~~54753~~
~~[illegible]~~
57260

03-95-19

TREATABILITY STUDY REPORT AND PROCESS FORMULATION REPORT

FOR

ADMIN RECORD

PONDCRETE

TEXT
APPENDIX A & B
VOLUME 1 OF 2

REVISION 0

HALLIBURTON NUS CORPORATION

JUNE, 1995

Halliburton NUS
CORPORATION

03-95-19

TREATABILITY STUDY REPORT
AND
PROCESS FORMULATION REPORT

FOR

PONDCRETE

REVISION 0

PREPARED FOR
EG&G ROCKY FLATS
GOLDEN, COLORADO

PREPARED BY:
HALLIBURTON NUS CORPORATION
PITTSBURGH, PENNSYLVANIA

JUNE, 1995

SUBMITTED BY:

RICHARD M. NINESTEEL, P.E.
PROJECT MANAGER

APPROVED BY:

DONALD R. BRENNEMAN
EXECUTIVE SPONSER

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

Am	Americium
ASTM	American Society for Testing and Materials
$Ca(OH)_2$	Calcium Hydroxide (Hydrated Lime)
CaO	Calcium Oxide (Quick Lime)
CAMUs	Corrective Action Management Units
COC	Constituents of Concern
CDR	Conceptual Design Report
Cs	Cesium
CSS	Chemical Stabilization and Solidification
cy	Cubic Yard
D&D	Decontamination and Decommissioning
DOE	Department of Energy
g/cc	Grams per Cubic Centimeter
HDPE	High-Density Polyethylene
HEPA	High Efficiency Particulate Air (Filter)
HNUS	Halliburton NUS
IM/IRA	Interim Measure/Interim Remedial Action
LDR	Land Disposal Restrictions
mg/L	Milligrams per Liter
MSDS	Material Safety Data Sheet
MTRs	Minimum Technology Requirements
mg/Kg	Milligrams per Kilogram
NTS	Nevada Test Site
OU4	Operable Unit 4
pCi/L	Pico-curies per Liter
PCM	Pondcrete Metals
PCTW	Pondcrete Triwalls
POC	Point of Compliance
PS	Performance Standards
psi	Pounds per Square Inch
Pu	Plutonium
Ra	Radium
RFETS	Rocky Flats Environmental Technology Site
RPM	Revolutions Per Minute
SEP	Solar Evaporation Ponds
SU	Standard Units

TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
TUs	Temporary Units
U	Uranium
UCS	Unconfined Compressive Strength
USEPA	United States Environmental Protection Agency
WAC	Waste Acceptance Criteria
W/P	Water-to-Pozzolan

EXECUTIVE SUMMARY

This report constitutes the Treatability Study and Process Formulation Report for Pondcrete. It has been prepared by Halliburton NUS Corporation (HNUS) as part of the EG&G Subcontract MTS 225471AS, Task Order 353010ST3. The purpose of this report is to summarize the treatability study work conducted at the HNUS Laboratory in Pittsburgh, Pennsylvania, in support of the pondcrete disposal efforts at the Rocky Flats Environmental Technology Site.

The Rocky Flats Environmental Technology Site (RFETS) is located in northern Jefferson County, Colorado. The site, whose former mission was producing component parts for nuclear weapons, is currently managed by EG&G Rocky Flats, Inc., for the United States Department of Energy (DOE). Key production activities involved the fabrication of parts from plutonium, uranium, and nonradioactive metals. The site's current mission is focused on environmental restoration, waste management, and decontamination and decommissioning of facilities.

An element of the Environmental Restoration Program at the RFETS is Operable Unit 4 (OU4), the Solar Evaporation Ponds. OU4 includes the five solar evaporation ponds designated 207A, 207B (north, center, and south), 207C, and the contents of the Building 788 Clarifier. Pondcrete will also be included in the OU4 closure.

As part of the closure plans for OU4, pondcrete is to be treated to satisfy specific Waste Acceptance Criteria (WAC) requirements and then placed in the OU4 closure area and covered with an engineered cap.

Pondcrete resulted from the previous remediation (June 1985) of the 207A pond sludge. Thickened 207A pond sludge was pumped to a pug mill for blending with Type I portland cement. The resultant material, pondcrete, was placed in cardboard boxes, which are referred to as triwalls. The mixture (pondcrete) was then allowed to cure and was labeled and transported to two outdoor asphalt pads for storage until shipment to the Nevada Test Site (NTS) for disposal. The hardened pondcrete was routinely disposed of at NTS during the cleanout of Pond 207A until the fall of 1986 when pondcrete was identified as low-level mixed waste.

In late May 1988, operations personnel observed that several of the pondcrete triwalls had deformed. Subsequently, the deteriorated triwalls were placed into metal containers for storage. Two to three triwalls were placed into each metal container.

Inventory pondcrete consists of approximately 8,200 triwalls of pondcrete (includes 2,500 pondcrete triwalls that have been placed into metal containers), 50 half-crates of previously reprocessed pondcrete, and several 55-gallon drums of inventory pondcrete. The pondcrete triwalls currently not in metal containers will be placed in new metal containers by the end of 1995.

Specific Waste Acceptance Criteria (WAC) and Performance Standards (PS) have been established for disposal of pondcrete within the OU4 closure. The WAC and PS which must be met are as follows:

- The treatment shall be the minimum needed to meet all WAC and PS.
- The treated waste shall not, prior to placement, contain free liquids as determined by the Paint Filter Liquids Test, Method 9095 (SW 1992).
- The treated waste can be delivered as a monolith or in particulate form. If a monolith:
  - Shall fit within a rectilinear envelope 12" x 24" x 48"
  - Shall not exceed 3,000 pounds per square inch (psi) compressive strength
  - Shear and tensile strengths shall not exceed those of 3,000 psi concrete
  - Shall not be delivered in molds, containers, or packaging that cannot be returned

  If in a particulate form:

  - Shall pass a 3-inch screen
  - Shall not agglomerate into particles greater than 3 inches during storage. If agglomeration does occur, the material shall meet all the criteria specified for a monolith, listed above.
- When treated waste is mixed with site soils, no agglomeration greater than 3 inches shall occur.
- Treated waste shall be resistant to dispersion by wind.
- During storage, treated waste shall not produce dust or dispersable fines, and will not degrade upon wetting.

- Treatment additives shall not cause the proposed remedy to fail to be protective of human health and the environment.

- Pathogens shall be removed or rendered innocuous.

- Treated waste shall not produce gas at a rate or volume greater than that produced by natural site soil.

- Total treated waste volume shall be less than 20,000 cubic yards (cy).

- Leachate shall not contain constituents at concentrations that, when modeled, are not protective of human health and the environment.

Baseline analysis of the pondcrete was performed at the start of the treatability study. TCLP leachate data were compared to preliminary modeling data to assess the potential impact of the disposal of untreated pondcrete in the OU4 closure. The information shows that both pondcrete triwalls and pondcrete metals would eventually leach contaminants (plutonium-239/240 and cadmium) from the OU4 closure at levels that are not protective of human health, based on current OU4 closure design conditions. This indicates that treatment of pondcrete is required due to the leachability of these constituents.

The general concept used for developing process formulations for treatment of pondcrete followed a progression from performing initial analysis and testing of the raw waste, to screening various additives to determine whether a friable, soil-like treated waste could be produced, through a more comprehensive evaluation of additive formulations. Then, the selected candidate formulations that passed all of the previous evaluation criteria were subjected to final WAC compliance testing. A major objective of the treatability study was to develop data showing compliance with the WAC over a wide operating range for key process parameters. The most important parameters were the waste loading, measured as percent total solids of the pondcrete, and the water-to-pozzolan ratio, which controls the amount of pozzolan (defined as cement plus fly ash) required for effective treatment. The amount of lime required to raise the pH of the pondcrete for disinfection and to reduce the leachability of metals and radionuclides was also a key parameter.

The treatability study evaluated numerous additives, singly and in combination, including cement, fly ash, lime, and silica flour. A treatment system consisting of the addition of hydrated lime, Type C fly ash, and Type I/II Portland cement is recommended for treating pondcrete. The hydrated lime is necessary to raise the pH to greater than 12 to stabilize the pondcrete and inhibit gas generation via biological decomposition of the organics in the waste, as well as to reduce the leachability of most metals and radionuclides. The cement and fly ash are required to eliminate the free water in the waste, a WAC requirement for disposal in the OU4 closure, and to aid in the production of a friable product. All WAC, with the exception of total volumes of treated waste (which includes treated pond sludge), were satisfied with the selected lime/fly ash/cement treatment system.

The selected formulation for lime/fly ash/cement is the same system investigated for pond sludges in 1992 for the production of monoliths for offsite disposal (HNUS, 1992b). The current treatability study for the production of a friable product, as well as the previous treatability study, both selected a ratio of fly ash/cement of 2/1, as the desired operating ratio.

The process operating ranges of key parameters for pondcrete treatment are as follows:

- Pondcrete Triwalls (PCTW)
  - Waste loading total solids: . . . . 25% to 40%
  - Water-to-pozzolan ratio tested that met WAC: . . . . 0.20 to 0.30
  - Water-to pozzolan ratio that produces a friable product: . . . . 0.22 to 0.27
  - Lime addition by weight of waste feed: . . . . 7.5% ± 2.5%

- Pondcrete Metals (PCM)
  - Waste loading total solids: . . . . 38.8% to 48.6%
  - Water-to-pozzolan ratio tested that met WAC: . . . . 0.35 to 1.0
  - Water-to-pozzolan ratio that produces a friable product: . . . . 0.45 to 0.55
  - Lime addition by weight of waste feed: . . . . 7.5% ± 2.5%

1.0 PROJECT DESCRIPTION

1.1 AUTHORIZATION

This report has been prepared by Halliburton NUS Corporation (HNUS) as part of the EG&G Subcontract MTS 225471AS, Task Order 353010ST3. The purpose of this report is to summarize the treatability study work conducted at the NUS Laboratory in Pittsburgh, Pennsylvania, in support of the Pondcrete disposal efforts at the Rocky Flats Environmental Technology Site (RFETS), Golden, Colorado. This report provides supporting documentation for compliance with all treatment-related Waste Acceptance Criteria (WAC) required for ultimate waste disposal into the Operable Unit 4 (OU4) closure.

This report constitutes the Treatability Study Report and Process Formulation Report for Pondcrete. Included as appendices are the Equipment Recommendation Report and Modeling Report (Appendices A and B respectively).

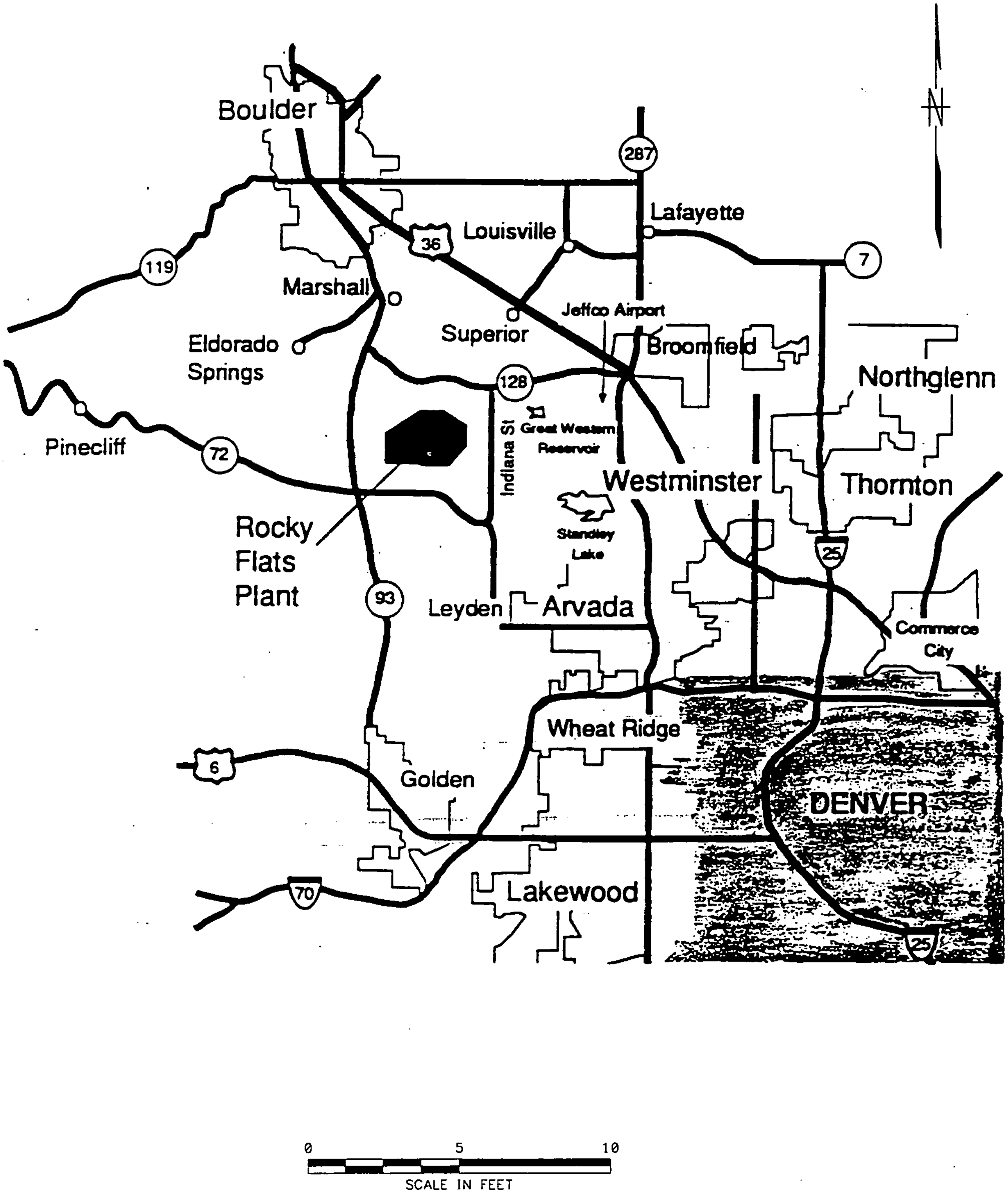
1.2 SITE DESCRIPTION

RFETS is located in northern Jefferson County, Colorado. The site is currently managed by EG&G Rocky Flats, Inc., for the United States Department of Energy (DOE). The plant consists of 6,550 acres of Federal land, bounded by Colorado Highways 93 and 128 on the west and north, respectively; Indiana Street on the east; and Colorado Highway 72 on the south (Figure 1-1). The plant structures are centrally located within the site inside a security fenced area of about 384 acres, as shown in Figure 1-2.

1.2.1 Rocky Flats Plant Background

The RFETS is a government-owned, contractor-operated facility whose former mission was producing component parts for nuclear weapons. Key production activities involved the fabrication of parts from plutonium, uranium, and nonradioactive metals, principally beryllium, stainless steel, and aluminum. Components made at the RFETS were shipped elsewhere for final assembly. The site began operations in 1952 in 20 buildings and grew continually to more than 100 buildings. In 1989 production operations were halted at the RFETS.

ACAD: O:\DATA\CADD\3A23\95032803.DWG 06/02/95 DT



AREA MAP OF RFETS AND SURROUNDING COMMUNITY GOLDEN, COLORADO

FIGURE 1-1

Halliburton NUS CORPORATION

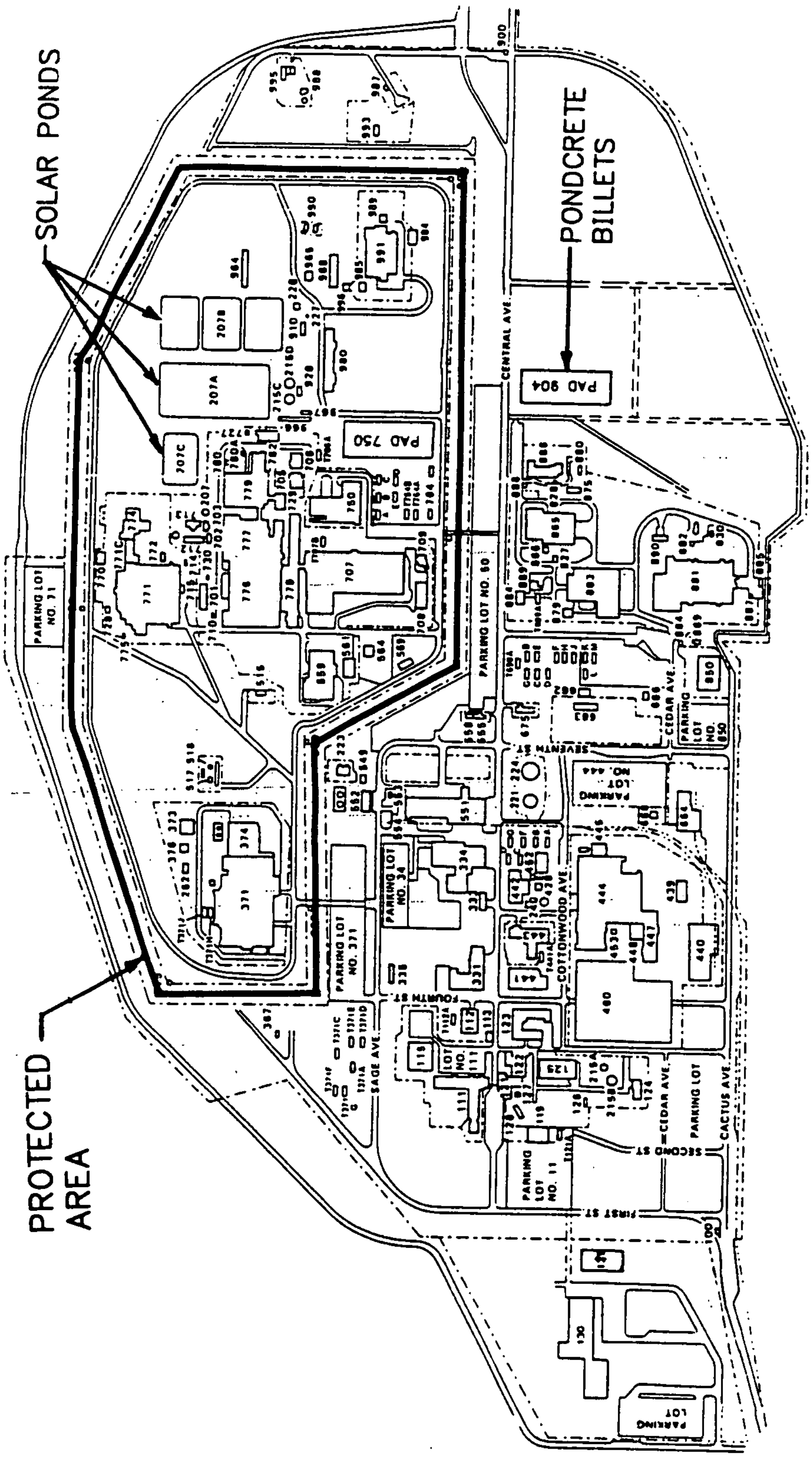


FIGURE 1-2

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
GOLDEN, COLORADO

Halliburton NUS
CORPORATION

AD: O:\DATA\CADD\3A23\9503283A.DWG 06/05/95 DT

The plant's historical production mission was officially discontinued in 1992 with the end of the Cold War and the administration's decision not to resume weapons component production activities at the RFETS. Subsequently, EG&G formed a Transition Management organization to help the RFETS undertake a new mission focusing on environmental restoration, waste management, decontamination and decommissioning (D&D) of facilities, and economic development. The activities at the RFETS are currently continuing in these areas.

1.2.2 Operable Unit 4 Description

Operable Unit 4 (OU4), the Solar Evaporation Ponds, is an element of the DOE Environmental Restoration Program at the RFETS. OU4 includes the five solar evaporation ponds designated 207A, 207B (north, center, and south), 207C, and the contents of the Building 788 Clarifier. Pondcrete will also be included in the OU4 closure.

During construction of the Rocky Flats Plant in the early 1950s, a clay-lined solar evaporation pond was installed. The pond was designed for the impoundment of aqueous waste products discharged from the Process Waste Treatment Plant. The waste contained high levels of chemical contaminants, such as fluoride, nitrates, and various metallic ions. As a result of the changing plant operations and environmental requirements, additional evaporation ponds were constructed. On occasion these ponds were used for the disposal of untreated waste products, such as metallic lithium, acids, sewage sludge, plating residues, and several other wastes associated with operations at the RFETS (Wienand & Howard, 1992).

As part of the closure plans for OU4, pondcrete is to be treated to satisfy specific Waste Acceptance Criteria (WAC) requirements and then placed in the OU4 closure area and covered with an engineered cap.

1.3 WASTE DESCRIPTION

The pondcrete waste is classified as low-level mixed waste. United Sates Environmental Protection Agency (USEPA) Hazardous Waste Numbers associated with the pondcrete are F001, F002, F003, F005, F006, F007, F009, and D006.

Waste characterization studies (HNUS, 1992d) were conducted in 1991 and 1992 to determine the physical and chemical composition of pondcrete.

Pondcrete resulted from the previous remediation (June 1985) of the 207A pond sludge. The remediation process consisted of pumping the water on top of the pond sediments/sludges to Building 374 for treatment. The sludge was then slurried and pumped to the pondcrete facility at Building 788, from which it was transferred to the Building 788 Clarifier for thickening. The thickened sludge was then pumped to a pug mill for blending with Type I portland cement. The resultant material, pondcrete, was placed in cardboard boxes, which are referred to as triwalls. The mixture (pondcrete) was then allowed to cure and was labeled and transported to two outdoor asphalt pads for storage until shipment to Nevada Test Site (NTS) for disposal. The hardened pondcrete was routinely disposed of at NTS during the cleanout of Pond 207A until the fall of 1986 when pondcrete was identified as low-level mixed waste.

In late May 1988, operations personnel observed that several of the pondcrete triwalls had deformed. Subsequently, the deteriorated triwalls were placed into metal containers for storage. Two to three triwalls were placed into each metal container.

Inventory pondcrete consists of approximately 8,200 triwalls of pondcrete (includes 2,500 pondcrete triwalls that have been placed into metals containers), 50 half-crates of previously reprocessed pondcrete, and several 55-gallon drums of inventory pondcrete.

Pondcrete triwalls were placed in new metal containers during 1995. These new metal containers are known as "V boxes" and are easily distinguished from the "old metals." All of the new metals are smooth sided, have bolted-on steel lids, and have steel feet on the bottom to enable movement by fork truck. They measure approximately 4 feet x 7 feet.

Pondcrete in metals are physically failed triwalls that were placed into these metals sometime during the period 1988 to 1992. These "old metals" are known as "sandboxes" and measure approximately 4 feet x 4 feet x 7 feet, having corrugated sides, a fiberglass lid/cover (not bolted), and a smooth outside bottom. Almost all sandboxes are on wooden pallets to expedite movement by forklift.

No triwalls from (old, sandboxes) metals were to be repacked into the new V boxes during 1995, and therefore it is anticipated that the two pondcrete populations can be easily distinguished by visual inspection of the exterior of the metal box.

Pondcrete triwalls were sampled, and field and laboratory analyses were performed. Field measurements taken during the sampling of the pondcrete triwalls indicated that the majority of the triwalls were wet to damp with penetrometer readings from 0 to 2.5 tons/ft^2. Analytical results from the pondcrete triwalls characterization indicate the moisture content ranged from 46.5 to 69.7 percent with an average of 62.8 percent. Results for volatile organics ranged from 550 μg/kg to 8,600 μg/kg, with acetone detected at the highest concentrations. The Total Organic Carbon (TOC) averaged approximately 4,100 mg/kg, which indicates significant organic content in the waste. In the Toxicity Characteristic Leaching Procedure (TCLP) extract, cadmium and chromium were detected at average concentrations of 20,600 $\mu g/L$ and 5,290 $\mu g/L$, respectively. Baseline characterization data of the pondcrete triwalls used for this treatability study are provided in Section 3.1.1.

Pondcrete metals were sampled, and field and laboratory analyses were performed. Field measurements taken during the sampling of the pondcrete metals indicated that the majority ranged from very wet to moist with penetrometer readings from 0 to >4.5 tons/ft^2. Analytical results from the pondcrete metals characterization indicate the moisture content ranged from 45.8 percent to 74.4 percent with an average of 63.2 percent. Results for volatile organics ranged from 310 $\mu g/kg$ to 7,900 $\mu g/kg$, with acetone detected at the highest concentrations. Methanol was detected at 15.4 mg/kg. The TOC averaged approximately 2,600 mg/kg, which indicates significant organic content in the waste. In the TCLP extract, cadmium and chromium were detected at average concentrations of 10,800 $\mu g/L$ and 1,520 $\mu g/L$, respectively. Historical characterization data (Weston, 1991) indicated the pondcrete metals contained higher concentrations of radionuclides, specifically americium and plutonium, than the triwalls. Baseline characterization data of the pondcrete metals used for this treatability study are provided in Section 3.1.1.

Comparing the 1991 characterization data, the pondcrete triwalls and pondcrete metals both exceeded the current Land Disposal Restrictions (LDR) criteria for cadmium and chromium. Based on the current LDR criteria, the criteria for methanol could potentially be exceeded for the pondcrete metals, although results are not conclusive. No other analytes exceeded their respective LDR criteria for pondcrete triwalls or metals.

The 1991 characterization was completed to evaluate the waste according to LDR standards and support the processing and offsite disposal of the treated product. Currently, the treated waste is to be placed within the OU4 closure area. This treatment and subsequent placement will take place under the Corrective Action Management Units (CAMUs) regulations, as promulgated by the United States Environmental Protection Agency (USEPA 40 CFR 264 and USEPA 40 CFR 265) and the State of Colorado (Colorado 6 CCR 1007-3). These regulations allow remediation wastes to be consolidated or processed without triggering LDRs or Minimum Technology Requirements (MTRs), which were promulgated to control hazardous waste production from ongoing manufacturing activities. It is anticipated that treatment process trains will probably be permitted under RCRA Subpart X rather than Temporary Unit (TU) regulations.

The current plan to dispose of the pondcrete within the OU4 closure area must prove to be protective of human health and the environment and must meet the WAC requirements and Performance Standards.

Protection of human health must be demonstrated by computer modeling. The computer model predicts which contaminants have a potential to migrate from the waste area and potentially affect human health. These contaminants have been evaluated in the treatability study.

1.4 REMEDIAL TECHNOLOGY DESCRIPTION

The goal of the treatability study is to develop a treatment process that meets the Waste Acceptance Criteria (WAC) and Performance Standards (PS) for onsite closure (see Section 1.4.1), as well as the system engineering requirements defined by the preferred treatment system (see Section 1.4.2).

1.4.1 Waste Acceptance Criteria

The objective of the treatability study is to produce a minimally treated waste that will pass the following WAC and Performance Standards (PS):

- The treatment shall be the minimum needed to meet all WAC and PS.

- The treated waste shall not, prior to placement, contain free liquids as determined by the Paint Filter Liquids Test, Method 9095 (SW 1992).

- The treated waste can be delivered as a monolith or in particulate form. If a monolith:

  - Shall fit within a rectilinear envelope 12" x 24" x 48"
  - Shall not exceed 3,000 pounds per square inch (psi) compressive strength
  - Shear and tensile strengths shall not exceed those of 3,000 psi concrete
  - Shall not be delivered in molds, containers, or packaging that cannot be returned

  If in a particulate form:

  - Shall pass a 3-inch screen
  - Shall not agglomerate into particles greater than 3 inches during storage. If agglomeration does occur, the material shall meet all the criteria specified for a monolith, listed above.

- When treated waste is mixed with site soils, no agglomeration greater than 3 inches shall occur.

- Treated waste shall be resistant to dispersion by wind.

- During storage, treated waste shall not produce dust or dispersable fines, and will not degrade upon wetting.

- Treatment additives shall not cause the proposed remedy to fail to be protective of human health and the environment.

- Pathogens shall be removed or rendered innocuous.

- Treated waste shall not produce gas at a rate or volume greater than that produced by natural site soil.

- Total treated waste volume shall be less than 20,000 cubic yards (cy).

- Leachate shall not contain constituents at concentrations that, when modeled, are not protective of human health and the environment.

1.4.2 Process Description

As part of the conceptual design for the treatment of inventory pondcrete, Halliburton NUS prepared a Value Engineering Study that evaluated three potential pondcrete treatment alternatives and a variety of size reduction equipment to identify the treatment system that will satisfy the closure area WAC in the most efficient, reliable, and cost-effective manner, given the operating constraints present at the RFETS. The treatment alternatives evaluated were auger screw shedders, ring-and-pick shedders, and ball mills, all of which produce a friable product. A friable product is a material which resembles a cohesive soil having low strength and the properties of a treated waste in particulate form as outlined in Section 1.4.1. The evaluation considered the following criteria: effectiveness, implementability, operability, and cost.

The auger screw shedder, followed by secondary and tertiary size reduction mechanisms, is the treatment system recommended as the preferred alternative because it has the least potential impact on the overall project schedule, is the easiest to operate and maintain, offers the greatest operating reliability, and has the lowest total cost.

The pondcrete treatment system is shown on Figure 1-3. The additives proposed for the treatment process are lime, which is not only a proven biocide, but is also effective in controlling moisture content; cement, for its pozzolanic properties; and a bulking agent, such as fly ash, to ensure a friable product. This system consists of the following unit operations:

- Transfer of the Pondcrete from the interim storage to size reduction and treatment.
- Storage and feeding of treatment additives.
- Pondcrete size reduction and mixing/blending treatment with additives.
- Treated waste storage and testing.
- Treated waste transfer to OU4 closure area.

ACAD: O:\DATA\CADD\3A37\PONDWAST.DWG 05/05/95 VB

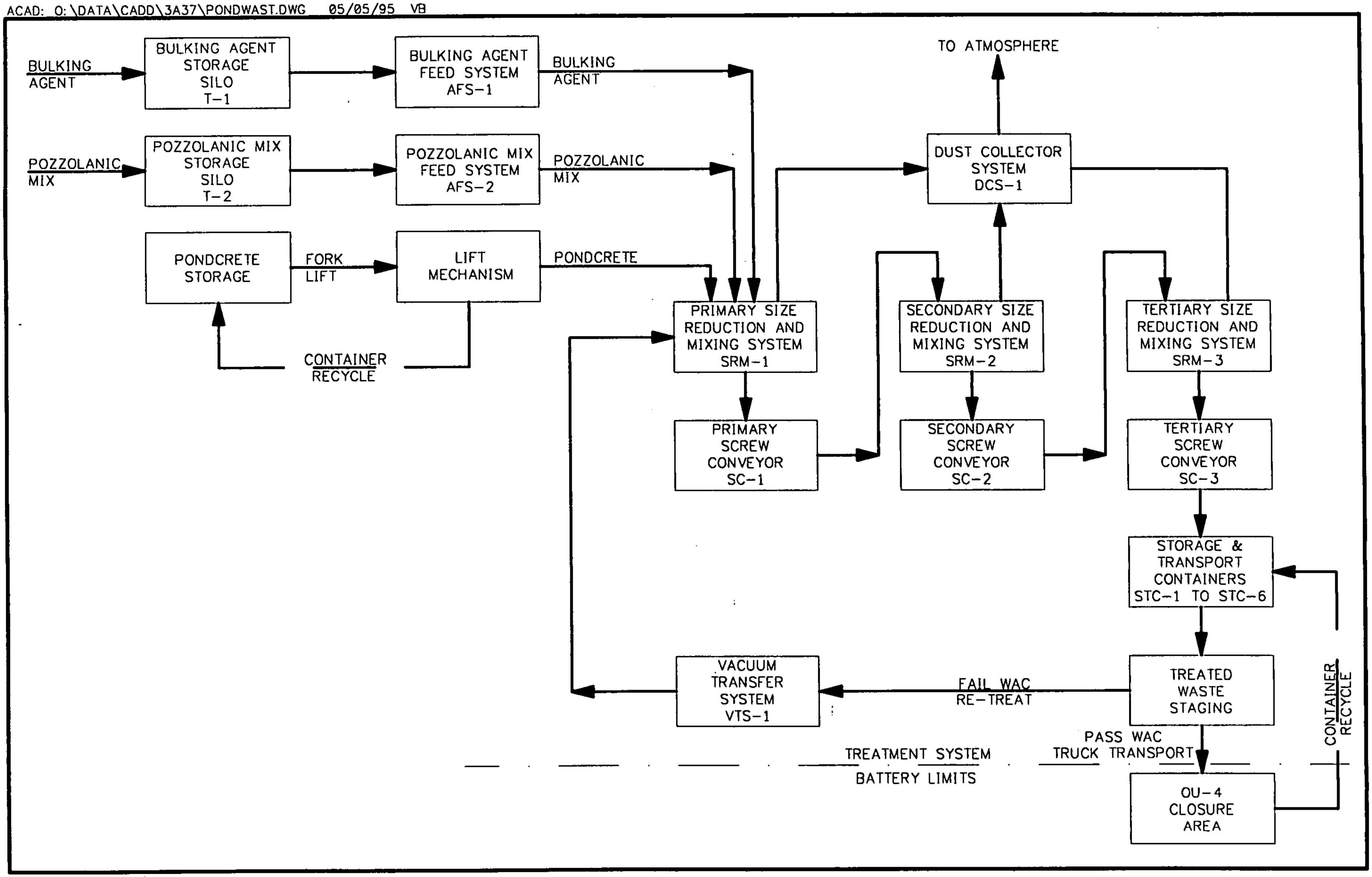


FIGURE 1-3
CONCEPTUAL BLOCK FLOW DIAGRAM
PONDCRETE SIZE REDUCTION AND TREATMENT SYSTEM
ROCKY FLATS, COLORADO

Halliburton NUS CORPORATION

2.0 TREATABILITY STUDY APPROACH

This section describes the requirements and procedures for conducting the treatability study used to develop the chemical stabilization/solidification (CSS) formulations for pondcrete at the Rocky Flats Environmental Technology Site (RFETS).

2.1 GOALS AND OBJECTIVES

The goal of the treatability study was to develop a CSS formula that is successful in producing a final waste product that can be certified for disposal in accordance with the requirements as stated in Section 1.4.1 and has a final consistency of a friable soil. During the treatability study, it was necessary to determine the appropriate additives and the optimum ratios of waste to admixture(s) to achieve acceptable physical characteristics and chemical leachability criteria.

2.2 TREATABILITY STUDY OVERVIEW

The general concept used for developing process formulations for the waste form followed a progression from performing initial analysis and testing of the raw waste to screening various additives (pre-WAC testing) through a more comprehensive evaluation of additive formulations (WAC-Phase I testing). Then, the selected candidate formulations that passed all of the previous evaluation criteria were subjected to final compliance testing (WAC-Phase II testing). The chronology of CSS formulation development is summarized in Table 2-1, and the logic is provided in Figure 2-1. An overview of the major phases of the treatability study is as follows:

- Initial Preparation and Characterization. The first step of the treatability study was to submit a uniform aliquot of the "as received" material for baseline analysis and TCLP leach analysis. This information provided a basis against which to evaluate the CSS mixes.

- Lime Addition Study. A lime addition study was performed to establish a minimum lime dosage needed to achieve and maintain a pH that would inhibit future biological activity.

- Process Formulation Development (Treatability Study Mixes). Treatability study mixes were performed in the friable mix development (pre-WAC) phase and the WAC compliance testing

TABLE 2-1

CHRONOLOGY OF FORMULATION DEVELOPMENT
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Phase	Waste Material	Date Performed	Testing	Objective	Results
Initial Preparation and Characterization (Baseline analysis)	Pondcrete Triwalls Pondcrete Metals	12/29/94 12/29/94	• Chemical Analysis, "As Received" and TCLP - Radionuclides - Metals (Be, Cd) • Bulk Density • Percent Moisture • pH	The "as received" material was analyzed to determine the makeup of the material. TCLP was performed on the "as received" material to determine the leachability of the untreated waste.	Results of TCLP testing, when compared to modeling data, showed that untreated pondcrete would not be protective of human health if disposed in the OU4 closure. Parameters predicted to leach above protective levels include: • Pondcrete triwalls: Pu-239/240, cadmium • Pondcrete metals: Pu-239/240, cadmium
Lime Addition Study	Pondcrete Triwalls	01/05/95	pH and plate count	Determine lime dosage required to achieve pH>12 for disinfection.	Able to create lime titration curve showing relationship between lime addition and pH in order to select an appropriate lime dosage.
Pre-WAC Mixes	Pondcrete Triwalls Pondcrete Metals	02/07/95 02/13/95	Physical observations, temperature change, volumetric increases	Pre-WAC testing was performed to evaluate various types of additives and quantities required to provide a friable soil consistency.	Based on this testing, three formulas were selected for evaluation: • $Ca(OH)_2$ and fly ash • $Ca(OH)_2$, fly ash, and silica flour • $Ca(OH)_2$, fly ash, and cement
Phase I WAC Mixes	Pondcrete Triwalls Pondcrete Metals	02/08/95-02/13/95 02/20/95-02/21/95	Physical observations, volumetric increases, TCLP analysis, UCS analysis	To establish a range of pozzolan addition that will pass both the physical requirements and WAC criteria.	Established correlation between TCLP leachate concentration and pH, narrowed formula test to one: • $Ca(OH)_2$, fly ash, and cement.
Phase II WAC Mixes	Pondcrete Triwalls	03/21/95	Physical observation and TCLP analysis.	To establish an operating range for key operating parameters for selected formula.	Established operating ranges for total solids content of the waste and water-to-pozzolan ratio of the treated waste.

(1) See Appendix B for development of WAC scenarios and Table B-6 for specific COC values.

(Phases I and II). All of the mixes were videotaped and are provided on VHS tapes. Still photographs (35mm) of the mixes and UCS testing were also taken and are provided in Appendix E.

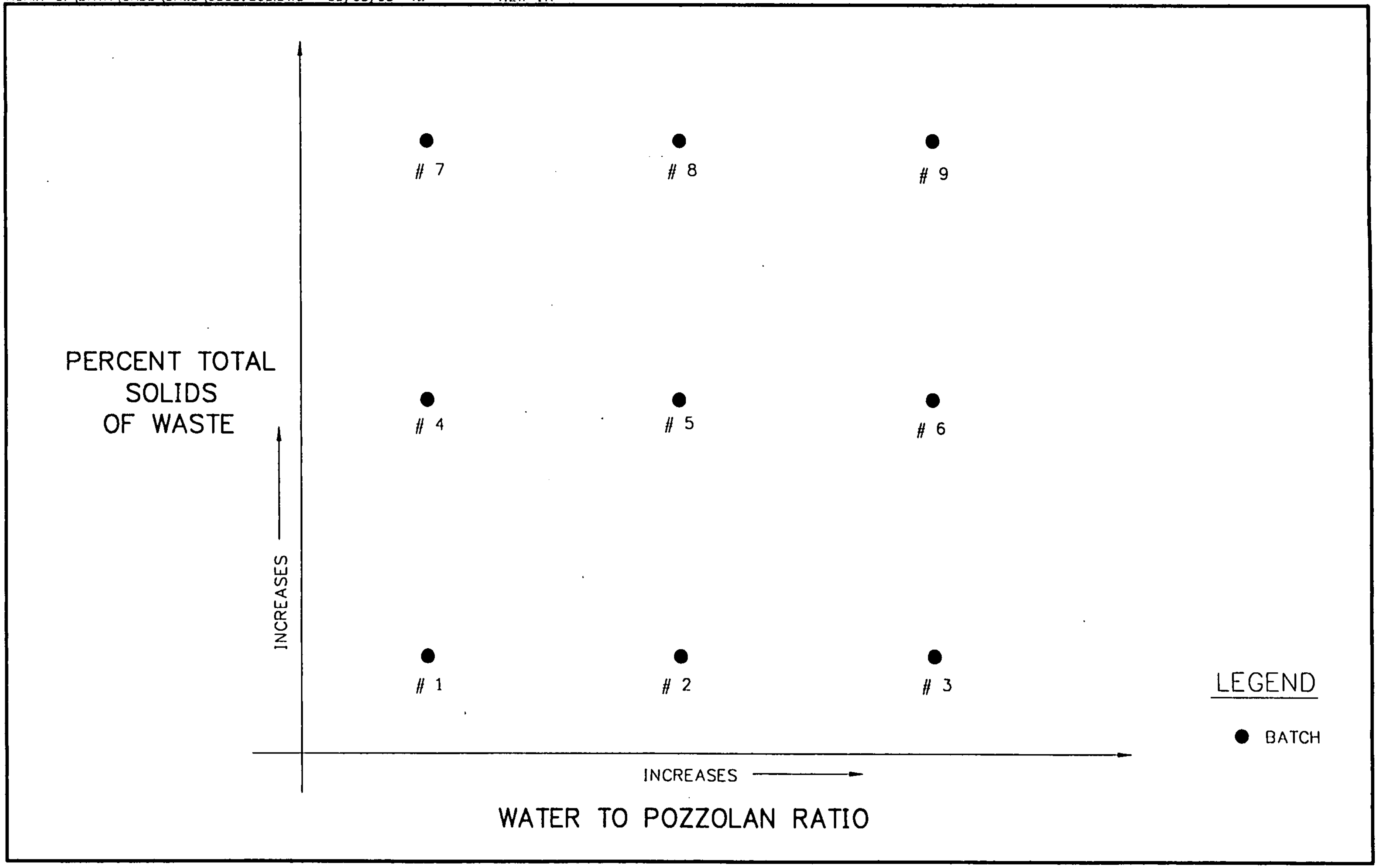
- **Pre-WAC Friable Mix Development**. This phase of testing was used to evaluate various additives for their ability to create a friable soil material. These tests also established the amount of the acceptable additives required to achieve the desired consistency. Selected additive combinations were further tested in the WAC compliance testing phases.

- **WAC Compliance Testing**. Mixes performed in the WAC compliance testing phases evaluated specific CSS formulas to determine WAC compliance. Two phases were performed as discussed below.

    - **Phase I**. Mixes performed in Phase I were used to evaluate the additive(s) selected in the pre-WAC testing for compliance with the WAC criteria. To develop an operating range of key process parameters, mixes were performed at different percent solids of the waste and water-to-pozzolan ratios. Figure 2-2 provides a schematic of the mixes performed.

    - **Phase II**. Mixes performed during Phase II were used to further evaluate the formula selected in Phase I. During preparation of these mixes, the percent solids of the waste feed, the water-to-pozzolan ratio, and the amount of lime added were adjusted to establish a process operating range for these parameters. A schematic of the mixes performed is provided in Figure 2-3.

ACAD: O:\DATA\CADD\3A23\95031302.DWG 05/05/95 VB VIEW=1A



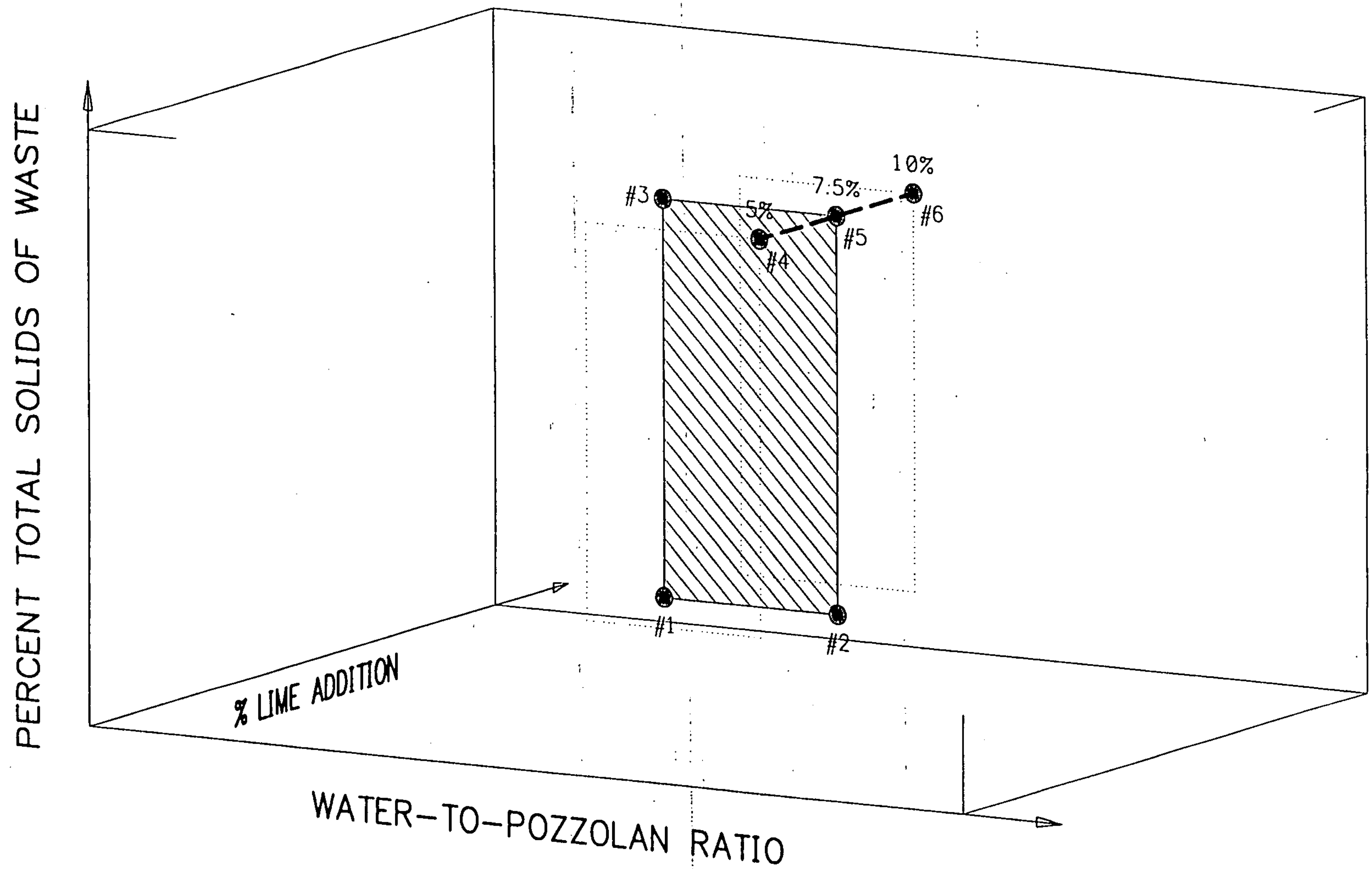
WASTE LOADING AND POZZOLAN ADDITION VARIATIONS
FOR WAC PHASE I TESTING
ROCKY FLATS, COLORADO

FIGURE 2-2

Halliburton NUS CORPORATION

03-95-19/P

ACAD: O:\DATA\CADD\3A23\95032401.DWG 05/05/95 VB



WASTE LOADING AND ADDITION VARIATIONS
FOR WAC PHASE II TESTING
ROCKY FLATS, COLORADO

FIGURE 2-3

Halliburton NUS CORPORATION

The analytical program for the WAC Compliance Phase testing is provided in Table 2-2. The rationale for each analysis is provided below.

- Unconfined compressive strength (UCS) provides an estimate of the final product's agglomerated strength and allows comparisons with other formulations.

- The Paint Filter Liquids Test is required to verify that there are no free liquids present.

- TCLP analysis is required to evaluate whether the final waste form meets the WAC requirement for protectiveness of human health.

2.3 EQUIPMENT AND MATERIALS

2.3.1 Mixed-Waste Treatability Study Laboratory

The testing conducted for the CSS treatability study was performed at the Halliburton NUS Laboratory in Pittsburgh, Pennsylvania. The work was performed in a treatability room that was specifically designed to accommodate low-level mixed waste materials. The room has double air locks for entrance and exit along with a negative air ventilation system which exhausts air through High Efficiency Particulate Air (HEPA) filters. All personnel entering this secured area are required to wear personal protective equipment (Tyvek coverall, booties, and nitrile gloves). Personnel must wear dosimetry badges and rings. Additionally, all personnel must submit annual bioassays for radionuclide analysis.

2.3.2 Laboratory Equipment

A list of the major equipment used for the solidification portions of the treatability study is provided in Table 2-3. This table provides the manufacturer, model number, and the pertinent equipment specification for the equipment.

TABLE 2-2

SUMMARY OF TESTING PERFORMED ON MIXES
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Analysis	Method		Test Performed	
	Sludges and Solids	Liquids and Extracts	WAC Phase I	WAC Phase II
Unconfined Compressive Strength (UCS)	ASTM D4219-83	NA	Yes	No
Paint Filter Liquids Test	SW 9095	NA	Yes	Yes
Specific Gravity	ASTM D34.02-025RE	ASTM 1429-76	Yes	No
pH	SW 9045	EPA 150.1	Yes	Yes
Bulk Density	(1)	(1)	Yes	No
TCLP Leach	SW 1311	---	Yes	Yes
Cadmium (ICP)	SW 3050/6010	SW 3010/6010	Yes	Yes
Beryllium (GFAA)	SW 3050/7091	SW 3020/7091	Yes	Yes
Sodium (ICP)	SW3050/6010	SW3010/6010	No	Yes
Arsenic (GFAA)	SW3050/6010	SW3020/7060	No	Yes
Chromium (ICP)	SW3050/6010	SW3010/6010	No	Yes
Lead (GFAA)	SW3050/7421	SW3020/7421	No	Yes
Nickel (ICP)	SW3050/6010	SW3010/6010	No	Yes
Sodium (ICP)	SW3050/6010	SW3010/6010	No	Yes
Nitrite/Nitrate	NA	EPA 353.2	No	Yes
Americium-241	(2)	(2)	Yes	Yes
Plutonium-239/240	(2)	(2)	Yes	Yes
Uranium-233/234	(2)	(2)	Yes	Yes
Uranium-235	(2)	(2)	Yes	Yes
Uranium-238	(2)	(2)	Yes	Yes

TABLE 2-2 (Continued)
SUMMARY OF TESTING PERFORMED ON MIXES
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Analysis	Methods		Test Performed	
	Sludges and Solids	Liquids and Extracts	WAC Phase I	WAC Phase II
Cesium-134	EPA 901.1	EPA 901.1	Yes	Yes
Cesium-137	EPA 901.1	EPA 901.1	Yes	Yes
Radium-226	EPA 903.1	EPA 903.1	Yes	Yes

(1) Agronomy No. 9 - "Methods of Soil Analysis, Part I," American Society of Agronomy, 1965.

(2) Alpha spectrometry preparation method: "Precipitation of Actinides as Fluorides or Hydroxides for High Resolution Alpha Spectrometry," Claude W. Sill, Nuclear and Chemical Waste Management, Vol. 7, pp. 201-215.
Alpha spectrometry counting reference: Digital Multiplexer Router II and instruction manual, Tennelac/Nucleus, Inc.

ASTM, 1988 "Annual Book of ASTM Standards," American Society for Testing and Materials.

EPA, 1983 "Methods for Chemical Analyses of Water and Wastes," Environmental Protection Agency, 1979, Revised March 1983.

SM, 1989 "Standard Methods for the Examination of Water and Wastewater," American Public Health Association. 17th Edition. EPA's list of approved methods (40 CFR 136) currently references the 17th edition.

SW, 1992 "Tests Methods for Evaluating Solid Waste-Physical/Chemical Methods," Environmental Protection Agency, SW846, 3rd Edition, Revised July 1992.

WAC Waste Acceptance Criteria, Phases I and II.

TCLP Toxicity Characteristic Leaching Procedure.

NA Not Applicable.

TABLE 2-3

LABORATORY EQUIPMENT SUMMARY
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Equipment	Manufacturer	Model No.	Pertinent Specifications
Mixer	Hobart	N-50	Motor Rating: 1/6 HP, 1725 RPM, Single Phase, 115V., 60 Hz, 2.85 Amps
Unconfined Compressive Strength	Geotest Instrument Corporation	S2013	Max. Load Ring = 2000 lb.
Balance	Denver Instrument Company	XD-12K	Range: 0.1 - 5,000.0 grams
Drying Oven	Fisher Scientific Isotemp® Oven	655F	Accuracy ±2°F
Stirrer (T-Line Laboratory Stirrer)	Talboys Engineering Company	134-1	NA
Temperature Gauge	Fisher Scientific Digital Thermometer	NA	-40.0 through 300°F -40.0 through 150.0°C
pH Meter	Fisher Scientific Digital pH Meter	Field Model	± 1 (non-analytical use only)

2.3.3 CSS Material Specifications

The materials used for the CSS formulas include lime, fly ash, silica flour, and cement. The Material Safety Data Sheets and product information for these additives are provided in Appendix D. These materials were submitted for radiological and metal laboratory analysis and the results are also provided in Appendix D. In addition, Stergo® was added to the pondcrete mixes to simulate onsite conditions.

