Field Lysimeter Studies for Performance Evaluation of Grouted Hanford Defense Wastes

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Preface

The original report that forms the basis for this document was written in early 1988, with the last draft dated March 5, 1988. Although some internal comments were received on this last draft, the document was never completed. Because this report contains valuable data on the construction and monitoring of the Grout Waste Test Facility, which is soon to be decommissioned, funding has been provided to update and finalize the report. With the exception of resolving comments and including more recent data, the report remains much as originally prepared. Many of the figures remain in their original manuscript state, and some figures may be somewhat rudimentary.

Summary

The Grout Waste Test Facility (GWTF) consisted of four large field lysimeters designed to test the leaching and migration rates of grout-solidified low-level radioactive wastes generated by Hanford Site operations. Each lysimeter was an 8-m-deep by 2-m-dia closed-bottom caisson that was placed in the ground such that the uppermost rim remained just above grade. Two of these lysimeters were used; the other two remained empty. The two lysimeters that were used (A-1 and B-1) were backfilled with a two-layer soil profile representative of the proposed grout disposal site. The proposed grout disposal site (termed the Grout Treatment Facility Landfill) is located immediately east of the Hanford Site's 200 East Area. This soil profile consisted of a coarse sand into which the grout waste forms were placed and covered by 4 m of a very fine sand. The A-1 lysimeter was backfilled in March 1985, with a grout-solidified phosphate/sulfate liquid waste from N Reactor decontamination and ion exchange resin regeneration. The B-1 lysimeter was backfilled in September 1985 and received a grout-solidified simulated cladding removal waste representative of waste generated from fuel reprocessing operations at the head end of the Plutonium Uranium Extraction (PUREX) plant. Routine monitoring and leachate collection activities were conducted for over three years, terminating in January 1989. Drainage was collected sporadically between January 1989 and December 1992.

The A-1 lysimeter reached equilibrium in its water storage capacity and began draining approximately 2 years after it was backfilled. By January 1988, significant drainage (79 L) had occurred. The annual water flux through the A-1 lysimeter was estimated to be on the order of one-half the annual precipitation ranging from 3.7 to 6.7 cm/yr.

By January 1991, staff had not successfully collected drainage from the B-1 lysimeter, suggesting a loss of the integrity of the caisson, raising the concern that meteoric water was infiltrating the lysimeter and any resulting leachate from the grout waste forms could be leaking into the surrounding soil beneath the lysimeter. In an effort to prevent further infiltration of meteoric water, and thus remove the primary driving force for contaminant movement, the surface of the B-1 lysimeter was covered and sealed. Decontamination and decommissioning of these lysimeters during the summer of 1994, confirmed the presence of a 15 to 20-cm-long hairline crack in one of the bottom plate welds.

This report discusses the design and construction of the GWTF, presents the routine data collected from this facility through January 1989 and subsequent data collected sporadically between 1989 and 1993, and provides a brief discussion concerning preliminary interpretation of the results.

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1.0 Introduction

The use of solidifying agents in onsite disposal of various low-level radioactive wastes generated by past Hanford Site defense operations is being investigated. A proposed Grout Treatment Facility (GTF) was to be located just east of the 200 East Area on the Hanford Site to convert low-level radioactive liquid wastes into a grout mixture that could be pumped to underground vaults where it would solidify and be disposed safely. The term grout refers to a mixture of various dry solids (e.g., portland cement, fly ash, and clay) and liquid wastes that become a solid waste form. This type of waste form is designed to physically and/or chemically contain the waste constituents by forming a low-permeability solid gel and stable minerals, respectively. Westinghouse Hanford Company (WHC) managed the GTF program and was to have operated the facility. Oak Ridge National Laboratory provided preliminary grout formulations for various waste streams. Pacific Northwest Laboratory (PNL)^(a) was responsible for testing the grout formulations and assessing their long-term performance to ensure that the grouts met all performance and regulatory requirements (Treat et al. 1985).

