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SUBSURFACE CONDITIONS DESCRIPTION OF THE U WASTE MANAGEMENT AREAS

M.I. Wood and T.E. Jones
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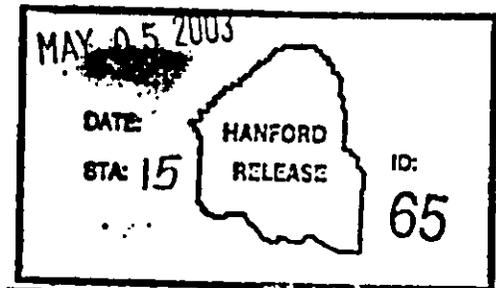
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Abstract: This document discusses the subsurface conditions relevant to the occurrence and potential migration of contaminants in the groundwater underlying the U Tank Farms. It describes the available environmental contamination data and contains a limited, qualitative interpretation of the data as they apply to contaminant behavior.

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**SUBSURFACE CONDITIONS DESCRIPTION OF THE U
WASTE MANAGEMENT AREA**

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Fluor Hanford**

**T.E. Jones
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April 2003

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LIST OF TERMS

CRBG	Columbia River Basalt Group
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
HDW	Hanford Defined Waste
MCL	maximum concentration level
PUREX	Plutonium-Uranium Extraction Plant
RCRA	Resource conservation and Recovery Act of 1976
REDOX	reduction-oxidation
SST	single-shell tank
TBP	tributyl phosphate
UPR	unplanned release
UR	Uranium Recovery
W MA	Waste Management Area

1.0 INTRODUCTION

This document, *Subsurface Conditions Description of the U Waste Management Area*, discusses the subsurface conditions relevant to the occurrence and potential migration of contaminants in the groundwater underlying the U tank farm. This tank farm, located in the 200 West Area of the Hanford Site, makes up the U Waste Management Area (WMA). 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 U WMA, and some other facilities in the 200 West Area. Figure 1-2 provides more detail on the U WMA, respectively. Surrounding area facilities are also shown. In Figure 1-2 (U tank farm) other auxiliary tank farm structures are shown including the 244-UR Vault, the 216-U-13 trench, the 241-U-301 catch tank, the 207-U retention basins and various diversion boxes. On either side of the U WMA are liquid discharge ditches including the 216-U-14 ditch to the east and several ditches to the west (e.g., 216-Z-19).

Evaluation of vadose zone contamination under U 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. 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 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 U WMA was not included in this action because there was no indication that vadose contamination in this WMA was a source of current nearby groundwater contamination when negotiations were being completed. 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 this WMA 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 U Waste Management Area and Related Facilities

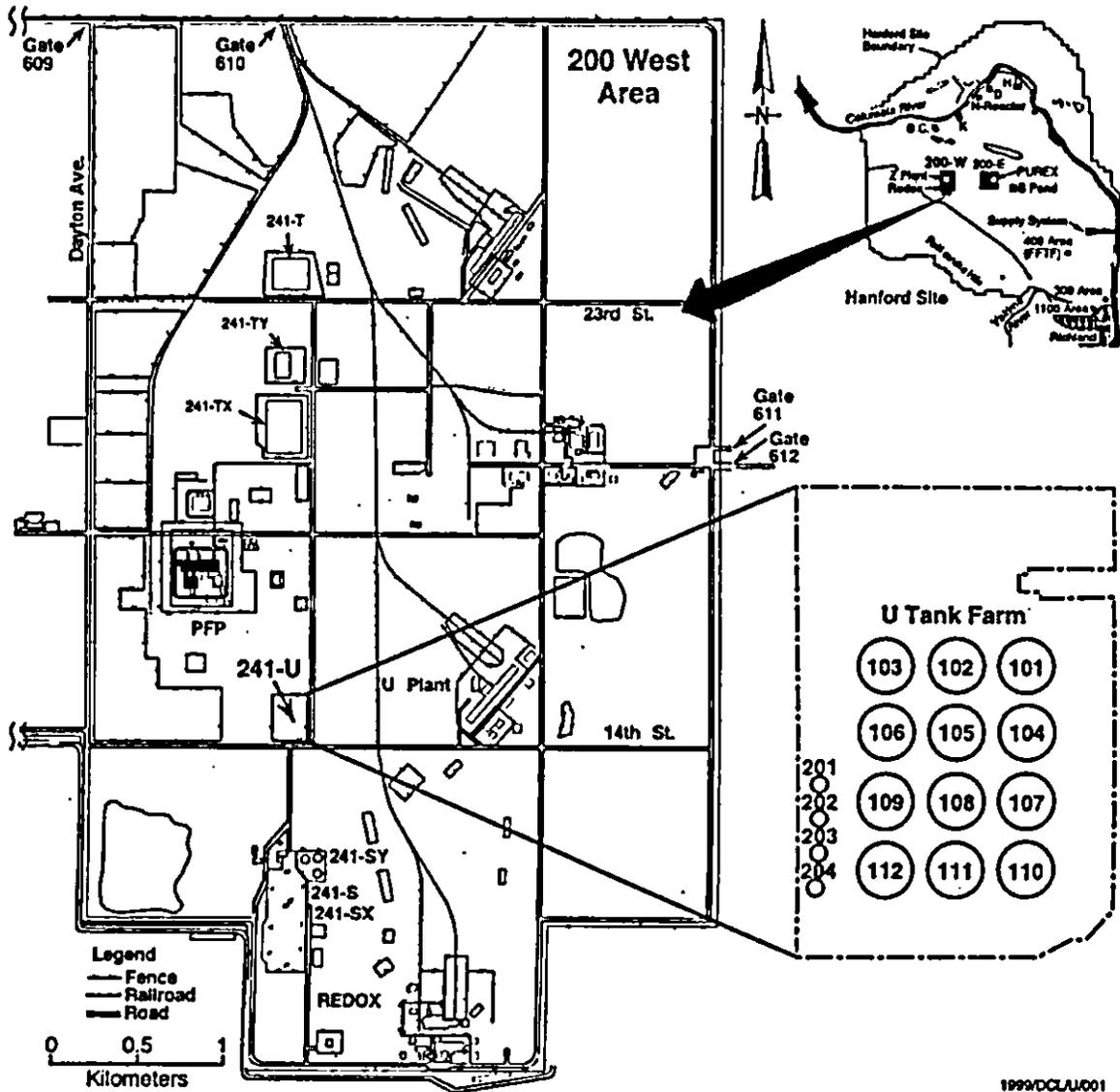
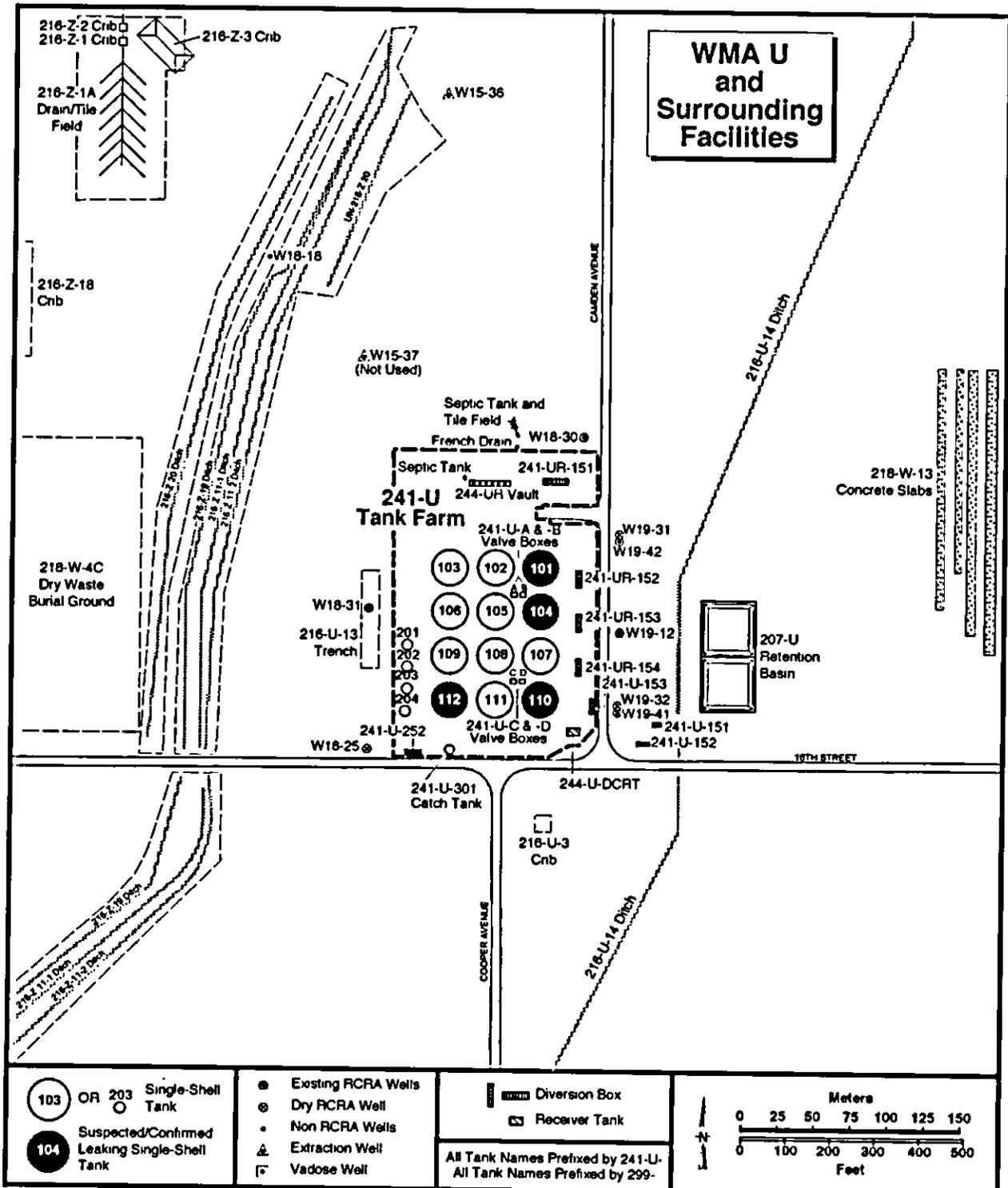


Figure 1-2. Location Map of U Tank Farm, the U WMA and Surrounding Facilities



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 U WMA and the contaminants contained within the WMA. 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 time 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 3.0. 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 U tank farm 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 3.0. 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. Leak inventory estimates are also provided.

Key uncertainties and data gaps that are important to understanding potential future contamination of the unconfined aquifer are identified in Chapter 5.0. Chapter 5.0 also provides recommendations for resolving these uncertainties.

Four appendices also are provided. Appendix A contains the text of the U WMA historical summary document (Williams 2001). Appendix B provides supporting stratigraphic information. Appendix C provides supporting meteorological and hydrologic data. Appendix D provides supporting gamma logging data.

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2.0 PHYSICAL SETTING

2.1 U WMA INFRASTRUCTURE AND OPERATIONS HISTORY

This section discusses the infrastructure and briefly summarizes the U 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). Excerpts from this report are provided in 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 U WMA Infrastructure

Within the U tank farm, the primary structures through which tank waste was stored, transported and discharged are the 12 primary tanks (C-101 through C-112) and four secondary tanks (U-201 through U-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 holds 0.2 million liters (55,000 gal). The 12 primary tanks were divided into 4 sets of 3 tanks each (e.g., tanks U-101, U-102, and U-103) with cascade lines attaching each set so that waste would flow from east to west by gravity feed. The cascade lines were about 21 ft (7 m) bgs. The U tank farm also contains an assortment of ancillary equipment used to move tank waste during operations. These include six diversion boxes, the 271-UR control house, the 244-CR process vault, the 244-U double-contained receiver tank (DCRT), and waste transfer lines.

Outside the U tank farm and the WMA boundary are various liquid storage, transfer and discharge facilities including two diversion boxes east of the U WMA, the 216-U-3 crib south the of the WMA, the 207-U Retention Basin and several north-south running ditches. These include the 216-U-14 ditch east of the U WMA and a series of trenches west of the U WMA (216-Z-11-2, 216-Z-11-1, 216-Z-19 and 216-Z-20).

2.1.2 Operations History

The U tank farm complex received waste generated by all of the major chemical processing operations that occurred at Hanford including bismuth phosphate fuel processing, REDOX fuel reprocessing, PUREX fuel processing, and tank farm interim stabilization (saltwell pumping) and isolation activities.

The U tank farm was constructed between 1943 and 1944 and first received metal waste and first cycle waste generated by the bismuth phosphate process from B Plant beginning in 1946. Ultimately, tanks U-101 through U-109 received metal waste and tanks C-110 through C-112 received first cycle waste. All tanks were filled with bismuth phosphate waste by the end of 1948. Subsequently a decision was made to recover the uranium present in the metal waste. Therefore, the stored metal waste was removed from the U tank farm beginning in 1952 and

transferred to U plant for uranium recovery. Ancillary equipment involved in the metal waste transfer included the 271-UR control house, the 244-UR vault and diversion boxes 241-UR-151, -152 -153 and -154. Subsequently, tributyl phosphate (TBP) waste, a byproduct of uranium recovery was returned to several tank farms, but not U farm. Uranium recovery operations concluded in 1957.

Both intentional and unintentional discharges to ground occurred during these two major operations. Uncontaminated and slightly contaminated water from facilities outside the U tank farm were discharge to several nearby ditches, particularly 216-U-14.

Several unintentional bismuth phosphate process waste releases to the environment occurred during this time period. In 1950 during construction at diversion boxes 241-U-151 and 241-U-152, a leak occurred whose source and volume were unspecified (UPR-200-W-6). In 1953, metal waste spray was ejected from a riser in the 244-UR vault created by a violent chemical reaction in the vault (UPR-200-W-24). The geyser rose about 30 ft (9 m) into the air for thirty seconds. The volume of waste released was unspecified but should not have exceeded the 15,000 gallon (56,800 L) storage capacity of the vault. The contamination spread to the southeast covering the eastern half of the tank farm. Finally, in 1956, two events occurred. Five hundred gallons (1,900 L) of metal waste overflowed from the 241-UR-151 diversion box at the northeast corner of the U tank farm (UPR-200-W-132) and tank U-104 leaked an estimated 55,000 gallons (208,000 L) of metal waste (UPR-200-UW-155).

Before the uranium recovery program was completed in 1957, the REDOX plutonium and uranium separations process was implemented in 1952. By 1954 waste generated by this process was transferred to tanks C-110, C-111 and C-112. Two kinds of waste were mixed in this stream including high level waste (R) which contained most of the fission products and aluminum nitrated and coating waste (CWR). Because the waste was self-boiling a reflux condenser was added to tank U-110 and tank condensate was transferred to the 216-U-3 french drain (identified as the 216-U-3 crib in Figure 1.1) until the tanks stopped boiling. In 1954 and 1955 about 209,000 gallons (791,000 L) were discharged to this facility. Additional REDOX waste was transferred to U Farm in 1956 and 1957 with tanks U-101, -102 and -103 receiving R waste and tanks 107, -108, and -109 receiving CWR.

Four unintentional releases were reported that involved REDOX waste, three tank leaks and an underground pipe leak. Tanks U-101, U-110, U-112 were reported to have leaked respectively 30,000 gallons (114,000 L) of R waste in 1959, 8,000 gallons (31,000 L) of CWR in 1969, and 10,000 gallons (38,000 L) of R waste in 1975. Of these, the U-101 leak is unlikely to have occurred (see Section 3). The underground pipe leak (UPR-200-W-128) occurred near tank U-103 when a worker cut through the line in 1971. The waste type is presumably R waste, which was present in tank U-103 at the time and the leak volume is unknown.

The last major stage of U farm activity was the removal of waste by supernate pumping and saltwell pumping of interstitial liquids, which started in 1972. This process has occurred intermittently and is nearing completion. Other than the tank U-112 leak in 1975, no other discharges to the vadose zone have occurred that are significant. A wind blown contamination

event (UPR-200-W-161) in 1990 is thought to be a redistribution of contamination initially discharged to the atmosphere in 1953 from the 244-UR vault (UPR-200-W-24).

2.2 GEOLOGY

This section summarizes the geologic setting and presents a physical model of the vadose zone and unconfined aquifer geohydrology in the vicinity of the U WMA. This analysis is based on the stratigraphic characterization of soils in 13 boreholes, whose locations are shown in Figure B-1. 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. Stratigraphic cross sections are shown in Appendix B.

2.2.1 Geomorphology

The U WMA lies within a shallow, north/south-oriented topographic low. This low formed within the southwestern extent of a flood bar deposit known as the Cold Creek bar and likely represents a braided stream channel that cut across the bar. Within the U tank farm, isolated man-made topographic depressions occur just southwest of tank U-110 and northwest of tank U-109. Until run on and runoff controls were recently constructed around the site, these depressions were conducive to the collection and subsequent infiltration of surface runoff.

2.2.2 General Stratigraphy

The U WMA is located on a sequence of sediments that overlie the Columbia River Basalt Group (CRBG) on the north limb of the Cold Creek syncline. The syncline axis runs in a generally northwest to southeast just south of the 200 West Area; the CRBG dips slightly to the southwest. The sediments include the upper Miocene to Pliocene age Ringold Formation, the Plio-Pleistocene unit or Cold Creek Unit Bjornstad (2002), the Pleistocene cataclysmic flood gravels and slack water sediments of the Hanford formation and Holocene eolian deposits. The sediment sequence is about 170 m (560 ft) thick at the U WMA and the individual strata are relatively uniform in their thicknesses. A more detailed description of these is provided below.

2.2.3 Methodology, Physical Model Development and Uncertainties

Geologic characterization in and near the U WMA is primarily based on borehole logging data (drillers' logs, geologists' logs, geophysical logs), and physical characterization data (grain size distribution, and calcium carbonate and moisture content) of borehole samples. Both Hanford site wide borehole data and local well data have been used to define the U WMA geology. Numerous investigations of the U WMA geology and the various major stratigraphic units have also been completed (e.g., Price and Fecht 1976, Horton and Hodges 1999, Lindsey 1995, Smith et al 2002). From this information a stratigraphic model of the supra basalt sediments has been developed.

Several types of uncertainty are inherent in the development of the stratigraphic model. These uncertainties may hamper the identification of a specific stratigraphic unit or the contacts between stratigraphic units at any given location, as well as the correlation of stratigraphic units between boreholes. Significant factors include the drilling method, primarily cable tool, and its impact on the ability to retrieve intact samples (e.g., variable sample depth control and sample cohesiveness), the quality of the observational and geophysical logs, and the inherent spatial variability of strata (e.g., facies formation within a major unit). A more detailed discussion of these uncertainties is provided in Wood et al 2001.

2.2.4 Stratigraphy Summary

A thick series of basalt flows forms the bedrock underlying the U WMA. The top flow bed is the Elephant Mountain member of the Saddle Mountains Basalt formation, which is the youngest flow in the area. The Elephant Mountain member is about 25 m (80 ft) thick in the 200 West Area (Reidel and Fecht 1981) and dips gently to the southwest (< 1 degree).

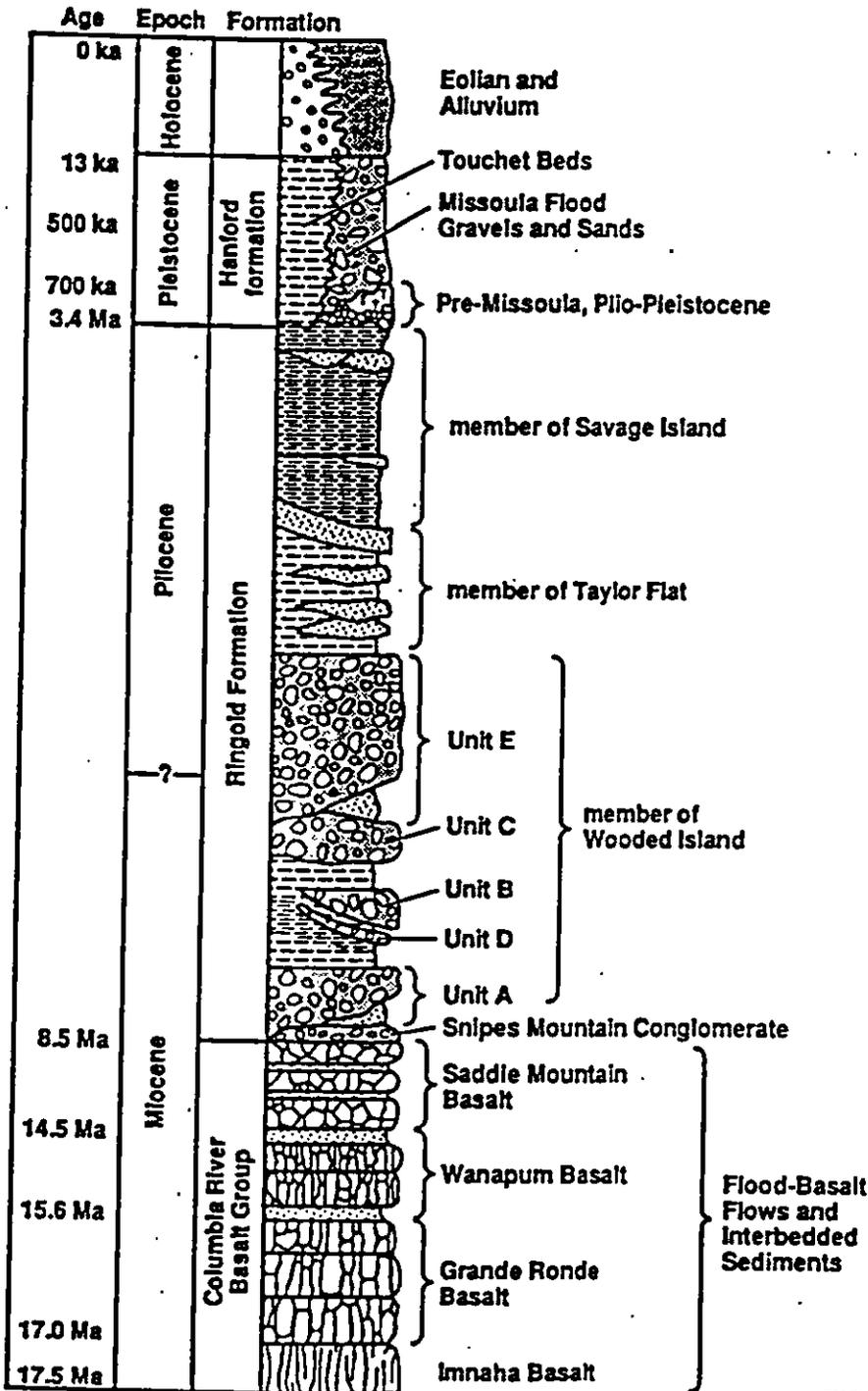
The first sediment layer overlying the Elephant Mountain member is the Ringold Formation, a fluvial-lacustrine deposit associated with the ancestral Columbia River drainage system that developed after the last basalt flow eruption. The Ringold contains several subunits that are not present everywhere on the Hanford Site. A generalized stratigraphic sequence was defined by Lindsey (1995) and is shown in Figure 2-1. At the U WMA, Ringold Unit A, the Lower Mud Unit (between Unit A and Unit D and not labeled in Figure 2-1) and Unit E are present in ascending order. No local boreholes extend all the way through the Ringold, but regional boreholes provide an indication of thickness listed below for the various subunits. Unit A, the lowest subunit, is a fluvial gravel, up to 30 m (98 ft) thick. The Lower Mud Unit, a lacustrine mud deposit, is approximately 15 m (50 ft) thick and is considered sufficiently impermeable to be the bottom of the unconfined aquifer in this area. Unit E, about 90 m (295 ft) thick, is a fluvial sandy gravel with variable grain size distribution ranging from sand to silty sandy gravel and cobble gravel. The water table is currently within this unit about 67 m (220 ft) bgs.

The Plio-Pleistocene unit overlies the Ringold Formation and consists of the two subunits. The lower subunit is a caliche-rich zone about 1 to 2 m (3 to 6 ft) thick that developed on the paleo surface of the Ringold formation. It is a calcium carbonate-rich layer with locally derived basalt detritus, silt-rich deposits and reworked Ringold Formation material. The calcium carbonate zones are probably discontinuous and occur as layers, nodules and clast coatings. The upper subunit is a silt-rich, sandy soil about 3 to 6 m (9 to 15 ft) thick that is relatively uniform and shows little depositional structure. Both subunits dip slightly to the southwest (Figure B-2).

The Hanford formation is the thickest vadose zone layer and consists of two units. The lower unit, H2, is primarily a sand and silt-dominated layer that averages about 24 m (79 ft) thick across the U WMA. The H2 unit thins to the east and northeast (Figure B-2). Repetitive sequences of very thin, flat-lying lamina of silt and sand have been observed in intact core samples and apparently provide a sedimentary structure that influences moisture movement in the vadose zone. The tank waste migration pattern indicated by uranium deposition in the H2 unit illustrates the influence of these sedimentary features (see Section 3.3).

The upper unit, H1, is distinguished from the H2 unit by a marked difference in grain size distribution. A significant fraction of the H1 soils are gravels and coarse sands indicating deposition in a higher energy environment. In the vicinity of the U WMA, the contact between the H2 and H1 units, identified by the grain size distribution contrast, is irregular and appears

Figure 2.1 Generalized Stratigraphic Column of the 200 West Area (Lindsey 1995)



H9210011.1b

to dip to the northeast in contrast to the other vadose zone contacts that dip to the southwest. At the U tank farm, the H1-H2 contact is near the tank farm excavation base along the eastern edge. The contact gets closer to the surface toward the west and northwest and therefore has had little influence on tank waste migration.

Clastic dikes are vertical to subvertical linear structures that are found frequently in the Hanford formation at the Hanford Site. These structures probably occur at the U WMA although neither Smith et al (2001) nor Hodges and Chou (2000) mention their presence. They tend to occur randomly in the H1 unit and as regularly shaped polygons in the H2 unit. Regular-shaped polygonal networks consist of 4- to 8-sided polygons, individual clastic dikes typically range from 3 cm to 1 m (1 in. to 3 ft) wide, from 2 m to more than 20 m (6 to more than 65 ft) deep, and from 1.5 m to 100 m (5 to 325 ft) along their strike. These clastic dikes typically have an outer skin of clay with coarser in-filling material.

2.3 RECHARGE SOURCES AND EVENTS

The facility infrastructure, infiltration of water from natural sources and tank farm operations, 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 C.

Fluid infiltration into the soil column from natural sources and tank farm operations had a substantial effect on current environmental contamination conditions in the U WMA. Temporal changes in vadose zone moisture distribution and water table elevation in response to historical variations in natural and artificial recharge, combined with aquifer properties, 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 infiltration from transient high-intensity events. Precipitation, runoff, and rapid snowmelt are the primary types of events that can cause recharge from natural sources.

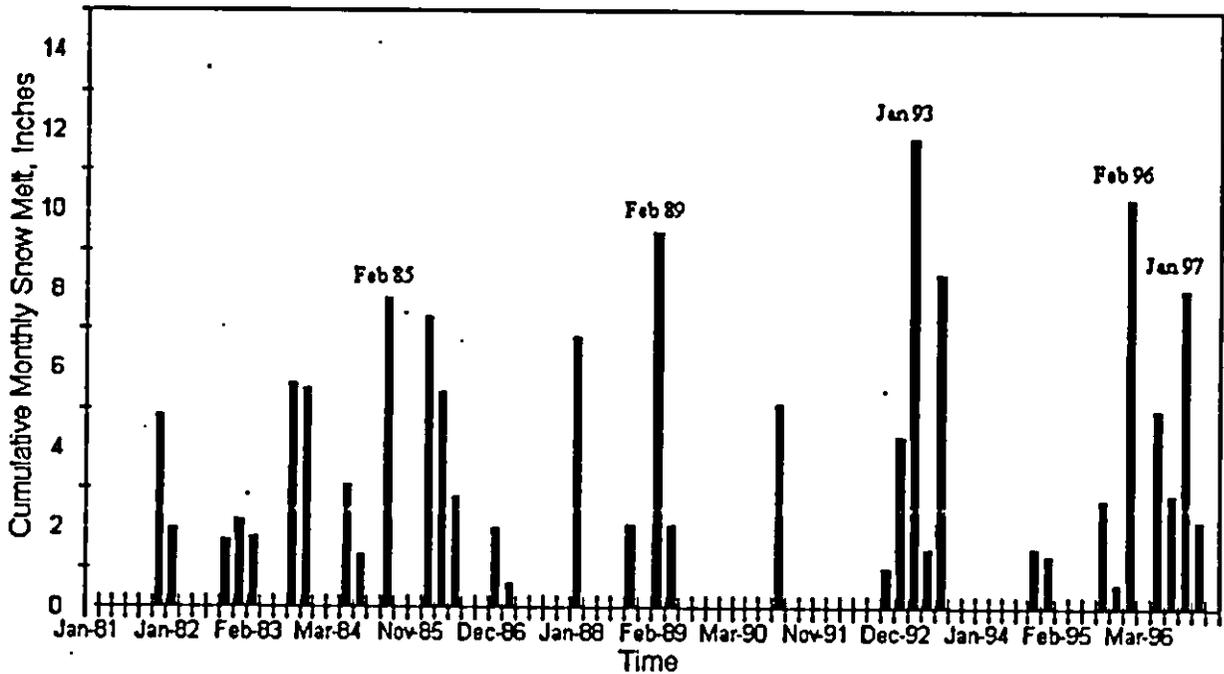
The natural infiltration rate through the U WMA has not been measured directly. However, observations from similar disturbed gravel-covered areas on the Hanford Site indicate that as much as 10 cm/year (3.9 in./year) can infiltrate a vegetation-free coarse gravel surface (Gee et al. 1992; Fayer and Walters 1995; Fayer et al. 1996). This represents about 60 percent of the average annual precipitation (rainfall plus snowmelt). Fayer and Walters indicate that the U WMA is in an area estimated to receive about 5 to 10 cm/year (1.97 to 3.9 in./year) of recharge from natural infiltration. This averaged infiltration estimate is based on soil type, lack of vegetation, and land use. Actual recharge is non-uniform because of the presence of the tanks

and the surrounding disturbed soil. Recharge is blocked by the tank domes and “shed” into the soil near the tank walls. Thus, infiltration rates near tank edges and between tank rows are higher than average areal infiltration rates.