The lime used was a high calcium hydrated lime manufactured by Mississippi Lime Company, St. Genevieve, Missouri. The typical specifications for a high-calcium hydrated lime are as follows:

- Specific Gravity: 2.3 to 2.4
- Bulk Density: 25 to 35 lb./cu. ft.
- Specific Heat at 100°F: 0.29 BTU/lb.
- Contains less than 5% magnesium oxide
- Contains less than 1% unhydrated oxides

The cement used for the CSS formula development is classified as Type I/II cement manufactured by Southwestern Portland Cement, Mountain Division, Lyons, Colorado. Type I/II is a general purpose cement with moderate exposure resistance to sulfate attack.

The fly ash that was used for the CSS formulas was Type C, which meets the American Society for Testing and Materials (ASTM) C618 specification. Two different sources of Type C fly ash were used, both supplied by the Western Ash Company. One was from the Comanche power plant, and the other was from the Pawnee power plant. The Pawnee fly ash was used for the majority of the testing. The two fly ashes are similar in chemical make-up and physical characteristics.

2.3.4 Solubility Considerations

Waste acceptance criteria (WAC) for various metals and radionuclides at the site are based upon the proposed Interim Measure/Interim Remedial Action (IM/IRA) closure plan which includes a cap with no lateral groundwater controls and an estimated infiltration rate of 0.0068 inches per year. A numerical model was applied to the OU4 closure to estimate the concentrations of contaminants in the leachate that are protective of human health at the point of exposure. These criteria are applied by comparing the leachability (as measured by the Toxicity Characteristic Leaching Procedure [TCLP]) of the various chemically stabilized/solidified waste sludges evaluated in this treatability study. The treated waste is deemed to be protective of human health if the TCLP leachate concentration is less than the criteria predicted by the model.

The selected CSS formulation included additions of lime, fly ash, and cement to the waste. These additives supplied alkalinity in the form of hydroxides and some carbonate to the waste mixtures in sufficient quantities to raise the pH above 12. At this pH the addition of acid in the TCLP procedure still results in the pH of the leachate in excess of 11. Leachability or contaminant mobility in this high pH matrix is tied to the solubility of various radionuclide and metal hydroxide species (Linke, W.F., 1958) and (Dean, J.A., 1979). In water chemistry, there typically exists a pH range where the speciation of certain metal hydroxides is such that the greatest portion will form an insoluble precipitate (Faust & Aly, 1983).

Optimum pH ranges for the radionuclide and metal hydroxides present in OU4 are shown in Figure 2-4. These optimum pH ranges vary by compound and are typically in the range of 8 - 12. At lower pH, there is not sufficient hydroxide concentration to create significant amounts of the insoluble compound, while above the high end of the optimum pH range, the formulation of soluble complexes tend to redissolve the insoluble precipitates (Stumm & Morgan, 1970).

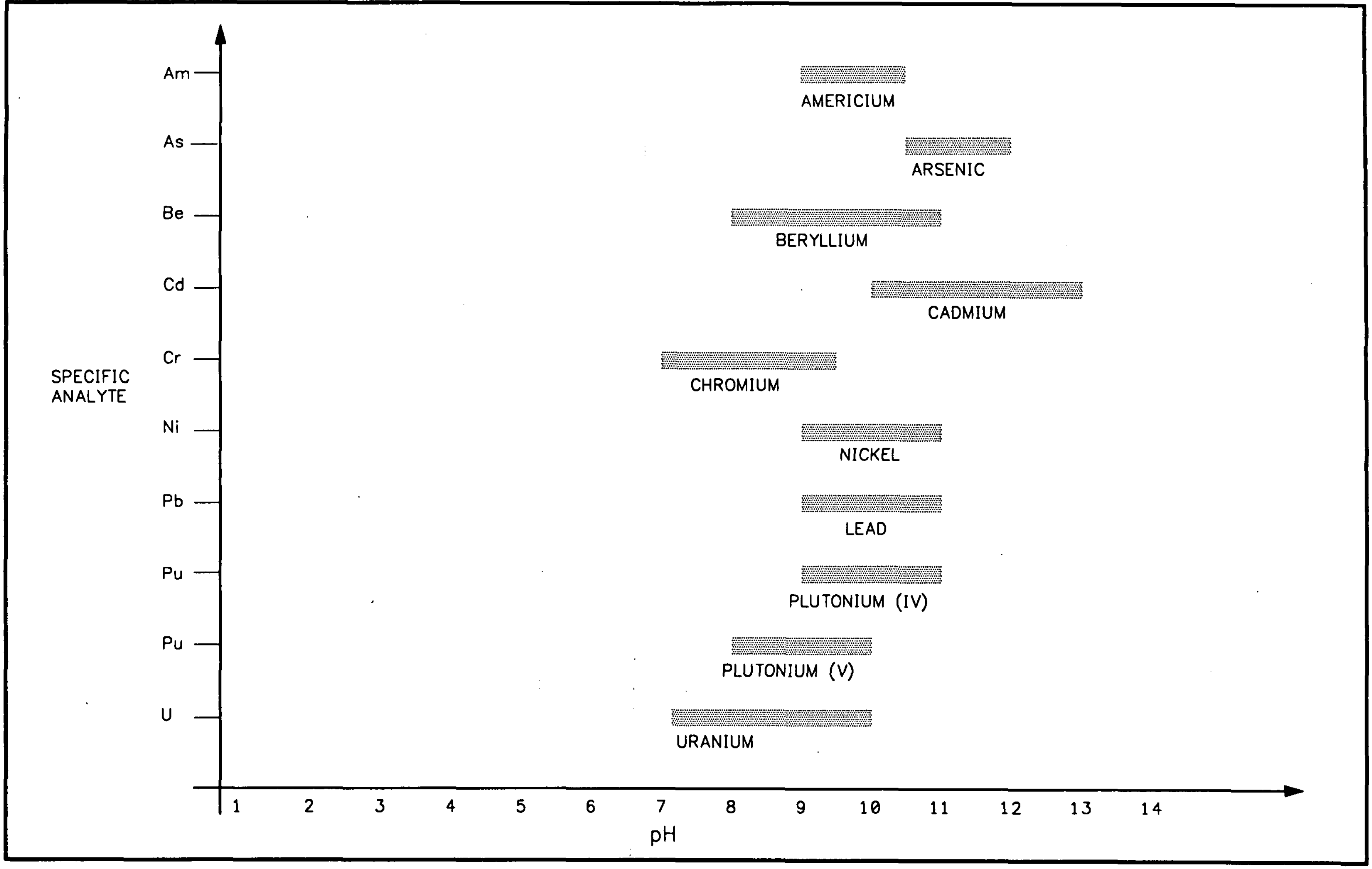
Although a problem in wastewater treatment, exceeding the high end of the optimum pH range is not a concern in the solidification/stabilization process. Because of their large size compared to free metal ions present at lower pH, most soluble complexes which tend to form are more susceptible to being chemically bound in the matrix of the solidified/stabilized material (Conner, J.R., 1990). The ability to stabilize the waste is the same whether the material is solidified into a monolith or into a friable soil-like material such as in the case at Operable Unit 4 (OU4). In addition, the ability of the cement to take up excess moisture in the final product also aids in reducing the mobility of the various radionuclides and heavy metals of concern.

2.4 PONDCRETE TREATABILITY STUDY TESTING

Pondcrete is described or defined by the type of containers in which it is stored. There are two types of pondcrete which were evaluated in this treatability study: pondcrete triwalls (PCTW), which is pondcrete stored in cardboard boxes called triwalls; and pondcrete metals (PCM), which is pondcrete in triwalls which have been placed in metal containers.

Testing performed on the pondcrete was different for each material. Pondcrete triwalls testing included a baseline evaluation of the "as received" material and TCLP leachate, a lime addition study, friable mix development (pre-WAC mixes), and WAC compliance testing, (Phase I and Phase II mixes). The pondcrete

ACAD: O:\DATA\CADD\3A23\95040701.DWG 05/08/95 VB



OPTIMUM pHs FOR PRECIPITATION
OF VARIOUS METAL HYDROXIDES
ROCKY FLATS, COLARADO

FIGURE 2-4

Halliburton NUS
CORPORATION

metals testing included a baseline evaluation of the "as received" material and TCLP leachate, friable mix development (pre-WAC mixes), and WAC compliance testing (Phase I mixes).

2.4.1 Initial Preparation and Characterization

Both PCTW and PCM material delivered to the NUS Laboratory were the consistency of a pudding or light brownish mud. The PCM material had hard chunks about 2 to 3 inches in diameter in the bottom of the buckets. The PCTW appeared to contain no chunks. The PCTW and PCM material were submitted for "as received" baseline analysis and TCLP leachate analysis.

2.4.2 Lime Addition Study

One of the waste acceptance criteria for disposal of pondcrete on site under an engineered barrier is that the treated waste cannot generate gas at a rate greater than the rate associated with native soil. Gas can be generated by the biological decomposition of organic material. Previous characterization data have shown that the pond sludges from which the pondcrete was produced contain a significant amount of organic material, measured as total organic carbon (TOC), which is available for biological decomposition by microorganisms. The average TOC concentration was 5,175 mg/kg in the clarifier sludge, which was the feed material for pondcrete. This TOC confirms the potential of the pondcrete to violate the WAC.

A study was conducted on pondcrete triwalls to assess the effectiveness of lime in stabilizing the material by elevating the pH. Considerable data are available supporting the use of lime to raise the pH to stabilize biological sludges. Most of the data are from studies conducted on the stabilization of municipal sewage sludges and septage in support of land disposal of these materials. This information is readily available from guidance documents and process design manuals published by the U.S. Environmental Protection Agency (USEPA). A brief synopsis of several documents is as follows:

- In the USEPA's Process Design Manual for Upgrading Existing Wastewater Treatment Plants (USEPA, 1974), the authors cite several studies that "have reported that the addition of lime to raw or digested sludges to pH ranges of 10.2 to 12.5 has effectively reduced the number of pathogenic organisms present. Current USEPA-sponsored work indicates that the pH should be increased to 12.0 for more effective disinfection."

- The USEPA's Process Design Manual, Wastewater Treatment Facilities for Sewered Small Communities (USEPA, 1977) states that "if the pH is raised to between 12.2 to 12.4 and then kept above 11 for 14 days, the sludge will be stabilized."

- More recent guidance contained in the USEPA's Guide to Septage Treatment and Disposal (USEPA, 1994) indicates that increasing the pH to 12 for 30 minutes meets the federal requirements for lime stabilization of septage.

Based on the references cited, it appears that achieving and maintaining a pH of 12 is sufficient to stabilize municipal sewage sludge or septage.

The goals of the lime addition study were to determine the dosage of lime needed to stabilize the pondcrete and to determine whether hydrated lime or quicklime was more advantageous. Small dosages of lime (both hydrated lime and quicklime) were incrementally added to a known quantity of the pondcrete material. Samples were collected for pH analysis and bacterial standard plate count. pH was measured during testing to ensure that pH values were obtained over the pH range from that of the raw waste to the treated pondcrete. This data was then plotted to graphically show the dosages of lime needed to achieve the target pH.

A lime addition study was performed only on PCTW because of the limited quantity of PCM. Hydrated lime [$Ca(OH)_2$] was added at 1.7%, 17%, and 33% by weight of waste material and quick lime [CaO] was added at 1.7%, 8.3%, and 17% by weight of waste material to determine the effect various dosages of lime had on the pH of the material. These samples were also submitted for bacteriological analysis (plate count).

2.4.3 Process Formulation Development

Mixes were performed to develop a process formulation and subsequent process range that achieves the established goals. Mixes performed in the friable mix development phase were used to evaluate a wide range of additives to establish a formulation that provided a friable mix. The mixes performed in the WAC compliance testing phase were used to establish a process range and to evaluate the formulas for WAC acceptance. These phases are discussed in further detail below.

2.4.3.1 Pre-WAC Friable Mix Development

The pre-WAC mixes were used to determine the approximate amount of pozzolans which need to be added to the waste to form a final product with the consistency of a friable soil. The additives selected to be evaluated were confined to those which were found successful in the 207A/B, 207C, and clarifier mixes. Those additive combinations include the following:

- Lime and Fly Ash. The lime was added at 5% by weight of the pondcrete material for all pre-WAC mixes. The pre-WAC mix using lime and fly ash added the fly ash in increments of 50 grams until a friable soil consistency was achieved.

- Lime, Fly Ash and Silica Flour. The pre-WAC mix which evaluated lime, fly ash, and silica flour added the fly ash and silica flour at a ratio of 85% to 15%, respectively, in increments of 50 grams until a friable soil was achieved.

- Lime, Fly Ash, and Cement. The third and final pre-WAC mix added fly ash and cement at a ratio of 2:1 in increments of 50 grams until the desired consistency was achieved. Physical observations were taken after each addition and recorded in the logbook.

2.4.3.2 WAC Compliance Testing

The information developed during the pre-WAC testing was then used to develop a testing range for the WAC compliance mixes.

Phase I. During this phase of the treatability study, mixes were performed to develop a range of key operating parameters for which the pondcrete material met the WAC. The PCTW material was evaluated using the three combinations of additives selected based on the pre-WAC testing. The additive combinations included:

- Lime and fly ash.
- Lime, fly ash, and silica flour.
- Lime, fly ash and cement.

The amount of lime added was 5% by weight of the PCTW material for all Phase I mixes. The ratio of the pozzolans added was 2:1 (fly ash to cement) and 5.67:1 (fly ash to silica flour). Additives were added in a combined bulk addition. To establish data for a range of potential operating conditions, the waste loading was tested at 25% total solids, 34.8% total solids, and 41.3% total solids. This gives a range which is slightly diluted, "as received," and slightly dried. One group of mixes was performed diluting the PCTW to 15% total solids, but this was determined to be an unrealistically low solids content. Therefore, these samples were not submitted for analysis. The water-to-pozzolan (W/P) ratio was also adjusted to provide data for a range of operating conditions. The ratios tested were 0.28, 0.34, and 0.40 for the lime, fly ash, cement mixes at the 15%, 25%, and 34.8% total solids, and 0.20, 0.25, and 0.30 ratios for the 41.3% total solids. The lime and fly ash mixes and the lime, fly ash, and silica flour mixes were tested at W/P ratios of 0.2, 0.25, and 0.30. A summary of the mixes performed for the PCTW is provided in Table 2-4.

The PCM material was tested using the same three additive combinations. The waste loading was only tested "as received" and slightly dried, which corresponds to 38.8% and 48.6% total solids, respectively. The mixes performed using lime and fly ash were tested at a W/P range of 0.25, 0.30, and 0.35 for the "as received" material, and 0.25, 0.35, and 1.0 for the dried material. The mixes performed using lime, fly ash, and silica flour, and lime, fly ash, and cement were performed at a W/P range of 0.35, 0.65, and 1.0. Because of damage to the mixer caused by the PCM material, mixes 1C and 6C were not able to be performed. A summary of the mixes performed for the PCM is provided in Table 2-5.

Phase II. Not all PCTW Phase I mixes successfully met the leachability criteria for protection of human health. Since the leachability of metals and radionuclides is strongly related to the pH of the TCLP extract, additional mixes were performed to look at a wider range of lime dosages. The CSS formula tested was lime, fly ash, and cement. The ranges of key parameters tested was 25% and 40% for total solids, 0.2 and 0.3 W/P ratio, and 5.0%, 7.5%, and 10.0% lime by weight of the PCTW material. A summary of the PCTW mixes is provided in Table 2-6.

It was not necessary to test PCM during Phase II since all WAC were successfully met during Phase I.

TABLE 2-4

SUMMARY OF PONDCRETE TRIWALL PHASE I WAC MIXES
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Batch Number	Date Mixed	Waste % Total Solids	Water/ Pozzolan Ratio	Lime (% by weight of waste)	Flyash/Cement/ Silica Flour Ratio
1A	02/08/95	15	0.28	5.0	2 / 1 / 0
2A	02/08/95	15	0.34	5.0	2 / 1 / 0
3A	02/08/95	15	0.40	5.0	2 / 1 / 0
4A	02/08/95	25	0.28	5.0	2 / 1 / 0
5A	02/08/95	25	0.34	5.0	2 / 1 / 0
6A	02/08/95	25	0.40	5.0	2 / 1 / 0
7A	02/08/95	34.8	0.28	5.0	2 / 1 / 0
8A	02/08/95	34.8	0.34	5.0	2 / 1 / 0
9A	02/09/95	34.8	0.40	5.0	2 / 1 / 0
10A	02/10/95	41.3	0.20	5.0	2 / 1 / 0
11A	02/10/95	41.3	0.25	5.0	2 / 1 / 0
12A	02/10/95	41.3	0.30	5.0	2 / 1 / 0
13A	02/10/95	34.8	0.20	5.0	2 / 1 / 0
1B	02/09/95	25	0.20	5.0	5.67 / 0 / 1
2B	02/09/95	25	0.25	5.0	5.67 / 0 / 1
3B	02/09/95	25	0.30	5.0	5.67 / 0 / 1
4B	02/09/95	34.8	0.20	5.0	5.67 / 0 / 1
5B	02/09/95	34.8	0.25	5.0	5.67 / 0 / 1
6B	02/09/95	34.8	0.30	5.0	5.67 / 0 / 1
7B	02/10/95	41.3	0.20	5.0	5.67 / 0 / 1
8B	02/10/95	41.3	0.25	5.0	5.67 / 0 / 1
9B	02/10/95	41.3	0.30	5.0	5.67 / 0 / 1
1C	02/09/95	25	0.20	5.0	1 / 0 / 0
2C	02/09/95	25	0.25	5.0	1 / 0 / 0
3C	02/10/95	25	0.30	5.0	1 / 0 / 0
4C	02/10/95	34.8	0.20	5.0	1 / 0 / 0
5C	02/10/95	34.8	0.25	5.0	1 / 0 / 0
6C	02/13/95	34.8	0.30	5.0	1 / 0 / 0
7C	02/13/95	41.3	0.20	5.0	1 / 0 / 0
8C	02/13/95	41.3	0.25	5.0	1 / 0 / 0
9C	02/13/95	41.3	0.30	5.0	1 / 0 / 0

Note: Mixes 7A through 9C each have 1.14 g of Stergo® additive.
The above mixes were recorded on video tape #5 entitled, "Pondcrete Triwall (PCTW) Pre-WAC and WAC Mixes."

TABLE 2-5

SUMMARY OF PONDCRETE METAL PHASE I WAC MIXES
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Batch Number	Date Mixed	Waste % Total Solids	Water/ Pozzolan Ratio	Lime (% by weight of waste)	Flyash/Cement/ Silica Flour Ratio
1A	02/20/95	38.8	0.25	5.0	1 / 0 / 0
2A	02/20/95	38.8	0.30	5.0	1 / 0 / 0
3A	02/20/95	38.8	0.35	5.0	1 / 0 / 0
4A	02/20/95	48.6	0.25	5.0	1 / 0 / 0
5A	02/20/95	48.6	1.00	5.0	1 / 0 / 0
6A	02/20/95	48.6	0.35	5.0	1 / 0 / 0
1B	02/20/95	38.8	0.35	5.0	5.67 / 0 / 1
2B	02/20/95	38.8	0.65	5.0	5.67 / 0 / 1
3B	02/20/95	38.8	1.00	5.0	5.67 / 0 / 1
4B	02/20/95	48.6	0.35	5.0	5.67 / 0 / 1
5B	02/20/95	48.6	0.65	5.0	5.67 / 0 / 1
6B	02/20/95	48.6	1.00	5.0	5.67 / 0 / 1
2C	02/21/95	38.8	0.65	5.0	2 / 1 / 0
3C	02/21/95	38.8	1.00	5.0	2 / 1 / 0
4C	02/21/95	48.6	0.35	5.0	2 / 1 / 0
5C	02/21/95	48.6	0.65	5.0	2 / 1 / 0

Note: The above mixes were recorded on video tape #6 entitled "Pondcrete Metal (PCM) Pre-WAC and WAC Mixes."

TABLE 2-6

SUMMARY OF PCTW PHASE II WAC MIXES
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Batch Number	Date Mixed	Waste % Total Solids	Water/ Pozzolan Ratio	Lime (% by weight of waste)	Flyash/Cement Ratio
1	03/21/95	25	0.20	7.5	2 / 1
2	03/21/95	25	0.30	7.5	2 / 1
3	03/21/95	40	0.20	7.5	2 / 1
4	03/21/95	40	0.30	5.0	2 / 1
5	03/21/95	40	0.30	7.5	2 / 1
6	03/21/95	40	0.30	10.0	2 / 1

Note: The above mixes were recorded on video tape #5 entitled "Pondcrete Triwalls (PCTW) Pre-WAC and WAC Mixes."

3.0 RESULTS AND DISCUSSION

These sections describe the results of the testing performed on pondcrete triwalls and pondcrete metals. Section 3.1 discusses pondcrete triwalls and Section 3.2 discusses pondcrete metals.

3.1 PONDCRETE TRIWALL RESULTS

Testing performed on pondcrete triwalls included initial characterization, a lime addition study, friable mix development (pre-WAC), and a waste acceptance criteria (WAC) evaluation, Phase I and Phase II.

3.1.1 Initial Characterization Data

The "as received" material was submitted for baseline analysis and TCLP leachate analysis. The results of the TCLP leachate analysis are used for comparison against the TCLP leachate of the CSS mixes to determine the effectiveness of the treatment process. Analysis was conducted for selected contaminants (analytes) determined to be of potential concern when the treated waste is eventually placed in the OU4 closure. A summary of the results are provided in Table 3-1.

Pondcrete Triwalls tested using TCLP to determine the leachability of the as received material indicate that plutonium-239/240 and cadmium leached at concentrations above the design WAC and the WAC associated with a 1-inch-per-year infiltration rate. Americium-241 and beryllium leached at concentrations above the WAC associated with 1-inch-per-year infiltration rate, but below the design WAC of 0.0068 inch/year infiltration.

3.1.2 Lime Addition Study

The lime addition study for pondcrete triwalls was conducted using as received materials, at approximately 34.8 percent solids. As described in Section 2.4.2, small dosages of both hydrated lime [$Ca(OH)_2$] and quicklime (CaO) were added incrementally to the pondcrete, and samples were collected for measurement of pH and bacterial plate count. As explained in Section 2.4.2, the goal of the study was to determine the dosage required to achieve a pH of 12, which is sufficient to stabilize the sludge from the perspective of reducing the bacterial population present and thus inhibit any future biological degradation of organics in the waste.

TABLE 3-1

SUMMARY OF BASELINE ANALYTICAL RESULTS
PONDCRETE TRIWALL
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample ID:		WAC for Scenario 1		Pondcrete Triwall "As Received"	Pondcrete Triwall TCLP
Sample No.:		0.0068 in/yr Infiltration	1 in/yr Infiltration	P0297078	P0297079
Date:				12/29/94	12/28/94
W/P:				NA	NA
% Solids:				34.8%	NA
Analyte	Units(1)				
Am-241	pCi/L	17,100	74.5	4600 ± 1600 pCi/g	83 ± 9
Cs-134	pCi/L	3,510,000	12,800	< 1 pCi/g	< 4
Cs-137	pCi/L	111,000	737	< 2 pCi/g	5.4 ± 1.8
Pu-238	pCi/L	NA	NA	36 ± 10 pCi/g	62 ± 16
Pu-239/240	pCi/L	1,070	4.43	1,400 ± 200 pCi/g	2,600 ± 300
Ra-226	pCi/L	117,000	415	4.1 ± 0.6 pCi/g	1.3 ± 0.4
U-233/234	pCi/L	35,200	254	16 ± 2 pCi/g	540 ± 60
U-235	pCi/L	1,410	10.2	1.1 ± 0.2 pCi/g	23 ± 10
U-238	pCi/L	24,500	177	18 ± 2 pCi/g	610 ± 70
Strontium-89	pCi/L	NA	NA	< 0.4 pCi/g	< 0.6
Strontium-90	pCi/L	NA	NA	< 0.5 pCi/g	< 0.7
Arsenic	mg/L	13.6	0.142	NA	NA
Beryllium	mg/L	1.43	0.0142	130 mg/kg	0.39
Cadmium	mg/L	5.19	0.0518	926 mg/kg	12
TCLP Extraction Fluid	--	NA	NA	NA	2
pH	Units	NA	NA	13.0	6.4 (Leachate)
Bulk Density	g/cc	NA	NA	1.45	NA

NA Not applicable.

(1) Units unless otherwise specified.

[shading] Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

A summary of the bacterial standard plate count data is presented in Table 3-2. Plots of lime dosage versus pH are presented in Figure 3-1. The initial pH of the pondcrete triwall was already 12.6, and was most likely the result of previous addition of cement, which is alkaline and subsequently raises pH. As can be seen by the data plotted on Figure 3-1, the addition of minimal dosages of both hydrated lime and quicklime resulted in a slight rise of pH from the initial pH of 12.6 to 12.8-13.0. The breakpoints occurred at dosages of less than 2 percent for both limes. It is recommended that the process operate to the right of the breakpoint on the curve so that any variations in the dosage will have minor affects on the pH. The lime dosages that achieve the stated goals are approximately two percent for both hydrated lime and for quicklime.

The standard plate count data are less useful for evaluating the effectiveness of increased pH in reducing the bacterial count due to the low plate count of aerobic and facultative bacteria observed in the untreated sample.

3.1.3 Process Formulation Development Data

This section describes the results of the friable mix development (pre-WAC) and the waste acceptance criteria testing for WAC Phase I and Phase II.

3.1.3.1 Pre-WAC Friable Mix Development Results

Testing was performed using the additives selected from the pond sludge pre-WAC testing as outlined in the "Treatability Study Report and Process Formulation Report for Ponds 207A/207B (North, Center and South), 207C, and Clarifier." These additives included lime plus fly ash, lime plus fly ash and silica flour, and lime plus fly ash and cement. The pondcrete triwall pre-WAC phase was used to determine the approximate quantity of these additives required to achieve a friable mix. The results of these mixes are summarized in Table 3-3.

The results indicated that a friable product could be achieved using the three selected additives. Compared to the previously tested pond sludge material (207A/B and 207C) a relatively low water/pozzolan ratio (approximately 0.2) was required. This indicates that extra pozzolan is needed to react with the free water in the short mixing time.

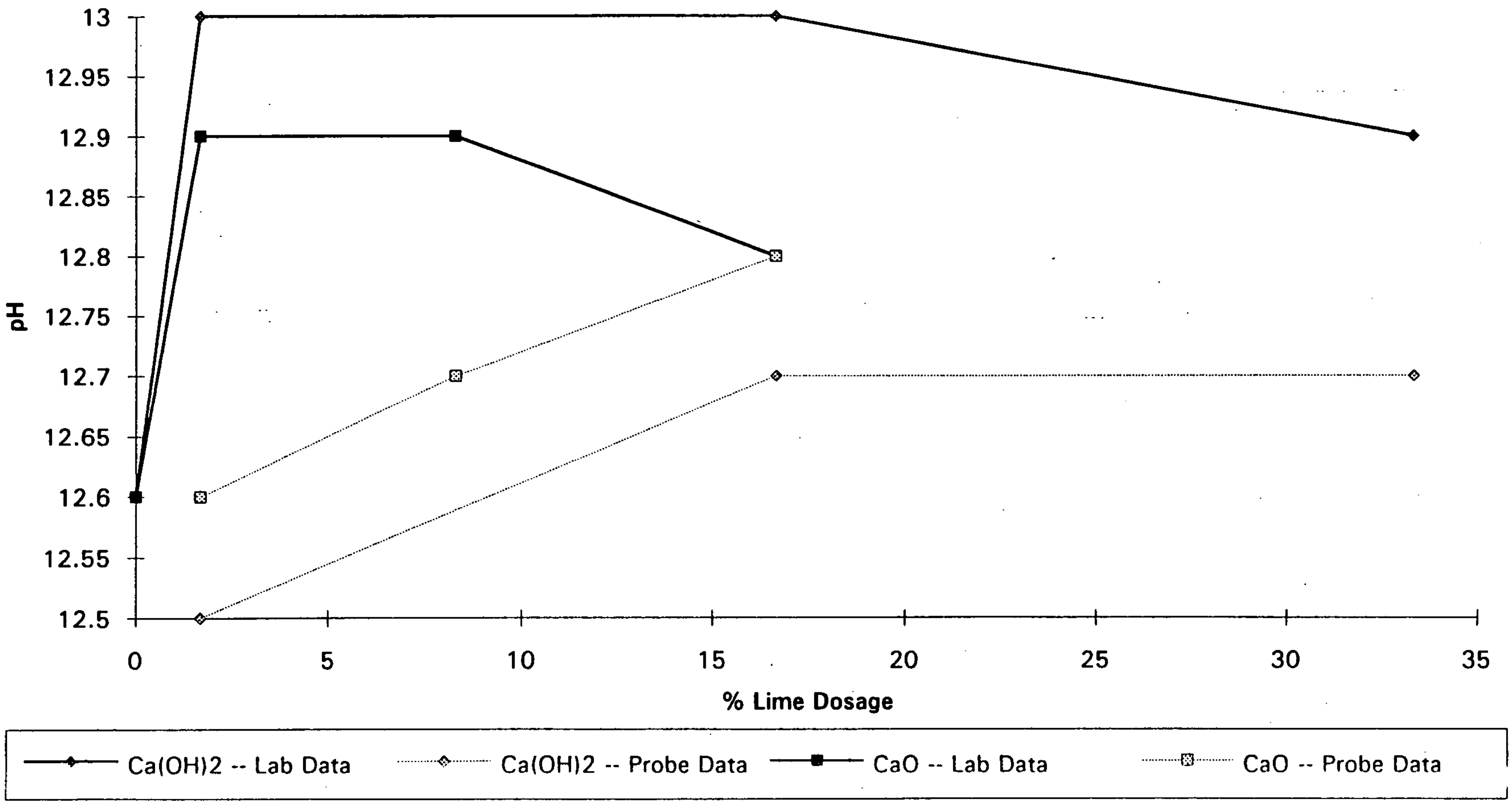
TABLE 3-2

SUMMARY OF BACTERIOLOGY RESULTS FOR THE LIME ADDITION STUDY
PONDCRETE TRIWALLS MATERIAL
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample Number	Lime Addition (g)	% Lime Addition by Weight (%)	Type of Lime	Amount of Material (g)	Plate Count
25	0	0	NA	300	<1000
26	5	1.7	$Ca(OH)_2$	300	<1000
27	50	17	$Ca(OH)_2$	300	<1000
28	100	33	$Ca(OH)_2$	300	<1000
29	5	1.7	CaO	300	<1000
30	25	8.3	CaO	300	<1000
31	50	17	CaO	300	<1000

NA Not applicable, no lime added.

Figure 3-1
Rocky Flats Treatability Study
Lime Addition Study for PCTW
Rocky Flats, Colorado



- Probe Data -- pH check performed in Treatability Lab using field pH instrument
- Lab Data -- pH value received from Inorganic Lab following full QA/QC procedures

LIMEPCTW.XLC

TABLE 3-3

SUMMARY OF PRE-WAC MIXES
PONDCRETE TRIWALLS MATERIAL
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives	Additive Weight Ratios	W/P	Bulk Volumetric Increase: Not Compacted	Bulk Volumetric Increase: Compacted	Temperature Increase	Observations
1	PCTW 250 g $Ca(OH)_2$ 12.5 g Fly ash 800 g	1 0.05 3.2	0.20	4.7 X	N/A	63.7°F → 64.5°F	Pellets, small, round and hard. Able to break with finger pressure.
2	PCTW 250 g $Ca(OH)_2$ 12.5 g Fly ash 681 g Silica Flour 120 g	1 0.05 2.72 0.48	0.20	4.7 X	N/A	62.4°F → 64.0°F	Pellets, round, hard. Poured out of mixing bowl. Able to break pellets with finger pressure.
3	PCTW 250 g $Ca(OH)_2$ 12.5 g Fly ash 480 g Cement 240 g	1 0.05 1.92 0.90	0.22	4.5 X	N/A	62.5°F → 63.8°F	Round hard pellets. Note: chunks or smooth balls formed back at a W/P ratio of 0.29.

Note: Lime mixed into sludge and allowed to react before the addition of other additive(s).

N/A Not available. Hard pellets formed, therefore did not attempt vibration compaction (tamping on table top).

3.1.3.2 WAC Compliance Testing Results

Phase I. Based on the results of the pre-WAC testing, additional testing was performed to determine WAC compliance over the anticipated operating ranges for waste loading and water-to-pozzolan ratio (W/P). A summary of the mixes performed using lime, fly ash, and cement is provided in Table 3-4. A summary of the mixes performed using lime, fly ash, and silica flour is provided in Table 3-5. A summary of the mixes performed using lime and fly ash is provided in Table 3-6. Several of the mixes included STERGO, an adsorbent material, which is currently being added to the pondcrete as part of the repackaging effort.

The samples were submitted for analysis and the results of the mixes prepared using lime, fly ash, and cement are presented in Table 3-7. The mixes prepared using lime, fly ash, and silica flour are presented in Table 3-8. The mixes prepared using lime and fly ash are presented in Table 3-9. The TCLP leachate data were plotted against pH and are provided in Appendix G.

The data shown on Tables 3-7 through 3-9 indicate that some of the analytes are leachable under certain conditions. In all cases where the TCLP extract pH was above 6.5, none of the leachate concentrations exceeded the concentrations for the design (0.0068 in/yr. infiltration) WAC. In three cases where the TCLP extract pH dropped below 6.5, cadmium leached at concentrations which exceeded the 1-inch-per-year WAC concentrations. Thirteen of the 31 mixes performed had analyte leachate concentrations which exceeded the 1-inch-per-year WAC concentration. The WAC concentrations based on 1-inch-per-year infiltration through the OU4 closure are considered worst-case conditions, while the WAC concentrations based on the 0.0068-inch-per-year infiltration through the OU4 closure are based on the current closure design and assume no degradation of the cap.

The graphs of pH versus TCLP leachate concentration, in Appendix G, are useful for determining the relationship between pH and leachate concentration. The isotopic uranium data shows that as the pH drops below 7.0, the concentration in the leachate increases. Cadmium concentrations in the leachate increase as the pH of the leachate decreases to below 8.0. Nitrate/nitrite leached at concentrations exceeding the WAC concentration, although this phenomenon is not related to pH.

Phase II. Phase II WAC compliance tests were required to demonstrate compliance with the leachability criteria, which was not consistently demonstrated during Phase I. For the Phase II WAC compliance tests, the lime, fly ash, and cement additive combination was selected as the preferred formulation. The lime, fly ash, and cement mixture consistently resulted in higher TCLP extract pH compared to the lime and fly ash mixture. A higher pH is more favorable for reducing leachate concentrations. Based on the Phase I results, the fly ash and silica flour formulation offered no advantage compared to the lime, fly ash, and cement

TABLE 3-4

SUMMARY OF WAC PHASE I MIXES
PCTW (ADDITIVES: LIME, FLY ASH AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives	Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
				Not Compacted	Compacted		
1A	PCTW sludge @ 15% Solids 400 g $Ca(OH)_2$ 20 g Cement 405 g Fly ash 810 g	1 0.05 1.01 2.02	0.28	N/A *	2.6 X	> 637 psi	After 30 seconds of mixing made a clay or moist bread dough consistency which turned into a final product of cake icing. Did not submit for analysis because determined PCTW at 15% solids is out of waste loading range. WET MIX.
2A	PCTW sludge @ 15% Solids 400 g $Ca(OH)_2$ 20 g Cement 333 g Fly ash 667 g	1.0 0.05 0.83 1.67	0.34	N/A *	2.3 X	> 637 psi	Immediately formed a clay ball which turned to cake icing after 30 seconds. Final product a moist cake icing. Did not submit for analysis because determined PCTW at 15% solids is out of processing range. WET MIX.
3A	PCTW sludge @ 15% Solids 400 g $Ca(OH)_2$ 20 g Cement 283 g Fly ash 567 g	1.0 0.05 0.71 1.42	0.40	N/A *	2.1 X	> 637 psi	This produced a very wet clay mix. Did not submit for analysis because determined PCTW at 15% solids is out of processing range. WET MIX.
4A	PCTW sludge @ 25% Solids 400 g $Ca(OH)_2$ 20 g Cement 357 g Fly ash 714 g	1.0 0.05 0.89 1.79	0.28	N/A **	2.6 X	> 637 psi	Produced a final product with the consistency of cake icing. WET MIX.
5A	PCTW sludge @ 25% Solids 400 g $Ca(OH)_2$ 20 g Cement 294 g Fly ash 588 g	1.0 0.05 0.74 1.47	0.34	N/A **	2.1 X	> 637 psi	Produced a final product which was a wet monolithic mix, the consistency of a wet clay. WET MIX.
6A	PCTW sludge @ 25% Solids 400 g $Ca(OH)_2$ 20 g Cement 250 g Fly ash 500 g	1.0 0.05 0.62 1.25	0.40	N/A **	2.0 X	> 637 psi	Produced a final product which was a monolithic clay. WET MIX.

TABLE 3-4 (Continued)
SUMMARY OF WAC PHASE I MIXES
PCTW (ADDITIVES: LIME, FLY ASH AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
7A	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 311 g 621 g 1.14 g	1 0.05 0.78 1.55 0.003	0.28	4.6 X	3.5 X	0 psi	Produced a final product with the consistency of clay, monolithic. WET MIX.
8A	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 256 g 512 g 1.14 g	1.0 0.05 0.64 1.28 0.003	0.34	4.3 X	3.2 X	395 psi	Produced a final product of a clay. Monolith. WET MIX.
9A	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 218 g 435 g 1.14 g	1.0 0.05 0.55 1.09 0.003	0.40	N/A *	2.0 X	> 637 psi	After one minute produced large clay clumps with heavy packing on sides of bowl. Final product a stiff clay or bread dough. GOOD MIX, SLIGHTLY WET.
10A	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 391 g 782 g 1.14 g	1.0 0.05 0.98 1.96 0.003	0.20	7.2 X	5.0 X	89.8 psi	Produced a final product of a moist powder, some packing on sides of bowl. DRY MIX.
11A	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 313 g 626 g 1.14 g	1.0 0.05 0.78 1.56 0.003	0.25	6.3 X	3.8 X	62.4 psi	Produced a final product of a moist powder, some packing occurred. DRY MIX.

TABLE 3-4 (Continued)
SUMMARY OF WAC PHASE I MIXES
PCTW (ADDITIVES: LIME, FLY ASH AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
12A	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 261 g 522 g 1.14 g	1.0 0.05 0.65 1.30 0.003	0.30	5.3 X	3.2 X	86.3 psi	Final product a moist powder. Mix had some packing of material on side of bowl. DRY MIX.
13A	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Cement Fly ash STERGO®	400 g 20 g 435 g 870 g 1.14 g	1.0 0.05 1.09 2.18 0.003	0.20	7.4 X	4.9 X	73.6 psi	Final product a moist powder. Some packing on sides of bowl occurred. DRY MIX.

N/A * Too much moisture to allow for uncompacted cake.
N/A ** Clay-like material - could only do packed volume.

TABLE 3-5

SUMMARY OF WAC PHASE I MIXES
PCTW SLUDGE (ADDITIVES: LIME, FLY ASH, AND SILICA FLOUR)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
1B	PCTW sludge @ 25% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 1275 g 225 g 1.14 g	1.0 0.05 3.18 0.56 0.003	0.20	6.2 X	3.8 X	51 psi	This mix produced a moist powder. The product formed a hard pack on the sides of the bowl. Final product a moist powder. DRY MIX.
2B	PCTW sludge @ 25% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 1020 g 180 g 1.14 g	1.0 0.05 2.55 0.45 0.003	0.25	5.2 X	2.7 X	201 psi	After 1 minute of mixing the product went from a moist powder to large clay clump. After 2 minutes, went to a medium-curd-size friable soil (worm dirt). Final product a clumpy dry clay mix. GOOD MIX.
3B	PCTW sludge @ 25% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 850 g 150 g 1.14 g	1.0 0.05 2.12 0.38 0.003	0.30	N/A	2.3 X	>637 psi	After 30 seconds a heavy pack on sides of bowl with clay clumps in center. After 1 minute mixing formed bread dough. Final product is a stiff clay. GOOD MIX, SLIGHTLY WET.
4B	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 1109 g 196 g 1.14 g	1.0 0.05 2.77 0.49 0.003	0.20	6.6 X	3.3 X	39 psi	Final product a moist powder. DRY MIX.
5B	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 887 g 157 g 1.14 g	1.0 0.05 2.22 0.39 0.003	0.25	5.6 X	3.8 X	0 psi	This mix formed a heavy pack of material on sides of bowl. The final product was a moist powder. DRY MIX.

TABLE 3-5 (Continued)

SUMMARY OF WAC PHASE I MIXES
PCTW SLUDGE (ADDITIVES: LIME, FLY ASH, AND SILICA FLOUR)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
6B	PCTW sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 740 g 130 g 1.14 g	1.0 0.05 1.85 0.33 0.003	0.30	4.3 X	3.0 X	90 psi	Final product a moist powder. DRY MIX.
7B	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 998 g 176 g 1.14 g	1.0 0.05 2.50 0.44 0.003	0.20	7.7 X	4.3 X	0 psi	Final product formed a moist powder. DRY MIX.
8B	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 798 g 141 g 1.14 g	1.0 0.05 2.00 0.35 0.003	0.25	6.1 X	3.4 X	126 psi	Final product formed a moist powder. DRY MIX.
9B	PCTW sludge @ 41.3% Solids $Ca(OH)_2$ Fly ash Silica Flour STERGO®	400 g 20 g 665 g 117 g 1.14 g	1.0 0.05 1.66 0.29 0.003	0.30	5.3 X	3.5 X	0 psi	Final product formed a moist powder. DRY MIX.

N/A No loose form since additions resulted in a stiff clay.

TABLE 3-6

SUMMARY OF WAC PHASE I MIXES
PCTW SLUDGE (ADDITIVES: LIME AND FLY ASH)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48 Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
1C	PCTW Sludge @ 25% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1500 g 1.14 g	1.0 0.05 3.75 0.003	0.20	5.9 X	4.0 X	69 psi	Final product produced was a moist powder. DRY MIX.
2C	PCTW Sludge @ 25% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1200 g 1.14 g	1.0 0.05 3.00 0.003	0.25	4.7 X	2.3 X	513 psi	After 30 seconds of mixing produced clay clumps and packing on side of bowl. After 1.5 minutes, became a cookie dough. Final product consistency of bread dough, but dry like a friable soil. GOOD MIX.
3C	PCTW Sludge @ 25% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1000 g 1.14 g	1.0 0.05 2.50 0.003	0.30	N/A	2.4 X	>637 psi	After 30 seconds produced a clumps soil or worm dirt approximately 1 inch in diameter. After 1 minute, consistency of bread dough which turned to cookie dough. Final product a stiff pasty clay. After 4-hour cure, became hard. GOOD MIX, SLIGHTLY WET.
4C	PCTW Sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1305 g 1.14 g	1.0 0.05 3.26 0.003	0.20	7.1 X	3.9 X	36.3 psi	Produced a moist powder. DRY MIX.
5C	PCTW Sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1044 g 1.14 g	1.0 0.05 2.61 0.003	0.25	5.3 X	3.2 X	166.2 psi	Produced a moist powder. DRY MIX.
6C	PCTW Sludge @ 34.8% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 870 g 1.14 g	1.0 0.05 2.18 0.003	0.30	4.6 X	2.8 X	155 psi	After 1.5 minutes mixing, a hard pack on sides of bowl formed. Moist powder was final product. DRY MIX.

TABLE 3-6 (Continued)
SUMMARY OF WAC PHASE I MIXES
PCTW SLUDGE (ADDITIVES: LIME AND FLY ASH)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
7C1	PCTW Sludge @ 43.3% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 1134 g 1.14 g	1.0 0.05 2.84 0.003	0.20	7.1 X	4.4 X	0 psi	Final product a moist powder. DRY MIX.
7C2	PCTW Sludge @ 43.3% Solids $Ca(OH)_2$ Fly ash STERGO®	300 g 20 g 134 g 1.14 g	1.0 0.07 0.45 0.004	1.12	3.6 X	1.8 X	111 psi	Immediately formed large clay clumps which turned to cake icing, then to a friable soil or worm dirt for a final product. GOOD MIX.
8C	PCTW Sludge @ 43.3% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 907 g 1.14 g	1.0 0.05 2.27 0.003	0.25	6.1 X	3.4 X	0 psi	Final product a moist powder. DRY MIX.
9C	PCTW Sludge @ 43.3% Solids $Ca(OH)_2$ Fly ash STERGO®	400 g 20 g 756 g 1.14 g	1.0 0.05 1.89 0.003	0.30	5.2 X	3.2 X	77.4 psi	Final product a moist powder. DRY MIX.

N/A No loose form since additions resulted in a stiff clay.

TABLE 3-7
WAC PHASE I ANALYTICAL RESULTS
PCTW MIXES (ADDITIVES: LIME, FLY ASH, AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

	Sample ID:	WAC for Scenario 1		4A-PCTW	5A-PCTW	6A-PCTW	7A-PCTW	8A-PCTW	9A-PCTW	10A-PCTW	11A-PCTW	12A-PCTW	13A-PCTW
	Sample No.:	0.0068 in/yr Infiltration	1 in/yr Infiltration	P0300818 P0300817	P0300819	P0300821 P0300820	P0300823 P0300822	P0300824	P0301004 P0301003	P0301069 P0301068	P031070	P031072 P031071	P0301074 P0301073
	Date:			02/08/95	02/08/95	02/08/95	02/08/95	02/08/95	02/09/95	02/10/95	02/10/95	02/10/95	02/10/95
	W/P:			0.28	0.34	0.40	0.28	0.34	0.40	0.20	0.25	0.30	0.20
	% Solids:			25%	25%	25%	34.8%	34.8%	34.8%	41.3%	41.3%	41.3%	34.8%
Analyte	Units												
Am-241	pCi/L	17,100	74.5	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Cs-134	pCi/L	3,510,000	12,800	< 6	NS	< 4	< 6	NS	< 4	< 5	NS	< 5	< 5
Cs-137	pCi/L	111,000	737	5.5 ± 2.2	NS	< 5	6.0 ± 2.3	NS	< 5	< 5	NS	4.0 ± 1.9	< 6
Pu-239/240	pCi/L	1,070	4.43	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Ra-226	pCi/L	117,000	415	0.4 ± 0.1	NS	0.1 ± 0.1	0.3 ± 0.1	NS	0.2 ± 0.1	0.3 ± 0.1	NS	< 0.2	0.4 ± 0.1
U-233/234	pCi/L	35,200	254	55 ± 6	NS	65 ± 7	0.68 ± 0.29	NS	0.6 ± 0.3	0.32 ± 0.21	NS	0.20 ± 0.10	0.11 ± 0.07
U-235	pCi/L	1,410	10.2	2.2 ± 0.5	NS	3.1 ± 0.6	<0.2	NS	0.12 ± 0.12	<0.1	NS	0.07 ± 0.05	0.041 ± 0.040
U-238	pCi/L	24,500	177	60 ± 6	NS	72 ± 8	0.49 ± 0.25	NS	0.54 ± 0.25	0.54 ± 0.24	NS	0.27 ± 0.11	0.12 ± 0.08
Arsenic	mg/L	13.6	0.142	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Beryllium	mg/L	1.43	0.0142	<0.0006*	NS	<0.0006*	<0.0007*	NS	<0.0006*	<0.0006*	NS	<0.0006*	<0.0007*
Cadmium	mg/L	5.19	0.0518	0.24	NS	0.21	0.05	NS	<0.005	<0.005	NS	<0.005	0.006
Chromium	mg/L	142	0.881	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Nitrate/Nitrite	mg/L	15,900	166	76	NS	91	130	NS	140	94	NS	180	75
Sodium	mg/L	1,750	14.9	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
TCLP Extraction Fluid	NA	NA	NA	2	NS	2	2	NS	2	2	NS	2	2
Final Leachate pH	Units	NA	NA	7.2	NS	7.2	8.6	NS	8.2	9.2	NS	9.6	9.5
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0	0	0	0	0
Bulk Density	g/cc	NA	NA	1.31	1.27	1.22	1.07	1.08	1.29	1.03	1.00	1.04	1.05

Note: Mixes 1A-PCTW, 2A-PCTW, and 3A-PCTW not submitted for analysis.
*Results determined by a single-point method of standard additions.

NA Not Applicable
NS Not Submitted for analysis
NT Not Tested for this analyte

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

TABLE 3-8

WAC PHASE I ANALYTICAL RESULTS
PCTW MIXES (ADDITIVES: LIME, FLY ASH, AND SILICA FLOUR)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample ID:		WAC for Scenario 1		1B-PCTW	2B-PCTW	3B-PCTW	4B-PCTW	5B-PCTW	6B-PCTW	7B-PCTW	8B-PCTW	9B-PCTW	6Dup.-
Sample No.:		0.0068 in/yr Infiltration	1 in/yr Infiltration	P0301006 P0301005	P0301007	P0301009 P0301008	P0301011 P0301010	P0301012	P0301014 P0301013	P0301076 P0301075	P0301077	P0301079 P0301078	P0301418
Date:				02/09/95	02/09/95	02/09/95	02/09/95	02/09/95	02/09/95	02/10/95	02/10/95	02/10/95	02/17/95
W/P:				0.20	0.25	0.30	0.20	0.25	0.30	0.20	0.25	0.30	0.20
% Solids:				25%	25%	25%	34.8%	34.8%	34.8%	41.3%	41.3%	41.3%	34.8%
Analyte	Units												
Am-241	pCi/L	17,100	74.5	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Cs-134	pCi/L	3,510,000	12,800	< 4	NS	< 4	< 4	NS	< 6	< 5	NS	< 7	< 6
Cs-137	pCi/L	111,000	737	< 5	NS	< 5	< 4	NS	5.6 ± 2.1	< 5	NS	< 7	< 7
Pu-239/-240	pCi/L	1,070	4.43	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Ra-226	pCi/L	117,000	415	<0.1	NS	<0.2	<0.2	NS	<0.1	0.2 ± 0.1	NS	0.3 ± 0.1	<0.1
U-233/-234	pCi/L	35,200	254	5.3 ± 0.8	NS	5.3 ± 0.8	2.8 ± 0.5	NS	11 ± 2	53 ± 8	NS	190 ± 20	0.12 ± 0.08
U-235	pCi/L	1,410	10.2	0.38 ± 0.21	NS	0.4 ± 0.2	<0.3	NS	0.61 ± 0.29	3.5 ± 2.0	NS	7.2 ± 1.1	0.043 ± 0.042
U-238	pCi/L	24,500	177	4.2 ± 0.7	NS	4.2 ± 0.7	3.8 ± 0.7	NS	14 ± 2	65 ± 9	NS	210 ± 30	0.10 ± 0.06
Arsenic	mg/L	13.6	0.142	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Beryllium	mg/L	1.43	0.0142	<0.0006*	NS	<0.0006*	<0.0006*	NS	<0.0006*	<0.002**	NS	<0.002**	0.013
Cadmium	mg/L	5.19	0.0518	<0.005	NS	0.015	0.046	NS	0.042	2.0	NS	4.2	5.6
Chromium	mg/L	142	0.881	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
Nitrate/Nitrite	mg/L	15,900	166	120	NS	91	130	NS	110	120	NS	160	73
Sodium	mg/L	1,750	14.9	NT	NS	NT	NT	NS	NT	NT	NS	NT	NT
TCLP Extraction Fluid	N/A	NA	NA	2	NS	2	2	NS	2	2	NS	2	2
Final Leachate pH	Units	NA	NA	9.4	NS	8.8	7.9	NS	6.8	7.1	NS	6.4	6.4
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0	0	0	0	NA
Bulk Density	g/cc	NA	NA	1.04	1.18	1.28	1.07	1.01	1.06	1.00	1.03	1.06	NA

(1) QA/QC field duplicate mix of 020995-4B-PCTW
* Result determined by a single-point method of standard additions.
** Elevated detection limit reported due to sample matrix interference.

