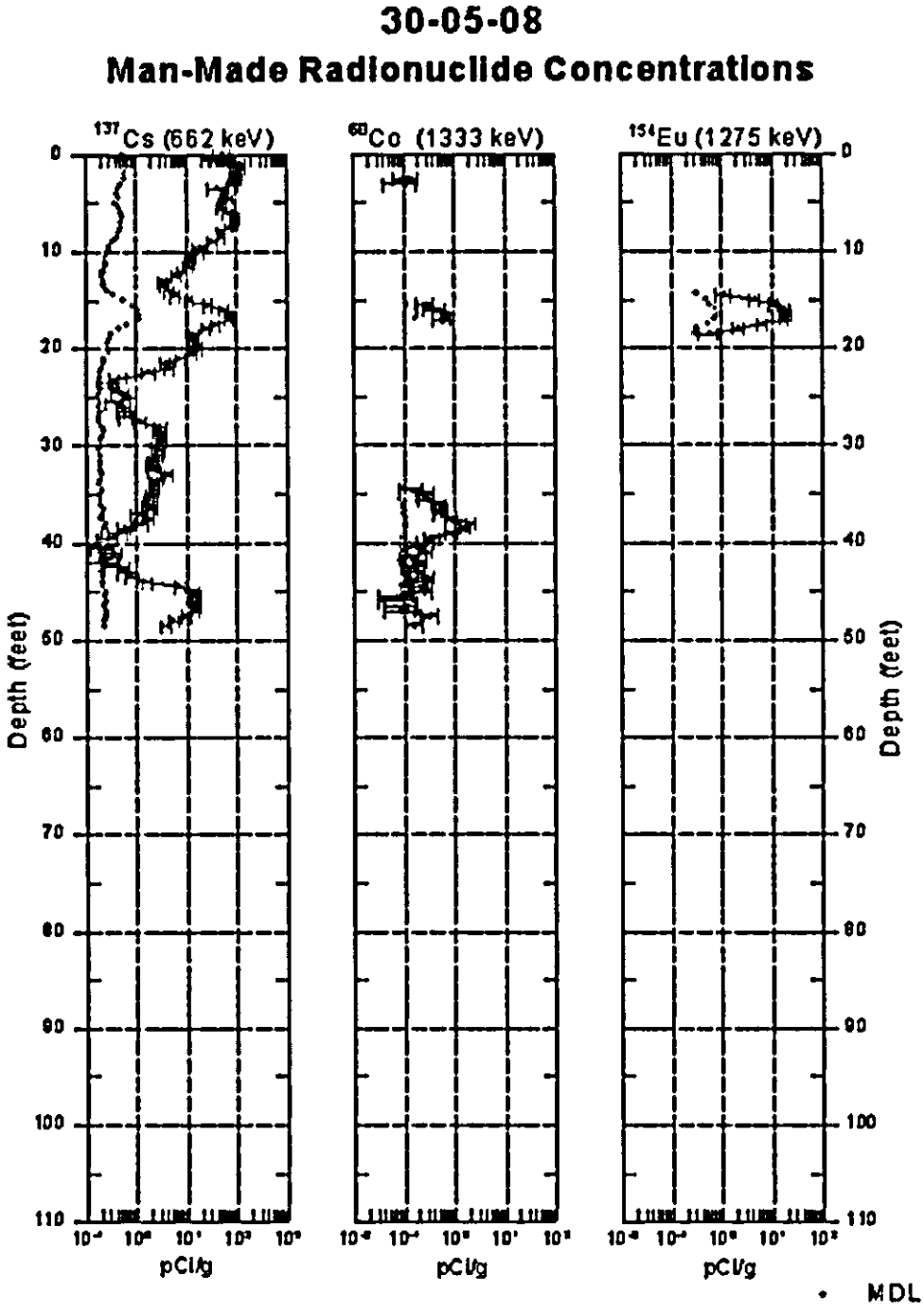


Figure E-17. 30-06-04 Man-Made Radionuclide Concentrations from DOE-GJO 1997g.

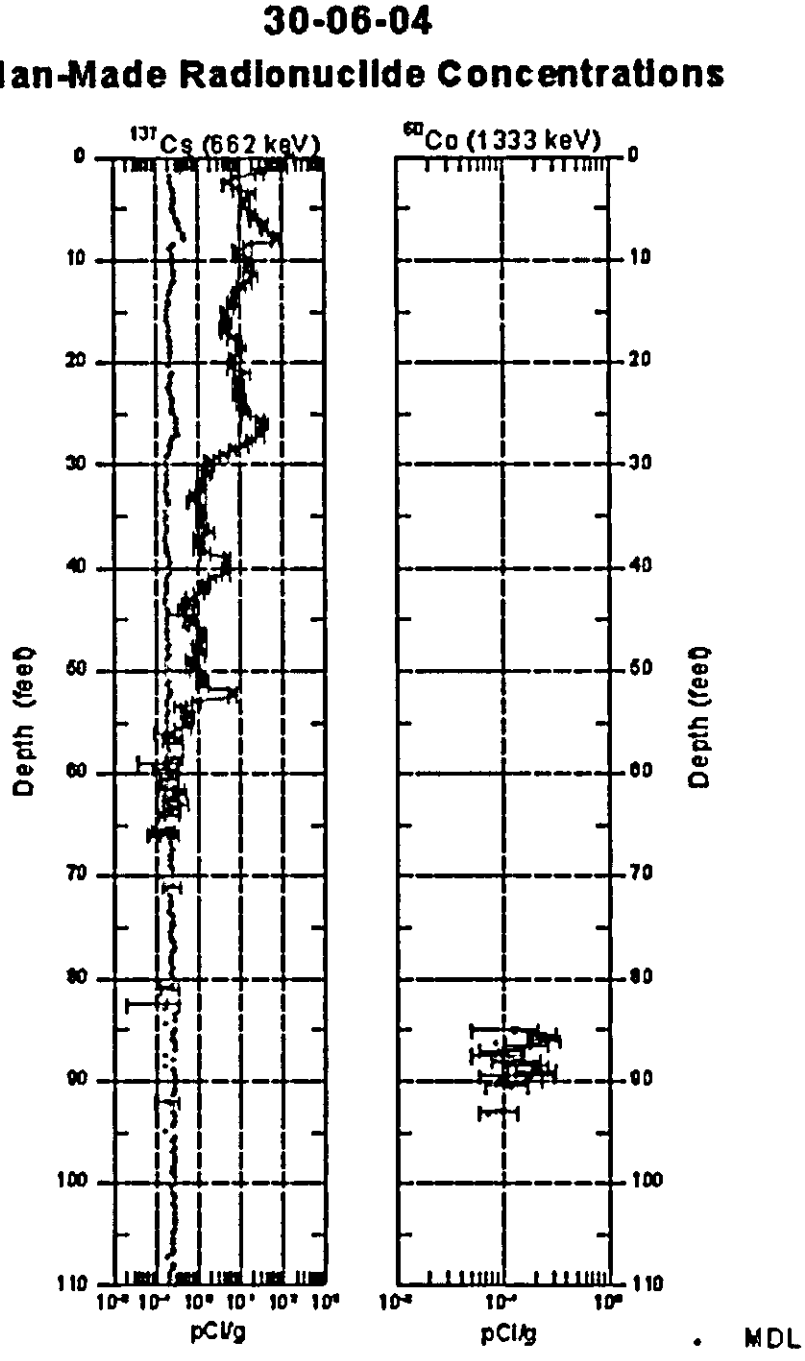


Figure E-18. 30-06-10 Summary of Repeat Logging Results for the C Tank Farm from DOE-GJO 2000b.

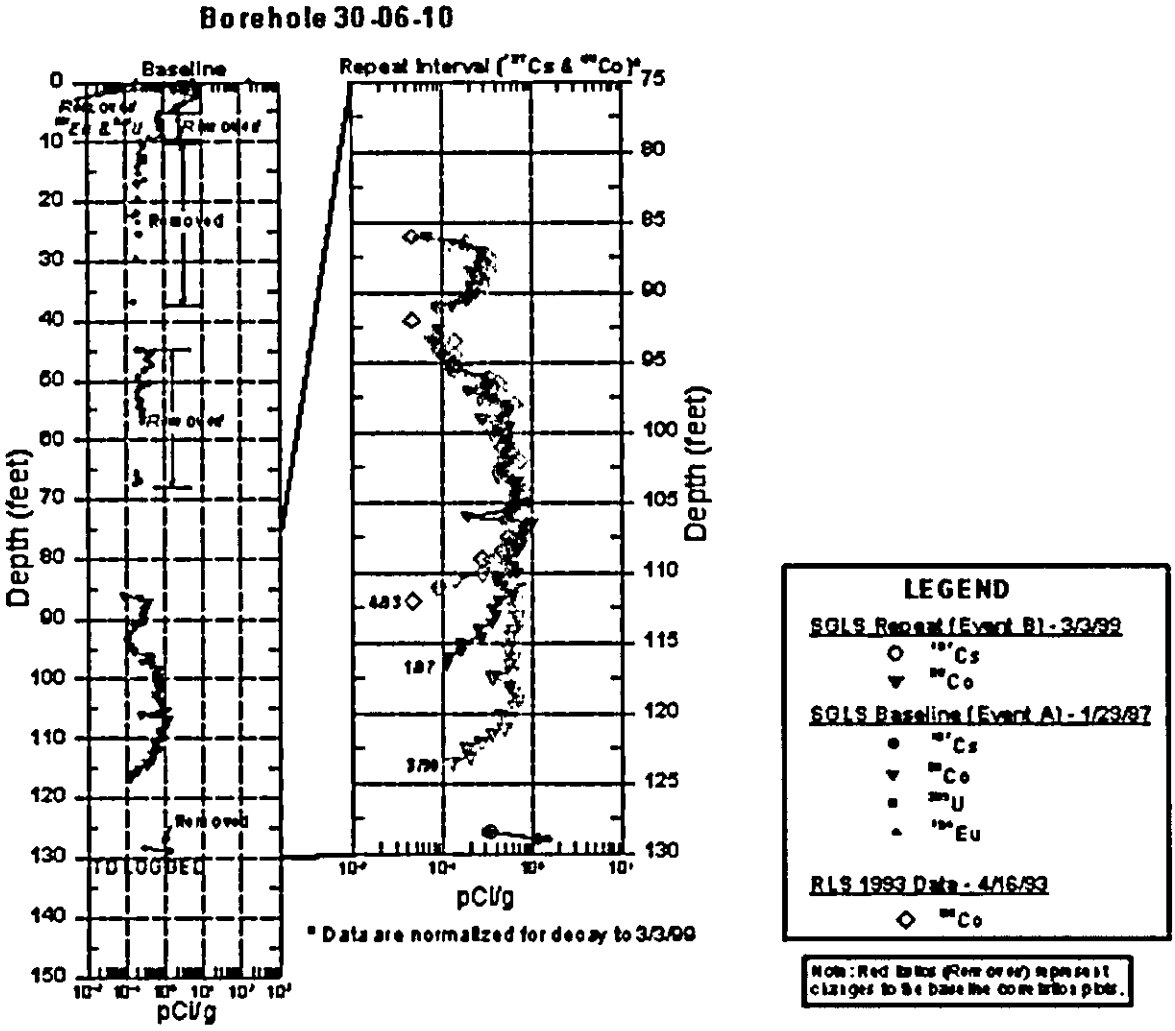


Figure B-2. Summary of Repeat Logging Results for the C Tank Farm

Figure E-19. 30-06-12 Man-Made Radionuclide Concentrations from DOE-GJO 1997g.

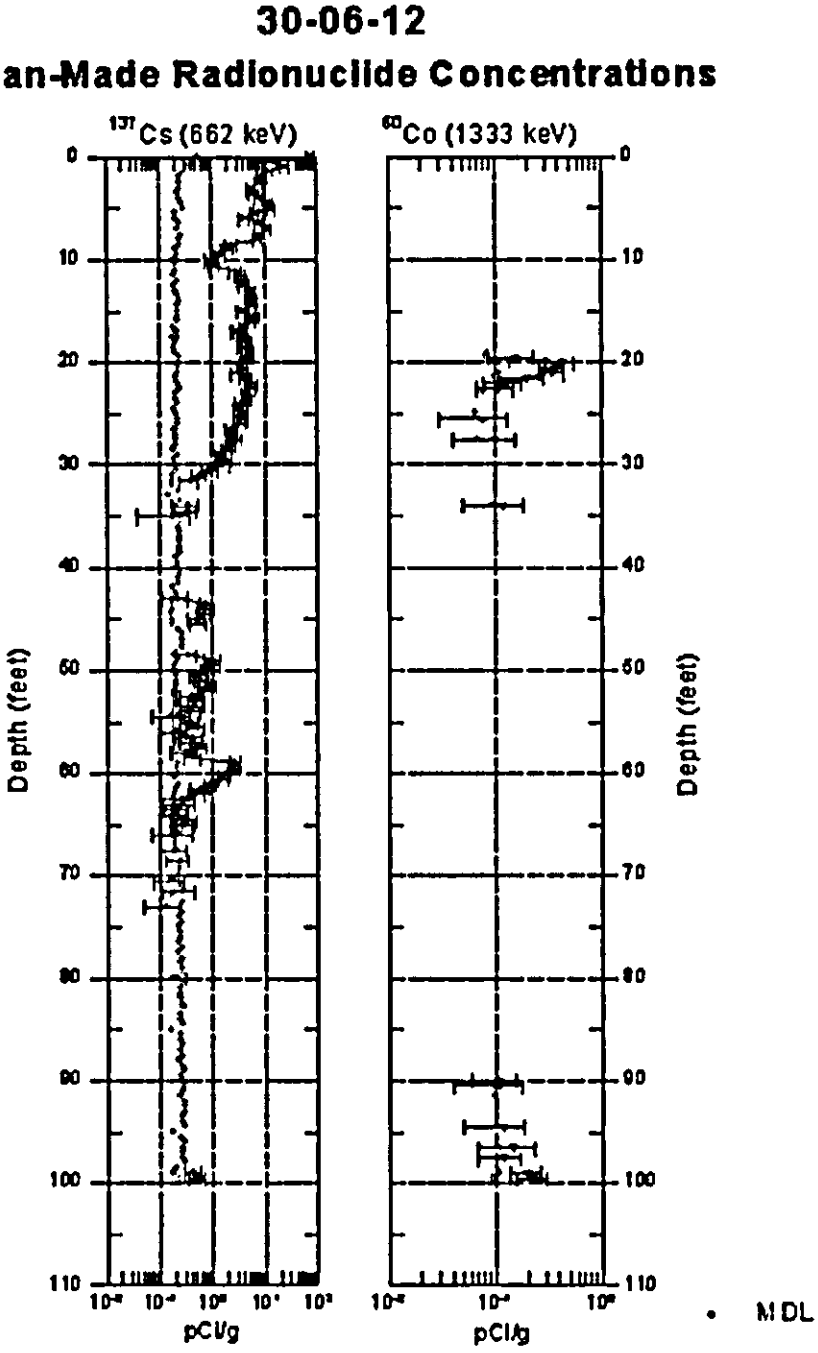


Figure E-20. 30-07-11 Summary of High Rate Logging Results for the C Tank Farm from DOE-GJO 2000b.

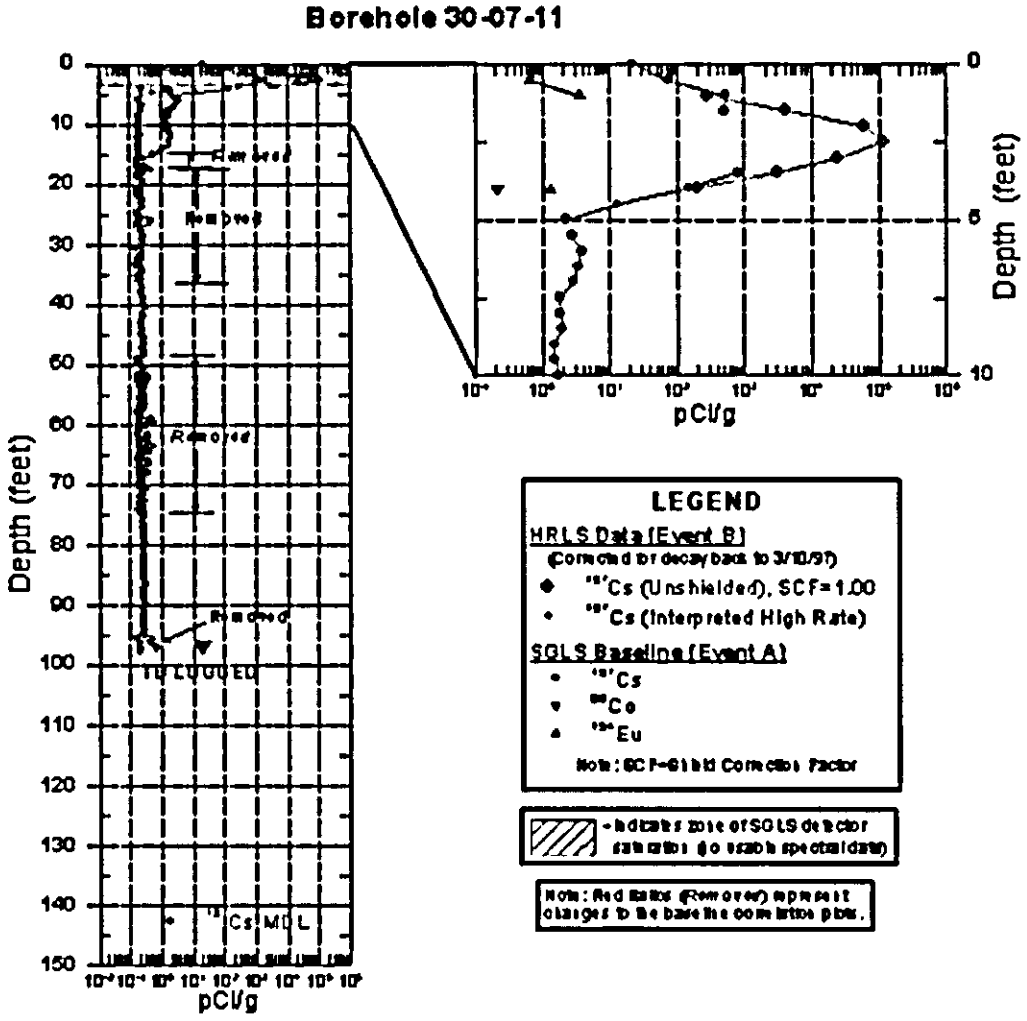


Figure A-2. Summary of High Rate Logging Results for the C Tank Farm

Figure E-21. 30-08-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997l.

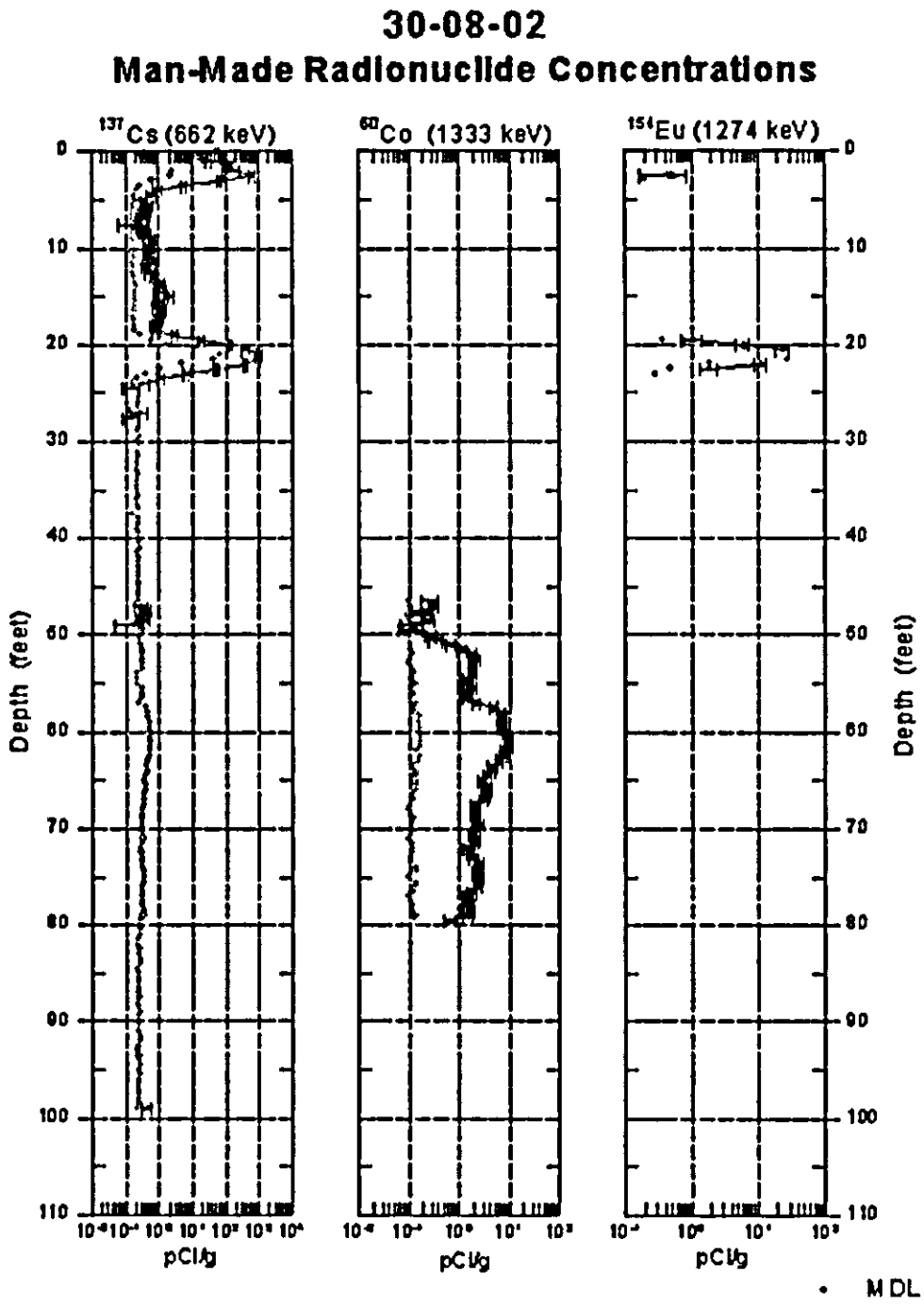


Figure E-22. 30-09-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997m.

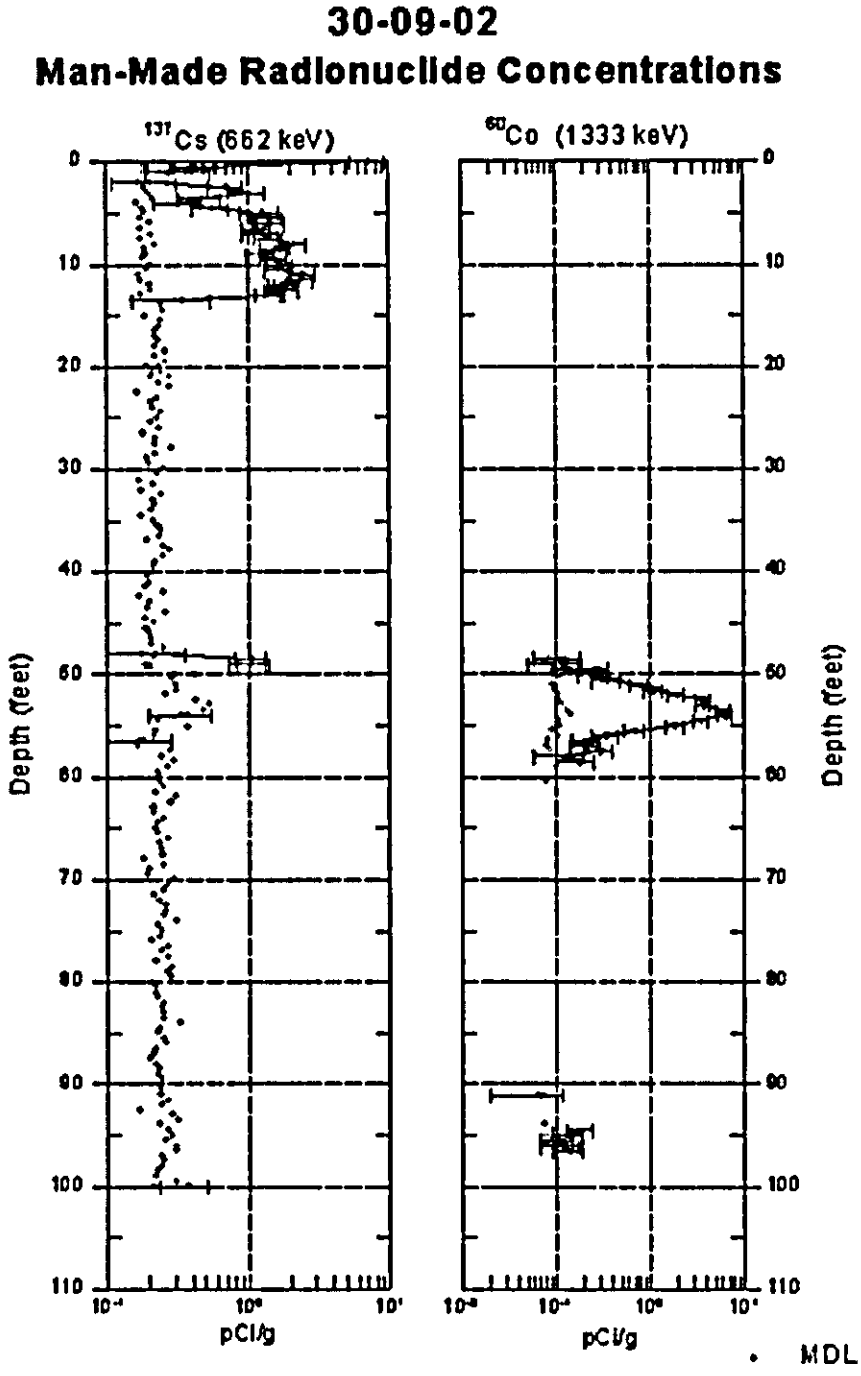


Figure E-23. 30-09-06 Man-Made Radionuclide Concentrations from DOE-GJO 1997m.