This report documents the design and construction of the Grout Waste Test Facility (GWTF), formerly referred to as the Hanford Grout Lysimeter Facility. The GWTF (Figure 1.1) was built to test the leaching and waste migration rates of selected Hanford grout waste forms under simulated burial conditions. Two 2-m-dia by 8-m-deep field lysimeters (A-1 and B-1) were backfilled with simulated grout waste forms and instrumented.

In response to concerns about possible leakage from the B-1 Lysimeter, a plywood-composite shingle lid was placed over it on November 13, 1990 (Appendix A). In January 1991, an evaluation of the B-1 Lysimeter concluded that harsh placement of the initial gravel layer in the bottom of the lysimeter may have ruptured the welds and that the lysimeter was leaking water. This leakage was estimated at 300 L (Refer to Appendix A). Decommissioning (removal) activities during the summer of 1994 discovered a 15 to 20-cm-long hairline crack in one of the bottom welds.

This report discusses the design and construction of the GWTF, presents the routine data collected from this facility through January 1989 and sporadic leachate drainage data collected between January 1989 and December 1992, and provides a brief discussion concerning preliminary interpretation of the results.

(a) The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

Figure 1.1. Location of the Grout Waste Test Facility.

2.0 Waste Form Description

Two types of grouted waste were acquired and placed into the caisson lysimeters. A solidified phosphate/sulfate waste (PSW) from N Reactor decontamination and ion-exchange resin regeneration was emplaced in the A-1 lysimeter. The B-1 lysimeter received simulated solidified Cladding Removal Waste (CRW) from the fuel reprocessing operation at the head end of the plutonium and uranium extraction (PUREX) process.

2.1 Phosphate/Sulfate Waste

The PSW forms (also referred to as the Hanford Facilities Waste) placed in the A-1 lysimeter were produced specifically to support this study. An aliquot of actual phosphate waste (from decontamination of N Reactor) was received from Rockwell Hanford Operations (now Westinghouse Hanford Company). This waste was diluted and neutralized with 19 M sodium hydroxide (NaOH) resulting in a final dilution of 1:2.5. Sodium nitrite (NaNO_2) was then added at a ratio of 0.88 g/L. The chemical characteristics of this waste are provided in Table 2.1. The sulfate waste was simulated by using 0.03 M sodium sulfate (Na_2SO_4) and 0.02 M NaNO_2 ; the pH was then adjusted to > 12 with 19 M NaOH. This was then spiked with 0.25 mCi/L ^{137}Cs and 0.08 mCi/L ^{90}Sr . The first batch (first 4 waste forms) was also spiked with ^{85}Sr . The second batch (second 4 waste forms) probably contained some residual ^{85}Sr from the first batch. The remaining batches likely contained no ^{85}Sr . The chemical characteristics of this waste are provided in Table 2.2. The waste solution used for grout

Table 2.1. Actual N Reactor Phosphate Waste Characteristics.

Component	Concentration	Unit
Total Pu	5.2×10^{-9}	Ci/L
^{51}Cr	1.9×10^{-5}	Ci/L
^{54}Mn	1.4×10^{-5}	Ci/L
^{59}Fe	2.5×10^{-5}	Ci/L
^{58}Co	1.2×10^{-5}	Ci/L
^{60}Co	1.6×10^{-4}	Ci/L
^{103}Ru	2.9×10^{-5}	Ci/L
Na^+	1.110	<u>M</u>
OH^-	0.010	<u>M</u>
NO_2^-	0.014	<u>M</u>
PO_4^{3-}	0.363	<u>M</u>

Table 2.2. Simulated Sulfate Waste Characteristics.