NA Not Applicable
NS Not Submitted for analysis
NT Not Tested for this analyte

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

TABLE 3-9

WAC PHASE I ANALYTICAL RESULTS
PCTW MIXES (ADDITIVES: LIME AND FLY ASH)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample ID:		WAC for Scenario 1		1C-PCTW	2C-PCTW	3C-PCTW	4C-PCTW	5C-PCTW	6C-PCTW	7C-1-PCTW	7C-2-PCTW	8C-PCTW	9C-PCTW	7Dup-(1)
Sample No.:		0.0068 in/yr Infiltration	1 in/yr Infiltration	P0301015 P0301016	P0301017	P0301080 P0301081	P0301082 P0301083	P0301084	P0301147 P0301148	P0301149 P0301150	P0301151 P0301152	P0301153	P0301154 P0301155	P0301419
Date:				02/09/95	02/09/95	02/10/95	02/10/95	02/10/95	02/13/95	02/13/95	02/13/95	02/13/95	02/13/95	02/17/95
W/P:				0.20	0.25	0.30	0.20	0.25	0.30	0.20	1.48	0.25	0.30	0.20
% Solids:				25%	25%	25%	34.8%	34.8%	34.8%	43.3%	43.3%	43.3%	43.3%	34.8%
Analyte	Units													
Am-241	pCi/L	17,100	74.5	NT	NS	NT	NT	NS	NT	NT	NT	NS	NT	NT
Cs-134	pCi/L	3,510,000	12,800	<6	NS	< 4	< 6	NS	< 7	< 7	< 5	NS	< 6	< 6
Cs-137	pCi/L	111,000	737	4.4 ± 2.1	NS	< 4	< 6	NS	< 7	< 7	4.8 ± 2.2	NS	< 7	< 7
Pu-239/-240	pCi/L	1,070	4.43	NT	NS	NT	NT	NS	NT	NT	NT	NS	NT	NT
Ra-226	pCi/L	117,000	415	<0.1	NS	<0.1	NT(2)	NS	0.7 ± 0.1	<0.2	0.4 ± 0.1	NS	0.7 ± 0.1	1.1 ± 0.2
U-233/-234	pCi/L	35,200	254	0.36 ± 0.21	NS	24 ± 3	780 ± 80	NS	98 ± 10	5.5 ± 0.8	2100 ± 220	NS	80 ± 8	44 ± 5
U-235	pCi/L	1,410	10.2	<0.1	NS	1.2 ± 0.4	36 ± 6	NS	4.5 ± 0.7	0.4 ± 0.24	95 ± 14	NS	4.7 ± 0.8	1.2 ± 0.5
U-238	pCi/L	24,500	177	0.25 ± 0.16	NS	29 ± 3	890 ± 90	NS	110 ± 20	5.7 ± 0.9	2600 ± 260	NS	94 ± 10	46 ± 5
Arsenic	mg/L	13.6	0.142	NT	NS	NT	NT	NS	NT	NT	NT	NS	NT	NT
Beryllium	mg/L	1.43	0.0142	<0.0005	NS	0.0008*	1.1	NS	0.0035	< 0.0007*	1.6	NS	0.0021*	0.0019*
Cadmium	mg/L	5.19	0.0518	<0.005	NS	1.2	8.0	NS	4.3	0.71	24	NS	3.2	3.1
Chromium	mg/L	142	0.881	NT	NS	NT	NT	NS	NT	NT	NT	NS	NT	NT
Nitrate/Nitrite	mg/L	15,900	166	47	NS	55	83	NS	150	150	370	NS	200	81
Sodium	mg/L	1,750	14.9	NT	NS	NT	NT	NS	NT	NT	N	NS	NT	NT
TCLP Extraction Fluid	NA	NA	NA	2	NS	2	2	NS	2	2	2	NS	2	2
Final Leachate pH	Units	NA	NA	9.6	NS	7.3	5.3	NS	6.7	7.0	5.6	NS	6.7	6.3
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0	0	0	0	0	NA
Bulk Density	g/cc	NA	NA	1.06	1.17	1.28	1.01	1.07	1.02	1.01	1.00	1.03	1.06	NA

(1) QA/QC field duplicate mix of 021995-4C-PCTW
(2) Sample interferance presented accurate results - method could not be run

NA - Not Applicable
NS - Not Submitted for analysis
NT - Not Tested for this analyte

*Result determined by a single-point method of standard additions.

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

formulation. In addition, the lime, fly ash, and cement formulation has been demonstrated to be successful in previous treatability studies with the 207A/B material which has chemical properties similar to pondcrete (HNUS, 1992c).

Phase II involved a series of tests that were performed at the high and low W/P ratios identified from Phase I, with different lime dosages to test compliance with leachability criteria. A summary of the mixes performed is provided in Table 3-10. A summary of the analytical results are provided in Table 3-11. Graphs plotting the TCLP extract concentrations vs. extract pH are provided in Appendix G.

The TCLP leachate results for the pondcrete triwalls provided in Table 3-11 are compared to the WAC. Two WAC were established, one is associated with the design infiltration rate of 0.0068 inches per year and the other is associated with a greater infiltration rate of 1 inch per year. The development of the WAC are discussed in Appendix B.

All analytes leached at concentrations less than the design WAC concentrations. All analytes also leached at concentrations less than the 1-inch-per-year WAC concentrations with the exception of sodium. Sodium leached in all of the mixes at concentrations in excess of this more stringent WAC and ranged from 280 mg/l to 530 mg/l. As shown on Table 3-11, the TCLP extracts were also analyzed for lead and nickel during this phase of testing to determine compliance with applicable LDR standards. These data, together with the data for cadmium and chromium, show that the selected mix of lime, fly ash, and cement meets the LDR standards applicable to pondcrete.

The figures provided in Appendix G indicate that the increase in the lime dosage from 5 percent to 7.5 percent resulted in an increase in the TCLP leachate pH. The leachate pH for the Phase II mixes ranged from 10.8 to 11.7 Standard Units (SU) as shown on Figure G-2A. Minimal relationship between TCLP leachate pH and concentrations of contaminants can be distinguished from the figures shown in Appendix G. This observation is because of the high pH ranges which resulted in low leachate concentrations (near detection limits) for the analytes. Sodium leachate concentrations are not dependent on pH.

3.2 PONDCRETE METAL RESULTS

Testing performed on pondcrete metals included an initial characterization, friable mix development (pre-WAC), and a waste criteria acceptance (WAC Phase I) evaluation.

TABLE 3-10

SUMMARY OF WAC PHASE II MIXES
PCTW (ADDITIVES: LIME, FLY ASH, AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Observations
1	PCTW Sludge @ 25% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	400 g 30 g 999 g 499 g 1.14 g	1.0 0.075 2.50 1.25 0.003	0.20	N/A
2	PCTW Sludge @ 25% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	400 g 30 g 666 g 333 g 1.14 g	1.0 0.075 1.67 0.83 0.003	0.30	N/A
3	PCTW Sludge @ 40% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	300 g 22.5 g 600 g 300 g 0.86 g	1.0 0.075 2.0 1.0 0.003	0.20	N/A
4	PCTW Sludge @ 40% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	300 g 15 g 400 g 200 g 0.86 g	1.0 0.05 1.33 0.67 0.003	0.30	N/A
5	PCTW Sludge @ 40% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	300 g 22.5 g 400 g 200 g 0.86 g	1.0 0.075 1.33 0.67 0.003	0.30	N/A
6	PCTW Sludge @ 40% Solids $Ca(OH)_2$ Fly ash, Type C Cement, Type I/II STERGO®	300 g 30 g 400 g 200 g 0.86 g	1.0 0.10 1.33 0.67 0.003	0.30	N/A

TABLE 3-11

WAC PHASE II ANALYTICAL RESULTS
PCTW (ADDITIVES: LIME, FLY ASH, AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

	Sample ID:	WAC for Scenario 1		#1-PCTW	#2-PCTW	#3-PCTW	#4-PCTW	#5-PCTW	#6-PCTW
	Sample No.:	0.0068 in/yr Infiltration	1 in/yr Infiltration	P0304313 P0304314	P0304315 P0304316	P0304317 P0304318	P0304319 P0304320	P0304321 P0304322	P0304323 P0304234
	Date:			03/21/95	03/21/95	03/21/95	03/21/95	03/21/95	03/21/95
	W/P:			0.20	0.30	0.20	0.30	0.30	0.30
	% Solids:			25	25	40	40	40	40
Analyte	Units								
Am-241	pCi/L	17,100	74.5	< 0.6	< 0.3	< 0.3	< 0.3	< 0.2	< 0.4
Cs-134	pCi/L	3,510,000	12,800	< 6	< 5	< 6	< 5	< 4	< 7
Cs-137	pCi/L	111,000	737	< 6	< 6	< 6	< 6	< 4	< 6
Pu-238	pCi/L	NA	NA	< 0.03	< 0.2	< 0.2	< 0.08	< 0.03	< 0.1
Pu-239/240	pCi/L	1,070	4.43	< 0.03	< 0.03	< 0.2	0.039 ± 0.038	< 0.08	< 0.03
Ra-226	pCi/L	117,000	415	1.7 ± 0.2	0.2 ± 0.1	< 0.1	< 0.2	1.6 ± 0.2	4.6 ± 0.5
U-233/234	pCi/L	35,200	254	0.031 ± 0.036	0.070 ± 0.052	0.082 ± 0.057	< 0.03	< 0.08	0.029 ± 0.033
U-235	pCi/L	1,410	10.2	< 0.03	< 0.03	<0.03	< 0.08	< 0.03	<0.03
U-238	pCi/L	24,500	177	0.042 ± 0.041	< 0.1	< 0.08	0.062 ± 0.050	0.029 ± 0.033	0.029 ± 0.033
Arsenic	mg/L	13.6	0.142	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Beryllium	mg/L	1.43	0.0142	<0.0005	<0.0005	<0.0006*	<0.0005	<0.0005	<0.0005
Cadmium	mg/L	5.19	0.0518	< 0.005	< 0.005	< 0.005	< 0.005	< 0.01**	< 0.005
Chromium	mg/L	142	0.881	0.12	0.13	0.34	0.36	0.15	0.09
Nitrate/Nitrite	mg/L	15,900	166	45	59	110	150	150	150
Sodium	mg/L	1,750	14.9	280	300	400	500	470	530
Lead	mg/L	NA	NA	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Nickel	mg/L	NA	NA	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
TCLP Extraction Fluid	N/A	NA	NA	2	2	2	2	2	2
Final Leachate pH	Units	NA	NA	11.5	10.8	11.6	11.4	11.6	11.7
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0

NA - Not Applicable
*Result determined by a single-point method of standard additions.
**Elevated detection limit reported due to sample matrix interference.
Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

3.2.1 Initial Characterization Data

The "as received" pondcrete metals were submitted for baseline analysis and leachate (TCLP) analysis. A summary of the results are provided in Table 3-12.

Sample analysis was conducted for selected contaminants determined to be of potential concern when the treated waste is eventually placed in the OU4 closure. The data reveal similar levels of contaminants in comparison to the pondcrete triwalls.

A sample of the pondcrete metals was tested using TCLP to determine the leachability of the as received material. The results indicate that plutonium-239/240 and cadmium leached at concentrations above the WAC associated with the design infiltration rate and the 1-inch-per-year infiltration rate. Uranium-238 and beryllium also leached at concentrations above the WAC associated with the 1-inch-per-year infiltration rate.

3.2.2 Lime Addition Study

A lime addition study was not performed for this material because of limited material availability. It is assumed that the results from the triwall study (Section 3.1.2) will be applicable to the pondcrete metals.

3.2.3 Process Formulation Development Data

This section describes the results of the friable mix development (pre-WAC) and the Phase I waste acceptance criteria (WAC) testing.

3.2.3.1 Pre-WAC Friable Mix Development Results

Testing was performed using the additives selected from the pond sludge pre-WAC testing performed on 207A/B and 207C contents. These additives included lime/fly ash, lime/fly ash/cement, and lime/fly ash/silica flour (HNUS, 1995, Pond Sludge Process Formulation and Treatability Study Report). This pre-WAC phase was used to determine the approximate quantity of these additives required to achieve a friable mix. The results of these mixes are summarized in Table 3-13.

The results indicated that a friable product could be achieved using the three selected additives. Compared to the previously tested pond sludge waste (207 A/B and 207C), relatively lower water-to-pozzolan ratios (approximately 0.24 to 0.30) were required. This indicates that extra pozzolan is needed to react with the free water in the short mixing time.

TABLE 3-12

BASELINE ANALYTICAL RESULTS SUMMARY
PONDCRETE METALS MATERIAL
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample ID:		WAC for Scenario 1		Pondcrete Metals "As Received"	Pondcrete Metals TCLP
Sample No.:		0.0068 in/yr Infiltration	1 in/yr Infiltration	P0297080	P0297081
Date:				12/29/94	12/28/94
W/P:				NA	NA
% Solids:				38.8%	NA
Analyte	Units[1]				
Am-241	pCi/L	17,100	74.5	6500 ± 2000	66 ± 7
Cs-134	pCi/L	3,510,000	12,800	< 1 pCi/g	< 3
Cs-137	pCi/L	111,000	737	< 1 pCi/g	6.2 ± 1.5
Pu-238	pCi/L	NA	NA	52 ± 9 pCi/g	41 ± 9
Pu-239/240	pCi/L	1,070	4.43	1900 ±/-200 pCi/g	1,800 ± 200
Ra-226	pCi/L	117,000	415	3.9 ± 0.6 pCi/g	1.2 ± 0.4
U-233/234	pCi/L	35,200	254	15 ± 2 pCi/g	490 ± 60
U-235	pCi/L	1,410	10.2	0.87 ± 0.14 pCi/g	10 ± 8
U-238	pCi/L	24,500	177	16 ± 2 pCi/g	470 ± 60
Strontium-89	pCi/L	NA	NA	<0.4 pCi/g	0.55 ± 0.16
Strontium-90	pCi/L	NA	NA	<0.4 pCi/g	1.3 ± 0.4
Arsenic	mg/L	13.6	0.142	NA	NA
Beryllium	mg/L	1.43	0.0142	170 mg/kg	0.22
Cadmium	mg/L	5.19	0.0518	1,320 mg/kg	13
TCLP Extraction Fluid	--	NA	NA	NA	2
pH	Units	NA	NA	13.0	6.4 (Leachate)
Bulk Density	g/cc	NA	NA	1.47	NA

NA Not Applicable.
(1) Units unless otherwise noted.

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

TABLE 3-13

SUMMARY OF PRE-WAC MIXES PONDCRETE METALS MATERIAL
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		Temperature Increase	Observations
					Not Compacted	Compacted		
1	PCM STERGO® $Ca(OH)_2$ Fly ash	400 g 1.14 g 20 g 775 g	1 0.003 0.05 1.94	0.31	3.8 X	NA	NA	Dry, hard pellets.
2	PCM STERGO® $Ca(OH)_2$ Fly ash Cement	400 g 1.14 g 20 g 600 g 300 g	1 0.003 0.05 1.5 0.75	0.26	3.9 X	NA	NA	Dry, hard pellets.
3	PCM STERGO® $Ca(OH)_2$ Fly ash Silica Flour	400 g 1.14 g 20 g 862.6 g 152 g	1 0.003 0.05 2.1 0.38	0.24	4.3 X	NA	NA	Pellets, smooth, round.

All mixes performed in a Hobart mixer.
PCM "as received" at 38.2% solids.

* Lime mixed into sludge and allowed to react before the addition of other additive(s).

3.2.3.2 WAC Compliance Testing Results

Phase I. Based on the results of the three pre-WAC mixes, additional testing was performed to determine WAC compliance over the anticipated operating ranges for the W/P ratio and waste loadings. A summary of the mixes performed using lime and fly ash is provided in Table 3-14. A summary of the mixes performed using lime, fly ash, and silica flour is provided in Table 3-15. A summary of the mixes performed using lime, fly ash, and cement is provided in Table 3-16. Graphs plotting the TCLP leachate data vs. pH are provided in Appendix G.

The data shown on Tables 3-17 through 3-19 indicate that some of the analytes are leachable under certain conditions. Except for two mixes (1A and 3A) which had an exceptionally low pH of 6.5, none of the leachate concentrations exceeded the concentrations for the design (0.0068 in/yr infiltration) WAC. In the same lime and fly ash mixes, plutonium-239/240, uranium isotopes, cadmium, and nitrate/nitrite leached at concentrations which exceeded the 1-inch-per-year WAC concentrations. This was clearly related to the lower TCLP extract pH associated with two of the lime/fly ash mixes. For the lime/fly ash/silica flour formulation, nitrate/nitrite exceeded the 1-inch-per-year infiltration WAC. For the lime/fly ash/cement mixes only sodium exceeded the 1-inch-per-year infiltration rate WAC.

As shown on Table 3-19, the TCLP extracts were also analyzed for lead and nickel during this phase of testing to determine compliance with applicable LDR standards. These data, together with the data for cadmium and chromium, show that the selected mix of lime, fly ash, and cement meets the LDR standards applicable to pondcrete.

The graphs of pH versus TCLP leachate concentration, in Appendix G, are useful for determining the relationship between pH and leachate concentration. The isotopic uranium data shows that as the pH drops below 7.0, the concentration in the leachate increases. Cadmium concentrations in the leachate increase as the pH of the leachate decreases to below 9.0. Nitrate/nitrite leached at concentrations exceeding the WAC concentration, although this phenomenon is not related to pH.

No Phase II WAC mixes were conducted for the pondcrete metals. At the time when the Phase I data became available, the decision had been made to select a process formulation based on lime/fly ash/cement for the treatment of all wastes. This decision was based on data available for pond sludges from 207 A/B and 207C. Since the lime/fly ash/cement data for the Phase I testing of pondcrete metals showed consistently high TCLP extract pHs (which in turn controls the leachate concentrations of most metals and radionuclides of concern) it was not considered necessary to repeat the testing in a second phase.

TABLE 3-14

SUMMARY OF WAC PHASE I MIXES
PCM SLUDGE (ADDITIVES: LIME AND FLY ASH)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
1A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	400 g 20 g 979 g	1 0.05 2.45	0.25	5.9 X	3.7 X	113 psi	After 30 seconds of mixing, produced pea-size chunks which broke down to the consistency of brown sugar. Final product a moist powder. DRY MIX.
2A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	400 g 20 g 816 g	1 0.05 2.04	0.30	4.5 X	3.4 X	138 psi	After 30 seconds of mixing, produced small chunks of moist material which broke down to a moist powder. Final product a moist powder. DRY MIX.
3A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	400 g 20 g 699 g	1 0.05 1.75	0.35	4.0 X	3.0 X	73 psi	Immediately formed pea-size clumps with heavy packing on sides of bowl. Final product after scraping sides of bowl was a moist powder. DRY MIX.
4A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	400 g 20 g 822 g	1 0.05 2.05	0.25	4.8 X	3.3 X	0 psi	This mix produced a moist powder with heavy packing on sides of bow. Final product a moist powder. DRY MIX.
5A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	500 g 25 g 257 g	1 0.05 1.94	1.0	N/A	1.7 X	343 psi	Immediately formed large clay clumps approximately 2 inches in diameter which broke down to medium-size friable soil chunks (worm dirt). After 1.5 minutes, turned to a cake icing. Final product was a smooth cake icing consistency. GOOD MIX.
6A	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C	400 g 20 g 587 g	1 0.05 5.00	0.35	2.8 X	2.1 X	0 psi	This mix was a moist powder mix and produced a final product of a moist powder. DRY MIX.

N/A Not available, material too wet, already in compacted state.

TABLE 3-15

SUMMARY OF WAC PHASE I MIXES
PCM SLUDGE (ADDITIVES: LIME, FLY ASH, AND SILICA FLOUR)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives		Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
					Not Compacted	Compacted		
1B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	400 g 20 g 595 g 105 g	1 0.05 1.49 0.26	0.35	4.3 X	2.7 X	175 psi	This mix produced a final product with the consistency of moist powder. DRY MIX.
2B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	400 g 20 g 320 g 56 g	1 0.05 0.80 0.14	0.65	N/A	1.7 X	>637 psi	After 30 seconds of mixing, produced a friable soil (worm dirt) consistency which turned into a bread dough or clay, then to cake icing after 1 minute and 30 seconds. Final product consistency of molding clay. GOOD MIX, slightly wet.
3B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	400 g 20 g 208 g 37 g	1 0.05 0.35 0.06	1.0	N/A	1.4 X	328 psi	Immediately turned to consistency of cookie dough then to a dryish icing. Final product consistency of molding clay. WET MIX.
4B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	400 g 20 g 500 g 88 g	1 0.05 1.25 0.22	0.35	4.3 X	2.7 X	0 psi	Produced a final product of moist powder. DRY MIX.
5B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	500 g 25 g 269 g 47 g	1 0.05 0.67 0.12	0.65	4.1 X	2.6 X	65 psi	Moist powder mix with some sticking to side of bowl. Final product a moist powder. DRY MIX.
6B	PCM "As Received" $Ca(OH)_2$ Fly ash, Type C Silica Flour	400 g 20 g 218 g 39 g	1 0.05 0.44 0.08	1.0	N/A	1.4 X	0 psi	Immediately formed large clay clumps approximately 2 inches in diameter. After 30 seconds, made medium curd worm dirt which turned to cookie dough then to sticky bread dough. Final product is a dry, sticky, molding clay. GOOD MIX.

N/A Not available, material too wet, already in compacted state.

TABLE 3-16

SUMMARY OF WAC PHASE I MIXES
PCM SLUDGE (ADDITIVES: LIME, FLY ASH, AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Mix No.	Additives	Additive Weight Ratios	W/P	Bulk Volumetric Increase		48-Hour Cure Compacted Material UCS	Observations
				Not Compacted	Compacted		
1C	Equipment failure. No test.	---	0.35	---	---	---	Large clumps of concrete or rocks in the PCM material caused the Hobart's shear pin to break and lose a large quantity of the material.
2C	PCM "As Received" 400 g $Ca(OH)_2$ 20 g Cement, Type I/II 126 g Fly ash, Type C 251 g	1 0.05 0.31 0.63	0.65	N/A	1.4 X	> 637 psi	After 15 seconds of mixing produced a friable soil (worm dirt) which turned to bread dough, then a cake icing after 1 minute 30 seconds. Final product was the consistency of molding clay. GOOD MIX.
3C	PCM "As Received" 600 g $Ca(OH)_2$ 30 g Cement, Type I/II 122 g Fly ash, Type C 245 g	1 0.05 0.20 0.41	1.0	N/A	1.4 X	> 637 psi	After 15 seconds formed clay chunks 1 to 2 inches in diameter. Turned to cake icing after 30 seconds. Final product a moist stiff molding clay. GOOD MIX, SLIGHTLY WET.
4C	PCM "Dried Out" 400 g $Ca(OH)_2$ 20 g Cement, Type I/II 196 g Fly ash, Type C 392 g	1 0.05 0.49 0.98	0.35	4.3 X	3.2 X	27 psi	After 30 seconds produced soft pellets which became hard. These hard pellets broke down to form a final product of powder. DRY MIX.
5C	PCM "Dried Out" 374 g $Ca(OH)_2$ 19 g Cement, Type I/II 98 g Fly ash, Type C 197 g	1 0.05 0.26 0.53	0.65	3.0 X	1.7 X	357 psi	Immediately formed large chunks which broke down to small pea-size balls, which turned to a friable soil (worm dirt) after 1.5 minutes. Turned to large clumpy soil, then a final product of clumps stiff clay. GOOD MIX.
6C	Equipment failure. No test.	---	1.0	---	---	---	Attempting to mix, broke shear pin on two remaining Hobart mixers.

N/A Not available, material too wet, already in compacted state.

TABLE 3-17

WAC PHASE I ANALYTICAL RESULTS
PCM MIXES (ADDITIVES: LIME AND FLY ASH)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

Sample ID:		WAC for Scenario 1		1A-PCM	2A-PCM	3A-PCM	4A-PCM	5A-PCM	6A-PCM
Sample No.:		0.0068 in/yr Infiltration	1 in/yr Infiltration	P0301505 P0301506	P0301507	P0301508 P0301509	P0301510	P0301511 P0301512	P0301513 P0301514
Date:				02/20/95	02/20/95	02/20/95	02/20/95	02/20/95	02/20/95
W/P:				0.25	0.30	0.35	0.25	1.0	0.35
% Solids:				38.8%	38.8%	38.8%	48.6%	48.6%	48.6%
Analyte	Units								
Am-241	pCi/L	17,100	74.5	310 ± 40	NS	210 ± 30	NS	0.12 ± 0.03	0.12 ± 0.04
Cs-134	pCi/L	3,510,000	12,800	< 5	NS	< 7	NS	< 4	< 7
Cs-137	pCi/L	111,000	737	< 7	NS	< 7	NS	4.7 ± 1.7	< 7
Pu-238	pCi/L	NA	NA	4.7 ± 1.5	NS	6.8 ± 1.6	NS	0.03 ± 0.01	0.012 ± 0.009
Pu-239/240	pCi/L	1,070	4.43	140 ± 20	NS	300 ± 30	NS	1.4 ± 0.2	0.46 ± 0.05
Ra-226	pCi/L	117,000	415	< 0.1	NS	< 0.2	NS	< 0.1	< 0.1
U-233/234	pCi/L	35,200	254	280 ± 30	NS	320 ± 40	NS	7.9 ± 1.4	< 0.5
U-235	pCi/L	1,410	10.2	12 ± 2	NS	11 ± 2	NS	0.7 ± 0.4	< 0.5
U-238	pCi/L	24,500	177	320 ± 40	NS	370 ± 40	NS	8.9 ± 1.5	< 0.6
Arsenic	mg/L	13.6	0.142	NT	NS	NT	NS	NT	NT
Beryllium	mg/L	1.43	0.0142	0.019	NS	0.014	NS	<0.0007*	<0.0007*
Cadmium	mg/L	5.19	0.0518	6.6	NS	6.8	NS	0.014	<0.005
Chromium	mg/L	142	0.881	NT	NS	NT	NS	NT	NT
Nitrate/Nitrite	mg/L	15,900	166	100	NS	94	NS	210	130
Sodium	mg/L	1,750	14.9	NT	NS	NT	NS	NT	NT
TCLP Extraction Fluid	NA	NA	NA	2	NS	2	NS	2	2
Final Leachate pH	Units	NA	NA	6.5	NS	6.5	NS	9.2	9.9
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0
Bulk Density	g/cc	NA	NA	1.02	1.09	1.10	1.06	1.03	1.09

NA Not Applicable
NS Not Submitted for analysis
NT Not tested for this analyte
* Result determined by a single-point method of standard additions

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

TABLE 3-18

WAC PHASE I ANALYTICAL RESULTS
PCM MIXES (ADDITIVES: LIME, FLY ASH, AND SILICA FLOUR)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

	Sample ID:	WAC for Scenario 1		1B-PCM	2B-PCM	3B-PCM	4B-PCM	5B-PCM	6B-PCM
	Sample No.:	0.0068 in/yr Infiltration	1 in/yr Infiltration	P0301515 P0301516	P0301517	P0301518 P0301519	P0301520 P0301521	P0301522	P0301523 P0302028
	Date:			02/20/95	02/20/95	02/20/95	02/20/95	02/20/95	02/20/95
	W/P:			0.35	0.65	1.0	0.35	0.65	1.0
	% Solids:			38.8%	38.8%	38.8%	48.6%	48.6%	48.6%
Analyte	Units								
Am-241	pCi/L	17,100	74.5	0.13 ± 0.03	NS	0.12 ± 0.03	0.52 ± 0.36	NS	0.18 ± 0.10
Cs-134	pCi/L	3,510,000	12,800	<4	NS	<6	<5	NS	<6
Cs-137	pCi/L	111,000	737	<5	NS	<7	<6	NS	4.4 ± 3.9
Pu-238	pCi/L	NA	NA	< 0.02	NS	< 0.02	< 0.2	NS	< 0.03
Pu-239/240	pCi/L	1,070	4.43	0.79 ± 0.08	NS	0.39 ± 0.05	0.36 ± 0.15	NS	0.75 ± 0.18
Ra-226	pCi/L	117,000	415	< 0.1	NS	0.1 ± 0.1	0.2 ± 0.1	NS	< 0.1
U-233/234	pCi/L	35,200	254	< 0.7	NS	0.33 ± 0.09	< 0.6	NS	1.3 ± 0.5
U-235	pCi/L	1,410	10.2	< 0.5	NS	0.043 ± 0.030	< 0.4	NS	< 0.2
U-238	pCi/L	24,500	177	< 0.8	NS	0.36 ± 0.09	< 0.6	NS	0.94 ± 0.46
Arsenic	mg/L	13.6	0.142	NT	NS	NT	NT	NS	NT
Beryllium	mg/L	1.43	0.0142	<0.0006*	NS	<0.0006	<0.0005	NS	<0.0005
Cadmium	mg/L	5.19	0.0518	<0.005	NS	<0.005	<0.005	NS	<0.005
Chromium	mg/L	142	0.881	NT	NS	NT	NT	NS	NT
Nitrate/Nitrite	mg/L	15,900	166	180	NS	190	120	NS	190
Sodium	mg/L	1,750	14.9	NT	NS	NT	NT	NS	NT
TCLP Extraction Fluid	NA	NA	NA	2	NS	2	2	NS	2
Final Leachate pH	Units	NA	NA	9.6	NS	10.1	9.9	NS	9.9
Paint Filter Liquids Test	mL	NA	NA	0	0	0	0	0	0
Bulk Density	g/cc	NA	NA	1.03	1.15	1.05	1.05	1.06	1.08

NA Not Applicable
NS Not Submitted for analysis
NT Not tested for this analyte
* Result determined by a single-point method of standard additions

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

TABLE 3-19

WAC PHASE I ANALYTICAL RESULTS
PCM MIXES (ADDITIVES: LIME, FLY ASH AND CEMENT)
PONDCRETE TREATABILITY STUDY
ROCKY FLATS, COLORADO

	Sample ID:	WAC for Scenario 1		1C-PCM	2C-PCM	3C-PCM	4C-PCM	5C-PCM	6C-PCM
	Sample No.:	0.0068 in/yr Infiltration	1 in/yr Infiltration	---	P0302030 P0302031	P0302032 P0302033	P0302034 P0302035	P0302036 P0302037	---
	Date:			02/21/95	02/21/95	02/21/95	02/21/95	02/21/95	02/21/95
	W/P:			0.35	0.65	1.0	0.35	0.65	1.0
	% Solids:			38.8%	38.8%	38.8%	48.6%	48.6%	48.6%
Analyte	Units								
Am-241	pCi/L	17,100	74.5	NS	<0.1	<0.2	<0.1	<0.2	NS
Pu-238	pCi/L	NA	NA	NS	<0.03	<0.02	<0.06	<.08	NS
Pu-239/240	pCi/L	1,070	4.43	NS	<0.08	0.020 ± 0.019	<0.05	0.050 ± 0.044	NS
Ra-226	pCi/L	117,000	415	NS	0.4 ± 0.1	0.7 ± 0.1	1.6 ± 0.2	0.3 ± 0.1	NS
U-233/234	pCi/L	35,200	254	NS	<0.6	< 0.6	0.22 ± 0.17	<0.3	NS
U-235	pCi/L	1,410	10.2	NS	<0.5	< 0.8	<0.08	<0.07	NS
U-238	pCi/L	24,500	177	NS	<0.7	< 0.7	0.19 ± 0.14	<0.2	NS
Arsenic	mg/L	13.6	0.142	NS	<0.1	< 0.1	<0.1	<0.1	NS
Beryllium	mg/L	1.43	0.0142	NS	<0.0005	<0.0005	<0.0005	<0.0007*	NS
Cadmium	mg/L	5.19	0.0518	NS	<0.005	<0.005	<0.005	<0.005	NS
Chromium	mg/L	142	0.881	NS	0.15	0.14	0.09	0.21	NS
Nitrate/Nitrite	mg/L	15,900	166	NS	100	150	110	140	NS
Sodium	mg/L	1,750	14.9	NS	500	630	480	610	NS
Lead	mg/L	NA	NA	NS	<0.05	<0.05	<0.05	<0.05	NS
Nickel	mg/L	NA	NA	NS	<0.02	<0.02	<0.02	<0.02	NS
TCLP Extraction Fluid	N/A	NA	NA	NS	2	2	2	2	NS
Final Leachate pH	Units	NA	NA	NS	10.9	11.1	11.5	10.9	NS
Paint Filter Liquids Test	mL	NA	NA	NS	0	0	0	0	NS
Bulk Density	g/cc	NA	NA	NS	1.17	1.09	1.07	1.16	NS

NA Not Applicable
NS Not Submitted for analysis
* Result determined by a single-point method of standard additions

Shading indicates that the concentration in the TCLP extract exceeded the Waste Acceptance Criteria (WAC) for disposal in the OU4 closure, assuming 1 in/yr infiltration through the cap and no groundwater controls (Scenario 1). See Appendix B for details on the development of the WAC.

4.0 PROCESS FORMULATION/OPERATING ENVELOPE

This section provides a discussion of the treatability study results and the development of an operating envelope for key process parameters. The development of a large operating envelope for key parameters will facilitate the operation of the treatment system under variable waste feed conditions.

The treatability study evaluated various formulations to determine which resulted in a product that produced a friable product that met all Waste Acceptance Criteria (WAC). Once it was determined that a specified formulation resulted in an acceptable end product, testing was conducted to develop an operating envelope that could be used during remediation. The operating envelope was developed to be conservative enough to ensure that all samples passed the required criteria.

Based on the treatability testing, several parameters appear to be the most significant regarding process control. These include the pozzolanic mixture composition, the ratio of water-to-pozzolans in the process stream, and the solids/moisture content of the waste.

4.1 PONDCRETE TRIWALLS

4.1.1 CSS Formulation

A treatment system consisting of the addition of hydrated lime, Type C fly ash, and Type I/II Portland cement is recommended for treating pondcrete triwalls. The hydrated lime is necessary to raise the pH to greater than 12 to stabilize the sludge and inhibit gas generation via biological decomposition of the organics in the waste, as well as to reduce the leachability of most metals and radionuclides. The cement and fly ash are required to eliminate the free water in the waste, a WAC requirement for disposal in the OU4 closure, and to aid in the production of a friable product.

4.1.1.1 Fly Ash/Cement Ratio

The selected formulation for fly ash/cement is the same system investigated for pond sludges in 1992 for the production of monoliths for offsite disposal (HNUS, 1992c). The current treatability study for the production of a friable product, as well as the previous treatability study, both selected ratios of fly ash/cement of 2/1 as the desired operating ratio. The 1992 study looked at a wide range of fly ash/cement ratios (0/1 to 3.34/1) and concluded that the process performance was not sensitive to variations in the fly ash/cement ratio. Small variations from the target fly ash/cement ratio of 2/1 are likewise not expected to cause any problems in meeting the WAC. The fly ash and cement do not need to be pre-blended, and can be fed separately at the 2/1 ratio.

Because the testing in the final phase was centered upon developing a range for the water-to-pozzolan ratio and the solids loading, it was not considered necessary to develop a range for the fly ash to cement ratio. Therefore, all of the testing done in the final phase of the treatability study was conducted at a fly ash to cement ratio of 2 to 1.

4.1.1.2 Hydrated Lime Addition

A requirement for the treatment process is the addition of lime to inhibit biological activity. Lime is also used in the CSS formula to provide sufficient amounts of alkalinity to lower the solubility of most of the metals of concern. The solubility of many metals will remain low when the pH of the solution is alkaline, which results in successfully passing the WAC for protection of human health and the environment via the groundwater pathway. Although there are some metals which are amphoteric (solubility increases under acidic or alkaline conditions), such as arsenic, cadmium, chromium, and lead, no significant problems have been observed by maintaining sufficient amounts of alkalinity to maintain an alkaline pH in the TCLP extract.

In the final phase of testing, hydrated lime was added in a fixed percent (7.5 percent) by weight of raw waste. The addition of lime at this percentage resulted in a final leachate extract pH range of 10.8 to 11.5. Both hydrated and quick lime provided the desired result of pH adjustment, but hydrated lime was selected because it provided a more thorough mix with the waste material and did not generate excessive heat when added in large doses.

Because of the importance of the addition of the lime for adjusting the pH of treated waste, which in turn controls the leachability of metals and radionuclides, a range of lime dosages was investigated. In the Phase II WAC confirmatory testing, the worst-case mix (assumed to be the mix with the highest water content in the raw waste and the highest W/P ratio) was tested at 5 percent and 10 percent lime dosages in addition to the target dosage of 7.5 percent. The data indicate that this variation of lime dosage around the target concentration of 7.5 percent has no appreciable affect on WAC compliance. Therefore, the treatment system should be able to tolerate this amount of variation from the target lime dosage.

Although lime often requires several minutes to fully dissolve into solution and react, this is not required for pondcrete treatment because the curing time (at least 24 hours) is sufficient time to achieve the desired pH. The lime can be added to the treatment system, anticipated to be a pug mill, at the same time that fly ash and cement are added.

4.1.2 Operating Range of Key Parameters

The waste loading of the raw waste, measured as the total solids content of the pondcrete, and the W/P ratio of the treated waste (how much treatment additive is added as a percentage of the sludge water content) are the key parameters that control the operation of the treatment system. Figure 4-1 shows graphically the range of key operating parameters tested during the Phase II WAC compliance study.

4.1.2.1 Waste Loading (Percent Solids of Pondcrete)

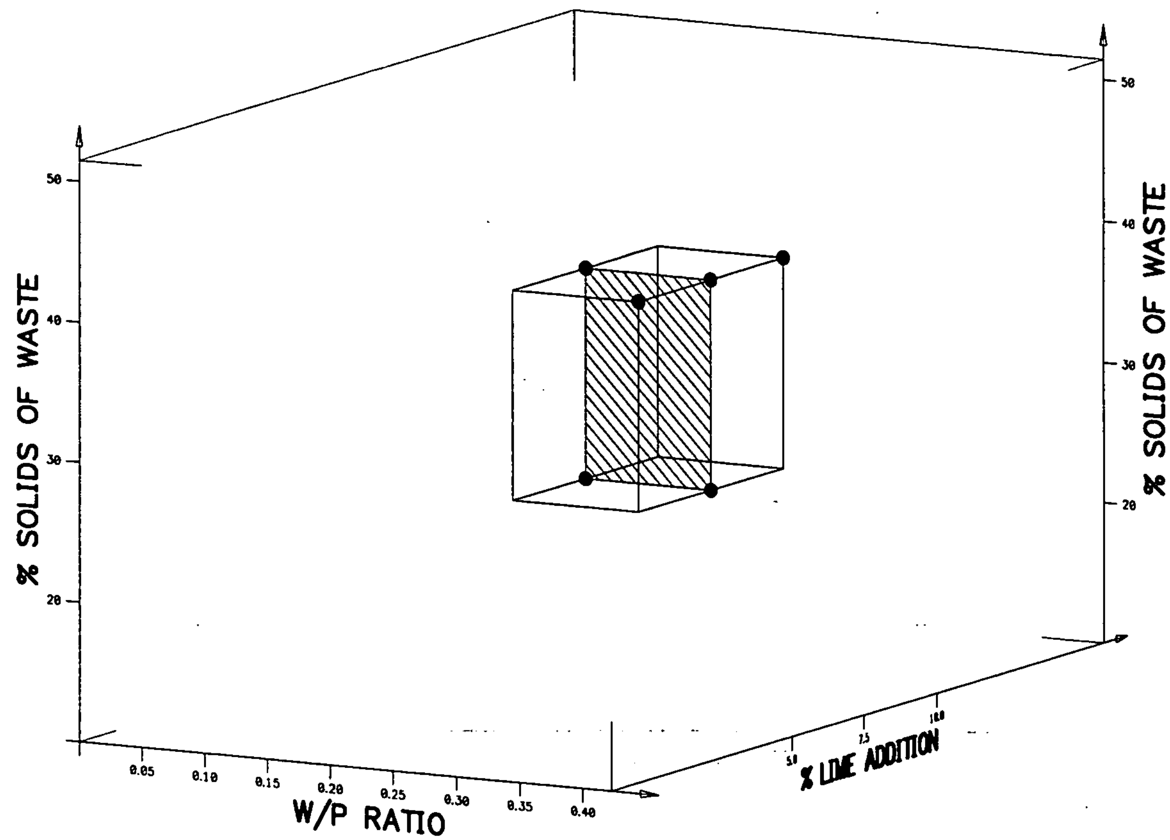
Phase I WAC testing was conducted at 25 percent, 34.8 percent (as received) and 43.3 percent total solids. The 34.8 percent total solids content represents an assumed average solids concentration. The upper range is a worst-case scenario to increase the loading of metals and radionuclides for leachability testing. It must be noted that lower solids content pondcrete could also be treated by adding enough treatment additives to achieve the desired W/P ratios as discussed in Section 4.1.3.

4.1.2.2 Water-to-Pozzolan Ratio

The criteria determined to be the most critical for successful production of a friable product that meets all WAC is the water-to-pozzolan (W/P) ratio. Once the percent solids of the pondcrete entering the screw auger shredder is determined, the weight of the water can be calculated. The quantity of pozzolans to be added is determined by dividing the weight of the water by the desired water-to-pozzolan ratio. For the purpose of testing during the treatability study, pozzolan was defined as fly ash plus cement in a ratio of 2:1.

The full-scale treatment system will operate within a water-to-pozzolan ratio range that is capable of achieving a friable product. This range was determined during the pre-WAC testing phase and is estimated to be 0.22 to 0.27. For the purpose of defining a W/P range for WAC compliance, the friable product range was expanded to bracket the probable operating range. The low end of the range (0.20) is probably too dry for full-scale operation, while the high end (0.30) is probably too wet. However, if these extreme conditions meet the WAC, then any operating points in between will also meet the WAC.

ACAD: O:\DATA\CADD\3A23\95032904.DWG 05/05/95 VB



% SOLIDS	W/P	% LIME
25	0.20	7.5
25	0.30	7.5
40	0.20	7.5
40	0.30	5.0
40	0.30	7.5
40	0.30	10.0

PONDCRETE TRIWALLS WASTE LOADING
AND ADDITIVES ADDITION VARIATION PROCESS
RANGE FOR WAC PHASE II TESTING
ROCKY FLATS, COLORADO

FIGURE 4-1

Halliburton NUS CORPORATION

The Phase II WAC compliance testing for pondcrete triwalls showed that the WAC requirements could be met at W/P ratios between 0.20 and 0.30, notably no free liquids and leachate concentrations within an acceptable range. The percent solids tested during Phase II WAC compliance testing was 25 percent and 40 percent.

4.2 PONDCRETE METALS

4.2.1 <u>CSS Formulation</u>

A treatment process consisting of the addition of hydrated lime, Type C fly ash, and Type I/II Portland cement is recommended for treating pondcrete metals. The hydrated lime is necessary to raise the pH to greater than 12 to stabilize the sludge and inhibit gas generation via biological decomposition of the organics in the waste, and to reduce the leachability of most metals and radionuclides. The cement and fly ash are required to eliminate the free water in the waste, a WAC requirement for disposal in the OU4 closure, and to aid in the production of a friable product. Only pre-WAC and Phase I WAC phases were required to complete the pondcrete metals testing.

4.2.1.1 Fly Ash/Cement Ratio

The selected formulation for fly ash/cement is the same system investigated for pond sludge in 1992 for the production of monoliths for offsite disposal (HNUS, 1992c). The current treatability study for the production of a friable product, as well as the previous treatability study, both selected ratios of fly ash/cement of 2/1 as the desired operating ratio. The 1992 study looked at a wide range of fly ash/cement ratios (0/1 to 3.34/1) and concluded that the process performance was not sensitive to variations in the fly ash/cement ratio. Small variations from the target fly ash/cement ratio of 2/1 are likewise not expected to cause any problems in meeting the WAC. The fly ash and cement do not need to be pre-blended, and can be fed separately at the 2/1 ratio.

Because the testing in the final phase was centered upon developing a range for the water-to-pozzolan ratio and the solids loading, it was not considered necessary to develop a range for the fly ash to cement ratio. Therefore, all of the testing done in the final phase of the treatability study was conducted at a fly ash to cement ratio of 2 to 1.

4.2.1.2 Hydrated Lime Addition

A requirement of the treatment process is the addition of lime to inhibit biological activity. Lime is also used in the CSS formula to provide sufficient amounts of alkalinity to lower the solubility of most of the metals of concern. The solubility of many metals remains low when the pH of the solution is alkaline, which results in successfully passing the WAC for protection of human health and the environment via the groundwater pathway. Although there are some metals which are amphoteric (solubility increases under acidic or alkaline conditions), such as arsenic, cadmium, chromium, and lead, no significant problems have been observed by maintaining sufficient amounts of alkalinity to maintain an alkaline pH in the TCLP extract.

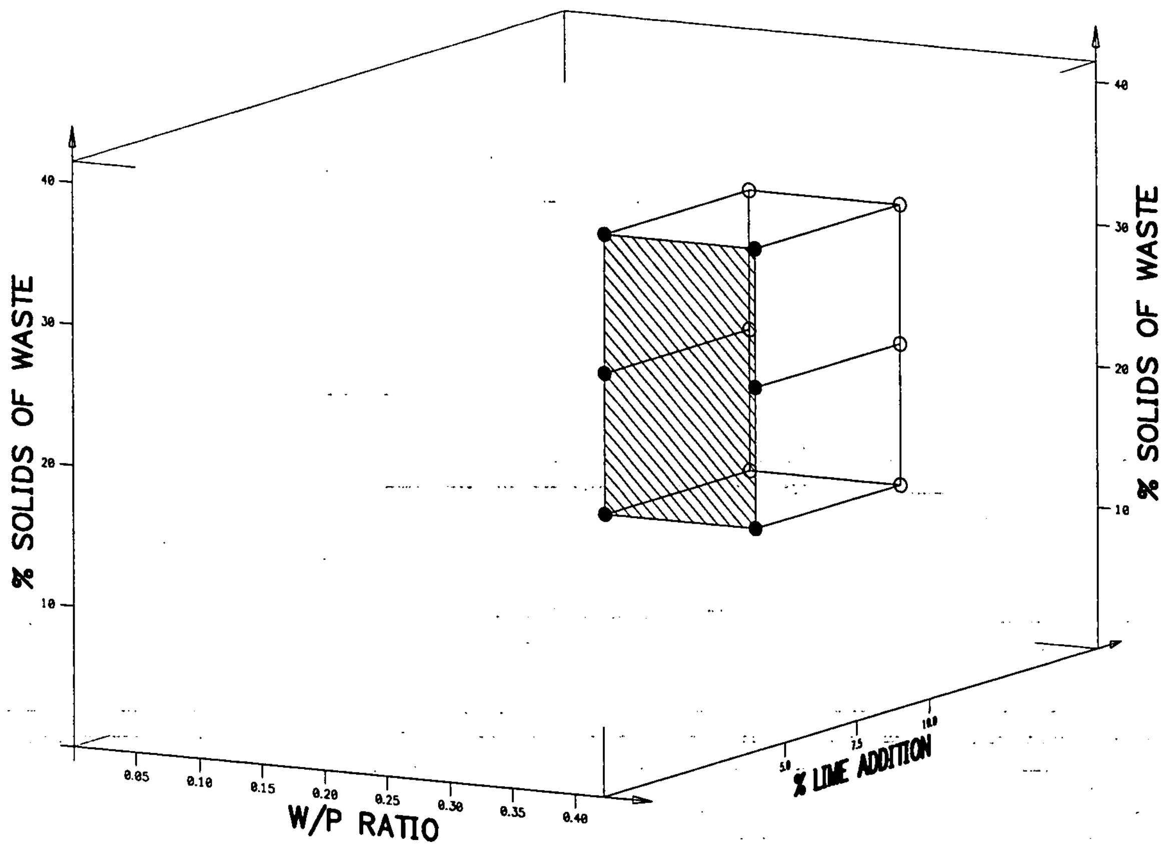
In the Phase I WAC testing, hydrated lime was added in a fixed percent (5.0 percent) by weight of raw waste. The addition of lime at this percentage resulted in a pH range of 10.7 to 11.5 in the TCLP leachate. Both hydrated lime and quicklime provided the desired result of pH adjustment, but hydrated lime was selected because it provided a more thorough mix with the waste material and did not generate excessive heat when added in large quantities.

The Phase I WAC testing of pondcrete metals, at a 5 percent the dosage, achieved WAC compliance. Therefore, no additional testing was conducted with varying lime dosages for the pondcrete metals. The pondcrete triwalls data indicate that slight variations of the lime dosage around the target concentration had no appreciable effect on WAC compliance. A lime dosage of 7.5 percent is recommended for the pondcrete metals, based on testing on the pondcrete triwalls.

Although lime often requires several minutes to fully dissolve into solution and react, this is not required for pondcrete treatment because the curing time (at least 24 hours) is sufficient time to achieve the desired pH. The lime can be added to the treatment system, anticipated to be a pug mill, at the same time that fly ash and cement are added.

4.2.2 Operating Range of Key Parameters

The waste loading of the raw waste, measured as the total solids content of the sludge, and the water/pozzolan ratio of the treated waste (how much treatment additive is added as a percentage of the sludge water content) are the key parameters that control the operation of the treatment system. Figure 4-2 depicts the range of key operating parameters tested during the Phase I WAC compliance study.



% SOLIDS	W/P	% LIME
15	0.28	5.0
15	0.40	5.0
25	0.28	5.0
25	0.40	5.0
34.8	0.28	5.0
34.8	0.40	5.0

PONDCRETE METALS WASTE LOADING
AND ADDITIVES ADDITION VARIATION PROCESS
RANGE FOR WAC PHASE I TESTING
ROCKY FLATS, COLORADO

FIGURE 4-2

Halliburton NUS CORPORATION

4.2.2.1 Waste Loading (Percent Solids of Pondcrete)

Phase I WAC testing was conducted at 38.8 and 48.6 percent solids. The 38.8 percent solids content represents an assumed average solids concentration. The upper range is a worst-case scenario to increase the loading of metals and radionuclides for leachability testing. It must be noted that lower solids content sludges could also be treated by adding enough treatment additives to achieve the desired water/pozzolan ratios (see next section).

4.2.2.2 Water-to-Pozzolan Ratio

The criteria determined to be the most critical for successful production of a friable product that meets all WAC is the water-to-pozzolan ratio. Once the percent solids of the pondcrete metals entering the screw auger shredder is determined, the weight of the water can be calculated. The quantity of pozzolans to be added is determined by dividing the weight of the water by the desired water-to-pozzolan ratio. For the purpose of testing during the treatability study, pozzolan was defined as cement plus fly ash.

The full-scale treatment system will operate within a W/P ratio range that is capable of achieving a friable product. This range was determined during the pre-WAC testing phase and is estimated to be 0.45 to 0.55. For the purpose of defining a W/P range for WAC compliance, the friable product range was expanded to bracket the probable operating range. The low end of the range (0.35) is probably too dry for full-scale operation, whereas the high end (1.0) is probably too wet. However, if these extreme conditions meet the WAC, then any operating points in between will also meet the WAC.

The Phase I WAC compliance testing showed that the WAC requirements could be met at W/P ratios between 0.35 and 1.0, notably no free liquids and leachate concentrations within an acceptable range. The percent solids tested during Phase I WAC compliance testing were 38.8 percent and 48.6 percent.

5.0 CONCLUSIONS

The objective of the treatability study was to develop a treatment system for the inventory pondcrete such that the treated wastes meet the waste acceptance criteria for disposal in the OU4 closure. The following sections summarize the conclusions of the treatability study for each of the waste materials investigated.

5.1 PONDCRETE TRIWALLS

Following are the conclusions of the treatability study conducted on the pondcrete in triwalls.