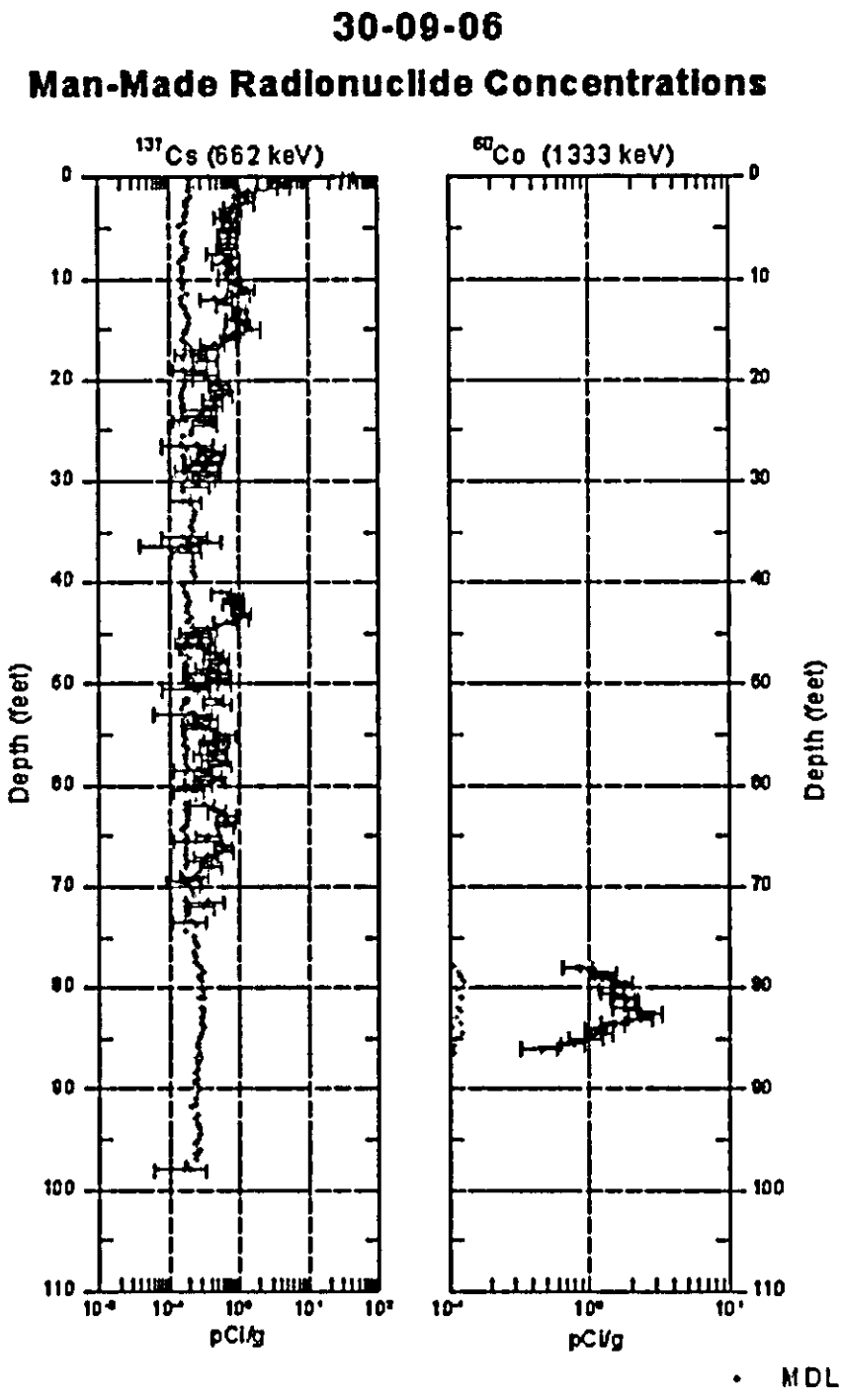


Figure E-24. 30-09-07 Man-Made Radionuclide Concentrations from DOE-GJO 1997m.

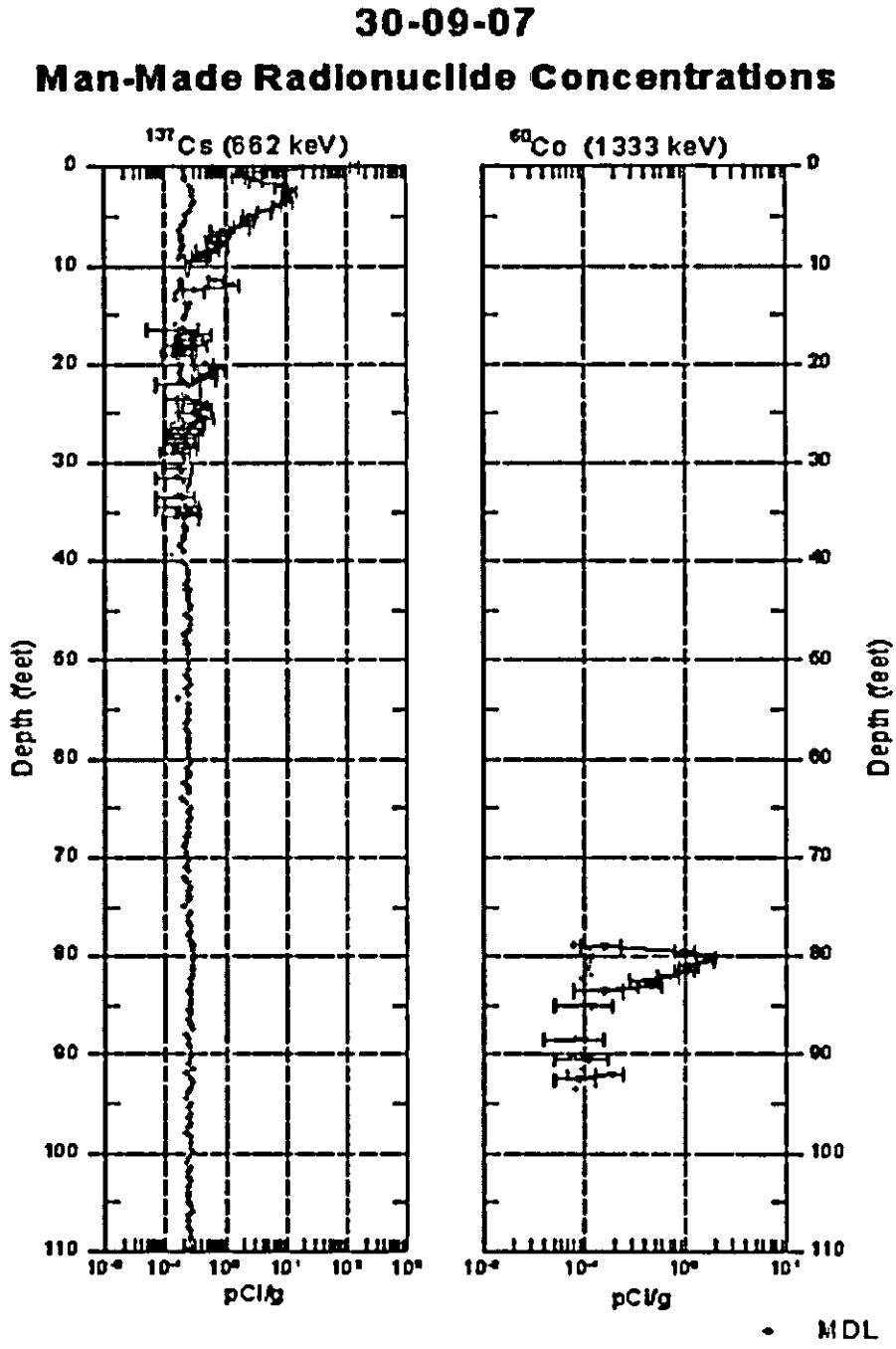


Figure E-25. 30-09-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997m.

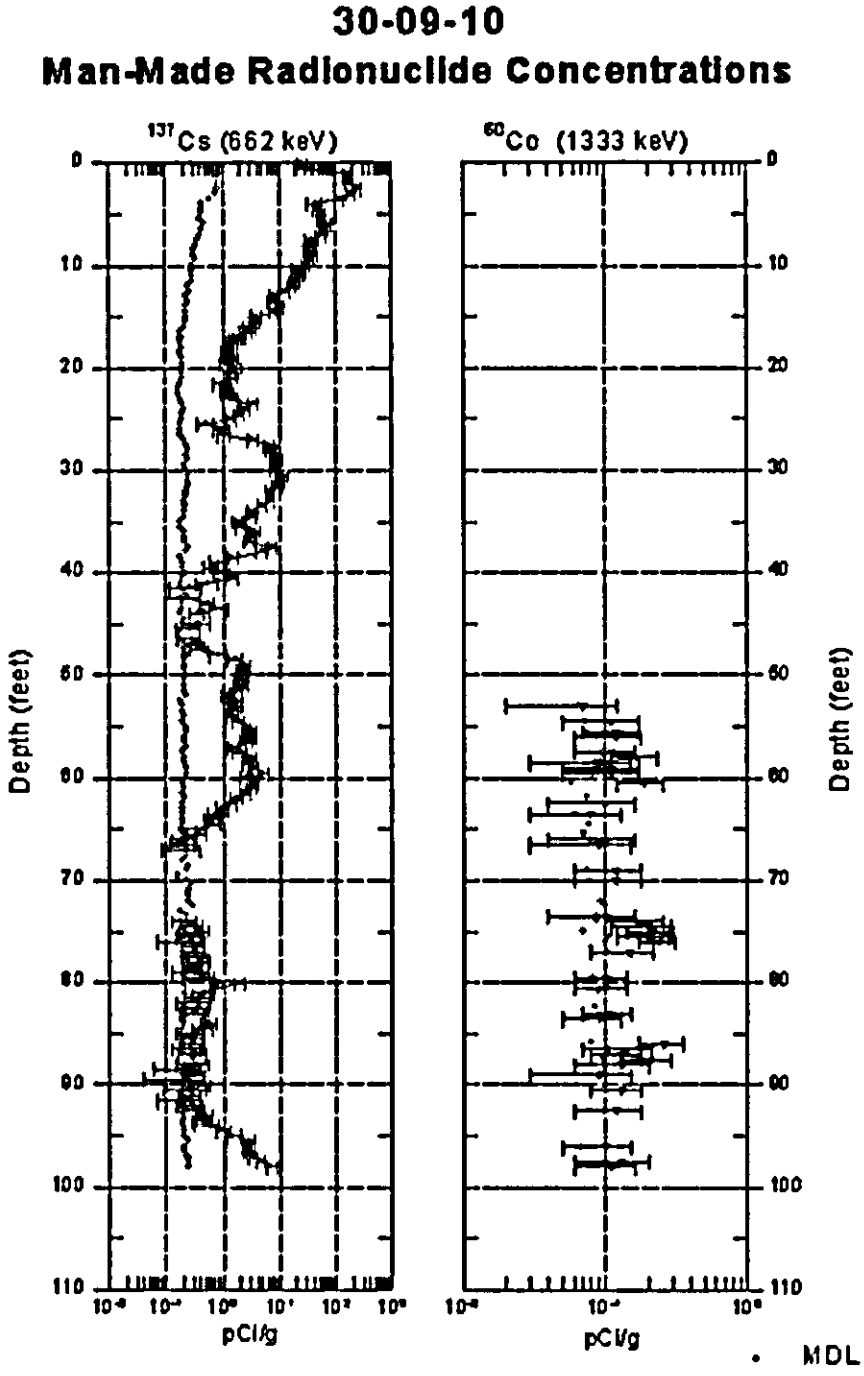


Figure E-26. 30-10-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997n.

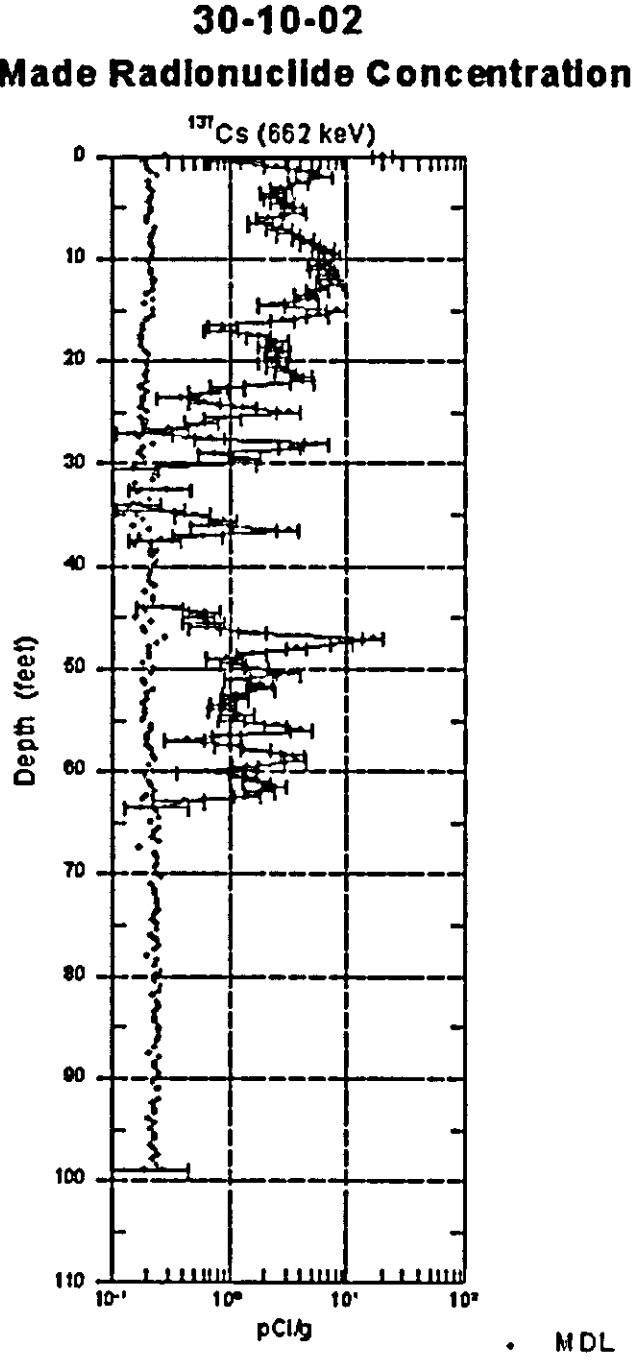


Figure E-27. 30-12-13 Man-Made Radionuclide Concentrations from DOE-GJO 1998b.

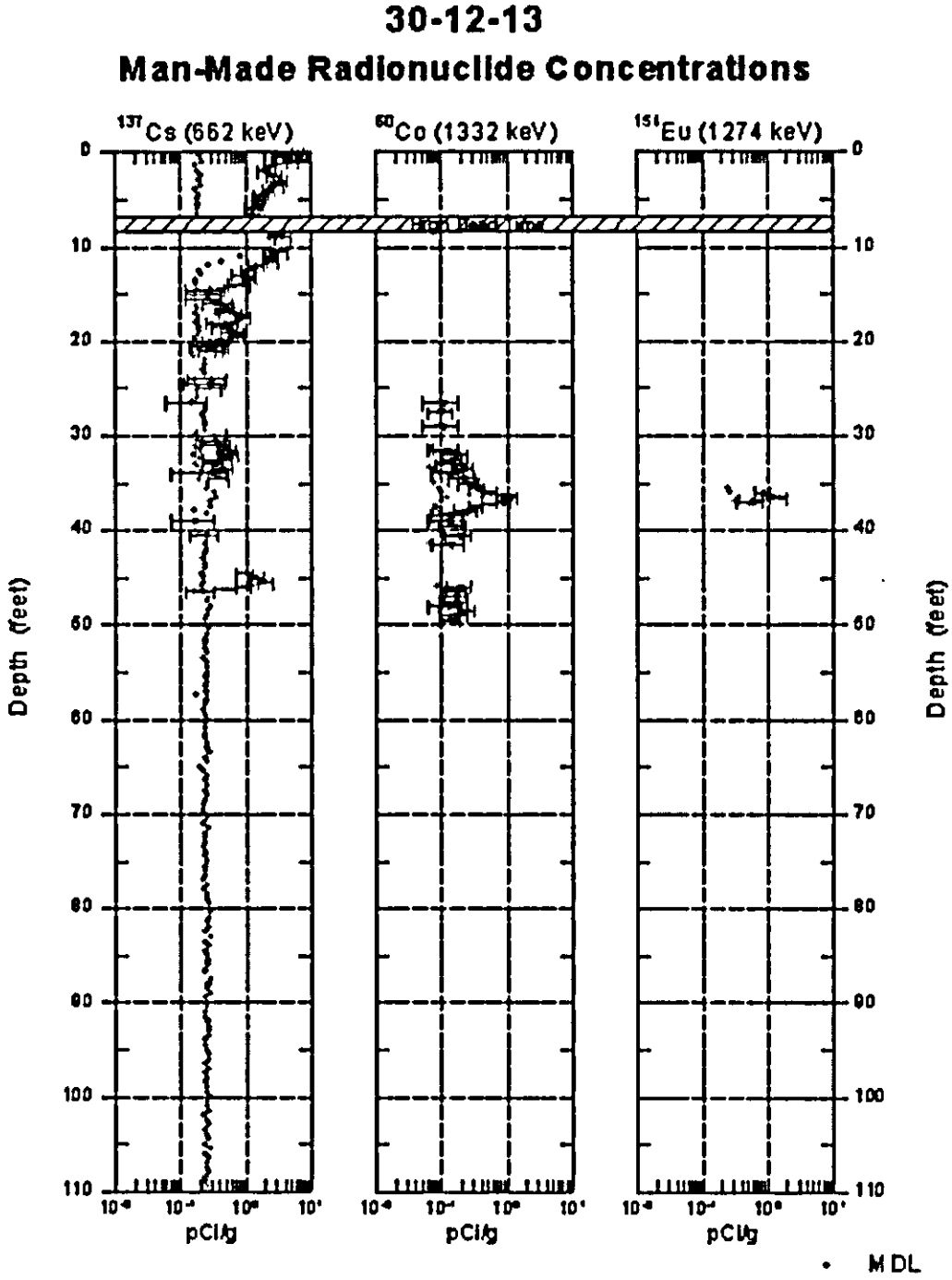


Figure E-28. 30-12-13 Summary of High Rate Logging Results for the C Tank Farm from DOE-GJO 2000b.

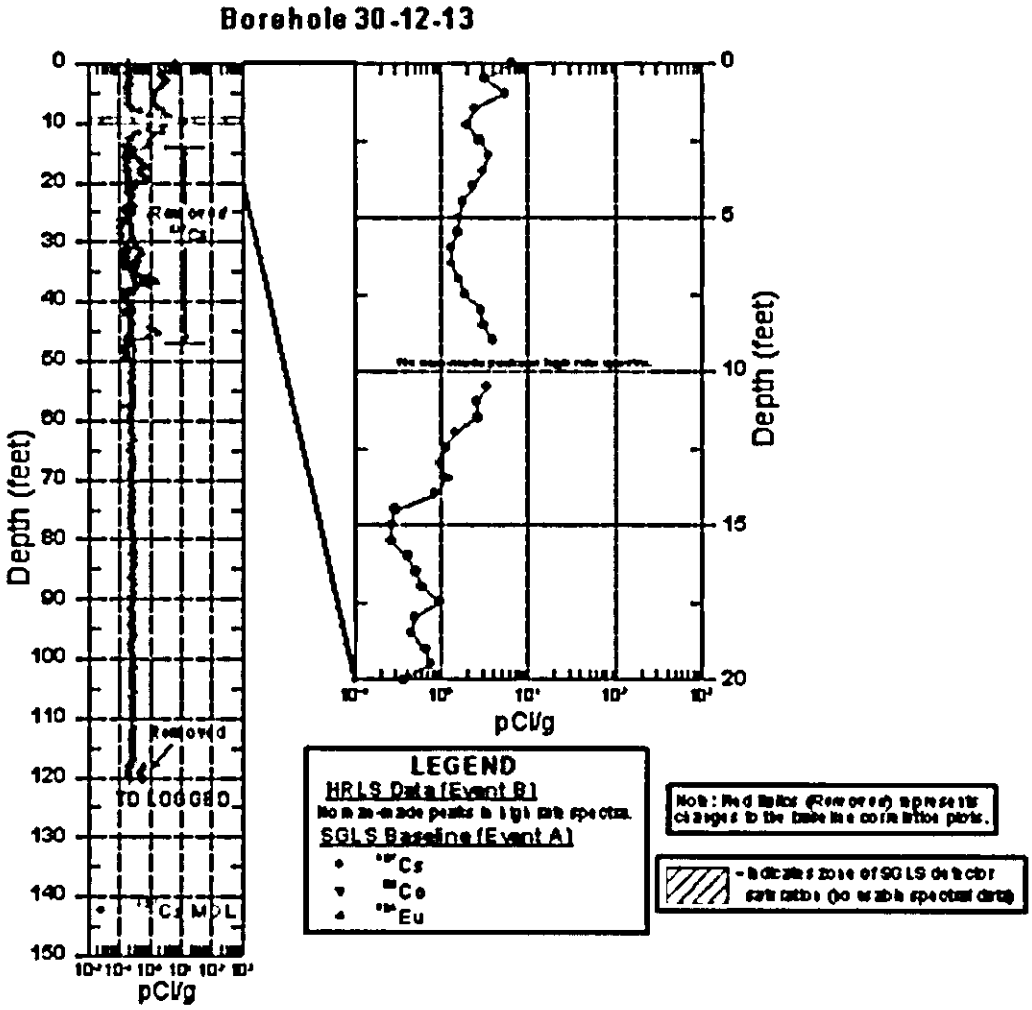


Figure A-3. Summary of High Rate Logging Results for the C Tank Farm

A TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-29. Plan Map of the A Tank Farm Showing the Location of the Tank Monitoring Boreholes and Leak Detection Laterals from DOE-GJO 1999.

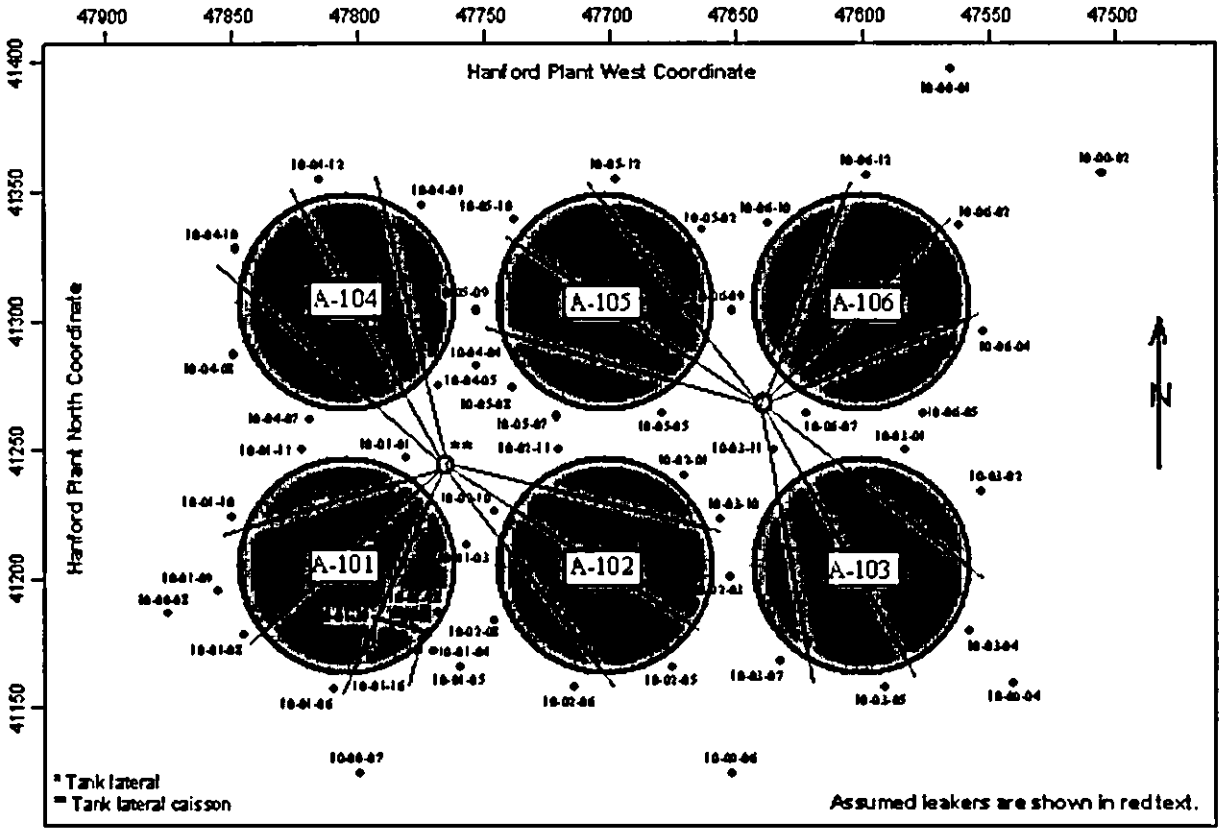


Figure 14-19. Plan Map of the A Tank Farm Showing the Location of the Tank Monitoring Boreholes and Leak Detection Laterals

Figure E-30. 10-01-03 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

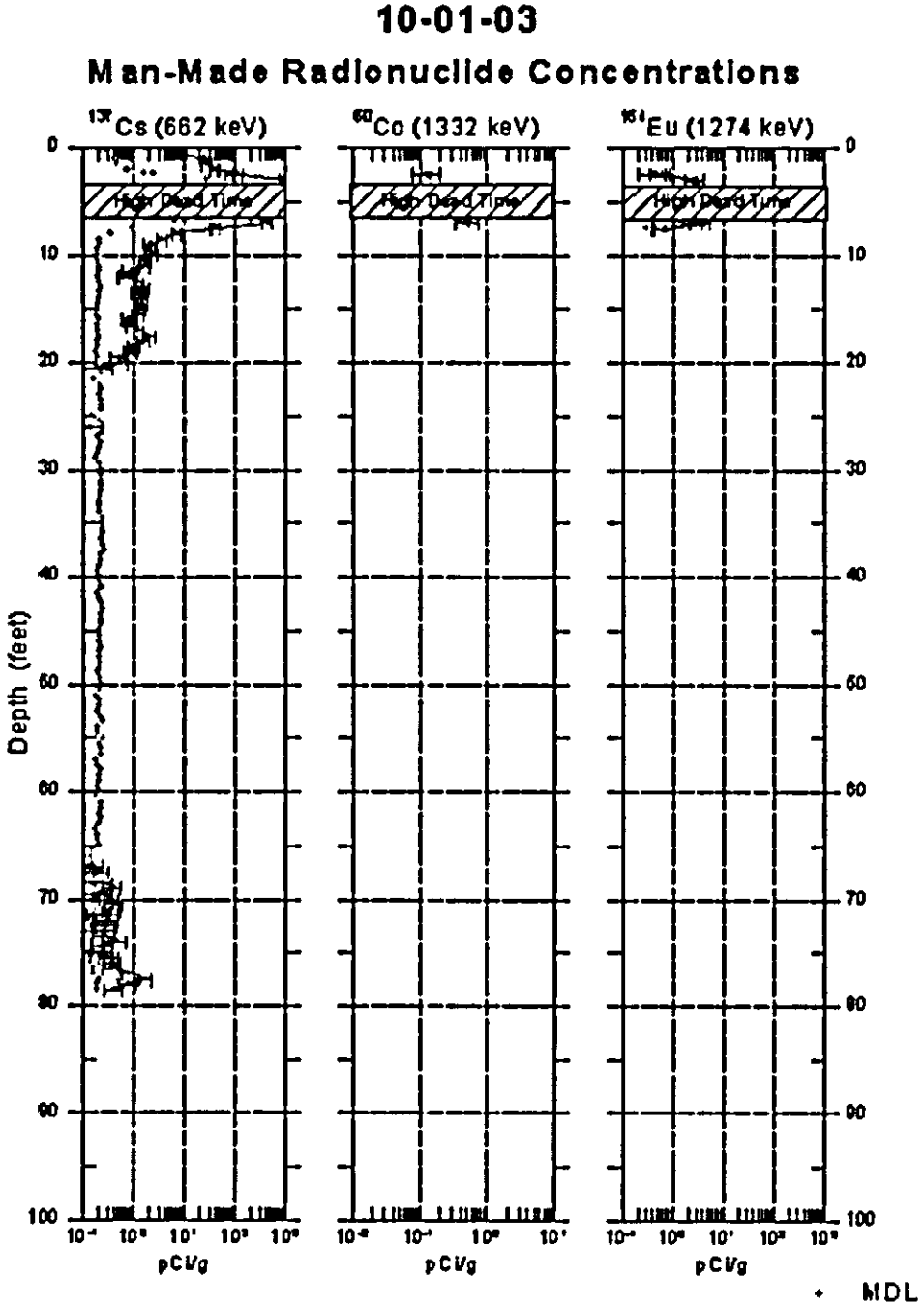


Figure E-31. 10-01-03 Summary of High Rate Logging Results for the A Tank Farm from DOE-GJO 2000c.