Transient saturation from runoff collected in low spots could 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 other tank farms (e.g., T tank farm [Hodges 1998]) but no similar record was identified for U tank farm. There are topographic lows at U tank farm that could have collected runoff in the past, particularly south of tank U-110 and northwest of tank U-109. Recently, mitigating actions have been taken to divert runoff away from waste sites in the U WMA.

Records of snowmelt have been kept since 1981 at the Hanford Meteorology Station, located between the 200 West and 200 East Areas. Figure 2-2 summarizes the total inches of snow (per month) that melted within a 24-hour period. These records indicate periods when unusual accumulations or ponding of water may have resulted in transient saturation events, particularly when preceded by a weather cold enough to freeze near-surface soils and facilitate surface migration, possibly leading to transport of contaminants through the vadose zone to groundwater. Several events in addition to the February 1979 snowmelt ponding event mentioned above likely have occurred over the last 20 years, as shown in Figure 2-3. The snowmelt events, along with maximum monthly precipitation since 1946 (Appendix C, Table C-1), are shown on a time line with tank leaks, unplanned releases and groundwater contamination occurrences in Figure 2-3.

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



2.3.2 Fluid Discharges from Tank Farm and Process Facility Operations

Throughout the U farm operational history, fluids were discharged both deliberately and inadvertently. To a large extent, the current state of environmental contamination has been caused by these discharges. Key characteristics include the location and time, volume, and contaminant inventory of these discharges. Where available, contaminant inventory information is summarized in Chapter 3. Williams (2001) provides a more detailed discussion of these events (see Appendix A).

High volume intentional discharges near the U WMA occurred in the 216-U-14 ditch east of the U WMA, a series of ditches west of the U WMA (216-Z-1D, 216-Z-11, 216-Z-19 and 216-Z-20), the 216-U-13 double crib west of the U WMA and the 216-U-3 crib south of the U WMA. The majority of discharges to these facilities occurred before 1981. The Z ditches were operated sequentially between 1959 and 1995 and mostly received slightly contaminated water from Z Plant and associated facilities. The 216-Z-20 was the last ditch used in this group and received waste water between 1981 and 1995 (with heavy use occurring before 1986 [Johnson 1993]).

Good records of volumes discharged were not kept for the older facilities but it is likely that hundreds of millions of gallons were discharged during operation. The 216-U-13 crib operated between 1952 and 1956 and received water used to decontaminate equipment used in the uranium recovery process. The 216-U-3 crib received U tank farm condensate (791,000 L [209,000 gal]) in 1954 and 1955.

The 216-U-14 ditch was the longest operating (1944 to 1995) trench in this group. During this time approximately 1.6×10^{11} L (4.2×10^{10} gal) of wastewater were discharged to the ditch from numerous facilities (Singleton and Lindsey 1994). The trench is a little over a mile long and received waste at different locations along the trench. The most recent impact to groundwater movement near the U WMA occurred in the early 1990s when a substantial wastewater volume (about 1.9×10^9 L [5×10^{10} gal]) from U and UO_3 Plant was discharged into the 216-U-14 ditch just east of the U WMA in 1991 (see Section 2.4.2 for further discussion).

One other high volume liquid disposal discharge facility, the 216-U-10 pond, influenced groundwater movement underneath the U WMA even though it lies a greater distance from the U WMA than the cribs and ditches discussed earlier, about 300 m or 1,000 ft to the southwest. The 216-U-10 pond received waste water primarily from the 216-U-14 ditch (1.63×10^{11} L (4.3×10^{10} gal)) from 1944 until 1985. This large amount of discharge was sufficient to raise the water table and influence regional groundwater flow (see Section 2.4.2 for further discussion).

Unintentional discharges of wastewater reported in and around the U WMA were minor and unlikely to have had any significant impact on contaminant migration. Perhaps the largest discharge occurred at the 244-UR vault at the north end of the U WMA in 1953 when a violent chemical reaction occurred and caused an atmospheric release of a conservatively estimated 15,000 gal (57,000 L) of metal waste. The next largest recorded unplanned release event occurred in 1956 when 500 gal (1900 L) of metal waste escaped from a failed check valve at the 241-UR-151 diversion box.

2.4 HISTORICAL AND CURRENT HYDROLOGIC CONDITIONS IN THE SUBSURFACE

2.4.1 Vadose Zone Conditions

The migration of water through the vadose zone depends on the hydrologic properties of the soils and the infiltration rate of water from the surface and occasionally from a lateral source, depending on local discharge events. A summary of vadose zone hydrologic properties measured on Hanford Site soils is provided in Khaleel and Freeman (1995). From this database hydrologic properties have been chosen that are most appropriate for the vadose zone underlying the U WMA (see Appendix C).

Generally speaking, unsaturated flow is the predominant infiltration mode in the vadose zone. Like many other parts of the Hanford Site vadose zone a strong tendency for lateral migration characterizes unsaturated flow conditions under the right circumstances. Frequent

near-horizontal layers of dissimilar soils (e.g., varying mixtures of sandy, silty, and/or coarse-grained materials) apparently induce this behavior. At the U WMA, a uranium plume emanating from tank U-104 and extending in a southwesterly direction in the vadose zone marks this lateral migration phenomenon. The gamma data indicate that uranium contamination leaked from the bottom of tank U-104 for an unknown time period. The uranium pattern extends as much as 200 ft (60 m) horizontally and about 40 ft (12 m) vertically at the maximum.

Over time, water infiltrating into the vadose zone must migrate to the unconfined aquifer. In the time period since the metal waste leak in the early 1950s to now, water has probably not passed all the way to the unconfined aquifer unless unintentional manmade local discharges have accelerated the movement. No specific events at the U WMA have been identified but there is some indication of tank waste contamination in the groundwater (see Section 3.5). Therefore, it is possible that limited short-term high infiltration events have occurred.

2.4.2 Unconfined Aquifer Conditions

Hydrologic properties of the unconfined aquifer are dependent on the hydrologic characteristics of the saturated soils (i.e., hydraulic conductivity and effective porosity), the various recharge sources affecting groundwater velocity and hydraulic gradient. Over time groundwater flow direction and flow velocity have changed as both natural and manmade sources have affected groundwater flow underlying the U WMA. In the following discussion, much of the information is taken from the most recent reviews of the U WMA hydrogeologic and contaminant conditions documented by Hodges and Chou (2000) and Smith et al (2001).

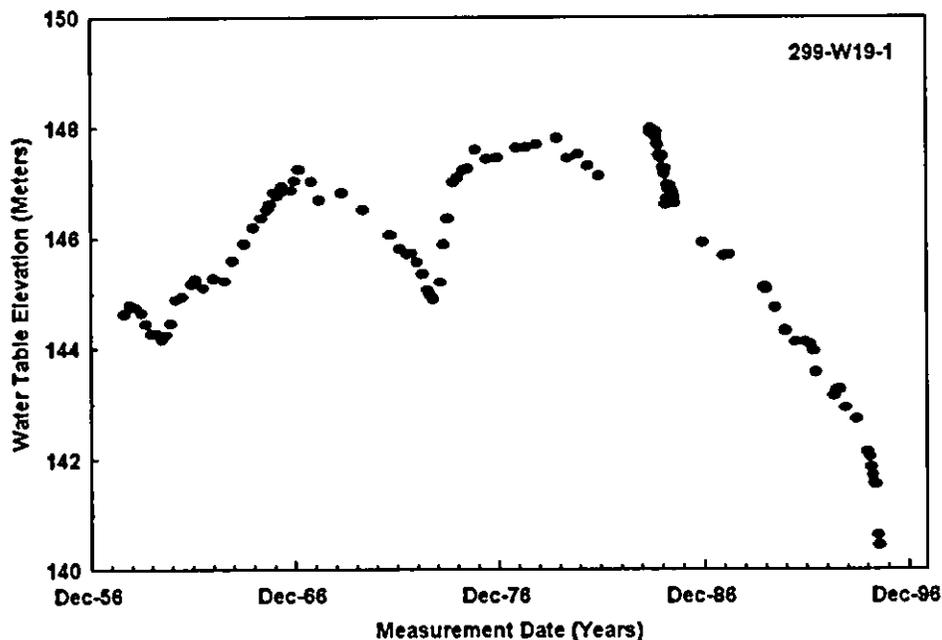
Prior to the initiation of fuel processing activities at the Hanford Site the regional flow across the site was generally west to east. The first significant perturbation to groundwater flow was probably discharge to T Pond north of the U WMA in the late 1940s, which would have had the effect of diverting flow direction to a more southerly direction under the U WMA and perhaps raising the water table. A similar scenario has been postulated groundwater flow under the S-SX WMA (Johnson, et al 1999). No groundwater wells were located near the U WMA in this time period to measure these postulated events.

The next significant perturbation created by Hanford operations was the development of U Pond and wastewater discharge to the unconfined aquifer. A water mound developed and groundwater flow direction was altered beginning in the mid 1950s. At the U WMA, elevation of the water table was measured at groundwater monitoring well 299-W19-1 (Figure 2-4). Given the location of the 216-U-10 Pond to the southwest of the U WMA and the radial flow induced by the expansion of the groundwater mound underneath the pond, groundwater flow changed toward a northeasterly direction under the U WMA. This directional control continued through 1985 when discharge to the pond ceased, at which point both the water table began to drop (Figure 2-5) and the general flow direction began to move toward the pre-Hanford easterly orientation.

The most recent perturbation to local flow direction was caused by the short-term large volume (1.6×10^{11} L (4.2×10^{10} gal)) discharge of wastewater from the U/VO₃ plants into the 216-U-14

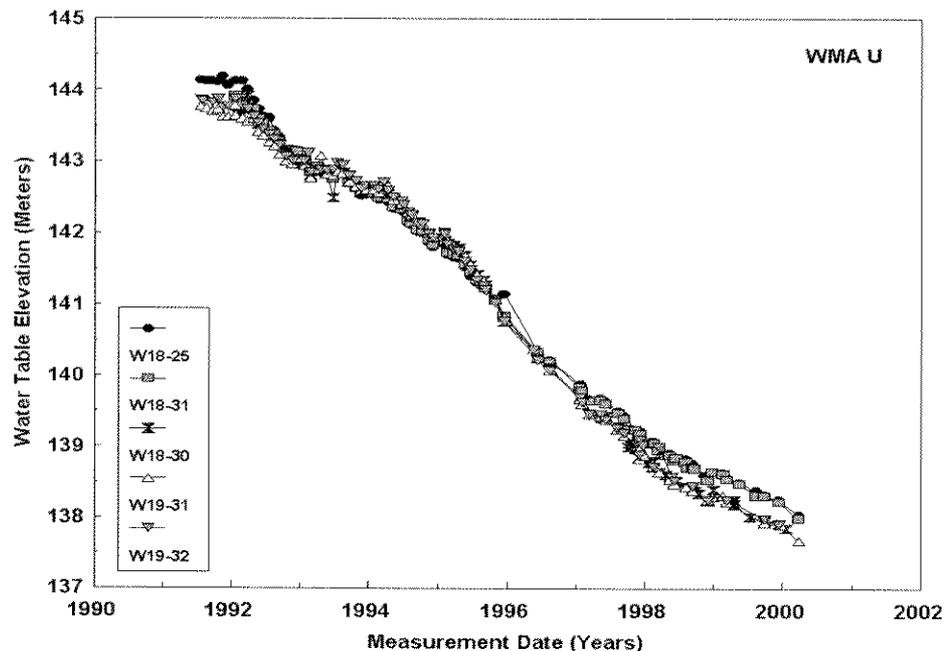
ditch in 1991 just east of the U WMA. In response to this high discharge, the local flow direction gradient changed from easterly to northerly and westerly in 1993. This gradient reversal lasted until early 1996, at which time a reversal to the predominantly easterly direction reoccurred. The gradient reversals are indicated in Figure 2-5 by the relative changes in the water levels of the RCRA monitoring wells around the U WMA over time. Recognizing that water levels are closer to the surface at upgradient wells, the figure shows that northern and western wells (299-W18-30, 299-W18-31 and 299-W18-25) compared to the eastern wells (299-W19-31 and 299-W19-32) are upgradient between 1990 and mid 1993, downgradient between mid 1993 and late 1995, and finally upgradient again beginning in 1996 until present.

Figure 2-4. Historical Depth above Mean Sea Level at Well 299-W19-1 just south of the U WMA (Hodges and Chou 2000)



Recent measurements of aquifer properties (Spaine et al 2001 and Smith et al 2001) in the U WMA RCRA monitoring wells indicate that hydraulic conductivity and effective porosity around well 299-19-42 are about 6.12 m/d and 0.17. The hydraulic gradient is about 0.002 based on water level measurements from nearby wells. Using these data, a flow velocity of about 30 m /yr is calculated. The flow direction across the U WMA is shows a generally easterly orientation with some radial component (e.g., at the northern end of the U WMA flow is more northeasterly). This suggests that the impact of the U Pond groundwater mound has not completely dissipated but these effects are diminishing as indicated by the steady decrease in water levels at all local wells. Additional water table decreases of 20-25 ft (6 to 8 m) at a rate of about 2 ft (1 m) per year were estimated to return to pre-Hanford values at the S-SX WMA just to the south (Johnson et al 1999). If so, pre-Hanford conditions should be achieved 10 to 20 years from now.

Figure 2-5. Recent Water Level Measurements from RCRA Monitoring Wells around the U WMA (Hodges and Chou 2000)



2.5 GEOCHEMISTRY

This section covers geochemical factors and material properties of the vadose zone and unconfined aquifer underlying the U WMA. 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 U WMA. 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 U WMA. 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 moderate 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 U WMA, quantitative, site-specific radionuclide sorption/solubility data are not available. Two sources of information provide an indication of tank waste chemistry effects on radionuclide chemical reactivity in the vadose zone. First, 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. Second, for uranium specifically, the recently completed field investigation of a uranium plume east of tank BX-102 in the B-BX-BY WMA (Knepp 2002) likely provides insight to the uranium chemistry associated with the uranium plume observed in the U WMA to the southwest of tank U-104. In both cases, the uranium plume is attributed to the loss of metal waste from the bismuth phosphate operation in the early 1950s. Given this database, the following observations are generally seen across the U tank farm for cesium-137 and uranium, the most commonly observed gamma-emitting radionuclides:

- Cesium-137 is concentrated in drywells near the likely sources of tank leaks. This suggests relatively rapid and complete sorption onto soil near the point of discharge. Vertical distribution in drywell 60-10-07 and 60-12-01 show very high cesium-137 concentrations (about 10^7 pCi/g) coincident with the tank bottom about 50 ft (15 m) bgs and extending no more than 10 m deeper into the soil column. Very high cesium-137 concentration zones also occur at drywell 60-12-01 in two distinct zones, one at the tank bottom and the other about 35 to 45 ft (11 to 14 m) below tank bottom.
- Uranium distribution is widespread in a distinct contaminant plume that was released from tank U-104, indicating a high level of mobility at one time. Drywell spectral gamma data indicate an oblong contamination zone that extends more than 200 ft (61 m) along the long axis and 100 ft (30 m) along the short axis. Vertical penetration is maximized near the source from about 55 ft (17 m) down to about 90 ft (27 m) bgs.

These data suggest that tank fluid chemistry has had little observable effect on cesium-137 mobility. In this tank farm, the abrupt edges of the high cesium-137 concentration zones that are close to the tank bottoms indicates high chemical reactivity and a nearby leak source location. Isolated small and sharply defined zones of high cesium-137 concentration at several near surface locations also suggest limited cesium-137 mobility once waste fluids enter the vadose zone. Assigning a K_d value of 100 mL/g or more is a reasonable estimate.

Tank fluid chemistry has had a significant, but temporary, effect on uranium mobility, reducing reactivity with the soil and enhancing mobility as indicated by the extent of its distribution. This is a reasonable expectation given that metal waste was chemically designed to dissolve high concentrations of uranium. However, interaction of tank waste fluid with soil and soil water over time appears to have precipitated the majority of uranium in hydrated uranium silicate phases. This hypothesis is supported by mineralogical characterization of uranium-bearing soils east of tank BX-102 (Knepp 2002), which identify uranium-silicate precipitates as the primary form of uranium in soil samples.

3.0 SUBSURFACE CONTAMINATION CHARACTERISTICS AND ASSOCIATED TANK WASTE INFORMATION

Subsurface contamination has been generated by tank farm operations in the U WMA 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 WMA 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. In Section 3.2, significant data is described by specific area of contamination. In Section 3.3, a summary of tank leak determinations based on evaluations in this report is provided. Finally, in Section 3.4 groundwater contamination around the U WMA is summarized. Groundwater chemistry near the U WMA indicates that contaminants from tank waste sources within the U WMA are present. However, the specific source is not known.

3.1 GAMMA RAY LOGGING INFORMATION OVERVIEW

Two types of gamma ray logging data were collected in the U tank farm. As part of a tank leak detection program (Isaacson and Gasper 1981), gross gamma logging was conducted from the early 1960s through 1994. Recently, the gross gamma logging data from the U tank farm was evaluated to assess potential movement of gamma-emitting radionuclides in the vadose zone (Randall and Price, 2001). Spectral gamma logging data were collected for the U tank farm (DOE-GJO 1997 and DOE-GJO 2000). Spectral gamma logging data reports have also been completed for individual tanks in these tank farms. In the summary sections below, quantitative information is taken from these reports.

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 U WMA. Specific spectral gamma data that identify the most contaminated areas within in the U WMA 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 D.

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.

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 same 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 due to the influx or loss of the initial inventory.

Appendix D summarizes the spectral and gross gamma logging results for the U tank farm that indicate the occurrence of tank waste losses to the vadose zone. The summary figure (Appendix D) indicates 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 U tank farm attributed to tank farm activity are listed in Appendix D. These changes occur within 30 ft (9m) 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 cesium-137) of 10 pCi/g to 100 pCi/g or occasionally higher near the surface diminishes with depth to about 1 pCi/g with depth. This pattern is considered 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 D) occurs at depths near the tank bottoms or lower. Over the time during which measurements were taken, unstable conditions are observed in 8 drywells in the U farm. The majority of unstable zones in the U tank farm are associated with the tank U-104 metal waste leak. Most involve movement of uranium after leakage from the tank.

3.2 U WMA TANK WASTE LOSSES EVENTS

Hanlon (2002) lists four primary tanks in the U tank farm, U-101, U-104, U-110 and U-112, as "confirmed or assumed leakers." Estimated leak volumes vary from 5000 gal (19,000 L) in tank U-110 to 55,000 gal (208,000 L) in tank U-104. In addition to these a riser leak at the 244-UR vault, a pipeline leak near tank U-103 and contamination from operations activities have been reported as unplanned releases (see Section 2.1.2 and Appendix A). Each of the major listed leaks is discussed below to evaluate the severity of the contamination. Evidence of tank waste losses to the vadose zone in these locations and other locations indicated by spectral gamma data, waste transfer records and operational records are summarized below. Also, the validity of the leak designations have been critically reviewed to determine if the observed contamination is significant enough to support the leaker designation and warrant further characterization.

Some additional locations were also considered because spectral gamma logging data indicates sufficient contaminant concentrations to warrant evaluation. These sites have not been clearly connected to tank waste losses to the vadose zone.

3.2.1 Tank U-101

Tank U-101 first received metal waste from the bismuth phosphate process followed by receipt of uranium recovery waste. After tank U-101 was no longer needed to support uranium recovery operations in 1956, it received 491,000 gallons of aged REDOX waste from tank SX-103 in 1958 to bring the total volume of waste in the tank to 540,000 gallons. This volume remained constant for almost 2 years and then waste level drops were noted. Both the waste transfer records and Hanlon (2002) indicate a 30,000-gallon loss from this tank in 1959. However, field data provide no indication of vadose zone contamination. A 30,000-gallon loss of REDOX high-level waste from tank U-101 would have created a cesium-137 plume comparable to the SX-108 plume. None of the drywells around tank U-101 display high cesium-137 content to indicate a tank leak, much less a leak of this magnitude. Without physical evidence for a cesium-137 plume associated with a waste loss event from tank U-101, no substantive vadose zone contamination can be assumed.

3.2.2 Tank U-104

A significant leak from tank U-104 occurred in the early 1950s when physical inspection of the tank interior in 1956 (Smith and Shadel 1956) revealed a tank bottom bulge in the northeast quadrant of the tank. A 55,000 gal (208,000 L) leak volume has been estimated (Hanlon 2002). Operations records indicate uranium-rich metal waste as the primary waste stream in the tank at this time. This waste stream, the resulting aqueous phase remaining after the co-precipitation of Pu (IV) with bismuth phosphate, carried almost all of the uranium, fission products and process chemicals. Being the first in a three-tank cascade (tanks U-104, U-105 and U-106), most of the uranium solids precipitated in this tank, along with the heat-producing fission products. This resultant heat buildup apparently was conducive to a tank bottom liner rupture.

Spectral gamma uranium activity data in ten drywells around tank U-104 and to the southwest also indicate the occurrence of a metal waste leak with tank U-104 being the source. Maximum uranium concentrations over the largest depth intervals occur in drywells 60-07-11, 60-07-10 and 60-04-08 on the south and southwest side of tank U-104. In these drywells, contamination occurs just below the tank bottom about 52 ft (16 m) bgs and extends to as much as 92 ft (28 m) bgs. Uranium-235 concentrations up to 100 pCi/g and U-238 concentrations approaching 1,000 pCi/g near tank bottom depth have been measured. These drywells were located closest to the leak location.

As the plume extended further to the southwest the peak concentrations and contaminated depth intervals decreased. Other drywells containing uranium contamination include 60-04-10, 60-07-01, 60-05-04, 60-05-05, 60-08-04, 60-11-12, and 60-11-07. In all the drywells uranium contamination began between 50 and 55 ft (15 and 17 m) bgs at the tank bottom. These drywell locations and the uranium distribution constrain the size of the uranium plume reasonably well to a roughly oval shape oriented toward the south-southwest with a long axis of about 225 ft (69 m) and a short axis of about 100 ft (30 m).

Historical gross gamma data in some of these drywells indicate subsequent migration of uranium at these locations, mostly in the early 1970s (Randall and Price 2001). These include drywells 60-07-10, 60-05-04, 60-05-04, 60-04-10, and 60-04-08. At drywell 60-07-11 which contains the maximum uranium contamination in this group of drywells vertical uranium migration is indicated throughout the monitoring period between 1975 and 1994.

3.2.3 Tanks U-110 and U-112

The tank U-110 leak was reported in 1975 on the basis of increased gamma activity in drywell 60-10-07 and a liquid level drop inside the tank. Both spectral gamma data and the historical gross gamma record are consistent with a tank leak. At drywell 60-10-07, a rapid increase in gamma activity was noted between May and September 1975 and continued to increase until 1984 (Welty 1988) at tank bottom depth. Subsequent spectral gamma measurements showed a high cesium-137 zone is present near the tank bottom between 52 and 56 ft (16 and 17 m) bgs. In this zone a sharp peak concentration approaching 10^7 pCi/g occurs at 55 ft (17 m) bgs. Given the high cesium-137 concentration, this drywell is assumed to be close to the leak location. The estimated leak volume of 5,000 to 8,100 gal (19,000 to 31,000 L) is not well constrained but appears to be consistent with the spectral gamma data because this is the only drywell indicating a leak.

Determination of the chemistry of the waste leaked from tank U-110 is uncertain because of complex waste receipt and transfer history at tank U-110 prior to the leak event in the early 1970s. Tank U-110 first received first cycle waste from the bismuth phosphate process in the late 1940s, a relatively dilute waste stream. This waste was transferred from tank U-110 in 1952. In 1954, tank U-110 was filled with REDOX high-level waste. In 1955 through 1957, tank U-110 began receiving REDOX cladding waste, another dilute waste type. Finally, from 1972 through 1975, tank U-110 received laboratory wastes from 222-S and PNNL. Given this operational history and the apparent leak event occurring in the 1970s, it is difficult to project a

waste composition for the leaked supernatant but it was likely a mixture of REDOX high-level supernatant mixed with various low activity waste streams. Given the high cesium-137 concentration, REDOX waste seems to be the largest contaminant contributor in the leaked tank fluid.

Tank U-112 appears to have leaked in a similar fashion to tank U-110. One drywell well, 60-02-01 shows two distinct high cesium-137 concentration zones. Near the tank bottom between 50 and 68 ft (15 and 21 m) bgs concentrations exceeding 10^7 pCi/g are common and a maximum value near 10^9 pCi/g occurs near 60 ft (18 m) bgs. A second less concentrated zone occurs between 83 and 97 ft (25 and 30 m) bgs where cesium-137 concentrations largely fall between 10^4 and 10^5 pCi/g. The bifurcated zones could indicate more than one leak. The leak may have occurred in the late 1960s when some indication of a liquid level drop inside the tank was observed beginning in 1967 and continuing until 1969 (DOE-GJO 1996). Historical gamma data do not indicate contaminant movement beginning in the early 1970s suggesting that cesium-137 migration had already finished. The estimated leak volume of 8,500 gal (32,000 L) is not well constrained and may be larger. The longer period of apparent liquid level drops in the tank and the greater amount of contamination in drywell 60-12-01 versus drywell 60-10-07 may indicate a somewhat larger leak. Tank U-112 stored similar waste to tank U-110 suggesting that REDOX waste was a significant component in the leaked tank fluid.

3.2.4 Additional Contamination Events

Some isolated pipeline leaks are indicated by shallow contamination in several drywells including:

60-02-01 (~ 1,000 pCi/g of cesium-137 between 8 and 10 ft (2 and 3 m) bgs),

60-03-08 (~ 100 pCi/g of cesium -137 at about 5 ft (2 m) bgs),

60-11-12 (~ 1,000 pCi/g of cesium -137 and ~100 pCi/g of Eu-154 at 3 ft (1 m) bgs),

60-12-01 (~1,000 pCi/g of cesium -137 at 3 ft (1 m) bgs),

60-11-03 (~1,000 pCi/g of cesium -137, 100 pCi/g of europium-154, and 10 pCi/g of cobalt-60 at 3 ft (1 m) bgs)

All of these locations are isolated contamination zones that extend no more than 20 ft (6 m) bgs and indicate no similar contamination in adjacent drywells. It is concluded therefore, that these contamination zones are insignificant contributors to vadose zone contamination.

3.3 CURRENT ASSESSMENT OF SINGLE-SHELL LEAK INFORMATION

The current status of tank leak information is summarized in Table 3-1 for the tanks in the U tank farm. All tanks listed as leakers in Hanlon (2002) are listed Table 3-1. Concurrence or disagreement with the Hanlon report is indicated in the fourth column and reflects the evaluation provided in this report.

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. Summary of Tank Leak Status

Tank	Hanlon Leak Volume (Gal)	Treated as Leaker Here	Volume Suggested
U-101	30,000	No evidence for leak	
U-104	55,000	Yes	Inventory estimate assumes 50 Kgal leak
U-110	8,100	Yes	Inventory estimate assumes 8.1 kgal leak
U-112	8,500	Yes	Inventory estimate assumes 8.5 kgal leak

3.4 GROUNDWATER CONTAMINANT INFORMATION

This section covers the historical and current state of groundwater contamination surrounding the U WMA. The history of local groundwater contamination is limited by the scarcity of nearby groundwater monitoring wells and systematic sampling and analyses of these wells prior to 1991. In 1991 a series of upgradient and downgradient monitoring wells were installed as part of a site-wide RCRA assessment program of Hanford facilities. The most comprehensive evaluation of groundwater monitoring data from these wells and other preexisting wells was documented by Hodges and Chou (2000) and is the primary source of information summarized below.

3.4.1 Data Summary

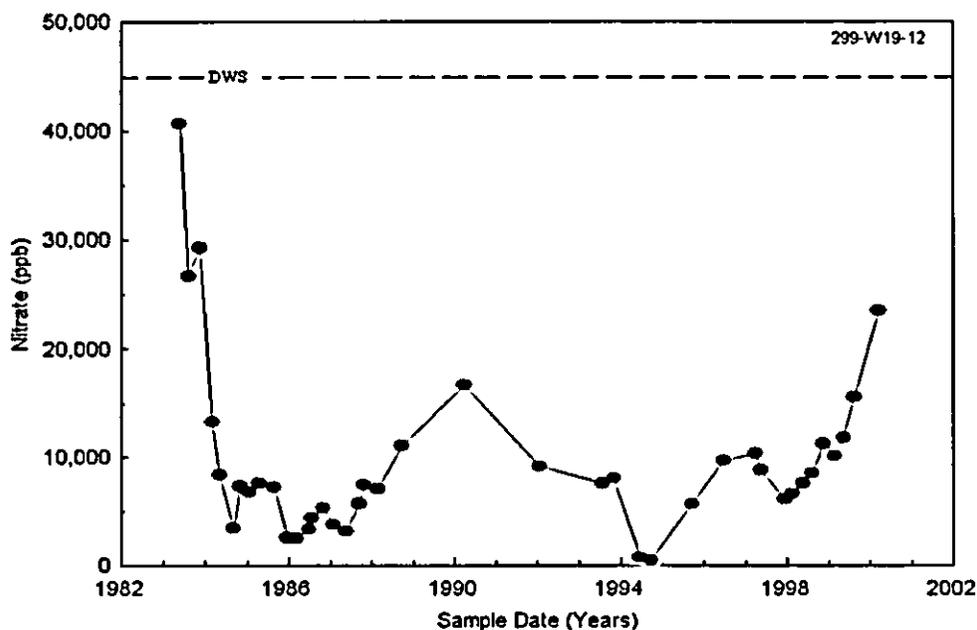
Eight groundwater monitoring wells have provided the most useful groundwater contaminant data near the U WMA. Prior to the installation of RCRA groundwater monitoring wells, the nearest sampled well was 299-W19-12 which was installed in 1983 and is located just east of tanks U-104 and U-107. To satisfy RCRA monitoring requirements for the U WMA, two upgradient wells (299-W18-25 and 299-W18-31) on the west side of the U tank farm and three downgradient wells (299-W19-30, 299-W19-31 and 299-W19-32) located on the northeast and east side of U tank farm (Figure 1-2) were installed in 1991 and 1992. Since then, water table subsidence eliminated sampling capability at some wells, necessitating the installment of some replacement wells including 299-W-42 to replace 299-W19-31, 299-W19-41 to replace 299-W19-32 in 1999 and 299-W18-40 to replace 299-W18-25 in 2001. When functional, these wells have been sampled and analyzed regularly since installation.