5.1.1 Formulation

The CSS formulation selected for the pondcrete triwalls includes hydrated lime, Type C fly ash, and Type I/II Portland cement. The lime is added at 7.5% by weight of the untreated waste. The fly ash and cement are combined in a 2:1 fly ash/cement ratio, and are added at a rate determined by the desired water-to-pozzolan ratio.

5.1.2 Water-to-Pozzolan Ratio

Compliance with waste acceptance criteria was achieved at water-to-pozzolan ratios from 0.2 to 0.3. The optimum range for achieving a friable product is a subset of this range, at water-to-pozzolan ratios from 0.22 to 0.27.

5.1.3 Waste Loading

The treatability study testing was conducted on waste with total solids concentrations that ranged from 25 percent to 40 percent total solids which brackets the material as it currently exists on site. The treatability study results indicate that the proposed stabilization formula will produce a final product that meets the waste acceptance criteria if the waste loading is within the above range. It should be noted that waste with lower solids concentrations can be effectively treated by adding additional pozzolans.

5.1.4 Waste Acceptance Criteria Compliance

Based on the results of the treatability study, it is concluded that the treatment process will meet all applicable waste acceptance criteria (with the exception of the total volume of treated waste) if the system is operated within the stated formulation, water-to-pozzolan ratio, and waste loading ranges. Specific waste acceptance criteria (WAC) requirements were addressed by the treatability study as follows:

- The treatment is the minimum needed to meet all WAC.
- The treated waste will not contain free liquids as measured by the Paint Filter Liquids Test Method 9095 (SW 1992).
- The treated waste will be in particulate form, not a monolith. The particle size will be less than 3 inches and will not tend to agglomerate when the system is operated on the drier end of the water-to-pozzolan range.
- The treated waste will not agglomerate into particles greater than 3 inches when mixed with site soil.
- The treated waste will be resistant to dispersion by wind. The conceptual design of the treatment system uses a screen to capture any fine particles and recycle them back into the treatment process, which will allow the system to operate at the dry end of the water-to-pozzolan range.
- The treated waste will have a pH of 12 or greater, which is sufficient to inhibit the biological degradation of any organics. The lack of biological activity will reduce the potential for gas generation.
- The volume of the treated waste, when added to the volumes of the other treated wastes, will slightly exceed 20,000 cubic yards (cy).
- The leachate will not contain any of the constituents of concern at concentrations that are not protective of human health and the environment. This is based on comparison of TCLP leach data with values predicted by a contaminant transport model using the design infiltration rate of 0.0068 inch per year for the OU4 closure. It is also noted that the leachate complies with the LDR standards applicable to pondcrete.

5.2 PONDCRETE METALS

Following are the conclusions of the treatability study conducted on the pondcrete triwalls in metal containers.

5.2.1 Formulation

The CSS formulation selected for the pondcrete triwalls includes hydrated lime, Type C fly ash, and Type I/II Portland cement. The lime is added at 7.5% by weight of the untreated waste. The fly ash and cement are combined in a 2:1 fly ash/cement ratio, and are added at a rate determined by the desired water-to-pozzolan ratio.

5.2.2 Water-to-Pozzolan Ratio

Compliance with waste acceptance criteria was achieved at water-to-pozzolan ratios from 0.35 to 1.0. The optimum range for achieving a friable product is a subset of this range, at water-to-pozzolan ratios from 0.45 to 0.55.

5.2.3 Waste Loading

The treatability study testing was conducted on waste with total solids concentrations that ranged from 38.8 percent (as received) to 48.6 percent which brackets the material as it currently exists on site (see Section 5.1.3). The treatability study results indicate that the proposed stabilization formula will produce a final product that meets the waste acceptance criteria if the waste loading is within the above range. It should be noted that waste with lower solids concentrations can be effectively treated by adding additional pozzolans.

5.2.4 Waste Acceptance Criteria Compliance

Based on the results of the treatability study, it is concluded that the treatment process will meet all applicable waste acceptance criteria (with the exception of the total volume of treated waste) if the system is operated within the stated formulation, water-to-pozzolan ratio, and waste loading ranges. Specific WAC requirements were addressed by the treatability study as follows:

- The treatment is the minimum needed to meet all WAC.

- The treated waste will not contain free liquids as measured by the Paint Filter Liquids Test Method 9095 (SW 1992).

- The treated waste will be in particulate form, not a monolith. The particle size will be less than 3 inches and will not tend to agglomerate when the system is operated on the drier end of the water-to-pozzolan range.

- The treated waste will not agglomerate into particles greater than 3 inches when mixed with site soil.

- The treated waste will be resistant to dispersion by wind. The conceptual design of the treatment system uses a screen to capture any fine particles and recycle them back into the treatment process, which will allow the system to operate at the dry end of the water-to-pozzolan range.

- The treated waste will have a pH of 12 or greater, which is sufficient to inhibit the biological degradation of any organics. The lack of biological activity will reduce the potential for gas generation.

- The volume of the treated waste, when added to the volumes of the other treated wastes, may slightly exceed 20,000 cubic yards (cy).

- The leachate will not contain any of the constituents of concern at concentrations that are not protective of human health and the environment. This is based on comparison of TCLP leach data with values predicted by a contaminant transport model using the design infiltration rate of 0.0068 inch per year for the OU4 closure. It is also noted that the leachate complies with the LDR standards applicable to pondcrete.

5.3 SUMMARY

The CSS formulation developed for pondcrete meets all of the goals of the treatability study. Following is a summary of the major conclusions of this treatability study:

- The treatment system is able to meet all waste acceptance criteria with the exception of total volume of treated waste, for the wastes studied.

- The formulation developed for pondcrete relies on the addition of a blend of fly ash and cement to eliminate the free water. Lime is also added to stabilize the treated waste to reduce the potential for biological decomposition of any organics. By slightly adjusting the lime dosage, the formulation is also able to achieve maximum reduction of leachability of most metals and radionuclides of concern.

- The treatment system produces a friable product, which is a more desirable final product than a monolith. The friable product can be transported directly to the OU4 closure area for disposal, whereas a monolith would require additional processing before disposal.

- The rapid curing of the treated waste, and thus the rapid compliance with the WAC, minimizes the staging area requirements for the treatment system. A curing time of 24 hours is sufficient before placement in the OU4 closure can occur. The treated pondcrete should be protected from fly ash during this curing period.

- A single formulation was developed for both types of pondcrete (also the same formulation for treatment of pond sludge). This enhances the operability of the system.

The process operating ranges of key parameters for treatment of pondcrete is as follows:

- Pondcrete Triwalls (PCTW)
  - Waste loading total solids: . . . . 25% to 40%
  - Water-to-pozzolan ratio tested that met WAC: . . . . 0.20 to 0.30
  - Water-to pozzolan ratio that produces a friable product: . . . . 0.22 to 0.27
  - Lime addition by weight of waste feed: . . . . 7.5% ± 2.5%

- Pondcrete Metals (PCM)
  - Waste loading total solids: . . . . 38.8% to 48.6%
  - Water-to-pozzolan ratio tested that met WAC: . . . . 0.35 to 1.0
  - Water-to-pozzolan ratio that produces a friable product: . . . . 0.45 to 0.55
  - Lime addition by weight of waste feed: . . . . 7.5% ± 2.5%

REFERENCES

ASTM (American Society for Testing and Materials), 1988. "1988 Annual Book of ASTM Standards," Section 4, Volume 4.08, D4219-83, American Society for Testing and Materials (ASTM), Philadelphia, PA.

Colorado 6 CCR 1007-3, Colorado Department of Health, Waste Management Division, "Standards for Owners and Operators of Permanent Hazardous Waste Treatment," and "Interim Standards for Owners and Operators of Interim Hazardous Waste Treatment, Storage and disposal Facilities," November 30, 1982 (revised through May 31, 1984 and amended through October 31, 1994).

Conner, J. R., 1990. Chemical Fixation and Solidification of Hazardous Wastes, 1990. Van Nostrand Reinhold, New York, NY.

Dean, J. A., 1979. Lange's Handbook of Chemistry, 1979. McGraw-Hill Book Company, 12th Edition, New York, NY.

Faust & Aly 1983. Chemistry of Water Treatment, 1983. Butterworth Publications, Boston, MA.

HNUS 1992b, "Treatability Study Report and Process Formulation Report for Pond 207C and Clarifier (Deliverable 235A, 236A, 235E, 236E)," July 1992. Prepared by Halliburton NUS Environmental Corporation for EG&G Rocky Flats, Inc.

HNUS 1992c, "Pond Sludge Treatability Study Report and Process Formulation Report/Ponds 207A, 207B North, 207B Center and 207B South" (Deliverable 235A1, 236A1)," Prepared by Halliburton NUS Environmental Corporation for EG&G Rocky Flats, Inc., July 1992.

HNUS, 1992d, "Pondcrete Waste Characterization Report (Deliverable 224B)," September 1992. Prepared by Halliburton NUS Corporation for EG&G Rocky Flats, Inc.

Linke, W. F., 1958. Solubilities of Inorganic and Metal Organic Compounds, 1958. American Chemical Society, 4th Edition, Washington, D.C.

SM 1989. "Standard methods for the Examination of Water and Wastewater," American Public Health Association, 17th Edition, Washington, D.C.

Stumm & Morgan, 1970. Aquatic Chemistry, 1970. John Wiley & Sons, Inc., New York, NY.

SW 1992, "Test Methods for Evaluating Solid Waste - Physical/Chemical Methods," Revised July, 1992. U.S. Environmental Protection Agency, SW-846, 3rd Edition, Office of Water and Waste Management, Washington, D.C.

USEPA (U.S. Environmental Protection Agency) 1983. "Methods for Chemical Analysis of Water and Wastes," 1983. U.S. Environmental Protection Agency, EPA-600/4-79-020, Office of Research and Development, Cincinnati, OH.

USEPA, 1974. "Process Design Manual for Upgrading Existing Wastewater Treatment Plant," October 1974. U.S. Environmental Protection Agency, EPA-625/1-71-004a, Office of Technology Transfer, Washington, D.C.

USEPA, 1977. Process Design Manual, Wastewater Treatment Facilities for Sewered Small Communities," October 1977. U.S. Environmental Protection Agency, EPA-625/1-77-009, Office of Technology Transfer, Washington, D.C.

USEPA, 1994. "Guide to Septage Treatment and Disposal," September 1994. U.S. Environmental Protection Agency, EPA-625/R-94/002, Office of Research and Development, Cincinnati, OH.

USEPA 40 CFR 264, "EPA Regulations for Owners and Operators of Permitted Hazardous Waste Facilities," May 19, 1980 (revised through July 1, 1992 and amended through December 6, 1994).

USEPA 40 CFR 265, "EPA Interim Status Standards for Owners and Operators of Hazardous Waste Facilities," May 19, 1980 (revised through July 1, 1991 and amended through December 6, 1994).

Wienand & Howard 1992, "Rocky Flats Solar Program Lessons Learned."

Weston 1991. "Sampling and Analysis of Solar Pond Water and Sludge," July 1991. Prepared by Roy F. Weston, Inc. for EG&G Rocky Flats, Inc.

APPENDIX A

EQUIPMENT RECOMMENDATIONS REPORT

PONDCRETE EQUIPMENT RECOMMENDATION REPORT

Throughout the course of the treatability study for the Rocky Flats Environmental Technology Site (RFETS), physical and chemical properties of the pondcrete and of the final, friable soil type, product have been measured and observations noted. These data, combined with the applicable data/results from past treatability and characterization studies, were used to evaluate the compatibility of the recommended equipment, pondcrete waste, and additives. Also, physical properties of the friable product were evaluated during the selection of the materials handling equipment. All equipment selected for the process train are capable of handling a wide range of physical properties. Upon review of the equipment selected and the properties of the wastes and products, no vendor-specific equipment will be required. All equipment is of the "off-the-shelf" type. However, the Conceptual Design Report (CDR) will provide a vendor-specific listing of equipment in order to finalize the design and equipment lay down arrangement drawings. Following is a brief description of the major unit operations and equipment.

Transfer of the Pondcrete From the Interim Storage to Size Reduction and Treatment

The transfer of the Pondcrete from the interim storage to the processing train will be accomplished using standard fork-lift trucks. The fork-lift trucks will deposit the metal containers or triwalls onto a lifting mechanism located at the foot of the primary size reduction unit. This lifting mechanism will deposit the contents of the metal containers into the primary shredder. The empty metal container will then be placed on a temporary storage pad. These equipment are standard off-the-shelf items. However, the equipment must meet the design specifications as described in the pondcrete white paper and CDR.

Storage and Feeding of Treatment Additives

The treatment additives storage and feed unit process operation consists of bulk storage silos, rotary valve feeders, weigh-belt conveyors, and screw conveyors. This equipment is routinely used to store and feed dry bulk reagents, such as pozzolans and lime. These common additives (cement, fly ash, and lime) have no characteristics that preclude the use of commonly available, off-the-shelf type of equipment for this unit operation.

Pondcrete Size Reduction and Mixing/Blending Treatment With Additives

The pondcrete size reduction unit process operation will be completed using primary, secondary, and tertiary equipment to achieve 6", 1", and 0.5" size reductions, respectively. The primary size reduction equipment consists of a screw-auger type shredder. Both the secondary and tertiary units are either of the ring-and-pick type or screw-auger type shedder. The physical and chemical properties of the pondcrete and the packing material do not exclude the usage of "off-the-shelf" type of equipment for any of the size reducing steps. However, specific design criteria are specified within the pondcrete white paper and forthcoming CDR.

Treated Waste Storage and Testing

The equipment specified within the treated waste storage and testing unit process operation is roll-off type containers with removable covers. These containers are commonly used to transport soil-like materials. The potential for dusting will be controlled with the use of covers. The final product, being a friable soil-like material, will have minimal dusting properties as specified in the WAC. These containers will also be used for the treated waste transfer to the Operable Unit 4 closure area. Upon consideration of the physical and chemical properties of the final product, no specialized containers will be needed.

APPENDIX B

MODELING REPORT

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
OPERABLE UNIT 4 SOLAR PONDS DISPOSAL FACILITY
WASTE ACCEPTANCE CRITERIA DEVELOPMENT

TABLE OF CONTENTS

TABLES

FIGURES

NUMBER

APPENDIX B

MODELING REPORT

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
OPERABLE UNIT 4 SOLAR PONDS DISPOSAL FACILITY
WASTE ACCEPTANCE CRITERIA DEVELOPMENT

The liquid-phase Waste Acceptance Criteria (WAC) is the chemical-specific leachate concentration generated from the waste material in an engineered disposal facility which will ensure an acceptable groundwater concentration at the point of compliance (POC) within a required protective time frame. The waste material to be placed in the disposal facility is from the Solar Evaporation Ponds (SEP)s at the Rocky Flats Environmental Technology Site (RFETS). The leachate concentrations of treated or untreated waste materials which are proposed to be placed in the disposal facility will be estimated using the Toxicity Characteristic Leaching Procedure (TCLP). The material-specific TCLP results will then be compared to the WAC value to determine whether the material is acceptable for placement in the disposal facility.

B.1.0 INTRODUCTION AND OBJECTIVES

This report presents WACs for the SEP disposal cell and a brief description of their development. The objective of the WAC development is to support the treatability study by providing a measure that can be used to determine the acceptability of either the untreated or treated waste material for placement in the disposal facility. For untreated waste material which is unacceptable to be placed in the disposal facility, the WACs will be used to determine the acceptability of the proposed mix designs to stabilize and treat the waste material. The WACs were developed for the same constituents of concern (COCs) that are to be tested for in the treatability study of Operable Unit 4 (OU4) waste materials (i.e., soil, sludge, debris, and pondcrete). The COCs are listed in Table B-1 along with the acceptable groundwater concentrations at the POC (Engineering Science/Parsons, 1995).

A computer groundwater contaminant fate and transport model for the SEPs was developed and calibrated using available site-specific data to support the WAC development. In the development of the model, previous modeling efforts conducted for the SEPs were reviewed. This task was performed so that information already available and concepts of groundwater flow could be efficiently incorporated into this modeling effort without duplicating work. The review of these previous modeling efforts is summarized in Section B.4.0. Site-specific data along with the available pertinent information from previous modeling was then used when appropriate in the development of the WAC development model. Once the model had been calibrated, it was used to determine WACs for various disposal facility designs and for a range of infiltration rates through the engineered infiltration barrier (cap). The range of infiltration rates will allow for design changes and/or changes in the assumptions of the long-term performance of the cap without the need for redeveloping the WACs.

B.2.0 CONCEPTUAL MODEL

The conceptual model of the contaminant fate and transport represents a simplified but conservative interpretation of the complex natural overburden and aquifer system under the RFETS and the movement of contaminants within it. The following paragraphs describe the groundwater flow beneath the SEPs and the simplified representation of it used in the WAC development model.

The SEPs currently consist of five ponds (207-A, 207-B [North, Central, and South], and 207-C). In the vicinity of pond 207-C, three ponds once existed but have since been removed and replaced by pond 207-C. The SEPs received process wastes (liquid and sludge) and sanitary effluent, which then evaporated from the ponds. The first ponds in this area were built in the mid-1950s. The ponds leaked and were repaired several times over their service life. It has been shown that the leakage from the ponds has adversely impacted groundwater quality beneath the SEPs (DOE 1993a). The groundwater in the vicinity of the RFETS has been grouped into upper and lower hydrostratigraphic units (UHSU and LHSU respectively). The UHSU, or "upper" aquifer, is unconfined and consists of surficial material (alluvium), weathered bedrock, and sandstone in hydraulic connection with the surficial deposits. The LHSU is a confined aquifer; however, the present understanding of the hydrogeologic relationships indicate that there are no known bedrock pathways through which groundwater contamination can directly leave the RFETS and migrate into a confined aquifer system off site (EG&G 1994). The groundwater table of the UHSU in the vicinity of the ponds is very close to the bottom elevation of SEPs. The material under the ponds consist of a relatively thin layer of alluvium on top of weathered bedrock, which in turn is on top of unweathered bedrock. Groundwater flow through the alluvium and the weathered bedrock under the ponds is generally to the north and east toward North Walnut Creek.

Conceptually, the liquids in the ponds leaked out of breaks in the pond liners into the unsaturated zone beneath the ponds. Some of the contaminants were adsorbed to the unsaturated soil as the contaminated liquids percolated to the saturated zone. When the leaks in the ponds were patched, the vertical flow of liquid through the contaminated soil was cut off so the contaminants had a tendency to remain in the unsaturated soil. In the saturated zone, some of the contaminant adsorbed to the soil and some traveled with the groundwater.

The historical loading of contaminants to the groundwater from the SEPs is very complex. The various construction techniques and timing of the construction of the SEPs, the varying contents and usage of the ponds, and the location and duration of leaks from the various ponds all contribute to a very heterogeneous contaminant loading pattern from the SEPs. This contaminant loading pattern has resulted in contaminant plumes under and around the SEPs that show a high degree of variability.

Comparison of the contaminant concentrations in the saturated zone over time with water-level measurements over time indicate that contaminant concentrations increase following rises in the water-table elevation beneath the SEPs. Figures B-1, B-2, and B-3 show plots of tritium, nitrate, and uranium-238 concentrations, respectively, in well 2886 with time. These figures also present the water-level in these wells over the same time period that the concentration measurements were made. As can be seen from the plots, following the period of high water around June 1987, the concentration for each of these constituents increased. The same effect is shown to a lesser degree following a period of high water in April 1992 for nitrate and tritium. This may have been caused by water entering soil that is generally unsaturated and washing previously adsorbed contaminants out of this zone. The smaller fluctuations in the groundwater table do not show the corresponding fluctuation in the concentrations because the portion of soil that is becoming saturated is regularly saturated so the release of constituents from the soil is more constant.

The WACs were developed for the future condition which includes the proposed disposal cell. The proposed disposal cell design incorporates a low permeability engineered cover approximately ten feet thick. The waste materials are in turn located under the engineered cover. There is no liner below the waste materials in the proposed design. The design does include a drainage layer beneath the waste to prevent the groundwater table from rising and coming in contact with the waste material. Conceptually, if the groundwater table rises, water will enter the drainage layer. This layer is designed to carry the flow laterally away before it can rise further and come in contact with the disposal cell contents. In the event that contaminants do leach out of the disposal cell (the focus of this study), the leachate will enter this drainage layer and travel laterally to the POC. In this case, if the leachate was not collected, the WACs would directly match the groundwater compliance criteria. The development of the WACs presented herein considers the time frame in which the maintenance of the disposal cell can no longer be assured. Since the design life of the disposal cell is 1000-years, it is unlikely that maintenance on the disposal facility will be continued for the entire design life. It is assumed then that the drainage layer beneath the disposal cell becomes plugged and does not function. The leachate leaving the disposal cell then migrates vertically down into the unsaturated and saturated zones beneath the disposal cell, where it travels with the groundwater.

WACs were developed for three design scenarios. The first scenario is the proposed design condition presented in the IM/IRA Decision Document (DOE, 1995a) and is the focus of the treatability study. The other two scenarios were conducted to determine the WACs under conditions where the groundwater flow under the disposal cell is cut off with shallow trenches. These two scenarios were developed during the WAC development to determine the effect of limiting the groundwater flow beneath the disposal cell. In scenario 2, shallow trenches would be constructed around the disposal cell to limit the fluctuation of the water table under the disposal cell. In scenario 3 the trenches are constructed deeper to the bedrock surface to cut off more groundwater flow under the disposal cell.

B.3.0 MODELING TOOLS

The WACs were determined using a computer groundwater contaminant fate and transport model. This model is implemented on the spreadsheet software Excel 4.0 and Crystal Ball 3.0 and is called ECTran (which stands for Excel-Crystal Ball Transport [Chiou 1993, DOE 1993b]). Based on a conceptual understanding of the site, the ECTran model of the SEPs was first calibrated to simulate the existing contaminant plumes, process which enabled the estimation and further refinement of flow and chemical mobility parameters. The following paragraph discusses how the conceptual groundwater flow and contaminant fate and transport at the SEPs discussed above was modeled with ECTran.

The conceptual model of the groundwater flow under the SEPs includes two layers, an unsaturated zone and a saturated zone. Based on the average high water-table elevation, a typical, conservative (thin) thickness of the unsaturated zone was estimated to be 3 feet and the saturated thickness above the bedrock was estimated to be 5 feet. For the WAC development of this modeling task, the ECTran simulation begins at the bottom of the disposal cell (i.e., leachate concentrations exiting the disposal cell are input into the ECTran simulation). The ECTran model uses constant layer thicknesses. The underlying bedrock and the flow through it were not simulated for most of the WAC development scenarios in the modeling since the flow through the bedrock of the UHSU is much slower than the alluvium (DOE 1993a). For the scenarios in which flow through the alluvium is not controlled, contaminants that leak out of the disposal facility will reach the POC quicker in the alluvium (than in the bedrock) so the model-predicted concentrations in the saturated alluvium were used to determine the WAC values. For the scenario in which the flow through the alluvium is controlled, the predicted concentration in the bedrock at the POC is used to develop the WACs. Additional constant water flow through the unsaturated zone was added in the model to simulate the washing effect on the unsaturated zone by the fluctuation of the groundwater elevation. The amount of this additional flow through the unsaturated zone was estimated during the model calibration.

B.4.0 REVIEW OF PREVIOUS MODELING EFFORT AT THE SEPS

In addition to the ECTran model set up to develop WACs and described in this appendix, three other modeling efforts have been under taken specifically for the SEPs. The three other models which have been or are being applied to the SEPs are as follows: infiltration estimation through the proposed low permeability cover with the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al, 1994, 1988), contaminant leaching from the disposal cells through the unsaturated zone beneath the disposal cell with the VLEACH model (as described in the IM/IRA Document [DOE, 1995]), and in an ongoing task, the VS2DT model (USGS, 1993) is being set up to provide a more detailed contaminant flow and transport analysis describing the leaching of the contaminated materials out of the disposal cells and the subsequent transport of the contaminants in the unsaturated and saturated zones. Results of the HELP model and the VLEACH model are presented in the IM/IRA Document (DOE, 1995a). A description of the VS2DT model is presented in the IM/IRA document and preliminary results of this ongoing modeling effort have been provided to HNUS to review. The following paragraphs will summarizes the modeling effort of each of these three tasks. A discussion will then be presented which describes the purposes of the WAC development in relationship to these other modeling efforts at the SEPs.

B.4.1 HELP Model Application

The annual infiltration through the proposed engineered cover of the disposal cell was estimated using version 2.05 of the HELP model. The HELP model simulated flow through the cover system using available site-specific and simulated climatological data. Six modeling scenarios are presented in the IM/IRA document. The modeling scenarios range from a normal condition to a condition assuming a 300 percent increase in precipitation due to possible climatic changes over the 1000-year design life of the disposal cell. The infiltration under normal conditions was estimated as 0.0068 inches of infiltration per year. For the 300 percent increase in precipitation case, the infiltration increased to 0.0075 inches of infiltration per year. Discussed in Section B.5.1, the current amount of infiltration around the SEPs was estimated to be about 1 inch of infiltration per year. These results indicate that the engineered cover as designed will significantly decrease the amount of infiltration which reaches the waste material even under a conservative assumption of substantial changes in the climatic conditions over the 1000-year design life of the facility.

B.4.2 VLEACH Model Application

The VLEACH model is a one-dimensional vadose zone leaching model developed for the EPA. The modeling at the SEPs was conducted using version 1.02 of this model. The model is capable of simulating the movement of contaminants in the vertical direction through an unsaturated zone. The VLEACH model used for the SEPs and described in the IM/IRA document modeled a 27 foot thick column representing the disposal cell. This 27 foot column was divided into 27 one foot thick finite difference cells. Each of the cells in the VLEACH model must be described by the same physical parameters but can contain varying contaminant concentrations. The top ten feet of the column represented the engineered cover which was assumed to be clean, the next fourteen feet represented the waste materials, and the final three feet represented the drainage layer under the landfill (also assumed to be clean).

The VLEACH model simulated the leaching of contaminants from the disposal cell contents down to the drainage layer. The concentration of the disposal cell contents was estimated based on a volumetric average of the proposed contents of the disposal cell without treatment. The leaching of seven COCs were modeled using VLEACH assuming literature values for the soil / water partitioning coefficient, K_d. Four model scenarios were run using infiltration rates through the disposal cell estimated with the HELP model. One scenario assumed no action at the SEPs, and three scenarios were run assuming the proposed engineered cover was in place and varying climatic changes (normal, 300 percent increase in precipitation, and a projected 100 year storm event). The maximum leachate concentration was then converted to a depth averaged concentration in the groundwater beneath the disposal cell. This concentration was then compared to the compliance criteria. The no action scenario produced contaminant concentrations above the compliance criteria. All of the capping scenarios estimated contaminant concentrations below the compliance criteria.

B.4.3 VS2DT Model Application

The VS2DT model of the SEPs is currently under development. The VS2DT model is intended to be used primarily as a design tool during the Title II design. The VS2DT (Version 2.0) is a numerical two-dimensional multi-layer, variably saturated contaminant transport computer model developed by the U.S. Geological Survey (Lappala, et al., 1993, Healy 1990). The VS2DT model will allow a more detailed analysis of the leaching of contaminants from the disposal cell contents. The VS2DT results are expected to confirm or validate the VLEACH model results (DOE, 1995a). Advantages of the VS2DT code over the VLEACH model is the ability to simulate the lateral flow of contaminants in the drainage layer under the disposal cell, and the VS2DT model will allow different physical parameters to be assigned to various cells in the model which was not possible in the VLEACH model. The VS2DT model will also allow for a varying distribution of contaminant parameters in the horizontal plane. This ability will allow a more detailed analysis of the leaching of contaminants from the waste disposal cell.

Preliminary model runs have been made for four COCs with the VS2DT model. (ES/Parsons 1994) The preliminary runs consisted of a two-dimensional model grid of a cross section through the proposed disposal cell. The VS2DT model grid includes the contaminated material, the drainage layers under the disposal cell contents, the variably saturated underlying soil, and an assumed impervious bedrock layer beneath the soil. The K_d values used in the preliminary VS2DT runs were based on literature values. In the description of the preliminary results, the need for using site specific partitioning and physical soil parameters was expressed. At the present time the VS2DT modeling is awaiting completion of lab tests conducted to estimate these site specific parameters.

B.4.4 Comparison of Modeling Applications

Each of the contaminant transport codes, VLEACH, VS2DT, and the ECTran (described in Section B.3.0) use the HELP model predicted average infiltration amounts thought the disposal cell. The WAC development incorporates a very conservative approach by determining the maximum leachate concentration leaving the disposal cell which will result in an acceptable groundwater concentration if that leachate concentration was being uniformly released under the entire disposal cell. In this way, no matter where the waste is placed within the disposal cell as long as it does not produce a leachate concentration higher than the WAC, the groundwater concentration at the point of compliance will not be exceeded. In this way the ECTran model objective is to create a bound on the contaminant concentrations in the groundwater (i.e., WAC only attempts to ensure that the groundwater concentration is below a certain value). The VS2DT model in contrast when completed, will attempt to predict the groundwater concentration knowing the types, location within the disposal cell, and quantity of each of the materials being placed in the engineered cover. The VS2DT model will be used to confirm the other modeling which was completed for the SEPs. The WACs were developed with the ECTran model so that conservative criteria could be developed in a timely manner and used for the treatability study of the material to be placed in the disposal cell.

B.5.0 ECTran MODEL CALIBRATION

The ECTran model calibration is used to ensure that the computer model set up in accordance with the conceptual understanding of the site is accurately or conservatively simulating the transport of contaminants. The calibration is completed by refining estimations of model input parameters (e.g., flow parameters and chemical mobilities). Once the model has been calibrated, it was used to determine the WACs. During the model calibration, the past loading of contaminants are simulated and the input parameters adjusted until the predicted groundwater contaminant concentrations match the groundwater sample results. The computer model of the SEPs is a simplified representation of the subsurface movement of contaminants. Due to the heterogeneous nature of the contaminant loading and the corresponding variation of the contaminant concentrations in the groundwater, the simplified, modeled representation of the contaminant transport only attempts to yield an acceptable prediction of the typical measured groundwater data and is not intended to match every data point.

The calibration allowed the estimation of parameters which could not be or had not been measured and therefore were unavailable for use in the current modeling. The model calibration resulted in estimates of model parameters such as layer- and COC-specific soil/water partitioning coefficients (K_ds), infiltration rate, and lateral flow rates in both the unsaturated and saturated zones.

Calibration data were available from: previous modeling efforts for the SEPs, groundwater analytical data, lysimeter analytical results in the unsaturated zone beneath and around the SEPs, soil analytical results from samples taken from the lysimeter bore holes, and characterization of the pond contents for two periods (1984-1988, and 1991).

Groundwater analytical data were available for 46 wells in the vicinity of the SEPs. Only the wells which were screened in the UHSU were considered in the calibration. The wells were grouped into three categories: upgradient, under-source, and downgradient wells. Wells which were cross gradient to the average high water-level contours were not used in the calibration. The model was then calibrated to predict concentrations which were representative of the measure groundwater concentrations. Table B-2 lists the wells used in the calibration. The well data span the time frame from 1987 to the present; however, most of the data are more recent.

B.5.1 Hydraulic Parameters

Simulating the past loading of contaminants requires knowing the amount of water leaking from the ponds to the groundwater. This was estimated by calculating the groundwater flow rate upgradient and downgradient of the SEPs and performing a mass balance to determine how much water entered the system. The water entering the system would represent the amount of water infiltrating into the pervious ground surface surrounding the ponds and the amount of water leaking from the bottom of the ponds. It was assumed that the water infiltrating vertically to the bedrock was negligible for this estimate of the infiltration rate, since the groundwater velocity in the bedrock has been estimated to be much less than the alluvium, which would indicate a lower hydraulic conductivity. Calculation of flow velocities and gradients were based on the average high water-table elevations. The hydraulic conductivities were based on the values presented in a previous modeling effort at the SEPs (i.e., preliminary VS2DT runs).

The model was first calibrated using tritium because the mobility of tritium is very close to that of water (DOE, 1995a) so that a good estimate of the soil/water partitioning coefficient (K_d) (e.g., very close to zero) can be made. Since tritium's mobility is already known, it was used to estimate or refine the flow parameters in the model, such as the infiltration rate, the flow used to simulate the fluctuating groundwater table in the unsaturated zone, and the flow parameters in the saturated zone. Some of the tritium concentrations in the groundwater were higher than the available characterization of the contents of the ponds. The source of contamination must have been higher at some time prior to the characterization available from 1984-1988 and 1991 to cause these higher groundwater concentrations. Because the source loading must have been higher than the characterization concentrations of the ponds, the source concentration for tritium was then calibrated along with the flow parameters. The length of source loading was taken as 32 years for tritium (the time that pond 207-A was put into operation in 1956 until the sludges were cleaned out of this pond in 1988). For the model calibration, ponds 207-A and the 207-B ponds were simulated using a single source area because of the proximity of the ponds. The groundwater flow from pond 207-C appears to travel almost directly north rather than north and east for the other ponds, therefore, 207-C was not included in the calibration source area (See Figure B-4). Figure B-4 is a plot of the mean seasonal high groundwater elevations with the source area used in the ECTran model for calibration superimposed on it. Figure B-4 is reproduced from the OU4 IM/IRA Decision Document (DOE, 1995a). Figure B-5 presents the conceptual model used for calibration.

Tritium was calibrated to three points in the flow system below the SEPs, in the unsaturated zone under the source, the saturated zone under the source, and the saturated zone downgradient of the source area. Lysimeter 43193 upper cup results were used as the calibration target for the unsaturated zone. Tritium sample results from the under source wells (both alluvium and bedrock) were used for the saturated zone, and results from wells P209889 and P209589 were used for the downgradient targets. Both of these wells are screened in the bedrock but were still used in the calibration of tritium, since no downgradient wells screened in the alluvium were available for calibration. Plots of the predicted and measured groundwater concentrations for tritium for each of these points are shown in Figures B-6 through B-8. As can be seen in Figures B-6 through B-8, the measured concentration data fluctuates. The model calibration is intended to predict typical concentrations and so the predicted concentrations do not fluctuate to the same degree as the measured data.

Figure B-7 includes the upgradient well concentrations in addition to the under-source wells for reference. As can be seen from the plots, the concentration of tritium decreases rapidly under the source as the source loading decreases. This indicates that the tritium is being "washed" out from underneath the source. The downgradient wells do not show this same effect as rapidly because the washing effect is delayed by the groundwater travel time to the downgradient wells. The predicted downgradient concentration matches the data from well P209889 much better then well P209589. Well P209589 tritium concentration is higher than well P209889. This may be the result of a quicker washing effect at well P209889, which indicates a higher flow of water around this well. Calibrating to this well should result in more conservative flow parameters to be used in the development of the WACs. The calibrated hydraulic flow parameters are shown in Table B-3.

B.5.2 COC Mobility Parameters

The fate and transport calibration of the COCs used the hydraulic parameters defined from the calibration of tritium. The COCs were primarily calibrated to concentrations in the under-source wells, since the POC for the WAC development is essentially under the source.

The initial values of the mobility parameters (K_ds) were estimated two ways and then refined by the model calibration. The first estimate of the K_d values was made by reviewing literature values and values used in previous modeling at the SEPS for each of the COCs (see section B.4.0). The second method calculated K_d values based on liquid concentrations of pore water in the vadose zone from the lysimeter data and soil concentration data from soil samples taken in the same location and depths as the lysimeter cups. It was assumed that the liquid and soil concentrations were at equilibrium. Based on this assumption, a K_d value was then estimated from this data by dividing the solid concentration by the liquid concentration after subtracting out the background concentrations. Any data pairs in which one or both of the solid and liquid concentrations were either nondetect or below background were not used in the calculation of K_d. Positive data for both solid and liquid samples were available to calculate K_d values for cadmium, uranium, and radium-226. The geometric mean of the chemical-specific K_d values calculated with the lysimeter data was used as the initial values in the calibration.

The K_d values were then refined by the model calibration. By definition, the K_d value represents the soil water partitioning coefficient, which is a measure of a chemical's affinity to adsorb to soil from the liquid phase and is therefor a measure of the chemical's mobility through its interaction of adsorption and desorption to soil. When a chemical is calibrated to groundwater data in a model which uses only the K_d value to simulate chemical mobility, the K_d value no longer only accounts for the adsorption and desorption of the chemical to the soil but also other mechanisms which are affecting the mobility of the chemical such as colloidal transport. The calibrated K_d values can then be thought of as a lumped mobility parameter accounting for the various mobility mechanisms which are occurring between the source and the measurement point of the groundwater concentration. It would not be unexpected then that the K_d values determined through calibration could be lower than literature values determined through tests which only considered adsorption and desorption.

The concentration of the liquids in the SEPs was assumed to be the source-loading concentration to the groundwater. The concentration of the contents of the SEPs were only available for two time periods; 1984-1988 and 1991. Prior to this, the concentration of the source loading to the groundwater in the model was assumed. In most cases of the calibrations, the source loading prior to 1984 was assumed to be the same as the source loading from 1984 to 1988. The source loadings used in the model were taken from the range of measured concentration data in the 207-A and the 207-B ponds. All of the calibrations of the COCs then used a two-step loading to the groundwater; the first step from years 1956 to 1988 (32 years) and the second step from 1988 on. The characterization of the SEPs in 1984 to 1988 was used for the first loading step and the characterization from 1991 was used for the second loading step.

Based on the amount of information available and the relationship of the various data available to the calibration, the calibration of the COCs can be grouped in to several categories that contain different levels of confidence in the calibration results. Most of the COC's source-loading concentrations were available for the calibration, and an ample number of groundwater sample results under the source were also available. The following are exceptions. No source-loading data was available for radium-226. The source loading was calibrated using the K_d values calculated with the lysimeter data. This calibration was conducted primarily to determine whether if it was possible for the model to predict concentrations in the groundwater similar to the measured concentrations using the calculated K_d value. The calibration of arsenic is similar in that the available source-loading matched the measured concentration under the source. The concentration of the source-loading must have been higher than the concentration under the source at sometime during the operation of the SEPs. The source concentration was then also assumed for arsenic. Only total cesium source data were available for the SEPs. It was assumed that the mobility of total cesium is similar to the cesium isotopes and could be used for cesium-134 and -137. In addition, only two sample results were available for total cesium under the source to be matched to the predicted concentration during the calibration. Due to the limited data for radium, cesium, and arsenic, the calibrated mobility values for these COC should be viewed as more uncertain that the other COCs. Very few positive detections of the organic COCs exist in the vicinity of the SEPs. Because of the lack of positive detections, calibration of the organic COCs could not be performed for these chemicals. Literature values of the K_d values were used in developing the WACs for these chemicals.

Table B-4 lists the COC-specific K_d values determined during the calibration, the literature values, and calculated K_d values from the lysimeter data. The mobility of all of the uranium isotopes was assumed to be the same so only U-238 was calibrated. For comparison purposes, Table B-5 lists K_d values used for radionuclides at other DOE facilities. The K_d values used in this study are generally within the lower range of values used at other DOE facilities. None of the K_d values used in this study are higher than this range of values and two K_ds are lower. Cesium and Plutonium K_d values for the saturated zone are lower than K_d

values reported from these other sites. This comparison shows that the K_d values used in this study are generally conservative compared to the K_d values used at the other DOE sites listed. Table B-6 lists the K_d values used for the organic COCs. The same K_d values were used for both the saturated and unsaturated zones. Figures B-9 through B-19 present plots of the calibration results under the source for each of the COCs.

B.6.0 WASTE ACCEPTANCE CRITERIA

As was discussed previously, the WAC is the leachate concentration from the waste that will not exceed the acceptable groundwater criteria at the point of compliance if the leachate percolates out of the disposal facility. The WACs were calculated for three design scenarios and a range of infiltration rates through the cap for each scenario. The range of infiltration rates will allow for the changes in the design of the cap and/or changes in the assumptions of the long-term performance of the cap. This range is much wider than those used in the previous modeling efforts (see section B.4.0) since they did not consider the potential failure of the engineered cover.

Figures B-20 through B-22 provide drawings of the conceptual models of Scenarios 1, 2, and 3, respectively, for reference during the following discussion. The first scenario is the proposed design condition presented in the IM/IRA Decision Document (DOE, 1995a) and is the scenario used to develop the WACs that the treatability study results are compared to. The other two scenarios were developed during the WAC development to determine the effect of limiting the groundwater flow beneath the disposal cell with shallow trenches and reflect potential improvements to the proposed design. Each of the scenarios is described in greater detail in the following subsections.

The radiological and environmental degradation rates of each of the COCs where taken into account when developing the WACs. The half-lives for the radionuclides are shown in Table B-4 (inorganic COCs were conservatively assumed to not degrade) . The half-lives for the organics are shown in Table B-6. As can be seen from Table B-6, the half-lives of the organic COCs are all relatively short. The source leachate loading (WAC) for the radionuclide and the inorganic COCs were assumed to be constant (time invariant) over the entire 1000 year time frame. This is a conservative assumption since the amount of contaminant leaching from the disposal cell is limited by the amount of contaminant originally in the disposal cell. Since the half-lives of the organics are relativity short, the assumption of a constant loading may be too conservative (e.g., the organic COCs may nearly completely degrade during the 1000-year modeling time frame). A depleting source modeling approach was then used for the organic COCs. The depleting source was characterized by a 14 foot thick layer of waste (matching the VLEACH waste layer, see section B.4.0) with an assumed K_d equal to the K_ds used in the saturated and unsaturated zones. The WAC for the organic

COCs was the initial waste concentration converted to a liquid phase leachate concentration with the K_d value. The development of the WACs for each of the three modeling scenarios are discussed in the following subsections.

B.6.1 Scenario 1 (Currently Proposed Design)

Scenario 1 considers the placement of the engineered cover over the waste materials, but no groundwater cut off trenches to limit the flow of groundwater beneath the disposal cell. This scenario is conceptually similar to the current hydrologic conditions except that the infiltration through the waste material is reduced due to the engineered cover. Figures B-5 and B-20 present drawings of the conceptual models of the scenarios used for calibration and Scenario 1 respectively. The range of infiltration rates for which the WACs were developed will allow for conservative assumptions concerning the long-term performance of the cap (i.e., what would the WAC be if the impermeable layer fails after a certain number of years). The WACs were determined for a range of infiltration rates between 0.0068 to 2.5 inches per year. The estimated initial infiltration through the cap under normal conditions is 0.0068 inches per year (DOE, 1995a).
The source-area size used in the development of the WAC was based on the footprint size of the disposal facility. The POC for all of the scenarios is groundwater under the edge of the disposal facility. The ECTran model calculates an average concentration in the saturated zone beneath the source area. This average concentration was compared to the acceptable groundwater concentration in developing the WACs. The initial source leachate concentration in the model is iteratively adjusted until the modeled maximum groundwater concentration in 1000 years matches the water criteria. Figures B-23 through B-37 present the WACs for each of the COCs. These figures contain plots of the WAC values for each of the three design scenarios, which were modeled for comparison purposes.

The combination of relatively short half-lives, slow flow velocities, and high K_d values resulted in the contaminant plumes from all of the organic COCs, except arochlor-1254 , from reaching the POC. Theoretically this would result in a pure product concentration for the WACs so plots are not presented for these COCs. The half-live values for arochlor-1254 was not available from literature so no degradation of this organic was assumed. This resulted in the WAC values for arochlor-1254 being less than a pure product concentration. The WAC results for arochlor ar presented in Figure B-37.

B.6.2 Scenario 2 (Potential Improvements to the Proposed Design)

Scenario 2 is similar to Scenario 1 except that shallow trenches are dug around the waste disposal facility to limit the fluctuation of the groundwater table and shallow barrier walls are constructed around the waste disposal facility. This was modeled by removing the additional flow in the unsaturated zone determined during the hydraulic calibration. Figure B-21 presents the conceptual model of Scenario 2. The other assumptions and ranges of input values are the same as Scenario 1. The same iteration process that was used in Scenario 1 is used to determine the acceptable source leachate concentration for Scenario 2. Figures B-23 through B-37 present plots of the WAC for each of the COCs which were less than a pure product concentration.

B.6.3 Scenario 3 (Potential Improvements to the Proposed Design)

Scenario 3 is similar to Scenario 2 except that the trenches around the waste disposal cell are deepened to the bedrock surface and barrier walls are constructed around the waste disposal facility. This is intended to cut off the flow in the surficial materials from migrating under the waste disposal cell. Conceptually the only movement of water under the waste disposal facility is driven by the infiltration through the cap. Also the two overburden layers in the model are both assumed to be unsaturated in this scenario. However, it is assumed that the water infiltrating through these layers flows out radially from the waste disposal facility through the underlying bedrock layer. Looking at the cell in cross section half, of the flow would flow in one direction and the other half in the other direction. The distance that the average plume concentration would need to transverse and discharge into the cutoff trench would be one quarter of the width of the disposal cell. This distance was then used to calculate the travel distance of the average plume concentration through the bedrock to the edge of the disposal facility (the POC). Figure B-22 presents the conceptual model of Scenario 3.

Figures B-23 through B-35 present the plots of the WAC for each of the COCs which were less than a pure product concentration. The WAC for some of the COCs for Scenario 3 are not presented because the combination of the slow flow velocity in the bedrock and the relatively high K_d values result in the contaminant plume not reaching the POC within the 1000 year time frame. This is similar to the organic COC case, therefore, like the organic COCs, WAC plots were not included on the figures.

B.6.4 Summary of WAC Results

The WACs developed in this study allow for many combinations of design scenarios and assumed representative infiltration rates through the disposal facility. For comparison between the WAC and the TCLP leachate results of the treated and untreated waste materials, a specific scenario and infiltration rate must be chosen. Since the current disposal facility design matches Scenario 1, this scenario is recommended to be used for comparison. The WACs for Scenario 1 are generally lower than the other two scenarios evaluated. The infiltration rate of 1 inch per year was estimated as the current infiltration rate through the SEPs area (see Section 4.1). Using this infiltration rate for the WACs will provide an additional factor of safety and could account for potential degradation of the effectiveness of the cap. The actual infiltration through the cap will likely be much less (0.0068 inches per year predicted using the HELP model, DOE 1995), therefor the WACs used are conservative. Table B-6 lists the WACs for Scenario 1 and two infiltration rates through the disposal cell; 0.0068 and 1 inch per year. Waste treatment based on the lower WACs developed using a higher infiltration rate will provide an additional safety factor for the long-term protection of the groundwater.

B.7.0 SENSITIVITY ANALYSES

Sensitivity analyses were conducted to help describe the uncertainty of the WACs and the relative sensitivity of the WACs to certain model parameters. Deterministic and probabilistic sensitivity analyses were performed to determine the conservativeness of the WAC model. In both the sensitivity analyses a base simulation was chosen with which the sensitivity runs were compared. The deterministic analysis involved varying three input parameters one at a time to see the effect on the WAC values. The probabilistic sensitivity analysis used a Monte Carlo simulation and varied the same three input parameters as were varied in the deterministic analysis. The Monte Carlo simulation allowed the three input variables to be varied at the same time to determine the combined sensitivity effects. The Monte Carlo simulation was able to quantify the conservativeness of the WAC development by analyzing several cases assuming the potential failure of the impermeable liner in the engineered cover. The entire disposal cell is designed to last for 1000 years, however, this probabilistic analysis allows the estimation of the conservativeness of the WACs assuming that sometime in the next 1000 years an unforeseen event occurs which causes the impermeable layer to degrade. The time when this degradation (changing the infiltration rate) begins was one of the input parameters varied in the Monte Carlo simulation.

B.7.1 Ranges of Input Parameter Values

The three input parameters varied in the sensitivity analyses were, the K_d values, the infiltration rate (the time when the infiltration rate starts to change in the Monte Carlo simulation), and the additional flow in the unsaturated zone used to simulate the fluctuation of the groundwater table beneath the SEPs. The required input for the sensitivity analyses is different for the deterministic and probabilistic approaches. For the deterministic sensitivity analysis, the range of values for each of the input parameters to be varied is required. For the probabilistic analysis, parameters to define the statistical distribution (i.e., type of distribution[normal, lognormal, uniform, etc.], the mean, and the standard deviation) of the input parameters to be varied are required. The base simulation used to compare the sensitivity results used a source loading based on the WAC for uranium-238 and 1 inch of infiltration per year (177 pCi/L). The selection of the ranges of input values to be varied and the base simulation are described in the following paragraphs.

Soil/Water Partitioning Coefficient, K_d

Uranium was chosen from the COCs to be used in this sensitivity analysis and base simulation because it had the greatest number of lysimeter pore water/soil concentrations pairs used to estimate the K_d values. The calculated K_d pairs were used to determine the distribution of the K_d values. Eight pairs were available for uranium 233/234 and 7 pairs were available for uranium-238. It is assumed that all the uranium isotopes exhibit similar mobility characteristics so both the uranium-233/234 and uranium-238 can be used to estimate the distribution of the uranium K_d value. The 15 uranium K_d values correlated well to a lognormal distribution. A lognormal distribution was then assumed for the K_d values in the saturated and unsaturated zones with the mean of the distribution set at the K_d values determined during the model calibration. The standard deviation was assumed to be twice the mean value of the distribution. These statistical parameters were then used in the Monte Carlo simulation. The mean K_d value plus and minus the standard deviation was used as the range for the deterministic sensitivity analysis.

Additional Flow in the Unsaturated Zone

The additional flow in the unsaturated zone was assumed to be uniformly distributed with a mean value matching the flow rate determined in the model calibration (3460 l/day). The maximum flow rate for the uniform distribution (5460 l/day) was determined by calculating the maximum flow in the unsaturated zone assuming the entire unsaturated zone was saturated and assuming the same groundwater velocity used in the saturated zone. The maximum flow is 1820 l/day higher than the mean. The minimum flow rate for the uniform distribution was estimated as the mean minus 1820 l/day which is also 1820 l/day. These ranges of flow were used in both the probabilistic and deterministic sensitivity analyses.

Infiltration Rate Through the Engineered Cover

The engineered cover is designed to function without losing its integrity for 1000 years. The sensitivity simulations allowed the estimation of the effectiveness of the WACs should some unforeseen events or mechanisms occur which would cause the impervious layer to degrade within 1000 years. The first step in this process was to determine the infiltration rates through engineered cover assuming a range of different hydraulic conductivities for the impervious liner which would simulate the liner under various degrees of degradation. This range of infiltration rates were used in the deterministic sensitivity analysis. The smallest hydraulic conductivity in the range equaled the hydraulic conductivity (1 x 10^{-9} cm/s) assumed for the cap in HELP modeling completed for the IM/IRA Decision Document. The highest conductivity was assumed to equal the that of the soil cover of the top layer of the landfill (1 x 10^{-1} cm/s).

In January of 1995, a new version of HELP (Version 3.03 dated December 31, 1994) was distributed. To determine the infiltration through the cap for this sensitivity analysis the most recent version of HELP was used. The same inputs used in the HELP runs presented (based on version 2.05) in the IM/IRA Decision Document were used as inputs to the version 3 HELP model. Some changes have been made in the HELP model between versions 2.05 and 3.03 (e.g., a different evapotranspiration routine is now used) so that it was not unexpected that the results of the models differed somewhat. The infiltration under normal conditions reported in the IM/IRA Decision document using HELP version 2.05 was 0.0068 inches per year, the output using the same inputs and version 3.03 of the HELP model was 0.01 inches per year. All other infiltration rates discussed in this section were determined using version 3.03 of the HELP model. The infiltration rate through the cap became fairly constant around 2.1 inches of infiltration per year at a hydraulic conductivity greater than 1 x 10^{-4} cm/s. The range of infiltration rates used in the sensitivity analyses were 0.01 to 2.1 inches of infiltration per year. The pattern of infiltration and timing used in the Monte Carlo simulation are described in Section B.7.3.