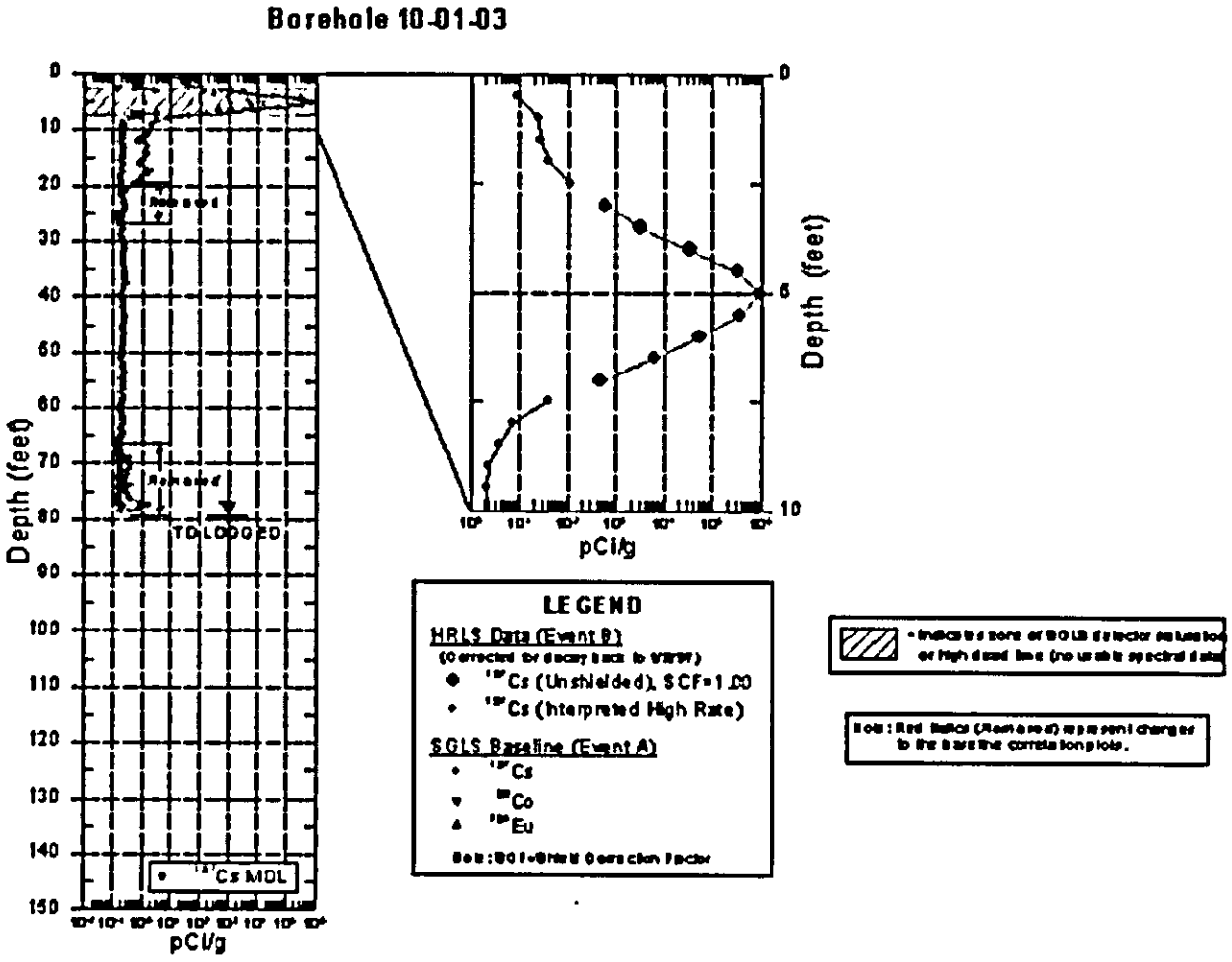


Figure A-1. Summary of High Rate Logging Results for the A Tank Farm

Figure E-32. 10-01-28 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

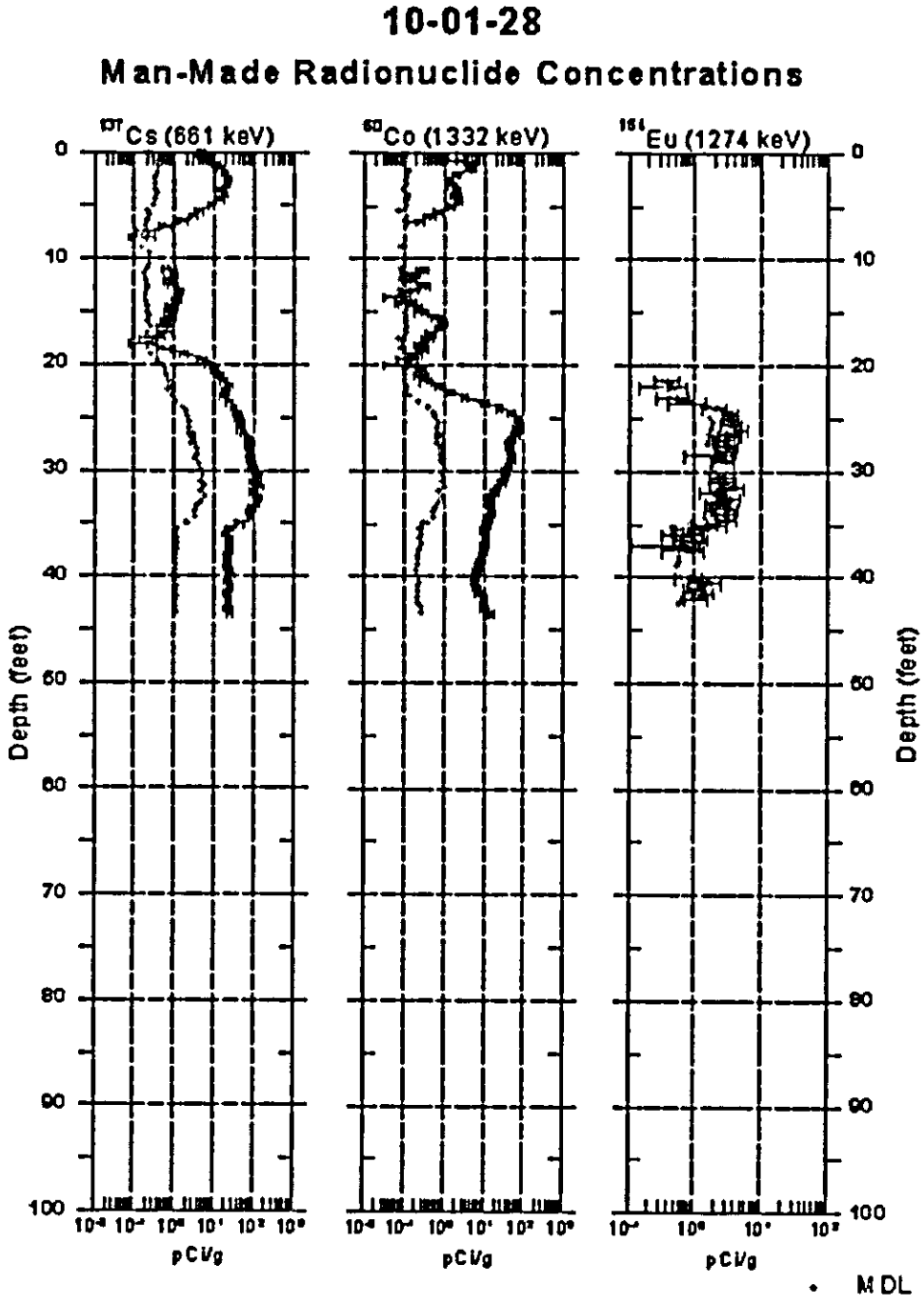


Figure E-33. 10-01-39 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

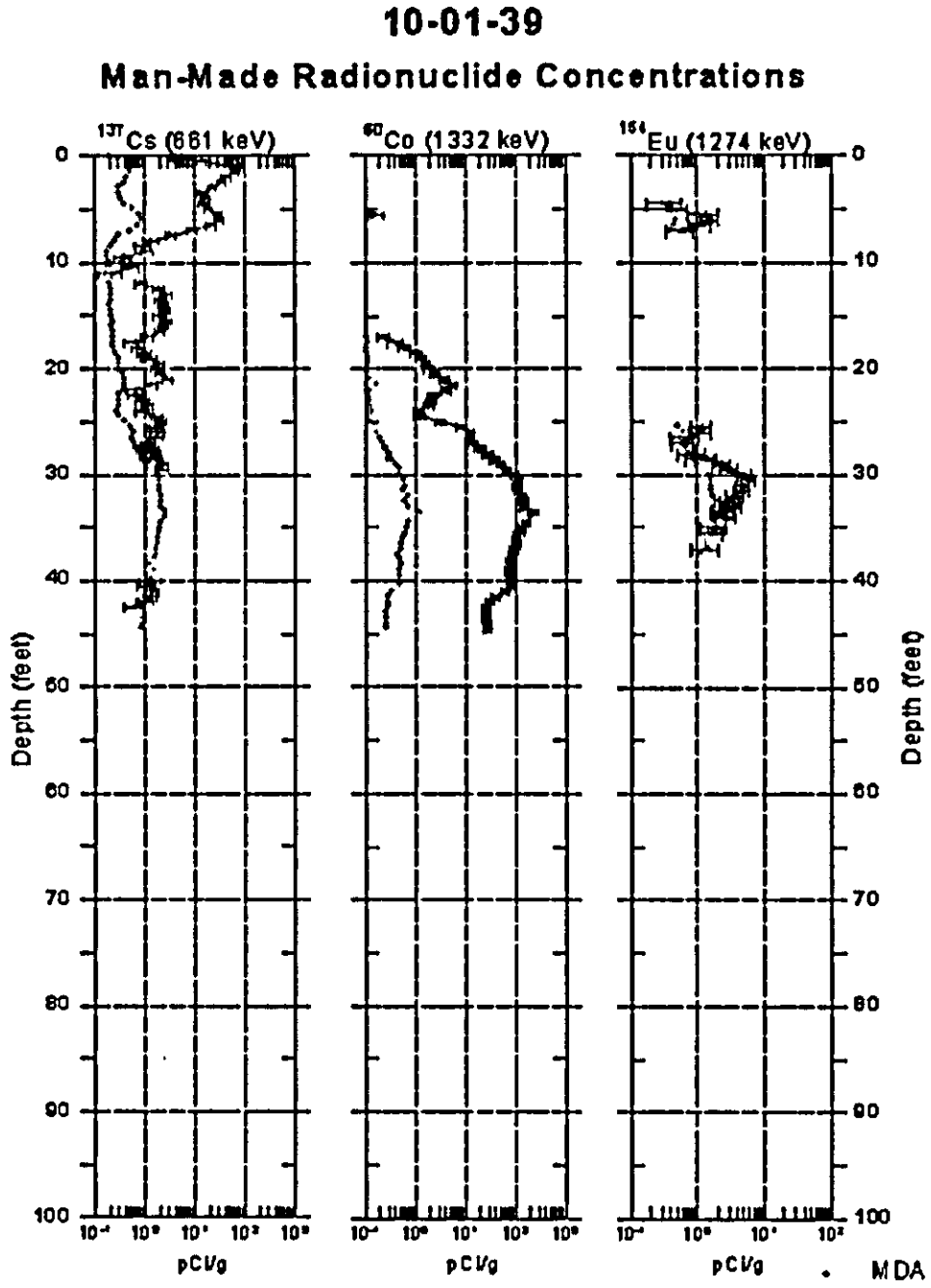


Figure E-34. 10-01-16 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

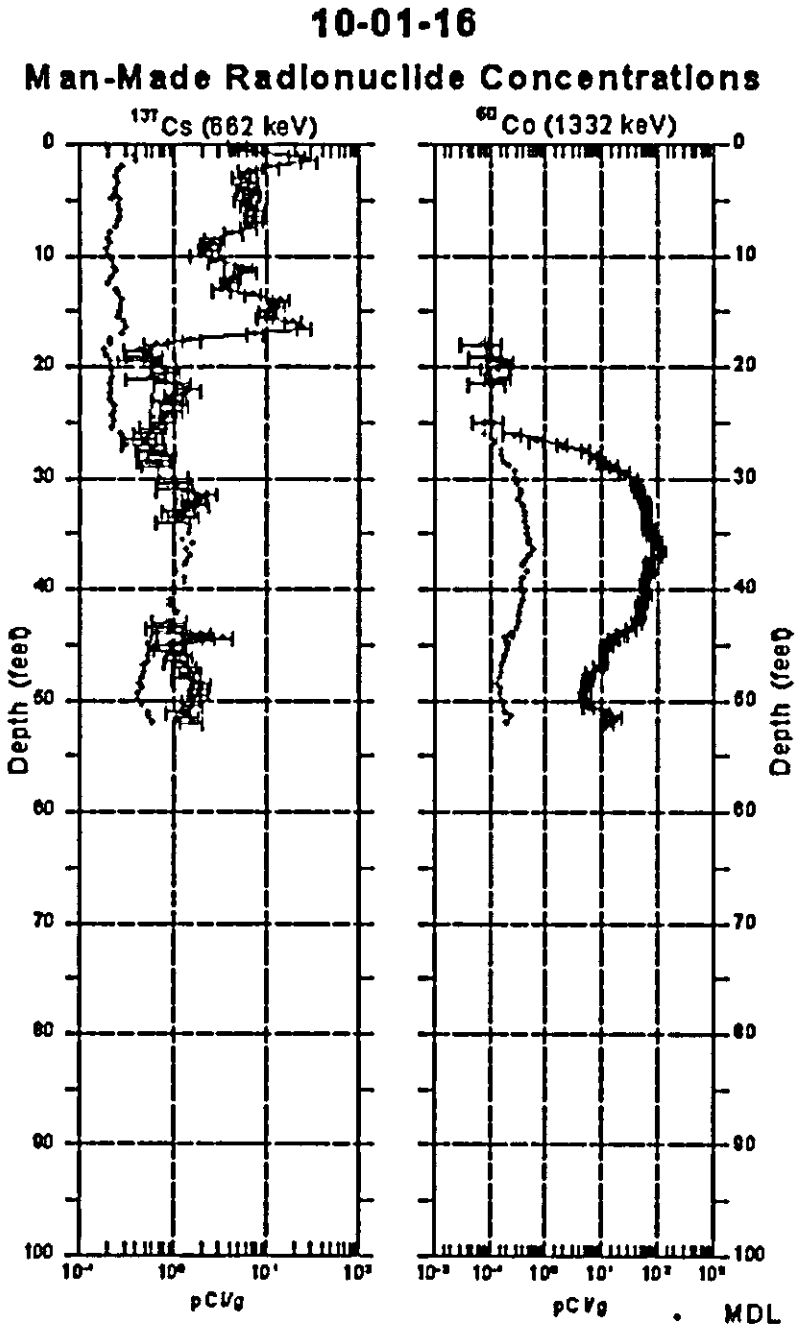


Figure E-35. 10-01-04 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

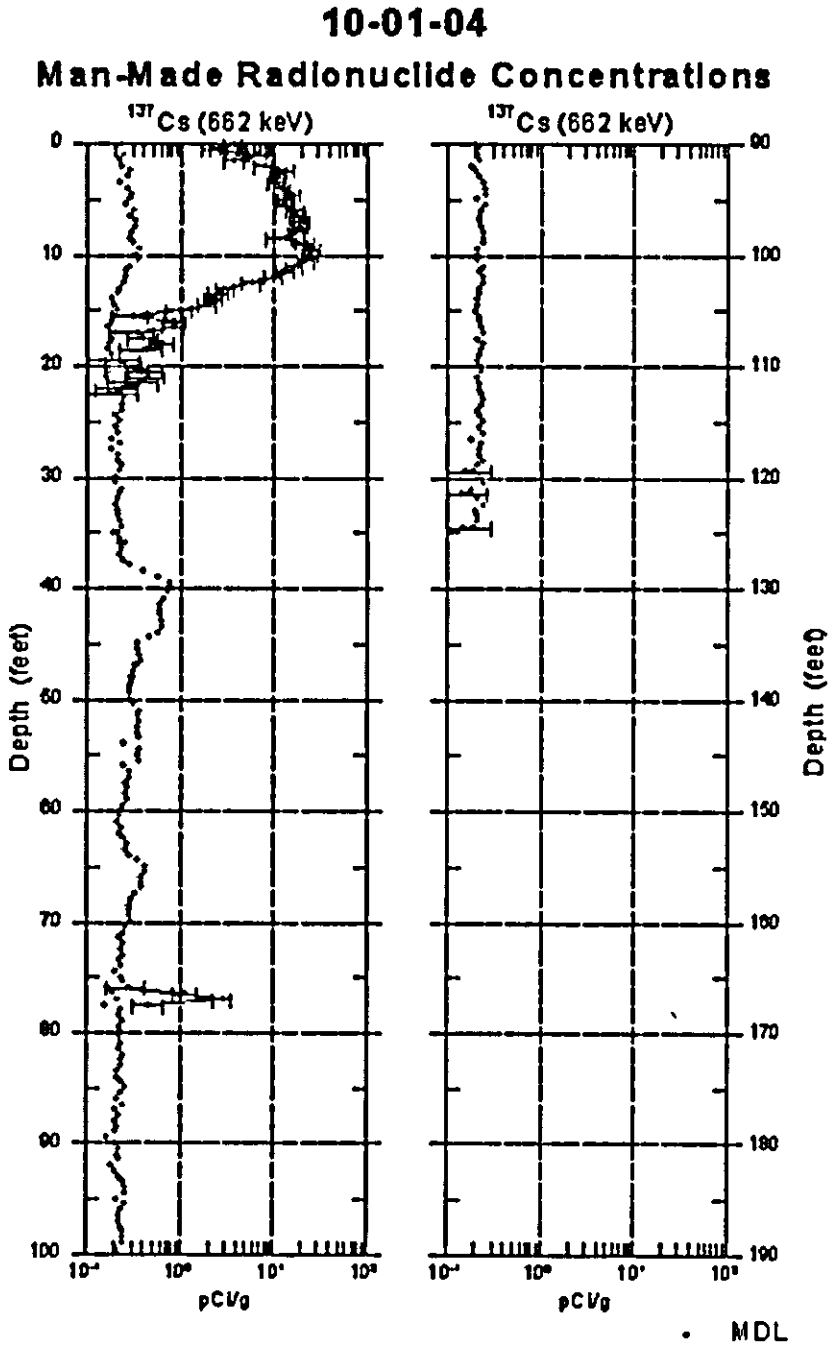


Figure E-36. 10-01-04 Man-Made Radionuclide Concentrations from DOE-GJO 1998c.

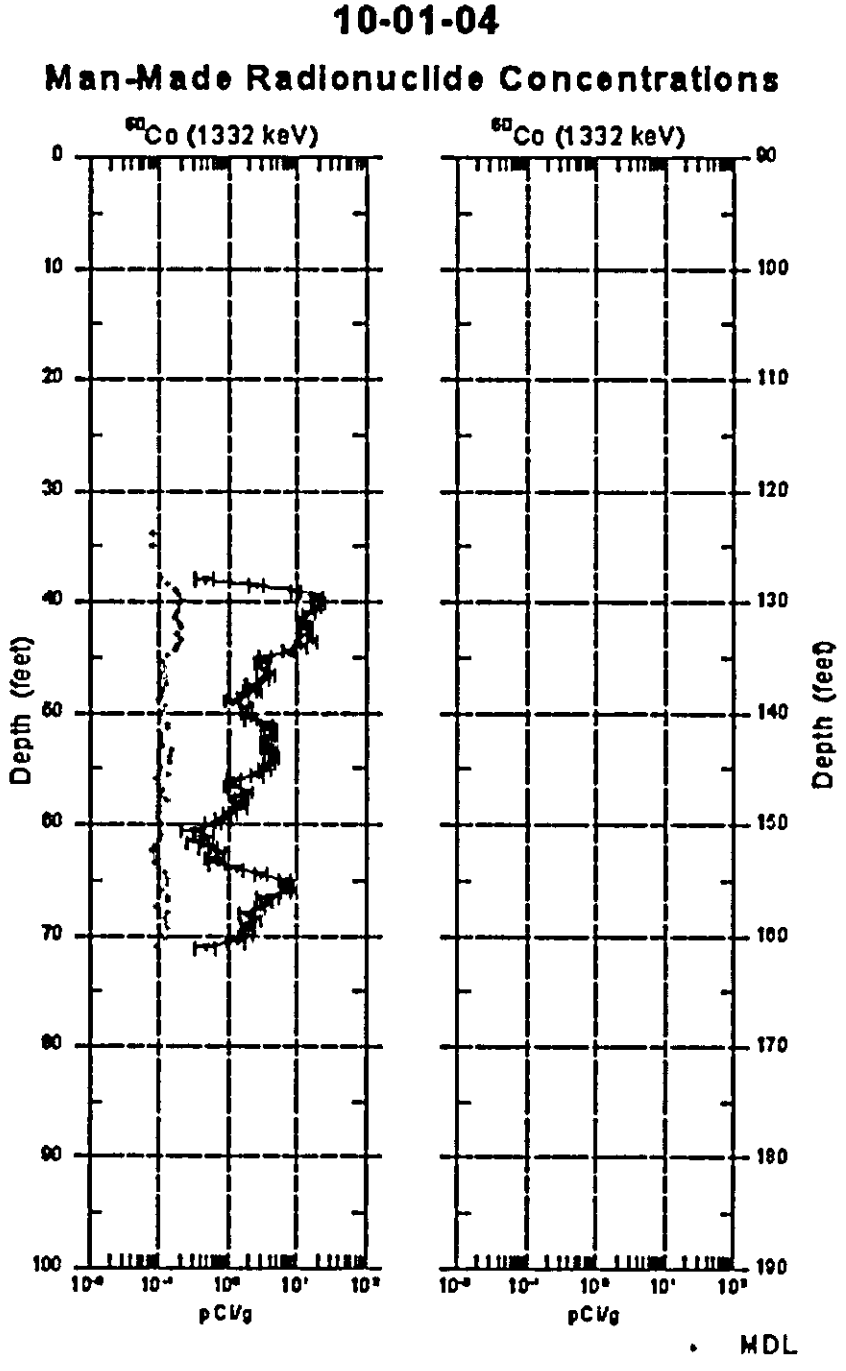


Figure E-37. 10-02-08 Man-Made Radionuclide Concentrations from DOE-GJO 1998d.