Generally speaking, groundwater flows in an easterly to northeasterly direction. However, during this sampling period, the upgradient-downgradient relationship was temporarily reversed between mid 1993 and early 1996 (see figure 2-6) because of large liquid discharge events in the 216-U-14 ditch just east of the U tank farm in 1991 and 1993 (Singleton and Lindsey 1994). The discharge volume over a short period (about 2×10^9 L (5×10^8 gal) in 1991) was sufficient to affect local groundwater flow. This event was apparently sufficient to affect the contaminant concentration histories in the RCRA monitoring wells (Figures 3-1 through 3-7).

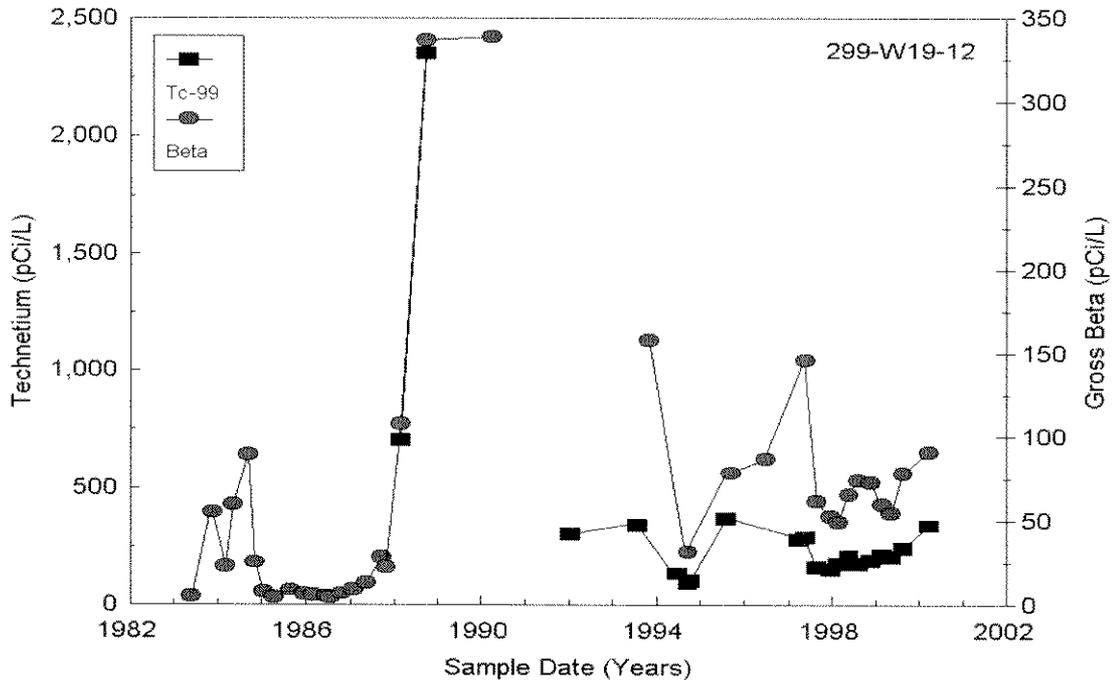
In these monitoring wells the groundwater contaminants that are present and apparently derived from waste processing sources are technetium-99 and nitrate. The first indication of tank waste contaminants in groundwater occurred at borehole 299-W19-12 where a nitrate concentration of about 40,000 parts per billion (ppb) was measured in 1983 (Figure 3-1). At the same time, a gross beta peak was also observed (Figure 3-2). Presumably, technetium-99 was the primary contributor but no direct measurements are available. Subsequently, around 1990, secondary peak concentrations of nitrate and technetium-99 were measured at this well (Figures 3-1 and 3-2). The technetium-99 peak concentration period is less well defined than the nitrate peak because technetium-99 was not measured as frequently (i.e., a measurement gap occurs between 1989 and 1992). Maximum technetium-99 and nitrate values of 2,350 pCi/L and about 18,000 ppb, respectively, were measured. Finally, after falling to minimum values between 1994 and 1995, concentrations have been rising in this well (see Figures 3-3 and 3-6 for nitrate and Figures 3-4 and 3-7 for technetium-99). Last reported nitrate and technetium-99 values in 2001 (Figures 3-6 and 3-7, respectively) were about 23,000 ppb and 400 pCi/L.

Sampling data from the RCRA monitoring wells show that relative changes in constituent concentrations with time have been similar in normally upgradient monitoring wells 299-W18-25, 299-W18-31 and 299-W18-30 and different from the downgradient wells. In these wells, technetium-99 has been either not present or in low concentrations. The dominant characteristic is the occurrence of a nitrate concentration peak in early 1995 (see Figure 3-3).

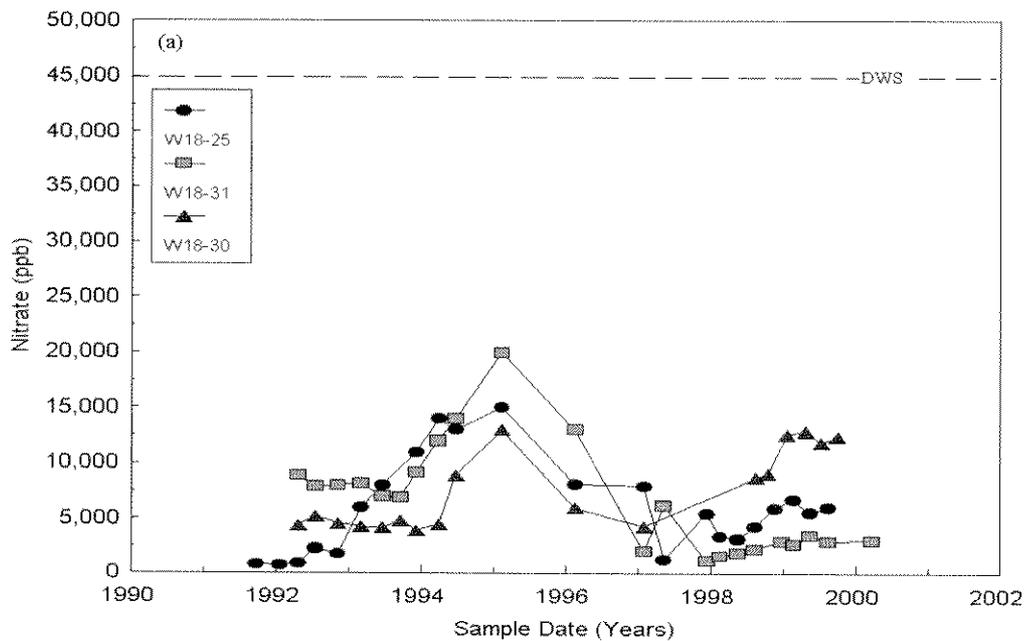
Figure 3-1. Nitrate Measurements at Monitoring Well 299-W19-12 (Hodges and Chou 2000)



**Figure 3-2. Technetium-99 and Gross Beta Measurements at Monitoring Well 299-W19-12
Hodges and Chou (2000)**



**Figure 3-3. Nitrate Measurements at Monitoring Wells 299-W18-25, 299-W18-30, and
299-W18-31 (Hodges and Chou 2000)**



Sampling data from the normally downgradient wells, 299-W19-12, 299-W19-31/299-W19-42, and 299-W19-32/299-W19-41 show more complex patterns. In the northern wells (299-W19-31/299-W19-42) nitrate and technetium-99 peak values (Figures 3-4 and 3-5) occur fairly close together, first in 1992 (about 20,000 ppb and 250 pCi/L) and then in late 1996 to early 1997 (about 43,000 ppb and about 750 pCi/L). Minimum values (< 1,000 ppb and < 50 pCi/L) occur in 1994. In the most recently published data, nitrate and technetium-99 values at these wells (Figures 3-6 and 3-7) remain low or are decreasing (Hartman et al 2001). In the southern wells (299-W19-12, and 299-W19-32/299-W19-41) nitrate and technetium-99 peaked in late 1993 (about 18,000 ppb and 2,000 pCi/L at 299-W19-32). Values then remained low for the most part until 1997 to 1998 and began to rise (Figures 3-6 and 3-7). This trend diverges from that shown in the remaining functional northern well (299-W19-42) where technetium-99 concentrations have decreased to very low values.

3.4.2 Data Interpretation

Three primary observations from the groundwater monitoring well data indicate that tank waste has been a source of groundwater contamination at the U WMA. First, the occurrence of several short-term pulses of linked nitrate and technetium-99 concentrations in several downgradient groundwater monitoring wells on the east side of the U WMA indicates a nearby tank waste source. This inference is supported by the observation that technetium-99 has been detected at elevated concentrations only in the downgradient monitoring wells. A high chromium concentration (about 100 ppb) was also noted in monitoring well 299-W19-32 in July 1993 that coincided with the high technetium-99 peak (about 2,000 pCi/L) in the same sample suggesting a potential tank waste source for chromium as well. However, two later chromium peaks were measured at this same well that were associated with increases in metal corrosion elements nickel and iron. Therefore, it seems more likely that well casing corrosion products are the source of occasional elevated chromium concentrations.

Second, sequential nitrate/technetium-99 pulse occurs at several downstream monitoring wells indicating more than one contamination event. Also, nitrate to technetium-99 concentration ratios change between pulses. These observations suggest multiple contamination sources that may be different vadose zone tank waste sources or a combination of a primary tank waste source and sources outside the WMA. While the source of technetium-99 is probably tank waste, nitrate sources in addition to tank waste are abundant. Sources that could have contributed nitrate contamination to local groundwater includes U pond discharges, the 216-U-14 ditch discharges, the suite of ditches and cribs just to the west of the U WMA (e.g., 216-Z-1D and 216-Z-20), and contaminated vadose zone soil in the U WMA. Discharges from the 216-Z-20 crib are the most recent (Johnson, 1993).

Third, migration of tank waste away from the U WMA has been retarded by local groundwater flow perturbations caused by liquid waste discharge into the 216-U-14 ditch just east of the U WMA in the early 1990s. Recharge from this event caused a temporary reversal of the upgradient downgradient conditions in the nearby groundwater monitoring wells. Normally, the wells on the west side of the U WMA are upgradient relative to the wells on the eastern side of

the U WMA. However, from mid 1993 to early 1996 water level measurements were lower in the western versus eastern wells indicating a reversal in the hydraulic gradient orientation. Since 1996, the normal condition of a dominant easterly flow direction has been reestablished. The impact of this event on tank waste migration is discussed below.

The combination of apparent multiple contamination events and short-term changes in local groundwater flow conditions complicates data interpretation. An approach for explaining the chronology of various contamination and migration events is to consider pulse events that are characterized by similar nitrate to technetium-99 ratios in the context of well location and the temporal changes in hydraulic gradient orientation.

The most concentrated technetium-99 contamination event (maximum concentration of 2,350 pCi/L) was first observed at 299-W19-12 in 1990. A nitrate peak of about 18,000 ppb occurred about the same time in this well. This occurrence is the clearest indication of tank waste migration to the unconfined aquifer and presumably that with the highest observed impact on groundwater contamination. At the time the predominant flow direction was probably easterly suggesting that the plume originated underneath the U WMA and was migrating eastward. A second occurrence of a similar peak (maximum technetium-99 and nitrate values of about 2,000 pCi/L and 18,000 ppb, respectively) occurs at 299-W19-32 in late 1993 just south of 299-W19-12. By late 1993, the impact of the 216-U-14 ditch discharges on groundwater flow was indicated by the reversal of upgradient-downgradient relationships between eastern and western wells such that the potential for groundwater flow was no longer easterly. It is suggested that these two peak concentration observations are measurements of the same volume of contaminated groundwater that had migrated east of 299-W10-12 and was then diverted southward by recharge created by the 216-U-14 discharge event in 1991.

A different and earlier contamination event is suggested by the more nitrate-rich peak concentrations (about 40,000 ppb) that were measured in late 1983 at 299-W19-12. A gross beta peak of about 750 pCi/L was also closely associated with the nitrate and may be largely technetium-99. A second indication of this peak may have occurred at 299-W19-31 in mid 1996 when a nitrate peak of about 43,000 ppb was measured. A technetium-99 peak (about 750 pCi/L) occurred in mid 1996, preceding the nitrate peak slightly. It is noteworthy that this nitrate to technetium-99 ratio is distinctly different than that described above. If the pulses at these two monitoring wells indicate migration of the same groundwater volume, the relationship between the migration path and the groundwater flow perturbations is not simple. By mid to late 1996, water level measurements once again showed an easterly flow direction. If the contamination seen in 1983 at 299-W19-12 had passed to the east of that location prior to 1993, perhaps recharge from the 216-U-14 discharge event forced northwesterly migration of this contamination and subsequent reversal to the east past 299-W19-32 after 1996.

A third distinct contamination and migration event may be indicated by the nitrate pulse occurring between 1993 and 1996 in the upgradient wells 299-W18-25, 299-W18-30 and 299-W18-31. Maximum nitrate concentrations from 12,500 to 20,000 ppb were measured in early 1995. Essentially no technetium-99 is associated with this pulse. The timing of the nitrate pulse coincides with reversal of the local hydraulic gradient from easterly to westerly suggesting that the observed nitrate could have been under the U WMA. However, the lack of

technetium-99 suggests sources other than tank waste. It is conceivable that by the time the 216-U-14 recharge effects took place, the technetium-99 from tank waste had migrated too far east to reverse migrate as far as the western and northern sides of the U WMA. Subsequent migration of this contamination, presumably to the east, is not clearly identifiable in downstream wells.

Since the mid 1990s, the southeastern wells (299-W19-12 and 299-W19-41) show gradually increasing nitrate and technetium-99 concentrations although the ratios are not constant. On the other hand, the northeastern well (299-W19-42) shows lower, quasi steady state concentrations of nitrate and greatly diminished technetium-99 concentrations. These data may indicate the commingling of various contaminants from other events that are now at the southeastern corner of the U WMA and are migrating away from the U WMA as easterly flow continues. The reduction of contamination in the northern well may indicate some southerly component to the migration pattern.

Figure 3-4. Nitrate Measurements at Monitoring Wells 299-W19-12, 299-W19-31, 299-W19-32, 299-W19-41 and 299-W19-42 (Hodges and Chou 2000)

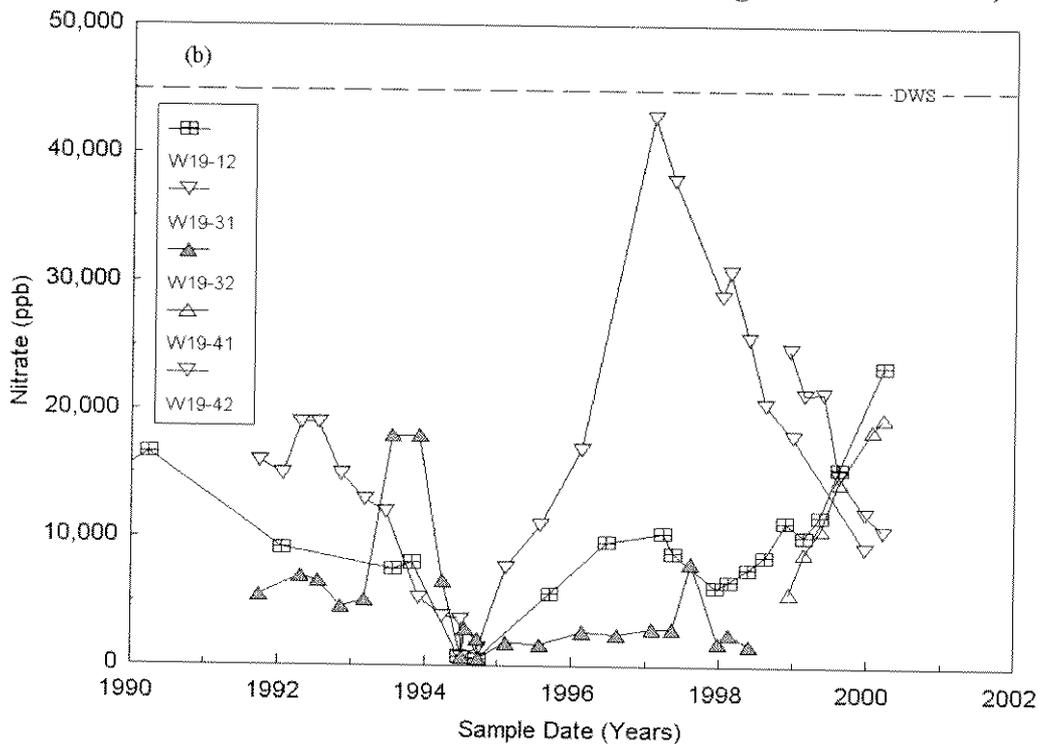


Figure 3-5. Technetium-99 Measurements at Monitoring Wells 299-W19-12, 299-W19-31, 299-W19-32, 299-W19-41 and 299-W19-42 (Hodges and Chou 2000)

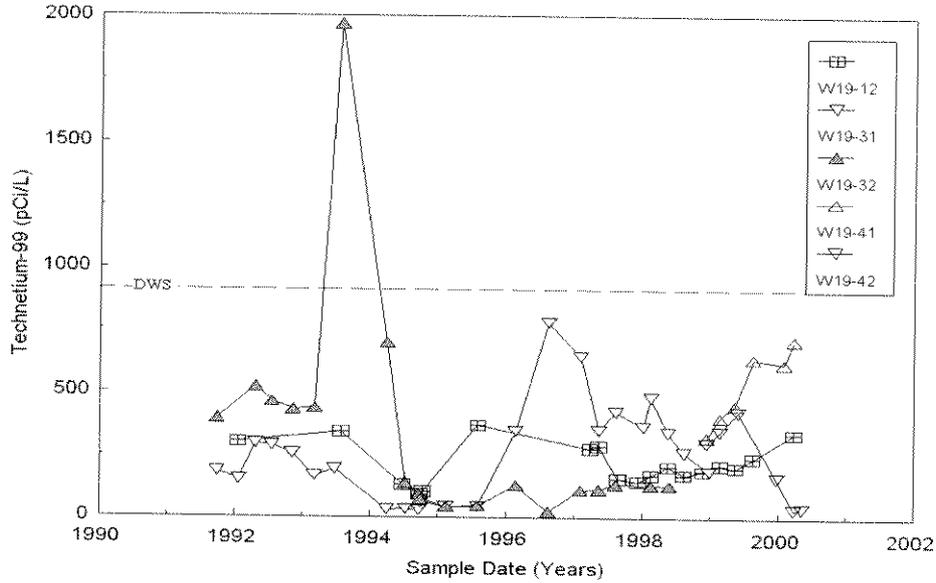
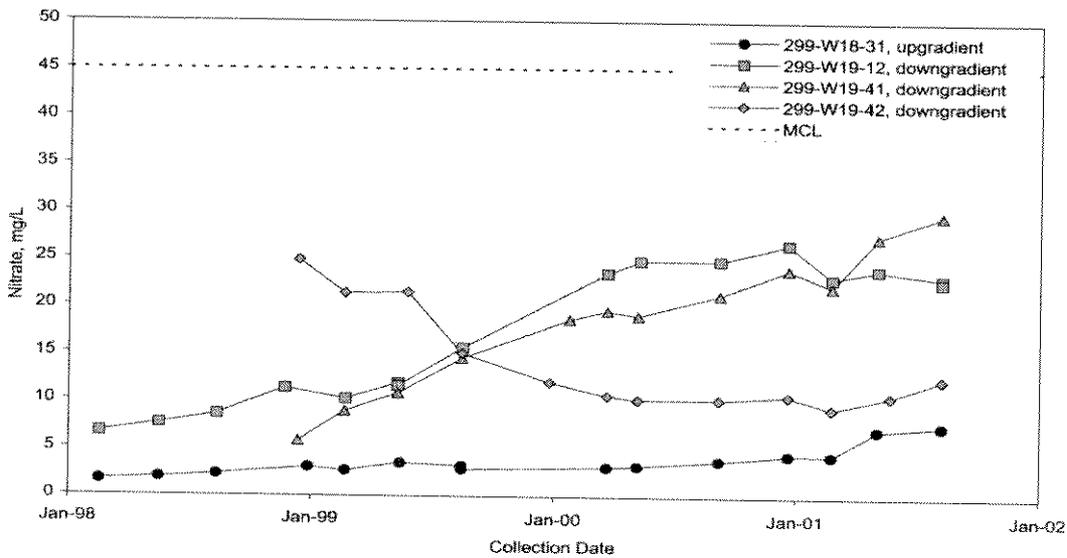
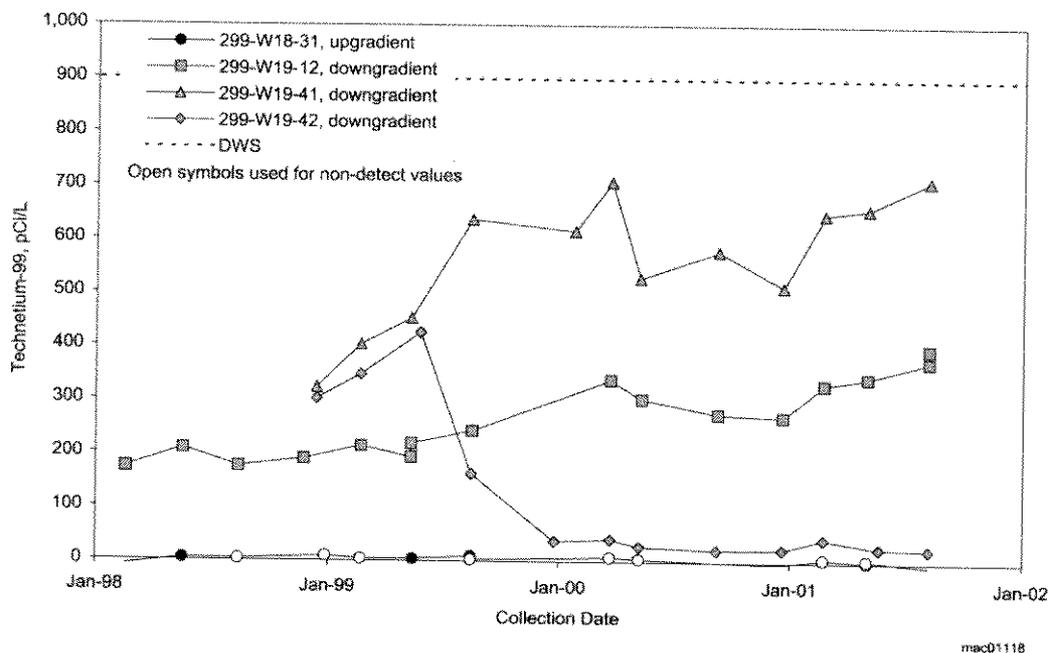


Figure 3-6. Nitrate Measurements at Wells 299-W18-31, 299-W19-12, 299-W19-41 and 299-W19-42 (Hartman et al 2001)



mac01119

Figure 3-7. Technetium-99 Measurements at Wells 299-W18-31, 299-W19-12, 299-W19-41 and 299-W19-42 (Hartman et al 2001)



The preceding discussion of groundwater contamination indicates the complexity of contamination and migration events that have occurred in the U WMA. Given the measured technetium-99 concentrations and the sharp changes in concentration observed in the 299-W19-12 well in 1988, a nearby relatively concentrated source is indicated. It is reasonable to hypothesize that a contaminated vadose zone source is the dominant source for the observed technetium-99 contamination. The particular vadose zone source is not known. At the same time, if vadose zone contamination is the source of technetium-99 in the unconfined aquifer, minimal contamination has been contributed. Only two measurements have exceeded the 900 pCi/L maximum concentration level (MCL) and these have only occurred once in each of two monitoring wells.

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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 U WMA. 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 U WMA. 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 U WMA are uranium and cesium-137.
- Spectral gamma drywell measurements of uranium show a large footprint in the vadose zone southwest of tank U-104. The largest activities were measured at drywells 60-07-11, 60-04-08 and 60-07-01 next to tank U-104 on the southwest sides. Considering the three drywells collectively, uranium-238 activities of 100 to 1,000 pCi/g occurred between tank bottom (about 52 ft [16 m]) and 90 ft (27 m) bgs. The drywell most distant from tank U-104 that contained trace quantities of uranium-238 (about 1 pCi/g at 65 ft [20 m] bgs) was 60-11-07 about 290 ft (87 m) from the southwest side of tank U-104.
- Cesium-137 high activity zones were measured in two drywells (60-10-07 and 60-12-01) near tank bottom depth. At 60-10-07, cesium-137 activities of 1,000 to 10^7 pCi/g occurred between 52 and 57 ft (16 and 20 m) bgs. At 60-12-01, high cesium-137 activities were measured in two zones, between 50 and 67 ft (15 and 20 m) and 83 and 97 ft (25 and 30 m) bgs. Activities ranged from 10^5 to 10^9 pCi/g in the upper zone and from 10^4 to 10^5 pCi/g in the lower zone.
- Isolated near surface high cesium-137 activity zones were measured in drywells 60-02-01, 60-03-08, 60-11-12, 60-12-01 and 60-11-03. Maximum Cesium-137 activities approaching 1,000 pCi/g were observed. Minor cobalt-60 and europium-154 activities were occasionally associated with cesium-137.
- A tank failure and subsequent leak is well documented in tank U-104. A bulge in the tank bottom was observed in 1956. This observation combined with the spectral gamma data measured in the 1990s clearly shows the tank leak event and its contamination of the local vadose zone.
- Groundwater flow directions have changed numerous times in the vicinity of the U WMA over the last 50 years because of liquid discharges to the vadose zone from Hanford Site operations. The most recent occurrence at the U WMA was a local reversal in flow that occurred because of a large discharge of wastewater from U and UO₃ Plants into the 216-U-14 ditch just east of the U tank farm in 1991. From 1993 to 1996 flow direction was dominantly westerly to northwesterly in contrast to the previous easterly to northeasterly direction. Since 1996 flow direction has returned to this pattern.
- Evidence of plausible unconfined aquifer contamination from U WMA leaks was indicated by anomalously high nitrate and technetium-99 concentrations in several groundwater

monitoring on the east side of the U WMA. The largest technetium-99 concentration of 2,350 pCi/L was measured in groundwater monitoring well 299-W19-12 in September 1988. Subsequent peaks measured in other nearby wells are lower and appear to be manifestations of additional contamination and migration events.

These observations indicate that three tank leak events have occurred in the U WMA and some degree of groundwater contamination can be attributed to one or more of these sources.

4.2 CONCEPTUALIZATION OF PRIMARY VADOSE ZONE CONTAMINATION EVENTS

Two types of vadose zone contamination events occurred in the U WMA. These include leaks from tanks U-104, U-110 and U-112 and near surface discharges attributed to various unspecified tank farm activities or waste transfer line leaks. Conceptual models are provided in the following sections for tank leaks that have discharged the largest inventories into the vadose zone. The U-101 tank leak reported in Hanlon (2002) is not discussed further because neither the historical record nor the field evidence support a substantive tank waste loss to the vadose zone.

Several small transfer line or surface spill discharges are indicated by peak activities of gamma emitting radionuclides in single drywells that occur between 5 and 40 ft (2 and 12 m) bgs. Usually, the indicator radionuclide is Cesium-137 and the high activity 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 U WMA include the following:

- A discharge on the north side of tank U-102 is indicated by elevated cesium-137 activities (1,000 pCi/g) between 8 and 10 ft (2 and 3 m) bgs in drywell 60-02-01. Cesium-137 contamination disappears below 15 ft (5 m) bgs. This appears to be the result of a small transfer line leak.
- A discharge on the west side of tank U-103 is indicated by elevated cesium-137 activities (1,000 pCi/g) at about 5 ft (2 m) bgs in drywell 60-03-08. This appears to be the result of a surface spill.
- A discharge on the north side of tank U-111 is indicated by elevated cesium-137 (1,000 pCi/g) and europium-154 (~100 pCi/g) activities at 3 ft (1 m) bgs in drywell 60-11-12. This contamination appears to be the result of a surface spill.
- A discharge on the east side of tank U-111 is indicated by elevated cesium-137 (1,000 pCi/g), europium-154 (~100 pCi/g) and cobalt-60 (~10 pCi/g) activities at 3 ft (1 m) bgs in drywell 60-11-03. This appears to be the result of a surface spill. The similarity of contamination in this drywell and drywell 60-11-12 may indicate the same discharge event.
- A discharge on the north side of tank U-112 is indicated by elevated cesium-137 activities (~1,000 pCi/g) at 3 ft (1 m) bgs in drywell 60-12-01.

The remaining contamination areas that are considered to be the largest inventory contributors to the vadose zone in the U WMA are tank leaks from tanks U-104, U-110, U-112. Conceptualizations of these leaks are provided below.

4.2.1 Conceptual Model of the Tank U-104 Leak

Historical records and spectral gamma data clearly indicate that tank U-104 leaked and caused the most extensive contamination of the vadose zone in the U WMA. The first indication of the leak from tank U-104 occurred in 1956 when Shadel and Smith (1956) reported a bulge near the center of the tank bottom. Subsequently, the bulge was located in the northeast quadrant of the tank at height of about 5 ft (2 m) and a tear in the liner was also observed. Historical records show that metal waste from the bismuth phosphate was present in the tank and was being sluiced around the time of the tank leak. The discharge of metal waste into the vadose zone was confirmed by the uranium spectral gamma measurements in nearby drywells completed in the 1990s.

The metal waste leak from tank U-104 event was similar in several respects to the tank BX-102 leak (Knepp 2002). The tank BX-102 leak also released metal waste and distributed uranium in the vadose zone in a pattern that is analogous to that shown in the U WMA. It was concluded from extensive evaluation of the tank BX-102 leak (Knepp 2002) that three factors dominated the observed contaminant migration behavior during the initial phase of the leak event. These were 1) a short term, high volume discharge of waste, 2) metal waste chemistry that temporarily solubilized uranium such that it migrated with tank fluid, and 3) the occurrence of horizontal soil layers in the vadose zone with differing hydrologic properties due different grain size distributions. These factors also are proposed to be those that controlled the tank U-104 leak.