B.7.2 Deterministic Sensitivity Analysis

The range of the input variables used in the deterministic sensitivity analysis are presented in Table B-8, The rational for these variable and the ranges was discussed in the previous subsection. In this deterministic sensitivity analysis, only one variable is changed at a time; all the other input variables are held constant. The sensitivity analysis changed the input parameters in the base run (the WAC simulation for uranium-238 and one inch of infiltration described in the previous section). Figures B-38 and B-39 present plots of the sensitivity of the WAC value to the unsaturated and saturated zone K_d values, respectively. As can be seen from the plots the WAC values are sensitive to the K_d values with the WAC values increasing with the K_d values. Figure B-40 shows that the WACs are also sensitive to the infiltration rate, however, in an opposite effect as the K_d values (i.e., as the infiltration rate increases, the WAC values decreases). Two sensitivity runs were made for the additional flow in the unsaturated zone. Depending on the infiltration rate, this parameter had opposite effects on the WAC value (See Figures B-41 and B-42). Under low infiltration rates, additional flow in the unsaturated zone tends to wash contaminants out of the soil, raising the groundwater concentration and therefore lowering the WACs. As can be seen from Figure B-41 as the additional flow in the unsaturated zone increases, the WACs decreases. Under high infiltration rates, enough flow (from infiltration) is available to carry the contaminant to the groundwater so additional flow in the unsaturated zone has a tendency to dilute the groundwater concentration and increase the WAC. Figure B-42 shows that, under higher infiltration rates, as the flow in the unsaturated zone increases the WACs also increase. The deterministic sensitivity analysis shows that the WACs are fairly sensitive to the three parameters tested.

B.7.3 Probabilistic Sensitivity Analysis

The Crystal ball portion of the ECTran model (see Section B.3.0) allows Monte Carlo simulations to be performed on several of the input parameters simultaneously to ascertain the combined effects of varying these input parameters. For each of the parameters varied in the Monte Carlo simulations, a statistical distribution must be assumed. Depending on the type of distribution other statistical parameters are also required such as the mean and the standard deviation. This sensitivity simulation used the constant WAC leachate concentration for uranium-238 considering design Scenario 1 and 1 inch per year of infiltration. The results of the simulation predict the likelihood that the compliance criteria at the POC will not be exceeded based on the WAC described above. Three input parameters were allowed to vary in the Monte Carlo simulation, and were briefly described in Section B.7.1 and are the same parameters used in the deterministic sensitivity analysis. The infiltration rate is changed in the probabilistic simulation, however, it varies according to a set pattern to simulate the degradation of the engineered cover. The time when this degradation begins is parameter described by a probability distribution in the Monte Carlo simulation.

The degradation of the liner was simulated in the sensitivity analysis with a set infiltration pattern that increased with time. It was assumed that the infiltration would take 800 years to increase linearly from the point (in time) of the beginning of the degradation and 0.01 inches of infiltration per year to an infiltration rate of 2.1 inches per year.

Four Monte Carlo cases were run. In all cases, all three of the input parameters are varied at the same time according to their respective probability distributions. One-thousand simulations were run for each case. The first case assumed that the degradation begins according to a normal distribution with a mean of 500 years and a standard deviation of 150 years. The second case assumed the same distribution for the time of initiation of degradation except the mean was 700 years. The third case had a mean of 800 years and the final case assumed that the impervious liner did not degrade in 1000 years. Table B-9 presents the input parameters and the results from the probabilistic sensitivity analysis. Figures B-43, 44, and 45 present the infiltration patterns assumed for cases 1,2, and 3, respectively. Figure B-46 presents a typical output report from the Monte Carlo simulation. The output presented is for case 1.

The compliance criteria at the POC for uranium-238 is 51.6 pCi/L. The sensitivity results show that based on the assumed degradation pattern of the impervious liner that if the liner began to degrade with a mean time of 500 years, the chance that the concentration at the point of compliance within 1000 years will not be exceeded is 65 percent. It should be noted here again that the liner is designed to last for 1000 years and these sensitivity analyses only represent "what if" scenarios in order to demonstrate the additional safety factor provided by the conservative WAC. As can be seen in Table B-9, for case 4 when the infiltration rate is not varied, the chance the contaminant concentration at the POC is below the compliance criteria is 100 percent. Also it can be seen that within 200 years the contaminant concentration is always below the compliance criteria. These simulations show that even if the liner begins to degrade during the assumed time frames and using a WAC based on one inch of infiltration a year, the WAC are still protective of groundwater the with high certainty within 1000 years and are always protective(based on the modeled cases) during the first two hundred years.

B.8.0 REFERENCES

Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor, 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture, ORNL-5786, Oak Ridges National Laboratory, Oak Ridge, Tennessee.

Chiou, J.D., Rich, C., Yu, W., 1993. "ECTran - A Spreadsheet Based Screening-Level Multimedia Fate and Transport Model with Monte Carlo Simulation Capability," Proceedings of the ER '93 Conference, U.S. Department of Energy, Augusta, Georgia, pp. 117-122.

DOE, 1995a. Operable Unit 4 Solar Evaporation Ponds Interim Measure/Interim Remedial Action Environmental Assessment Decision Document, U.S. Department of Energy, Rocky Flats Environmental Technology Site, Golden Colorado, Proposed, Section II.5 and IV.3, February.

DOE, 1995b. Draft table, "Comparison of K_d Values", DOE Disposal Working Group, Performance Evaluations for Mixed Low-Level Waste, Oak Ridge, Tennessee.

DOE, 1993. Development and Application of the ECTran Model to Support RI/FS at the Fernald Environmental Management Project, Prepared by Halliburton NUS for Fernald Environmental Restoration Management Corporation, submitted by U.S. Department of Energy, Fernald Office, Cincinnati, Ohio.

EG&G, 1994a. RCRA Groundwater Monitoring Report for Regulated Units at the Rocky Flats Plant, Prepared by EG&G Rocky Flats, Inc., Golden, Colorado.

EG&G, 1994b, Rocky Flats Environmental Technology Site, Site Environmental Report, January through December 1993, Golden Colorado.

Healy, R.W., 1990. Simulation of Solute Transport in Variably Saturated Porous Media with Supplemental Information on Modifications to the U.S. Geological Survey's Computer Program VS2D, Water-Resources Investigations Report, 90-4085, U.S. Geological Survey, Denver, Colorado.

"Handbook of RCRA Groundwater Monitoring Constituents:Chemical and Physical Properties," 1992. Appendix IX to 40 CFR Part 254, Washington, District of Columbia.

Howard, P.H., R.S. Boething, W. F. Jarvis, W. M. Meylan, and E. M., Michalenko, 1991. Handbook of Environmental Degradation Rates, Lewis Publishers, Inc., Chelsea, Michigan.

Maidment, D. R., Editor in Chief, 1993. Handbook of Hydrology, McGraw-Hill, Inc., New York, New York.

Lappala, E.G., Healy, R.W., and Weeks, E.P., 1993. Documentation of Computer Program VS2D to Solve Equations of Fluid Flow in Variably Saturated Porous Media, U.S. Geological Survey, Water-Resources Investigations Report 83-4099, Denver Colorado.

Engineering Science/Parsons, Inc. February 17, 1995. Letter from Phil Nixon (Engineering Science/Parsons) to A. Ledford (EG&G), SP307:0211795.03, Denver, Colorado.

Engineering Science/Parsons, Inc. December 1, 1994. Letter from Phil Nixon (Engineering Science/Parsons) to A. Ledford (EG&G), SP307:120194.06, Denver, Colorado.

Schroeder, P. R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., and Peyton, R.L., 1994. "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3," EPA/600/9-94/168b, U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, Ohio.

Schroeder, P.R., Peyton, B. M., McEnroe, B.M., and Sjostrom, J.W., 1988. "The Hydrologic Evaluation of Landfill Performance (HELP) Model. User's Guide for Version 2," U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, OH.

Thibault, D.H., M.I. Sheppard and P.A. Smith, 1990. A Critical Compilation and Review of Default Soil Solid/Liquid Partition Coefficients, K_d for use in Environmental Assessments, AECL-10125, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Center, Pinawa, Manitoba, Canada.

United States Environmental Protection Agency (USEPA), Risk Reduction Engineering Laboratory, "Treatability Database," Revision 3. Cincinnati, Ohio.

TABLE B-1

CONSTITUENTS OF CONCERN AND GROUNDWATER CRITERIA AT THE POINT OF COMPLIANCE[1] ROCKY FLATS, COLORADO

Constituents of Concern	Acceptable Groundwater Criteria	Unit
Americium-241	2.11	pCi/L
Cesium-134	81.3[2]	pCi/l
Cesium-137	119[2]	pCi/L
Plutonium-239/240	0.207	pCi/L
Radium-226	0.63	pCi/L
Uranium-233/234	74.22	pCi/L
Uranium-235	2.98	pCi/L
Uranium-238	51.6	pCi/L
Arochlor-1254	1	ug/L
Arsenic	50	ug/L
Benzo(a)anthracene	1	ug/L
Benzo(b)fluoranthene	1	ug/L
Benzo(a)pyrene	1	ug/L
Benzo(g,h,i)perylene	1	ug/L
Benzo(k)fluoranthene	1	ug/L
Beryllium	5	ug/L
Bis-(2-ethylhexyl)phthalate	6.07	ug/L
Cadmium	18.2	ug/L
Chromium	182	ug/L
Chrysene	11.6	ug/L
Indeno(1,2,3-CD)pyrene	1	ug/L
Nitrate	58400	ug/L
Phenanthrene	1	ug/L
Sodium	5000	ug/L

1 Acceptable groundwater criteria are from Parsons Letter SP307:021795.03 from P. Nixon to A. Ledford dated February 17, 1995 (See column labeled Comparison Criteria).

2 Acceptable groundwater criteria for the cesium isotopes are equivalent to 4 mrem/yr assuming 2 liters of daily intake.

TABLE B-2

GROUNDWATER MONITORING WELLS USED IN THE MODEL CALIBRATION
ROCKY FLATS, COLORADO

Upgradient Wells	Under-Source Wells	Downgradient Wells
P207489	P209089	P209589
P209389	P210289	P209889
2486	P208989	
	P209489	
	05193	
	3086	
	2886	
	2786	

TABLE B-3

INPUT PARAMETERS USED IN THE ECTRAN MODEL ROCKY FLATS, COLORADO

Parameter	Calibration	WAC Development
Source Area Size Length (ft) Width (ft)	 590 390	 650 865
Unsaturated Zone Thickness (ft)	3	3
Saturated Zone Thickness (ft)	5	5
Soil Density (g/cm^3)	1.7	1.7
Porosity	0.338	0.338
Hydraulic Conductivity[1] (ft/yr)	141	141
Infiltration (in/yr)	1	0.0068 to 2.5
Flow in the Unsaturated Zone(Used to Simulate the Fluctuation of the Groundwater Table[2] (L/day)	1490	3640
Flow in the Saturated Zone[3] (L/day)	1370	3050
Groundwater Velocity[4] (ft/yr)	26.7	26.7

1 Hydraulic conductivity from previous modeling at the SEPs.

2 Flow in the unsaturated zone was calibrated using tritium. The flow volume was adjusted for the WAC development to account for the change in source area size.

3 Flow based on groundwater velocity, saturated zone thickness, and width of source area.

4 Groundwater flow velocity based on hydraulic conductivity and the average gradient in the model area from the mean seasonal high groundwater elevations.

TABLE B-4

CALIBRATED SOIL/WATER PARTITIONING COEFFICIENTS (K_ds), LITERATURE VALUES, AND CALCULATED VALUES FROM LYSIMETER DATA ROCKY FLATS, COLORADO

Constituent of Concern	Calibrated Kd Unsaturated Zone, L/kg	Calibrated Kd Saturated Zone, L/kg	Literature Value[1] L/kg	Literature Value[2] L/kg	Kd Calculated From Lysimeter Data, L/kg[3]	Number of Lysimeter Data Pairs Used to Calculate K_d	Half-Life (Years)
Americium-241	100	10	8.2 - 3 x 10^5	700	NA[4]	NA	432
Arsenic	2	0.5	--[6]	200	NA	NA	--
Beryllium	5	1	250	650	NA	NA	--
Cadmium	5	1	2.7 - 625	6.5	597	2	--
Cesium-134	1	0.1	40-3968	1000	NA	NA	2.05
Cesium-137	1	0.1	40-3968	1000	NA	NA	30.2
Chromium	35	1.5	1.7-1729	850	NA	NA	--
Nitrate	0.01	0.01	--[5]	--[5]	0.127	11	--
Plutonium-239/240	100	20	27-36000	4500	NA	NA	24,100
Radium-226	690	106	57-21000	450	690	1	1,600
Sodium	10	1.5	--[6]	100	NA	NA	--
Uranium-233/234	17	2	0.03-2200	450	19.8	8	245,000
Uranium-235	17	2	0.03-2200	450	NA	NA	7.04 x 10^8
Uranium-238	17	2	0.03-2200	450	14.5	7	4.47 x 10^9

1 Thibault et al., 1990
2 Baes et. al., 1984
3 Value represents the geometric mean of the calculated Kd values from the pairs of water/soil concentrations
4 Not Applicable; No pairs of data were available to calculate Kd values
5 Values for Nitrate were not reported in these sources. A Kd value of 0 was used for Nitrate in previous modeling at the SEPs.
6 Values were not reported in this source.

TABLE B-5

K_d VALUES USED FOR RADIOLOGICAL COCs AT OTHER DOE FACILITIES[1] ROCKY FLATS, COLORADO

COC	Oak Ridge L/kg	Savannah River Site L/kg	Hanford Site L/kg	Idaho National Engineering Laboratory (unsat'd) L/kg	Idaho National Engineering Laboratory (sat'd) L/kg	Fernald Environmental Management Project (unsat'd) L/kg	Fernald Environmental Management Project (sat'd) L/kg	Rocky Flats Environmental Technology Site (Unsat'd) L/kg	Rocky Flats Environmental Technology Site (Sat'd) L/kg
Americium-241	40	150	100	NA	NA	100	10	100	10
Cesium-137	3000	100	1	20	20	1810	1370	1	0.1
Plutonium-239/240	40	100	100	2000	200	1700	100	100	20
Radium-226	3000	500	10	50	5	696	106	690	106
Uranium-233/234	40	50	0	1000	100	3.1	1.78	17	2
Uranium-235	40	50	0	1000	100	3.1	1.78	17	2
Uranium-238	40	50	0	1000	100	3.1	1.78	17	2

1 All data except RFETS data from the draft table "Comparison of K_d Values" DOE Disposal Working Group, Performance Evaluations for Mixed Low-Level Waste, 1995.

TABLE B-6

ORGANIC K_d VALUES AND HALF-LIVES
ROCKY FLATS, COLORADO

Constituent of Concern	K_{OW}	Reference	K_d (3) L/kg	Half Life, Yrs (4)
Arochlor-1254	1.07×10^6	(1)	3.10×10^3	NA (5)
Benzo(a)anthracene	4.00×10^5	(2)	1.16×10^3	3.73
Benzo(a)pyrene	9.55×10^5	(2)	2.77×10^3	2.90
Benzo(b)fluoranthene	3.72×10^6	(2)	1.08×10^4	3.34
Benzo(g,h,i)perylene	1.70×10^7	(2)	4.93×10^4	3.60
Benzo(k)fluoranthene	6.92×10^6	(2)	2.01×10^4	11.7
Bis(2-ethylhexyl)phthalate	2.00×10^5	(2)	5.78×10^2	1.07
Chrysene	4.00×10^5	(2)	1.16×10^3	5.48
Indeno(1,2,3-cd)pyrene	4.57×10^7	(2)	1.32×10^5	4.00
Phenanthrene	2.90×10^4	(2)	8.40×10^1	1.10

1 USEPA, " Treatability Data Base" Risk Reduction Engineering Laboratory.
2 RCRA Handbook of Groundwater Monitoring Constituents, 1992.
3 K_d's are calculated based on the following equations from (Maidment, 1990)
$K_d = K_{OC} \times F_{OC}$ where $F_{OC} = 0.0046$ (DOE 1995, Page II.3-197) and
$K_{OC} = 0.63 \times K_{OW}$ (Maidment, 1990).
4 Howard et. al. 1991.
5 Half-life not available from literature, in the WAC development it was conservatively assumed that Arochlor-1254 does not decay.

TABLE B-7

WAC FOR SCENARIO 1
0.0068 AND 1 INCH OF INFILTRATION PER YEAR
ROCKY FLATS, COLORADO

COC	Unit	WAC for Scenario 1 0.0068 in/yr Infiltration	WAC for Scenario 1 1 in/yr Infiltration
Am-241	pCi/L	17,100	74.5
Cs-134	pCi/L	3,510,000	12,800
Cs-137	pCi/L	111,000	737
Pu-239/240	pCi/L	1,070	4.43
Ra-226	pCi/L	117,000	415
U-233/234	pCi/L	35,200	254
U-235	pCi/L	1,410	10.2
U-238	pCi/L	24,500	177
Arsenic	ug/L	13,600	142
Beryllium	ug/L	1,430	14.2
Cadmium	ug/L	5,190	51.8
Chromium	ug/L	142,000	881
Nitrate	mg/L	15,900	166
Sodium	mg/L	1,750	14.9
Arochlor-1254[1]	mg/L	17,200	59.1

1 The contaminant plumes of the other organic COCs did not reach POC at concentrations higher than the compliance criteria during the 1000-yr modeling time frame. Theoretically this would result in a pure product concentration for the WAC.

TABLE B-8

SUMMARY OF DETERMINISTIC SENSITIVITY ANALYSIS INPUT ROCKY FLATS, COLORADO

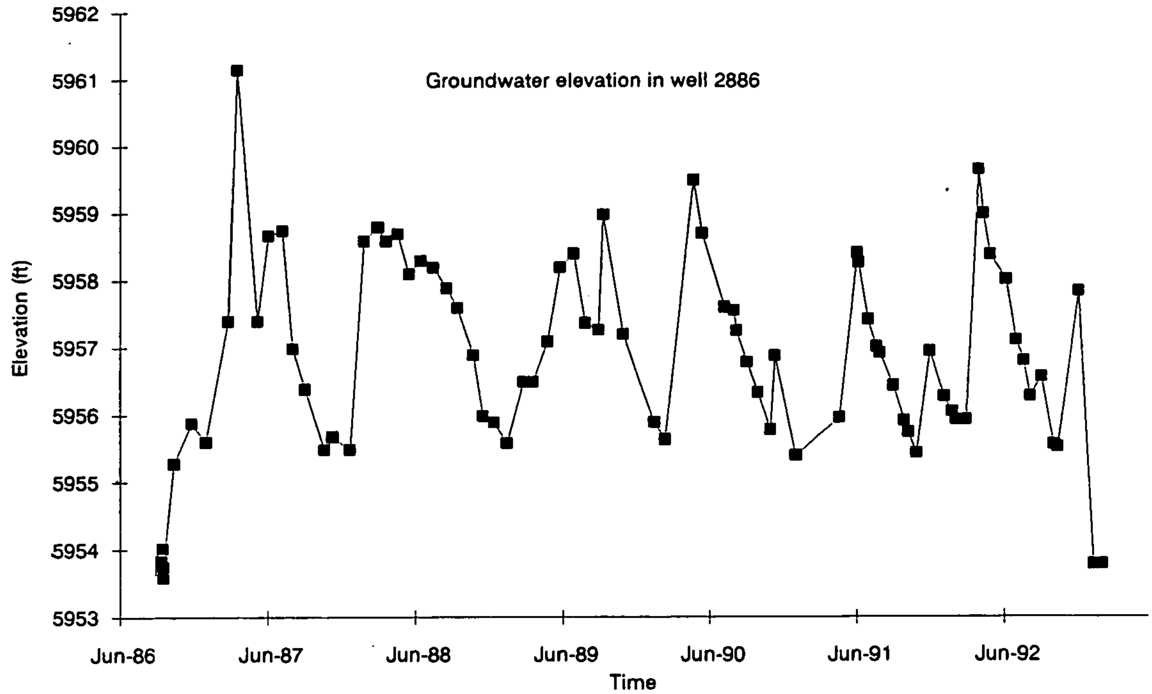
Input Parameter	Minimum	Maximum
Infiltration Rate (in/yr)	0.01	2.1
K_d (L/kg) in Unsaturated Zone	0.5	80
K_d (L/kg) in Saturated Zone	0.1	10
Additional Flow (L/Day) in Unsaturated Zone	1820	5460

TABLE B-9

SUMMARY OF PROBABILISTIC SENSITIVITY ANALYSIS INPUT AND RESULTS
ROCKY FLATS, COLORADO

Constant Source Loading of U-238 (WAC): 177 pCi/L

	Assumptions in Monte Carlo Simulation:								Monte Carlo Simulation Results:	
	Time of Barrier Layer Beginning to Lose Its Function (Year) Normal Distribution		Unsaturated Layer Kd (L/kg) Lognormal Distribution		Saturated Layer Kd (L/kg) Lognormal Distribution		Vertical Fluctuation Flow in Unsaturated Layer (L/Day) Uniform Distribution		Percentile of the Saturated Layer Concentration at 1000 yr Less Than Risk Criteria (51.6 pCi/L)	Percentile of the Saturated Layer Concentration at 200 yr Less than Risk Criteria (51.6 pCi/L)
	Mean	Standard Dev.	Mean	Standard Dev.	Mean	Standard Dev.	Minimum	Maximum		
Case 1	500	150	17	34	2	4	1820	5460	65%	100%
Case 2	700	150	17	34	2	4	1820	5460	88%	100%
Case 3	800	150	17	34	2	4	1820	5460	94%	100%
Case 4	Barrier Layer Keeps Its Function in 1000 Years		17	34	2	4	1820	5460	100%	100%



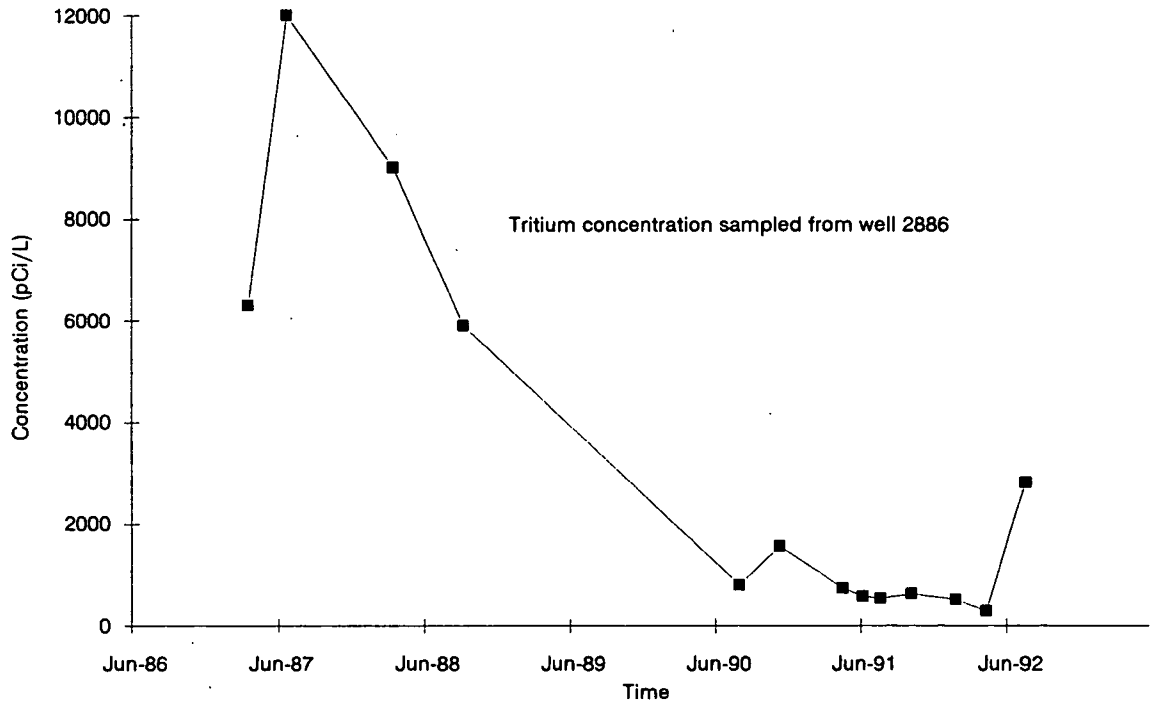
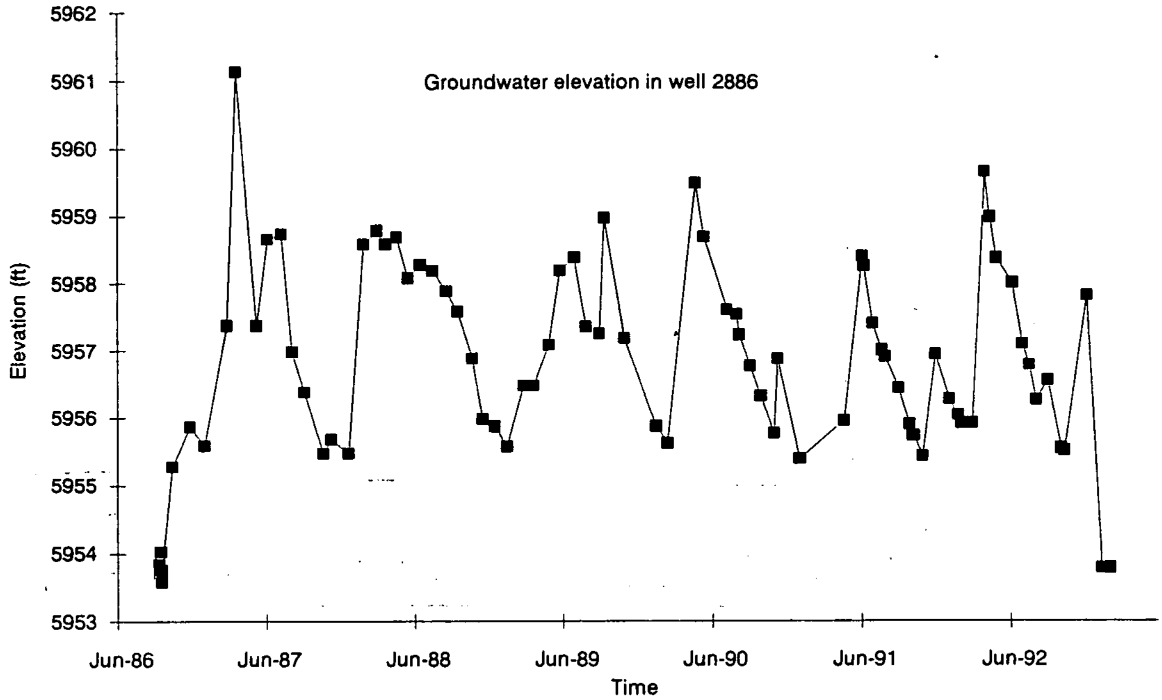


FIGURE B-1 TRITIUM CONCENTRATION VS. WATER ELEVATION IN WELL 2886



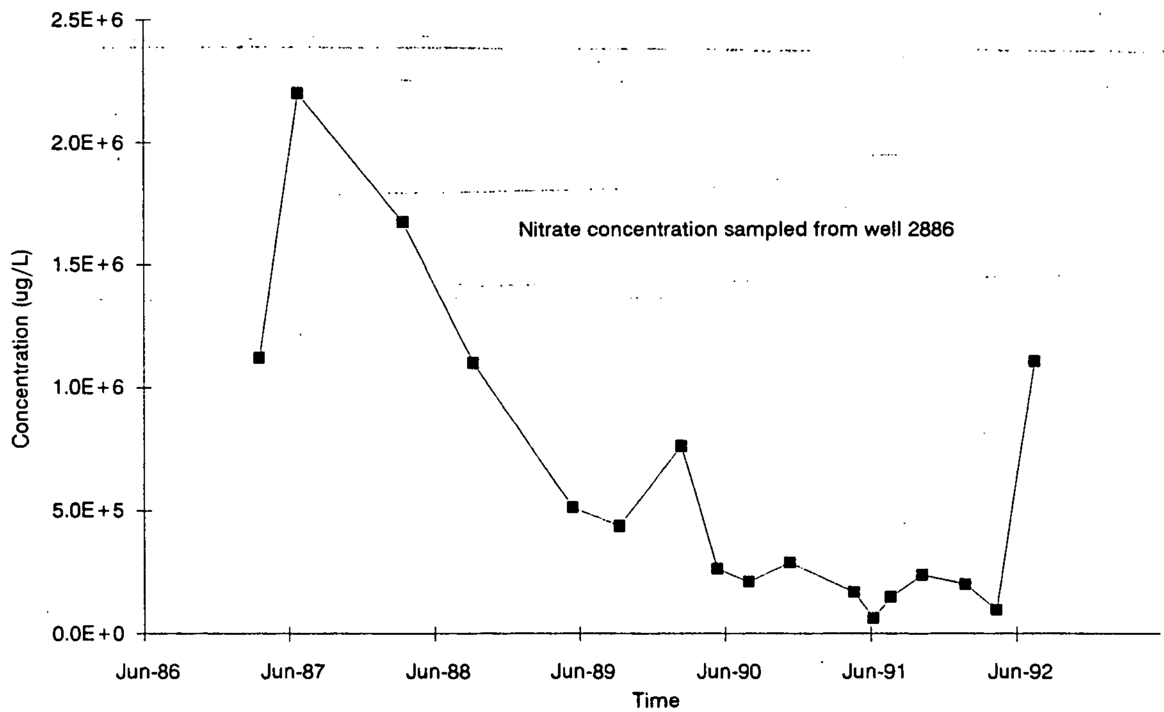
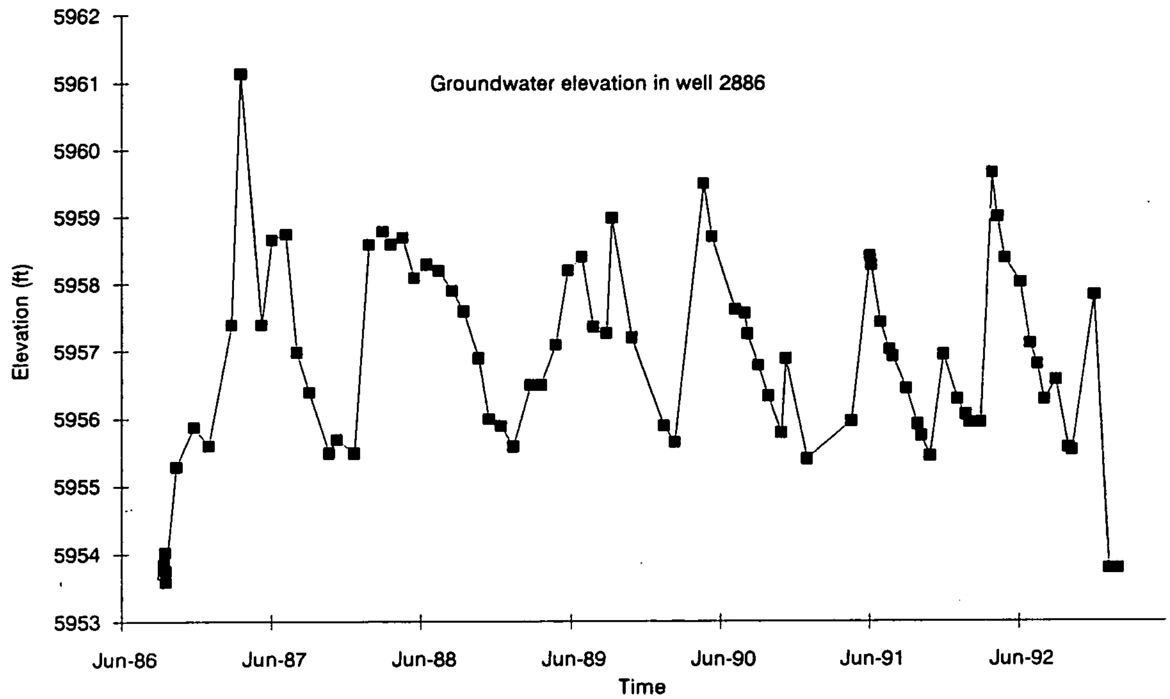


FIGURE B-2 NITRATE CONCENTRATION VS. WATER ELEVATION IN WELL 2886



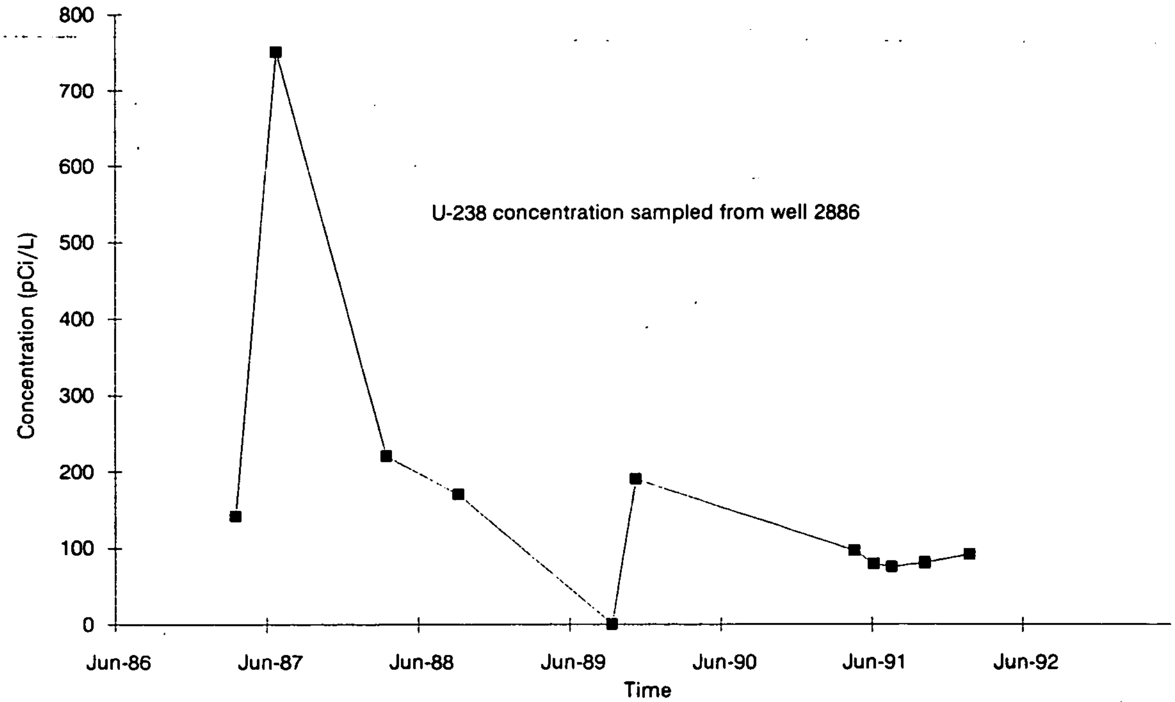
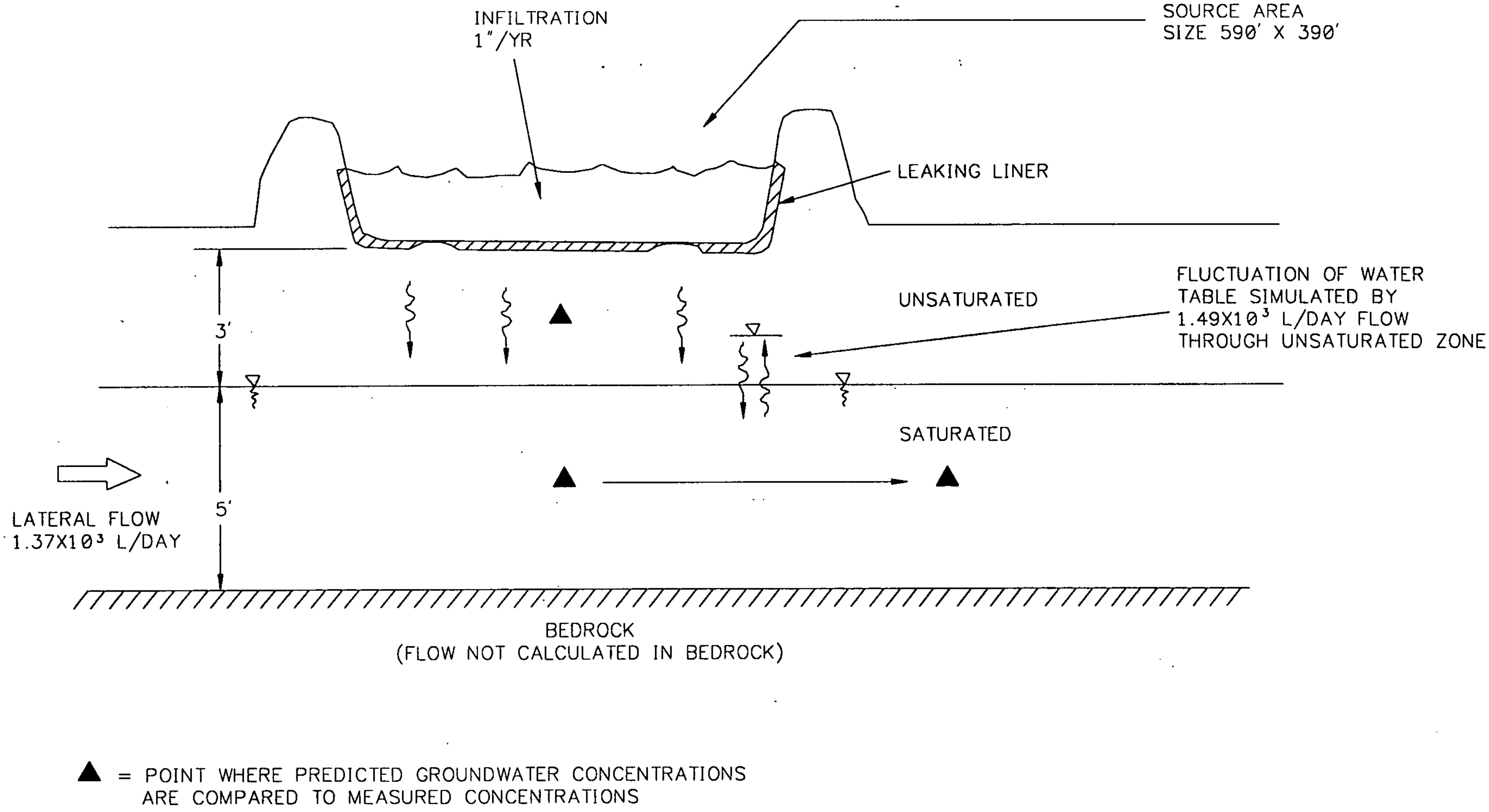