Component	Concentration	Unit
^{85}Sr	?	Ci/L
^{90}Sr	8.0×10^{-5}	Ci/L
^{137}Cs	2.5×10^{-4}	Ci/L
Na^+	0.106	<u>M</u>
OH^-	0.010	<u>M</u>
NO_2^-	0.014	<u>M</u>
SO_4^{2-}	0.041	<u>M</u>

preparation consisted of 60% by volume phosphate waste and 40% by volume spiked simulated sulfate waste. This waste solution was then mixed in several small batches with the grout forming dry solids at a ratio of 0.84 kg dry solids per liter of waste solution. The dry solids consisted of 41 wt% type I and II LA portland cement, 40 wt% Class F fly ash, 11 wt% attapulgite 150 clay, and 8 wt% Indian red pottery clay. Tributyl phosphate $[(\text{C}_4\text{H}_9)_3\text{PO}_4]$ was added at 0.02% by volume to control foaming. A total of approximately 20 L (4-L/batch x 5 batches) of grouted PSW were produced. Twelve liters were designated for use in the GWTF lysimeters, while the rest was used for laboratory column experiments or stored for future reference. To facilitate leaching, numerous small samples were preferred over one large sample. Therefore, the grout mixture designated for this study was poured into 24 0.5-L plastic containers. These containers were right circular cylinders 5.4 cm tall by 5.4 cm in radius, with a known volume of 0.5 L. This produced waste forms with a surface area to volume ratio of 0.74:1.0. These waste forms were poured on November 30, 1984, and were allowed to cure in the closed plastic containers for over 3.5 months until their emplacement in the lysimeters on March 21, 1985. No free water was found when the waste forms were removed from their curing containers. A total inventory for the A-1 lysimeter is provided in Table 2.3.

2.2 Simulated Cladding Removal Waste

The simulated Cladding Removal Waste (CRW) placed in the B-1 lysimeter was also generated specifically for this study. This waste form was produced in five small batches as was the grouted PSW. Each batch consisted of 2.108 L simulated CRW neutralized with 0.392 L 19 M technical-grade NaOH. After settling, 60% of the total volume was removed as supernate. This left 1.0 L of concentrated neutralized CRW, which was then diluted with an equal volume of tap water, to form a slurry. The five batches resulted in 10 L of slurry, which was then mixed with the grout dry solids at a ratio of 0.84 kg per liter of slurry. The dry solids were added in the same proportions described in Section 2.1 for the phosphate/sulfate waste. This grout mixture was spiked with radio-nuclides to produce the concentrations listed in Table 2.4. The grout formulation was prepared and poured into 24 0.5-L plastic containers on August 20, 1985. These waste forms were identical in size to those of the PSW. These waste forms were allowed to cure for less than a month before they were placed in the B-1 lysimeter on September 12, 1985. Again, no free water was observed when the waste forms were removed from the containers. A total inventory for the B-1 lysimeter is provided in Table 2.5.

Table 2.3. Total Inventory for the A-1 Lysimeter (i.e. in 12 liters of grout).

Component	Actual Phosphate Waste (60%) 7.2 L	Simulated Sulfate Waste (40%) 4.8 L	Total 12 L
Total Pu	3.74×10^{-8} Ci	---	3.74×10^{-8} Ci
^{51}Cr	1.37×10^{-4} Ci	---	1.37×10^{-4} Ci
^{54}Mn	1.01×10^{-4} Ci	---	1.01×10^{-4} Ci
^{59}Fe	1.80×10^{-4} Ci	---	1.80×10^{-4} Ci
^{58}Co	8.64×10^{-5} Ci	---	8.64×10^{-5} Ci
^{60}Co	1.15×10^{-3} Ci	---	1.15×10^{-3} Ci
^{85}Sr	---	NA	NA
^{90}Sr	---	3.84×10^{-4} Ci	3.84×10^{-4} Ci
^{103}Ru	2.09×10^{-4} Ci	---	2.09×10^{-4} Ci
^{137}Cs	---	1.20×10^{-3} Ci	1.20×10^{-3} Ci
Na^+	7.99 <u>M</u>	0.51 <u>M</u>	8.50 <u>M</u>
OH^-	0.07 <u>M</u>	0.05 <u>M</u>	0.12 <u>M</u>
NO_2^-	0.10 <u>M</u>	0.07 <u>M</u>	0.17 <u>M</u>
PO_4^{3-}	2.61 <u>M</u>	---	2.61 <u>M</u>
SO_4^{2-}	---	0.20 <u>M</u>	0.20 <u>M</u>

NA = Data not available.