The tank U-104 leak began with a substantial rupture of the steel liner at the bottom of the tank, which was probably accelerated by high temperatures inside the tank. Given the occurrence of the tank liner rupture and the presence of a large fluid volume in the tank at the time of the leak, it is likely that the initial loss of tank waste fluid was a high rate, high volume discharge. Also, waste release may have been enhanced by a leak test that was completed after discovery of the tank bottom bulge in 1956. The leak volume estimate of 50,000 gal (190,000 L) in Hanlon (2002) is not well supported and may be low. If the size of the contaminant footprint in the vadose zone is roughly proportional to the leak volume, then the tank U-104 leak may be larger than the current estimate. The tank BX-102 leak volume was well constrained by tank farm operations records to be about 92,000 gal (327,000 L) (Knepp 2002). However, the U-104 uranium distribution is larger than the BX-102 footprint (e.g., each plume is roughly oval in map view with the long axis of the U-104 plume being about 200 ft (61 m) versus the BX-102 plume being about 100 ft (31 m) long).

Once tank waste was discharged underneath the tank, fluid flow behavior was greatly influenced by sedimentary structures that favored lateral versus vertical migration, although both occurred during the release event. The migration path is marked by the uranium distribution pattern in a sequence of drywells to the southwest of tank U-104. The uranium was clearly mobile during this time since trace amounts are found more than 200 ft (61 m) from tank U-104. On the other

hand, uranium is measured not much more than 40 ft (12 m) below the tank bottom. A similar lateral to vertical ratio is seen at the BX-102 site. At BX-102 site, this distribution is partly attributed to the presence of horizontal layers of sediments with different grain size distributions and correspondingly different hydrologic properties. At the U-104 contamination site, uranium is present in the H2 unit of the Hanford formation, which is characterized by a laminate structure of alternating thin layers of sandy versus silty soils. These characteristics apparently promoted lateral migration during the initial phase of the leak migration.

The observation that uranium is still present in relatively large concentrations confined to relatively cohesive depth intervals also indicates that uranium mobility decreased rapidly some time after the initial leak event and stabilized in the vadose zone. Extensive soils characterization at the BX-102 contamination site shows that uranium largely precipitated in the vadose zone and is currently rather immobile. It is proposed that the same process has occurred at the U-104 contamination site.

Once the metal waste fluid stopped leaking from the tank and spreading rapidly through the vadose zone, drainage began. Drainage was driven by natural infiltration rates and perhaps by occasional manmade discharges that accelerated vertical migration. By this time, the uranium had largely precipitated. More mobile radionuclides and chemicals, particularly technetium-99 and nitrate, migrated more deeply into the vadose zone and some fraction of the inventory may have reached the unconfined aquifer. The elevated technetium-99 and nitrate concentrations that have peaked sporadically and more or less coincidentally in the groundwater monitoring wells on the eastern side of the U WMA may have drained from this contaminated zone. Because of the changes in flow direction that have occurred under the U WMA in the 1990s, it appears that this contamination has not migrated far from the U WMA, first migrating easterly until 1993, then back towards the U WMA (perhaps radially) from 1993 to about 1996, and finally back to easterly, the current general flow direction.

It is not certain that the source of this contamination is the tank U-104 leak. At the BX-102 site, uranium was observed in groundwater coincident with technetium-99 and nitrate. At these wells, no uranium has been measured in groundwater. The reason for this difference is unclear. Technetium-99 and nitrate may have originated from another source or uranium may be less mobile. Given the relative location of vadose zone contamination to groundwater monitoring wells containing these elevated contaminants and the upgradient/downgradient relationships indicated by general groundwater flow directions, the tank U-104 leak appears to be the most logical contamination source. If the U-104 vadose zone contamination has reached the unconfined aquifer, elevated liquid discharges through the contamination zone, either natural (e.g., snowmelt) or manmade (e.g., pipe leaks), must have played a role in accelerating travel time through the vadose zone.

4.2.2 Conceptual Model of the Tank U-110 and U-112 Leaks

Small leaks from tanks U-110 and U-112 are indicated by spectral gamma measurements of high cesium-137 concentration zones near the tank bottom from single drywells near each tank. The drywells (60-10-07 on the southwest side of tank U-110 and 60-12-01 on the north side of tank

U-112) suggest leaks occurred near the tank bottoms at these locations. Both tanks contained high temperature wastes with the significant waste type being REDOX supernate. At tank U-110, the leak probably occurred in 1975 when increased gamma activity was noted in drywell 60-10-07. At tank U-112, apparent liquid level drops in the tank in the late 1960s may have indicated a leak. In both tanks there is no indication of a prolonged leak and this hypothesis is supported by the spectral gamma drywell data.

Subsequent distribution of tank waste contaminants following the leak events are not known. The only available marker is cesium-137 which apparently sorbed very rapidly to the soil upon contact. In neither case does the high cesium-137 concentration zone extend more than 10 ft (3 m) below the tank bottom. More mobile constituents have undoubtedly migrated deeper, both laterally and vertically in the vadose zone. However, because there appears to be no substantive liquid discharge at the time of the leaks, extensive lateral migration is not anticipated. The extent of vertical migration is unknown. A connection between these contamination zones and the technetium-99 and nitrate contamination in the eastern groundwater monitoring wells cannot be ruled out.

4.3 TANK LEAK 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, 2000b). 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. Inventory estimates are provided for tanks U-104, U-110 and U-112 in Table 4-1. The U-104 inventory estimate assumes leakage of 55,000 gal of metal waste in 1956. The U-110 and U-112 inventory estimates assume leakage of 6,500 and 8,500 gal, respectively of primarily REDOX supernate.

Table 4-1. Tank Leak Inventory Estimates for U Tank Farm (3 sheets)

Tank	U-104	U-110	U-112	U Farm
Leak Vol.	50 kgal	6.5 kgal	8.5 kgal	Sum
Analyte	kg	kg	kg	kg
Na	1.28E+04	1.38E+03	3.60E+03	1.77E+04
Al	0.00E+00	2.93E+02	6.49E+02	9.42E+02
Fe	8.11E+01	2.55E+00	3.49E+00	8.72E+01
Cr	1.59E+01	2.54E+01	1.59E+02	2.00E+02
Bi	0.00E+00	1.68E+00	2.57E+00	4.25E+00
La	0.00E+00	6.45E-07	0.00E+00	6.45E-07
Hg	0.00E+00	2.00E-02	8.97E-03	2.90E-02
Zr	0.00E+00	2.33E-01	9.35E-02	3.26E-01
Pb	0.00E+00	2.65E+00	4.58E-01	3.11E+00
Ni	1.80E+01	2.29E+00	3.30E+00	2.36E+01
Sr	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 4-1. Tank Leak Inventory Estimates for U Tank Farm (3 sheets)

Mn	0.00E+00	5.44E-01	0.00E+00	5.44E-01
Ca	1.01E+02	8.25E+00	1.15E+01	1.21E+02
K	2.03E+01	1.04E+01	2.29E+01	5.35E+01
NO3	6.24E+03	1.34E+03	3.50E+03	1.11E+04
NO2	4.03E+02	6.43E+02	1.21E+03	2.26E+03
CO3	7.33E+03	8.25E+01	4.61E+01	7.46E+03
PO4	6.49E+03	3.60E+01	6.93E+01	6.60E+03
SO4	4.20E+03	8.59E+01	9.26E+01	4.38E+03
Si	2.16E+01	1.11E+01	1.54E+01	4.80E+01
F	0.00E+00	8.30E+00	1.13E+01	1.96E+01
Cl	8.43E+01	2.85E+01	9.53E+01	2.08E+02
DBP	0.00E+00	1.37E+01	0.00E+00	1.37E+01
Butanol	0.00E+00	4.83E+00	0.00E+00	4.83E+00
TBP	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
U-Total	5.16E+03	1.51E+01	2.69E+01	5.20E+03

Analyte	Ci	Ci	Ci	Ci
H-3	4.80E+00	7.11E-01	1.46E+00	6.97E+00
C-14	1.65E-01	8.57E-02	1.13E-01	3.63E-01
Ni-59	7.19E-02	1.06E-02	1.44E-02	9.69E-02
Ni-63	6.56E+00	1.03E+00	1.34E+00	8.93E+00
Co-60	6.80E-02	8.20E-02	4.43E-02	1.94E-01
Se-79	5.41E-02	1.13E-02	2.39E-02	8.94E-02
Sr-90	1.62E+03	2.88E+02	9.38E+02	2.85E+03
Y-90	1.62E+03	2.88E+02	9.40E+02	2.85E+03
Zr-93	2.57E-01	5.58E-02	1.13E-01	4.26E-01
Nb-93m	2.15E-01	4.04E-02	9.25E-02	3.48E-01
Technetium-99	1.79E+00	6.20E-01	7.89E-01	3.20E+00
Ru-106	3.52E-08	1.24E-05	1.24E-07	1.25E-05
Cd-113m	6.76E-01	2.79E-01	3.48E-01	1.30E+00
Sb-125	7.05E-02	3.02E-01	6.49E-02	4.38E-01
Sn-126	8.20E-02	1.70E-02	3.68E-02	1.36E-01
I-129	3.38E-03	1.19E-03	1.52E-03	6.09E-03
Cs-134	2.12E-04	1.55E-02	1.11E-03	1.68E-02
Cesium-137	1.93E+03	2.10E+03	2.34E+03	6.37E+03
Ba-137m	1.84E+03	1.99E+03	2.21E+03	6.03E+03
Sm-151	2.00E+02	3.97E+01	8.56E+01	3.25E+02
Eu-152	1.43E-02	1.14E-02	8.32E-03	3.40E-02
Eu-154	1.32E+00	1.48E+00	1.07E+00	3.87E+00
Eu-155	9.58E-01	7.02E-01	3.95E-01	2.05E+00
Ra-226	1.10E-05	5.33E-07	1.72E-06	1.33E-05
Ra-228	3.93E-11	4.19E-05	1.11E-11	4.19E-05
Ac-227	2.89E-05	3.53E-06	9.69E-06	4.21E-05
Pa-231	7.64E-05	1.61E-05	3.58E-05	1.28E-04
Th-229	7.51E-09	2.02E-06	2.12E-09	2.03E-06

Table 4-1. Tank Leak Inventory Estimates for U Tank Farm (3 sheets)

Th-232	6.78E-11	9.23E-06	2.95E-11	9.23E-06
U-232	4.06E-05	1.92E-03	3.27E-07	1.96E-03
U-233	1.85E-06	7.36E-03	1.30E-08	7.36E-03
U-234	1.68E+00	5.64E-03	8.85E-03	1.70E+00
U-235	7.44E-02	2.30E-04	3.84E-04	7.50E-02
U-236	1.73E-02	2.02E-04	1.25E-04	1.76E-02
U-238	1.72E+00	5.05E-03	9.01E-03	1.74E+00
Np-237	1.08E-02	2.30E-03	5.12E-03	1.82E-02
Pu-238	9.76E-03	3.67E-03	3.55E-03	1.70E-02
Pu-239	1.22E+00	1.51E-01	2.74E-01	1.64E+00
Pu-240	1.19E-01	2.29E-02	3.68E-02	1.79E-01
Pu-241	4.30E-01	2.17E-01	2.07E-01	8.54E-01
Pu-242	1.96E-06	1.07E-06	9.48E-07	3.99E-06
Am-241	5.83E-01	1.81E-01	4.00E-01	1.16E+00
Am-243	4.22E-06	5.11E-06	3.73E-06	1.31E-05
Cm-242	2.77E-04	3.35E-04	1.91E-04	8.04E-04
Cm-243	5.72E-06	2.51E-05	4.38E-06	3.52E-05
Cm-244	1.13E-04	3.07E-04	1.33E-04	5.53E-04

All radionuclides decayed to 1/1/1994

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5.0 RECOMMENDATIONS FOR FURTHER CHARACTERIZATION OF THE U WMA

Chapters 1 through 3 present information pertinent to the occurrence of contaminants in the vadose zone underlying the U WMA. 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 in the vicinity of 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, and uranium, a moderately mobile constituent. Other contaminants, particularly cesium-137 and cobalt-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. Finally, spectral gamma and neutron probe logging for moisture is recommended where feasible.

Table 5-1 lists the most highly contaminated vadose zone areas in the U WMA and the critical factors that influence future characterization decisions. These factors are primary indicators of the nature and extent of contamination underlying this WMA 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. 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.

Table 5-1. Critical Factors and Recommendations for Field Characterization at The U WMA

Critical Factors	Vadose Zone Contamination Areas					
	Tank Leaks			Near Surface Leaks (Transfer Lines or Surface Spills)		
	U-104	U-110	U-112	drywell 60-02-01	drywell 60-11-03	drywell 60-11-12
Discharge Volume Estimate (gal)	^b 50000	6,500	8,500	Unknown	Unknown	Unknown
Drywell/Lateral Coverage	Good	Fair	Fair	Fair	Fair	Fair
Leak Boundary Controls	Good	Fair	Fair	Fair	Fair	Fair
Gamma-Emitting Radionuclide Contamination Depth (ft below ground surface [bgs])	55 to 95 (max)	50 to 65	50 to 100	8 to 11	Surface to 10	Surface to 5
Relative Vadose Zone Contamination Level Among U Sites	High	Medium	Medium	Low	Low	Low
Maximum Cs-137 concentration in spectral gamma data (pCi/g)	0	$\sim 5 \times 10^6$	$\sim 5 \times 10^8$	3,000	525	900
Maximum U-238 concentration in spectral gamma data (pCi/g)	1,000	0	0	0	0	200
^c Estimated Uranium Inventory (Ci)	4	0	0	0	0	0
^c Estimated Cs-137 Inventory (Ci)	1,930	2,100	3,340	0.1	<0.1	<0.1
^c Estimated Tc-99 Inventory (Ci)	1.8	0.6	0.8	<0.001	<0.0001	<0.0001
Recommended Approach						
Kriegering	X					
Borehole	Drill below Plio-Pleistocene just southwest of tank U-104 and sample regularly		Drill below Plio-Pleistocene near drywell 60-12-01 and sample regularly			

^aEstimate of volume discharged to the vadose zone

^bHanlon (2002)

^cEstimated values from this report

The second part of Table 5-1 lists the primary additional characterization options that are available to improve the estimate of the nature and extent of contamination in the vadose zone underlying single shell tank farms. Applicability of each option was evaluated for each contamination region in the following ways:

- 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, 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.
- Kriegering 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.

5.2 RECOMMENDATIONS FOR ADDITIONAL CHARACTERIZATION IN THE U WMA

Proposed characterization options are indicated in Table 5.1. Characterization is recommended for the contamination zones caused by leaks from tanks U-104 and U-112. Further characterization is not recommended for the areas around drywells 60-02-01, 60-11-03 and 60-11-12 where spectral gamma data show contamination between the surface and 5 ft (2 m) bgs. All three drywells show maximum cesium-137 concentrations of about 1,000 pCi/g. These appear to be small isolated surface spills that are not expected to have contributed significant levels of mobile constituents to the vadose zone and therefore present negligible future risk to groundwater contamination. No other drywells in the U tank farm indicate more than 100 pCi/g of cesium-137 close to the surface.

Further characterization is also not recommended for the other two tanks (U-101 and U-110) listed as leakers in U tank farm in Hanlon (1999). The spectral gamma profile around tank U-101 shows no significant metal waste contamination and the historical record of the leak event is unsubstantiated. Therefore it is concluded that vadose zone contamination resulting from this leak is either fictitious, of insufficient contamination levels to be of concern or inaccessible to available characterization techniques. A leak has occurred at tank U-110, but because it is similar to the tank U-112 leak both in terms of observed vadose zone contamination and historical record of tank waste chemistry, the proposed borehole characterization at tank U-112 should be applicable to the evaluation of the tank U-110 leak.

5.2.1 Characterization of the Tank U-104 Leak

An extensive uranium plume has been mapped from drywell data originating just south of the tank U-104 and extending to the southwest as far away as drywells around tank U-111. It is proposed to drill a sampling borehole through the vadose zone in the area closest to the source of the leak. As the leak occurred under tank U-104 the closest available characterization location lies between drywells 60-07-11, 60-07-10, and 60-04-08. At this location the uranium is found between 50 and 90 ft (15 and 27 m) bgs. The mobile constituents of greatest interest are technetium-99 and nitrate. Being more mobile, these constituents should be found at greater depths in the vadose zone. For future risk evaluation, the current approximate location of the technetium-99 in the vadose zone is needed. Also, the characterization may provide an indication of the effectiveness of the Plio-Pleistocene unit as a barrier to the vertical migration of mobile constituents. An attempt should be made to drive the borehole below the Plio-Pleistocene unit (about 140 ft [43 m] bgs) and sample soils regularly to the borehole bottom.

The feasibility of conducting a kriging analysis of the uranium drywell data is also recommended. Uranium gamma readings are present in ten drywells and this may be a sufficiently large data population to develop an analysis. If feasible, the analysis should be completed to estimate leak volume and inventory. The correct leak volume estimate of 50,000 gal (189,000 L) was not well bounded by historical record and appears to be low. This conclusion is reached by noting the clearly greater extent of uranium distribution in the U farm vadose zone compared to that in the BX tank farm vadose zone from the tank BX-102 metal waste leak. Because the estimated leak from tank BX-102 is well bounded (Knepp 2002) at about 91,600 gal (347,000 L), the tank U-104 leak should be larger.

5.2.2 Characterization of the Tank U-112 Leak

Two high concentration zones of cesium-137 (up to 10^9 pCi/g) are present in drywell 60-12-01 adjacent to the north side of the tank, concentration values that exceed gamma concentrations in all other contaminated areas in the U WMA. This distribution strongly indicates the occurrence of a leak near the bottom of tank U-112. Historical data indicate a relatively small leak of REDOX waste in the late 1960's. REDOX waste was highly contaminated and while the size of the leak may limit the inventory of mobile constituents, it is important to quantify to some their current nature and extent in the vadose zone for purposes of risk assessment. Therefore it is recommended that a borehole be drilled as near to drywell 60-12-01 as possible. An attempt should be made to drive the borehole below the Plio-Pleistocene unit (about 140 ft [43 m] bgs) and sample soils regularly to the borehole bottom. Soil sample analyses will provide an indication of relative depth of tank fluid constituents in the vadose zone, particularly the mobile constituents, Tc-99 and nitrate. Also, by comparing the ratios of various measured constituents (e.g., technetium-99 versus cesium-137), the hypothesized source fluid chemistry may be corroborated.

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APPENDIX A
HISTORICAL BACKGROUND OF U TANK FARMS OPERATIONS AND
CONTAMINATION EVENTS

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A.1.0 HISTORICAL BACKGROUND OF U TANK FARM OPERATIONS AND CONTAMINATION EVENTS

This appendix includes narrative description from 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 REDOX waste storage) are provided in the referenced document.

HISTORICAL VADOSE ZONE CONTAMINATION FROM U FARM OPERATIONS

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Fluor Federal Services
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-99RL14047

EDT/ECN: 630080 *see 5/2* UC: 2000
Cost Center: ~~114101~~ 114631 Charge Code: BA10 HFCN 0601
B&R Code: N/A Total Pages: 43

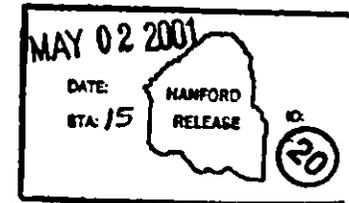
Key Words:
Vadose zone, U Tank Farm, historical, cribs, spills, groundwater, unplanned releases

Abstract:
This report compiles information on liquid waste discharged to the soil vadose zone in and around the 241-U Tank Farm. Planned discharges (i.e., transfers to cribs) and unplanned releases (spills or tank leaks) are considered. Discharges are presented chronologically and placed in the context of tank farm operations.

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**HISTORICAL VADOSE ZONE CONTAMINATION
FROM U TANK FARM OPERATIONS**

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- Appendix C. Figures

HISTORICAL VADOSE ZONE CONTAMINATION FROM U 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-U Tank Farm. Specifically, the historical information pertains to the tank farm, all known liquid radioactive waste disposal sites (cribs), and all known unplanned releases (UPRs) in the area. Releases are included from initial construction in 1944 to the present. A list of UPRs is included in Appendix A, and a timeline of events is included in Appendix B. The area of interest extends from the 207-U retention basin west to the 216-Z-20 crib, and from the 216-U-3 French drain north to approximately 30 m north of the farm. The area is shown in Figure 1 (Appendix C contains all figures).

Nonradioactive waste, such as fuel spills, septic tanks, and buried radioactive solid waste, is excluded from this report. Water discharges into the soil, either from precipitation, water line leaks, or decontamination activities are addressed in Gaddis (1999). Therefore, the carbon tetrachloride plume in the 200-West Area vadose zone is not discussed here. Additionally, the most highly contaminated area of the plume, which exceeds 6000 parts per billion (ppb), is centered at the Plutonium Finishing Plant (PFP) and is outside the area of interest. Carbon tetrachloride contamination in the vicinity of U Farm is on the order of 5-100 ppb (Swanson 1999).

Crib disposal outlets are typically located 3 to 10 m 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 the cribs is more than 100 times the volume of waste leaked from tanks (Consort 1994).

The groundwater beneath U Farm is 74 m under ground and the regional gradient is from west to east. Generally, groundwater in the 200-West Area moves to the east. The groundwater level beneath 200-West Area has been decreasing since crib and pond discharges were discontinued, and this represents the Hanford Site's greatest decline in groundwater elevations from 1979 to 1995. The groundwater mounds under the cribs are still decreasing, and additional groundwater level declines are occurring from the use of pump-and-treat injection wells (Hartman 1999).

The topography of U Farm 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 have occurred throughout the operating history of the Hanford Site. Some single-shell tank (SST) farms received hundreds of millions of liters of liquid radioactive waste that was discharged into the vadose zone. Compared to this amount, few significant discharges occurred at U Farm. The largest discharge occurred at the 216-U-3 crib, which received 787 000 liters of

tank headspace condensate. The estimated total discharge to U Farm from all cribs and spills is 1.2 million liters.

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 Farm complexes, U Farm 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-U Tank Farm contains 12 first-generation, reinforced concrete tanks with mild 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. The tanks in a row are piped together so that when the first tank fills, it overflows into the second tank, and the second into the third, e.g., 241-U-101 to -102 to -103. Four diversion boxes were originally provided in U Farm. Four more diversion boxes, the 244-UR vault, the 271-UR control house, and the 244-U double-contained receiver tank (DCRT) 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-U-252. The 207-U retention basin is across Camden Avenue from U Farm (see Figure 2).

U Farm operations can be separated into four distinct operational phases:

- From 1946 until 1952, U Farm received and stored liquid waste from bismuth phosphate operations conducted in T Plant (see Figure 3).
- From 1952 to 1957, high-level waste in U Farm was retrieved and sent to U Plant for uranium recovery (UR) operations (see Figure 4).
- From 1952 until REDOX shut down in 1967, U Plant received and stored REDOX high-level waste. Low-level liquid waste was intentionally discharged into the soil column during this period (see Figure 5).
- Removal of liquid waste from U Farm, interim stabilization (saltwell pumping), and tank farm isolation began in 1972 (see Figure 6).

Sanitary water was provided only to the 271-UR control house during uranium recovery operations. Sanitary water piping is currently capped off near the building and abandoned.

3.1 Bismuth Phosphate Operations (1946-1952)

As part of the Manhattan Project, Hanford was constructed to produce plutonium by chemical separation from irradiated fuel slugs using the bismuth phosphate process. U Plant (221-U) was originally constructed during World War II as a bismuth phosphate plant, and U Farm was constructed to provide storage for the radioactive liquid waste produced at U Plant.

However, U Plant was not needed for that purpose and was used as a simulator. U Farm was not used during World War II. Figure 2 shows Hanford facilities constructed at that time.

The bismuth phosphate process produced five waste streams (Anderson 1990):

- 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. MW was stored in U Farm after 1946.
- 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. The 1C was stored in U Farm after 1946.
- 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. The 2C was not stored in U Farm.
- The plutonium concentrator waste (224) was low-level liquid waste from the 224 Facility. This waste stream was the primary contributor to plutonium contamination of the soil. This waste was discharged to cribs that are outside the scope of this study.
- T Plant cell drainage waste (5-6) waste was low-level liquid waste from floor drains in individual process cells in the Canyon Building. Drainage from the cells was stored in the 5-6 tank before being discharged to a crib. The crib is outside the scope of this study.

During World War II, MW, 1C, and 2C were stored in tanks at T Farm, which is outside the scope of this report but is described in Williams (2000). In December 1945, underground lines were constructed from the 241-T-151 and 241-T-152 diversion boxes in T Farm to the 241-U-151 and 241-U-152 diversion boxes in U Farm (see Figure 3). MW from T Plant was stored in the 241-U-101/2/3, 241-U-104/5/6, and 241-U-107/8/9 cascades, and 1C from T Plant was stored in the 241-U-110/1/2 cascade (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 absorb radioactive material was tested at the Clinton Site in Tennessee (now 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).

Wastewater from the 283-W water treatment plant, the 284-W powerhouse, the 2723-W mask cleaning station (old laundry building), and the 2724-W laundry facility was discharged to the 216-U-14 ditch, part of which runs past U Farm. This water was normally uncontaminated. The 216-U-14 ditch drained to the 216-U-10 pond, which is outside the scope of this report. The

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volume of water discharged to the ditch was not recorded but is estimated at approximately 1.1 billion liters per year (Singleton 1994; WIDS).

Cooling water, steam condensate, and floor drainage from the 231-Z Plutonium Isolation Building was discharged to U Pond via the 216-Z-1D ditch. Part of this ditch runs past U Farm. When PFP began operations in 1949, stormwater runoff and chemical sewer waste were also discharged to this ditch. A 526 m (1725-ft) portion of the ditch from 231-Z to south of PFP was replaced by underground piping at this time. The volume of water discharged to the ditch was not recorded but is estimated at approximately 800 million liters per year (Singleton 1994, WIDS).

In September 1946, the Army Corps of Engineers, Manhattan District selected General Electric Company to replace DuPont as the Site 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 waste tanks). From 1947 to 1949, many new facilities were constructed at Hanford. Facilities for the planned UR mission (see Section 3.2) and other facilities beyond the scope of this report (BX, BY and TX Tank Farms; 241-TX-155 diversion box; PFP; H Reactor; DR Reactor) were all built during this period (Gerber 1991; Gerber 1992).

Construction work at the 241-U-151 and 241-U-152 diversion boxes in the spring of 1950 spread contamination to surrounding areas (UPR-200-W-6). Contamination was covered with clean soil (WIDS).

The 242-B and 242-T evaporators were built in 1951 to reduce the volume of stored 1C. U Farm 1C (in the 241-U-110/1/2 cascade) was retrieved in April 1952 and pumped to TX Farm for evaporation in 242-T. A dedicated underground line was built for the retrieval, and one of the existing lines between U Farm and T Farm was modified to route the waste to the 241-TX-153 diversion box (see Figure 3). Pumps installed in the tank risers discharged to the dedicated line via temporary overground lines. The 242-T operations are described in Williams (2000) (Anderson 1990, H-2-1204).

3.2 Uranium Recovery Operations (1952-1957)

The Uranium Recovery Mission retrieved MW stored in U Farm and other farms to enable recovery of the dissolved uranium. U Plant was modified in 1951 for UR operations using the tri-butyl phosphate (TBP) process. For this reason, U Plant was frequently referred to as the "TBP Plant." Beginning in February 1952, MW was sluiced from U Farm, treated in the 244-UR process vault, and transferred to U Plant via the 241-TX-155 diversion box. The recovered uranium was in the form of uranyl nitrate hexahydrate (UNH), which was sent to 224-U for calcining into uranium trioxide (UO₃) powder. For this reason, 224-U was frequently

called the "UO₃ Plant." Fresh MW from T Plant refilled the tanks as they emptied. Until T Plant was shut down in 1956, newly generated MW was sent to U Plant for uranium recovery, as was MW from other tank farms. MW retrieval was finished in early 1957 (Rodenhizer 1987; Anderson 1990; Gerber 1992; Gerber 1993).

Figure 4 shows facilities constructed for uranium recovery operations. Facilities constructed for uranium recovery include the 271-UR control house, the 244-UR vault, the 241-UR-151 master diversion box, and the 241-UR-152, -153, and -154 diversion boxes. Other facilities that are out of scope of this report, but relevant, include the cross-site transfer line and the 241-WR vault at the TBP Plant.

Uranium recovery operations produced two waste streams: high-level TBP waste (waste concentrator concentrate) and low-level waste (condensate from the waste concentrator, feed concentrator, and HNO₃ fractionator). 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 originally intended. A total of 215 million liters of TBP waste was produced. TBP waste was returned to some tank farms, but not to U Farm. Low-level waste was sent to various cribs that are outside the scope of this report. Nitric acid recovered in the UO₃ Plant was reused (Waite 1991; DiLorenzo 1994; Gerber 1993; General Electric 1951).

Cooling water from the TBP and UO₃ Plants was discharged to the 216-U-14 ditch via the 207-B retention basin, and cell drainage from both plants was discharged directly to the 216-U-14 ditch. This increased the flow through the ditch from approximately 1.1 billion liters per year to over eight billion liters per year. Cooling water from the 244-UR vault was discharged to the 216-Z-1D ditch via line 5712 (Singleton 1994).

Beginning in March 1952, equipment such as trucks, cranes, and large pumps was decontaminated in a steam cleaning pit inside the 216-U-13 trenches. In March 1956, vehicle decontamination operations were transferred to the 269-W regulated garage. The trenches were subsequently remediated and released from radiological controls (WIDS).

Alkaline MW supernate from 241-U-109 was being pumped to the blending tank 244-UR-002 in the 244-UR vault on April 30, 1953, when agitator failure caused a "violent chemical reaction" with nitric acid in the blending tank (UPR-200-W-24). The MW solution produced "a geyser of liquid rising 30 feet (9 m) above the vault cover blocks and persisting for some 30 seconds." A northwest wind blew droplets of solution, which quickly dried to a yellow powder, over the northeast quadrant of U Farm, including the 271-UR control house, and across Camden Avenue. Contamination levels varied from 35 R/hr at the vault cover blocks to 6 mR/hr at the east boundary to 500-1000 cpm further out. The area was covered with lead sheeting and dirt. The release quantity is not known, but 244-UR-002 held 15,000 gallons (56 800 L). The vault was repaired in four days and UR operations continued until the last of the MW sludge was sluiced out in February 1957. Upon isolation of the UR vault as part of project B-231 (see Section 3.4), the area was covered with shotcrete (Rodenhizer 1987; WIDS; Lindberg 1953).