FIGURE B-3 URANIUM-238 CONCENTRATION VS. WATER ELEVATION IN WELL 2886

ACAD: O:\DATA\CADD\3A75\95040302.DWG 05/03/95 TD VIEW=1A



CALIBRATION CONCEPTUAL MODEL
ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE
GOLDEN, COLORADO

FIGURE B-5

Halliburton NUS
CORPORATION

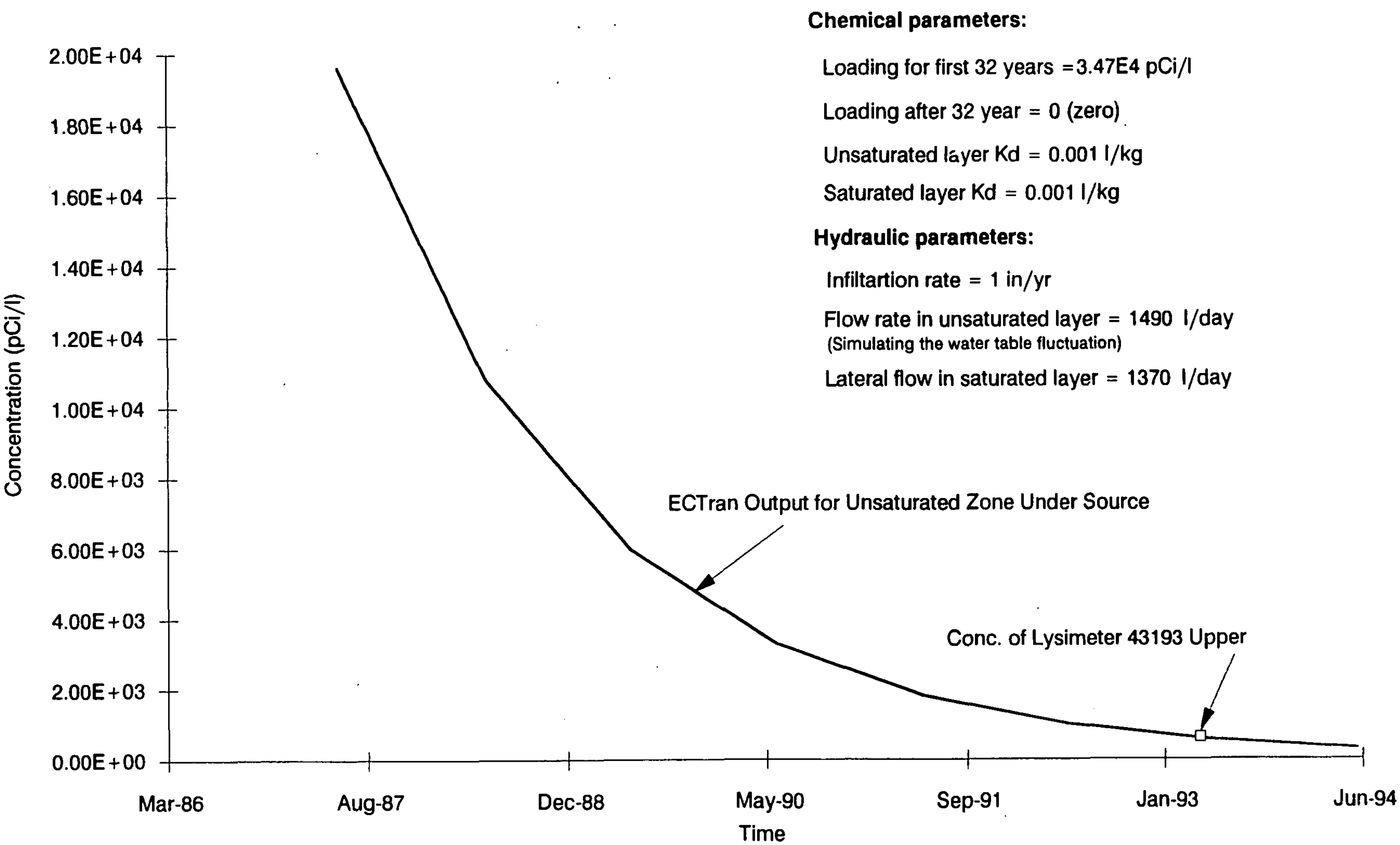


FIGURE B-6 TRITIUM CALIBRATION RESULTS IN THE UNSATURATED ZONE

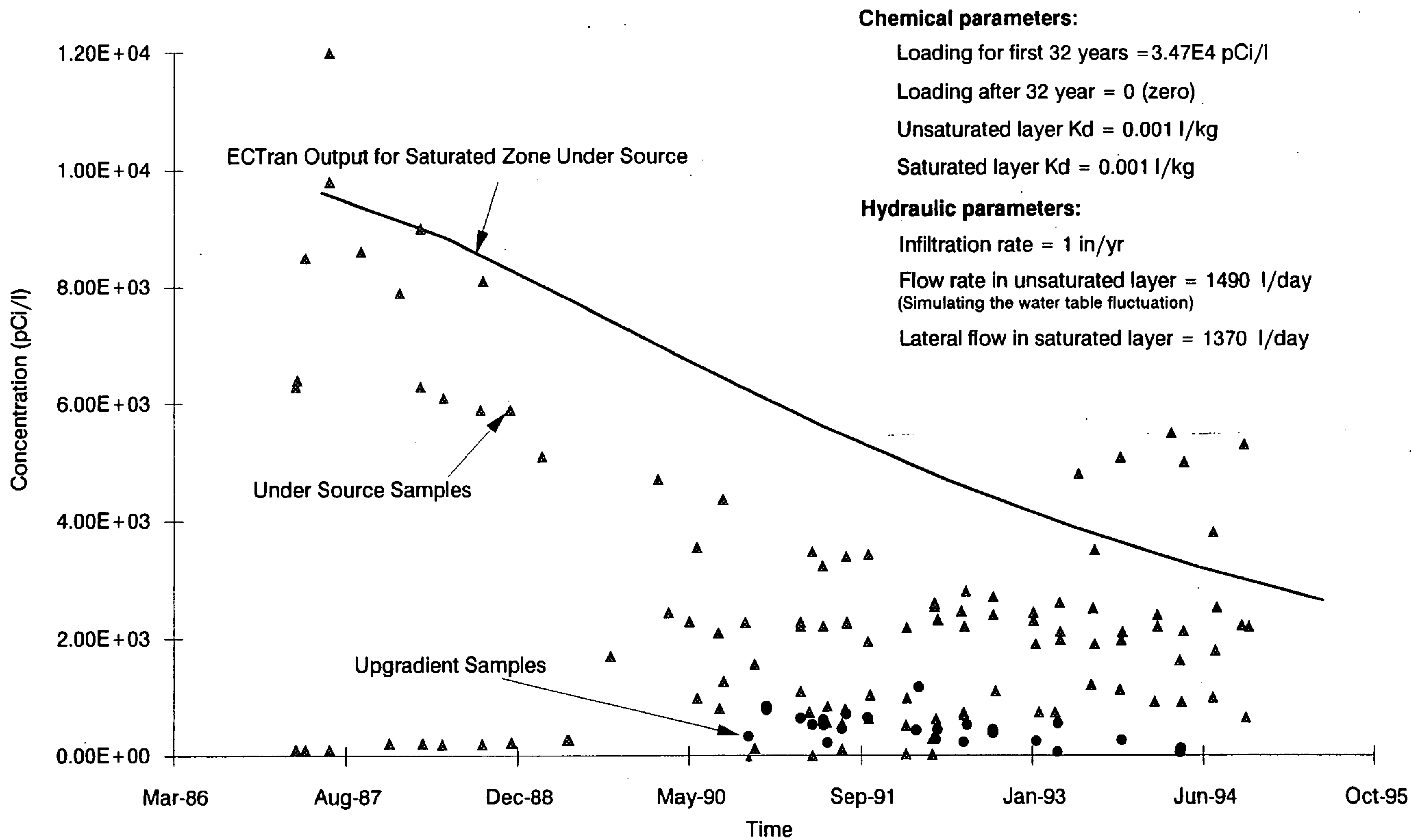


FIGURE B-7 TRITIUM CALIBRATION RESULTS IN THE SATURATED ZONE UNDER THE SOURCE

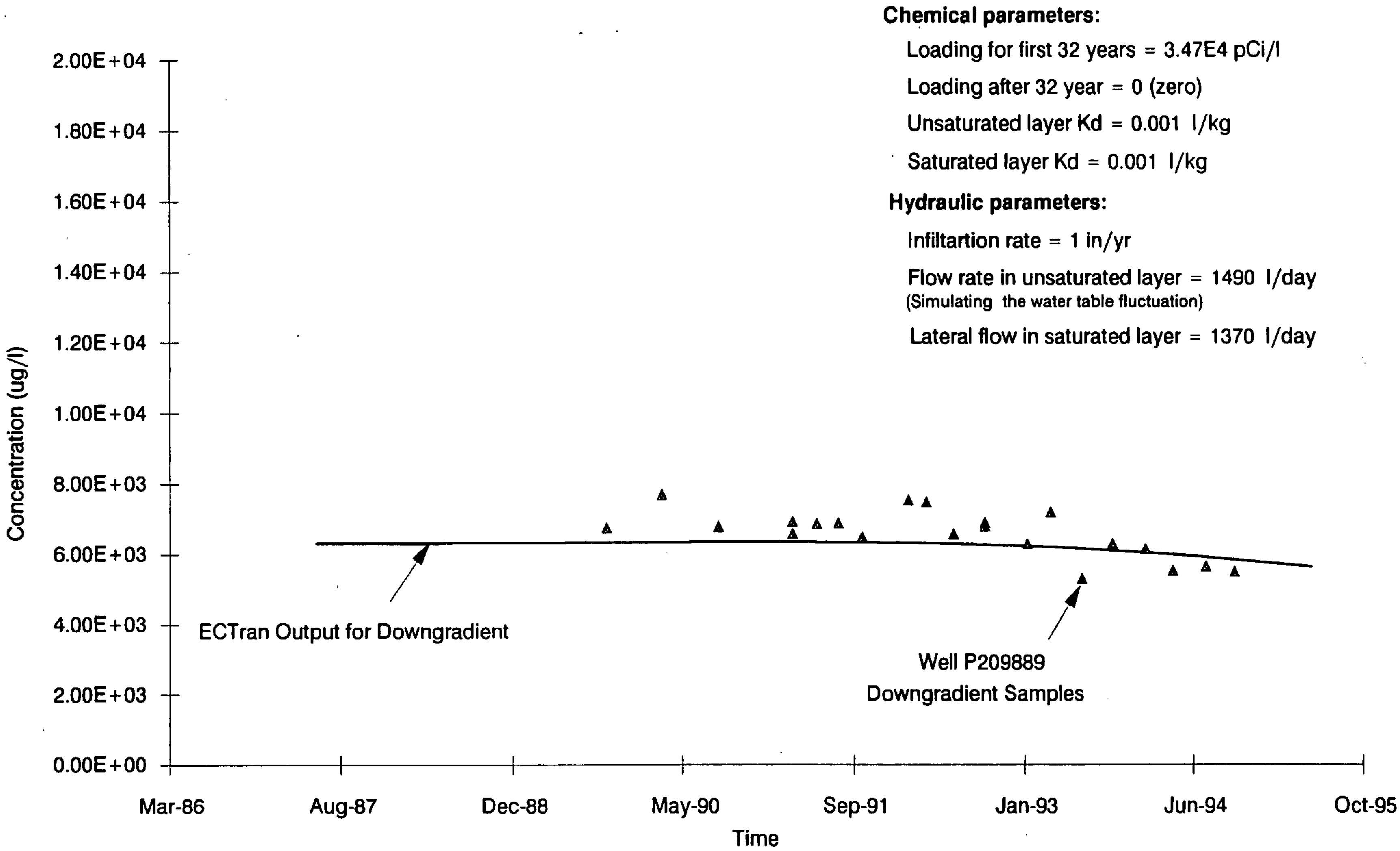


FIGURE B-8 TRITIUM CALIBRATION RESULTS IN THE SATURATED ZONE DOWN GRADIENT

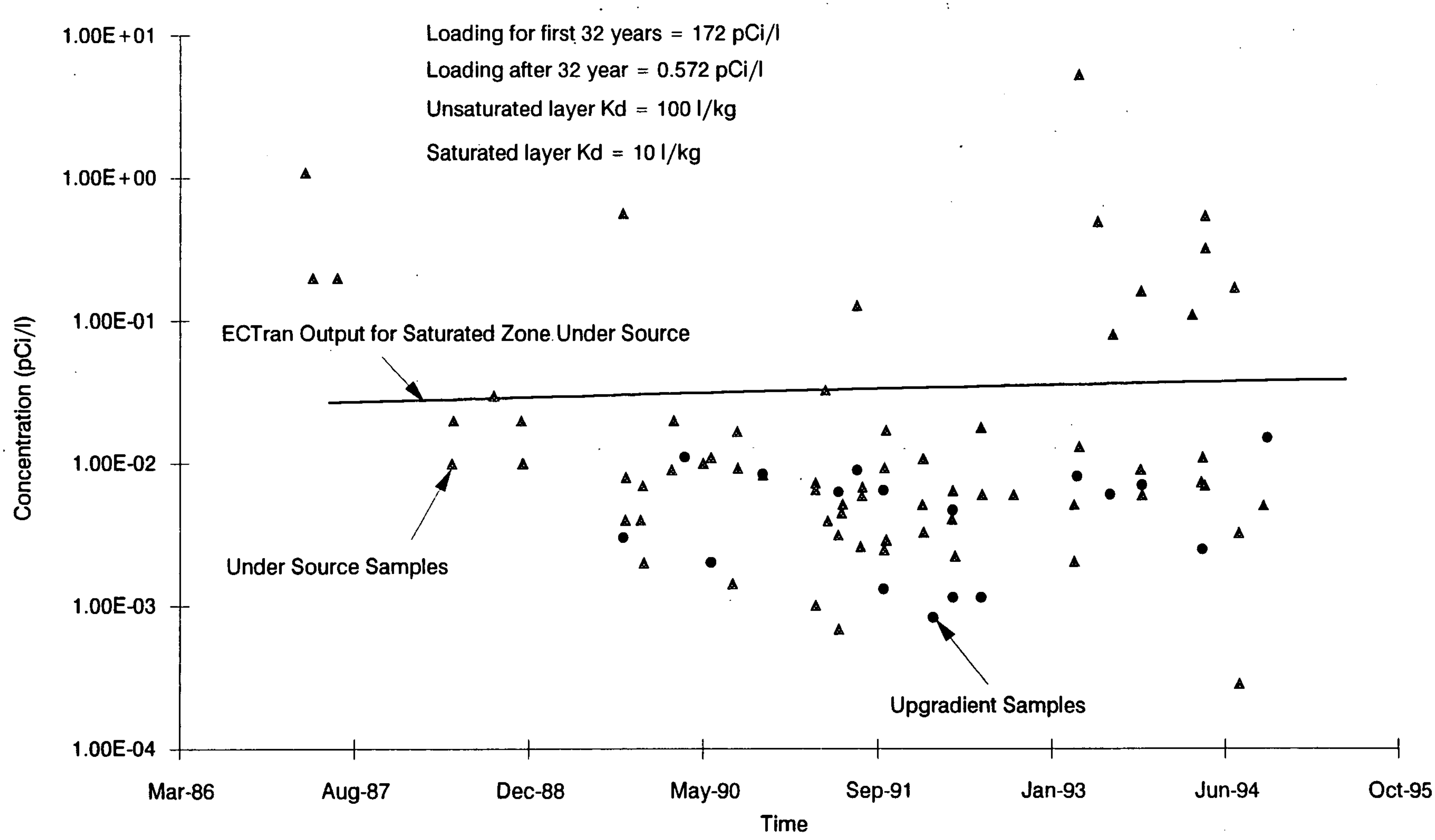


FIGURE B-9 AMERICIUM-241 CALIBRATION RESULTS

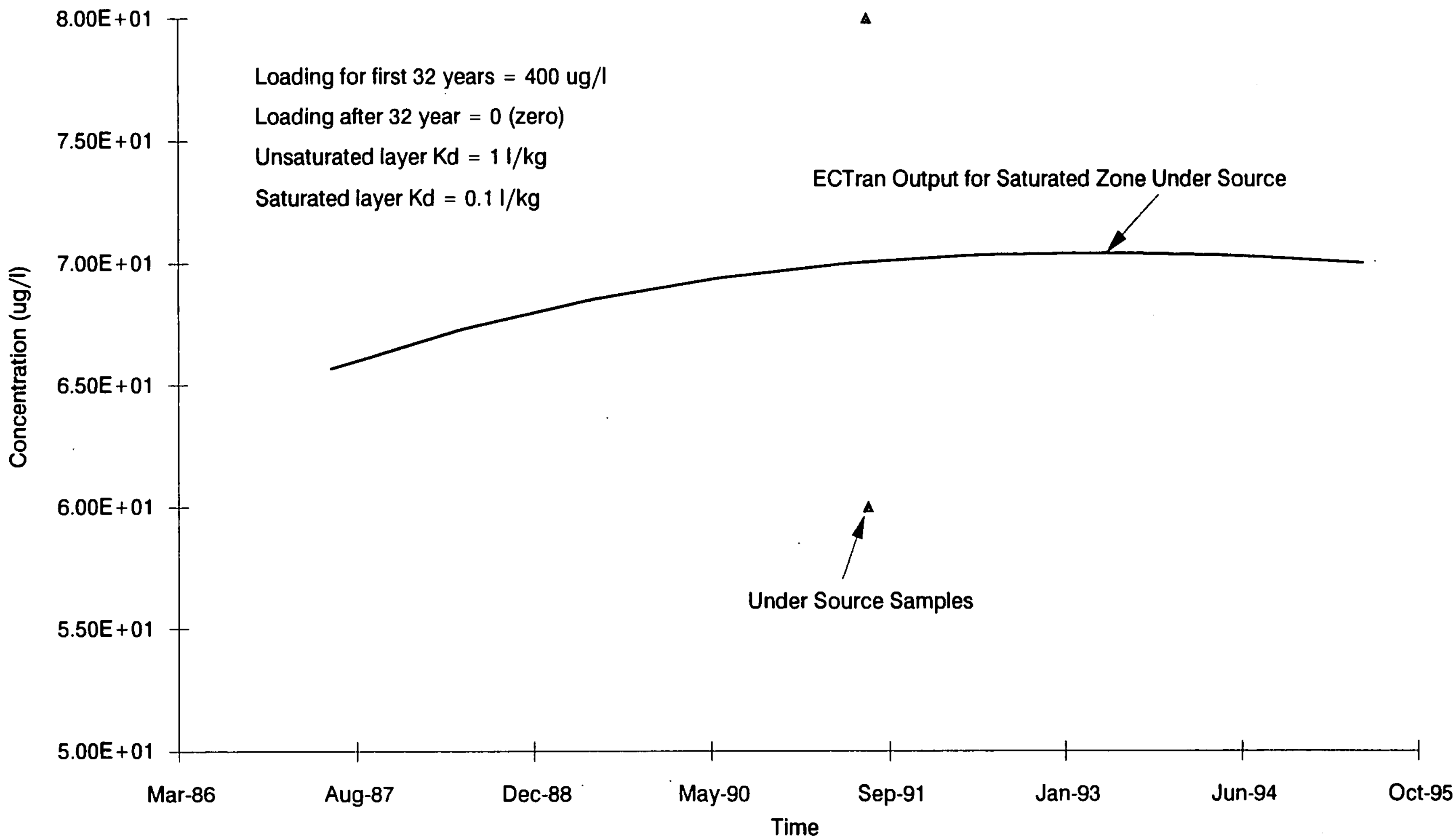


FIGURE B-10 CESIUM CALIBRATION RESULTS

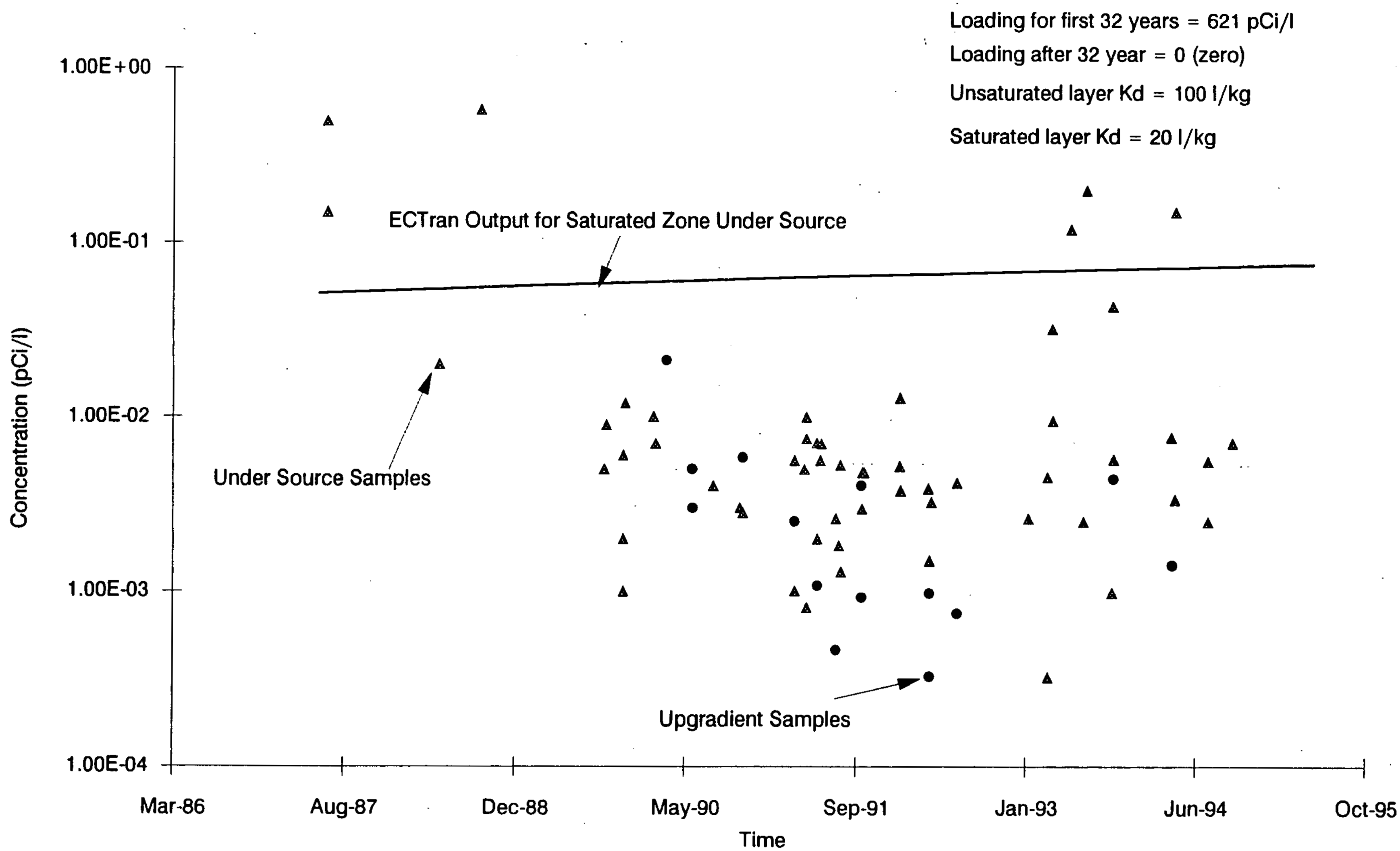


FIGURE B-11 PLUTONIUM-239/240 CALIBRATION RESULTS

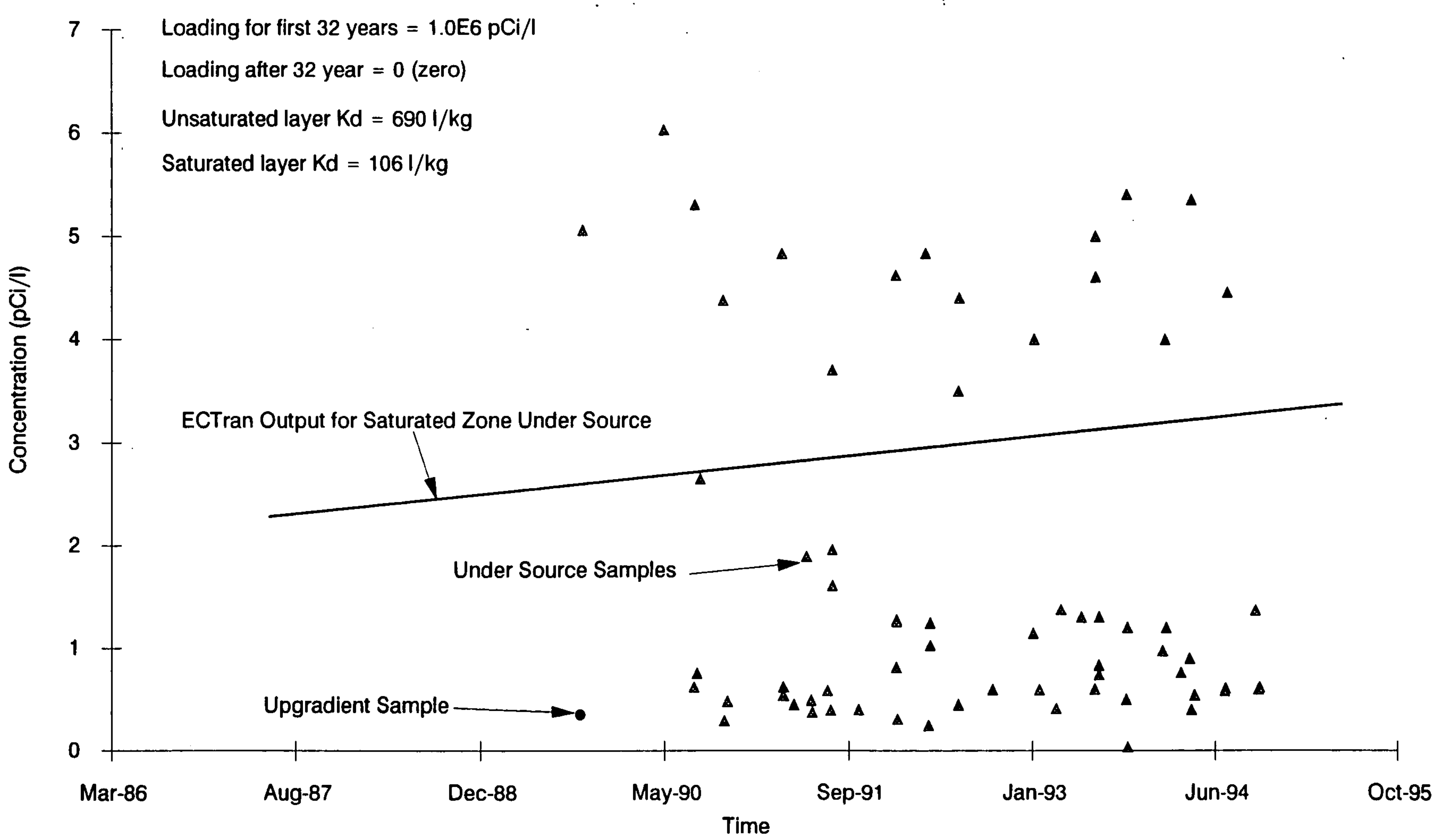


FIGURE B-12 RADIUM-226 CALIBRATION RESULTS

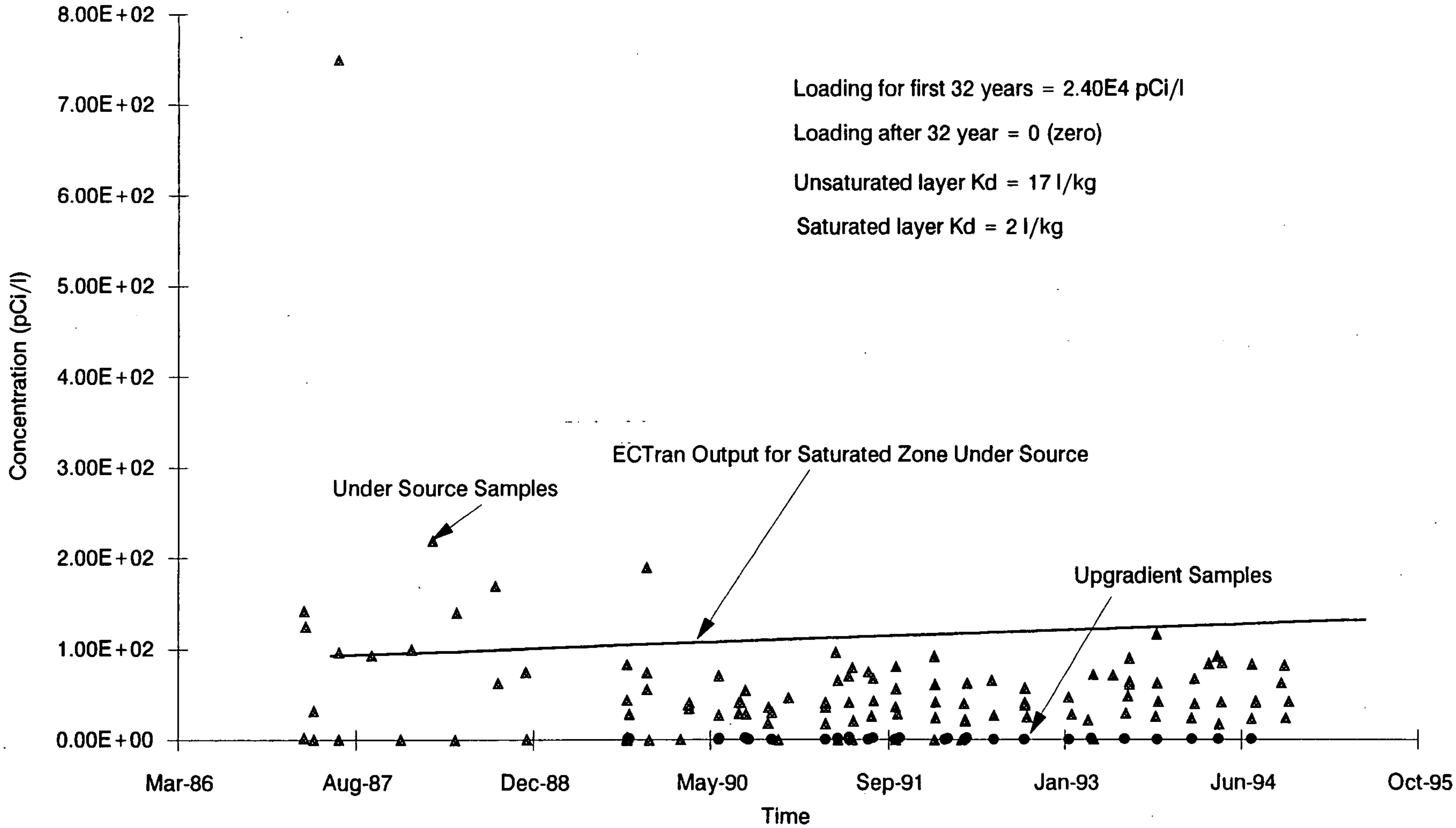


FIGURE B-13 URANIUM-238 CALIBRATION RESULTS

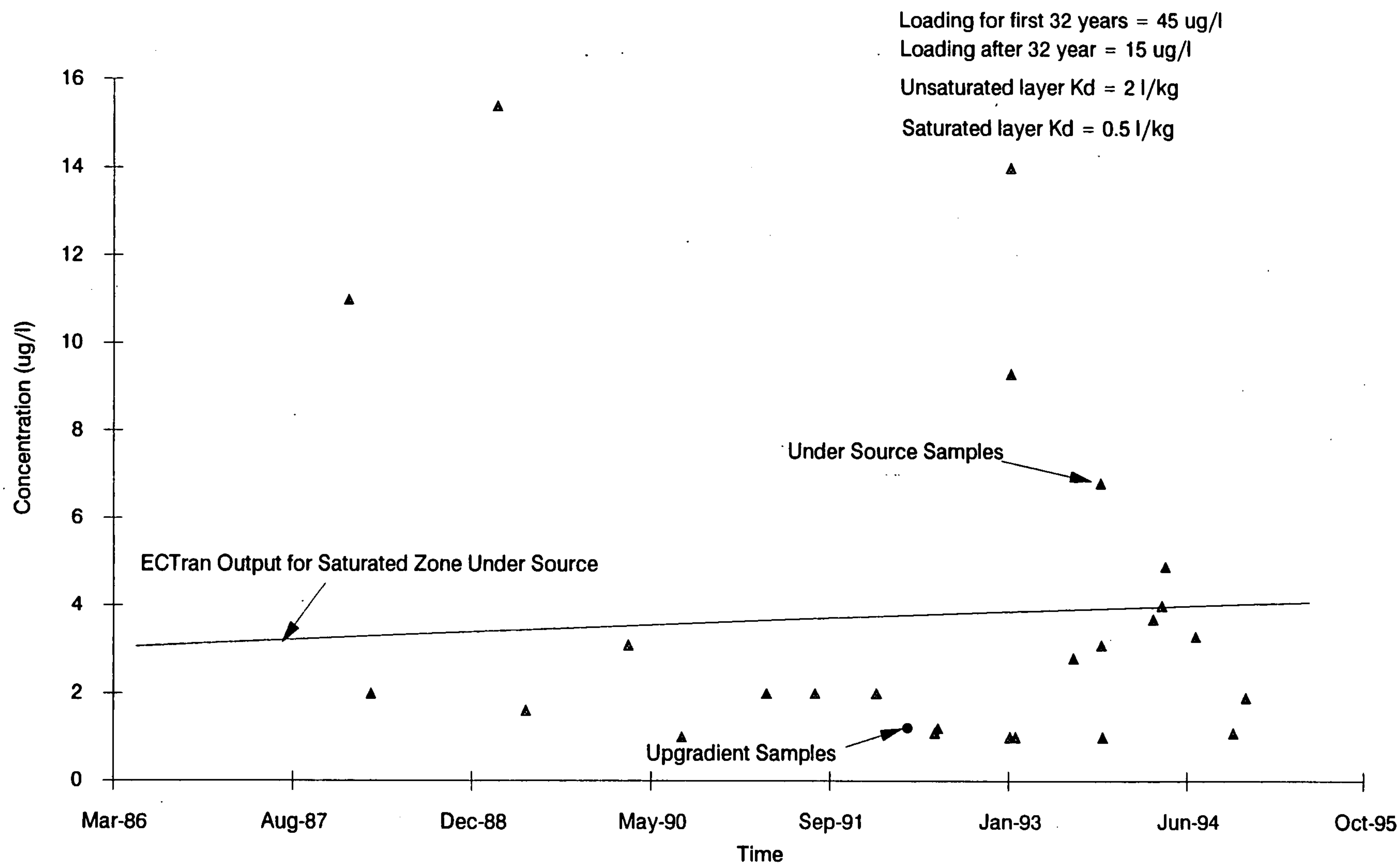


FIGURE B-14 ARSENIC CALIBRATION RESULTS

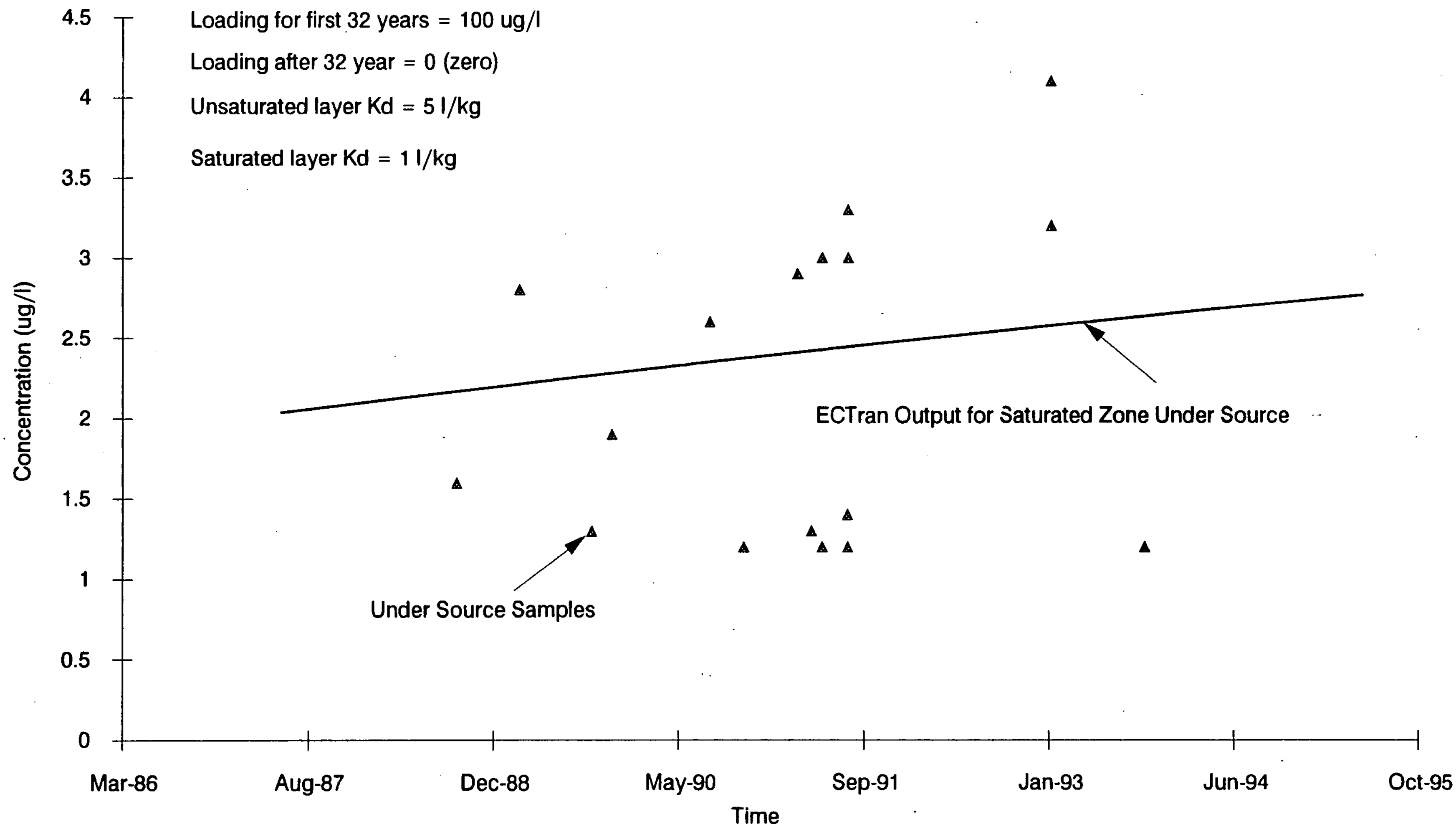


FIGURE B-15 BERYLLIUM CALIBRATION RESULTS

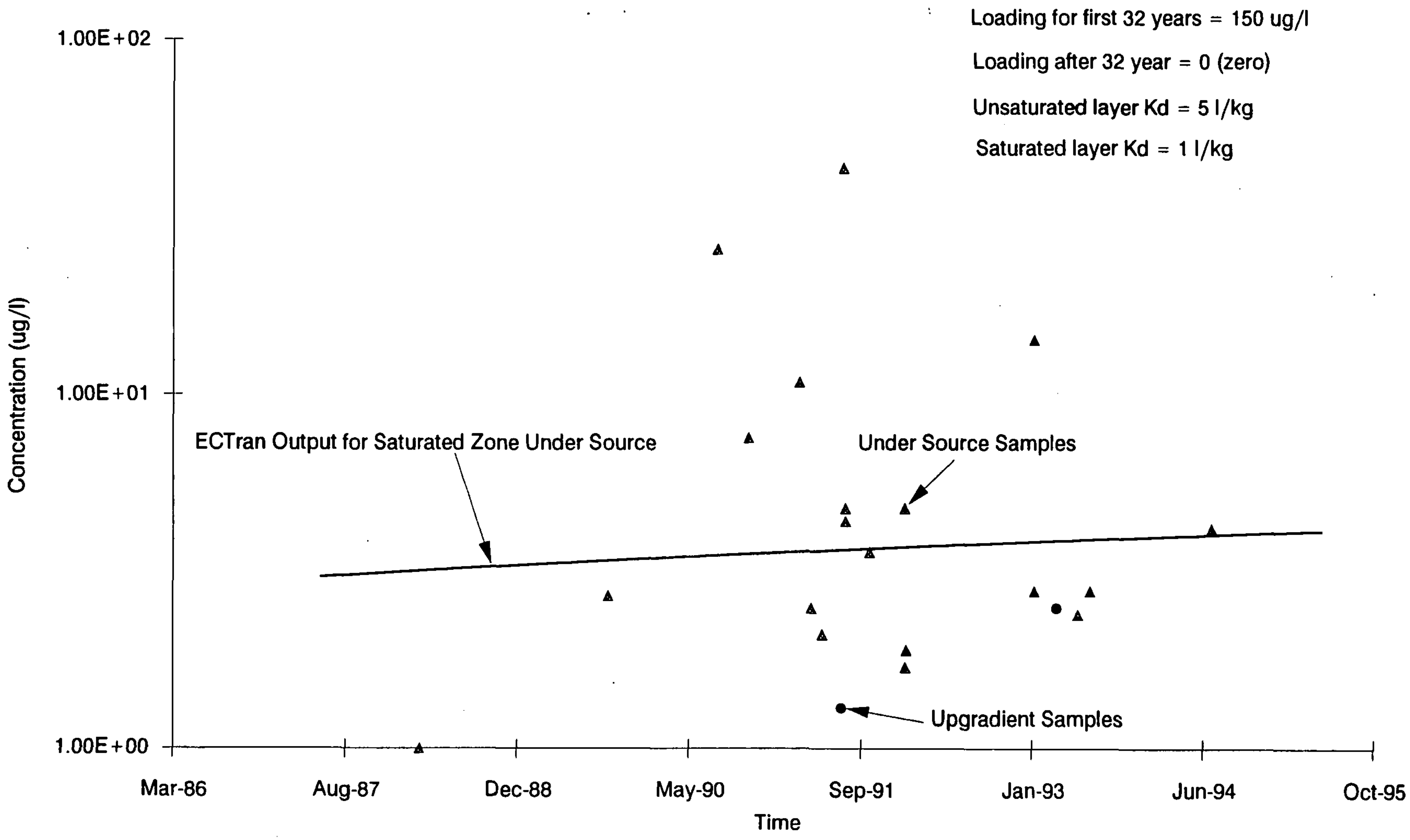


FIGURE B-16 CADMIUM CALIBRATION RESULTS

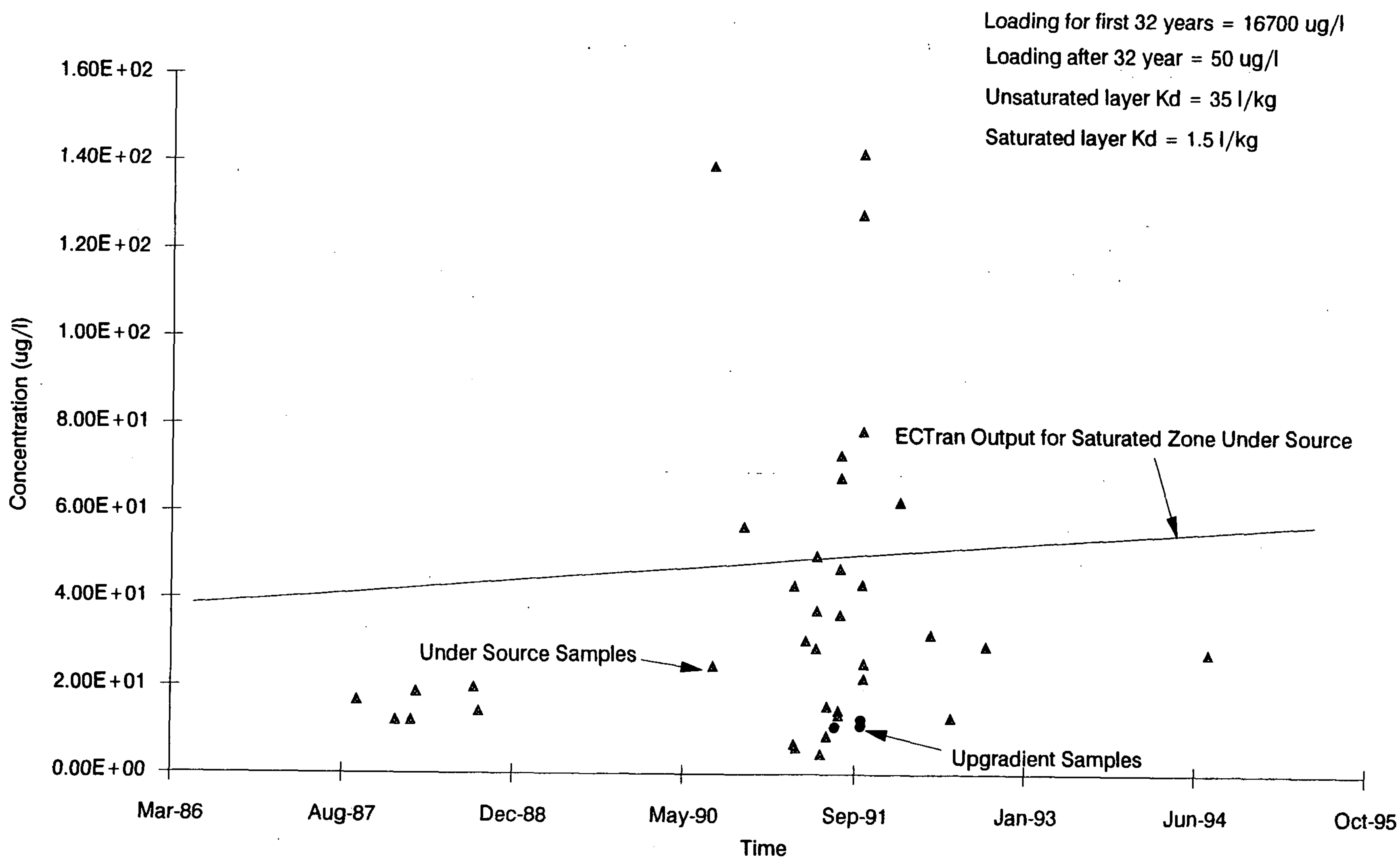


FIGURE B-17 CHROMIUM CALIBRATION RESULTS

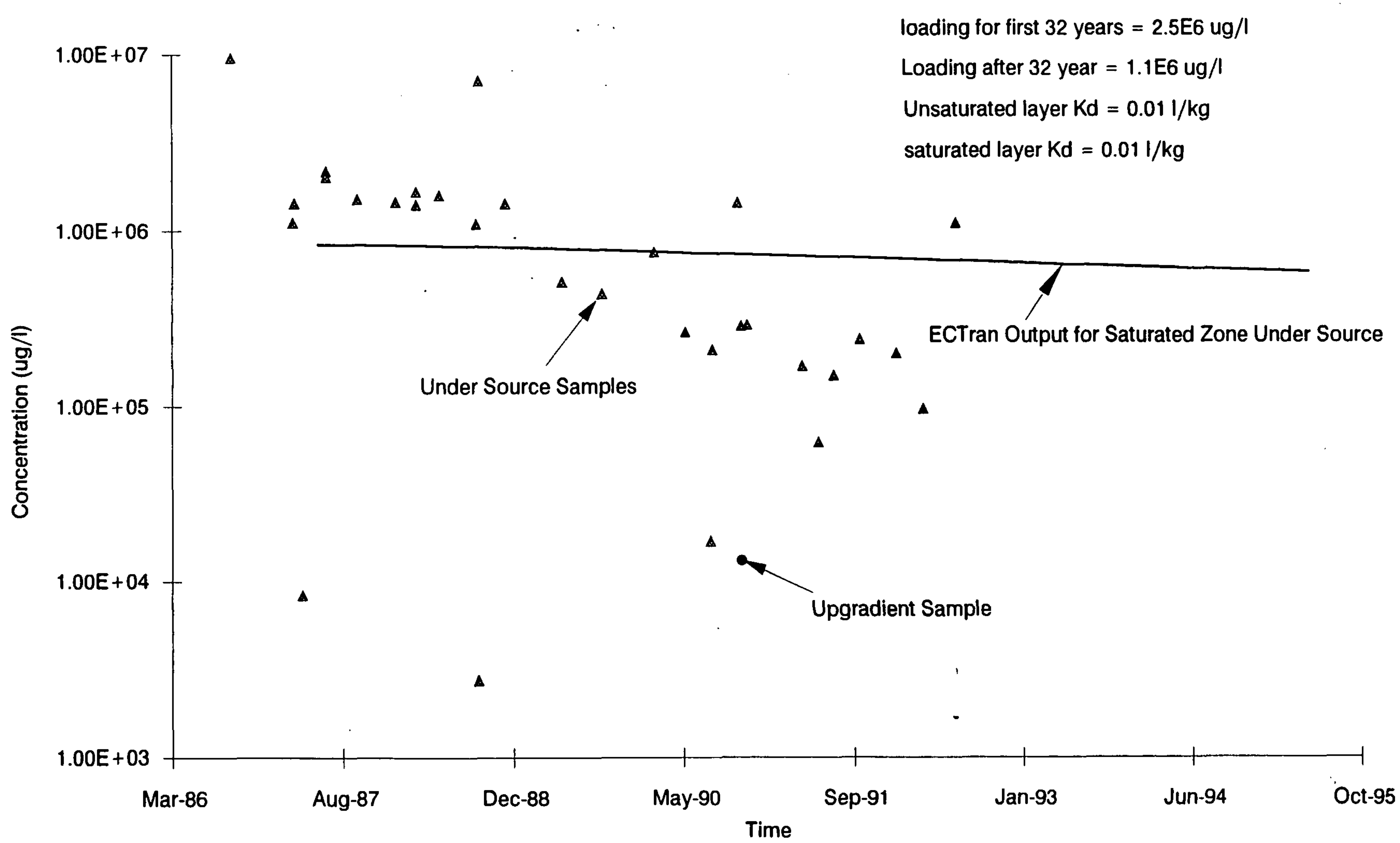


FIGURE B-18 NITRATE CALIBRATION RESULTS

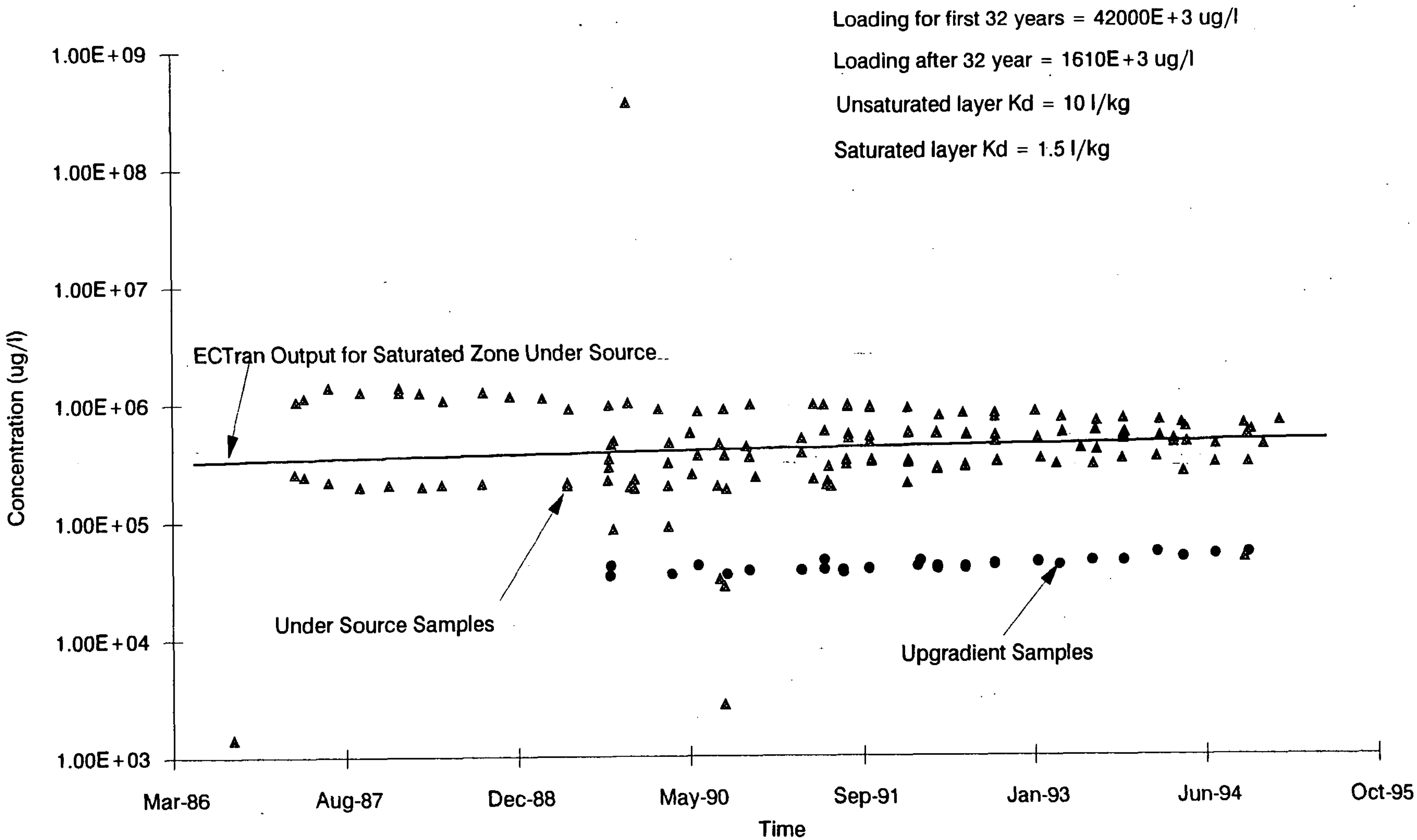
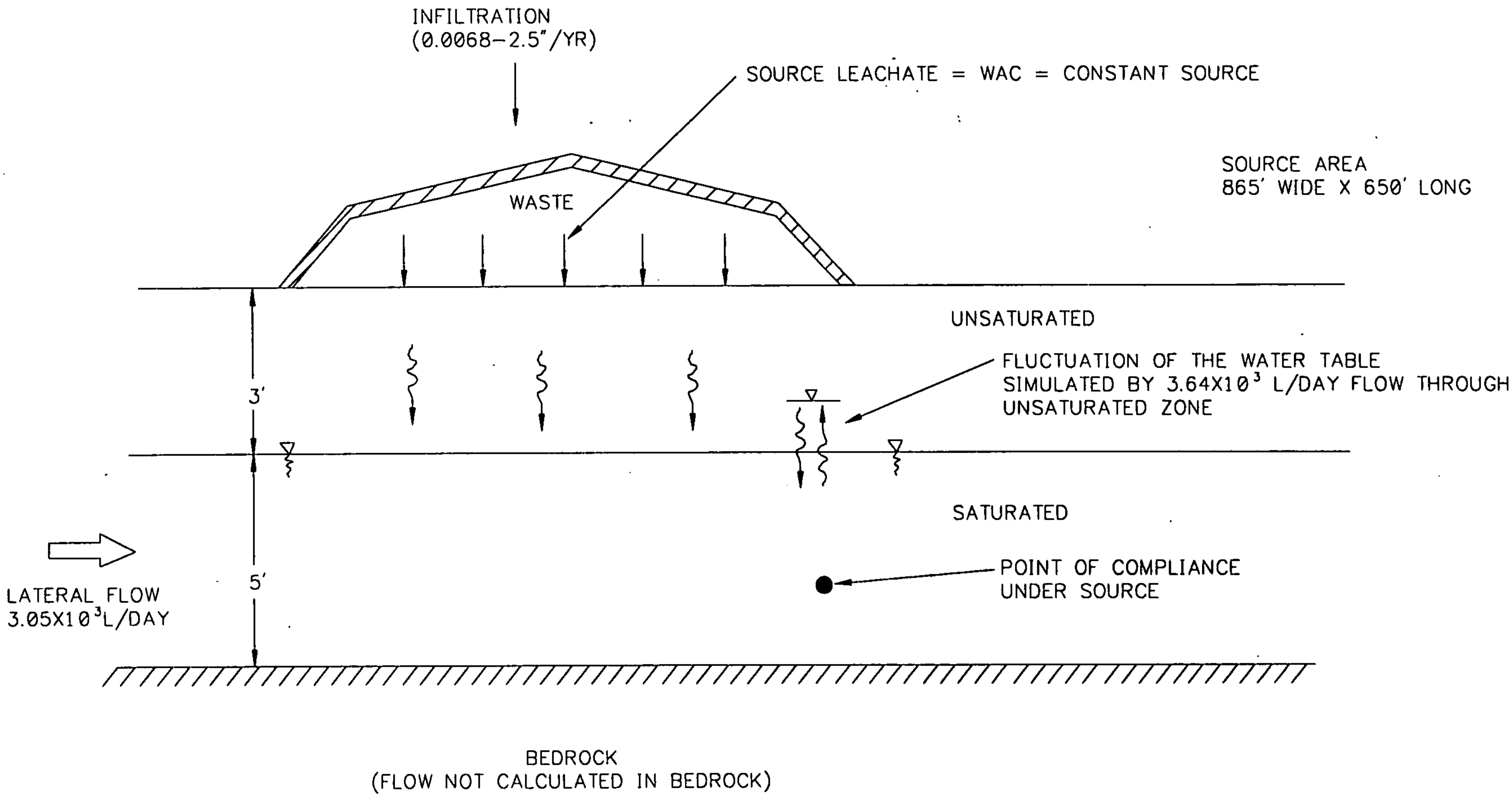