Table 2.4. Radionuclide Concentrations of the Spiked Cladding Removal Waste.

Component	Concentration	Unit
^{14}C	5.0×10^{-5}	Ci/L
^{90}Sr	1.2×10^{-3}	Ci/L(a)
^{99}Tc	5.0×10^{-5}	Ci/L
^{137}Cs	1.0×10^{-4}	Ci/L
^{241}Am	5.0×10^{-4}	Ci/L ^(b)
^{238}Pu	5.38×10^{-4}	Ci/L ^(b)

(a) Added to first batch of grout only (first 4 waste forms).

(b) Activities prior to neutralization. These constituents likely all precipitated and ended up in the grout.

Table 2.5. Total Inventory for the B-1 Lysimeter (i.e., in 12 L of grout).

Component	Total Inventory
^{14}C	$6.0 \times 10^{-4} \text{ Ci}$
^{90}Sr	$2.4 \times 10^{-3} \text{ Ci}$
^{99}Tc	$6.0 \times 10^{-4} \text{ Ci}$
^{137}Cs	$1.2 \times 10^{-3} \text{ Ci}$
^{241}Am	$6.0 \times 10^{-3} \text{ Ci}$
^{238}Pu	$6.5 \times 10^{-3} \text{ Ci}$

3.0 Facility Description

The GWTF is located on the Hanford Site near the 300 Area North burial ground, southeast of the Fast Flux Test Facility (Figure 1.1). This site lies at an elevation of 131 m (430 ft) mean sea level on an alluvial plain approximately 3.3 km west of the Columbia River. The environment is classified as shrub-steppe (Daubenmire 1970), with an average annual precipitation of 16 cm. The near-surface geology of the site consists predominately of unconsolidated sandy gravel (with some cobbles and boulders) and coarse to medium sand of the Hanford formation, covered by a thin veneer of eolian very fine sand to sandy silt. Groundwater lies at a depth of approximately 18 m (Kasza et al. 1993) and flows from west to east, discharging to the Columbia River.

3.1 Site Selection

The site was selected for construction of the GWTF based on its location adjacent to existing lysimeter facilities (i.e., the Buried Waste Test Facility and the Commercial Waste Test Facility), where long-term meteorological and lysimeter data were available. This site also had an existing micro-meteorological station, water supply, solar power, and telecommunications systems, making the site economically attractive. The site is approximately 10 km from PNL offices and approximately 20 km from the site originally selected for the Grout Treatment Facility Landfill (GTFL), adjacent to the 200-East Area.

3.2 Field Lysimeter Design

A conceptual design for the GWTF was first developed for an environmental evaluation (EE) of the pre-operational, operational, and post-operational consequences resulting from the GWTF. This environmental evaluation is provided in Appendix C. Following review and approval of the EE, the facility design was finalized and construction initiated.

The GWTF consists of four 8-m-deep by 2-m-dia closed-bottom caisson lysimeters (referred to as lysimeters throughout the remainder of this report) (Figure 3.1). Design details for the two operational lysimeters are shown in Figure 3.2. Four principal criteria were used in designing the lysimeters: 1) the lysimeter must simulate anticipated burial conditions (depth and soil type) for the actual grout wastes; 2) the instrumentation must be both appropriate for the desired measurements and compatible with existing lysimeter instrumentation; 3) the design must be technically defensible; and 4) the design must be economical.

When the GWTF was designed, the anticipated burial conditions for the actual grout wastes were disposal to lined trenches excavated into the native soils at the GTFL site (Figure 1.1). After the grout was solidified, the trenches were to be covered by 5 m of soil that had been stockpiled during excavation of the trenches. To simulate these burial conditions, the lysimeters were designed to accommodate 5 m of soil cover over the top of the waste forms. The soils to be used in the lysimeter were selected

Figure 3.1. Layout of the Grout Waste Test Facility.