In July 1956, 1900 liters (500 gallons) of MW overflowed from the 241-UR-151 diversion box when a check valve failed open (UPR-200-W-132). The area was backfilled to prevent further contamination (WIDS).

When the UR mission concluded in 1958, U Plant was shut down. The plant is currently used for storing contaminated equipment. The UO₂ Plant continued to process UNH from the REDOX and PUREX plants and to discharge cooling water and chemical sewer waste to the 216-U-14 ditch, but the volume of discharge was reduced from over eight billion liters per year to approximately two billion (Gerber 1993; Singleton 1994; WIDS).

3.3 REDOX and In-Tank Solidification Operations (1952-1971)

The REDOX process was the second chemical separation process used at the Hanford Site. In addition to increased efficiency over the bismuth phosphate process, the REDOX process recovered uranium as well as plutonium, and was a continuous rather than a batch process. Plutonium nitrate produced at the REDOX plant was trucked to 231-Z for rework, and then to PFP. The UNH generated at REDOX was sent to the UO₂ Plant via an aboveground pipeline. The REDOX process generated two waste streams: REDOX high-level waste (R), which contained fission products and large quantities of large amounts of aluminum nitrate, and REDOX coating waste (CWR). These wastes were combined until 1955, and segregated afterward. Beginning in 1956, plutonium nitrate was sent directly to PFP. The increased plutonium production of REDOX plant increased wastewater discharges from 231-Z and PFP to the 216-Z-1D ditch from 800 million liters per year to approximately four billion liters per year (Anderson 1990; Gerber 1992; Gerber 1993; WIDS; Last 1994; WADCP 1998). Figure 5 shows facilities constructed in U Farm for REDOX operations:

Since the 241-U-110/1/2 cascade had been emptied (see Section 3.1), it was filled in 1954 with combined R and CWR from the REDOX plant. At that time, 241-U-110 still held a substantial amount of IC sludge. Because the REDOX waste was self-boiling, a reflux condenser was installed on 241-U-110 to cool the waste. Condensate was discharged to the 216-U-3 French drain and cooling water went to the 216-U-14 ditch. As the waste self-concentrated, the tank was further filled with CWR (Anderson 1990).

The 216-U-3 French drain operated from May 1954 to August 1955, receiving 791 000 L. When the tank contents stopped boiling, the condenser was removed and the crib was valved out. Details of condensate discharges to 216-U-3, including analytical data, are provided in Table 1.

TABLE 1. 216-U-3 FRENCH DRAIN DISCHARGE HISTORY

Date	Volume (L)	U (g)	Pu (g)	β (Ci)	Reference
May-54	1.25E+05	28.5	0.005	0.007	HW-33591
Jun-54	1.29E+05	20.9	0.006	0.011	HW-33591
Jul-54	1.02E+05	116	0.006	0.002	HW-38562
Aug-54	7.90E+04	9.53	0.003	0.007	HW-38562
Sep-54	8.70E+04	18.3	0.007	0.339	HW-38562
Oct-54	3.80E+04	4.53	0.003	0.002	HW-38562
Nov-54	5.30E+04	17700	0.002	0.012	HW-38562
Dec-54	3.20E+04	3.86	0.001	0.002	HW-38562
Jan-55	3.40E+04	3.26	0.001	0.002	HW-38562
Feb-55	2.30E+04	2.76	0.001	0.002	HW-38562
Mar-55	2.20E+04	3.56	0.001	0.002	HW-38562
Apr-55	2.10E+04	2.51	0.001	0.022	HW-38562
May-55	4.00E+03	0.44	0.001	0.001	HW-38562
Jun-55	1.00E+03	0.01	0.001	0.001	HW-38562
Jul-55	1.89E+04	2.27	0.001	0.007	HW-44784
Aug-55	1.89E+04	6.89	0.002	0.001	HW-44784
Totals	7.87E+05	17923	0.041	0.420	

Curies are uncorrected for decay

When the other nine tanks were emptied in 1956-57 (see Section 3.2), they were refilled with REDOX waste. The 241-U-101/2/3 cascade received R waste from SX Farm. The 241-U-107/8/9 cascade received CWR. Since 241-U-104 had begun leaking in 1956 (UPR-200-W-155), the 241-U-104/5/6 cascade was not refilled at that time; however, 241-U-105 was later filled with REDOX waste. The REDOX plant was shut down in 1967, but the UO₂ Plant continued to process UNII from PUREX (Anderson 1990).

Wastewater discharges from the 231-Z Building ended in 1957, when the facility was converted into a plutonium metallurgy laboratory. In 1959, an unknown amount of plutonium and americium was inadvertently released from 231-Z into the 216-Z-1D ditch. Approximately 600 m (2,000 ft) of the ditch was backfilled and replaced with the 216-Z-11 ditch (WIDS; WADCP 1998).

Tank 241-U-101 leaked and was removed from service in 1959 (UPR-200-W-154). In accordance with the Hanford operating policy at the time, liquid waste removal from tanks of questionable integrity was expedited, and the tank was removed from service. The waste from 241-U-101 was pumped to 241-U-106. 241-U-101 was later used to store solid waste (Anderson 1990; WIDS; Liverman 1975).

Sometime in the 1960s, contaminated sludge from the bottom of the 207-U retention basin was scraped out and consolidated in two pits adjacent to the north and south walls of the basin (UPR-200-W-111 and UPR-200-W-112) (WIDS).

Concern over the integrity of SSTs in the 1960s resulted in the decision to remove all liquid waste supernate from SSTs. The in-tank solidification (ITS) program was initiated to concentrate non-boiling waste to produce a partially mobile saltcake. In 200-East Area, in-tank heaters were installed in two tanks to evaporate the waste. In 200-West Area, the 242-T evaporator was used as the ITS system. The 242-T operations are described in Williams (2000). Tank waste in 241-U-108, 241-U-109, 241-U-110, 241-U-111, and 241-U-112 was pumped to the 242-T evaporator and concentrated during 1968-1970 as part of the ITS program (Rodenhizer 1987; Anderson 1990).

On January 8, 1971, an inadvertent cut in an underground waste line near 241-U-103 resulted in minor contamination (UPR-200-W-128).

3.4 Interim Stabilization and Isolation (1972-Present)

After supernatant removal, interstitial liquid was removed by saltwell jet pumping. The process of removing all supernatant and as much interstitial liquid as possible is known as interim stabilization and was started in 1972. The stabilization system constructed for U Farm included a pump pit for each tank, four valve pits, and underground piping connecting the pump pits and the valve pits. Additionally, lines were constructed from the 241-U-D valve pit to the 241-S-152 diversion box at the 242-S evaporator facility. Figure 6 shows facilities constructed for interim stabilization operations.

From 1972 to 1975, 222-S laboratory waste was trucked to 241-U-110. From 1972 to 1976, T Plant central decontamination operations waste and 300-Area waste was sent to 241-U-107. T Plant waste was sent to U Farm via existing transfer lines, but the 300 Area waste would have had to be trucked. T Plant operations are outside the scope of this report but are described in Williams (2000). Supernatant waste in 241-U-102, 241-U-103, 241-U-105, and 241-U-106 was concentrated in the 242-S evaporator in 1974 (242-S operated from 1973 to 1980). The sound tanks (except for 241-T-107) were refilled with evaporator bottoms. Tank 241-U-110 leaked and was removed from service in 1975 (UPR-200-W-156). Tank 241-U-112 had leaked in 1969 and was removed from service in 1975 (UPR-200-W-157) (Liverman 1975; Anderson 1990; Brevick 1996).

In 1975, the AEC adopted a policy to direct all liquid waste to double-shell tanks. To avoid using a SST as the saltwell receiver, the 244-U DCRT was constructed in 1978, tying into existing piping between 241-U-D and 241-S-152. A sitewide interim stabilization program for all SST farms, using saltwell pumping, was initiated during this period (Anderson 1990; Liverman 1975; Smith 1975).

The 244-UR vault and four UR diversion boxes were isolated by the B-231 project in 1985. The project also isolated the 241-U-153 and 241-U-252 diversion boxes. Catch tank 241-U-301 and diversion boxes 241-U-151 and 241-U-152 were not isolated by project B-231, because these

diversion boxes were still used to transfer waste from T Plant or the 244-TX DCRT (via 241-TX-152) to 244-S or to the old cross-site transfer line. These diversion boxes drained to 241-U-301, which was fitted with a new pump pit to transfer waste to the 244-U DCRT. The diversion boxes have leak detectors that alarm in 242-S and 241-U-301 has a level instrument. After 242-S was shut down in 1980, piping from the 241-U-D valve pit to the 241-S-152 diversion box was modified (in 1985) to route waste from 241-U-D to the 241-SY-B valve pit (WIDS; Vitro 1980).

Although four tanks in U Farm leaked and were removed from service, the remaining tanks were sound. For this reason, saltwell pumping in U Farm was deferred until higher-priority tanks were stabilized. This was a 20-year wait and required some equipment modifications. After 20 years of being cannibalized for parts for other DCRTs, 244-U was bypassed in 1999 without ever being used (Elsen 1999; Hanlon 2001).

Saltwell pumping began in 1999. Current saltwell pumping transfers the waste liquid from the 241-U-D valve pit to the 241-SY-B valve pit and the 241-SY-102 receiver tank. Tank 241-SY-102 receives saltwell waste from S, SX, and U Farms and transfers it to 241-AP-107 in 200-East Area via the replacement cross-site transfer line (Wood 2000; Vladimiroff 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. This was done by cutting and blanking all process piping to and from the tank, blanking all risers, and equipping the tank with a filtered ventilation system. The 200-series tanks were interim stabilized and interim isolated in 1979. Leakers 241-U-101, 241-U-104, 241-U-110, and 241-U-112 have been interim stabilized and interim isolated. 241-U-103 has been interim stabilized and is partially interim isolated. The other tanks have been partially interim isolated and are scheduled for interim stabilization in 2001-2003. No U Farm tanks have been in service since 1980 (Hanlon 2001, Vladimiroff 2000; WIDS).

On January 24, 1974, a truck transporting contaminated equipment from U Farm to the 200-West Area burial ground dripped contamination down 16th Street and Dayton Avenue. After "extensive effort," the roadway was cleaned and released (UPR-200-W-71) (WIDS).

The 216-Z-11 ditch was retired and backfilled in 1971 and replaced by the 216-Z-19 ditch. During excavation, part of the backfilled 216-Z-1D ditch was inadvertently uncovered (UPR-200-W-110). In 1976, an estimated 60 grams of plutonium was released from 231-Z, but this event was not assigned a UPR number. The 216-Z-19 ditch was backfilled and replaced by the 216-Z-20 crib in 1981, to facilitate decommissioning U Pond. PFP shut down in 1989, and 216-Z-20 was closed in 1995. Contamination levels in the vicinity of U Farm are summarized below (Singleton 1994; WIDS Last 1994).

216-Z-19 Soil Contamination	
Isotope	pCi/g
Pu-239/240	32,000
Am-241	6550
Curies are uncorrected for decay	

Laundry discharges to the 216-U-14 ditch ended in 1981, when the 216-W-LWC laundry waste crib was built. Discharges from the 284-W powerhouse ended in 1984, when the 200-W-PP powerhouse ponds were constructed. The north part (above 16th St) of the 216-U-14 ditch was deactivated and stabilized in 1984. As part of deactivation, the ditch soil was analyzed for radioactive contaminants. Contamination levels in the vicinity of U Farm are summarized below (Singleton 1994; WIDS).

216-U-14 Soil Contamination	
Isotope	pCi/g
Co-60	42.0
Cs-137	37.0
U-238	9.6
Curies are uncorrected for decay	

The UO_3 Plant continued to discharge as much as 850 million liters per year of cooling water to the 216-U-14 ditch. To facilitate decommissioning the lower part of the ditch, the 216-U-16 crib was built near U Plant in 1984 to receive UO_3 Plant cooling water. Discharges to this crib flushed uranium out of the 216-U-1 and 216-U-2 cribs into the groundwater along the casings of existing groundwater wells (the uranium had been mobilized by earlier discharge of acidic waste to the cribs). Use of the 216-U-16 crib was discontinued and the UO_3 Plant cooling water was redirected back to the 216-U-14 ditch. A groundwater pump-and-treat effort to remove the uranium near U Plant was initiated as a result of this incident; however, this is outside the scope of this report. Shutdown of the PUREX Plant in 1988 reduced the amount of UO_3 Plant waste water discharge to the ditch to approximately 250 million liters per year. The UO_3 Plant was shut down in 1993, and the remainder of the 216-U-14 ditch was stabilized in 1995 (Baker 1988; Singleton 1994; WIDS).

In August 1986, approximately 2400 liters (625 gallons) of recovered nitric acid, containing approximately 86 pounds of uranium, were accidentally released from the UO_3 Plant into the chemical sewer and the 207-U basin (WHC 1988).

In January 1990, contamination was identified across Camden Avenue from U Farm. It was originally thought that this was part of UPR-200-W-24; however, this could not be proven. The contamination was then designated as UPR-200-W-161 (WIDS).

4.0 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. An extensive discussion of monitoring wells inside the tank farms is included in Gaddis (1999). Test wells were also drilled near cribs as part of original construction to monitor vadose zone contamination. Monitoring wells in other locations were drilled as needed. 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).

Test wells outside the tank farm are listed in Table 2 (see Figure 6a). Well 299-W19-1P was drilled in 1957 to monitor contamination at 216-U-3 (see Section 3.3). As part of 216-Z-19 decommissioning, numerous relatively shallow (20 m) wells were drilled in 1981 to characterize the PFP ditches. Two wells (299-W18-19 and 299-W18-20) were drilled in June 1982 to sample the groundwater under the PFP ditches. Other wells were drilled south and east of U Farm in the late 1980s and early 1990s to monitor the potential spread of contamination from the 1986 acid spill near 207-U (see Section 3.4) and to characterize UPR-200-W-161.

Table 2. Test Wells Surrounding U Farm

Location	Well Identification				Coordinates				Dimensions			Notes
	Hanford Site No.	Washington State No.	Date Installed	Hanford		Lambert		Dia. (in.)	Depth (ft)	Depth (m)		
				North	West	North	East					
PFPP ditches	299-W18-19	A7532	Jun 1982	38503	76403	135202.5	566610.5	6	250	76.2	1	
PFPP ditches	299-W18-20	A5471	Jun 1982	38103	76477	135081.7	566590.1	8	250	76.2	1	
SW of U Farm	299-W18-25	A4937	Dec 1990	37786	76034	134978.2	566721.5	6	215.4	67.5	None	
PFPP ditches	299-W18-29	A4941	Jun 1991	37952	76560	135028.4	566561.2	4	150	45.7	None	
N of U Farm	299-W18-30	A4942	Nov 1991	38934	75541	135194.0	56671.1	4	235.5	71.8	None	
216-U-13	299-W18-31	A4943	Dec 1991	38105	76032	135075.5	566721.8	4	227.6	69.4	None	
SE of U Farm	299-W18-177	A7659	Mar 1980	37680	75500	134876.7	566548.9	6	89	27.1	None	
PFPP ditches	299-W18-178	A7660	Mar 1980	38610	76240	135204.4	566644.8	6	77	23.5	1	
SE of U Farm	299-W18-187	A7669	Feb 1981	37425	76335	134867.7	566589.1	6	21	6.4	None	
PFPP ditches	299-W18-188	A7670	Feb 1981	38065	76413	135067.9	566605.8	6	20	6.1	2,3	
PFPP ditches	299-W18-189	A7671	Feb 1981	38605	76388	135227.4	566613	6	20	6.1	2	
PFPP ditches	299-W18-198	A7678	Mar 1981	38362	76363	135153.5	566620.8	6	14	4.3	2	
PFPP ditches	299-W18-199	A7679	Mar 1981	38366	76335	135154.6	566629.4	6	12	3.7	None	
PFPP ditches	299-W18-203	A7683	May 1981	38270	76482	135125.3	566584.6	6	20	6.1	2	
PFPP ditches	299-W18-204	A7684	May 1981	37830	76523	134991.2	566572.5	6	20	6.1	2	
PFPP ditches	299-W18-212	A7692	May 1981	38645	76355	135239.7	566623.1	Unk	16	4.9	3	
PFPP ditches	299-W18-213	A7693	May 1981	38564	76373	135215	566617.6	6	20	6.1	2,3	
PFPP ditches	299-W18-214	A7694	May 1981	38473	76395	135187.2	566610.9	Unk	17	5.2	3	
PFPP ditches	299-W18-215	A7695	May 1981	38370	76422	135155.8	566602.8	Unk	17	5.2	3	

Table 2. Test Wells Surrounding U Farm

Well Identification			Coordinates				Dimensions		Notes		
Location	Hanford Site No.	Washington State No.	Date Installed	Hanford		Lambert		Dia. (in.)		Depth (m)	
PFP ditches	299-W18-217	A7697	May 1981	38140	76459	135085.7	566591.7	Unk	17	5.2	3
PFP ditches	299-W18-218	A7698	May 1981	38058	76462	135060.7	566590.8	6	20	6.1	2,3
PFP ditches	299-W18-219	A7699	May 1981	37940	76470	135024.7	566588.5	Unk	16	4.9	3
PFP ditches	299-W18-220	A7700	May 1981	37840	76470	134994.3	566588.3	6	20	6.1	2,3
PFP ditches	299-W18-231	A7711	Aug 1981	37830	76522	134991.2	566572.8	Unk	12	3.7	3
PFP ditches	299-W18-232	A7712	Aug 1981	38060	76512	135061.3	566575.6	Unk	12	3.7	3
S of U Farm	299-W19-1P	A4944	Mar 1957	37613	73491	134925.9	566887.3	8	301	91.7	None
E of U Farm	299-W19-12	A4945	Jan 1983	38052	75456	135059.8	566897.4	6	250	76.2	None
SE of U Farm	299-W19-21	A4950	Jul 1986	37462	73273	134879.8	566953.4	6	226	68.9	None
SE of U Farm	299-W19-27	A4953	Apr 1987	37629	73072	134930.6	567014.4	5	230	70.1	1
E of U Farm	299-W19-31	A4956	Dec 1990	38275	73457	135127.5	566970.0	4	225.3	68.7	None
E of U Farm	299-W19-32	A4957	Jan 1991	37887	73459	135009.3	566896.6	4	223.1	68.0	None
E of U Farm	299-W19-41	B8551	Sep 1998			135994.5	566896.5	4	264.5	80.6	
E of U Farm	299-W19-42	B8553	Sep 1998			135122.9	566896.8	4	265.2	80.8	
SE of U Farm	299-W19-91	A4960	Mar 1987	37617	73269	134926.7	566954.5	8	150	45.7	4
SE of U Farm	299-W19-92	A4961	Mar 1987	37289	73431	134888.8	566939.4	8	120	36.6	4

Notes: 1 - Grouted
 2 - Casing pulled
 3 - Backfilled
 4 - Monitors perched water under 216-U-14

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WIDS printouts for spills.

5.2 Drawings

Number	Rev.	Title
M-2600-W	4	Topographic Map 200-W Area Hanford Works (sh 18)
M-2600-W	4	Topographic Map 200-W Area Hanford Works (sh 9)
M-2904-W	5	Outside Lines - Sewers 200 - Area Hanford Works (sh 19)
HW-72182	10	Tank Farm 241-U & Plot Plan (sh 2)
HW-72183	0	Diversion Boxes 241-U-151 & 241-U-152 Arrg't & Piping (sh 2)
W-72184	9	Hanford Engineer Works - Bldg. 241 Diversion Boxes - Arrg't & Piping Plans (sh 2)
W-73975	3	Hanford Engineer Works Bldg. 207 - T, U, B Retention Basins Arrangement
H-2-390	10	Piping Between 241T & 241 U
H-2-439	0	Schematic Layout Bldg. 241T & U
H-2-800	5	Key Plan General Layout Waste Storage 241-TX
H-2-803	8	Plot Plan No. 3 & Waste Storage 241-TX
H-2-804	4	Plot Plan No. 4 & Waste Storage 241-TX
H-2-840	6	Diversion Box Catch Tank & Piping at 241-TX-155
H-2-844	7	Diversion Box & Piping Layout at 151U & 152U

APPENDIX A

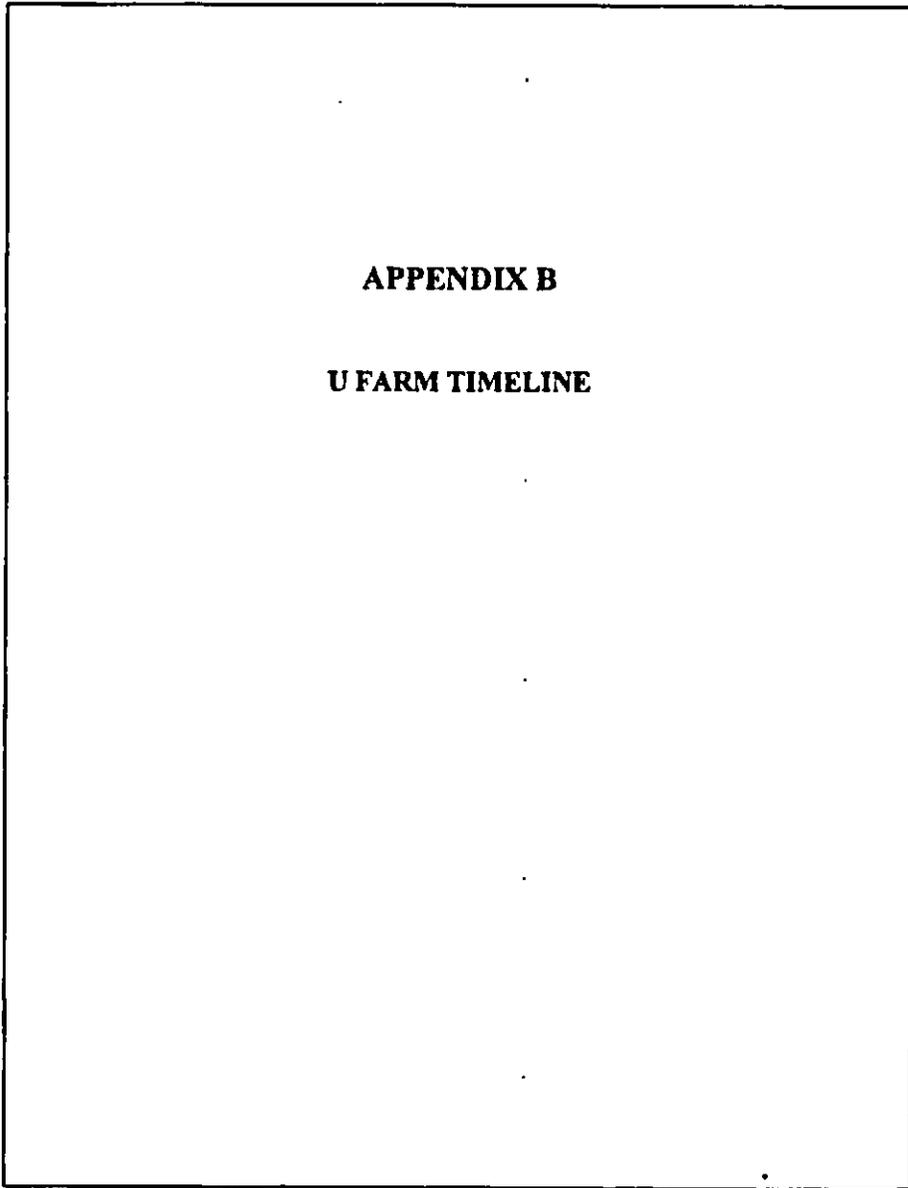
UNPLANNED RELEASE QUANTITIES

A-0

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Unplanned Release Quantities

Site Number	Location	Date	Leak Type	Waste Type	Quantity (L)	Comments
UPR-200-W-6	241-U-151 241-U-152	Spring 1950	Diversion box leak			See UPR-200-W-161
UPR-200-W-24	244-UR	4/30/53	Spray from riser	MW		
UPR-200-W-71	16th Street	1/24/74	Spill from truck	R		
UPR-200-W-111	207-U	1960s	Disposal	Contaminated soil	21 m ³	
UPR-200-W-112	207-U	1960s	Disposal	Contaminated soil	21 m ³	
UPR-200-W-128	241-U-103	1/8/71	Underground piping spill	R		
UPR-200-W-132	241-UR-151	7/6/56	Overflow	MW	1900	
UPR-200-W-154	241-U-101	1959	Tank leak	R	114 000	
UPR-200-W-155	241-U-104	1956	Tank leak	MW	208 000	
UPR-200-W-156	241-U-110	6/75	Tank leak	CWR	31 000	
UPR-200-W-157	241-U-112	1969	Tank leak	R	38 000	
UPR-200-W-161	207-U	1990	Wind-blown contamination			See UPR-200-W-24



APPENDIX B

U FARM TIMELINE

B-0

U FARM TIMELINE

1943-44	Construction of U Plant and U Farm
8/14/45	World War II ends
12/45	Pipeline constructed to U Farm from T Farm
2/46	T Plant MW sent to 241-U-101/2/3 cascade
7/46	T Plant 1C sent to 241-U-110/1/2 cascade
1/1/47	General Electric Company takes over from DuPont
1947	R&D started on uranium recovery. Construction of vaults, pipelines, BX and TX Farms
1949	TBP process chosen for uranium recovery
1949	Plutonium Finishing Plant startup
1950	UPR-200-W-6, diversion box contamination spread
1/52	REDOX operations begin
3/52	Begin decon operations in 216-U-13 double trench
4/52	1C from 241-U-110/1/2 evaporated in 242-T
11/52	First MW from U Farm sent to U Plant
4/30/53	244-UR vault spray leak (UPR-200-W-24)
1/54	241-U-110/1/2 tanks filled with REDOX waste
5/54	Condenser installed on 241-U-110; condensate to 216-U-3 crib
8/55	Condenser removed from 241-U-110; 216-U-3 valved out
1956	241-U-104 leaks (UPR-200-W-155)
3/56	End 216-U-13 decon operations
7/56	UPR-200-W-132, diversion box 241-UR-151 overflow
1957	231-Z discharges to 216-Z-1D ditch end
2/57	U Farm MW recovery complete
1958	241-U-101/2/3 cascade refilled with R from SX Farm
1958	241-U-107/8/9 cascade refilled with CWR
1959	241-U-101 leaks (UPR-200-W-154)
1959	216-Z-1D ditch backfilled and replaced by 216-U-11 ditch
1967	REDOX operations shut down
1969-1970	U Farm waste evaporated in 242-T
1971	216-Z-11 backfilled and replaced by 216-Z-19
1/8/71	Waste spill from accidentally cut line (UPR-200-W-128)
1972	Begin interim stabilization program at Hanford
1972-1975	222-S waste to 241-U-110
1972-1976	221-T and 300 Area waste to 241-U-107
1973	Saltwell piping construction
1/24/74	Waste spill from truck (UPR-200-W-71)
1974	U Farm waste evaporated in 242-S
1974	241-U-110 leaks (UPR-200-W-156)
1975	241-U-112 leaks (UPR-200-W-157)
1978	Construct 244-U DCRT
1981	216-Z-19 ditch backfilled and replaced by 216-Z-20 crib

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1981	Laundry discharges to 216-U-14 ditch end
1984	Powerhouse discharges to 216-U-14 ditch end
1984	North part of 216-U-14 ditch stabilized
8/86	Acid discharge to 207-U
1989	PFP discharges to 216-Z-20 crib end
1/90	Windblown contamination (UPR-200-W-161)
1993	UO ₂ Plant discharges to 216-U-14 ditch end
1994	Remainder of 216-U-14 ditch stabilized
1995	216-Z-20 crib stabilized
5/99	244-U DCRT bypassed
9/99	Begin saltwell pumping in U Farm
9/00	241-U-103 interim stabilized

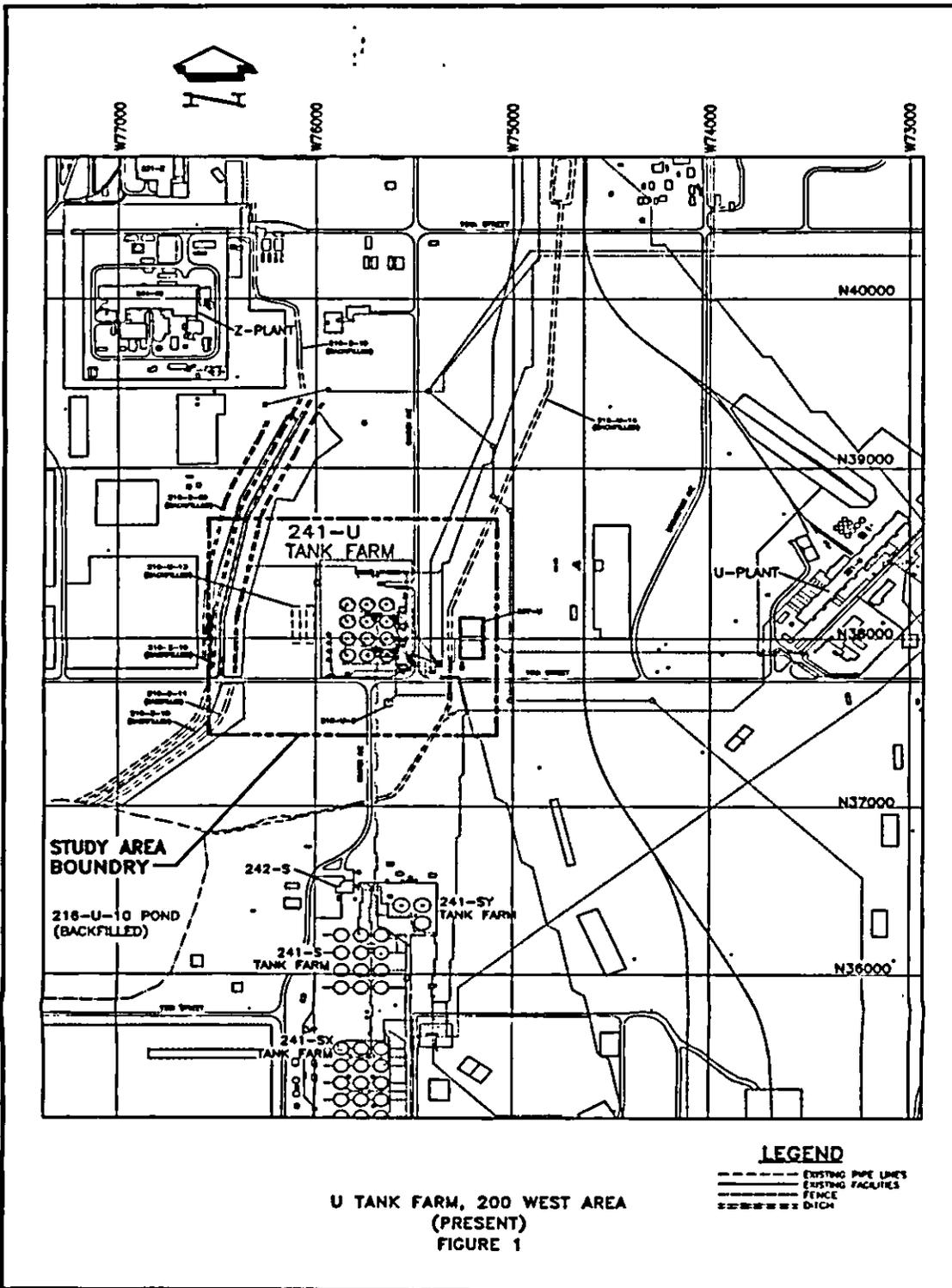
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APPENDIX C