FIGURE B-19 SODIUM CALIBRATION RESULTS

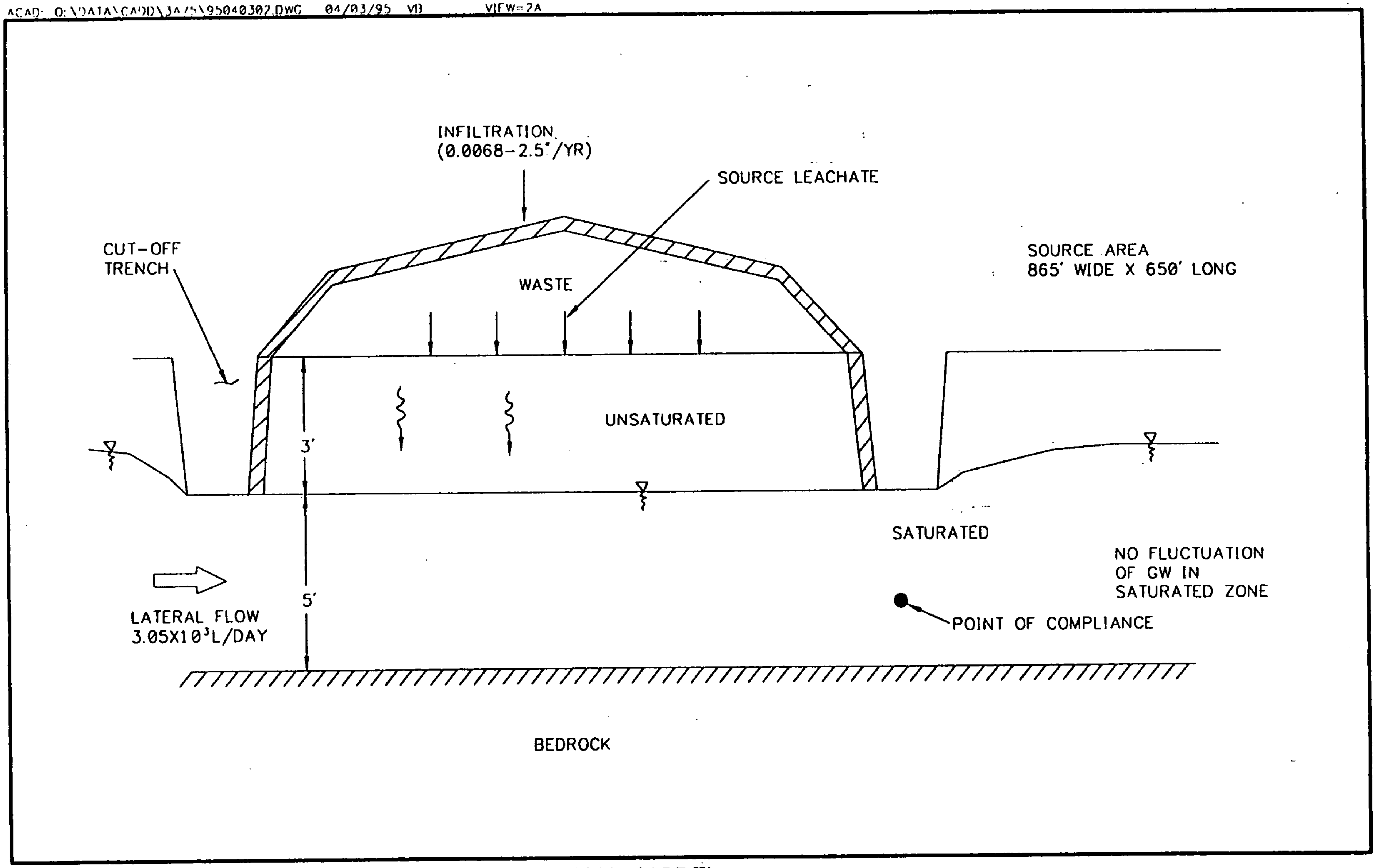


SCENARIO 1 – CONCEPTUAL MODEL
ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE
GOLDEN, COLORADO

FIGURE B-20

Halliburton NUS CORPORATION

ACAD: O:\DATA\CADD\3A75\95040302.DWG 04/03/95 VB VIEW=2A

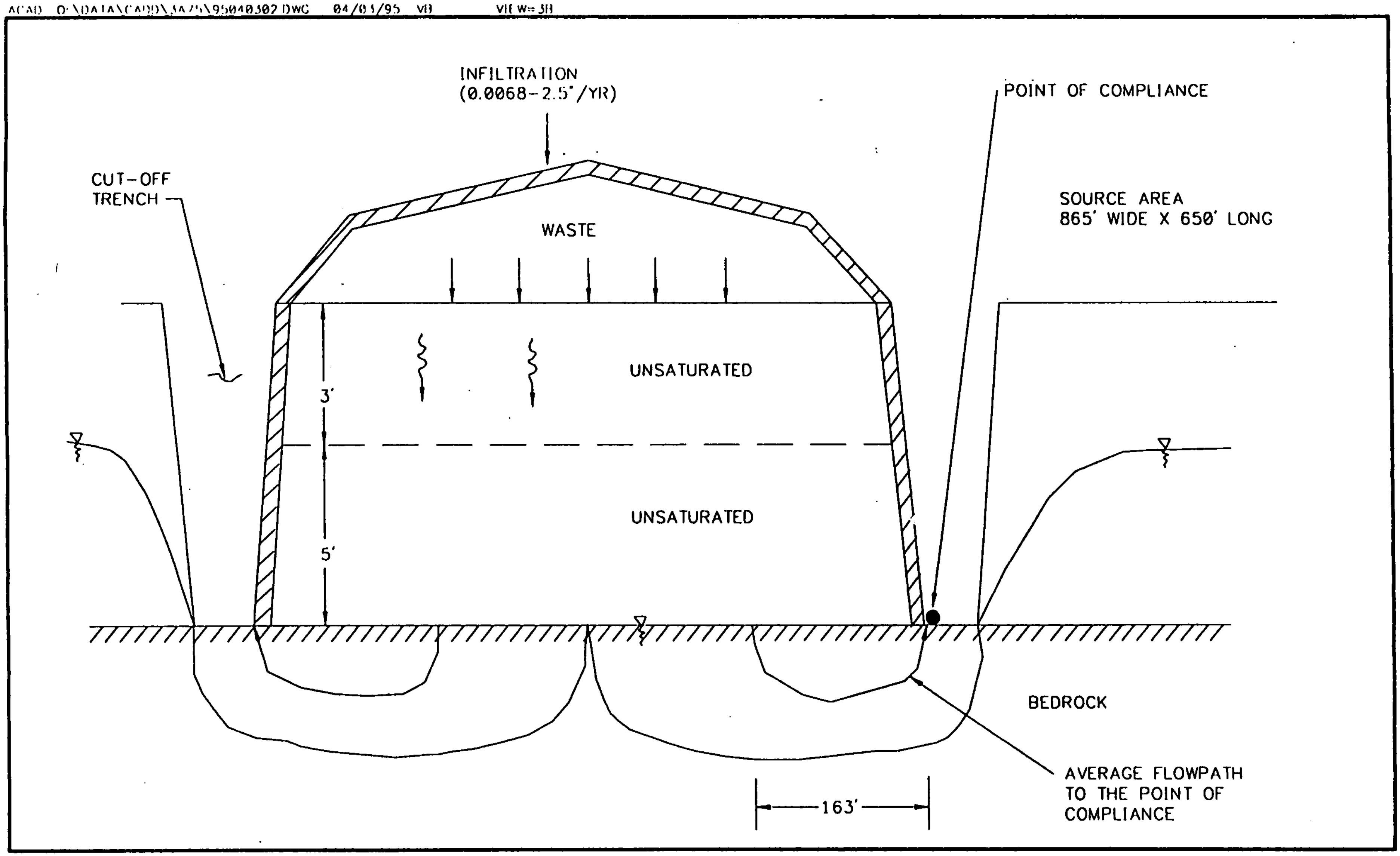


SCENARIO 2 - CONCEPTUAL MODEL
ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE
GOLDEN, COLORADO

FIGURE B-21

Halliburton NUS CORPORATION

ACAD O:\DATA\CADD\3A75\95040302.DWG 04/03/95 VB VIEW=3B



SCENARIO 3 – CONCEPTUAL MODEL
ROCKY FLATS ENVIRONMENTAL
TECHNOLOGY SITE
GOLDEN, COLORADO

FIGURE B-22

Halliburton NUS
CORPORATION

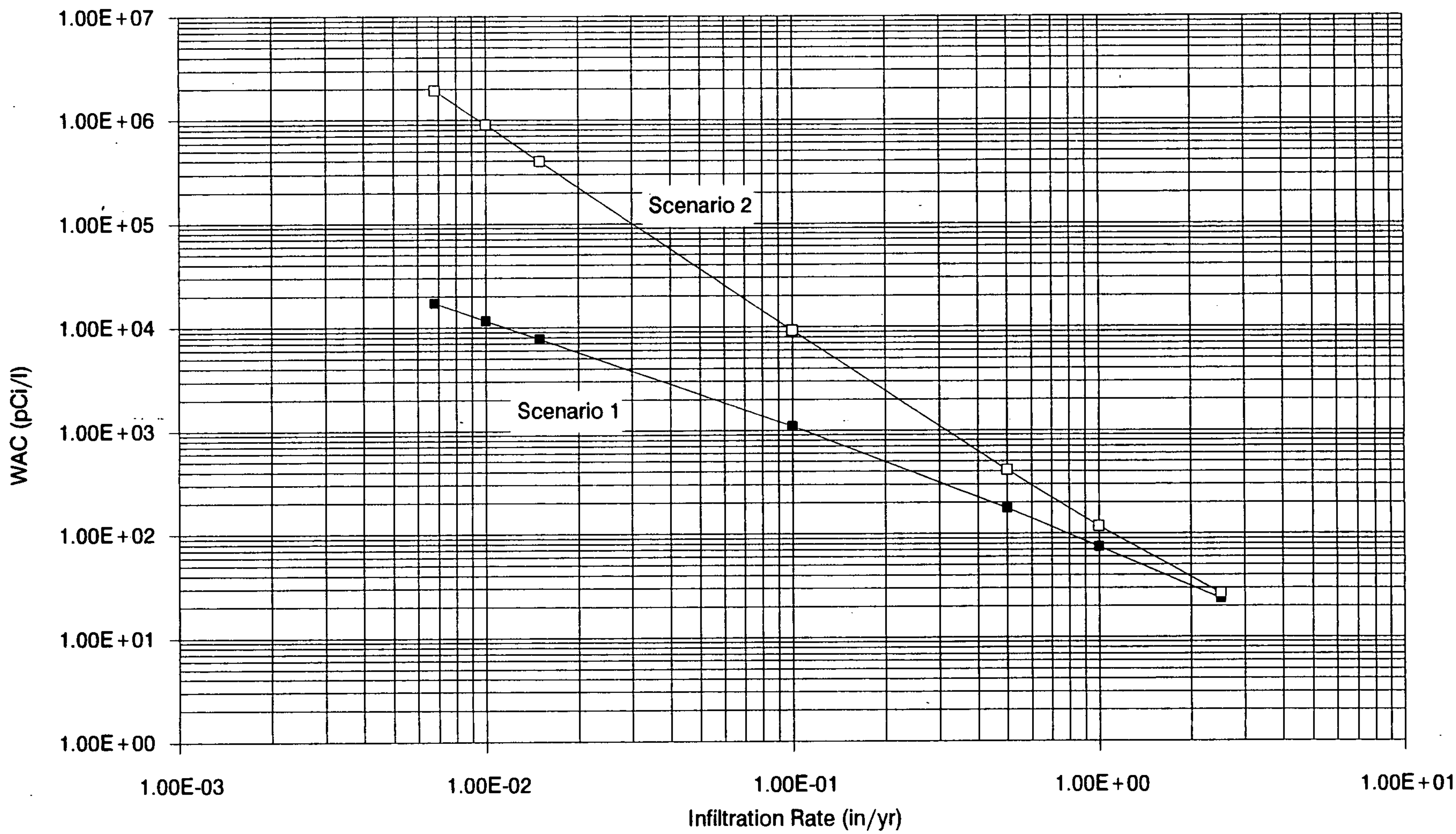


FIGURE B-23 AMERICIUM-241 WAC RESULTS

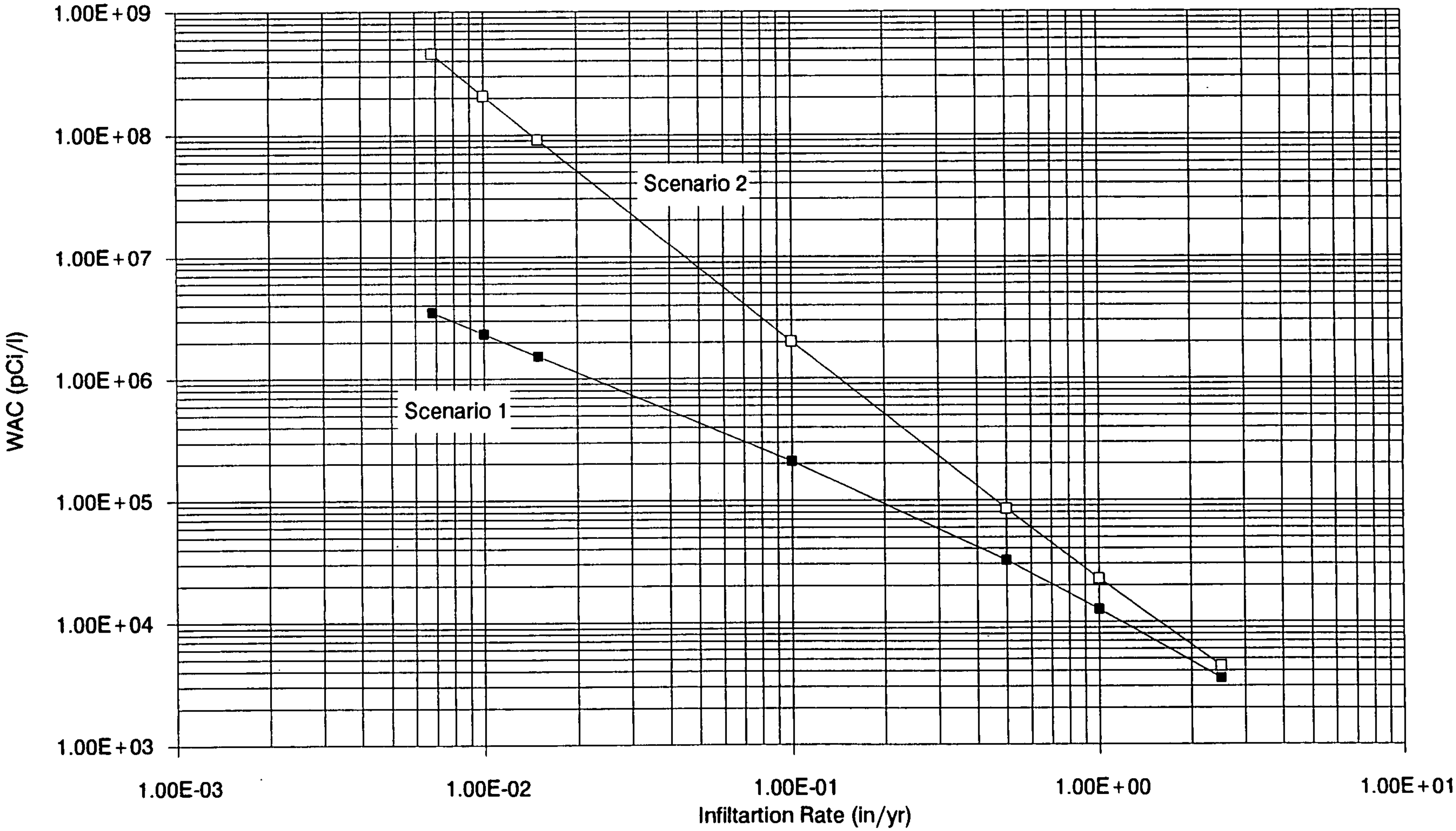


FIGURE B-24 CESIUM-134 WAC RESULTS

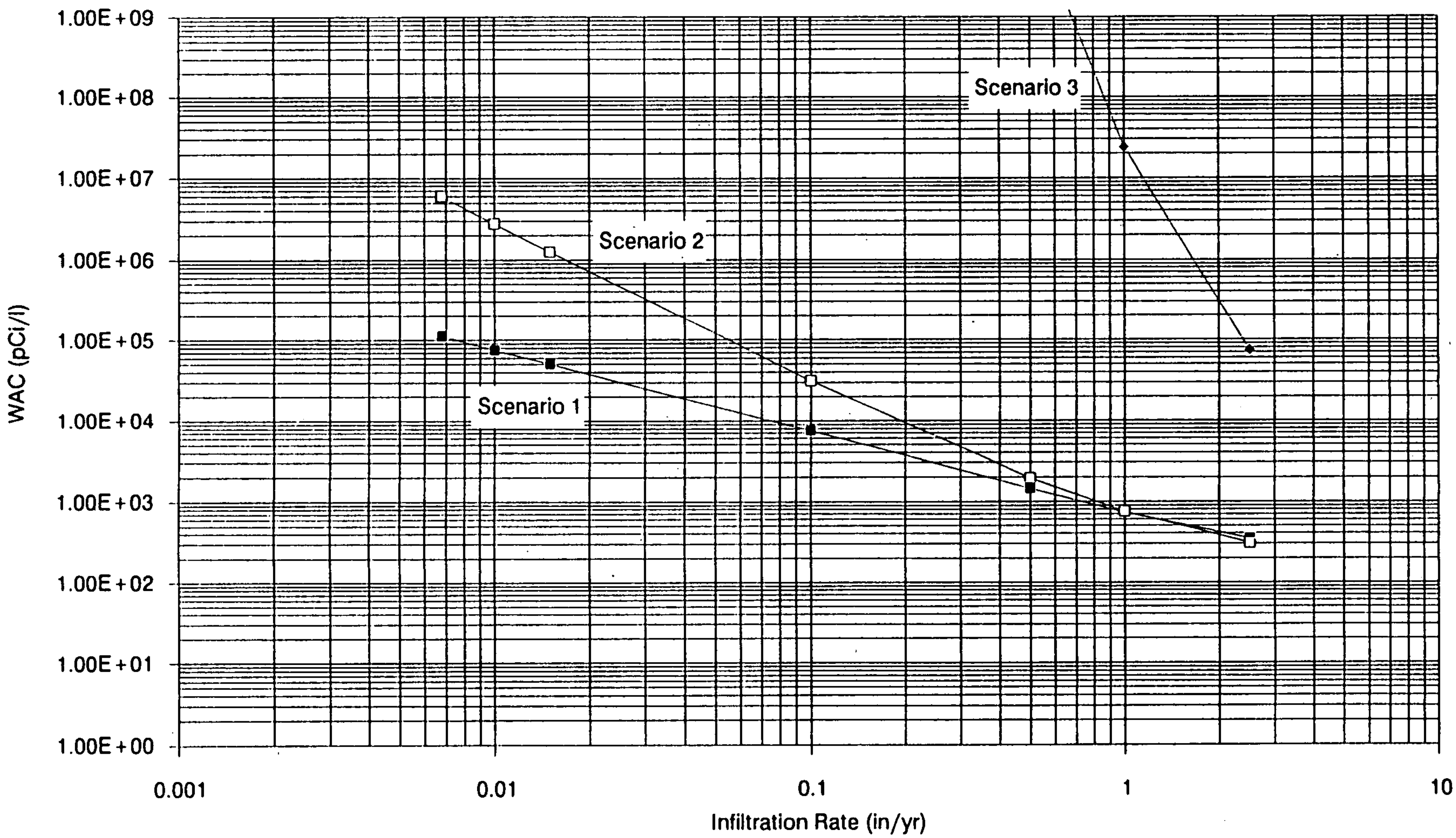


FIGURE B-25 CESIUM-137 WAC RESULTS

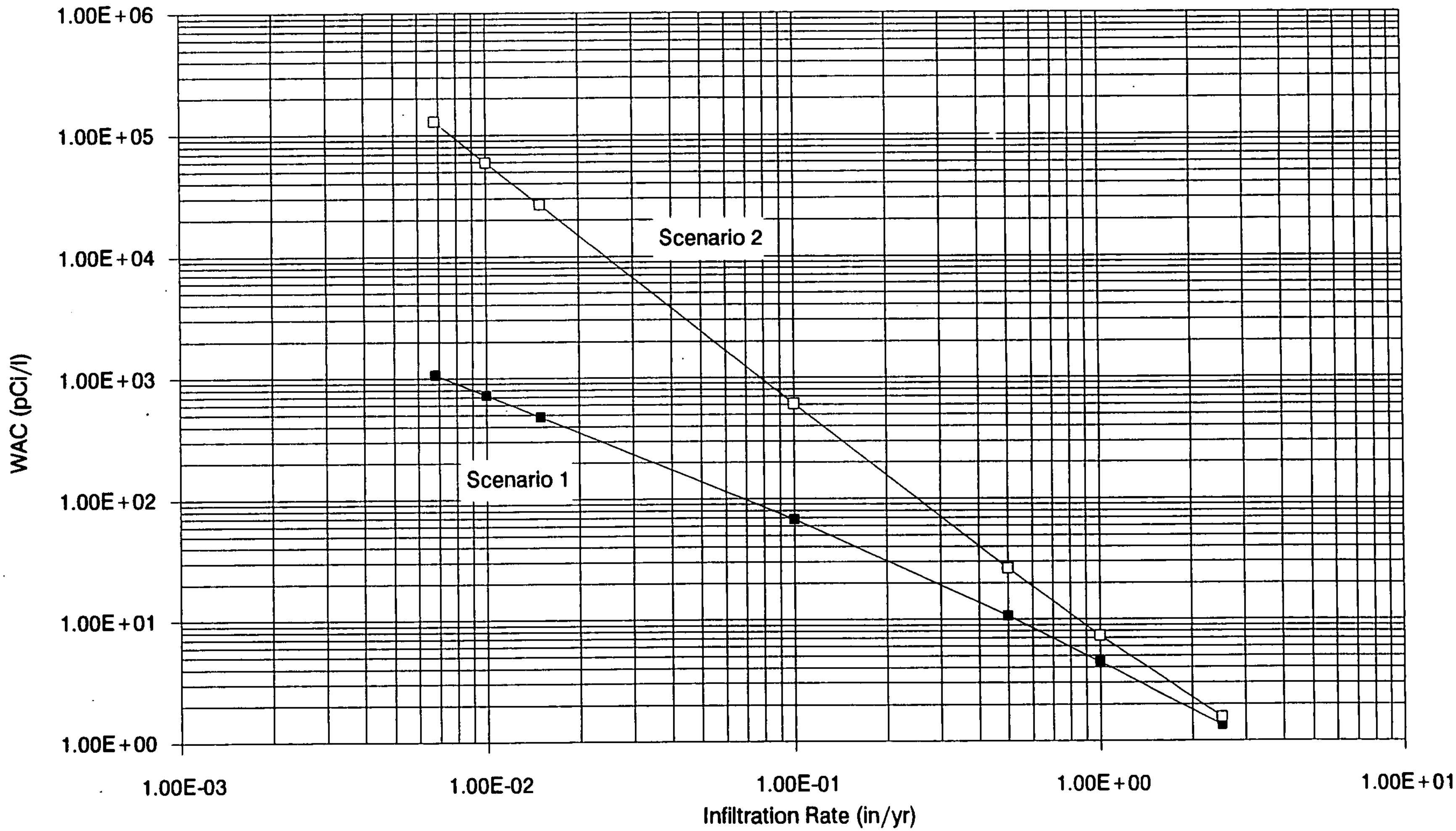


FIGURE B-26 PLUTONIUM-239/240 WAC RESULTS

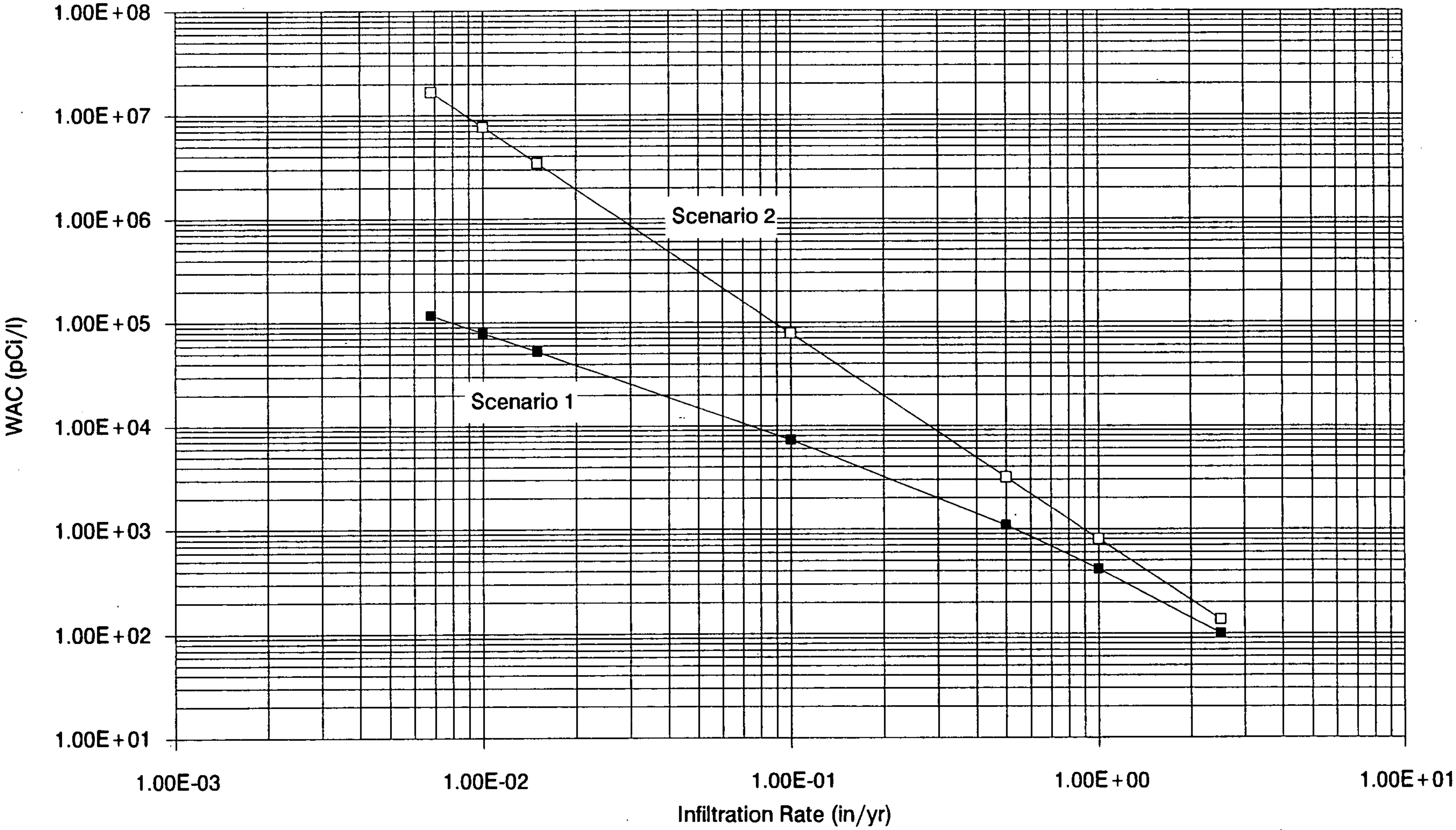


FIGURE B-27 RADIUM-226 WAC RESULTS

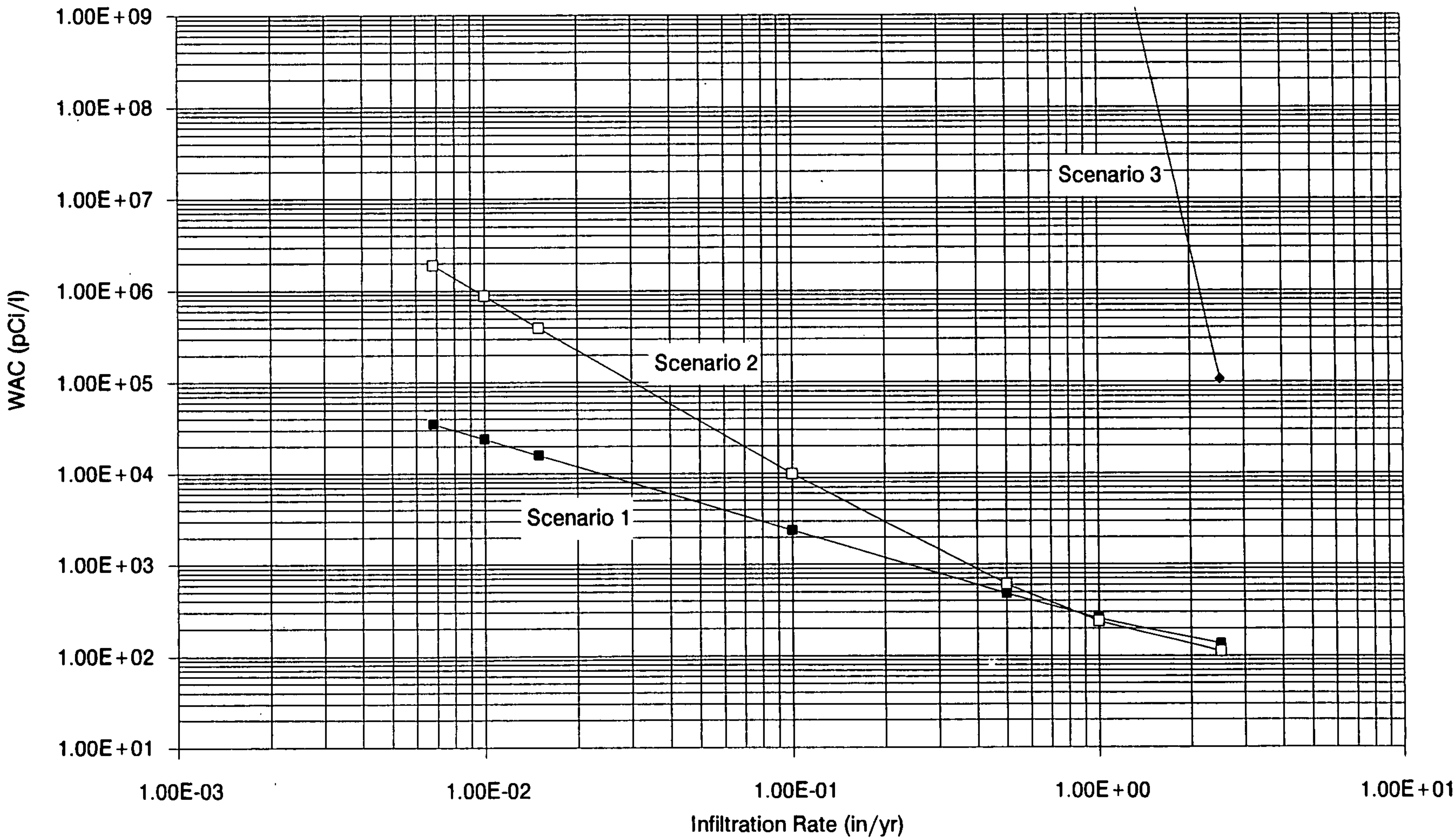


FIGURE B-28 URANIUM-233/234 WAC RESULTS

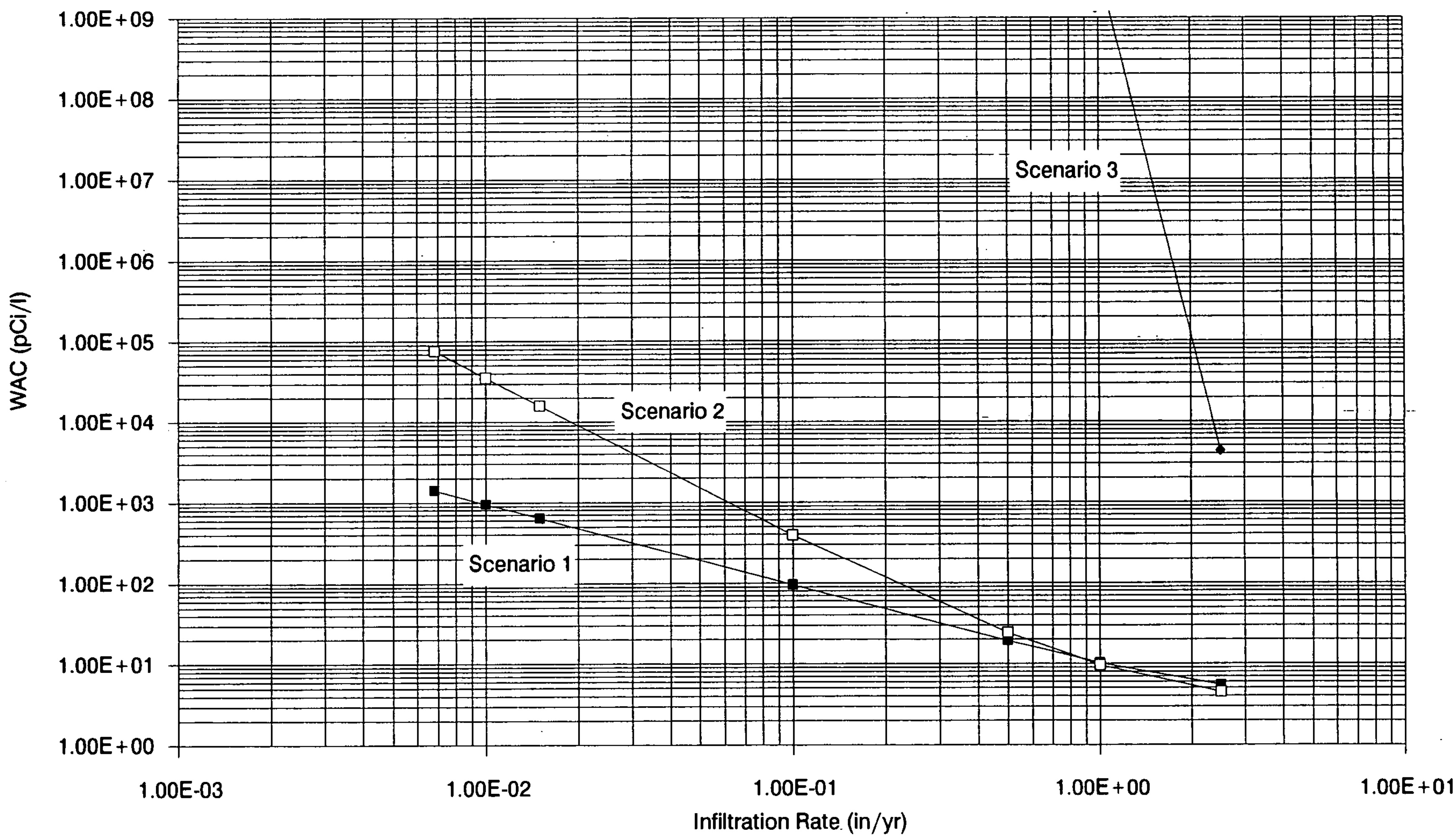


FIGURE B-29 URANIUM-235 WAC RESULTS

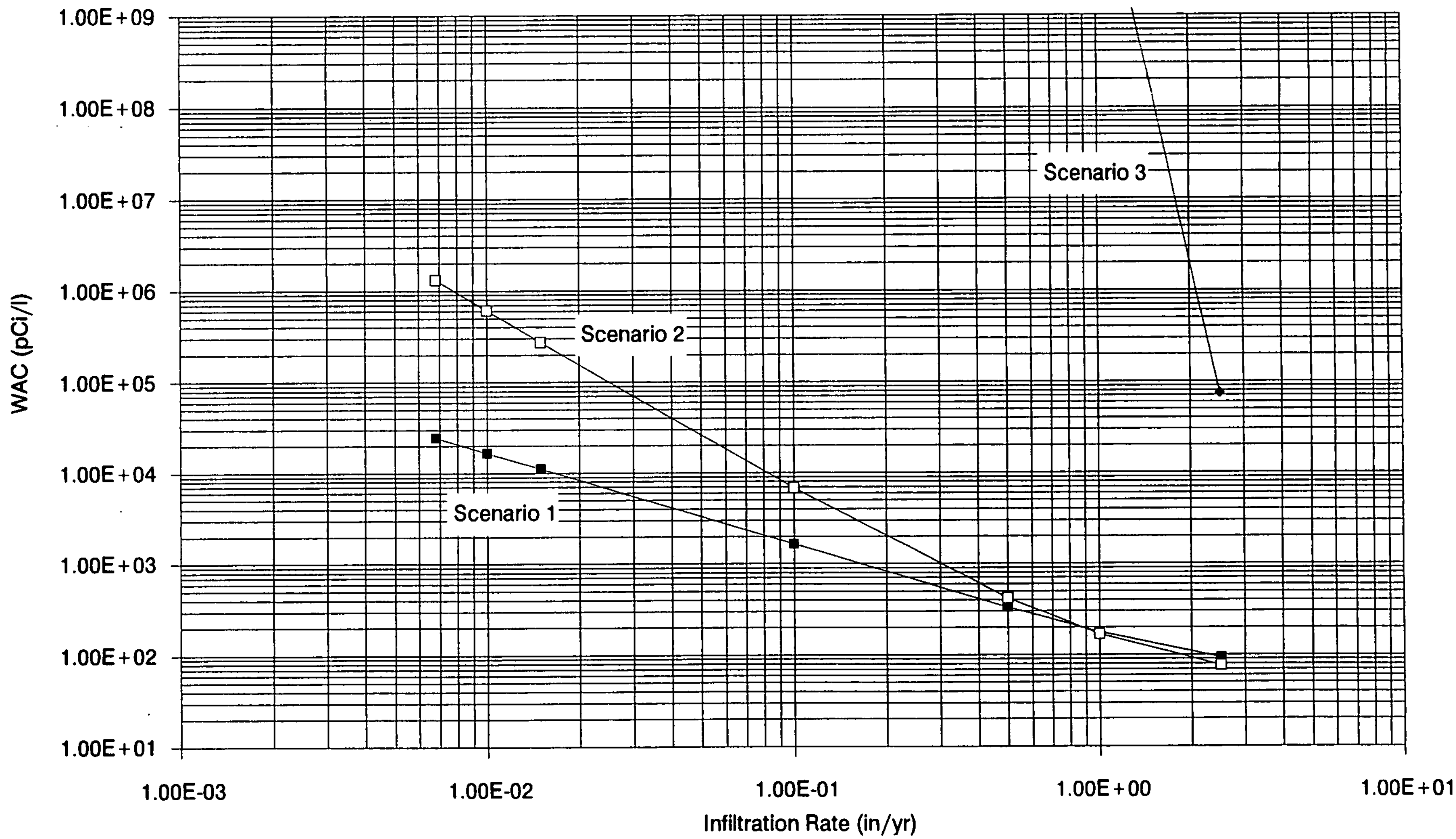


FIGURE B-30 URANIUM-238 WAC RESULTS

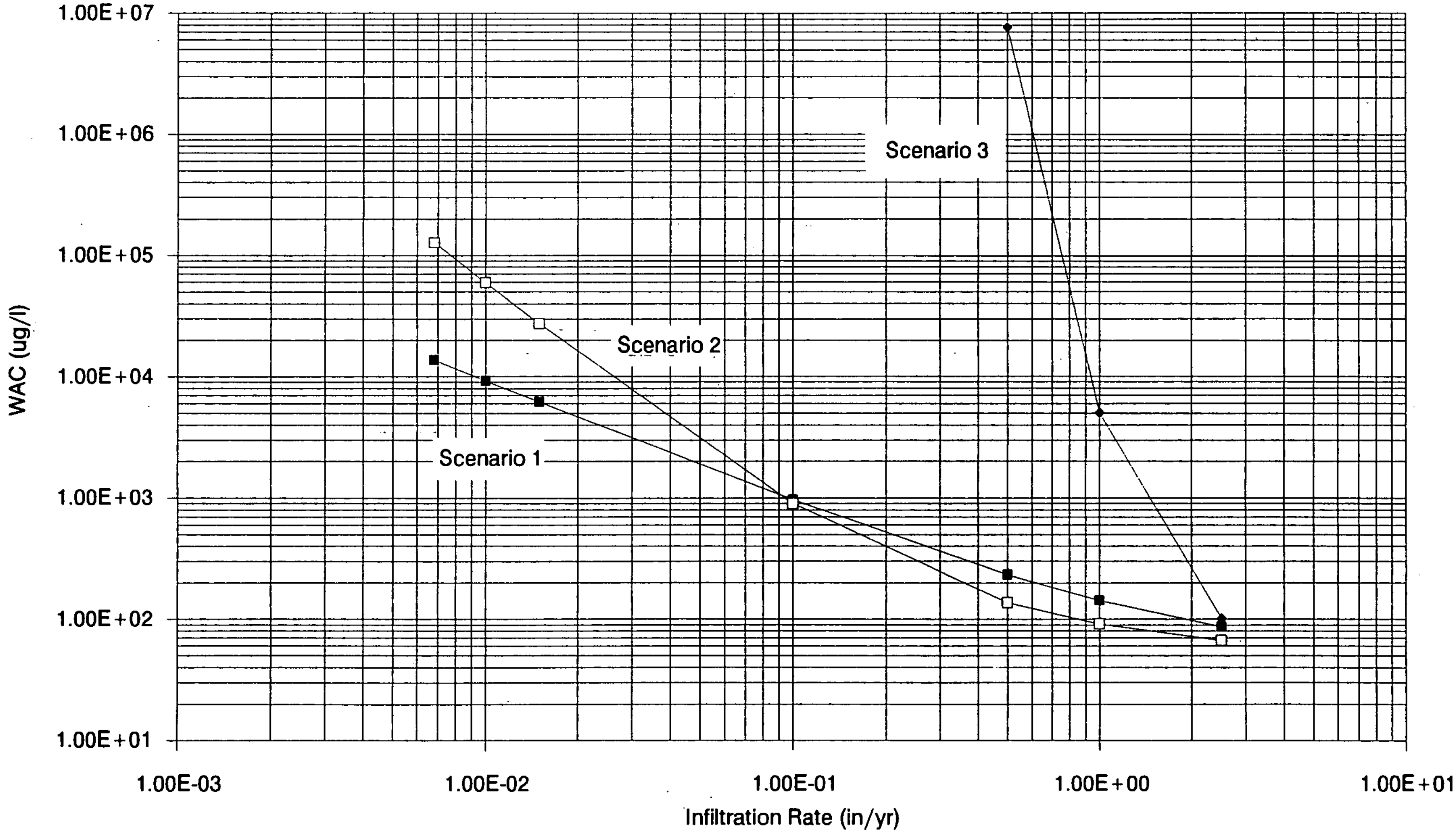


FIGURE B-31 ARSENIC WAC RESULTS

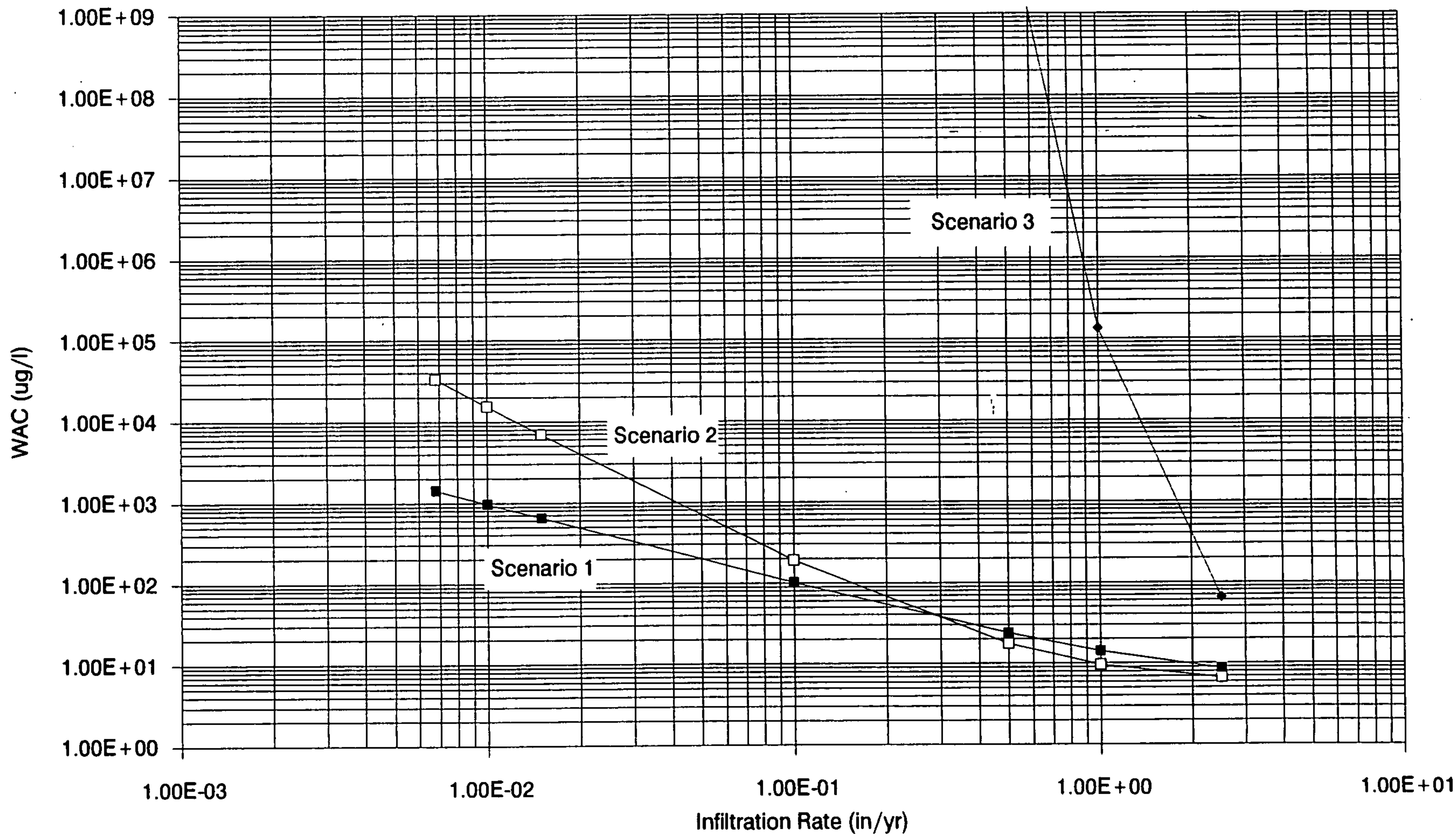


FIGURE B-32 BERYLLIUM WAC RESULTS

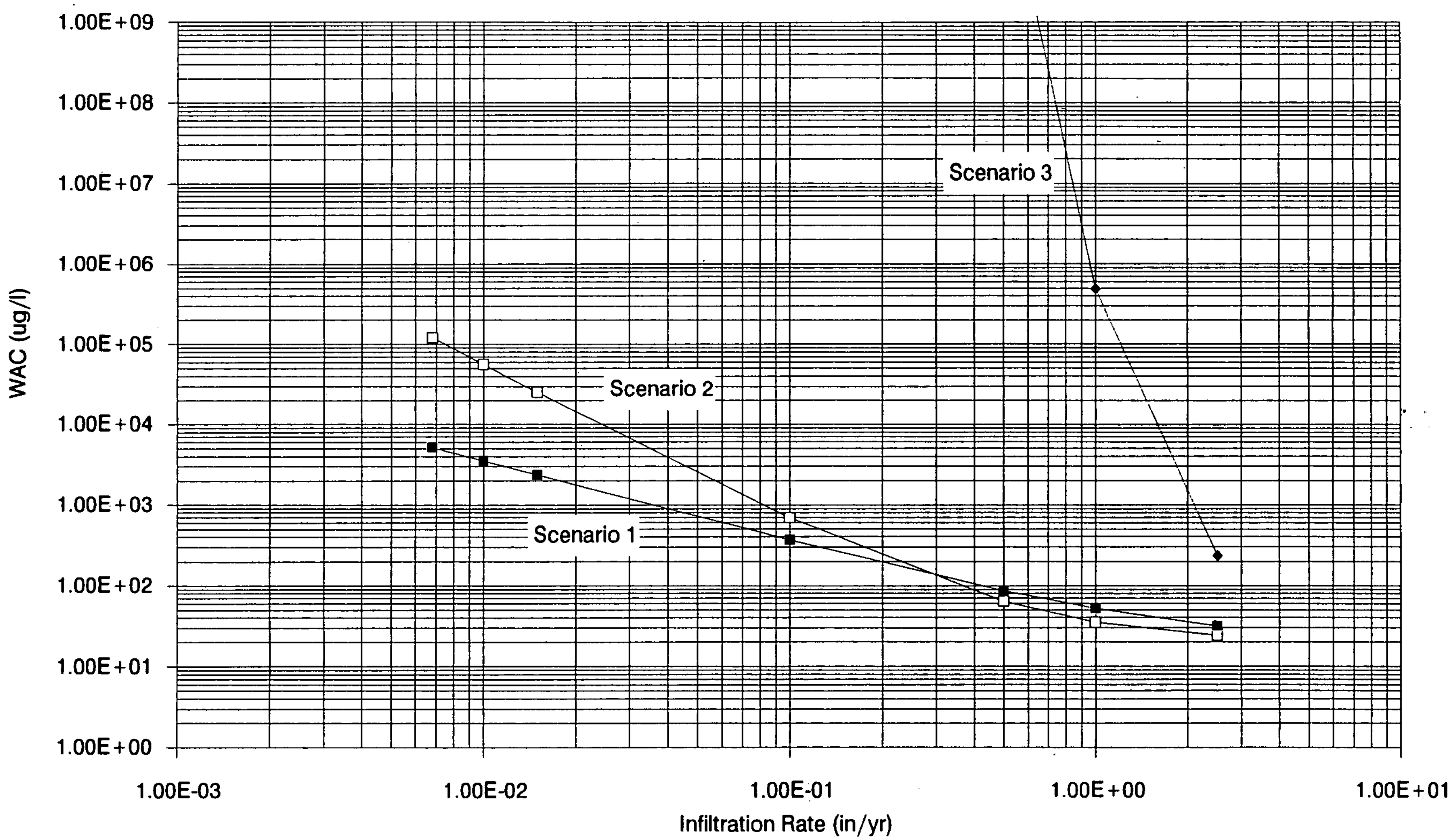


FIGURE B-33 CADMIUM WAC RESULTS

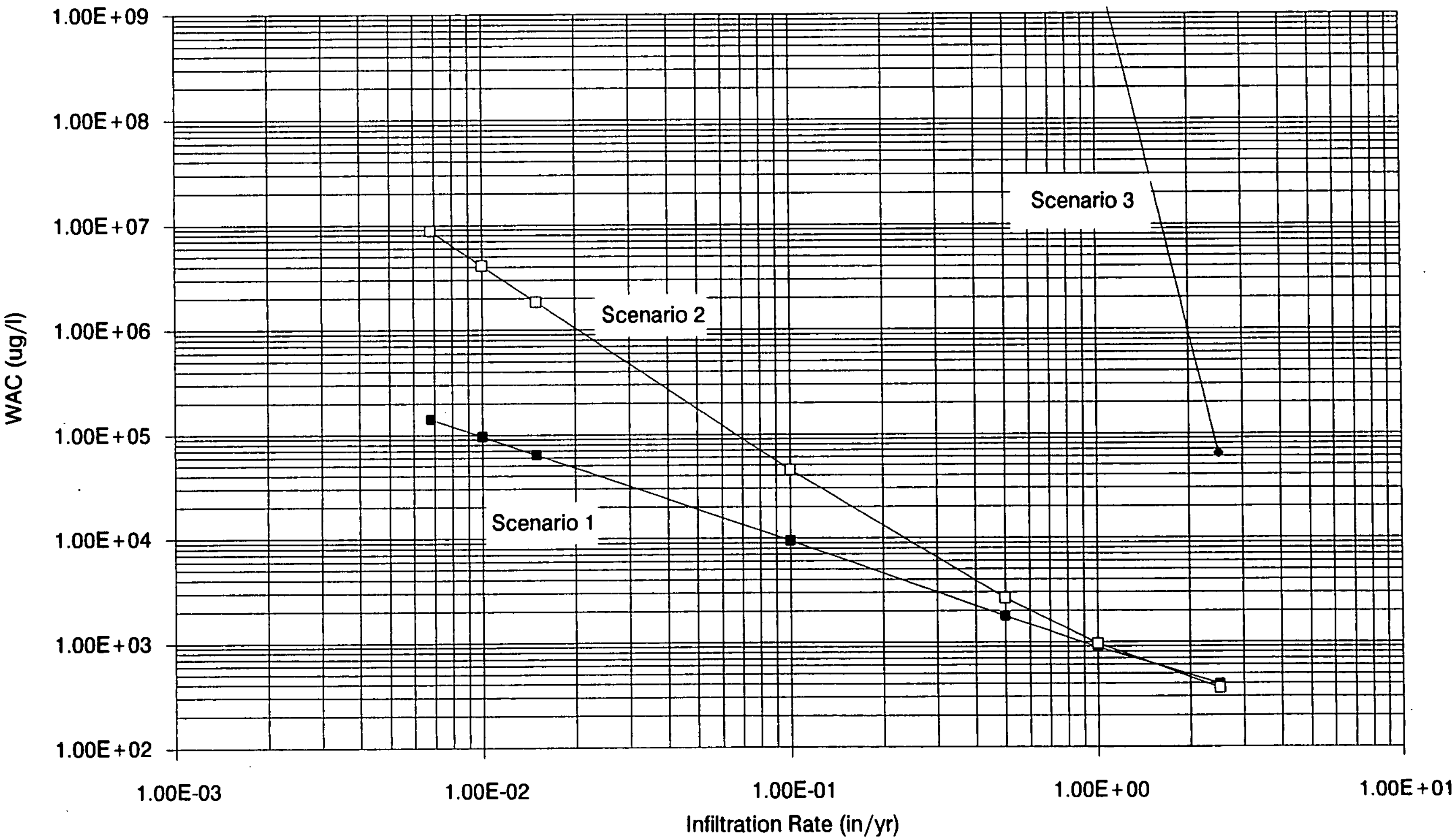


FIGURE B-34 CHROMIUM WAC RESULTS

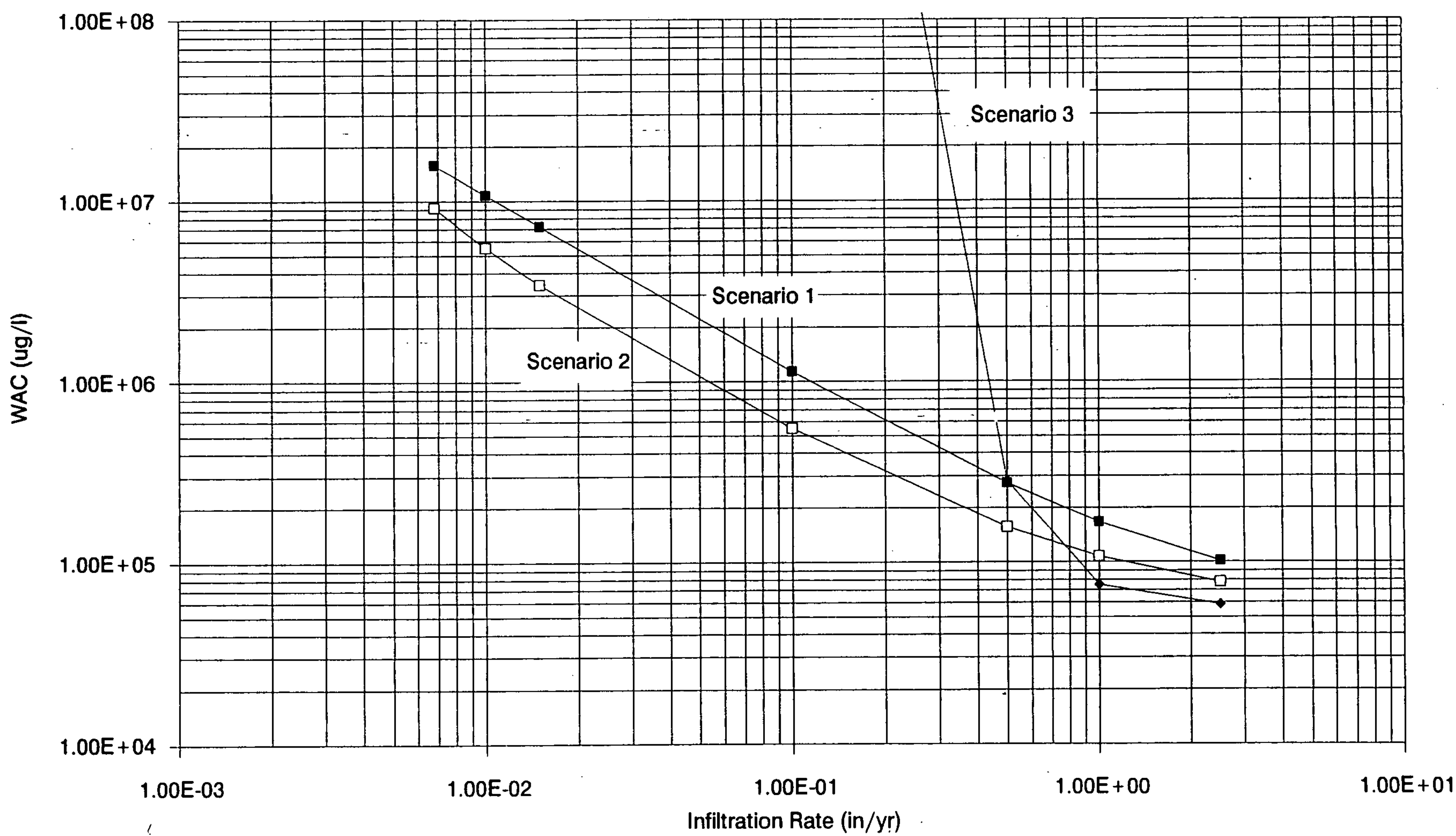


FIGURE B-35 NITRATE WAC RESULTS

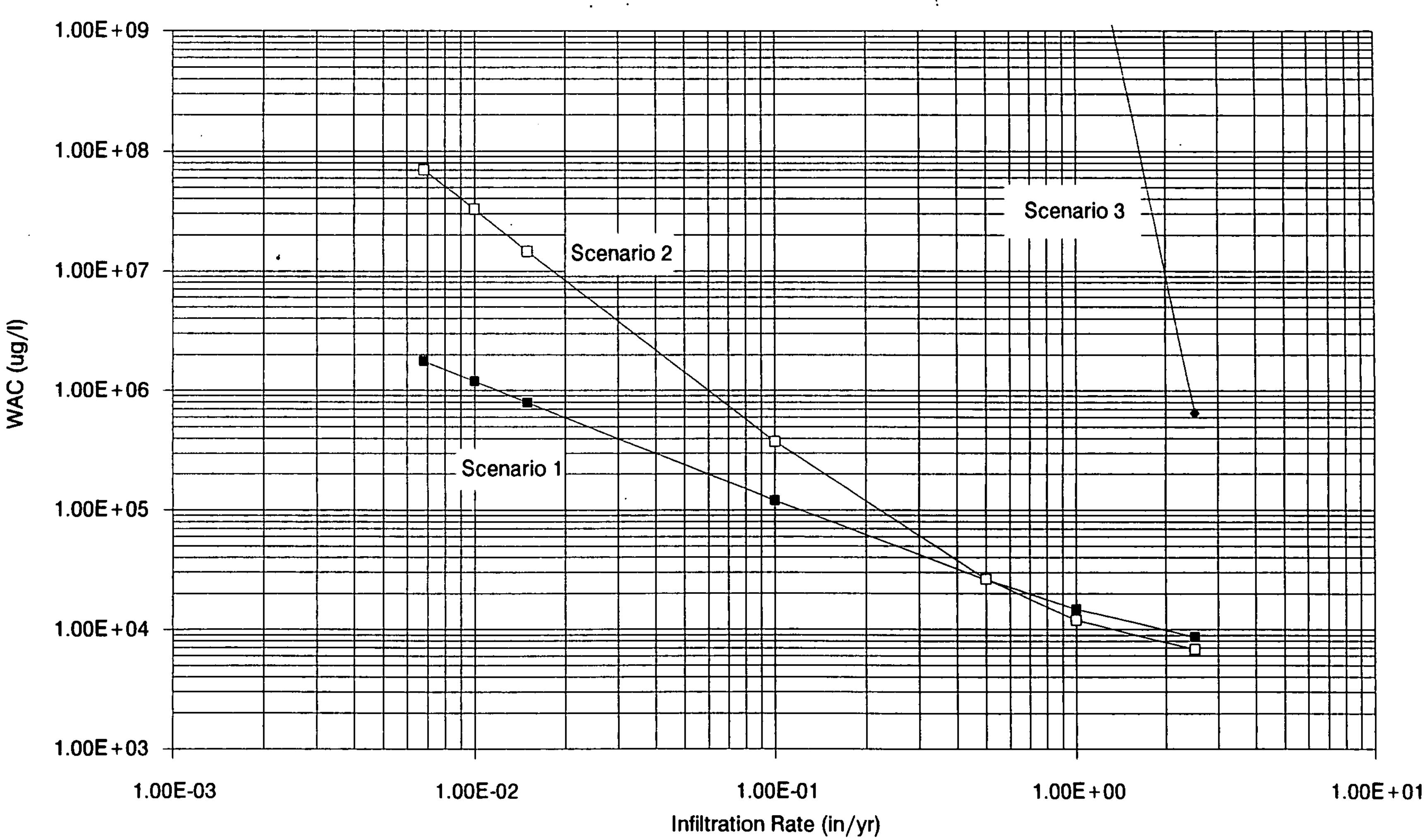


FIGURE B-36 SODIUM WAC RESULTS

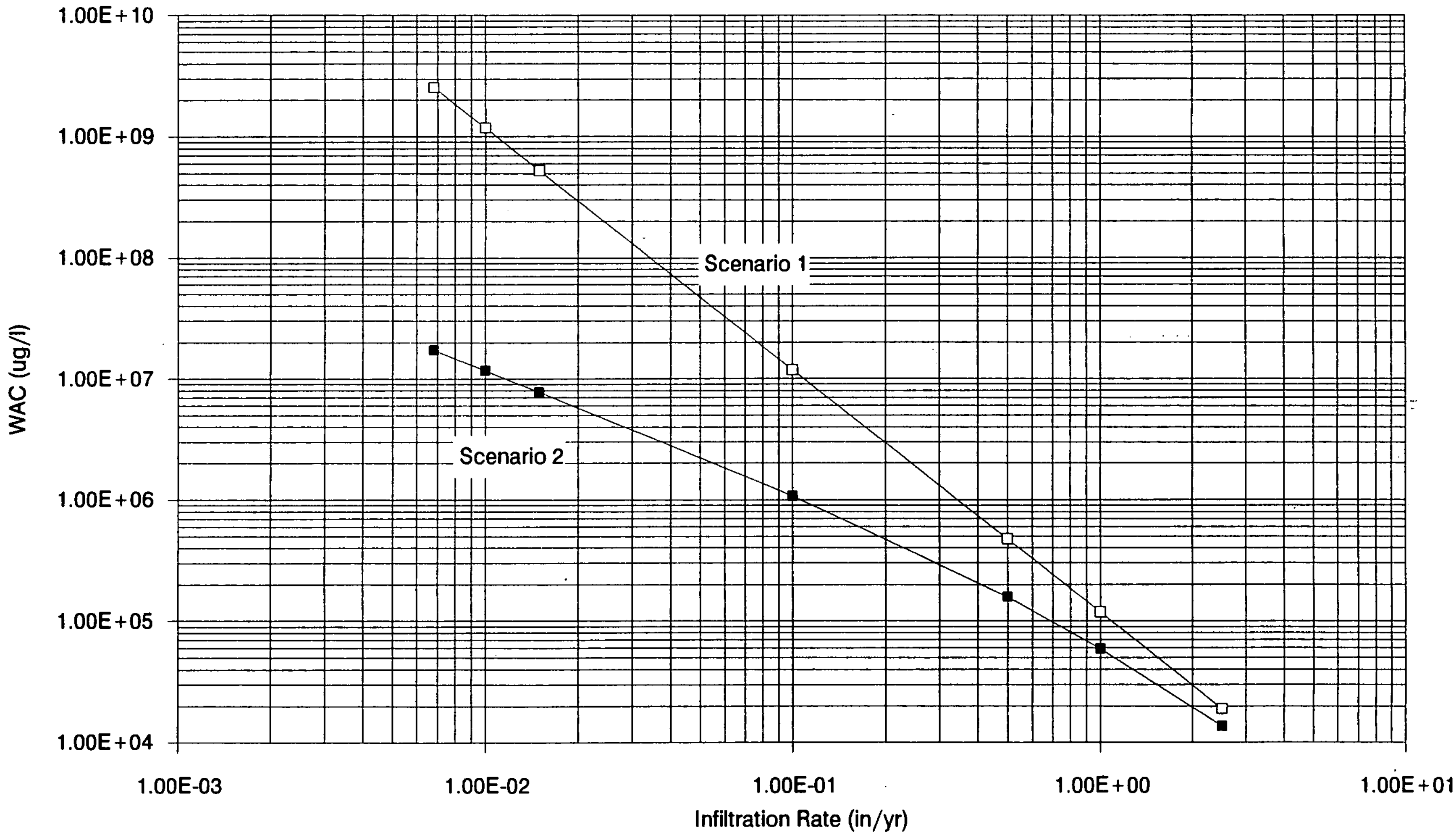


FIGURE B-37 AROCHLOR-1254 WAC RESULTS

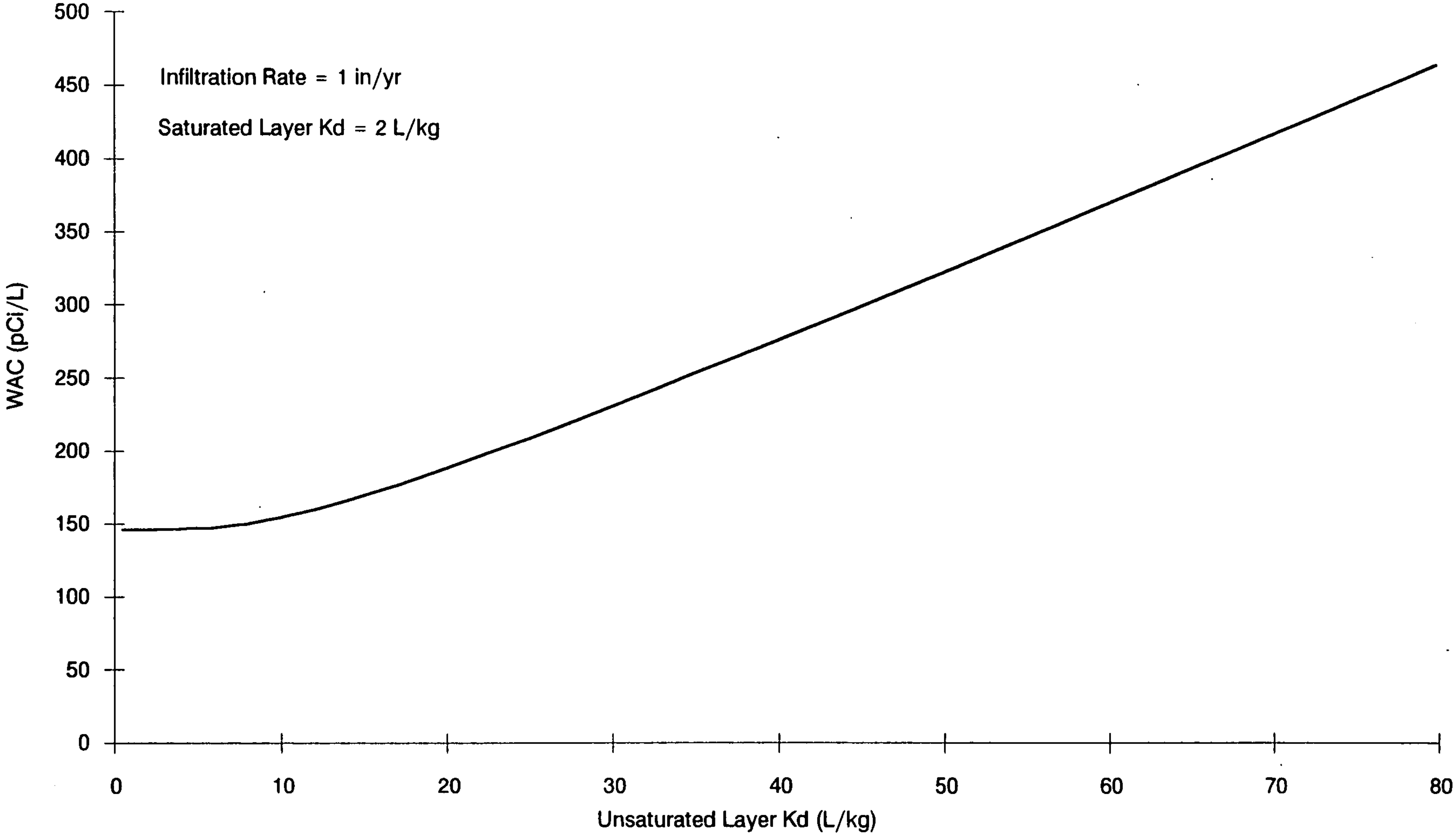


FIGURE B-38 SENSITIVITY OF URANIUM-238 WAC TO UNSATURATED LAYER Kd

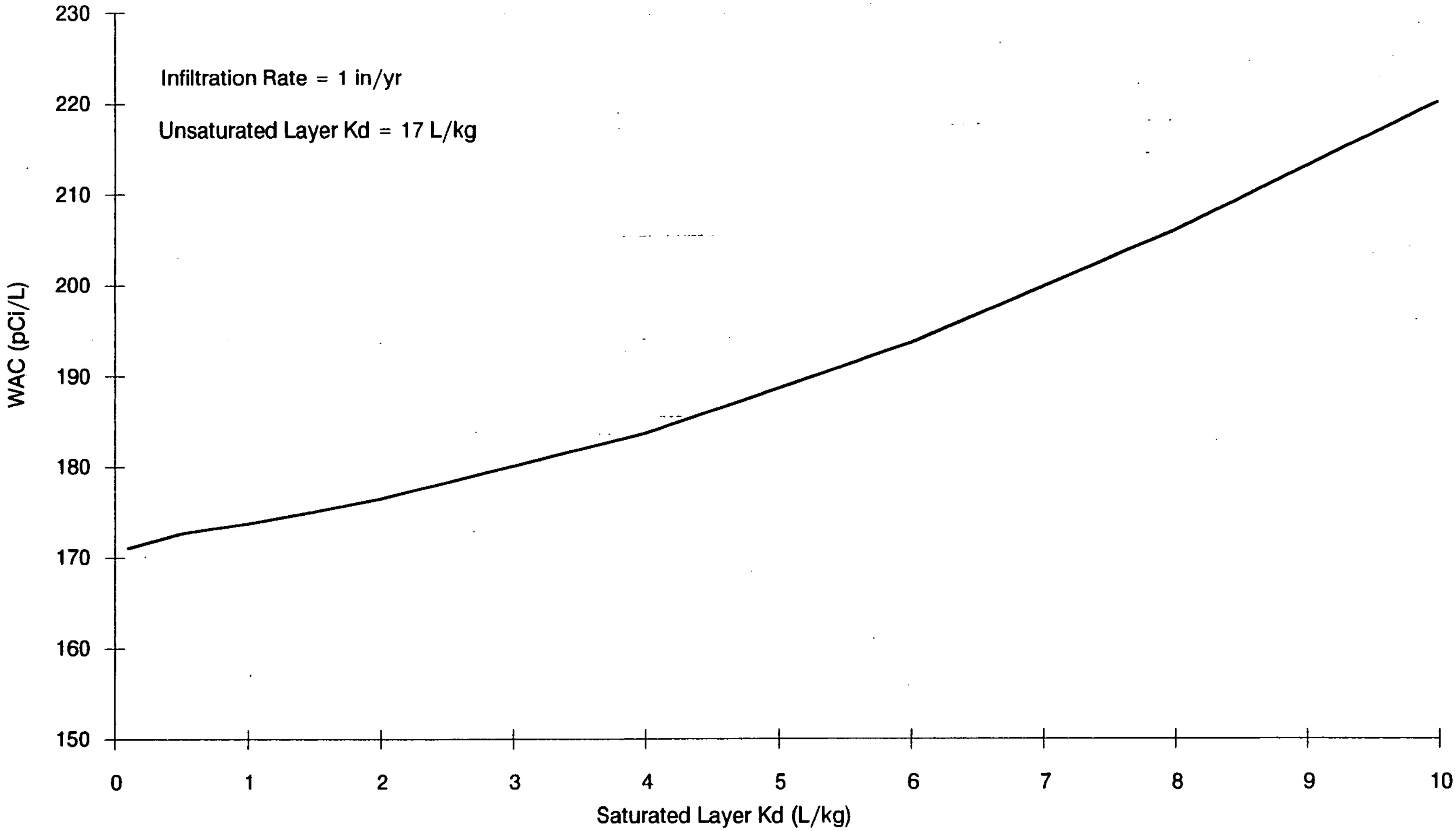


FIGURE B-39 SENSITIVITY OF URANIUM-238 WAC TO SATURATED LAYER Kd

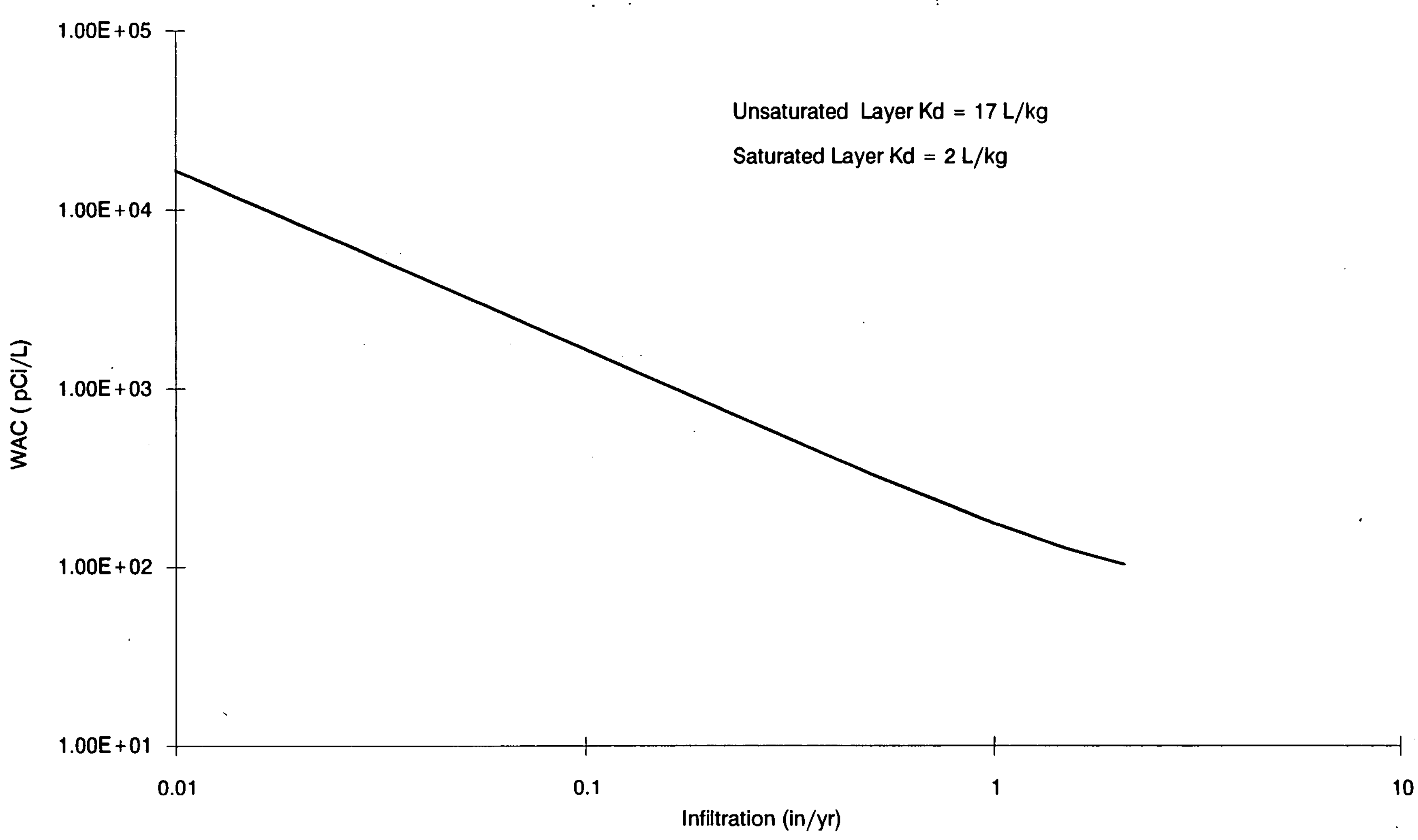


FIGURE B-40 SENSITIVITY OF URANIUM-238 WAC TO INFILTRATION RATE

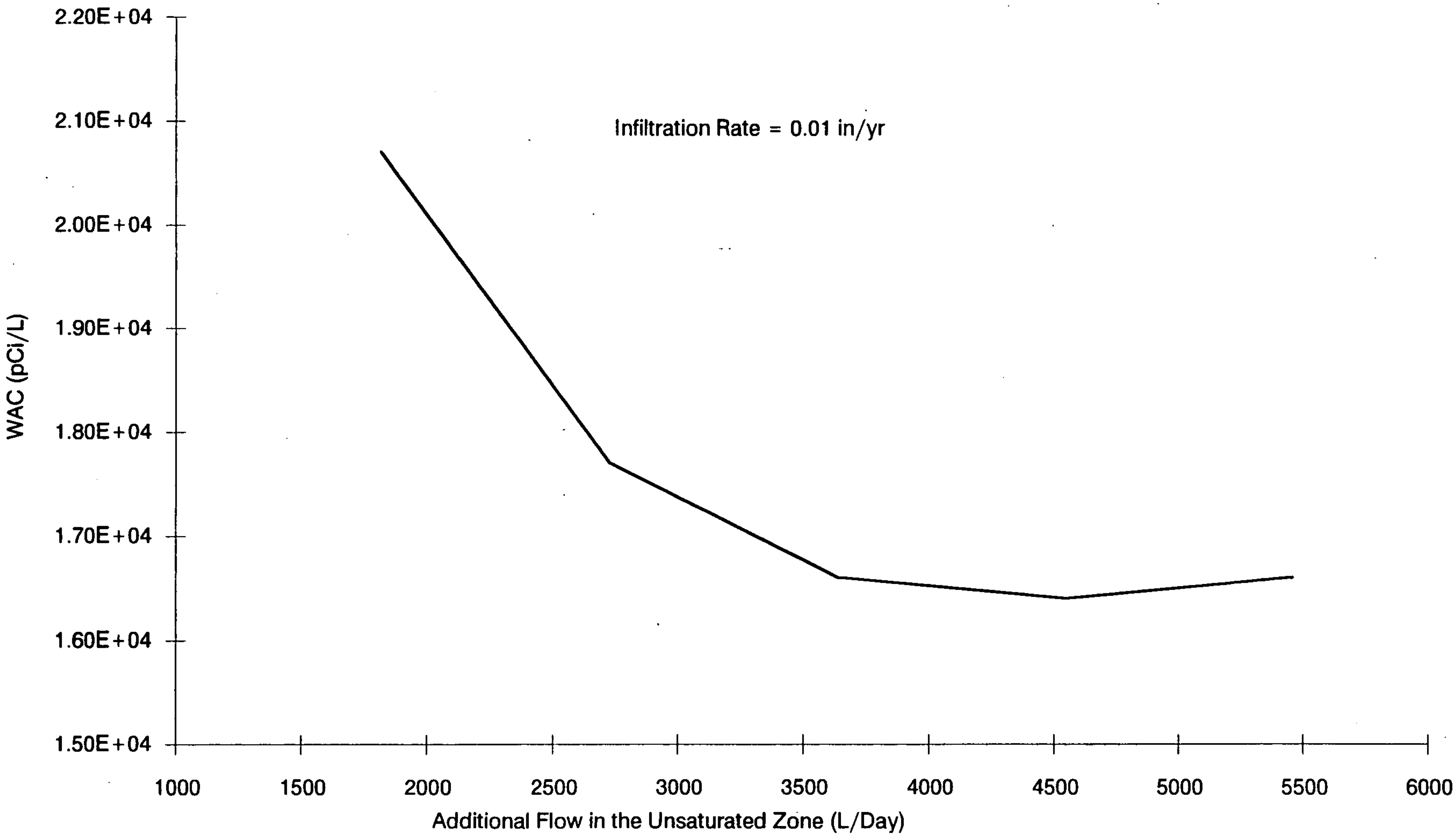


FIGURE B-41 SENSITIVITY OF URANIUM-238 WAC TO ADDITIONAL FLOW IN THE UNSATURATED ZONE (LOW INFILTRATION)

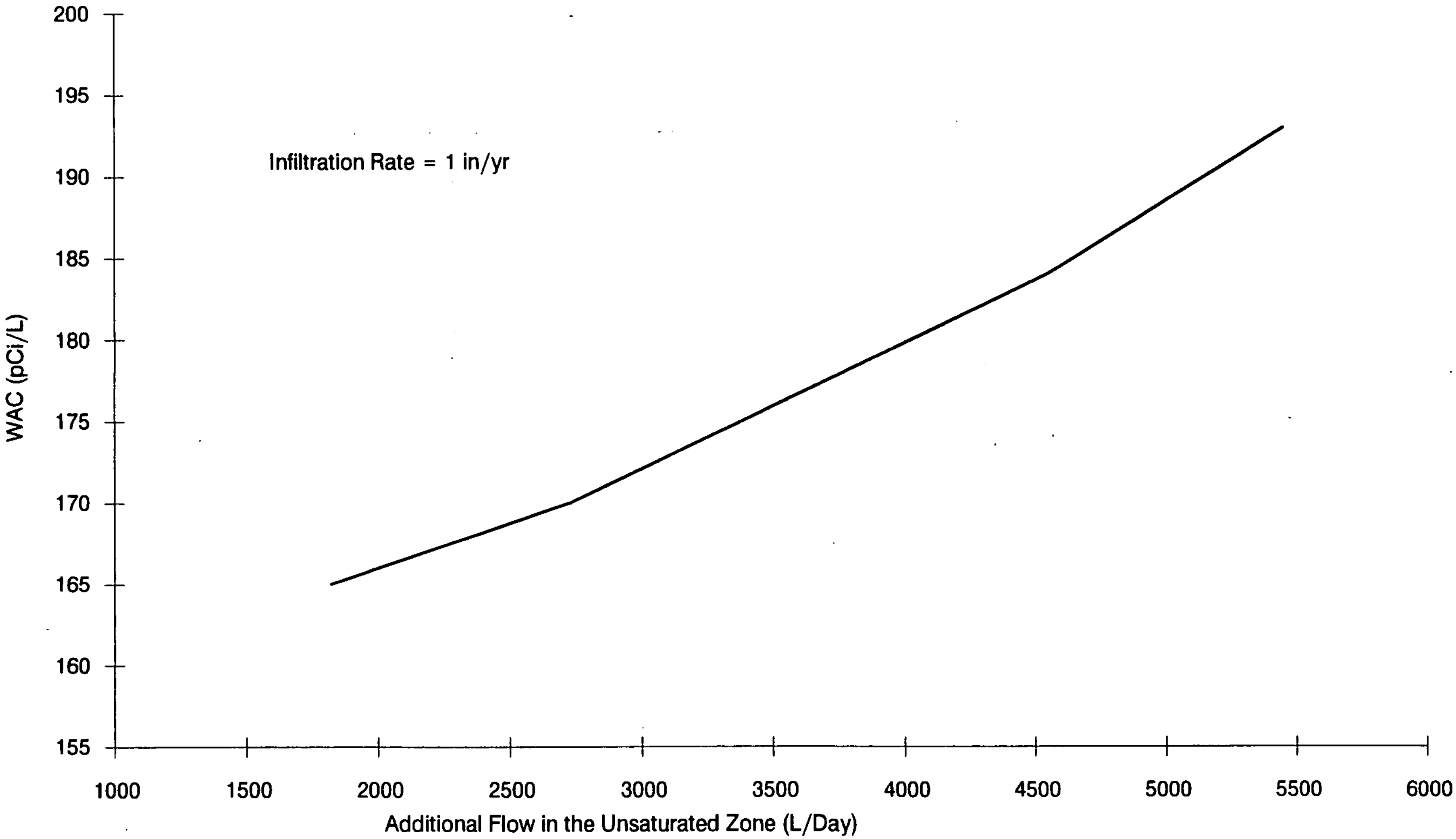
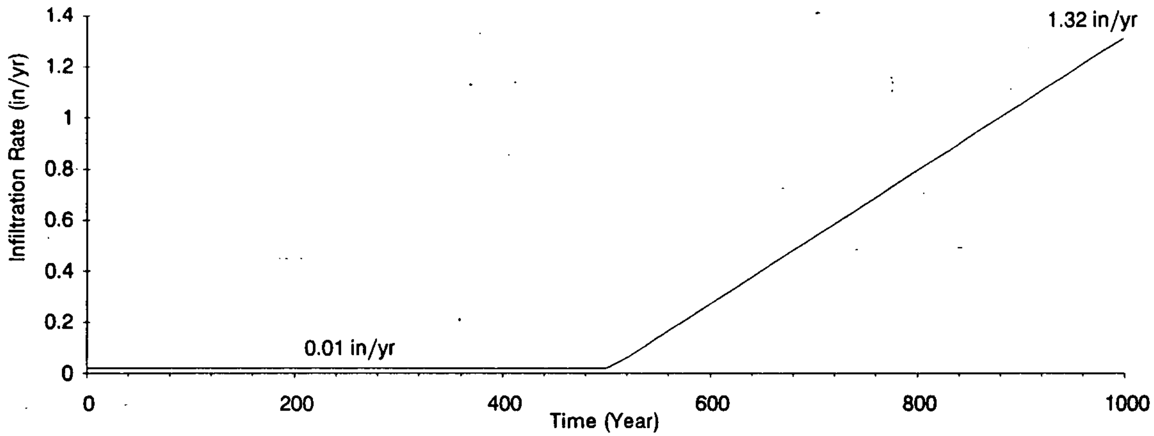
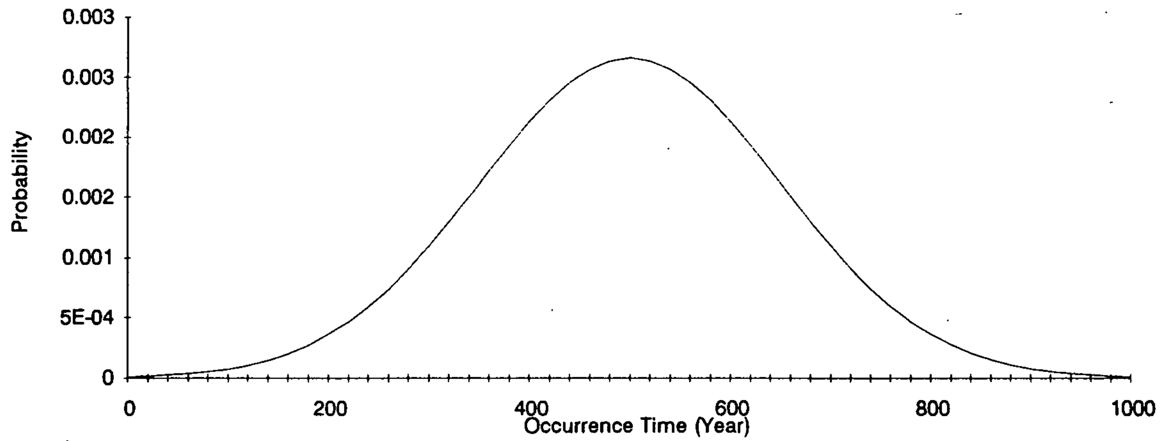


FIGURE B-42 SENSITIVITY OF URANIUM-238 WAC TO ADDITIONAL FLOW IN THE UNSATURATED ZONE (HIGHER INFILTRATION)

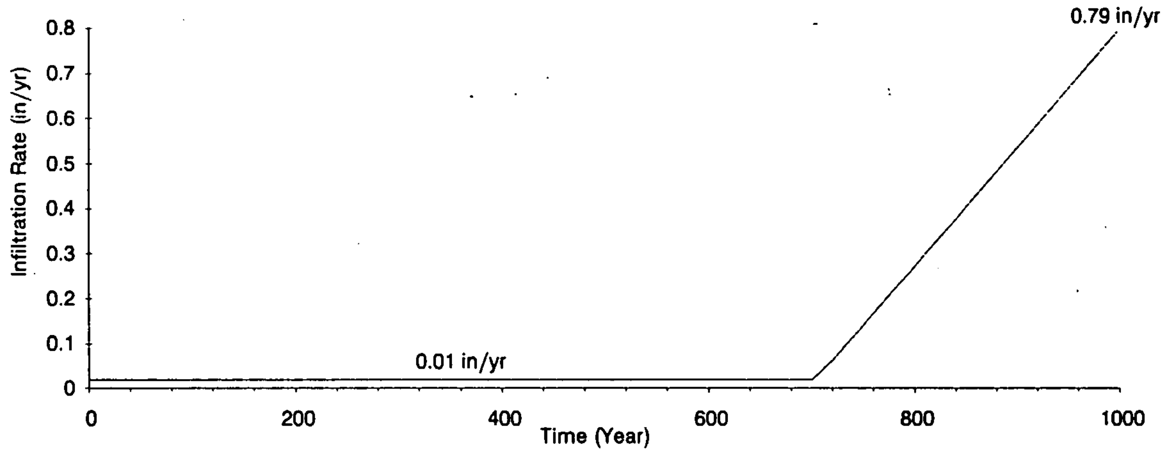


Pattern of Infiltration Rate (Case 1)

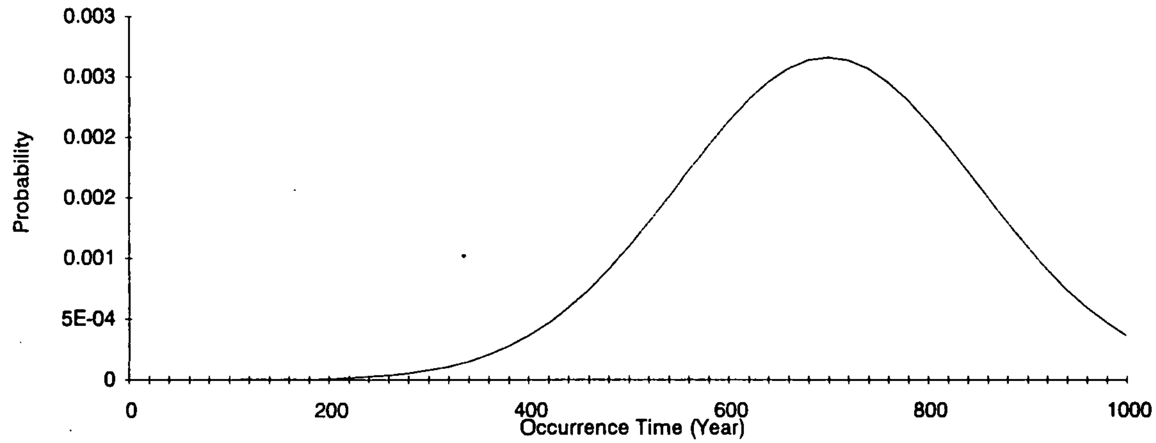


Probability Distribution of Initiation of Degradation of Impervious Liner (Case 1)

FIGURE B-43 INFILTRATION PATTERN FOR PROBABILISTIC SENSITIVITY CASE 1

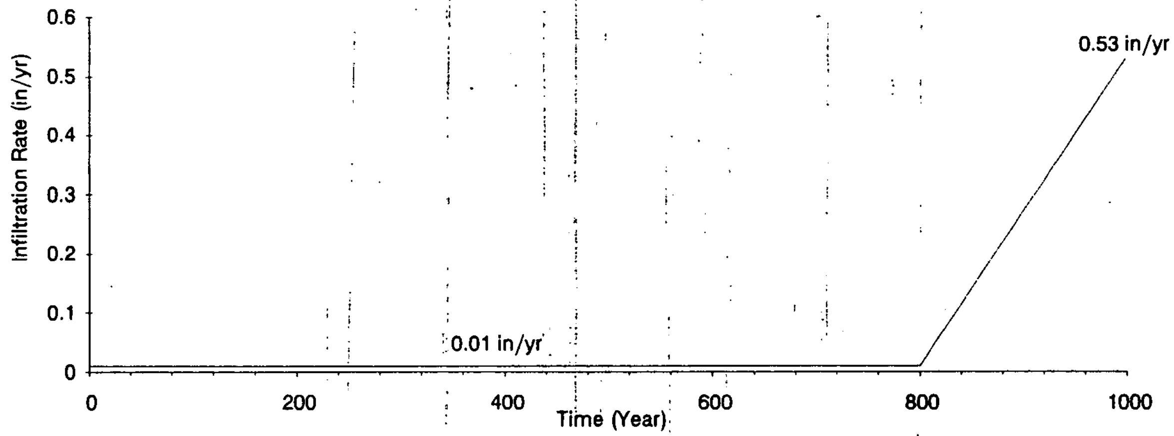


Pattern of Infiltration Rate (Case 2)

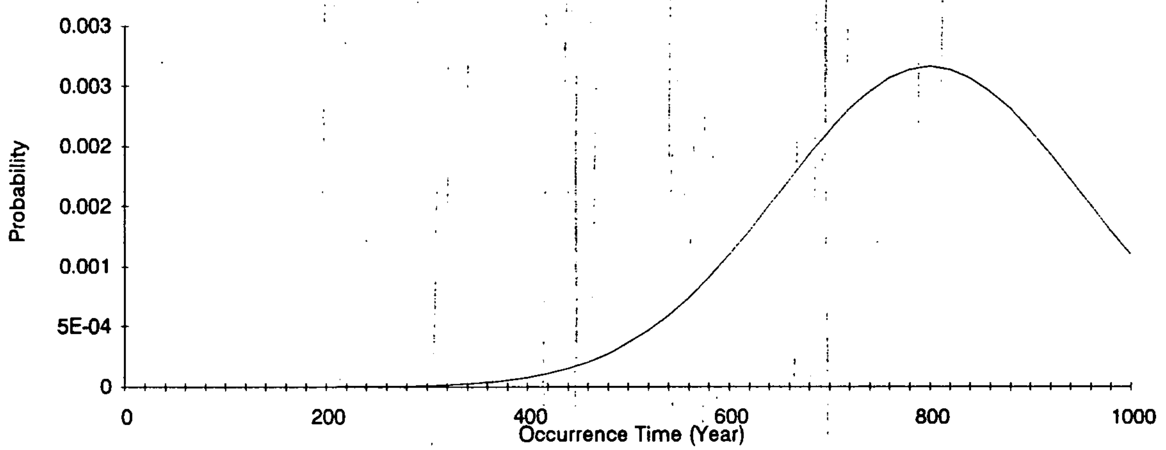


Probability Distribution of Initiation of Degradation of Impervious Liner (Case 2)

FIGURE B-44 INFILTRATION PATTERN FOR PROBABILISTIC SENSITIVITY CASE 2



Pattern of Infiltration Rate (Case 3)



Probability Distribution of Initiation of Degradation of Impervious Liner (Case 3)

FIGURE B-45 INFILTRATION PATTERN FOR PROBABILISTIC SENSITIVITY CASE 3