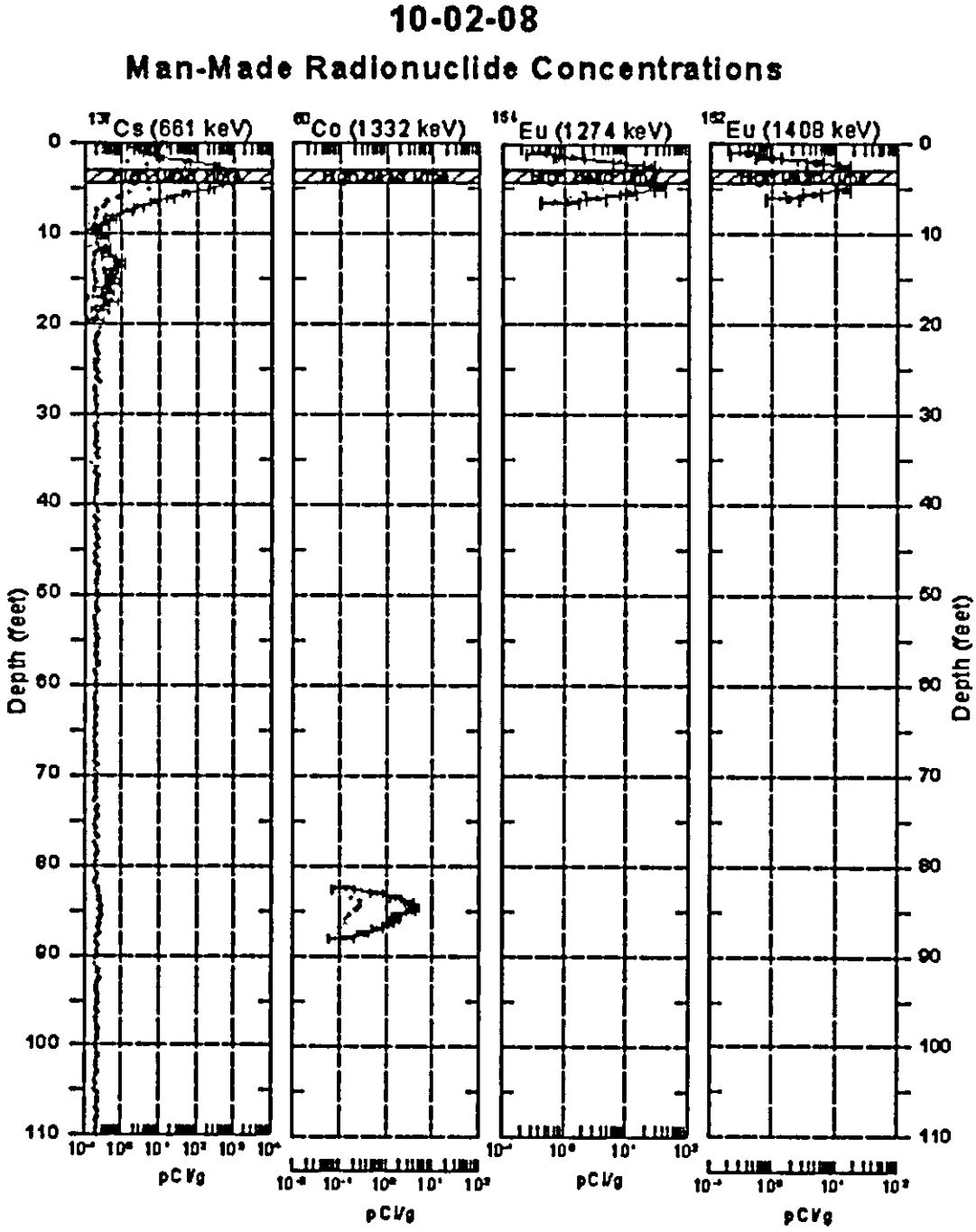


Figure E-38. Plan view of Tanks and Boreholes in the A Tank Farm from DOE-GJO 1998e.

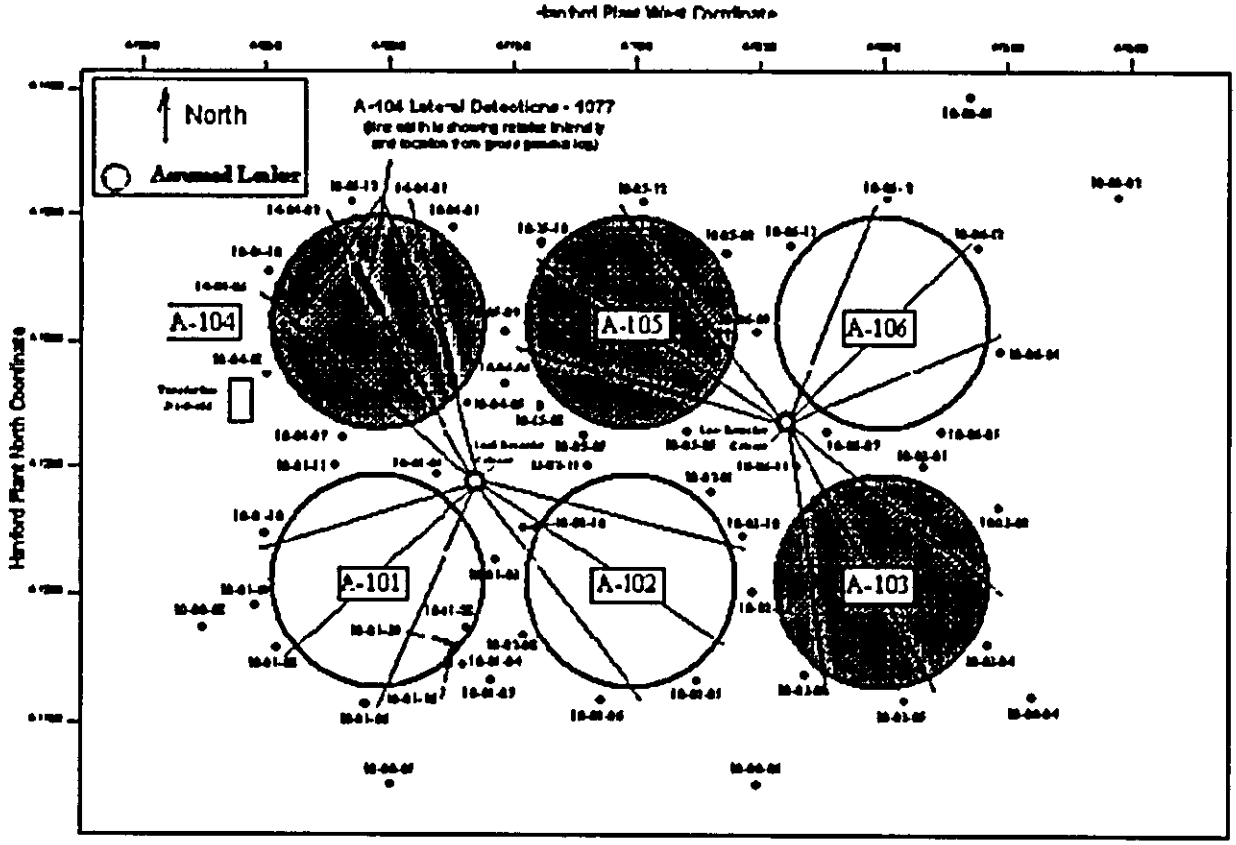


Figure 2. Plan View of Tanks and Boreholes in the A Tank Farm

Figure E-39. A-104 Laterals – Historical Gamma-Ray Correlations from DOE-GJO 1998e.

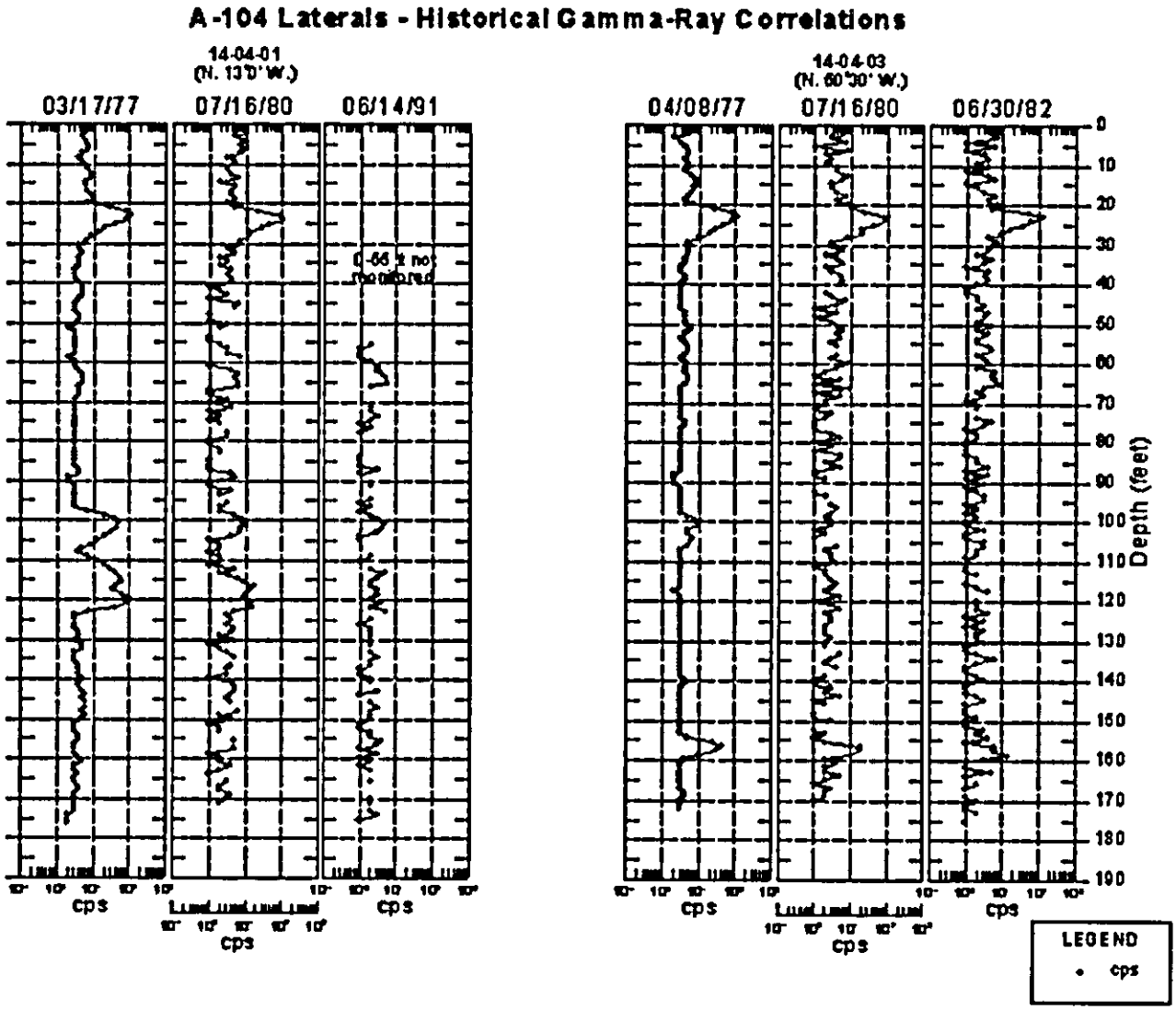


Figure E-40. 14-04-02 Lateral – Historical Gamma-Ray Correlations from DOE-GJO 1998e.

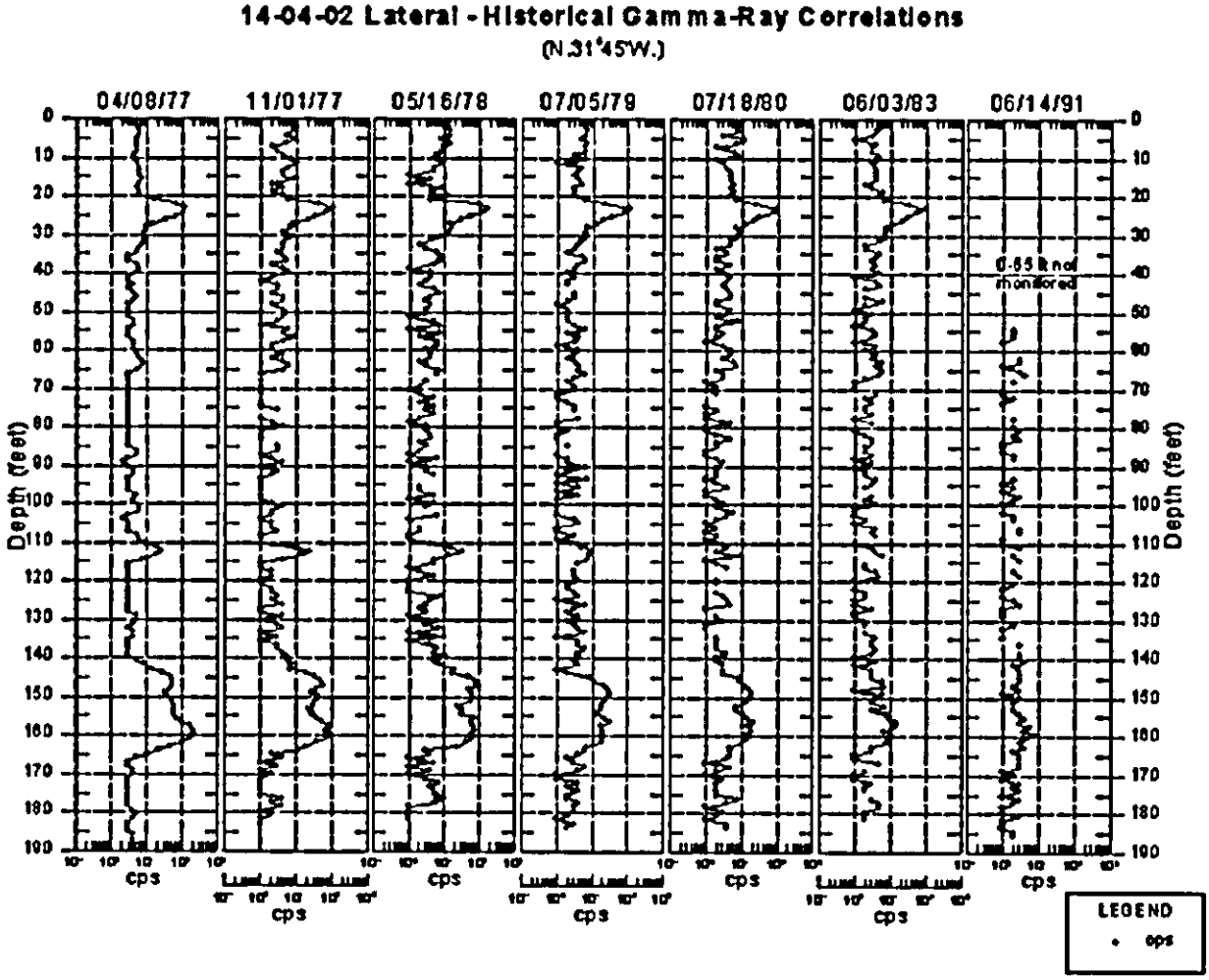


Figure E-41. Plan View of Tanks and Boreholes in the A Tank Farm from DOE-GJO 1998f.

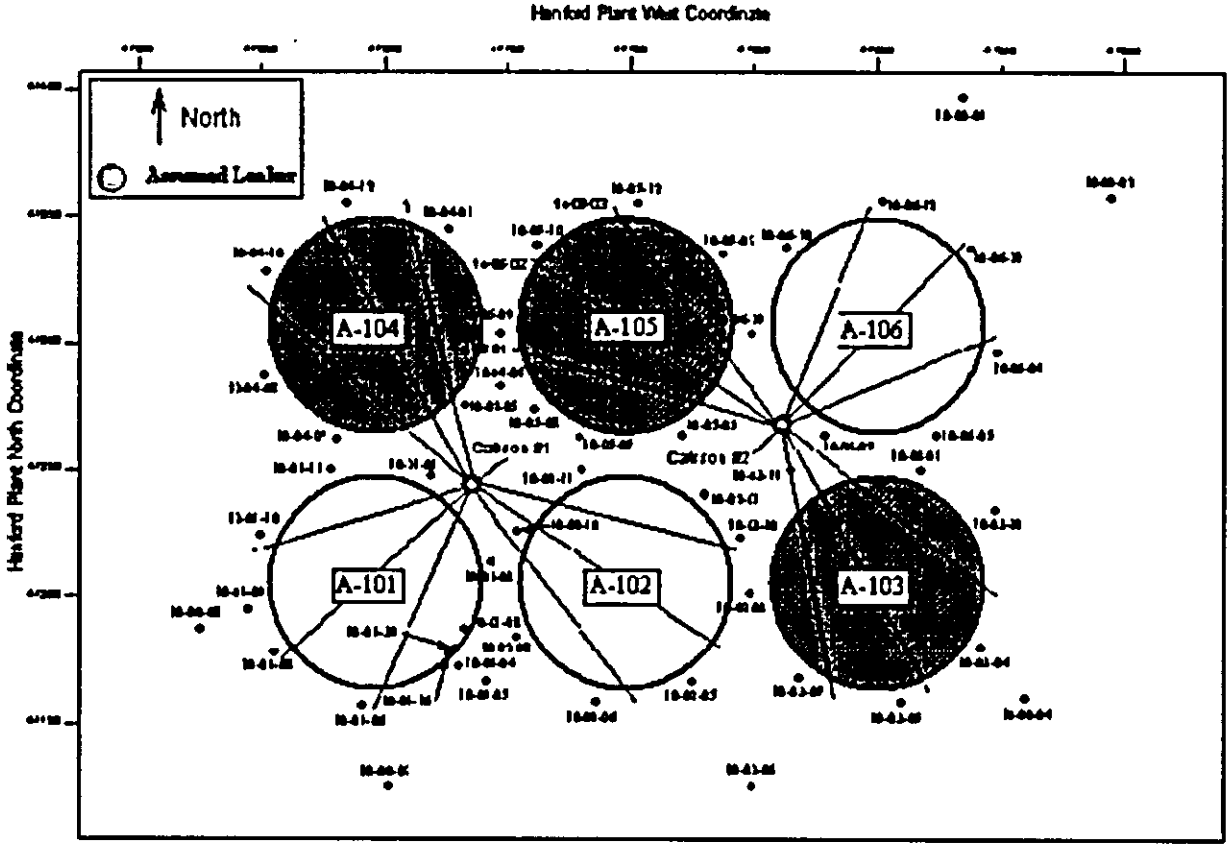


Figure 2. Plan View of Tanks and Boreholes in the A Tank Farm

Figure E-42. Lateral 14-05-01 Selected Historical Gamma-Ray Plots – Horizontal Segments from DOE-GJO 1998f.

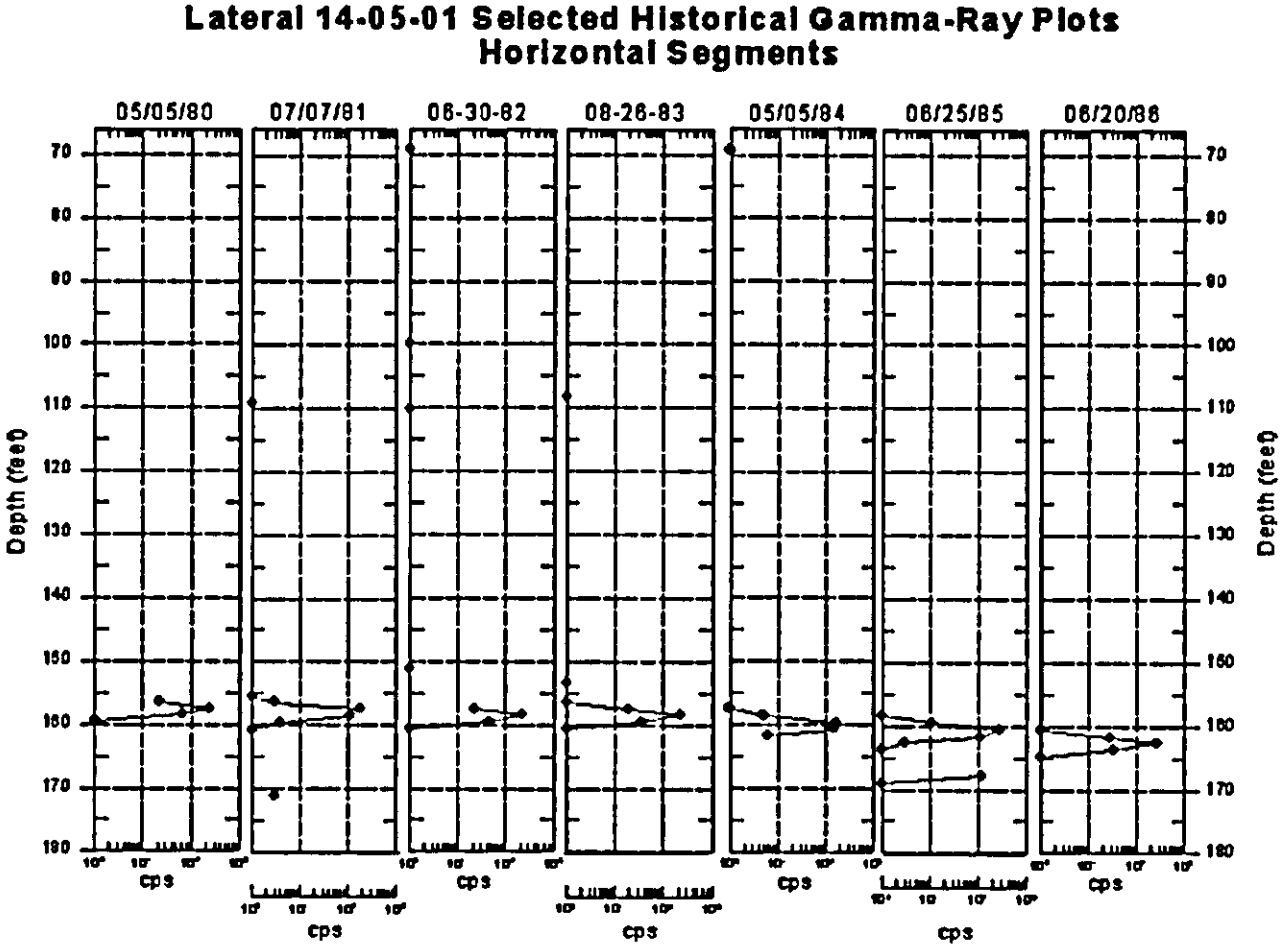


Figure E-43. Lateral 14-05-02 Selected Historical Gamma-Ray Log – Historical Segments from DOE-GJO 1998f.

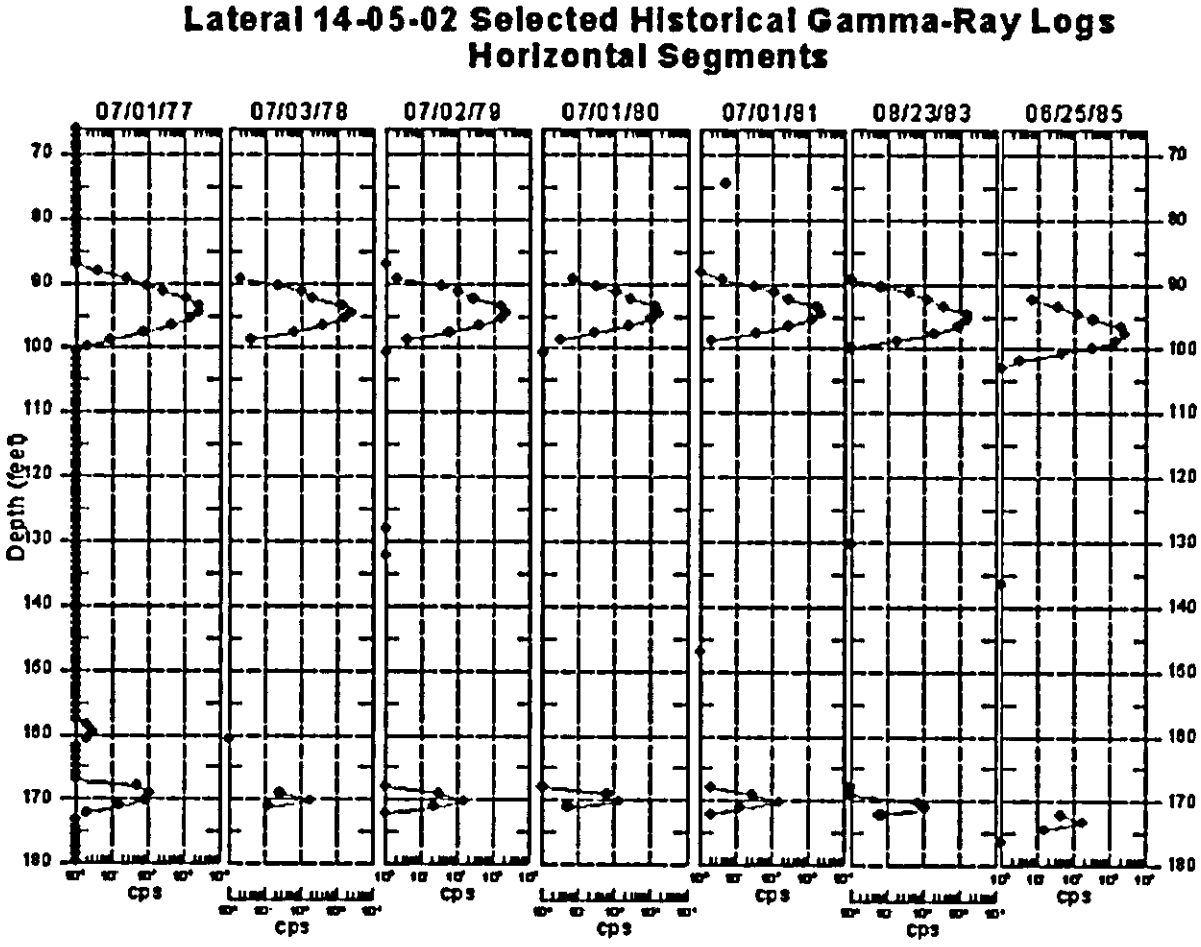
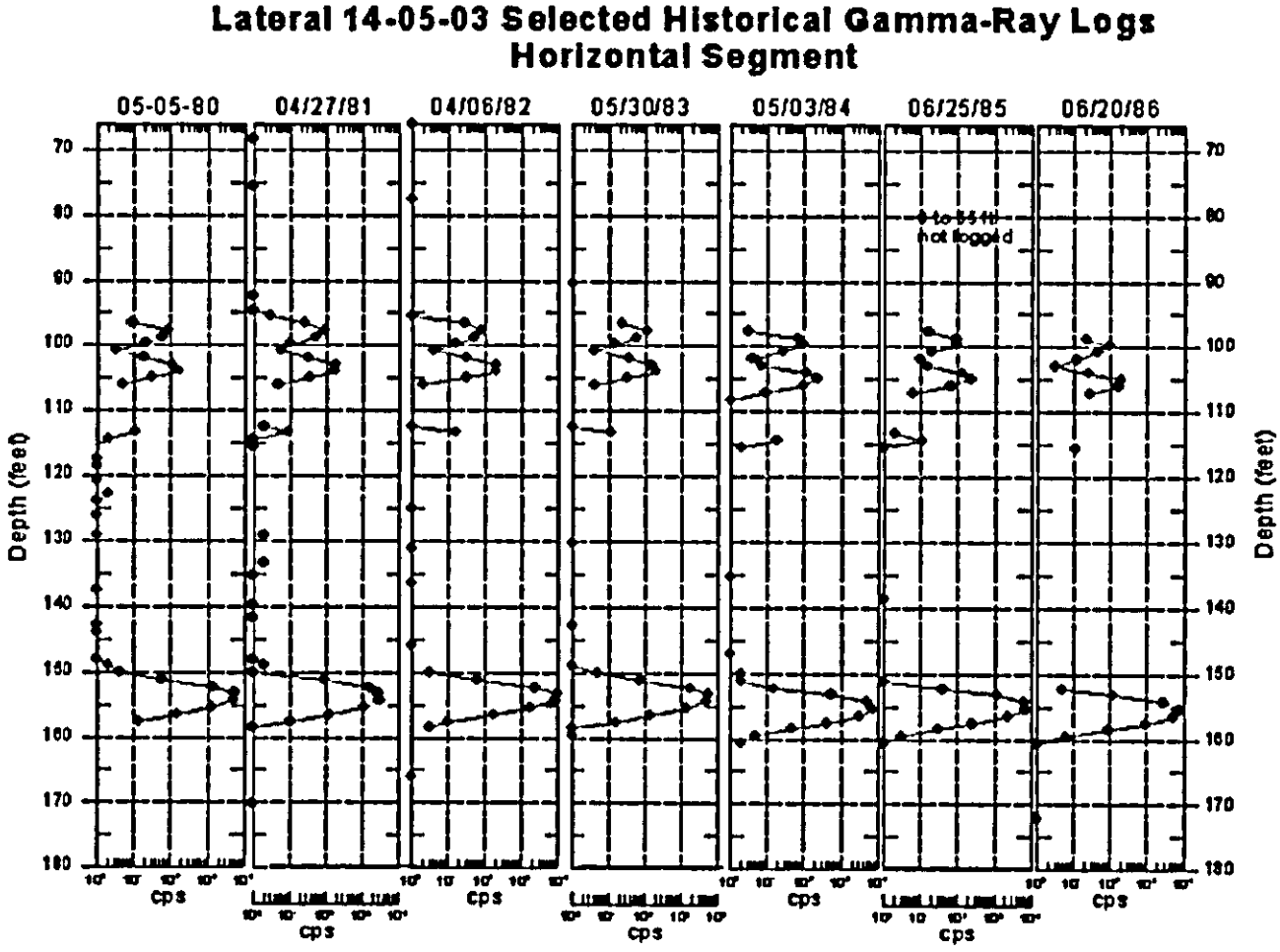


Figure E-44. Lateral 14-05-03 Selected Historical Gamma-Ray Log - Horizontal Segment from DOE-GJO 1998f.