Figure 3.2. Cross Section and Plan View Details of the Lysimeter Design.

from spoil from the 241-AP Tank Farm excavation located adjacent to the proposed GTFL site (Figure 1.1). These soils were selected by examining the near-surface materials of the proposed GTFL site. This was done by reviewing available well data and geologic interpretations from beneath nearby cribs and tank farm excavations (Fecht et al. 1979; Goldstrand 1984) and by geologic reconnaissance and sampling of the 241-AP Tank Farm excavation (Sewart et al. 1987). This evaluation indicated the presence of slightly silty to silty very fine sand to a depth of approximately 4 m, underlain by a coarse sand with some pebbles and cobbles to a depth of approximately 8 m. Physical analyses of the 241-AP Tank Farm soil samples are presented in Appendix D. Stockpiled sources of these materials were available from the spoil pile for the 241-AP Tank Farm excavation and were selected to represent this stratigraphy in the lysimeters. The coarse sand would be placed in the lysimeter up to a depth of within 5 m of the surface to represent the geologic host materials at the GTFL. The grouted waste form samples would then be placed at this anticipated GTFL burial depth. One meter of coarse sand and 4 m of very fine sand would then be placed over the waste zone to represent the backfill. This assumed that the last material excavated for the grout trenches (coarse sand) would be the first material used as backfill and that the finer material (very fine sand) would be saved for the uppermost surficial materials. Further discussion of the soils selected for use in the lysimeters is presented in the discussion of soil properties (Section 6.1). A 20-cm-thick gravel layer was added at the lysimeter caisson surface to promote infiltration of meteoric waters and enhance the flux through the lysimeter.

Two types of information were to be collected from the GWTF lysimeters: soil physics data and leachate chemistry data. Existing lysimeters on the Hanford Site primarily use thermocouple, soil moisture blocks, neutron moisture probes, and drainage collection systems for collection of soil physics data. All of these instruments were incorporated into the design of the GWTF lysimeters to provide comparable data. Existing lysimeters in which leachate is collected for chemical analysis use porous ceramic tubes (suction candles) to extract pore-water samples and/or drainage collection sumps for collection of the leachate. Both pore-water samplers and drainage collection systems were also incorporated into the design of the GWTF lysimeters. A detailed discussion of the instrumentation is presented in Section 5.0.

Two other technical issues concerning the design of existing lysimeters on the Hanford Site included 1) the depth of the lysimeters and 2) the integrity of the lysimeter bottom. To ensure that the design of the GWTF lysimeters was defensible, the lysimeters were designed to extend to a depth of 8 m, exceeding the zone of seasonal variation reported by Brownell et al. (1975) and Last et al. (1976). To ensure that the bottoms of the lysimeters were leak tight, they were designed of plate steel with watertight welds. Hydrostatic testing of the lysimeter bottoms was performed after installation of the caissons to verify their integrity. These data are presented later.

Finally, the lysimeters were designed to be economical using prefabricated caissons and only a small near-surface instrumentation housing. This instrumentation housing was located in proximity to existing solar power and telecommunications systems.

4.0 Installation of Lysimeters

Installation of the lysimeters was conducted in three stages: installation of the lysimeter caissons, backfilling of the A-1 lysimeter, and backfilling of the B-1 lysimeter. Excavation and installation of the lysimeter caissons was completed in September 1984. Backfilling (including waste form emplacement and instrumentation) of the A-1 lysimeter was completed in March 1985, and backfilling of the B-1 lysimeter was completed in September 1985. This section describes the methods used to install the lysimeter caissons, test their integrity, and emplace the soils, waste forms, and instrumentation.

4.1 Installation of Caissons

The 2-m-dia by 8-m-deep lysimeter caissons were prefabricated from 16-gauge galvanized steel with 2.5-cm x 7.6-cm corrugations. The spiral seams of the caissons were seal welded with a continuous watertight weld. Three 10-gauge galvanized steel plates were seal welded together, and to the caisson walls, with a continuous watertight weld to form a three-sided sloping bottom to the lysimeter (Figure 3.2). All welds were painted with a zinc-rich paint.