Forecast: Max. Saturated Layer Conc. **Cell: L79**

Summary:

Display Range is from 0.00E+0 to 1.10E+2 pCi/L
Entire Range is from 2.52E-1 to 1.01E+2 pCi/L
After 1,000 Trials, the Std. Error of the Mean is 8.05E-1

Statistics:	Value
Trials	1000
Mean	4.01E+01
Median (approx.)	3.75E+01
Mode (approx.)	1.19E+01
Standard Deviation	2.54E+01
Variance	6.47E+02
Skewness	0.31
Kurtosis	2.01
Coeff. of Variability	0.63
Range Minimum	2.52E-01
Range Maximum	1.01E+02
Range Width	1.01E+02
Mean Std. Error	8.05E-01

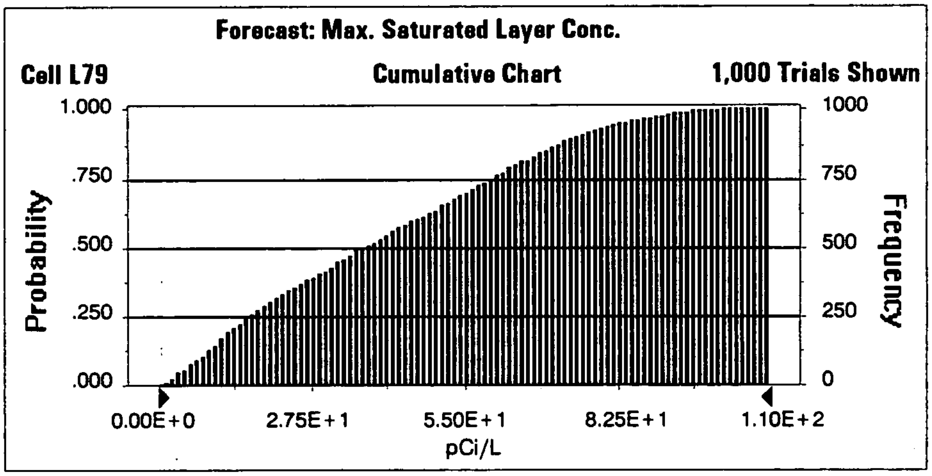


FIGURE B-46a SAMPLE MONTE CARLO SIMULATION OUTPUT

Forecast: Max. Saturated Layer Conc. (cont'd) **Cell: L79**

Percentiles:

Percentile	pCi/L (approx.)
0%	2.52E-01
10%	8.34E+00
20%	1.38E+01
30%	2.08E+01
40%	2.92E+01
50%	3.75E+01
60%	4.69E+01
70%	5.62E+01
80%	6.46E+01
90%	7.58E+01
100%	1.01E+02

End of Forecast

FIGURE B-46b SAMPLE MONTE CARLO SIMULATION OUTPUT

Forecast: Conc. in Saturated Layer at 200 yr **Cell: L37**

Summary:
Display Range is from 0.00E+0 to 1.20E+0 pCi/L
Entire Range is from 2.32E-3 to 6.20E+0 pCi/L
After 1,000 Trials, the Std. Error of the Mean is 1.05E-2

Statistics:	Value
Trials	1000
Mean	2.92E-01
Median (approx.)	2.02E-01
Mode (approx.)	3.33E-02
Standard Deviation	3.33E-01
Variance	1.11E-01
Skewness	7.19
Kurtosis	111.14
Coeff. of Variability	1.14
Range Minimum	2.32E-03
Range Maximum	6.20E+00
Range Width	6.20E+00
Mean Std. Error	1.05E-02

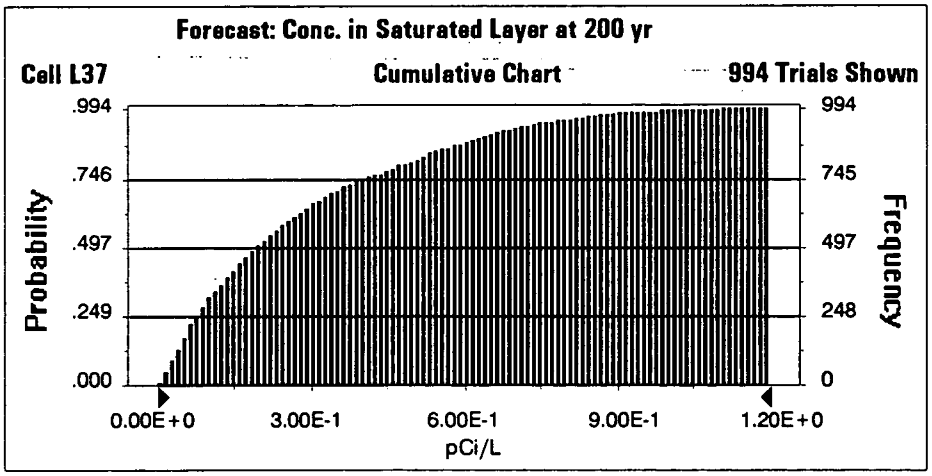


FIGURE B-46c SAMPLE MONTE CARLO SIMULATION OUTPUT

Forecast: Conc. in Saturated Layer at 200 yr (cont'd) **Cell: L37**

Percentiles:

Percentile	pCi/L (approx.)
0%	2.32E-03
10%	3.95E-02
20%	6.80E-02
30%	1.02E-01
40%	1.51E-01
50%	2.02E-01
60%	2.70E-01
70%	3.62E-01
80%	4.98E-01
90%	6.57E-01
100%	6.20E+00

End of Forecast

FIGURE B-46d SAMPLE MONTE CARLO SIMULATION OUTPUT

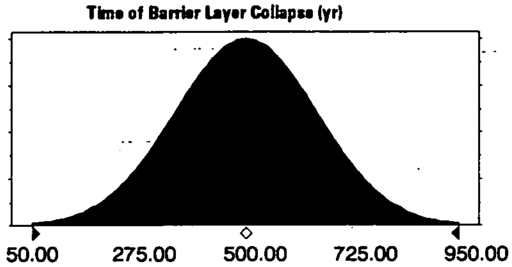
<u>Assumptions</u>

Assumption: Time of Barrier Layer Collapse (yr) **Cell: D18**

Normal distribution with parameters:

Mean	500.00
Standard Dev.	150.00

Selected range is from -Infinity to +Infinity
Mean value in simulation was 497.03



Assumption: Unsaturated Layer Kd (L/KG): **Cell: F16**

Lognormal distribution with parameters:

Mean	17.00
Standard Dev.	34.00

Selected range is from 0.00 to +Infinity
Mean value in simulation was 17.36

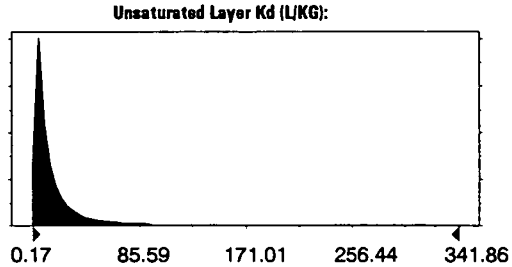


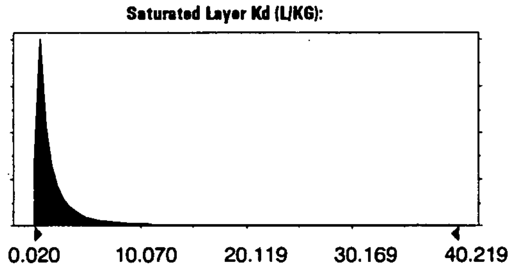
FIGURE B-46e SAMPLE MONTE CARLO SIMULATION OUTPUT

Assumption: Saturated Layer Kd (L/KG): **Cell: I16**

Lognormal distribution with parameters:

Mean	2.000
Standard Dev.	4.000

Selected range is from 0.000 to +Infinity
Mean value in simulation was 2.277

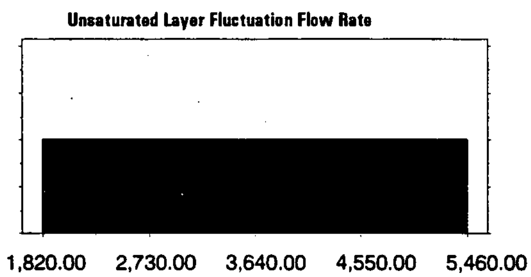


Assumption: Unsaturated Layer Fluctuation Flow Rate **Cell: F21**

Uniform distribution with parameters:

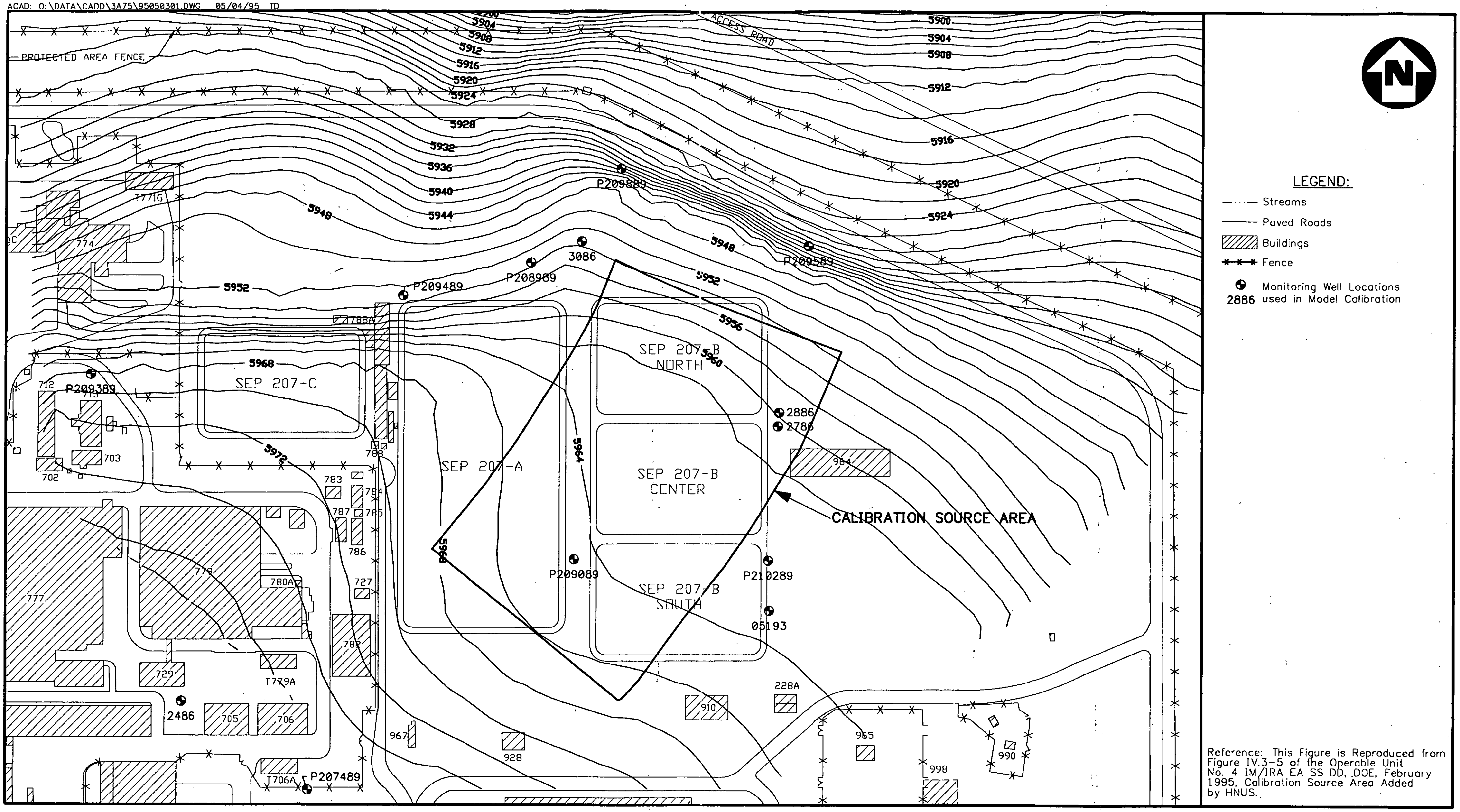
Minimum	1,820.00
Maximum	5,460.00

Mean value in simulation was 3,683.09



End of Assumptions

FIGURE B-46f SAMPLE MONTE CARLO SIMULATION OUTPUT



MEAN SEASONAL HIGH GROUNDWATER ELEVATION AND CALIBRATION SOURCE AREA ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE GOLDEN, COLORADO

0 150 300
SCALE IN FEET

FIGURE B-4

Halliburton NUS CORPORATION

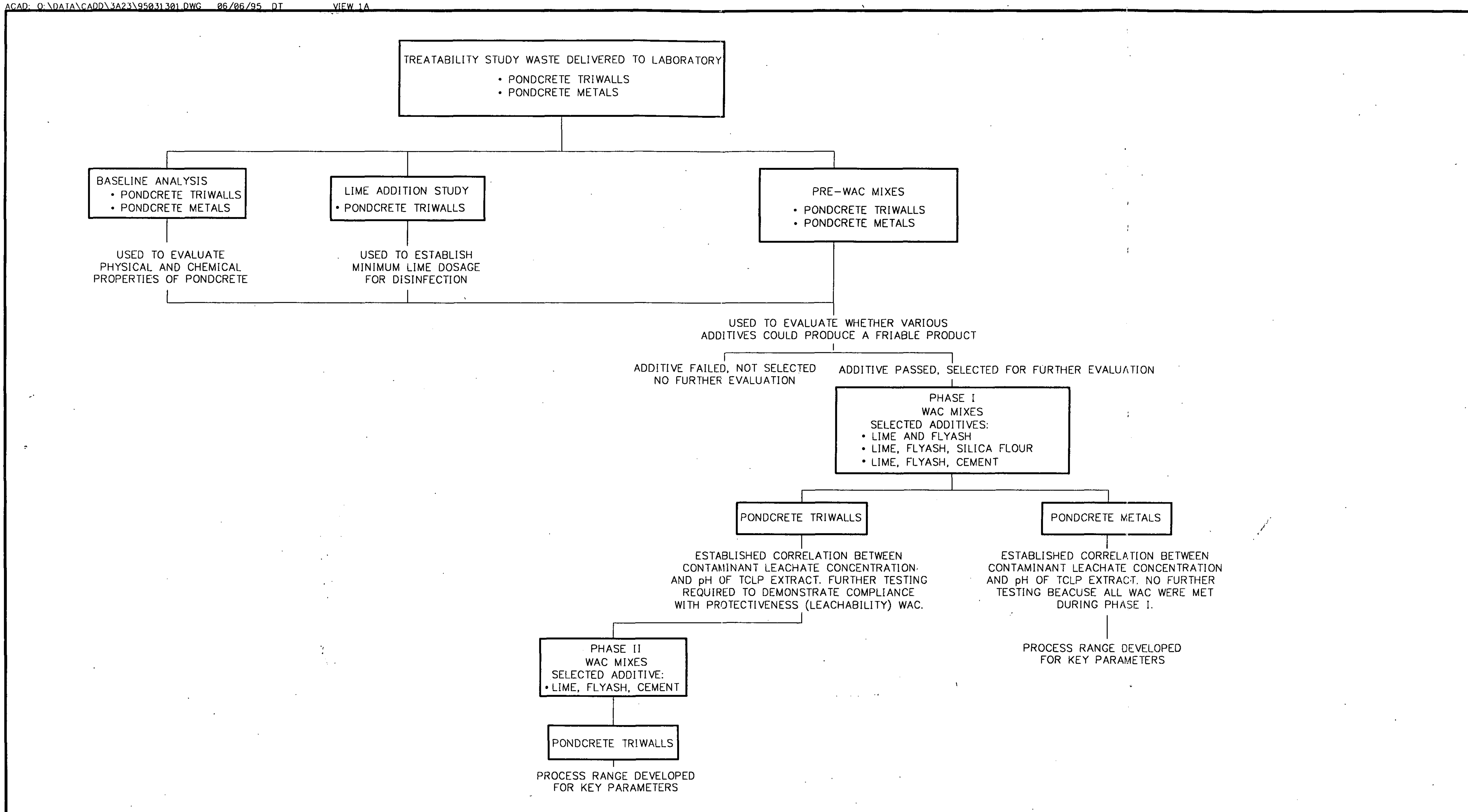


FIGURE 2-1

PONDCRETE TREATABILITY STUDY LOGIC DIAGRAM
ROCKY FLATS, COLORADO

Halliburton NUS CORPORATION