AX TANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure E-45. Plan Map of the Hanford Site AX Tank Farm Showing the Tank Monitoring Boreholes from DOE-GJO 2000a.

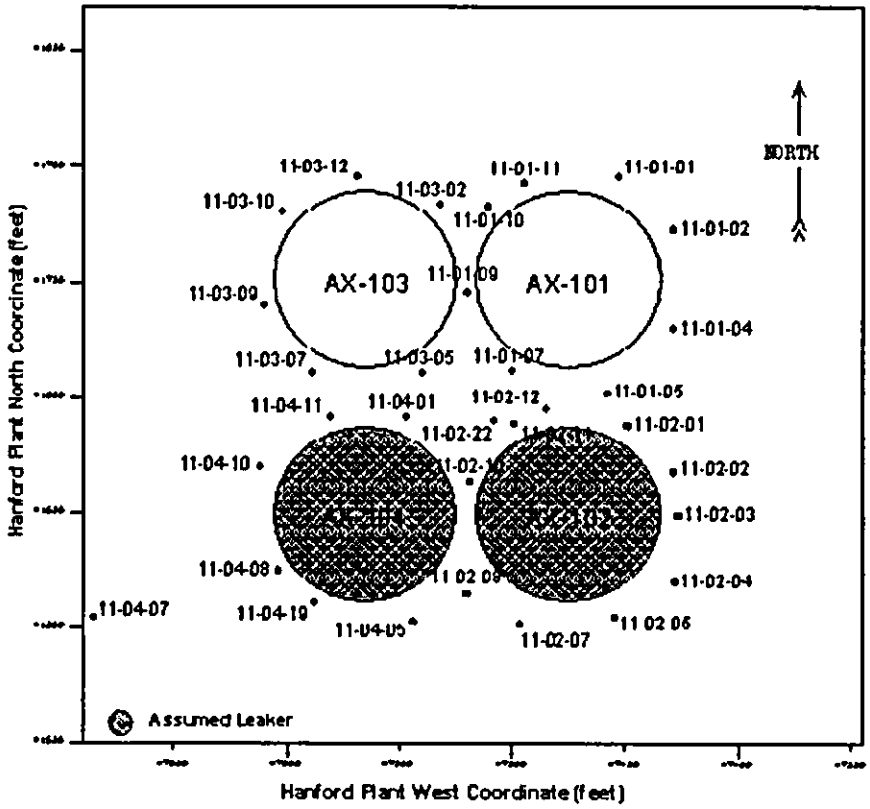


Figure 15-8. Plan Map of the Hanford Site AX Tank Farm Showing the Tank Monitoring Boreholes

Figure E-46. 11-01-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997a.

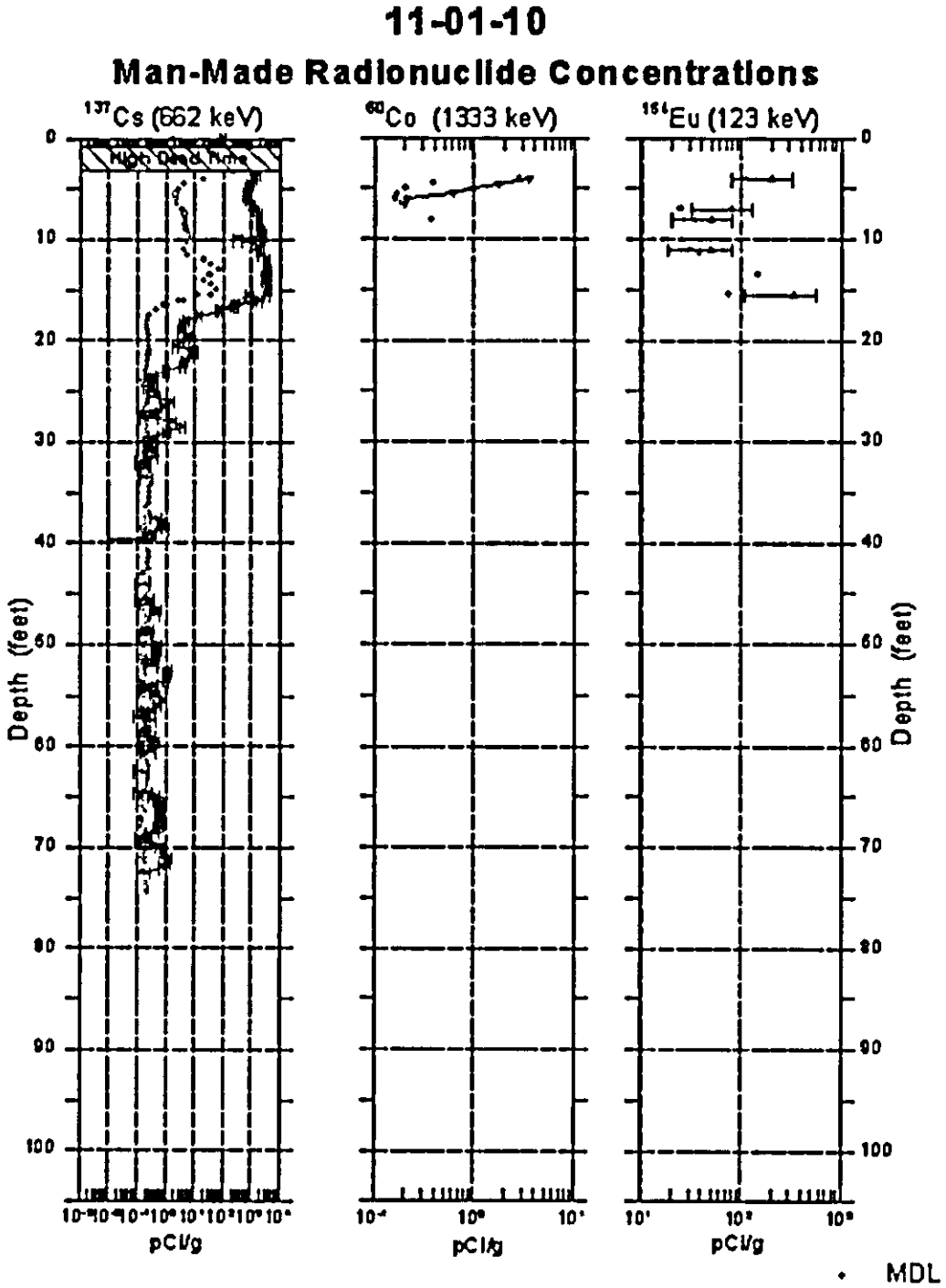


Figure E-47. 11-01-10 Summary of High Rate Logging Results for the AX Tank Farm from DOE-GJO 2000a.

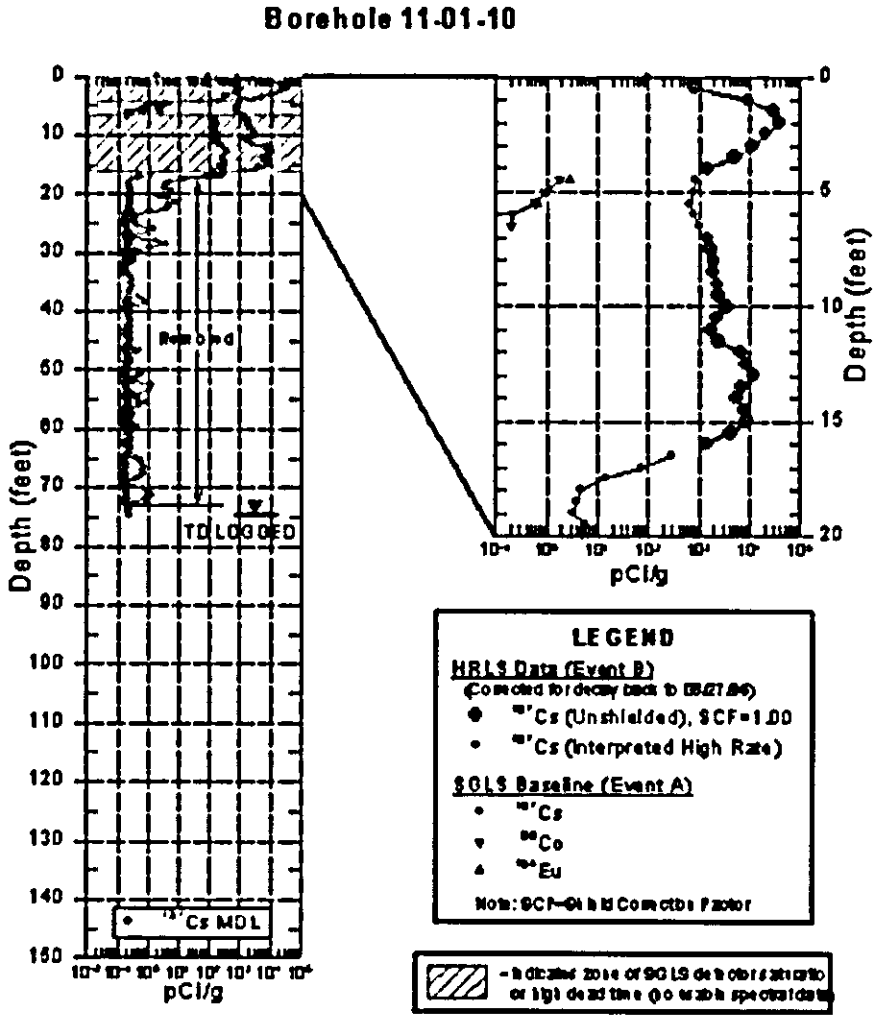


Figure A-1. Summary of High Rate Logging Results for the AX Tank Farm

Figure E-48. 11-02-12 Man-Made Radionuclide Concentrations from DOE-GJO 1997b.

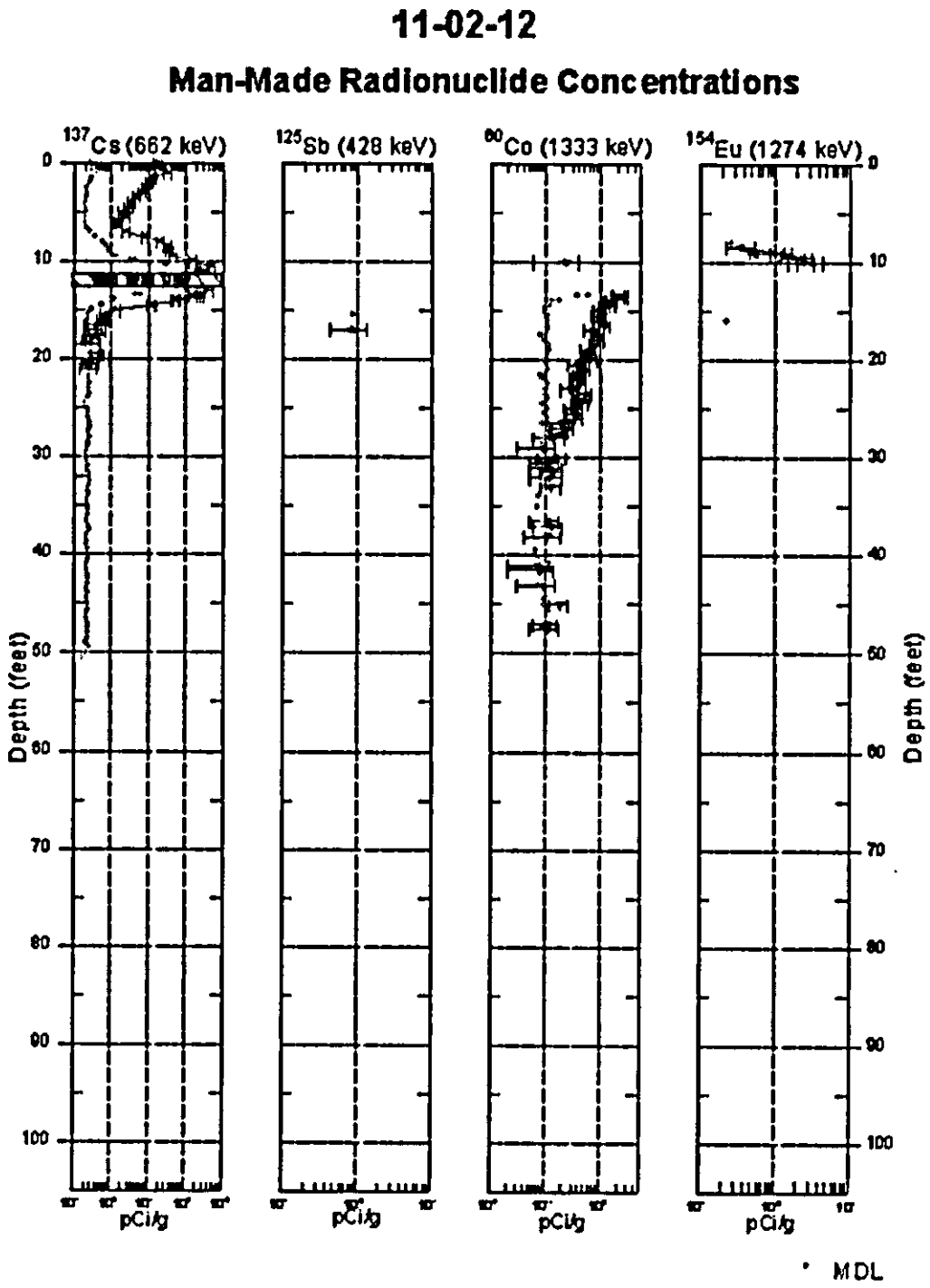


Figure E-49. 11-02-12 Summary of High Rate Logging Results for the AX Tank Farm from DOE-GJO 2000a.

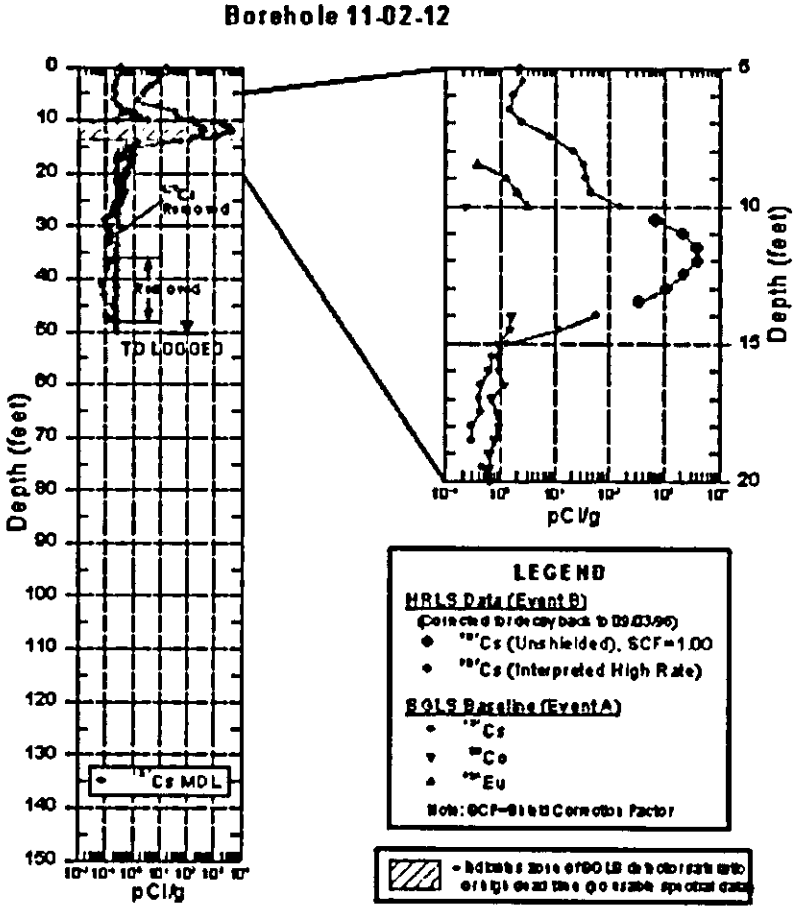


Figure A-2. Summary of High Rate Logging Results for the AX Tank Farm

Figure E-50. 11-03-02 Man-Made Radionuclide Concentrations from DOE-GJO 1997c.

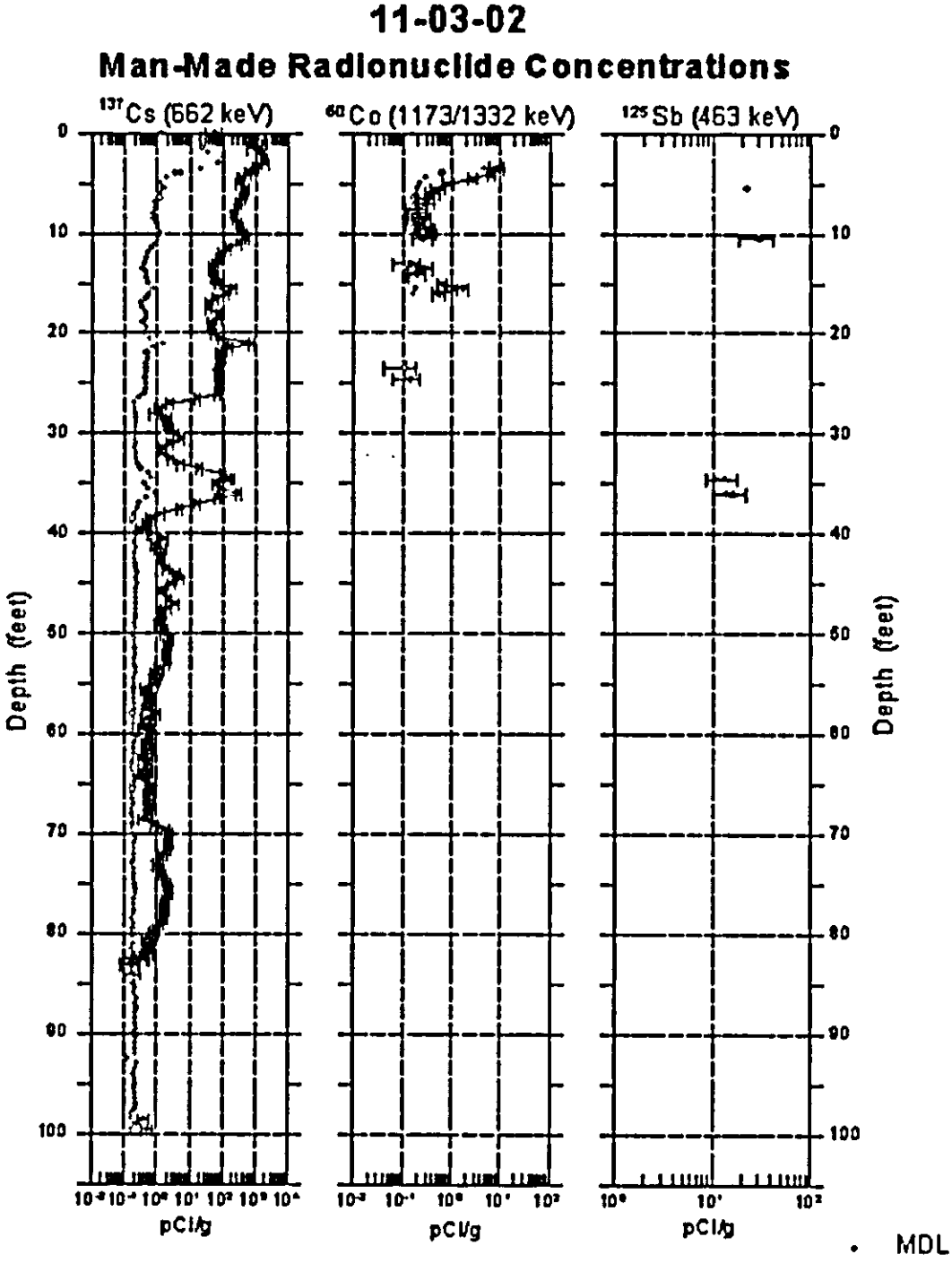
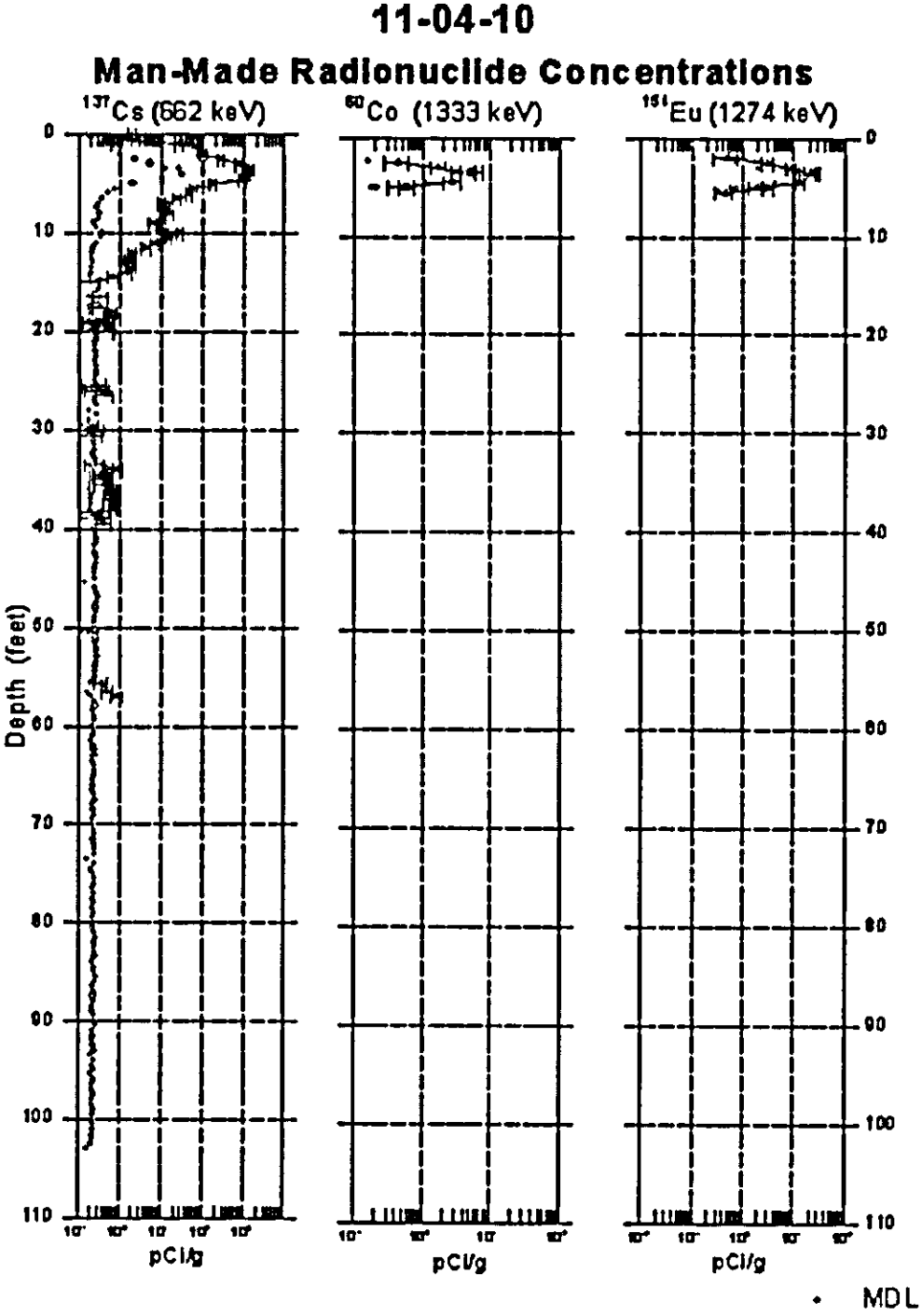
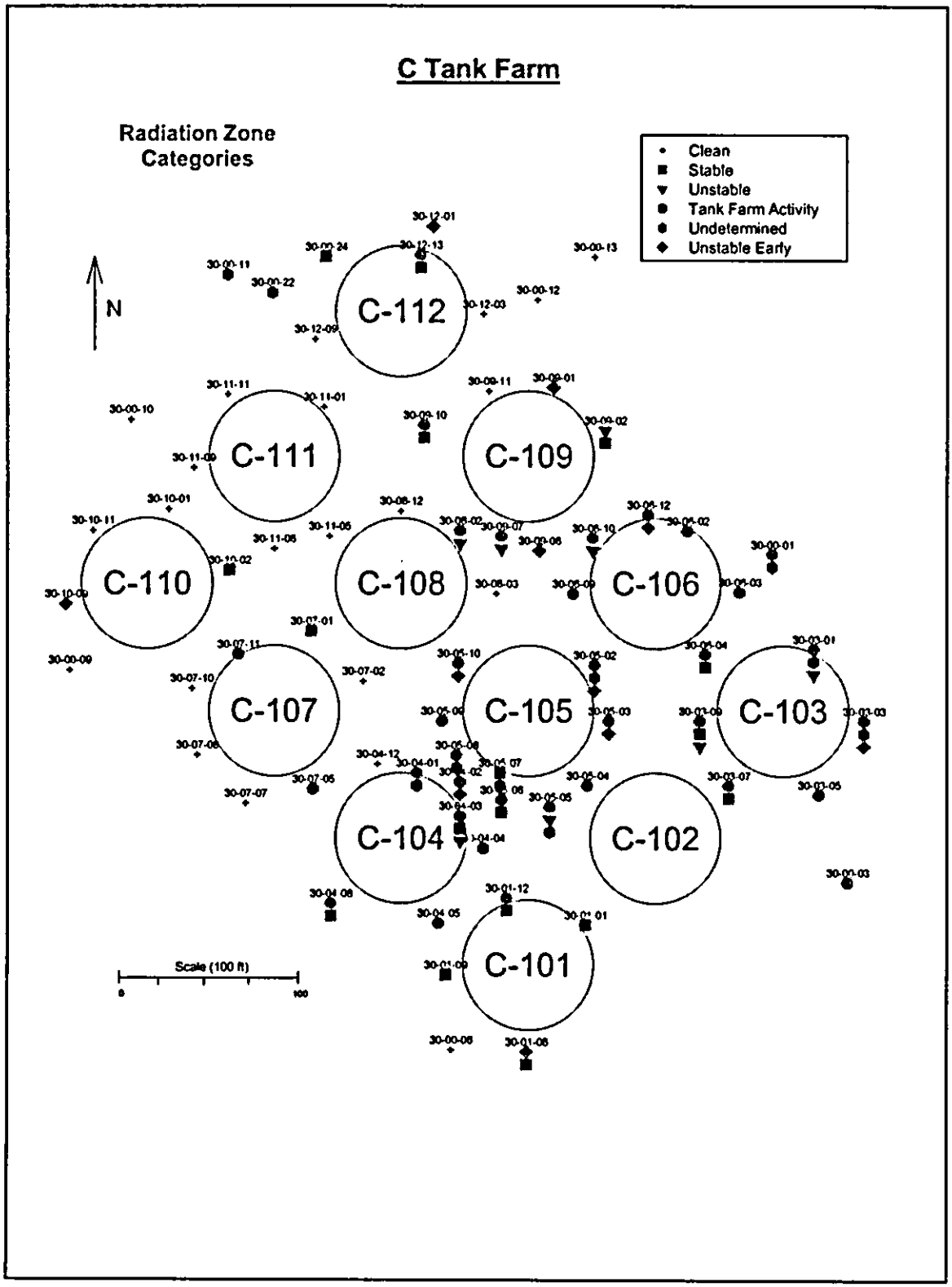


Figure E-51. 11-04-10 Man-Made Radionuclide Concentrations from DOE-GJO 1997d.