FIGURES

- Figure 1: U Tank Farm, 200 West Area
- Figure 2: Facilities Constructed for the Manhattan Project, 1943-1945
- Figure 3: Facilities Constructed for Postwar Bismuth Phosphate Operations, 1946-1952
- Figure 4: Facilities Constructed for Uranium Recovery Operations, 1952-1957
- Figure 5: Facilities Constructed for REDOX and ITS Operations, 1952-1971
- Figure 5a: Test Wells Constructed for REDOX and ITS Operations
- Figure 6: Facilities Constructed for Interim Stabilization and Isolation, 1972-2001
- Figure 6a: Test Wells Constructed for Interim Stabilization and Isolations

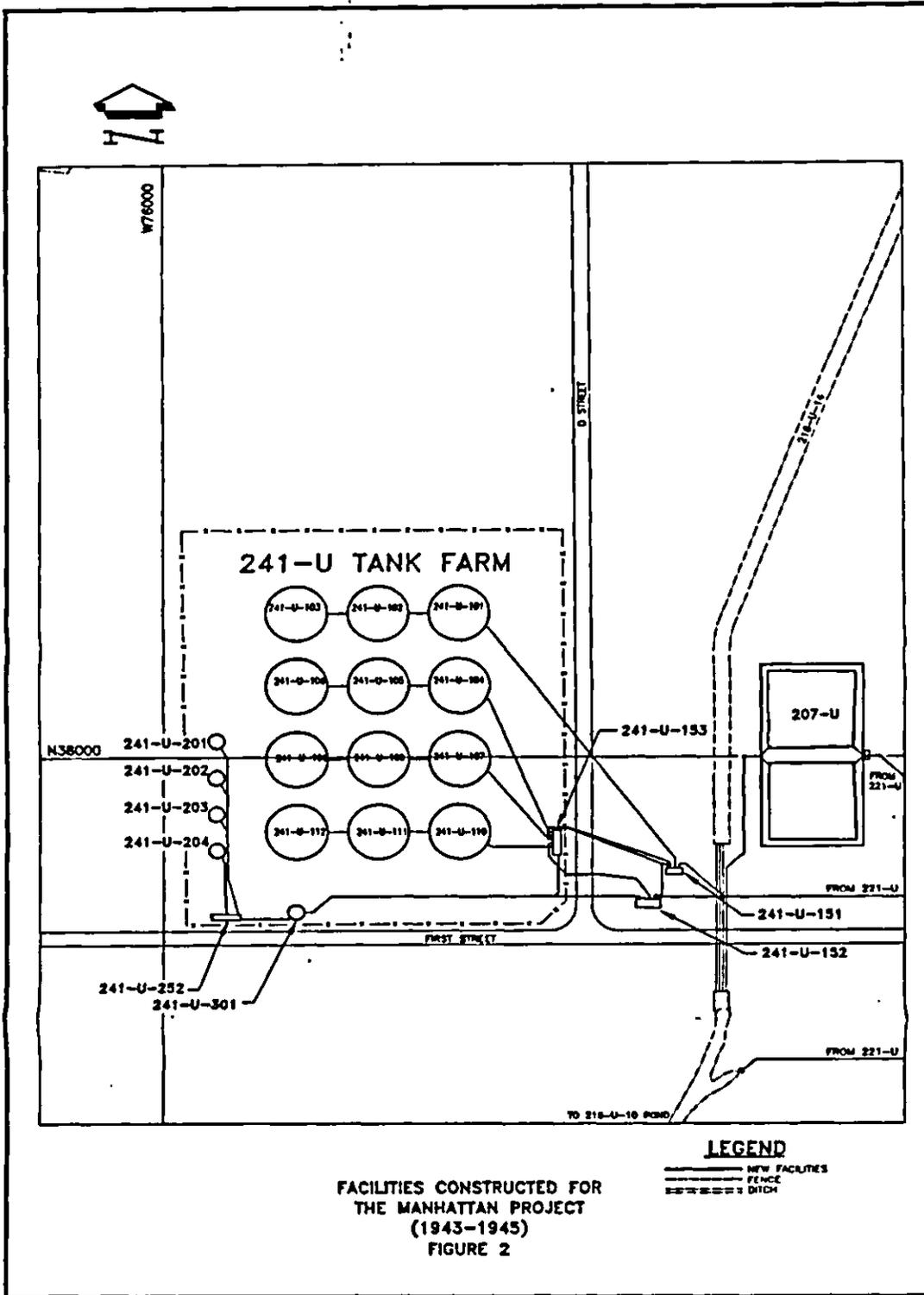
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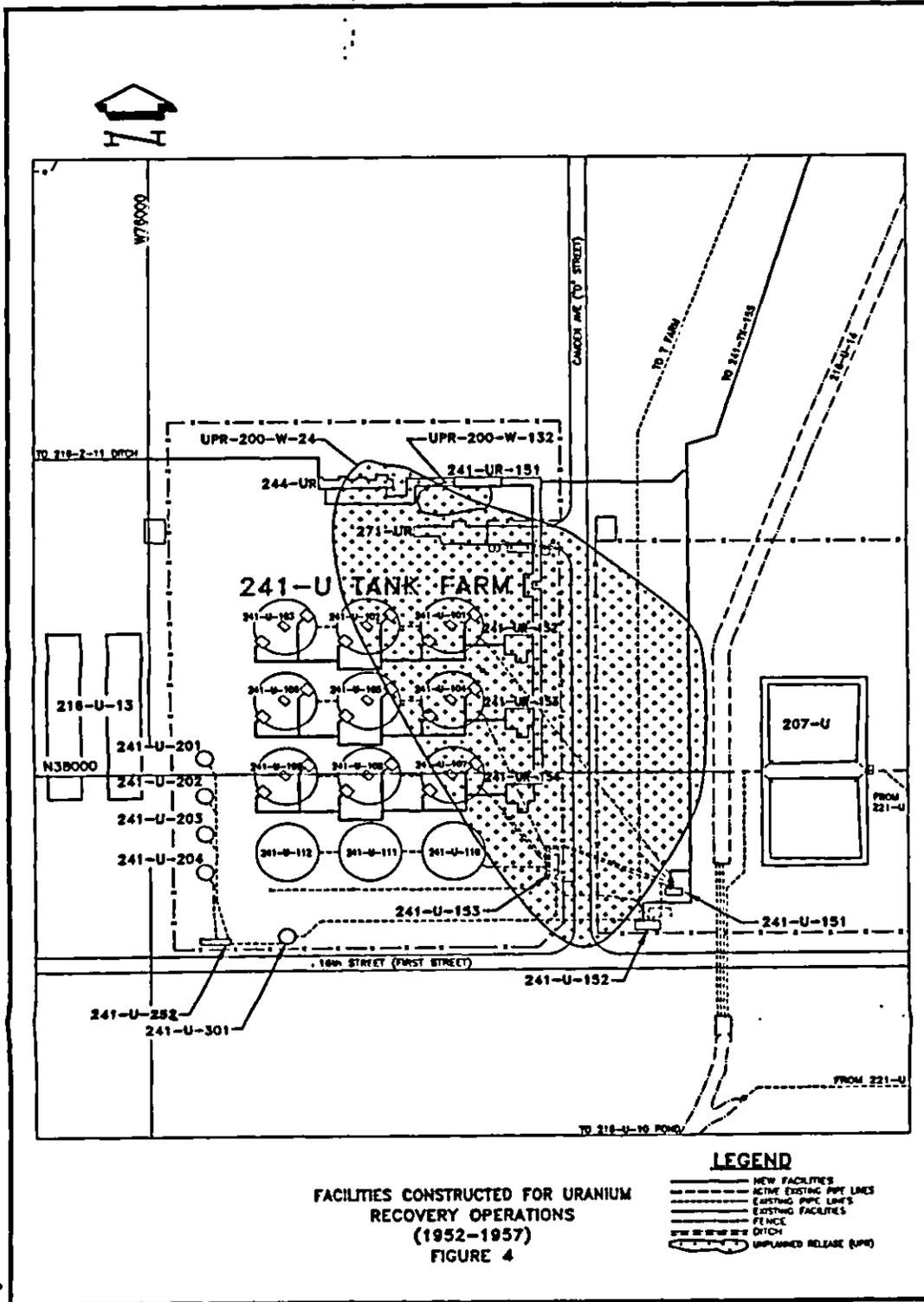
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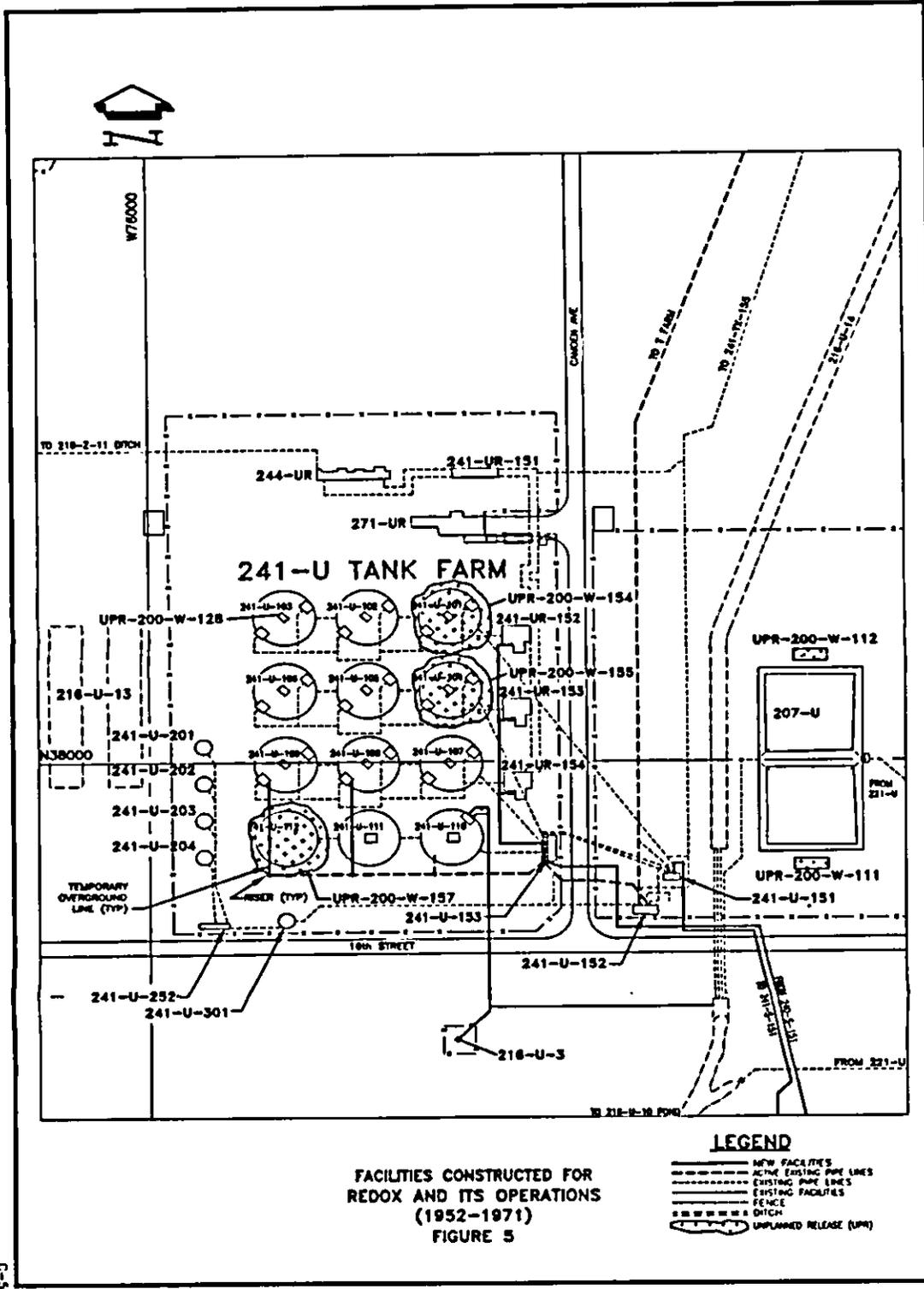
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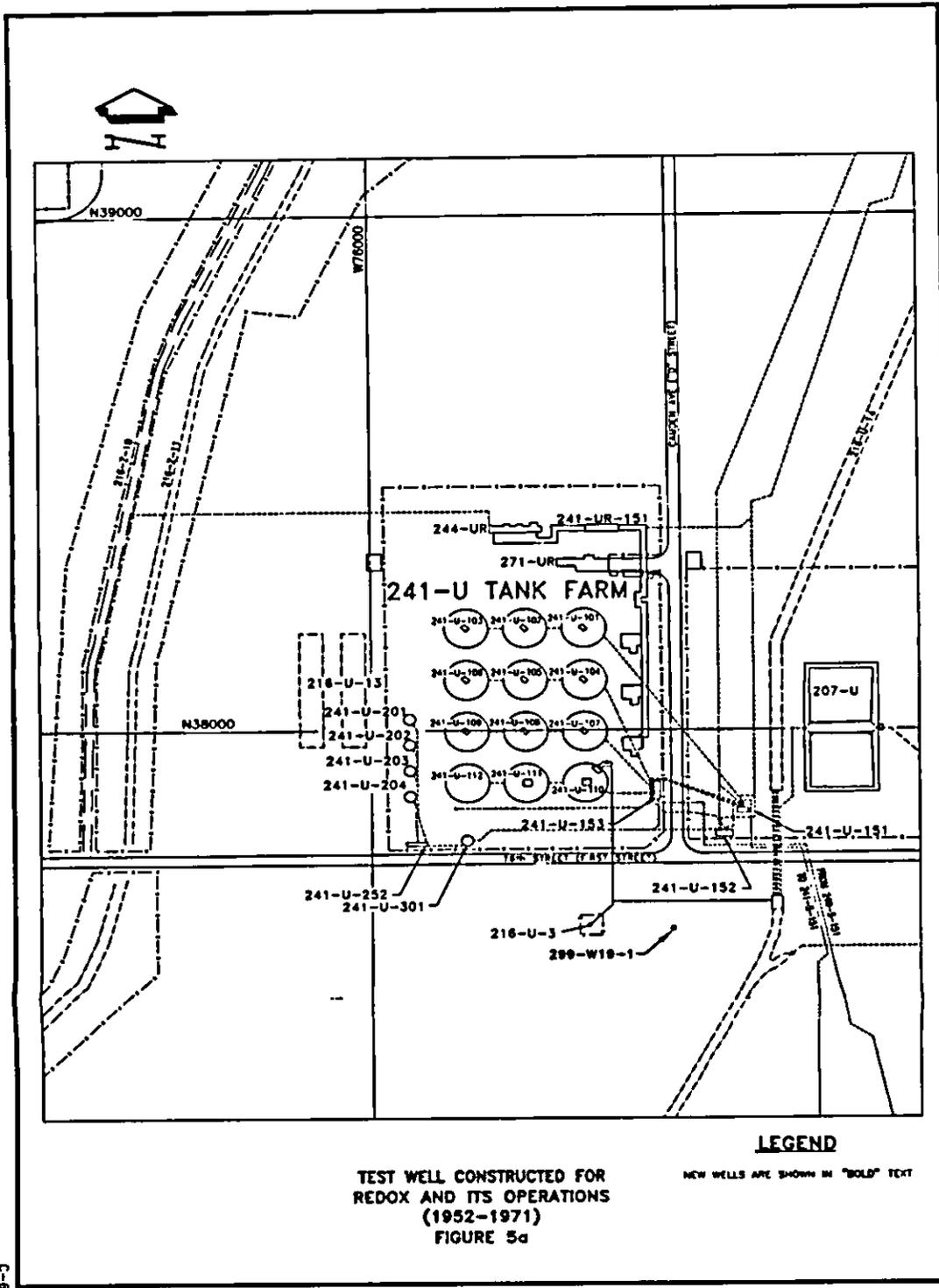
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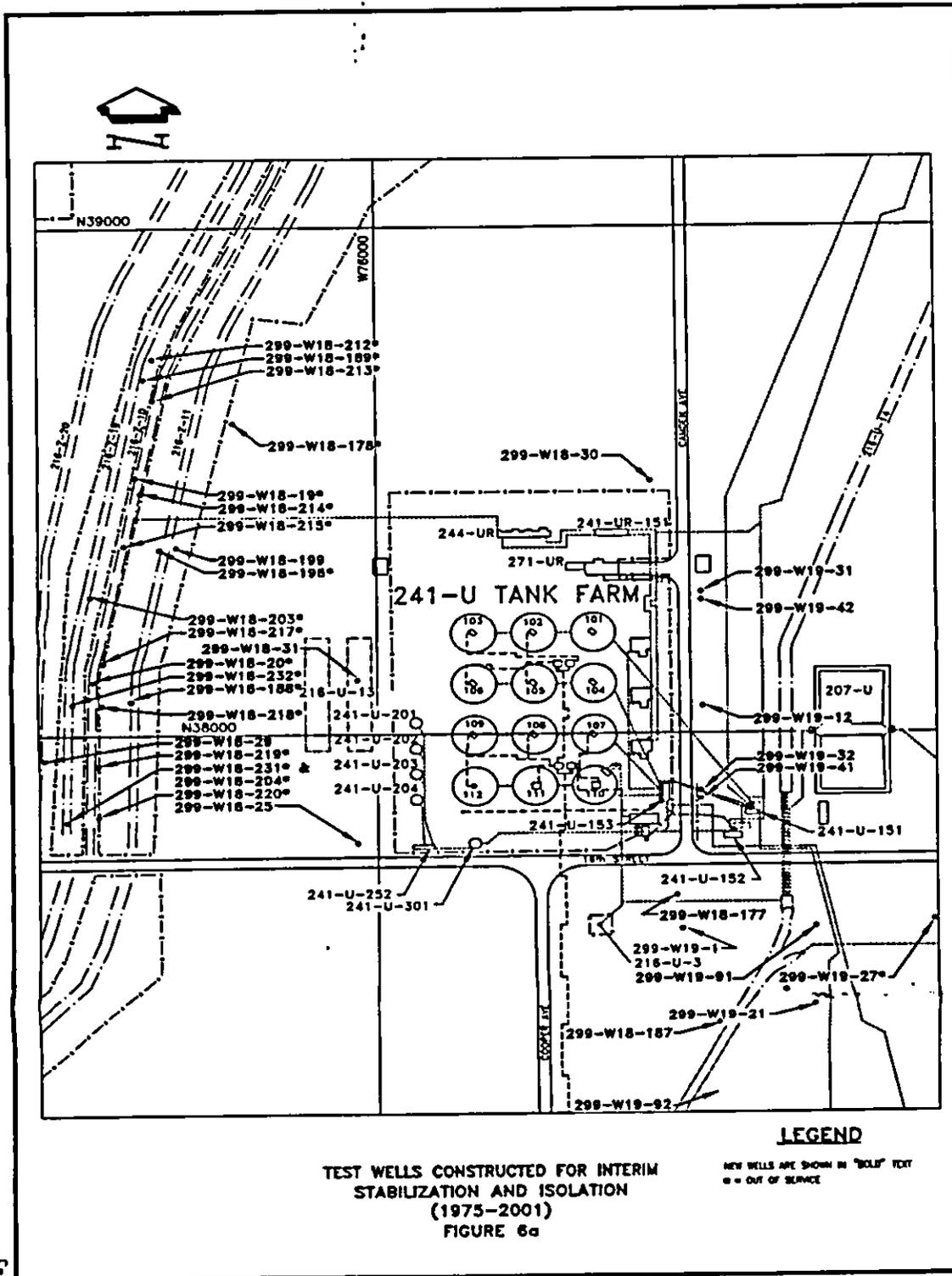
TEST WELL CONSTRUCTED FOR
 REDOX AND ITS OPERATIONS
 (1952-1971)
 FIGURE 5a

LEGEND
 NEW WELLS ARE SHOWN IN "BOLD" TEXT

C-6

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C-8

RPP-15808 REV0

A.2.0 References

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APPENDIX B

SUPPORTING STRATIGRAPHIC INFORMATION

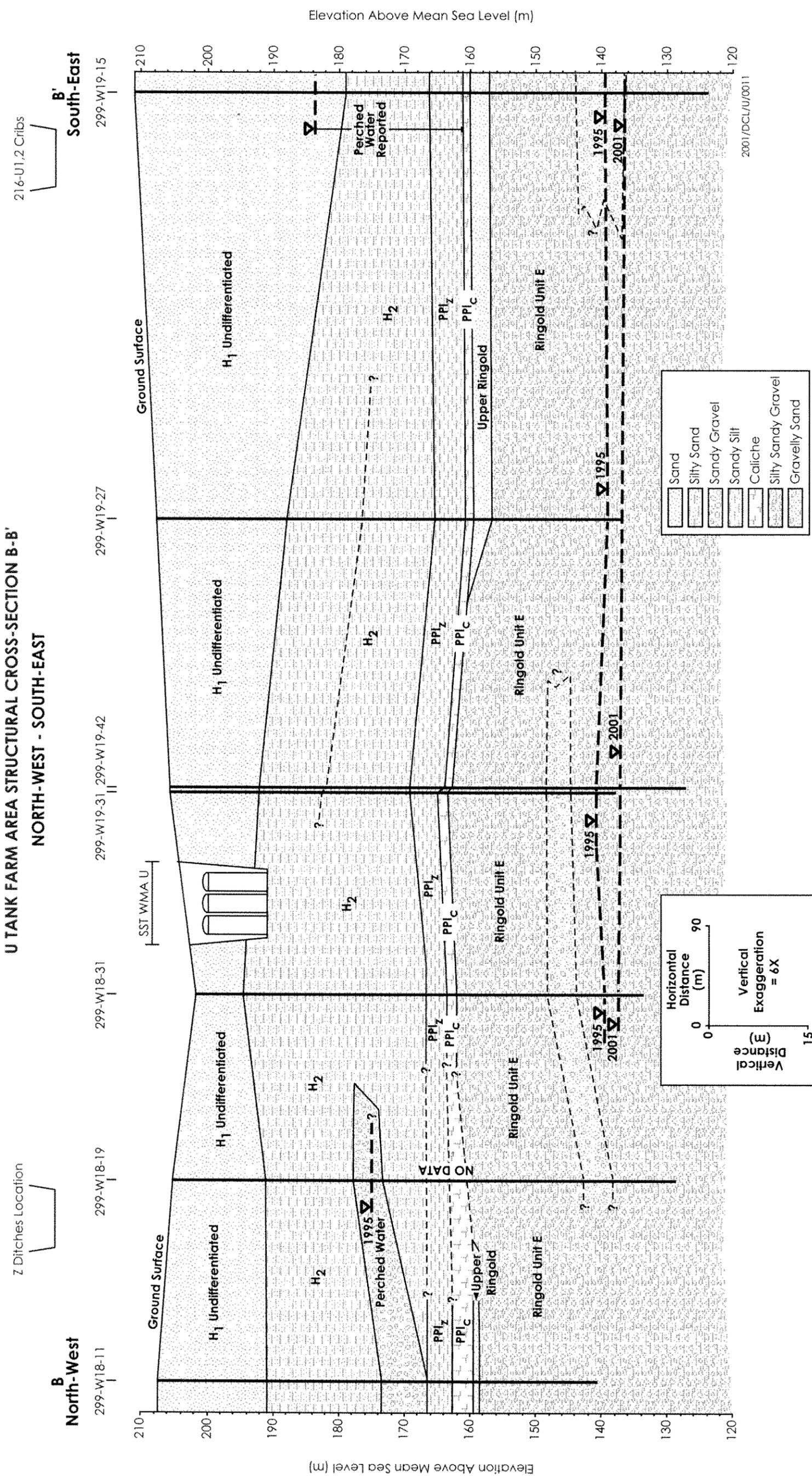
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B.1.0 SUPPORTING STRATIGRAPHIC INFORMATION

Appendix B provides the detailed stratigraphic cross sections used to construct the subsurface physical model of the U Waste Management Area. Figure B-1 shows the locations for boreholes used to construct two cross sections (Figures B-2 and B-3) of the U WMA.

Figure B-3. East-West Geologic Cross-Section (Smith et al 2001)



B.2.0 References

Smith, R.M., F.N. Hodges, and B.A. Williams, 2001, *Groundwater Quality Assessment Plan for Single-Shell Tank Waste Management Area U*, PNNL-13612, Pacific Northwest National Laboratory, Richland, Washington.

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APPENDIX C
SUPPORTING METEOROLOGICAL AND HYDROLOGIC DATA

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C.1.0 HISTORICAL BACKGROUND OF U TANK FARM OPERATIONS AND
CONTAMINATION EVENTS C-1

C.2.0 REFERENCES C-4

C.1.0 SUPPORTING METEOROLOGICAL AND HYDROLOGIC DATA

Table C-1 summarizes monthly and annual precipitation at the Hanford Site from 1946 to 1998. Tables C-2 through C-5 summarize the hydrologic soil property data and derived input parameter values used to model contaminant migration through the vadose zone underlying the U WMA. These data are not site-specific to the vadose zone sediments in the WMA U tank farm. However, as part of other Hanford Site projects, particle-size distribution, saturated hydraulic conductivity, moisture retention and unsaturated conductivity data have been collected in the vicinity of U tank farm. These sites include the ERDF, 241-T-106 tank site, Operable Units 200-UP-1 and 200-UP-2 in 200 West Area. Also available are physical and hydraulic properties data for the sandy gravel sediments in 100 Area along the Columbia River. These samples were used as surrogate to represent the hydraulic properties for the gravel-dominated (>2 mm size fraction) sequence at the U tank farm. These data are derived from soil hydrologic property measurements on Hanford soils collected from numerous sites across the Hanford Site (Khaleel and Freeman 1995).

Table C-1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998. (2 sheets)

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

Table C-1. Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998. (2 sheets)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
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
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
Avg	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 C-2. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the backfill (1) and Ringold sandy gravel (6) sediments.

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 C-3. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the sandy H2 (2) sequence.

Sample	Site/ Operable Unit	Borehole Number	Depth (m)	Percent Gravel	θ_r (cm ³ /cm ³)	θ_s (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 C-4. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the gravelly sand H1 (3) sequence.

Sample	Site/ Operable Unit	Well Number	Depth (m)	Percent Gravel	θ_r (cm ³ /cm ³)	θ_s (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 C-5. Van Genuchten parameters, fitted saturated hydraulic conductivity, and measured bulk density data for the Plio-Pleistocene silty sand unit (5).

Sample	Site/ Operable Unit	Borehole Number	Depth (m)	Percent Gravel	θ_r (cm ³ /cm ³)	θ_s (cm ³ /cm ³)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Bulk Density (g/cm ³)
4-1011	ERDF	699-35-69A	73.0	0	0.489	0.0608	0.0037	1.6486	2.81E-05	1.72
5-5001	218-W-5	299-W7-9	21.6	4	0.380	0	0.0061	2.3247	2.30E-04	1.60
5-5002	218-W-5	299-W7-9	24.9	2	0.352	0.058	0.0058	1.7911	1.27E-04	1.68
5-5005	218-W-5	299-W7-9	21.1	0	0.374	0	0.0066	2.0076	1.08E-04	1.61

C.2.0 REFERENCES

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.

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

APPENDIX D
SUPPORTING GAMMA LOGGING DATA

TABLE OF CONTENTS

D.1.0 SUPPORTING STRATIGRAPHIC INFORMATION D-1

D.2.0 REFERENCE.....D-23

D.1.0 SUPPORTING GAMMA LOGGING DATA

Appendix D contains the drywell spectral gamma logging profiles generated in the 1990s for the U tank farm. 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 the U tank farm. These data provide some indication of gamma-emitting radionuclide migration during the data collection time frame.