Construction of the facility began with an initial excavation to 6.7 m below land surface. This excavation, approximately 25 m x 25 m, removed approximately 3,800 m³ of soil. During the excavation, the sands were segregated and stockpiled for use in backfilling around the caissons. Secondary excavations to a depth of 1.3 m below the bottom of the initial excavation were then made using a clam shell and temporary casing. These smaller excavations (roughly 2.5-m-dia) were made one at a time just before each caisson was installed.

The one-piece caissons were lowered via crane into their secondary excavations. The annulus between the caisson and the temporary casing was then backfilled with sand and water, and the temporary casing was removed. After all the caissons were set into their secondary excavations, they were braced to remain vertical, and the main excavation was backfilled. Backfilling was done in short lifts using water and vibratory compaction machines. The stockpiled sands were used near the caissons while the coarser materials were used elsewhere. Approximately 113,550 L of water was used during backfilling of the excavation. At no time was water observed entering the caissons. Installation of the lysimeter caissons was completed on September 21, 1984. The open-top caissons were temporarily covered with plywood and later secured with steel lids.

4.2 Leak Tests

Hydrostatic testing of the caissons was conducted to evaluate whether the caisson bottoms were watertight. An estimated 2,500 - 3,000 L of warm water was poured into each of the caissons on December 14, 1984. This resulted in approximately 0.8 - 1.0 m of standing water in the bottom of each caisson. Following the introduction of water, the temporary plywood covers were placed back

over the caissons. The depth-to-water below the top of each caisson was periodically measured until February 22, 1985. Graphs of these measurements (Figure 4.1) show fairly consistent decreases in water levels in all caissons, suggesting evaporation, not leakage.

The calculated rate of decrease based on liner regression analysis of the hydrostatic testing data ranged from 1.5 cm/month in lysimeter A-2 to 2.2 cm/month in lysimeter A-1 (Appendix D). This reflects an estimated loss of 48 to 70 L per month (1.6 to 2.3 L per day). Calculation of the potential evaporation from the lysimeter caissons is difficult and few data are available to support such calculation. However, the potential evaporation (calculated from available meteorological data for the ground surface) for this time period averaged approximately 2.2 cm/month (Appendix D). The loss of the observed amount of water due solely to evaporation seems reasonable given the warm average subsurface (and water) temperature ($\sim 17^{\circ}\text{C}$), the cold outside air temperatures (averaging 0 to -7°C), the average wind speed (4.4 kph), and the potential evaporation. The A-2 lysimeter caisson exhibited a slower rate of water level decrease, which was possibly due to a slightly tighter fitting surface cover that could have reduced the rate of vapor exchange with the atmosphere. The addition of precipitation runoff water into this caisson is also a possibility.

The fairly consistent water level decreases between all lysimeter caissons and the reasonableness of the rate of water loss due to evaporation led the investigators to conclude that the integrity of the caisson bottoms was satisfactory.

4.3 Lysimeter Backfilling and Waste Form Emplacement

Backfilling of the A-1 lysimeter, including installation of the soil physics instrumentation and emplacement of the PSW waste forms, was performed from March 18 to March 22, 1985. The waste forms were emplaced on March 21, 1985. Backfilling of the B-1 lysimeter was conducted between September 9 and September 16, 1985, with the CRW waste forms emplaced on September 12, 1985. Lysimeters A-2 and B-2 were never backfilled.