ANALYSIS AND SUMMARY REPORT OF HISTORICAL DRY WELL GAMMA LOGS FOR THE 241-C TANK FARM – 200 EAST FROM RANDALL AND PRICE 2001A


C Tank Farm
Radiation Zone Categories
Clean
Stable
Unstable
Tank Farm Activity
Undetermined
Unstable Early
N
C-112
C-111
C-109
C-110
C-108
C-106
C-107
C-105
C-103
C-104
C-102
C-101
Scale (100 ft)
0
100

2.2.1 Tank Farm Activity

A sudden, significant change in the intensity of gross gamma rays between successive gross gamma surveys at or near the ground surface suggests that contamination may have resulted from tank farm activities or logging procedure changes. Radioactive contamination occurs at the surface in 35 wells, apparently as the result of tank farm activities (i.e., logging procedure changes, transfer line operations, valve box and conduit leaks, surface spills, etc.). These wells are listed in Table 3.

Table 3. C Tank Farm Activity Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotope Present
30-00-01	70	4	TF Activity	0-5	300	1984	^{137}Cs
30-00-03	120'	4	TF Activity	0-7	1300	1975	^{137}Cs
30-01-12	100	4	TF Activity	0-10	4500	1975	^{137}Cs
30-03-01	125	4	TF Activity	0-30	12K	1975	^{137}Cs
30-03-03	130	4	TF Activity	0-14	4K	1975	^{137}Cs
30-03-05	100	4	TF Activity	0-20	600	1984	^{137}Cs
30-03-07	130	4	TF Activity	0-12	2000	1980	^{137}Cs
30-03-09	100	4	TF Activity	0-12	8K	1980	^{137}Cs
30-04-01	50	4	TF Activity	0-8	3K	1975	^{137}Cs
30-04-02	135	4	TF Activity	0-12	2000	1975	^{137}Cs
30-04-03	50	4	TF Activity	0-15	600	1985	^{137}Cs
30-04-04	100	4	TF Activity	0-8	50K	1978	^{137}Cs
30-04-04	100	4	TF Activity	8-25	1800	1975	^{137}Cs
30-04-05	100	4	TF Activity	0-20	9K	1978	^{137}Cs
30-04-08	145	4	TF Activity	0-5	150	1975	^{137}Cs
30-05-02	130	4	TF Activity	0-14	5K	1975	^{137}Cs
30-05-03	100	4	TF Activity	0-39	9K	1985	^{137}Cs
30-05-04	120	4	TF Activity	0-8	900	1975	^{137}Cs
30-05-05	100	4	TF Activity	0-25	12K	1975	^{137}Cs
30-05-06	60	4	TF Activity	0-15	1100	1975	^{137}Cs
30-05-08	50	4	TF Activity	0-11	16K	1975	^{137}Cs
30-05-09	100	4	TF Activity	0-8	300	1985	^{137}Cs
30-05-10	135	4	TF Activity	0-17	300	1985	^{137}Cs
30-06-02	123	4	TF Activity	0-16	500	1984	^{137}Cs
30-06-03	100	4	TF Activity	0-10	800	1975	^{137}Cs
30-06-04	130	4	TF Activity	0-16	2000	1984	^{137}Cs
30-06-09	100	4	TF Activity	0-16	900	1985	^{137}Cs
30-06-10	130	4	TF Activity	0-10	800	1984	^{137}Cs
30-06-12	100	4	TF Activity	0-14	1500	1985	^{137}Cs
30-07-05	100	4	TF Activity	0-8	300	1975	^{137}Cs
30-07-11	100	4	TF Activity	0-10	80K	1993	^{137}Cs
30-08-02	100	4	TF Activity	0-6	4K	1985	^{137}Cs

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotope Present
30-08-02	100	4	TF Activity	13-28	55K	1980	^{137}Cs
30-09-07	125	4	TF Activity	0-14	300	1985	^{137}Cs
30-09-10	100	4	TF Activity	0-20	4K	1975	^{137}Cs
30-12-13	120	4	TF Activity	0-20	23K	1978	^{137}Cs

2.2.2 Undetermined

Infrequently, stability cannot be determined due to gross gamma energy levels exceeding the system design criteria (both upper and lower limits), insufficient data, possible effects of depth shift, and surface activities. 11 of 92 zones in the 48 contaminated dry wells examined in the C Tank Farm are undetermined: These zones are listed in Table 4.

Table 4. C Tank Farm Undetermined Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
30-00-01	70	4	Undetermined	58-70	300	1984	^{137}Cs
30-00-11	58	4	Undetermined	3-14	1000	1977	^{137}Cs
30-00-22	55	4	Undetermined	0-13	15K	1977	^{137}Cs
30-03-01	125	4	Undetermined	40-70	600	1976	^{137}Cs
30-03-03	130	4	Undetermined	14-40	2800	1975	^{137}Cs
30-04-01	50	4	Undetermined	8-22	400	1975	^{137}Cs
30-05-02	130	4	Undetermined	14-26	600	1975	^{137}Cs
30-05-05	100	4	Undetermined	56-80	1800	1975	^{137}Cs, ^{60}Co
30-05-07	67	4	Undetermined	45-66	400	1981	^{137}Cs
30-05-08	50	4	Undetermined	11-26	12K	1975	^{137}Cs, ^{60}Co, ^{154}Eu
30-05-08	50	4	Undetermined	26-53	14K	1975	^{137}Cs, ^{60}Co

2.2.3 Stable

The subsurface condition of a zone with radioactive contamination is considered stable when:

- The decay rate of the isotope(s) identified with SGLS matches the trend observed in the GTP of the gross gamma ray data, or
- Contaminants continue to decay at a rate consistent with the hypothesized isotope(s) half-life, and
- No noticeable change in concentration is apparent over the short time interval that data were collected.

Twenty-four are considered stable in C Tank Farm and these zones are listed in Table 5.

Table5. C Tank Farm Stable Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
30-00-24	60	4	Stable	14-24	800	1977	^{106}Ru
30-00-24	60	4	Stable	24-40	700	1977	^{106}Ru
30-01-01	100	4	Stable	30-53	1200	1975	^{137}Cs,^{106}Ru
30-01-06	100	4	Stable	71-83	600	1975	^{106}Ru
30-01-06	100	4	Stable	83-95	220	1975	^{106}Ru
30-01-09	100	4	Stable	20-33	40K	1975	^{137}Cs
30-01-09	100	4	Stable	33-60	14K	1975	^{137}Cs,^{106}Ru
30-01-12	100	4	Stable	10-18	100	1975	^{137}Cs
30-03-07	130	4	Stable	42-54	170	1975	^{137}Cs
30-03-09	100	4	Stable	40-52	150	1975	^{137}Cs
30-04-03	50	4	Stable	16-30	70K	1983	^{137}Cs
30-04-08	145	4	Stable	10-26	1000	1975	^{137}Cs
30-04-08	145	4	Stable	26-38	150	1975	^{137}Cs
30-04-08	145	4	Stable	38-50	120	1975	^{137}Cs
30-05-06	60	4	Stable	40-53	400	1975	^{137}Cs,^{60}Co
30-05-07	67	2	Stable	30-45	20K	1983	^{137}Cs
30-06-04	130	4	Stable	16-32	600	1975	^{137}Cs
30-07-01	100	4	Stable	0-14	120	1975	^{137}Cs
30-09-02	100	4	Stable	82-100	200	1975	^{60}Co
30-09-10	100	4	Stable	20-38	200	1975	^{137}Cs
30-09-10	100	4	Stable	50-70	100	1975	^{137}Cs
30-09-10	100	4	Stable	70-94	200	1975	^{137}Cs
30-10-02	100	4	Stable	42-50	80	1975	^{137}Cs
30-12-13	120	4	Stable	20-50	1800	1978	^{137}Cs, ^{60}Co, ^{154}Eu ^{106}Ru

The term "Stable", as used in this analysis, is defined as the apparent match of the decay curve to that for the isotopes known or hypothesized to be present, and does not refer to the inherent condition of the contamination. The mobility of the radioactive contaminants in the subsurface soils before or after the gross gamma ray and SGLS data collection period is undetermined. If a new driver were introduced (e.g., the influx of a large volume of liquid), contaminants could be remobilized. Similarly, a change in geochemical conditions in the soil could also affect mobility. Given the current gross gamma and SGLS data, it cannot be determined if remobilization will or will not occur.

2.2.4 Unstable

The subsurface condition of a zone with radioactive contamination is considered unstable when, at some point within the time interval of data collection, contamination was not decreasing at the decay rate of the isotope(s) identified with SGLS. In this case, the decay curve does not match the trend observed in the GTP of the identified or hypothesized isotope. In the C Tank Farm, 20 zones are identified which exhibited instability within the time period that gross gamma ray data were collected. In 11 of these zones, instability occurs during the earlier years of data collection for certain depth intervals; however, in later years, the GTP follows the decay curve of the known or hypothesized isotopes. A listing of "unstable early" and unstable zones is presented in Table 6.

Table 6. C Tank Farm Unstable Early and Unstable Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
30-01-06	100	4	Unstable Early	30-41	250	1980	137Cs
30-03-03	130	4	Unstable Early	78-100	1500	1975	60Co,106Ru
30-04-02	135	4	Unstable Early	32-60	3K	1975	^{60}Co
30-05-02	130	4	Unstable Early	68-84	250	1976	^{137}Cs,^{60}Co
30-05-10	135	4	Unstable Early	17-35	500	1976	^{137}Cs,^{60}Co,^{106}Ru
30-06-12	100	4	Unstable Early	14-26	300	1979	^{137}Cs,^{60}Co
30-09-01	100	4	Unstable Early	88-100	400	1977	^{137}Cs,^{60}Co
30-09-06	100	4	Unstable Early	72-88	1000	1983	^{60}Co
30-10-09	100	4	Unstable Early	40-60	1700	1975	^{106}Ru
30-12-01	100	4	Unstable Early	34-48	200	1978	^{60}Co,^{106}Ru
30-03-01	125	4	Unstable	90-125	300	1984	^{60}Co
30-03-09	100	4	Unstable	73-94	500	1988	^{60}Co
30-04-03	50	4	Unstable	30-48	8K	1981	^{60}Co
30-05-03	100	4	Unstable	67-80	400	1975	^{60}Co
30-05-05	100	4	Unstable	40-56	550	1976	^{137}Cs
30-06-10	130	4	Unstable	86-115	300	1989	^{60}Co
30-08-02	100	4	Unstable	46-55	1500	1980	^{60}Co
30-08-02	100	4	Unstable	55-84	12K	1980	^{60}Co
30-09-02	100	4	Unstable	40-58	1100	1976	^{60}Co
30-09-07	125	4	Unstable	72-90	1100	1983	^{60}Co

ANALYSIS AND SUMMARY REPORT OF HISTORICAL DRY WELL GAMMA LOGS FOR THE 241-A TANK FARM-200 EAST FROM RANDALL AND PRICE 2001B

Europium-154 is present in three zones in combination with cesium-137, and present in one of these three zones with both cesium-137 & cobalt-60.

Ruthenium-106 is present as the sole isotope in seven zones.

The isotopes identified in A Tank Farm with the SGLS exist primarily under three categories of subsurface conditions: tank farm activity, stable, and undetermined. Two unstable conditions, and five "unstable early" conditions are present in A Tank Farm. Dry well locations (centered on the borehole name) are labeled with the conditions of subsurface zones and are shown in Figure 2. A single symbol for a dry well may indicate multiple zones of the same designation.

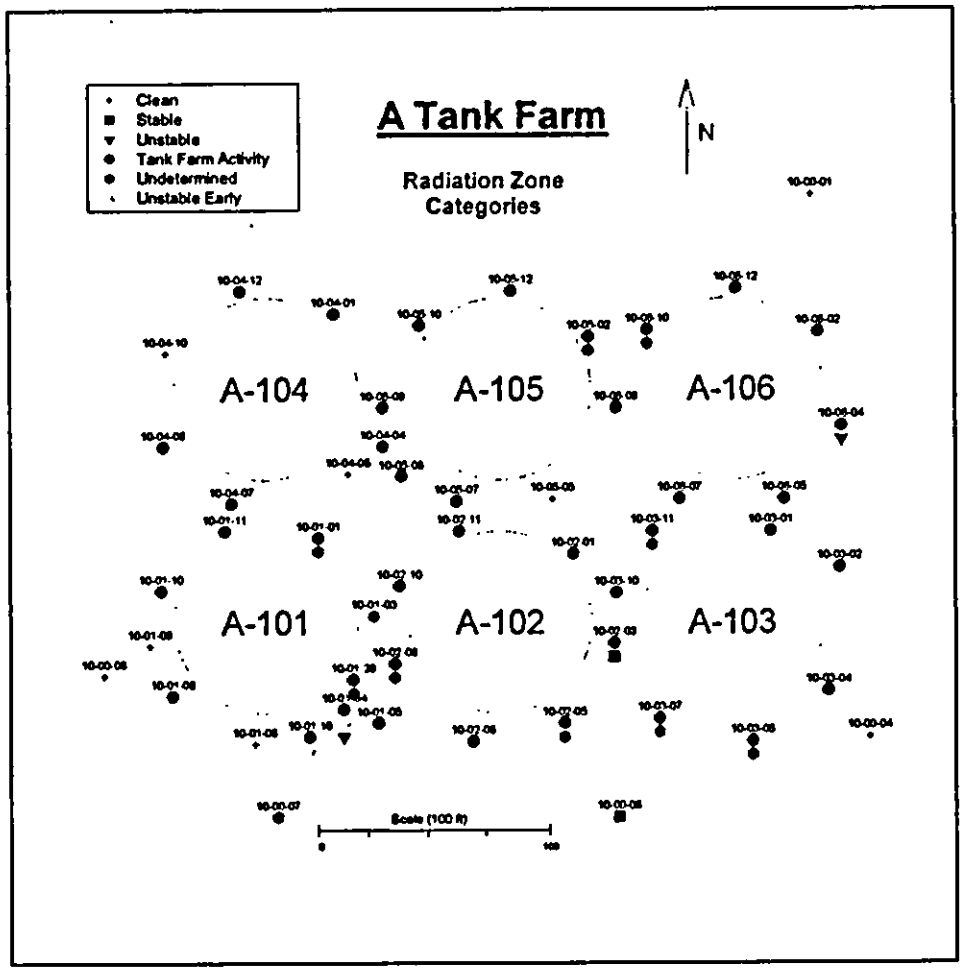


Figure 2. A Tank Farm Radiation Zone Categories

2.2.1 Tank Farm Activity

A sudden, significant change in the intensity of gross gamma rays between successive gross gamma surveys at or near the ground surface suggests that contamination may have resulted from tank farm activities or logging procedure changes. Radioactive contamination occurs at the surface in 40 wells as the result of tank farm activities (i.e., logging procedure changes, transfer line operations, valve box and conduit leaks, surface spills, etc.). These wells and two with deep tank farm activity are listed in Table 3.

Table 3. A Tank Farm Activity Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotope Present
10-01-01	125	4	TF Activity	0-16	1000	1985	^{137}Cs
10-01-04	125	4	TF Activity	0-16	1000	1984	^{137}Cs
10-01-05	155	4	TF Activity	0-10	1000	1976	^{137}Cs
10-01-08	125	4	TF Activity	0-13	700	1977	^{137}Cs
10-01-10	125	4	TF Activity	0-15	300	1984	^{137}Cs
10-01-11	125	4	TF Activity	0-18	1200	1984	^{137}Cs
10-01-16	55	4	TF Activity	0-16	500	1985	^{137}Cs
10-01-28	45	4	TF Activity	0-10	700	1984	$^{137}Cs, ^{60}Co$
10-02-01	125	4	TF Activity	0-18	4K	1980	^{137}Cs
10-02-03	125	4	TF Activity	0-20	600	1985	^{137}Cs
10-02-05	125	4	TF Activity	0-10	300	1984	^{137}Cs
10-02-06	90	4	TF Activity	0-10	600	1975	^{137}Cs
10-02-08	125	4	TF Activity	0-10	200K	1994	^{137}Cs
10-02-10	125	4	TF Activity	0-11	12K	1991	^{137}Cs
10-02-11	125	4	TF Activity	0-20	600	1984	^{137}Cs
10-03-01	125	4	TF Activity	0-16	1000	1985	^{137}Cs
10-03-02	130	4	TF Activity	0-25	600	1984	^{137}Cs
10-03-04	125	4	TF Activity	0-20	500	1984	^{137}Cs
10-03-05	125	4	TF Activity	0-20	600	1984	^{137}Cs
10-03-07	125	4	TF Activity	0-20	2K	1984	^{137}Cs
10-03-10	150	4	TF Activity	0-14	3K	1980	$^{137}Cs, ^{154}Eu$
10-03-11	90	4	TF Activity	0-12	15K	1976	^{137}Cs
10-04-01	125	4	TF Activity	0-10	200	1975	^{137}Cs
10-04-04	150	4	TF Activity	0-14	6K	1976	^{137}Cs
10-04-07	125	4	TF Activity	0-10	100	1975	^{137}Cs
10-04-08	125	4	TF Activity	0-10	250	1984	^{137}Cs
10-04-12	75	4	TF Activity	0-14	2K	1979	$^{137}Cs, ^{154}Eu$
10-05-02	125	4	TF Activity	0-10	200	1979	^{137}Cs
10-05-07	75	4	TF Activity	0-8	200	1984	^{137}Cs
10-05-08	60	4	TF Activity	0-18	3K	1975	^{137}Cs
10-05-09	75	4	TF Activity	0-10	500	1985	^{137}Cs

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotope Present
10-05-10	125	4	TF Activity	0-22	1000	1979	^{137}Cs
10-05-12	75	4	TF Activity	0-15	3K	1975	^{137}Cs
10-05-12	75	4	TF Activity	72-80	1000	1975	^{137}Cs
10-06-02	125	4	TF Activity	0-15	1000	1979	^{137}Cs
10-06-04	125	4	TF Activity	0-12	400	1984	^{137}Cs
10-06-05	75	4	TF Activity	0-18	4K	1980	^{137}Cs
10-06-07	125	4	TF Activity	0-18	600	1979	^{137}Cs
10-06-09	125	4	TF Activity	0-18	800	1985	^{137}Cs
10-06-09	125	4	TF Activity	80-90	300	1975	^{137}Cs
10-06-10	125	4	TF Activity	0-10	10K	1976	^{137}Cs
10-06-12	105	4	TF Activity	0-20	1400	1984	^{137}Cs

2.2.2 Undetermined

Infrequently, stability cannot be determined due to gross gamma energy levels exceeding the system design criteria (both upper and lower limits), insufficient data, possible effects of depth shift, and surface activities. Thirty-two of 95 zones in the 61 contaminated dry wells or laterals examined in the A Tank Farm are undetermined. These zones are listed in Table 4.

Table 4. A Tank Farm Undetermined Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
10-00-07	150	4	Undetermined	0-8	300	1991	^{137}Cs
10-01-01	125	4	Undetermined	68-80	600	1975	^{137}Cs
10-01-03	80	4	Undetermined	0-14	300K	1975	^{137}Cs
10-01-28	45	4	Undetermined	10-45	160K	1984	$^{137}Cs, ^{60}Co, ^{154}Eu$
10-02-05	125	4	Undetermined	10-17	100	1979	^{137}Cs
10-02-08	125	4	Undetermined	70-80	100	1975	^{137}Cs
10-02-08	125	4	Undetermined	80-90	50	1989	^{60}Co
10-03-05	125	4	Undetermined	70-85	200	1975	^{137}Cs
10-03-07	125	4	Undetermined	50-75	4K	1975	^{137}Cs
10-03-07	125	4	Undetermined	75-88	200	1978	^{137}Cs
10-03-11	90	4	Undetermined	80-90	400	1976	^{137}Cs
10-05-02	125	4	Undetermined	60-80	15K	1975	^{106}Ru
10-05-02	125	4	Undetermined	90-108	4K	1978	^{106}Ru
10-06-10	125	4	Undetermined	100-110	200	1979	^{106}Ru
Laterals							
10-01-01L	150	1	Undetermined	20-30	500	1978	^{137}Cs
10-01-02L	160	1	Undetermined	20-30	500	1978	^{137}Cs
10-01-03L	150	1	Undetermined	20-30	500	1978	^{137}Cs
10-02-01L	175	1	Undetermined	20-30	500	1978	^{137}Cs

10-02-02L	180	1	Undetermined	20-30	500	1978	^{137}Cs
10-02-03L	175	1	Undetermined	20-30	500	1978	^{137}Cs
10-03-01L	175	1	Undetermined	20-30	500	1978	^{137}Cs
10-03-02L	180	1	Undetermined	20-30	500	1978	^{137}Cs
10-03-03L	175	1	Undetermined	20-30	500	1978	^{137}Cs
10-04-01L	178	1	Undetermined	20-30	500	1978	^{137}Cs
10-04-02L	190	1	Undetermined	20-30	500	1978	^{137}Cs
10-04-02L	190	1	Undetermined	140-170	1K	1978	^{106}Ru
10-04-03L	175	1	Undetermined	20-30	500	1978	^{137}Cs
10-04-03L	175	1	Undetermined	152-164	50	1978	^{106}Ru
10-05-03L	175	2	Undetermined	148-163	20K	1981	^{137}Cs
10-06-01L	155	1	Undetermined	20-30	500	1978	^{137}Cs
10-06-02L	165	1	Undetermined	20-30	500	1978	^{137}Cs
10-06-03L	155	1	Undetermined	20-30	500	1978	^{137}Cs

2.2.3 Stable

The subsurface condition of a zone with radioactive contamination is considered stable when:

- The decay rate of the isotope(s) identified with the SGLS matches the trend observed in the GTP of the gross gamma ray data, or
- Contaminants continue to decay at a rate consistent with the hypothesized isotope(s) half-life, and
- No noticeable change in concentration is apparent over the short time interval that data were collected.

Fourteen zones are classified as stable in A Tank Farm and these zones are listed in Table 5.

Table 5. A Tank Farm Stable Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
10-00-06	150	4	Stable	12-25	200	1975	^{137}Cs
10-02-03	125	4	Stable	72-82	100	1980	^{137}Cs
10-03-01L	175	1	Stable	54-70	800	1978	^{137}Cs
10-03-02L	180	1	Stable	54-70	800	1978	^{137}Cs
10-03-03L	175	1	Stable	54-70	800	1978	^{137}Cs
10-04-01L	178	1	Stable	94-130	800	1977	^{106}Ru
10-04-02L	190	1	Stable	108-116	70	1977	^{106}Ru
10-04-02L	190	1	Stable	140-170	1500	1977	^{106}Ru
10-04-03L	175	1	Stable	152-164	100	1977	^{106}Ru
10-05-01L	175	2	Stable	150-170	400	1980	^{137}Cs
10-05-02L	185	2	Stable	85-110	7K	1977	^{137}Cs

10-05-02L	185	2	Stable	165-180	300	1977	^{137}Cs
10-05-03L	175	2	Stable	94-110	700	1980	^{137}Cs
10-06-01L	155	1	Stable	56-75	1000	1978	^{137}Cs
10-06-02L	165	1	Stable	56-75	1000	1978	^{137}Cs
10-06-03L	155	1	Stable	56-75	1000	1978	^{137}Cs

The term "Stable", as used in this analysis, is defined as the apparent match of the GTP values to the decay curve for the isotopes known or hypothesized to be present, and does not refer to the inherent condition of the contamination. The mobility of the radioactive contaminants in the subsurface soils before or after the gross gamma ray and SGLS data collection period is undetermined. If a new driver were introduced (e.g., the influx of a large volume of liquid), contaminants could be remobilized. Similarly, a change in geochemical conditions in the soil could also affect mobility. Given the current gross gamma and SGLS data, it cannot be determined if remobilization will or will not occur.