UTANK FARM DRYWELL SPECTRAL GAMMA LOGGING PLOTS

Figure D-1. Plan View of the U Tank Farm Showing Borehole Locations (DOE-GJO 1997a)

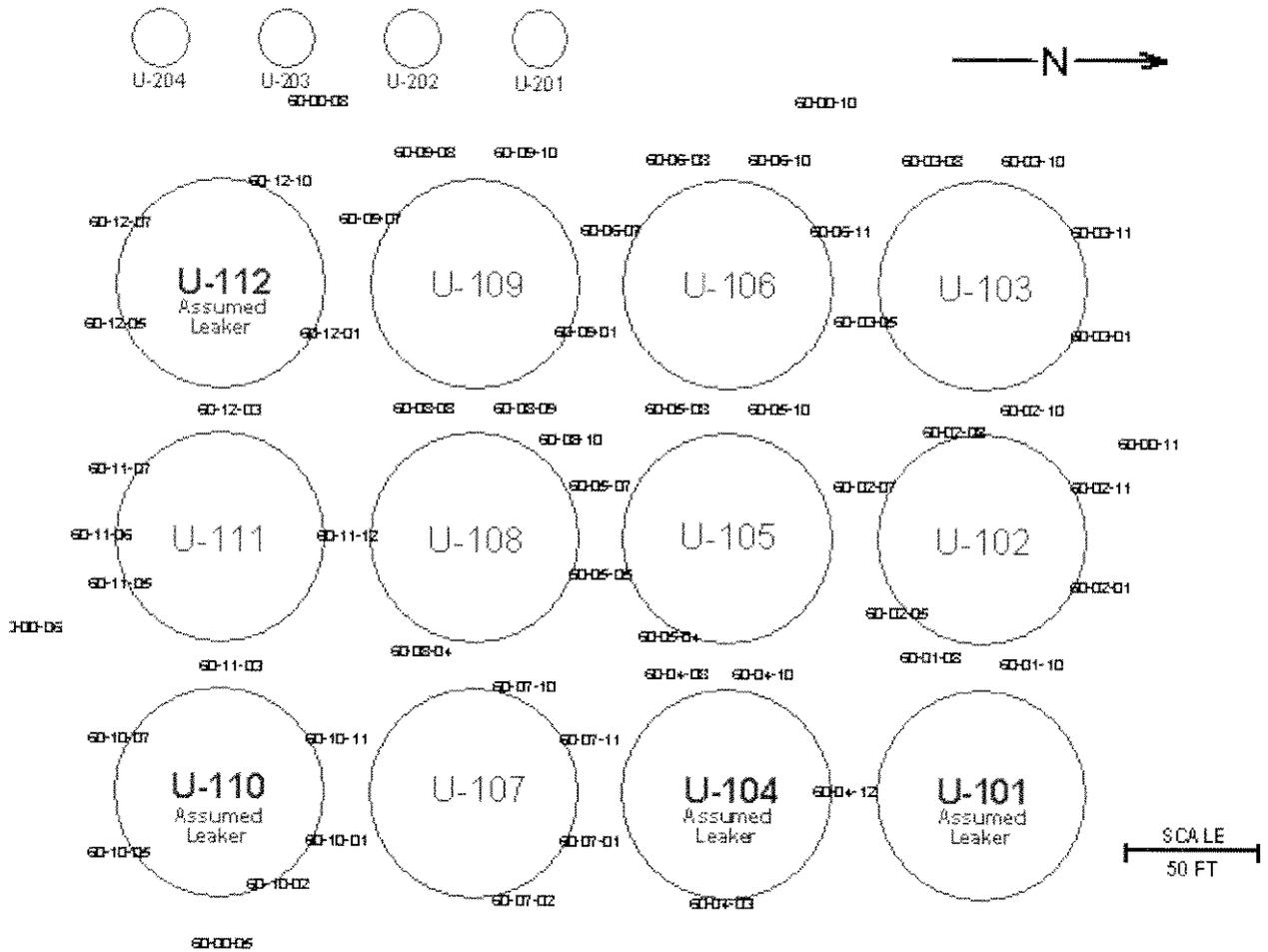


Figure D-2. 60-04-10 Man-Made Radionuclide Concentrations (DOE-GJO 1997b)

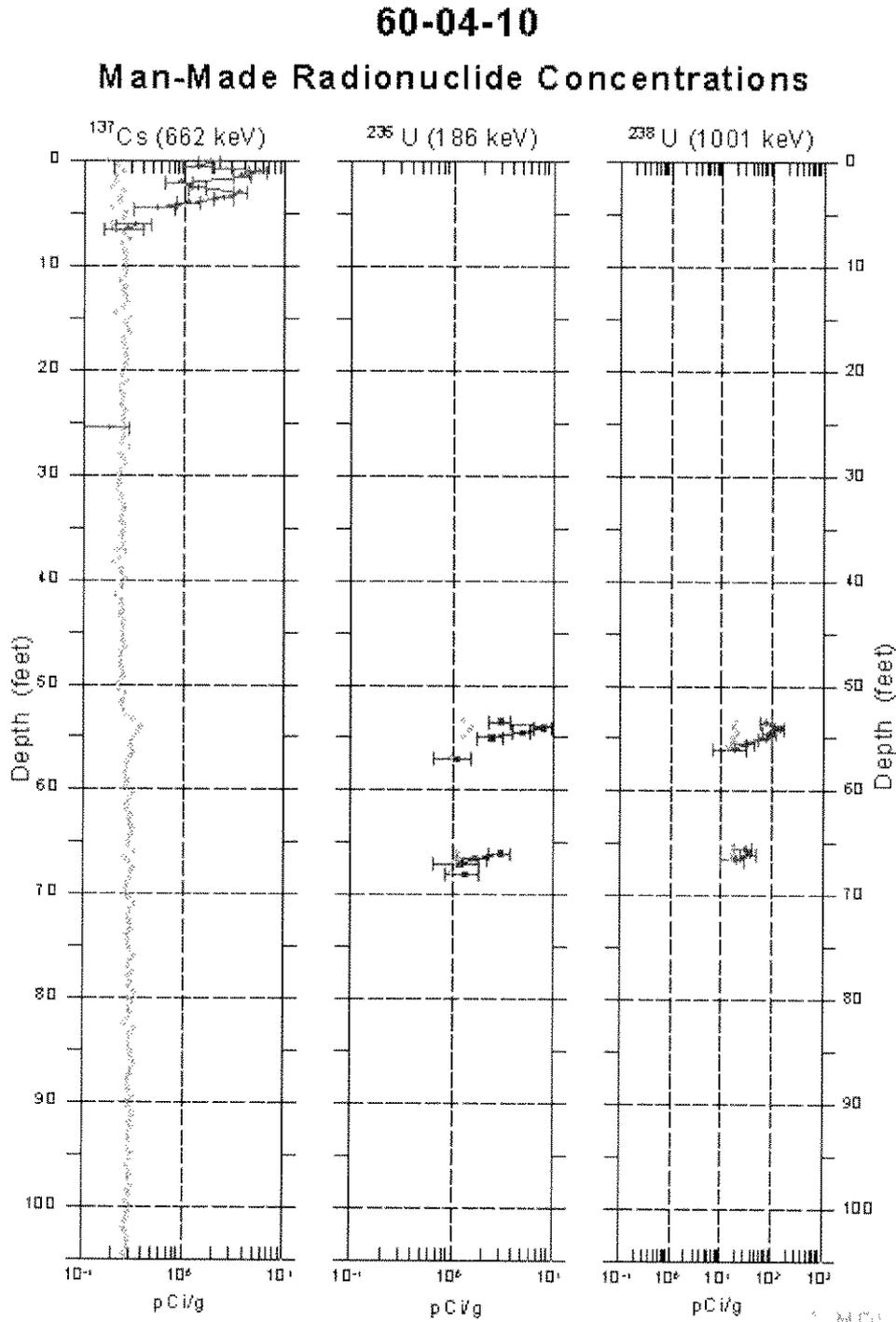


Figure D-3. 60-04-08 Man-Made Radionuclide Concentrations (DOE-GJO 1997b)

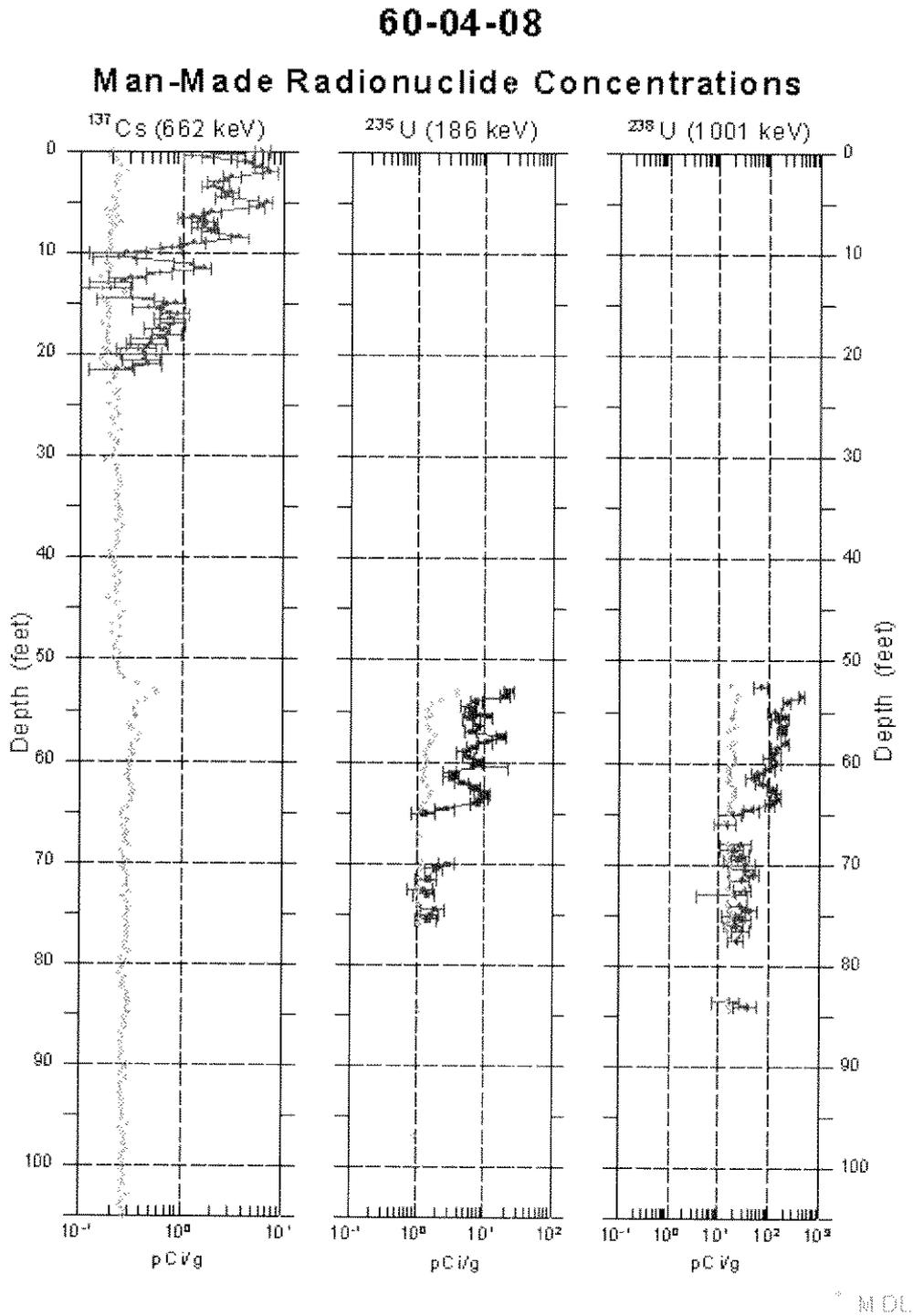


Figure D-4. 60-05-04 Man-Made Radionuclide Concentrations (DOE-GJO 1996a)

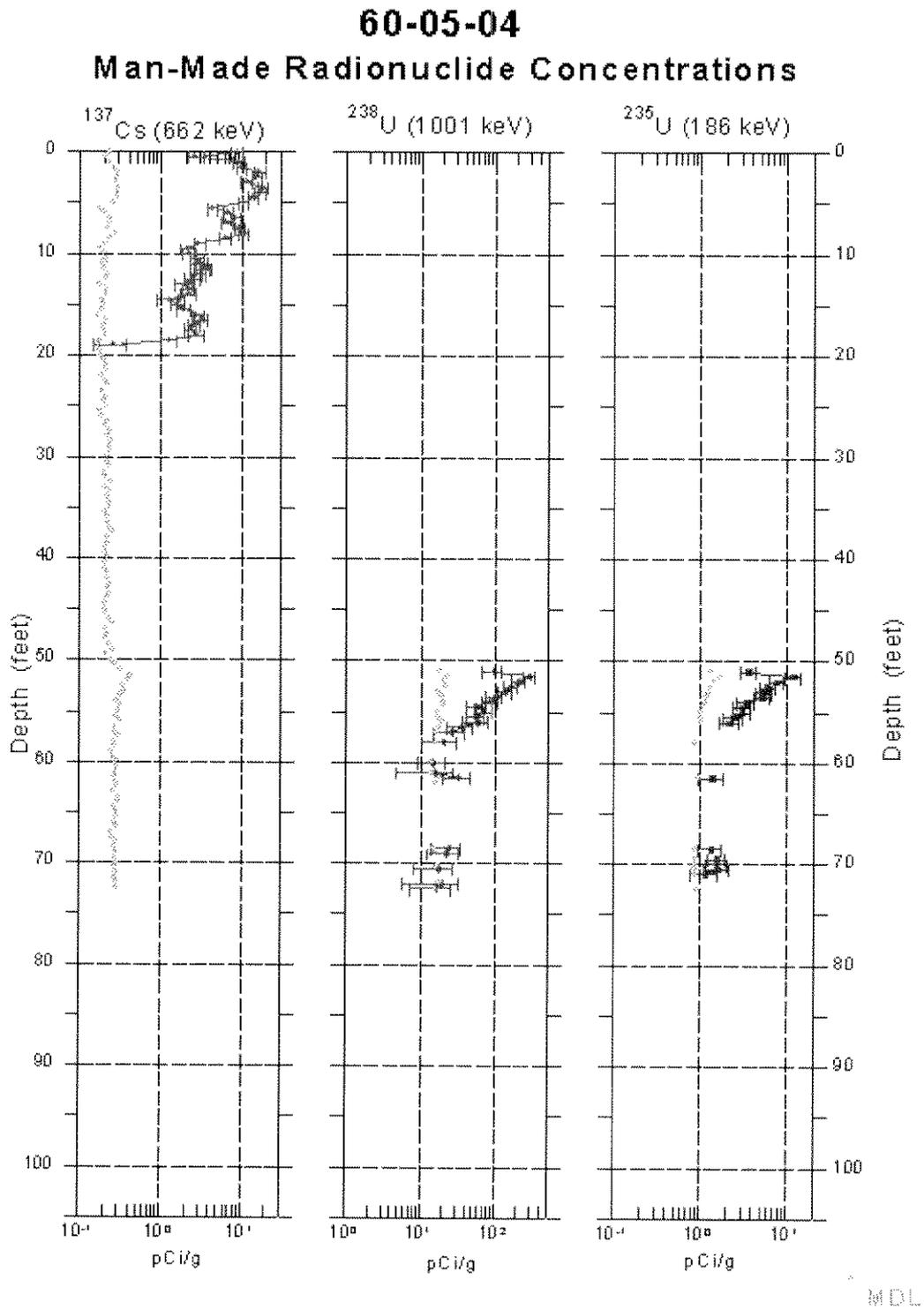


Figure D-5. 60-05-05 Man-Made Radionuclide Concentrations (DOE-GJO 1996a)

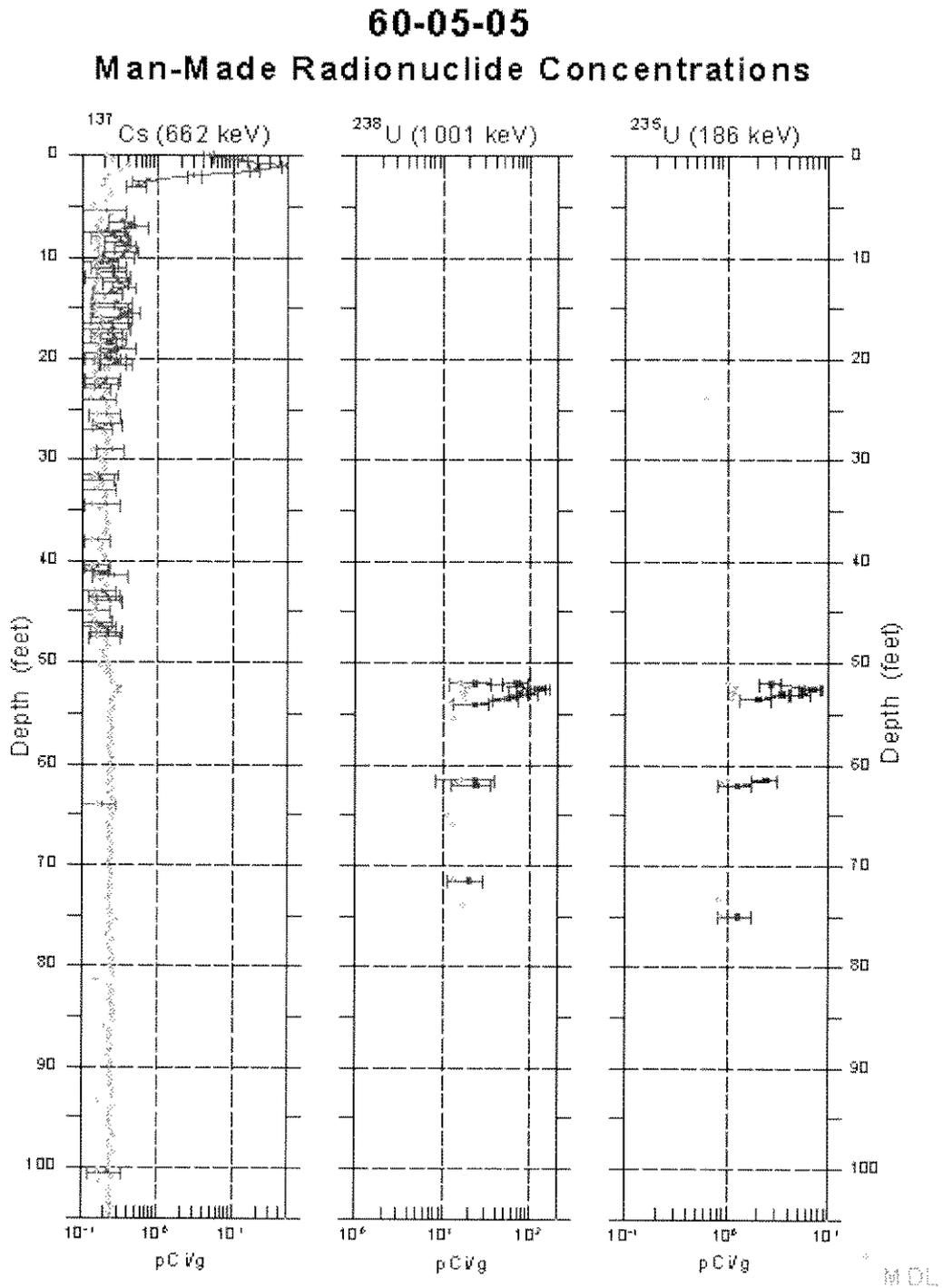


Figure D-6. 60-07-01 Man-Made Radionuclide Concentrations (DOE-GJO 1996b)

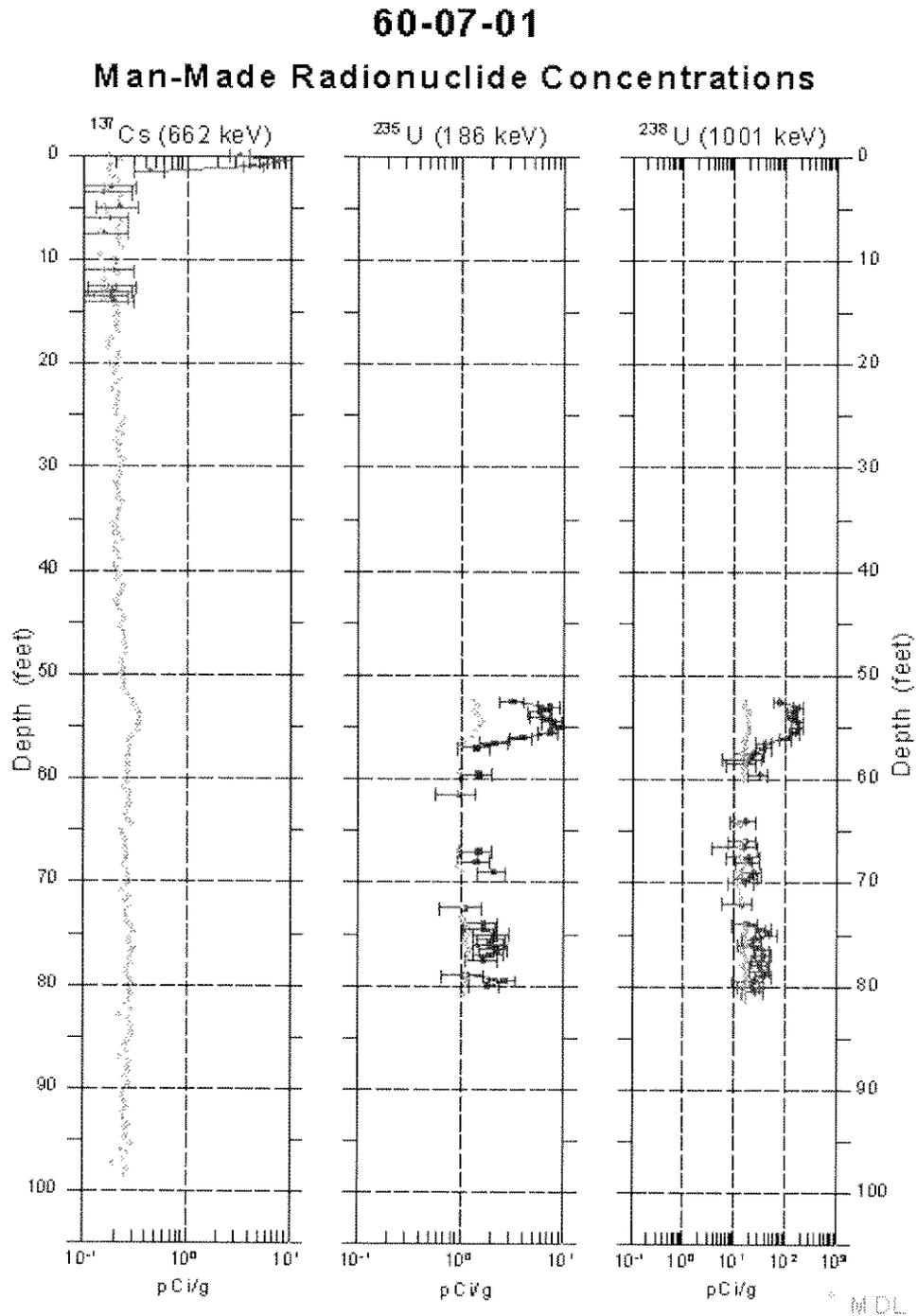


Figure D-7. 60-07-10 Man-Made Radionuclide Concentrations (DOE-GJO 1996b)

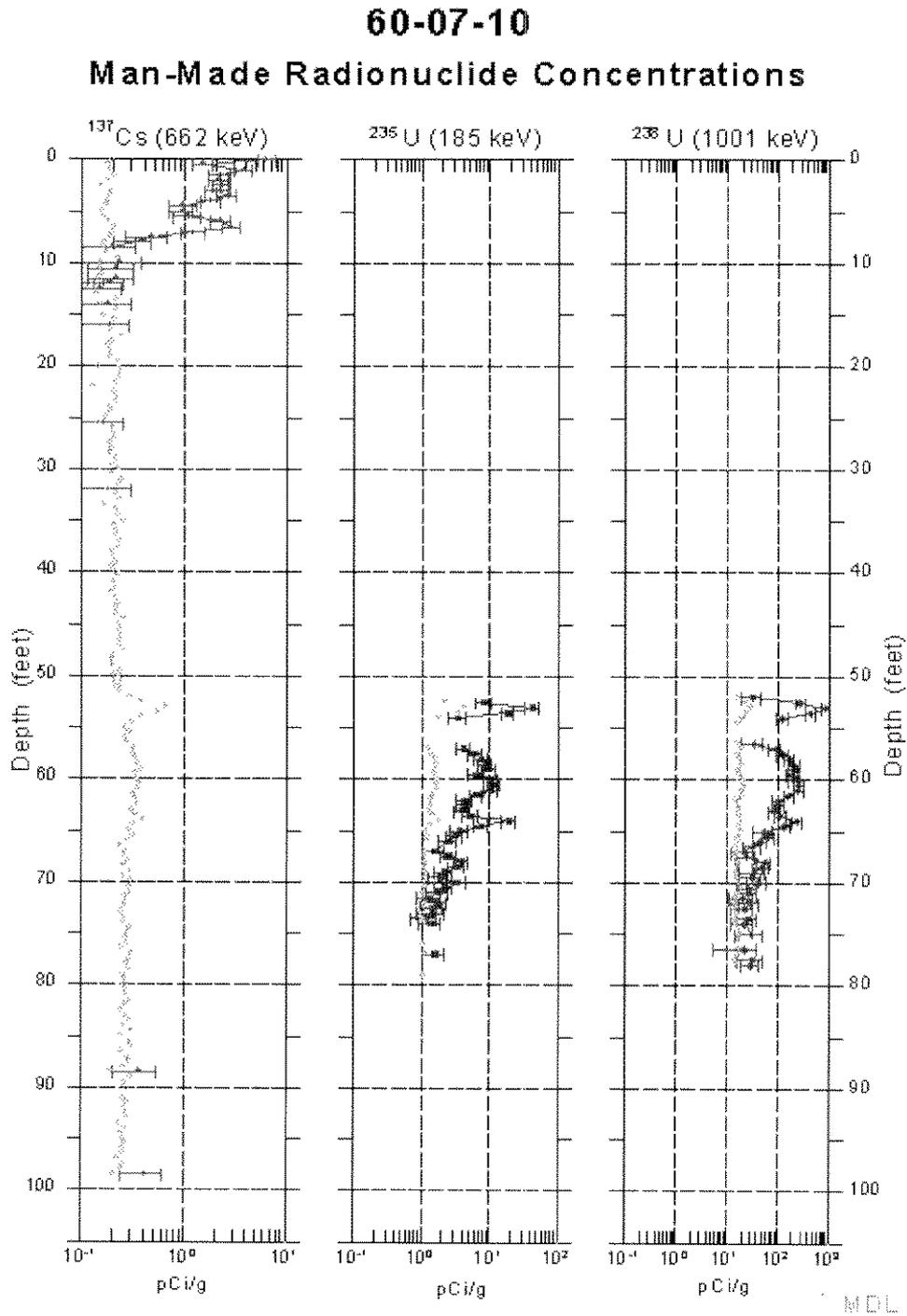


Figure D-8. 60-07-11 Man-Made Radionuclide Concentrations (DOE-GJO 1996b)

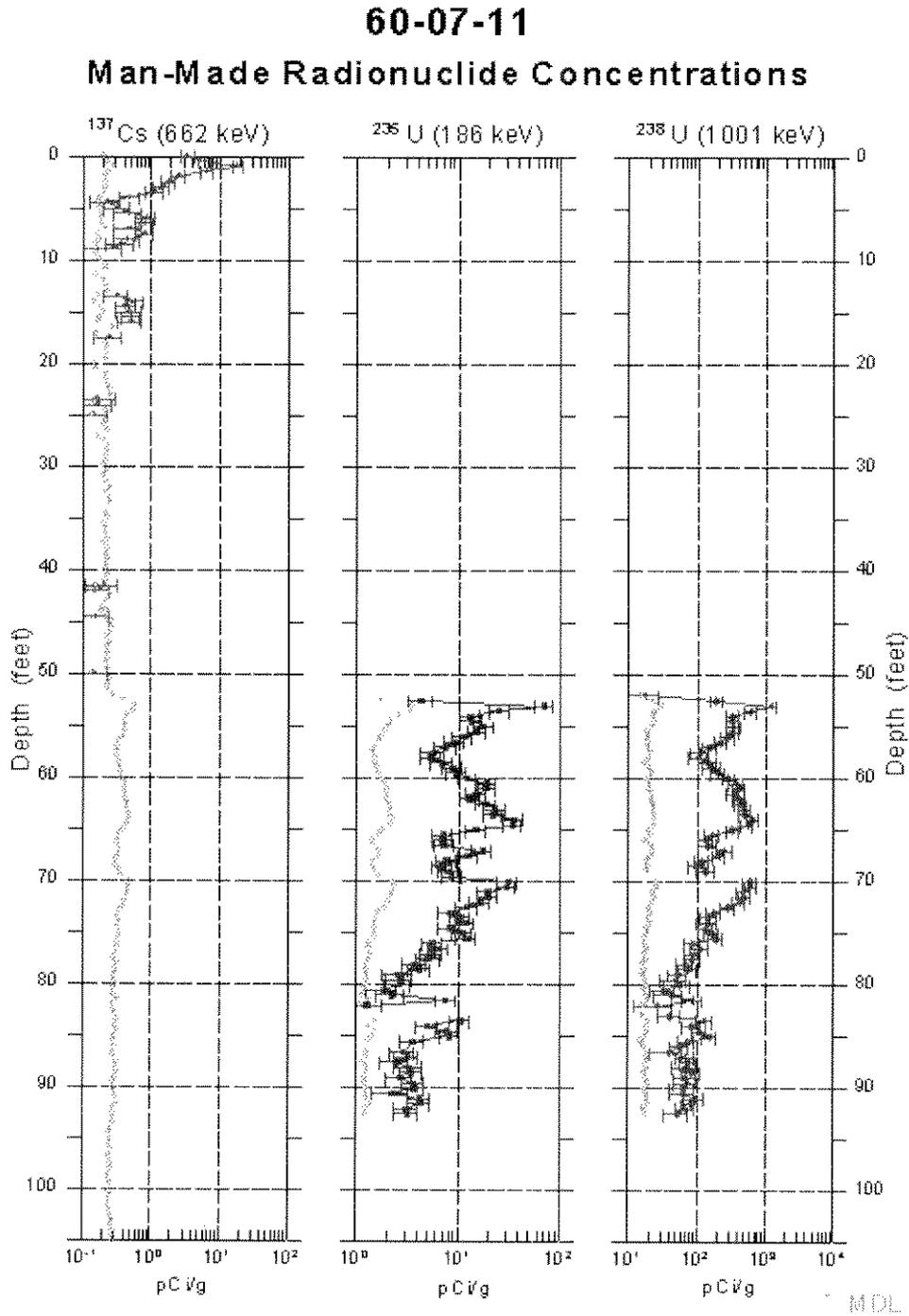


Figure D-9. 60-08-04 Man-Made Radionuclide Concentrations (DOE-GJO 1996c)