2.2.4 Unstable

The subsurface condition of a zone with radioactive contamination is considered unstable when, at some point within the time interval of data collection, contamination was not decreasing at the decay rate of the isotope(s) identified with SGLS. In this case, the decay curve does not match the trend observed in the GTP of the identified or hypothesized isotope. In the A Tank Farm, seven zones are identified which exhibited instability within the time period that gross gamma ray data were collected. In five of these zones, instability occurs during the earlier years of data collection for certain depth intervals; however, in later years, the GTP follows the decay curve of the known or hypothesized isotopes. A listing of "unstable early" and unstable zones is presented in Table 6.

Table 6. A Tank Farm Unstable Early and Unstable Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
10-01-04	125	4	Unstable-Early	33-48	6K	1984	^{60}Co
10-01-04	125	4	Unstable-Early	48-62	1100	1986	^{60}Co
10-01-16	55	4	Unstable-Early	16-54	50K	1984	^{60}Co
10-05-10	125	4	Unstable-Early	22-60	2K	1979	^{137}Cs
10-05-10	125	4	Unstable-Early	73-90	500	1975	^{137}Cs
10-01-04	125	4	Unstable	62-70	400	1987	^{60}Co
10-06-04	125	4	Unstable	12-24	600	1975	^{60}Co

3 Details of Contaminated Conditions

Characteristics of the contaminated zones are summarized in the following discussions.

3.1 Stable Zones

The fixed decay rate of the isotope(s) present is used to calculate the decay curves (Figure 3). Table 7 lists the half-life of the isotopes encountered in the A Tank Farm.

ANALYSIS AND SUMMARY REPORT OF HISTORICAL DRY WELL GAMMA LOGS FOR THE 241-AX TANK FARM – 200 EAST FROM PRICE 2001

Cesium-137 was identified in 18 zones, most often as the sole isotope in a zone, although it is found with other gamma-emitting isotopes in six zones.

Antimony-125, Cobalt-60, and europium-154 were identified by the HPGe survey in six total zones, always with other isotopes (generally cesium-137).

Ruthenium-106 is hypothesized as the sole isotope in nine zones and is present with cobalt-60 in one zone.

The isotopes identified in AX Tank Farm with the HPGe detector exist primarily under three categories of subsurface conditions: tank farm activity, unstable early, and stable. Nine unstable early conditions, two stable, and seventeen tank farm activity zones are present in AX Tank Farm. Dry well locations (centered on the borehole name) and the conditions of subsurface zones are shown in Figure 2. A single symbol for a dry well may indicate multiple zones of the same designation.

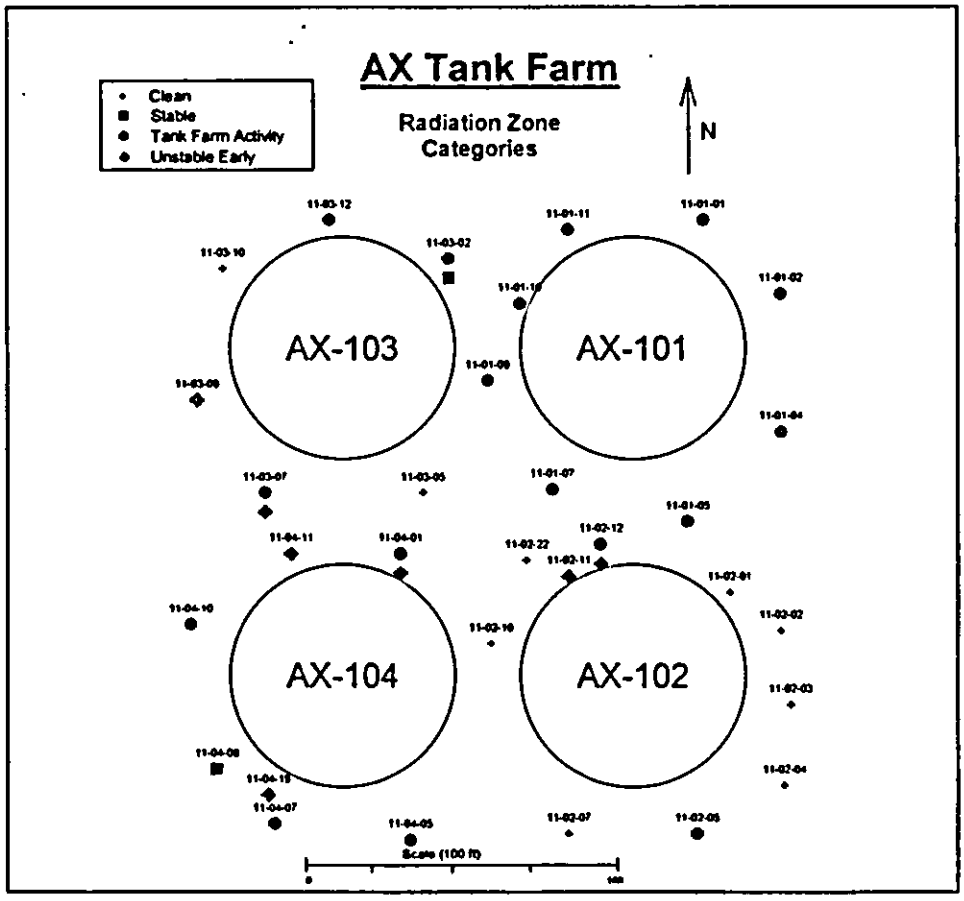


Figure 2. AX Tank Farm Radiation Zone Categories

2.2.1 Tank Farm Activity

A sudden, significant change in the intensity of gross gamma rays between successive gross gamma surveys at or near the ground surface suggests that contamination may have resulted from tank farm activities or logging procedure changes. Radioactive contamination occurs at the surface in seventeen wells, apparently as the result of tank farm activities (i.e., logging procedure changes, transfer line operations, valve box and conduit leaks, surface spills, etc.). These wells are listed in Table 3.

Table 3. AX Tank Farm Activity Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Top (feet)	Zone Base (feet)	Max GTP (ft x c/s)	Year Max	Isotopes Present
11-01-01	100'	4	TF Activity	0	22	400	1975	^{137}Cs
11-01-02	100'	4	TF Activity	0	10	300	1984	^{137}Cs
11-01-04	100'	4	TF Activity	0	12	200	1975	^{137}Cs
11-01-05	100'	4	TF Activity	0	18	500	1984	^{137}Cs
11-01-07	100'	4	TF Activity	0	12	4K	1975	^{137}Cs, ^{154}Eu
11-01-09	103'	4	TF Activity	0	14	400	1983	^{137}Cs
11-01-10	75'	4	TF Activity	0	20	350K	1985	^{137}Cs, ^{154}Eu
11-01-11	100'	4	TF Activity	0	8	400	1984	^{137}Cs
11-02-05	100'	4	TF Activity	0	8	300	1975	^{137}Cs
11-02-12	50'	4	TF Activity	0	27	200K	1975	^{137}Cs
11-03-02	100'	4	TF Activity	0	29	140K	1975	^{137}Cs
11-03-07	104'	4	TF Activity	0	14	75K	1975	^{137}Cs, ^{154}Eu
11-03-12	100'	4	TF Activity	0	20	5K	1975	^{137}Cs, ^{125}Sb
11-04-01	100'	4	TF Activity	0	12	200	1985	^{137}Cs
11-04-05	100'	4	TF Activity	0	10	400	1975	^{137}Cs
11-04-07	96'	4	TF Activity	0	8	400	1976	^{137}Cs
11-04-10	102'	4	TF Activity	0	15	35K	1985	^{137}Cs

2.2.2 Undetermined

Infrequently, stability cannot be determined due to gross gamma energy levels exceeding the system design criteria (both upper and lower limits), insufficient data, possible effects of depth shift, and surface activities. No zones in the AX Tank Farm are categorized as undetermined.

2.2.3 Stable

The subsurface condition of a zone with radioactive contamination is considered stable when:

- The decay rate of the isotope(s) identified with HPGe survey matches the trend observed in the GTP of the gross gamma ray data,

- Contaminants continue to decay at a rate consistent with the hypothesized isotope(s) half-life, and
- No noticeable change in concentration is apparent over the short time interval that data were collected.

Two zones are considered stable in AX Tank Farm and are listed in Table 5.

Table 4. AX Tank Farm Stable Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Top (feet)	Zone Base (feet)	Max GTP (ft x c/s)	Year Max	Isotopes Present
11-03-02	100'	4	Stable	29	40	2K	1975	^{137}Cs, ^{125}Sb
11-04-08	100'	4	Stable	60	72	500	1980	^{106}Ru

The term "Stable", as used in this analysis, is defined as the apparent match of the GTP values to the decay curve for the isotopes known or hypothesized to be present, and does not refer to the inherent condition of the contamination. The mobility of the radioactive contaminants in the subsurface soils before or after the gross gamma ray and HPGe data collection period is undetermined. If a new driver were introduced (e.g., the influx of a large volume of liquid), contaminants could be remobilized. Similarly, a change in geochemical conditions in the soil could also affect mobility. Given the current gross gamma and HPGe data, it cannot be determined if remobilization will or will not occur.

2.2.4 Unstable

The subsurface condition of a zone with radioactive contamination is considered unstable when, at some point within the time interval of data collection, contamination was not decreasing at the decay rate of the isotope(s) identified with HPGe detector. In this case, the decay curve does not match the trend observed in the GTP of the identified or hypothesized isotope. In the AX Tank Farm, nine zones are identified which exhibited instability within the time period that gross gamma ray data were collected. In each of these nine zones the instability occurred during the earlier years of data collection for certain depth intervals; however, in later years, the GTP follows the decay curve of the known or hypothesized isotopes. A listing of the nine unstable early zones is presented in Table 6.

The rate of decrease in the GTP for four of the unstable early zones is faster than the hypothesized isotope (^{106}Ru) which may indicate that either the isotope selection may need to be revised, or that the contaminant migration rate could be high, or both (boreholes: 11-03-07; 14-40 ft, 11-03-09, 11-04-01, and 11-04-11; 18-33 ft).

Table 5. AX Tank Farm Unstable Early Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Top (feet)	Zone Base (feet)	Max GTP (ft x c/s)	Year Max	Isotopes Present
11-02-11	100'	4	Unstable Early	50	65	700	1980	^{106}Ru
11-02-12	50'	14	Unstable Early	32	50	20K	1975	^{106}Ru, ^{60}Co

11-03-07	104'	4	Unstable Early	14	40	5K	1976	^{106}Ru
11-03-07	104'	4	Unstable Early	66	82	400	1976	^{106}Ru
11-03-09	120'	4	Unstable Early	48	106	14K	1975	^{106}Ru
11-04-01	100'	4	Unstable Early	14	68	50K	1975	^{106}Ru
11-04-11	125'	4	Unstable Early	18	82	11K	1975	^{106}Ru
11-04-11	125'	4	Unstable Early	90	102	300	1977	^{106}Ru
11-04-19	125'	4	Unstable Early	56	78	200	1978	^{106}Ru

3 Details of Contaminated Conditions

Characteristics of the contaminated zones are summarized in the following discussions.

3.1 Stable Zones

The fixed decay rate of the isotope(s) present is used to calculate the decay curves (Figure 3). Table 6 lists the half-life of the isotopes encountered in the AX Tank Farm.

When a contaminated interval contains multiple isotopes, the intensity of the slowest decay component is plotted to match the data over the most recent time period for which data exist. Faster decay isotopes are then clearly indicated as necessary to match the trend of the GTP values. When the decay curve fits the GTP plot, a stable condition is said to exist. When the decay curve does not fit any portion of the GTP plot, stability cannot be established. The factors responsible for instability are beyond the scope of this report.

Several zones within a number of wells in the AX Tank Farm exhibit gross gamma ray activity above natural background. Some of these radioactive intervals are observed to be stable as verified by the change in GTP over time which coincides with the decay rate of the isotope(s) identified or hypothesized to have been present in the soil surrounding the dry well during the time interval data were collected. The isotopes present in these zones vary and are presented above in Table 3 through Table 5. In general, they occur as follows:

- Cs-137 is present in all of the tank farm activity zones, in half (one) of the stable zones and in none of the unstable early zones.
- Ru-106 is hypothesized as present in half (one) of the stable zones and all of the unstable early zones. In several unstable early zones the rate of decline in the GTP is greater than the decay rate of Ru-106, which may indicate a contaminant with high mobility.
- Co-60 occurs in one zone (unstable early) and in combination with other isotopes.
- Eu-154 occurs in three tank farm activity zones, each time with Cs-137.
- Sb-125 occurs in two zones, one tank farm activity and one stable zone. Each time Sb-125 occurs with Cs-137.

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APPENDIX F

ADDITIONAL CHARACTERIZATION DATA OF UNPLANNED RELEASES UPR-200-E-82 AND UPR-200-E-86

CONTENTS

F.1.0 INTRODUCTION F-1
F.2.0 UPR-200-E-82 FIELD CHARACTERIZATION DATA F-2
F.3.0 UPR-200-E-86 FIELD CHARACTERIZATION DATA F-13
F.4.0 REFERENCE F-19

F.1.0 INTRODUCTION

Appendix F provides summary documentation from field investigations of transfer line leaks that occurred in the western part of the C WMA and released derivatives of PUREX high activity waste near surface (Maxfield 1979). The leaks occurred in 1969 (UPR-200-E-82) and 1971 (UPR-200-E-86). In these investigations, several shallow auger holes were drilled around the leak sources and soil samples collected and analyzed for Cs-137 content. From these data approximate three-dimensional mappings of the nature and extent of the leaks were determined, at least for the chemically reactive constituents in the waste.

F.2.0 UPR-200-E-82 FIELD CHARACTERIZATION DATA

B PLANT ION EXCHANGE FEED LINE LEAK

INTRODUCTION

One of the objectives of the Waste Management Program is to separate the long-lived heat emitter ^{137}Cs from the bulk of the high-level liquid wastes. This separation is accomplished by the ion exchange process in the 221-B Building. Interim storage of the cesium is in solution as a nitrate. The cesium will later be converted to a solid salt as cesium chloride and encapsulated for permanent storage.

The feed for the B Plant cesium ion exchange process is pumped from the lag storage tank, 105-C, through a pipeline and several diversion boxes to the 221-B Building. On December 19, 1969, a leak was discovered near the 241-C-152 diversion box in the section of this line, V-122, from the 105-C tank.

Although the leak represented a loss of feed for the processing of ^{137}Cs, more important, however, was the consequence of environmental contamination to the soil from the line leak. For this reason, an investigation was made to establish the extent of the radioactivity spread. This report summarizes the results of a well drilling operation undertaken to define the boundary and to estimate the extent of the leak.

SUMMARY

Ten wells were drilled at radial distances from 4 to 16 feet from the leak source and to depths of 30 feet, whenever possible. Analytical results of ^{137}Cs, the major constituent of the waste solution, were used as the basis for determining the configuration and content of the leak volume. Three general concentration zones of 550, 100, and 10 μCi ^{137}Cs/gram of soil were plotted from the analytical data. The highest concentration zone, 550 μCi ^{137}Cs/gm of soil, corresponds to soil saturated with waste solution that contains 4.0 Ci ^{137}Cs/gal. Within an error 10 percent, this saturated region is verified by the ion exchange feed concentration of 4.34 Ci ^{137}Cs/gal.

The volume of waste solution that leaked to the soil was estimated at 2600 gallons. This volume, which included an approximate 100 gallons that surfaced and collected near a

fence line, contained 11,300 Ci ^{137}Cs, 260 Ci ^{144}Ce, 260 Ci $^{95}ZrNb$, 130 Ci ^{106}Ru, and 100 Ci ^{134}Cs. About 705 cubic feet of soil was contaminated with ^{137}Cs. The ^{144}Ce and $^{95}ZrNb$ content of the soil is located in about 40 cubic feet of soil surrounding the leak source. The analytical results indicate that ^{106}Ru has a greater radial migration and deeper penetration than ^{137}Cs. Ruthenium-106 appears to have collected in a spheroidal band from 4 to 8 feet beyond the ^{137}Cs boundary.

No heat problems are expected to result from an estimated maximum temperature increase of 30 °F in the soil near the source of the leak. Also, the radioactivity from the leak will not reach the ground water because of the ion exchange properties of the soil, the depth of the water table level and the light regional rainfall.

LEAK DESCRIPTION

The ion exchange feed line, V-122, was buried about 11 feet below grade level. This line was installed in July 1964, and hydrostatic pressure tested to 200 psig for 30 minutes. It was placed into service in December 1967.

The leak was visually detected by Radiation Monitoring personnel who were passing in the vicinity of the 241-C-152 diversion box. The waste stream flowed through a surface area of about one square foot, northeastward, down a slightly declining grade, and pooled along the side of a small dike outside the tank farm fence line. The pool was estimated to be 5 feet square. Pumping from the 105-C tank to B Plant was immediately halted. Two to three feet of gravel and soil were spread over the leak area to absorb, cover, and shield the surface contamination.

The leak surfaced through an area directly above the location of the joint that connects a 3-inch stainless steel pipe to a 3-inch carbon steel pipe(1). Between the flanges of these pipes is a 3/16-inch linear polyethylene gasket which is speculated to have ruptured. No attempt was made to determine the exact cause of the leak, since the high radioactivity in the vicinity of the leak prohibited the excavation and direct examination of the pipeline.

EVALUATION METHOD

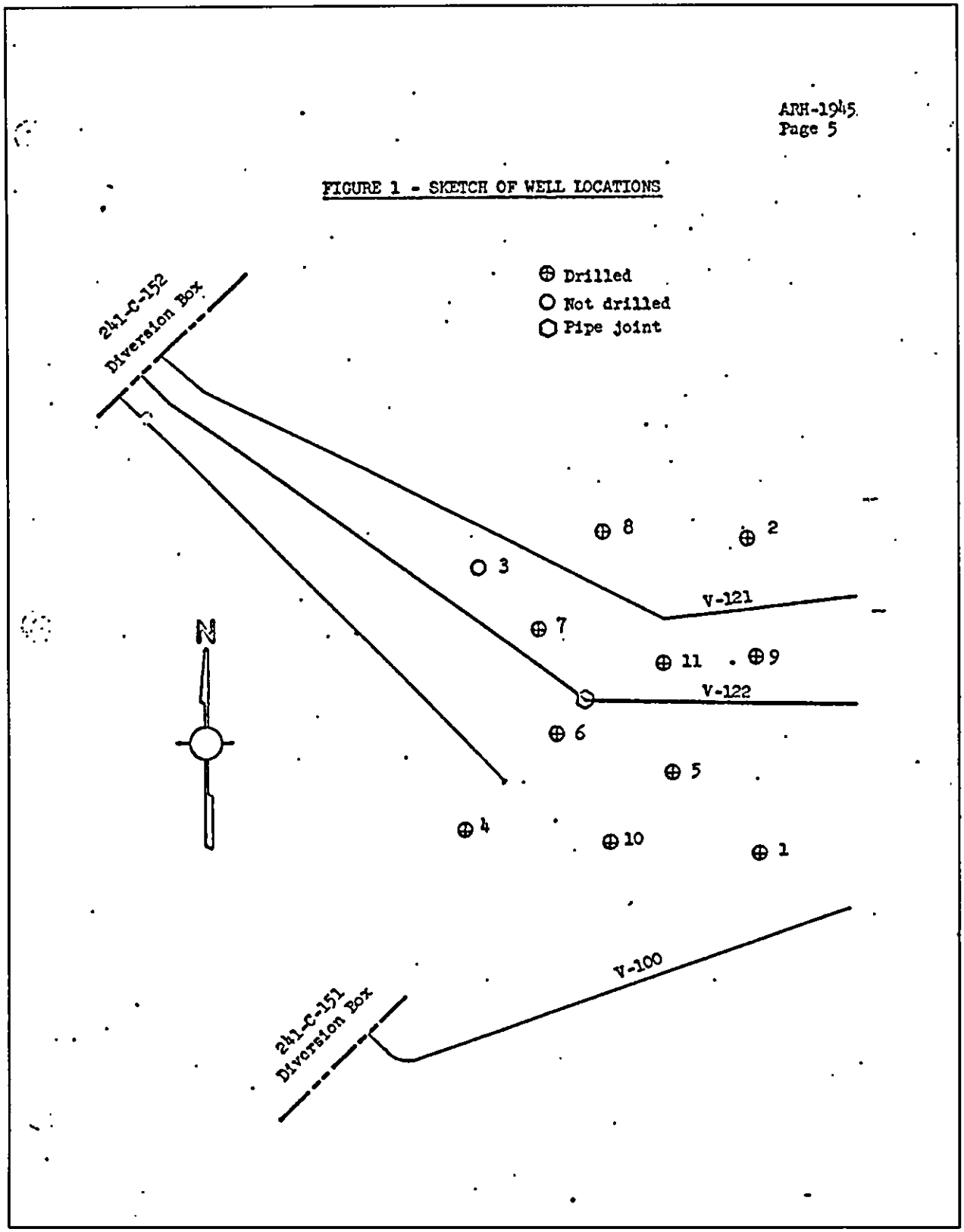
Pacific Northwest Laboratory's Earth Sciences Department personnel drilled 10 wells and obtained all soil samples. These samples were analyzed by the Redox Analytical Laboratory. An excavation permit was issued describing the location of the initial wells, precautions to be taken while drilling, instructions for RM coverage, timekeeping, survey of leak vicinity, and staking of the well locations.

The suspected leak source, the flange near a 36° bend in the pipeline, was used as a base point. From this base point, four initial wells were surveyed and staked to surround the area of the leak. Thereafter, wells were drilled at varied radii closer to the source to obtain data for iso-concentration lines at various depths. The location of these subsequent wells was based upon the position of other existing pipelines(2), the degree of contamination in preceding wells, and an effort to secure sufficient data to evaluate the leak. The number of wells was kept at a minimum to minimize the radiation exposure to the drillers. Well locations are shown in Figure 1.

The drilling rig used a 350-pound cylindrical hammer to drive the sectioned 2-1/4-inch OD steel pipe into the ground. Attached to the end of the steel pipe was a Shelby® sampler, a 24-inch long, split-barrel, stainless steel section with a tapered tip. With this sampler, 1-3/4-inch core samples were obtained. During drilling, the split-barrel sampler was withdrawn from the well at two-foot intervals, disassembled, and its contents examined. The exposed soil was then surveyed with a CP. If any contamination was detected, a field reading was recorded and samples were taken. For significantly high levels of radiation, greater than 50 mR/hr, samples were taken at smaller interval depths.

A variety of soil textures was encountered during drilling, as shown in Figures 2 and 3. The soil layers ranged from sandy clay to kaliche, an almost impenetrable rock-like layer. The very non-porous kaliche layer, nearly 6 inches thick, lay at a depth between 13 to 14 feet, sloping slightly eastward. Except for a few isolated areas, the results from the analytical data indicate that this layer had obstructed the movement of ^{137}Cs to lower depths. Most of the radioactive material was adsorbed more readily onto the sandy clay type of soil, rather than the coarser soils.

® Trade name


ARH-1945
Page 5
FIGURE 1 - SKETCH OF WELL LOCATIONS
Drilled
Not drilled
Pipe joint
241-C-152
Diversion Box
241-C-151
Diversion Box
V-121
V-122
V-100
N
1
2
3
4
5
6
7
8
9
10
11

Samples were placed in pint-size glass jars. As the drilling operations progressed, aluminum cans were found to be more suitable sample containers to eliminate the breakage hazard of glass jars. Also, the aluminum cans could be accommodated within a 75-pound lead-shielded "pig". Highly radioactive samples, i.e., greater than 5 rad/hr., were handled in a special waste container designed to minimize surface contamination and exposure to the drillers prior to transfer into sample containers.

An attempt was made to obtain uniform sample volumes to aid in the laboratory analyses. The soil samples were analyzed by the quantitative gamma spectrum analyses and the results reported on a weight basis, μCi/gm of soil. From these results, the vertical depth profiles were plotted. Concentration profiles for Wells 5 and 11 are shown in Figures 4 and 5. From these profiles, horizontal iso-concentration zones were mapped as shown in Figure 6. The slope of the soil layers and the incline of the pipeline places the center of the iso-concentration contours about two feet east of the base point.

The theoretical shape of the leak in the soil is a sphere for low leak rates of 3 to 10 gpm or teardrop-shaped for higher flow rate leaks of 10 to 20 gpm or greater. The actual shape of the contaminated region based upon the drilling data looks somewhat like that depicted in Figure 7. The kaliche layer and a high leak rate probably caused the leak to move laterally and upward, rather than uniformly outward from the leak source. The concentration contours were considered as circular-shaped in the horizontal plane for calculation purposes. The shape of the iso-concentration lines in the vertical plane is elliptical. The volumes in the lateral directions are calculated as the volumes of an oblate spheroid. The volumes in the vertical direction are one-half the volumes of a prolate spheroid. The major axis is along the center line from the base point to the point where the leak surfaced. See Figure 8.

The average ^{137}Cs concentration of the region surrounding the leak source was 550 μCi ^{137}Cs/gm of soil or 4.0 Ci ^{137}Cs/gal of solution, assuming the soil has a 35 percent void fraction with a volumetric ^{137}Cs distribution coefficient of 0.6 (Ci/ft^3 soil)/(ci/ft^3 sol'n)(3) and an average bulk density of 1.8 gm/cc. This value is within 10 percent of the ion exchange feed concentration of 4.34 Ci ^{137}Cs/gal of solution and verifies that this region around the leak source is saturated.