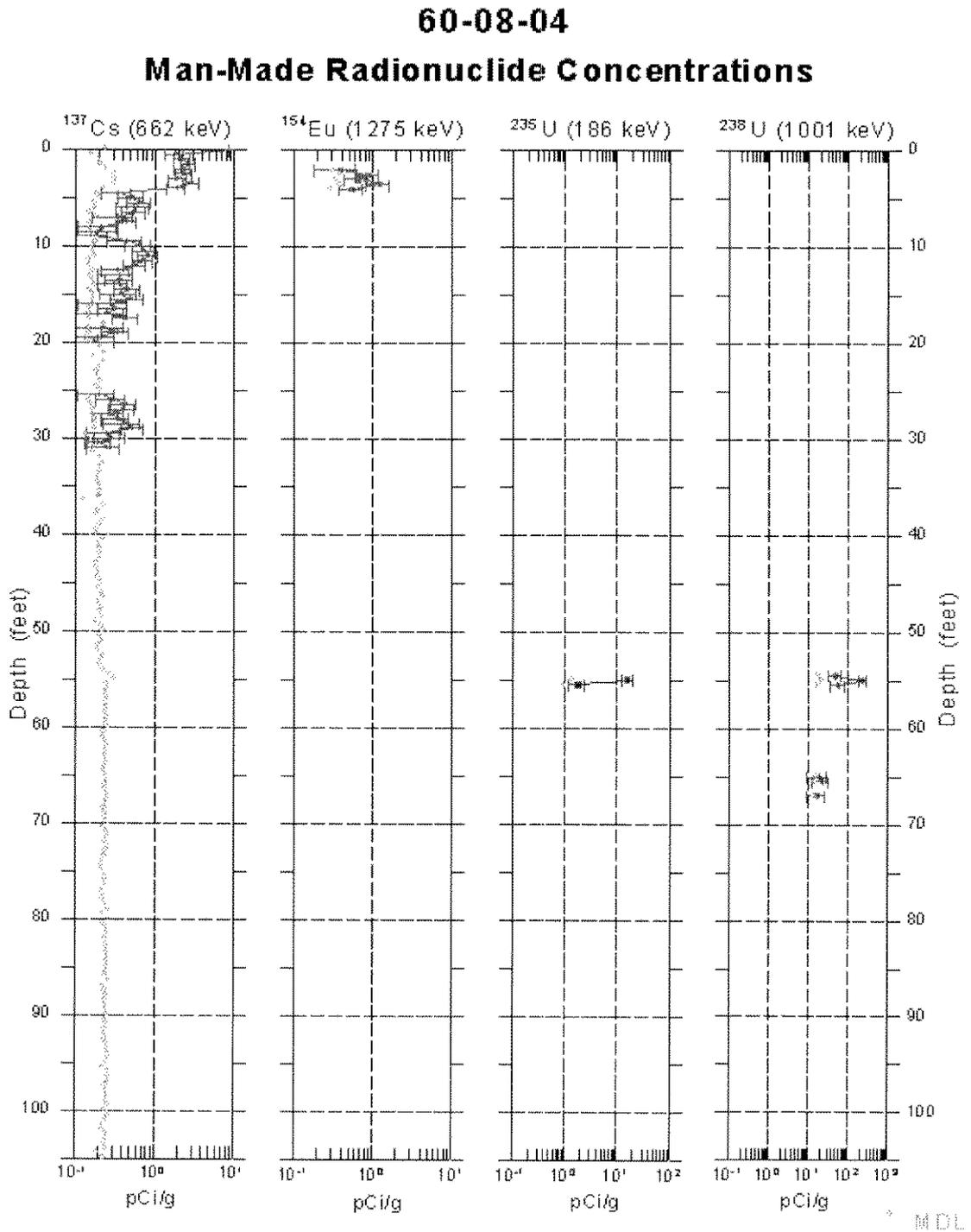


Figure D-10. 60-10-07 Man-Made Radionuclide Concentrations, High Rate Logging Results (DOE-GJO 2000)

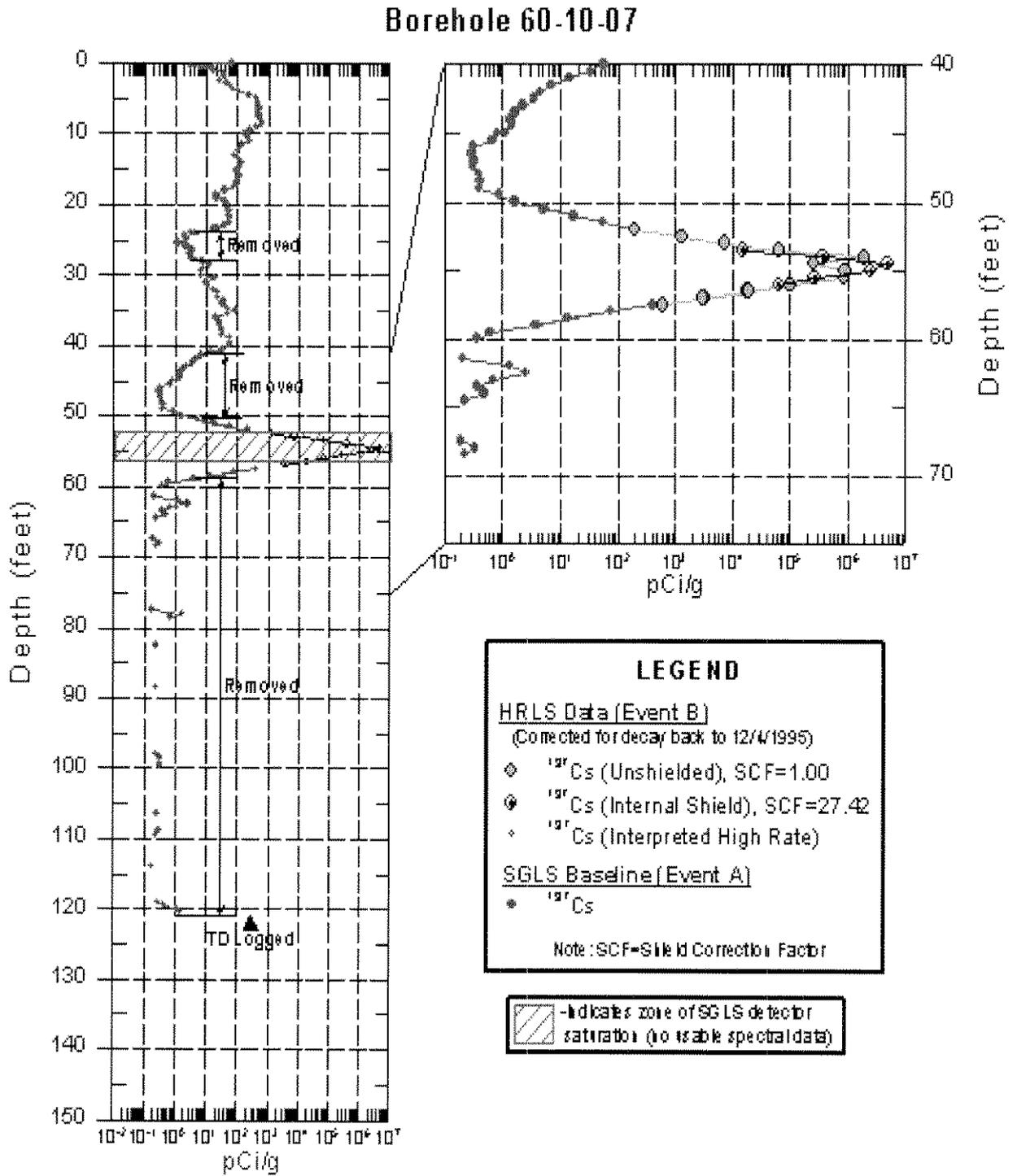


Figure D-11. 60-11-03 Man-Made Radionuclide Concentrations (DOE-GJO 1996e)

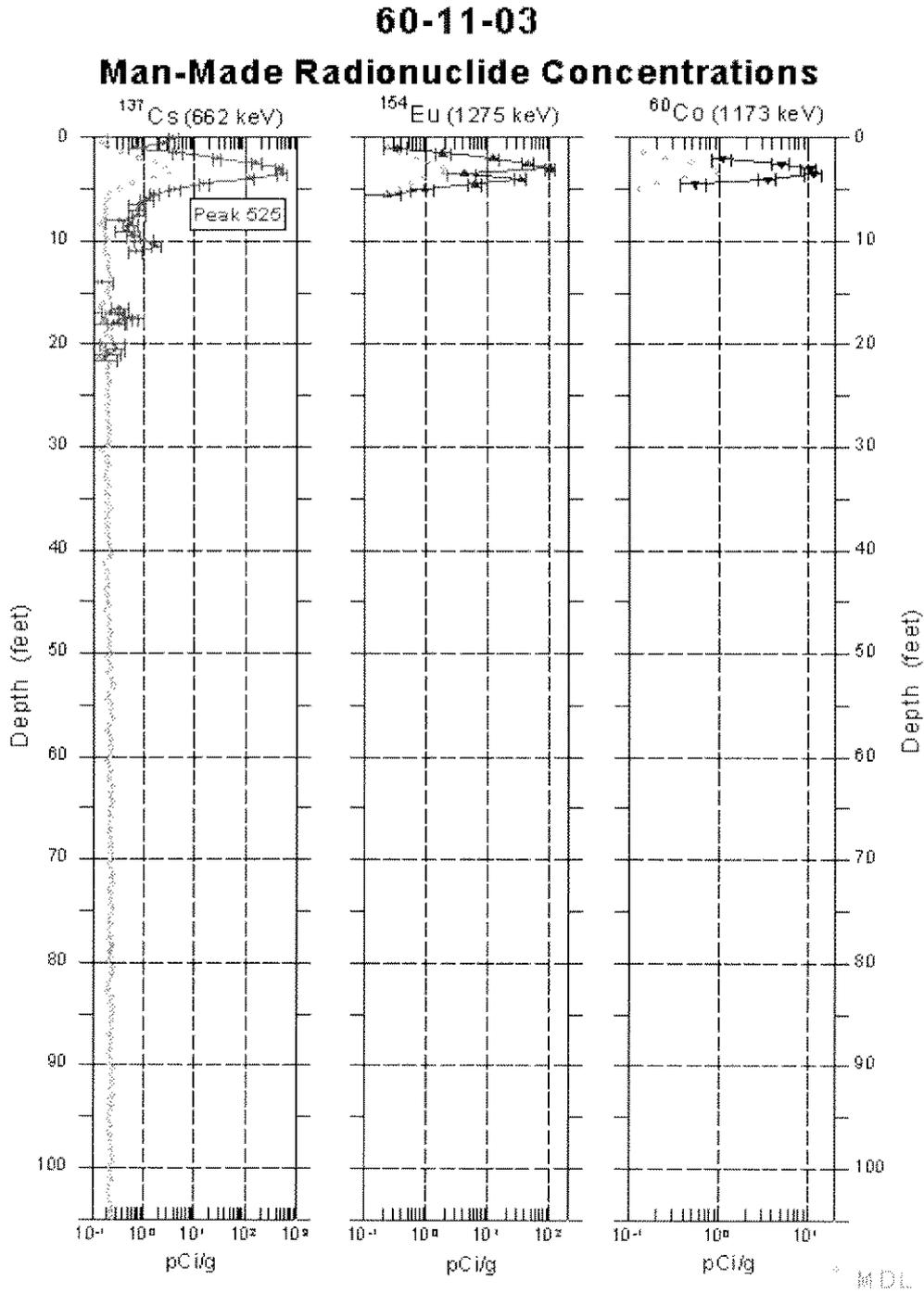


Figure D-12. 60-11-12 Man-Made Radionuclide Concentrations (DOE-GJO 1996e)

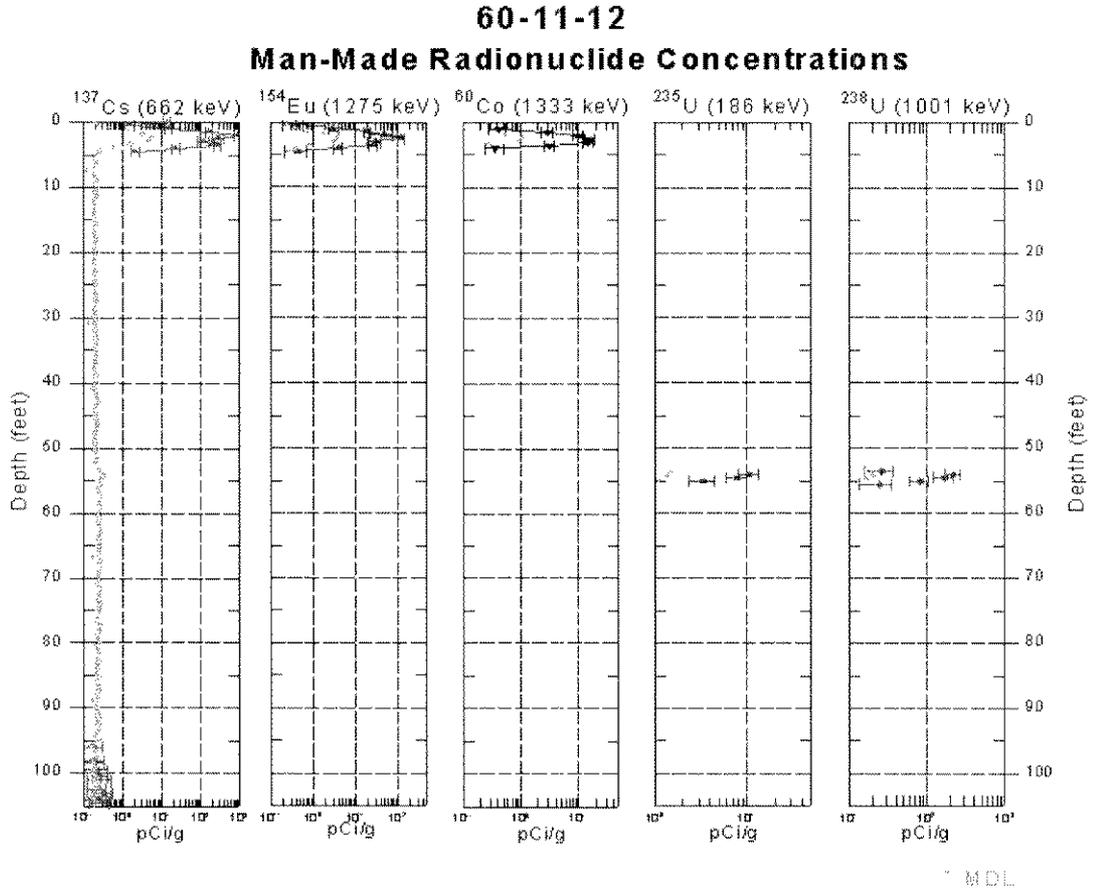
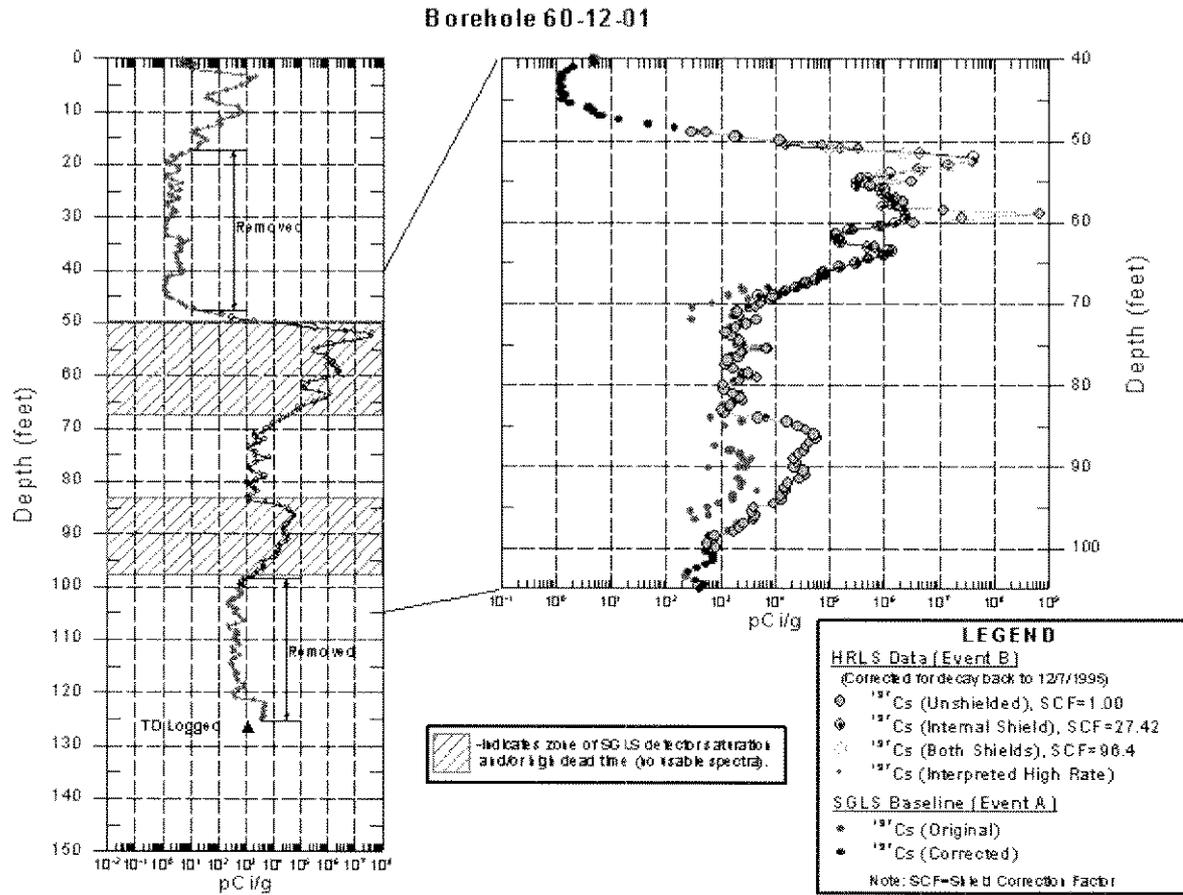


Figure D-13. 60-12-01 Man-Made Radionuclide Concentrations, High Rate Logging Results (DOE-GJO 2000)



U TANK FARM HISTORICAL GROSS GAMMA LOGGING DATA

2 Subsurface Condition Categories

2.1 Clean

A clean well is one that exhibits no observable change in the character of the activity over the logging history of the well, and does not have any isotopes identified by the SGLS greater than the average background levels of naturally occurring gamma ray emitting isotopes. Non-gamma emitting radionuclides or other contaminant species might be present but are not detected by either SDGLS or gross gamma logging. Although spurious surveys (those readings that do not repeat over time) may exist in the frequency clean and the average background plots, the trend of the data is clear. Thirty-one of 59 dry wells (i.e., 53%) in the U Tank Farm are considered clean (Figure 2) and are listed in Table 2. The remaining 28 wells are considered contaminated and are categorized and discussed in the following sections.

Table 1. U Tank Farm Clean Wells

Borehole Number	Survey Depth (feet)	Category
60-00-02	153	Clean
60-00-06	125	Clean
60-00-08	80	Clean
60-00-10	150	Clean
60-00-11	135	Clean
60-01-10	100	Clean
60-02-05	100	Clean
60-02-10	125	Clean
60-02-11	100	Clean
60-03-01	100	Clean
60-03-05	125	Clean
60-03-11	130	Clean
60-04-03	130	Clean
60-05-08	125	Clean
60-05-10	100	Clean
60-06-07	130	Clean
60-06-10	128	Clean
60-06-11	100	Clean
60-08-08	98	Clean
60-08-09	125	Clean
60-08-10	140	Clean
60-09-01	100	Clean
60-09-07	100	Clean
60-09-08	120	Clean
60-09-10	125	Clean
60-11-05	125	Clean
60-11-06	125	Clean
60-11-07	125	Clean
60-12-05	100	Clean
60-12-07	100	Clean
60-12-10	100	Clean

2.2 Contaminated

A total of 39 contaminated zones were identified in the remaining 28 boreholes, with up to four zones identified in a single borehole. In some cases, the zones are continuous; in others, there are non-contaminated intervals between zones of contamination. This is especially true for boreholes in which there are zones of Tank Farm Activity which, typically, occur in the upper 10 feet of a borehole. Other contaminated zones within a borehole with Tank Farm Activity usually begin at a depth of 25 feet or more.

Specific gamma-emitting isotopes that are in the subsurface are identified from data acquired by the SGLS. Integration of the decay rate of the radionuclide species identified by the SGLS with the gross gamma ray data collected during the dry well surveillance program provides insight as to the rate of change, if any, of radionuclides in the subsurface. During the analysis of U Tank Farm data, four gamma-emitting isotopes were identified or hypothesized to have occurred in one or more radioactive contamination zones. They are cesium-137 (Cs-137), cobalt-60 (Co-60), europium-154 (Eu-154), and uranium-238 (U-238). Even though, uranium-235 (U-235) is frequently detected with higher concentrations of uranium-238, it is not processed as a separate radionuclide for the gross gamma analysis, this is because the difference in the rate of decay for U-235 and U-238 is not discernable for the twenty year history of the gross gamma surveys.

Cesium-137 was identified in 30 zones, most often as the sole isotope in a zone, although it is found with other gamma-emitting isotopes in 2 zones.

Cobalt-60 was identified by SGLS in one zone in U Tank Farm boreholes. It exists in conjunction with other isotopes identified by SGLS in this zone.

Europium-154 (Eu-154) is present in two zones in combination with other isotopes.

Uranium-238 and uranium-235 are present in nine zones as the sole isotope(s). Uranium-235 and uranium-238 can not be separated during the analysis of the gross gamma log surveys.

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

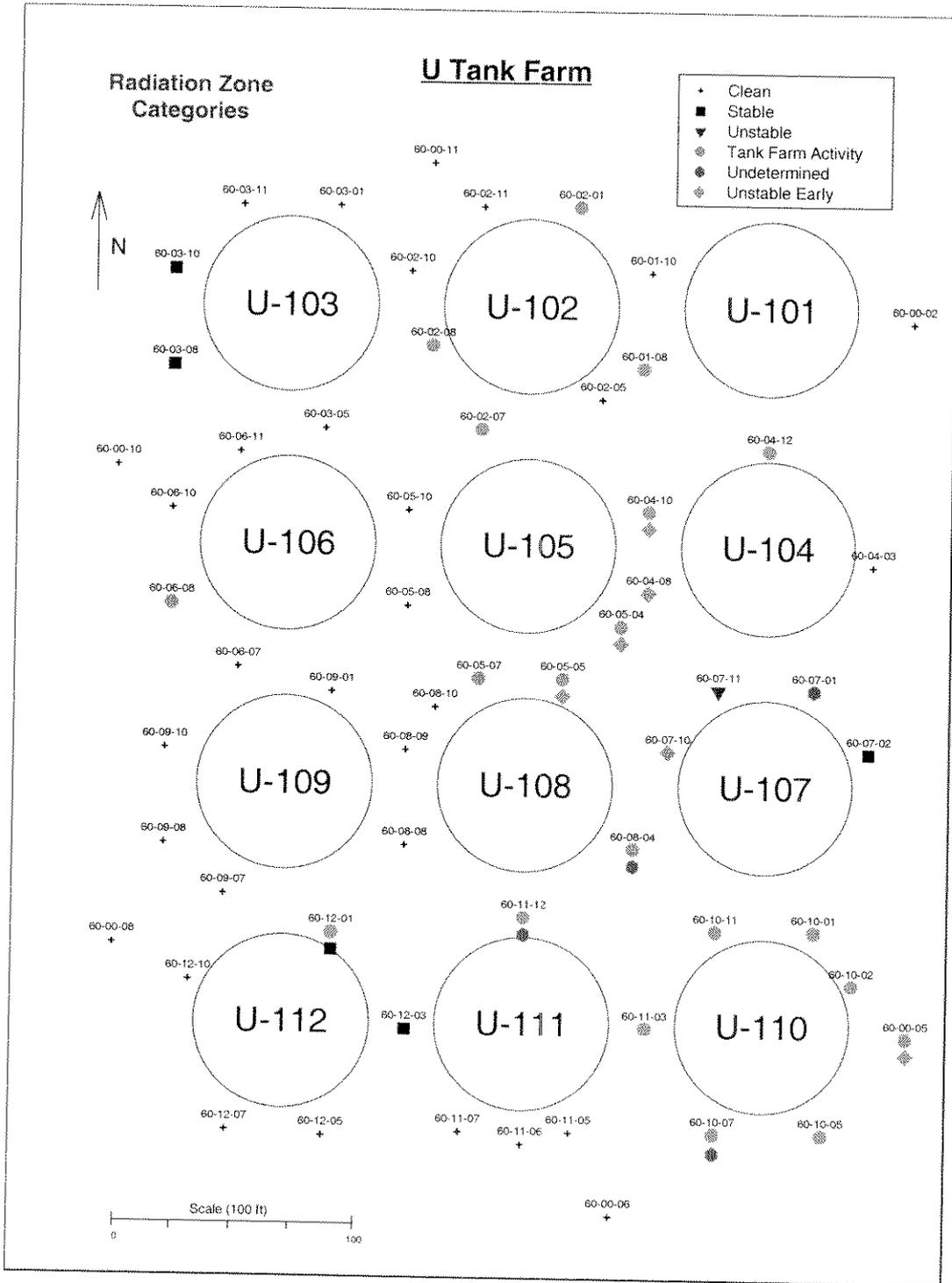


Figure 1. U Tank Farm Radiation Zone Categories

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 near the surface in 19 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 1. U Tank Farm Activity Zones

Borehole Number	Survey Depth (feet)	Probe	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotope Present
60-00-05	150	4	TF Activity	0-5	250	1975	¹³⁷ Cs
60-01-08	125	4	TF Activity	0-5	100	1975	¹³⁷ Cs
60-02-01	125	4	TF Activity	0-14	160K	1975	¹³⁷ Cs
60-02-07	130	4	TF Activity	0-6	120	1985	¹³⁷ Cs
60-02-08	100	4	TF Activity	0-10	120	1985	¹³⁷ Cs
60-04-10	120	4	TF Activity	0-8	200	1976	¹³⁷ Cs
60-04-12	130	4	TF Activity	0-10	150	1975	¹³⁷ Cs
60-05-04	75	4	TF Activity	0-10	400	1984	¹³⁷ Cs
60-05-05	125	4	TF Activity	0-5	300	1984	¹³⁷ Cs
60-05-07	125	4	TF Activity	0-5	100	1984	¹³⁷ Cs
60-06-08	100	4	TF Activity	0-10	300	1984	¹³⁷ Cs
60-08-04	128	4	TF Activity	0-10	500	1985	¹³⁷ Cs, ¹⁵⁴ Eu
60-10-01	125	4	TF Activity	0-14	200	1985	¹³⁷ Cs
60-10-02	100	4	TF Activity	0-10	100	1982	¹³⁷ Cs
60-10-05	125	4	TF Activity	0-25	200	1975	¹³⁷ Cs
60-10-07	120	1	TF Activity	0-20	600	1981	¹³⁷ Cs
60-10-11	100	4	TF Activity	0-14	200	1985	¹³⁷ Cs
60-11-03	130	4	TF Activity	0-10	20K	1975	¹³⁷ Cs
60-11-12	125	4	TF Activity	0-8	60K	1976	¹³⁷ Cs, ⁶⁰ Co, ¹⁵⁴ Eu
60-12-01	125	1	TF Activity	116-126	3K(01)*	1980	¹³⁷ Cs

*Probe type:

Caution must be used when relating GTP values in zones recorded with different probe types.

1 = Green GM, moderately sensitive; reads moderate levels of gamma ray activity.

2 = Red GM, least sensitive; reads highest level of gamma ray activity.

4 = NaI, most sensitive, reads lowest level of gamma ray activity and therefore used in zones of limited activity

*Category: defined above in 1.0 Introduction.

TF Activity; abbreviation for Tank Farm Activity

*Isotopes Present: Radionuclides used in GTP plot. Radionuclides identified as present by HPGe survey or hypothesized (e.g. Ru¹⁰⁶), see 1.2 Data Analysis Description.

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. Four of 39 zones in the 28 contaminated dry wells examined in the U Tank Farm are undetermined. These zones are listed in Table 4.

Table 1. U 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
60-07-01	100	4	Undetermined	48-62	300	1975	²³⁵ U
60-08-04	128	4	Undetermined	50-60	200	1980	²³⁵ U
60-10-07	120	4	Unstable	25-40	1800	1980	¹³⁷ Cs
60-10-07	120	2	Undetermined	46-62	2K	1976	¹³⁷ Cs
60-11-12	125	4	Undetermined	48-60	200	1976	²³⁵ U

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,
- 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.

Seven zones are considered stable in U Tank Farm and these zones are listed in Table 5.

Table 1. U 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
60-03-08	130	4	Stable	0-10	5K	1975	¹³⁷ Cs
60-03-10	100	4	Stable	0-10	500	1975	¹³⁷ Cs
60-07-02	126	4	Stable	0-24	500	1975	¹³⁷ Cs
60-12-01	125	1	Stable	0-15	600	1980	¹³⁷ Cs
60-12-01	125	2	Stable	46-70	15K	1980	¹³⁷ Cs
60-12-01	125	1	Stable	75-116	30K(01)	1980	¹³⁷ Cs
60-12-03	125	4	Stable	16-26	100	1975	¹³⁷ Cs

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 U Tank Farm, eight zones are identified which exhibited instability within the time period that gross gamma ray data were collected. In six 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 and "unstable early" zones is presented in Table 6.

Table 1. U Tank Farm Unstable and Unstable Early Zones

Borehole Number	Survey Depth (feet)	Probe Type	Category	Zone Depth (feet)	Max GTP (ft x c/s)	Year Max GTP	Isotopes Present
60-00-05	150	4	Unstable Early	5-18	21K	1975	¹³⁷ Cs
60-04-08	120	4	Unstable Early	46-65	800	1979	²³⁸ U
60-04-10	120	4	Unstable Early	47-58	180	1975	²³⁸ U
60-05-04	75	4	Unstable Early	48-57	200	1984	²³⁸ U
60-05-05	125	4	Unstable Early	48-58	150	1975	²³⁸ U
60-07-10	100	4	Unstable Early	48-70	1K	1980	²³⁸ U
60-07-11	125	4	Unstable	48-94	2K	1993	²³⁸ U

D.2.0 REFERENCES

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