FIGURE 4 - CONCENTRATION PROFILE OF WELL #5

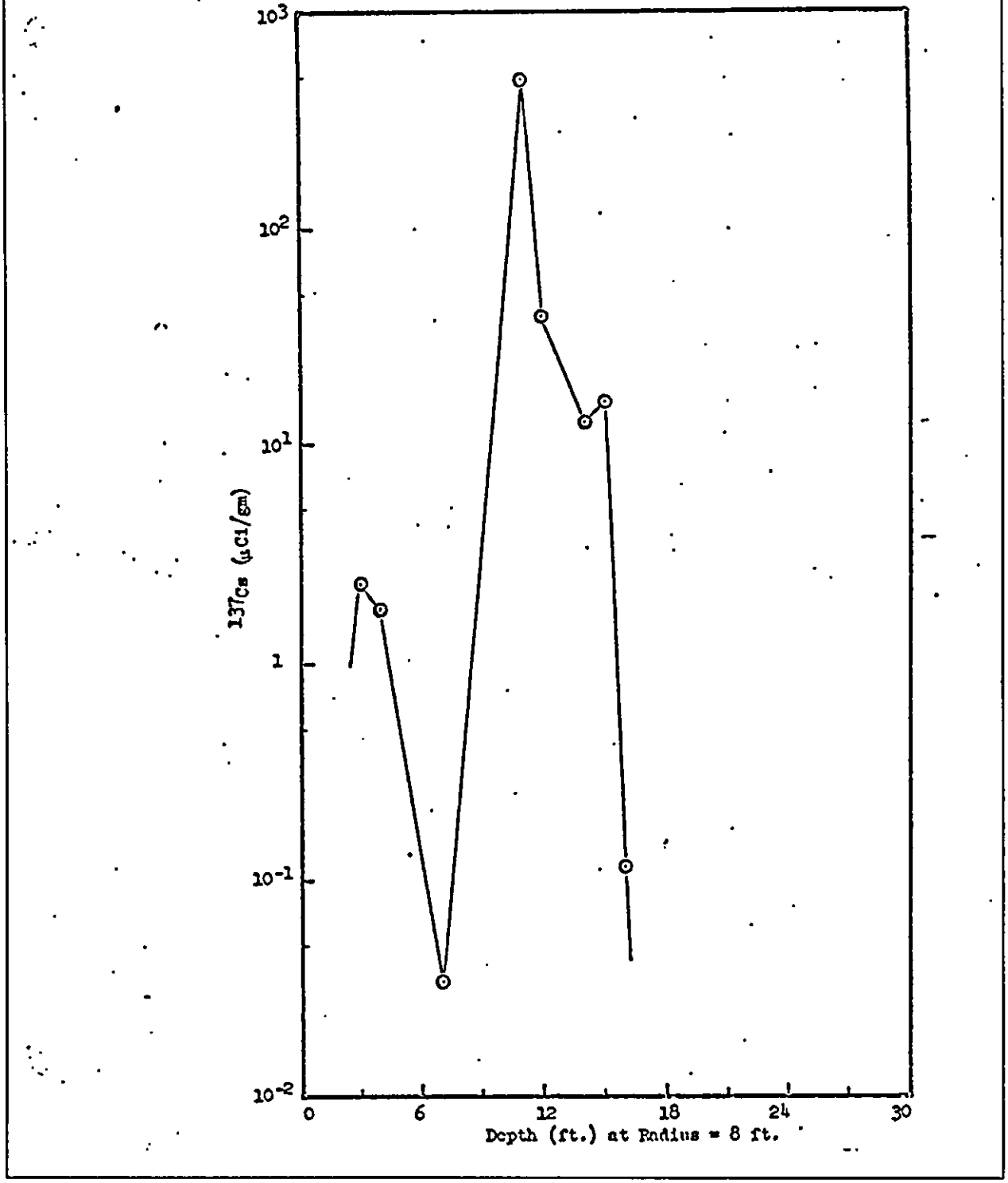


FIGURE 5 - CONCENTRATION PROFILE OF WELL #11

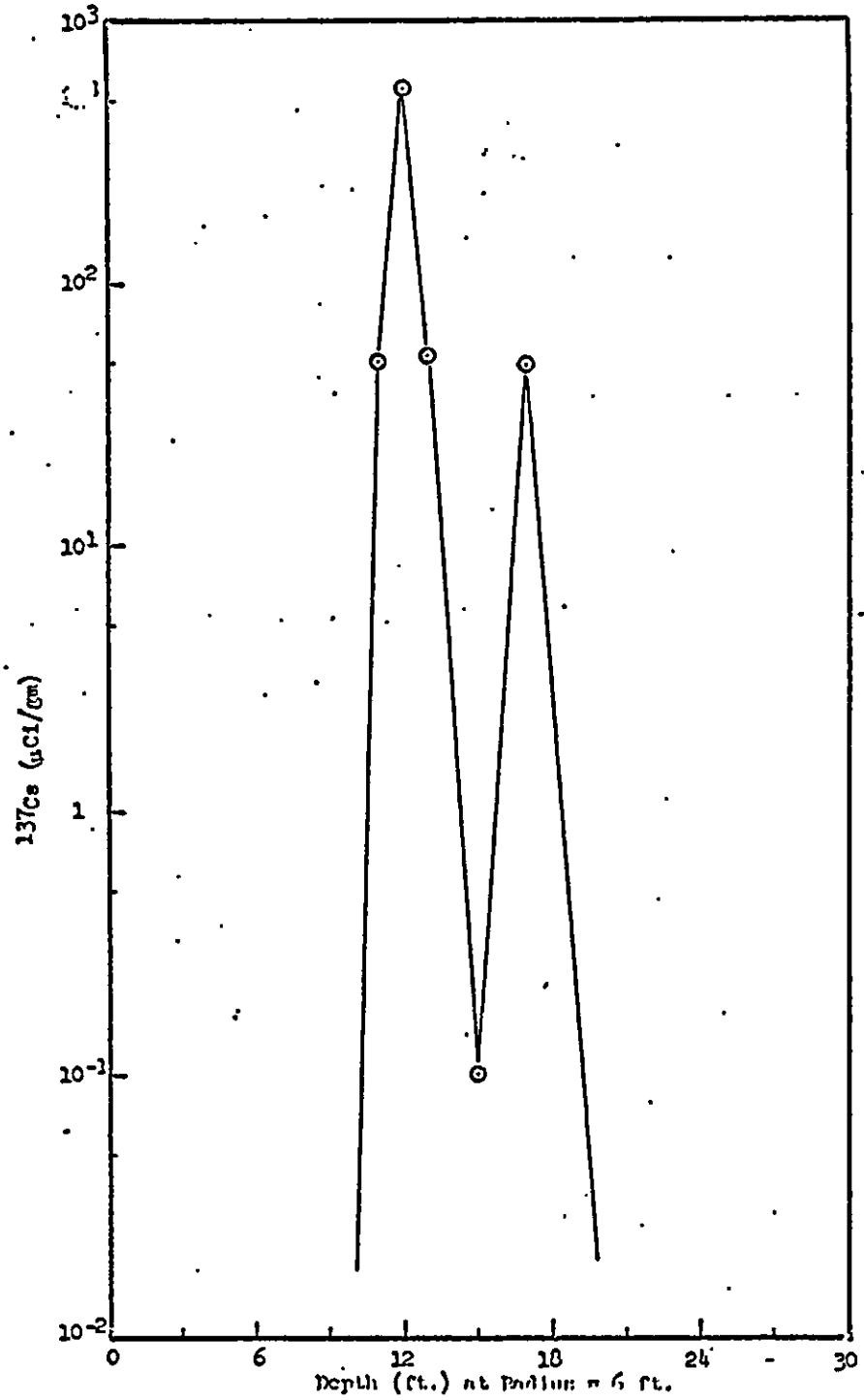


FIGURE 6 - ISO-CONCENTRATION CONTOURS

(μCi ^{137}Cs/gm soil) at a Depth of 11 feet
Relative to Test Wells and Pipe Line

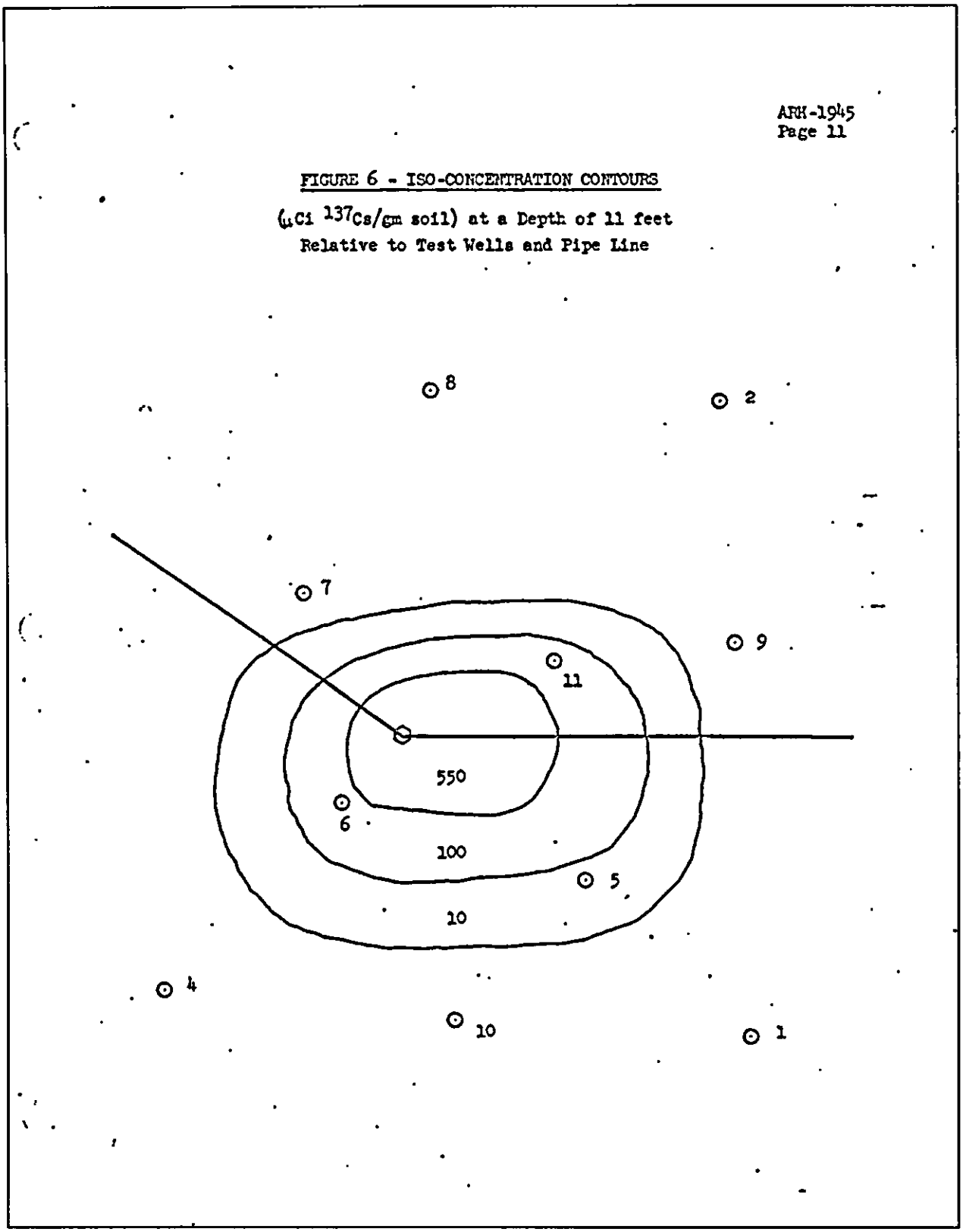


FIGURE 7 -- ACTUAL LEAK CONFIGURATION

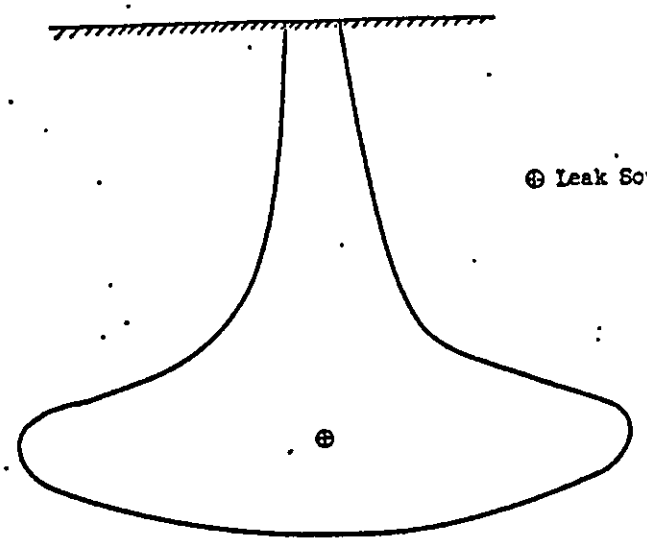
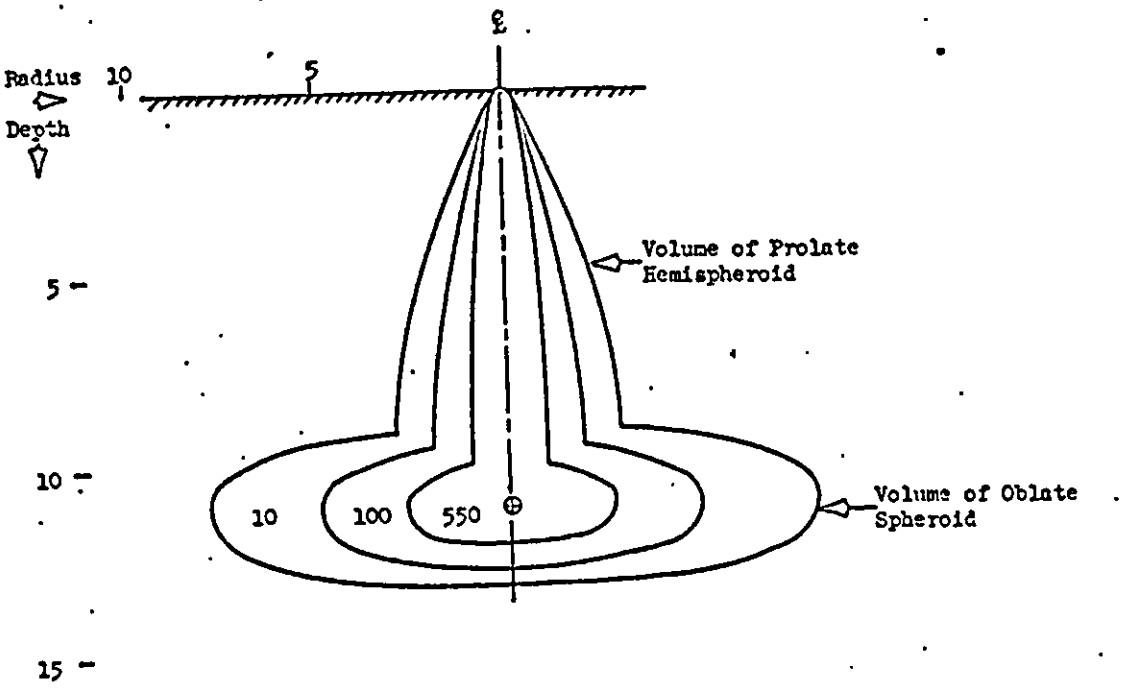


FIGURE 8 - CALCULATIONAL LEAK CONFIGURATION



The ^{137}Cs curie content of each of the iso-concentration regions was calculated from the product of the volume multiplied by the concentration. The total calculated volume of soil contaminated with ^{137}Cs was 705 cubic feet. The total curies of ^{137}Cs that leaked, the sum of each region and the quantity that surfaced, divided by the ion exchange feed solution concentration equals the number of gallons of feed lost through the leak. A leak loss of 2600 gallons and 11,300 curies of ^{137}Cs was calculated. Other radionuclide losses are listed in Table 1, together with the ion exchange feed composition.

TABLE 1

PSN-IX FEED COMPOSITION AND RADIONUCLIDES LEAKED TO THE SOIL

Radionuclide	Feed Composition μCi/gal	Activity Leaked to Soil, Ci
^{137}Cs	4.34	11,300
^{144}Ce	0.10	260
$^{106}RuRh$	0.05	130
$^{95}ZrNb$	0.10	260
^{134}Cs	0.04	130

Drilling in Well No. 6 was terminated when a sample reading of 110 rad/hr was encountered at a depth of 11 feet. Facilities for handling such a hot sample were not available at that time so the soil was knocked out of the sampler and left in the well. The 110 rad/hr soil undoubtedly contained, in addition to ^{137}Cs, ^{144}Ce and $^{95}ZrNb$ from the feed, since the radiation reading of 30 rad/hr was measured from a sample saturated with only ^{137}Cs. These radionuclides, whose volumetric distribution coefficient, K_D, is greater than 500, were sorbed or precipitated onto an estimated 40 cubic feet of soil around the leak source.

Analytical results indicate that a broader and deeper migration of ^{106}Ru than ^{137}Cs into a spheroidal band between 4 and 8 feet beyond the ^{137}Cs boundary. The short-lived ^{106}Ru (one year half-life) presents less of a potential hazard than ^{137}Cs (30-year half-life).

A complete thermal analysis of the pipeline leak was not made. Only a maximum temperature increase in the saturated region near the leak source was estimated. From a previous study(5), a computer program generated data for estimating the temperature increase in the soil of a leak from a waste tank containing the similar type of waste solution that was used for the ion exchange feed. Based on a calculated volumetric heat generation rate of 0.60 Btu/hr/ft^3 for the feed solution and the previously mentioned soil characteristics, a 30 °F maximum temperature increase in the soil was estimated.

Due to the ion exchange properties of the soil, the depth of the water table level, and the light regional rainfall, it is concluded that the radioactive contamination from the leak will not reach the ground water. The water table level in the vicinity of the leak is located more than 200 feet below the ground level. The average annual rainfall in this region is less than 6 inches and would require a flooding storm of disastrous proportions to force the migration of radioactivity to such depths through the soil. In addition, the ion exchange properties of the Hanford soil will sorb the radioactive contaminants before they could reach the ground water.

REFERENCES

1. H-2-32484, Cesium Transfer Line No. V-122 - 241-CR-05A to 241-C-152

2. H-2-35450, Line V-106 and Replacement Line V-122 - Details

3. G. Jansen, Jr., W. E. Willingham, and W. V. DeMier, Buried Radioactive Waste Storage Tank Temperatures and Soil Temperatures Near Leaks, BNWL-181, March 1966

4. J. R. Raymond and E. G. Shdo, Characterization of Subsurface Contamination in the SX Tank Farm, BNWL-CC-701, June 14, 1966

5. Op. cit., G. Jansen, Jr.

F.3.0 UPR-200-E-86 FIELD CHARACTERIZATION DATA

RHO-CU-673
I. NE

CONTAMINATED LIQUID DISPOSAL SITES

Name/Type of Facility	Past Designation	Number
Unplanned Release	241-C-Tank Farm Line Leak, SW Corner	UN-216-E-14

Location	Service Dates	Status
200 East, N.E. Quadrant Near SW corner of 241-C Tank Farm	2/25/71	--

Site Coordinates (Approximate)	Reference Drawings	Elevations	
N-42725, W-48746	H-2-44500 Sheet 7	Ground	680 ft
		Water Table	402 ft(1973)
		Site Depth	8 ft

Source and Description of Waste

Waste from process transfer line.

Description of Facility

A leak in the process transfer line No. 812 from AR Vault to 241-C Tank Farm near the SW corner of the 241-C Tank Farm. Contaminated soil volume estimated at 1300 ft^3. Test wells indicated penetration of waste to a depth of 20 ft.

Radionuclide Content (calculated from discharge data)

Radionuclide	At Time of Discharge	As of 12/31/73
^{137}Cs, Ci	~25,000	~21,000

History:

Process transfer line #812 from AR Vault to 241-C Tank Farm was found leaking near southwest corner of that farm. At that location, the line is eight-feet deep. Contaminated soil zone was estimated at 1,300 cubic feet. Test wells driven into the ground indicated the contamination did not extend below a depth of 20 feet.

(See Attachment)

NOV 28 1972

UN-216-E-14

2/25/71

Date: November 9, 1972

To: G. L. Borsheim

From: W. P. Metz

Subject: PSS LINE LEAK (LINE No. 812)

Reference:
(1) Letter, June 2, 1971, J. R. Irish to R. C. Tabasinske, "Line No. 812 Leak Investigation"
(2) Letter, June 22, 1971, J. R. Irish, G. C. Oberg to P. F. Pritchard, "PSS' Leak-Well Stake Out"
(3) Letter, August 19, 1971, W. P. Metz, G. L. Borsheim to R. C. Tabasinske, "Line No. 812 Leak Investigation
(4) B. W. Anderson, Monthly Report, February 1971.

INTRODUCTION

During routine line monitoring near C-Farm, in March 1971 a radiation zone was detected in the vicinity of line No. 812, the line used to transport PSS from AR Vault to C-Farm. An investigation was initiated to determine the extent of the fission product loss (references 1,2, and 3).

SUMMARY

The investigation concluded that about 25,000 curies of ^{137}Cs were lost via the leak. Eight wells were drilled in the leak area and the apparent boundaries of the contaminated soil were established. The ground surface in the leak vicinity should be stabilized to prevent contamination spread.

DISCUSSION

Evaluation of the AR Vault process data indicated that at or around February 25, 1971, 17,385 gallons of PSS (Containing about 1.35 Ci/gal of ^{137}Cs had been lost (reference 4). Routine line radiation monitoring indicated that a leak had occured in Line No. 812 near S-Farm. To assist in the investigation PNL was contacted to drill eight dry wells in the vicinity of the leak.

Figure I is a sketch of the leak vicinity in the vertical and horizontal view and shows the line, the eight wells, and the estimated extent of the contaminated soil. The contaminated soil zone is estimated to contain about 1300 feet^3. The contamination did not extend below a depth of 20 feet in any of the test wells.

Line 812 is a 2 inch direct buried line which is about 8 feet below grade. The line has a carbon steel to stainless steel joint near the bend as indicated. Well Nos. 1,2,3,6 and 7 were found to be uncontaminated to a depth of 15 to 20 feet. Well Nos. 4,5, and 8 were found to have soil contaminated up to 334 uCi of ^{137}Cs per gram. Wells 5 and 8 were drilled to a depth of 16 to 19 feet where uncontaminated soil was found. Drilling in well No. 4 was terminated at a depth of 6 feet due to radiation exposure. Table I lists various soil sample analyses at the depths of sampling for wells 5 and 8, and lists soil exposure rates for well 4.

The line has been abandoned. The wells should be closed. The ground surface should be sterilized to prevent plant growth and stabilized to prevent wind erosion.

WPM:bri

Att:

cc: RB Guenther
J Dunn
DJ Larkin
WP Metz
LW Roddy
File 1124-A
LB

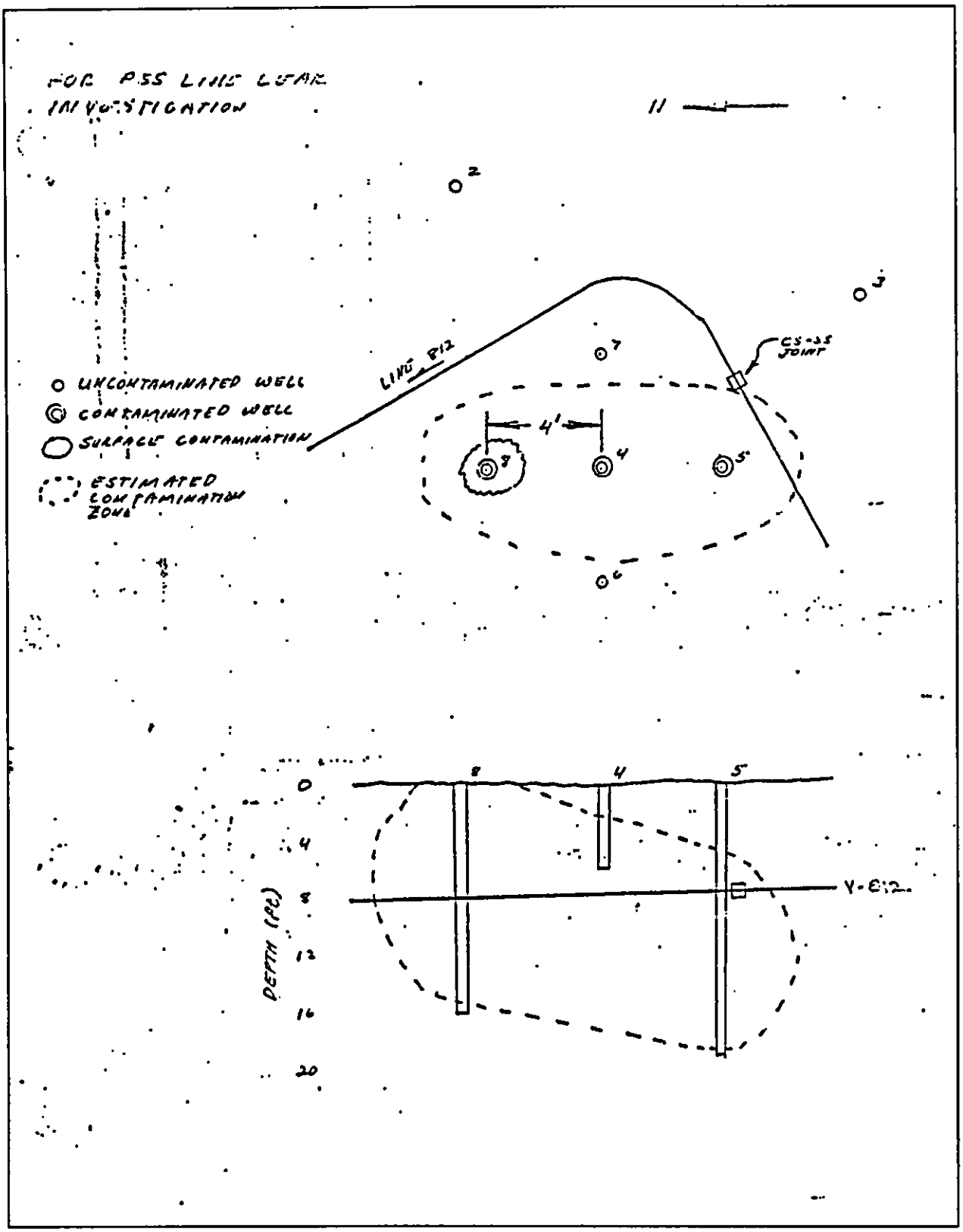

FOR P.S.S LINE LEAK
INVESTIGATION
UNCONTAMINATED WELL
CONTAMINATED WELL
SURFACE CONTAMINATION
ESTIMATED CONTAMINATION ZONE
LINE P12
CS-SS JOINT
4'
DEPTH (FT)
0
4
8
12
16
20
Y-E12

TABLE I

WELL LOGS FOR CONTAMINATED WELLS

	Well No. 4	5	8
Depth (Ft)	Exposure	uCi ^{137}Cs/gram	uCi ^{137}Cs/gram
0			
1	1000 cpm		
2			33⅓.
3	5R		
4			
5		0.035	
6	5R at 2"		0.10
7			
8			50.7
9			
10			
11			
12		3.48	.295
13			
14		0.268	0.064
15			
16		0.272	Clean
17			
18		0.291	
19		Clean	

F.4.0 REFERENCE

Maxfield, H.L., 1979, *Handbook 200 Areas Waste Sites*, RHO-CD-673, Rockwell Hanford Operations, Richland, Washington.