The general procedure for backfilling the lysimeters is provided in Appendix E. The backfilling process began with installation of the 10.2-cm-dia aluminum access tube and a 10-cm-thick layer of 1 to 3-cm intermediate diameter rounded gravel. The top of the gravel (7.7 m below the top of the caisson) was then covered with a layer of geotextile fabric. Successive layers (≤ 30 -cm-thick) of the stockpiled coarse sand were then added to a depth of 4.8 m below the top of the caisson. Each successive layer was tamped by hand (using a block of wood on the end of a pole) to a soil density of 1.6 to 1.7 g/cc (confirmed by sampling). Thermocouple and moisture blocks were installed at their designated locations during this backfilling. At the 6.6-m depth, the string of soil pore-water samplers was installed. Silica flour was installed around each of the porous Teflon sections to a thickness of 4.5 cm and a length of 22 cm (Figure 3.2). The silica flour around the 6.5-m deep porous section of the A-1 lysimeter was saturated with water after installation. However, difficulties were encountered when retrieving the temporary tube sleeve used during installation of the silica flour, and thus water was not added to any of the remaining silica flour layers. A 15-cm-long by 4.5-cm-thick layer of bentonite was placed between each porous Teflon section (Figure 3.2).

Figure 4.1. Hydrographs from Hydrostatic Testing of the Caisson Bottoms.

The grout waste forms were installed after backfilling had progressed to a 4.8-m depth. The general procedure used for installation of the waste forms is included in Appendix F. The waste forms were placed inside previously installed tube sleeves that were recessed into the soil to a depth of 5.1 m relative to the surface. The 12 sleeves were arranged in two circles around the centrally located string of pore-water samplers (Figure 4.2). Two waste forms were stacked inside the sleeves and were separated by and covered with the coarse sand. The sleeve was then removed and the soil cover leveled and compacted. The four PSW waste forms that were spiked with ^{85}Sr and the four CRW forms that contained ^{90}Sr (refer to Section 2) were located within the A-1 and B-1 lysimeters as shown in Figure 4.2.

Backfilling of the lysimeters continued as before using the coarse sand up to the 4-m depth. At this depth the backfilling medium was changed to the very fine sand. Backfilling again continued in <30-cm lifts, with compacting between lifts and installing thermocouple and soil moisture blocks as specified (Appendix E). The lysimeters were backfilled with the very fine sand to within approximately 20 cm from the top of the lysimeters. Moisture samples and bulk density samples were collected from each lift of backfilled soil. Thin (approximately 4-cm-thick) bentonite seals were placed around the lysimeter walls, aluminum access tube, and soil pore-water sampling string at two depths: 1.75 m and 0.2 m. A 20-cm-thick surface cover of 1 to 3-cm (intermediate diameter) rounded gravel brought the lysimeters up to grade.

Figure 4.2. General Configuration of Waste Forms within the Lysimeters.

5.0 Instrumentation and Measurement Techniques

Micrometeorological data are available from instruments that were installed near the GWTF to support other projects. The Hanford Site Performance Assessment (HSPA) Program operated and maintained this equipment until the summer of 1991. Descriptions of this instrumentation can be found in Walter et al. (1984).

Each lysimeter was instrumented with access wells for sampling drainage water and obtaining neutron and gross gamma-ray probe measurements, thermocouples and fiberglass moisture blocks, and soil pore-water samplers. Figure 4.2 illustrates the position of instruments as installed in the B-1 lysimeter, which has three more thermocouples near the interface between the coarse sand and the very fine sand than the A-1 lysimeter. The thermocouples and moisture blocks were more closely spaced near the waste forms and the soil interface to provide more detail near areas of greatest interest.

5.1 Thermocouples

The thermocouples consist of two dissimilar metal wires (copper and constantan) twisted and welded together at one end. A thermal electromotive force is produced when the welded end and the open end are at different temperatures. The welded end acts as a measuring junction while the open end, connected to the data logger, acts as a reference junction. Thermocouples were placed vertically throughout the lysimeters and surrounding the radioactive waste forms to monitor the natural thermal gradient and possible temperature effects induced by the waste forms.

5.2 Soil Moisture Blocks

Fiberglass soil moisture blocks were installed to measure the soil moisture content as a function of the resistance between two electrodes embedded in a fiberglass matrix that is in equilibrium with the soil. The resistance is actually a measurement of the soil matric potential; soil salinity, texture, temperature, and minor reactance effects are presumed to be constant (Morrison 1983). Moisture block measurements were obtained with a moisture bridge (based on the Wheatstone principle) via a data logger. The fiberglass moisture blocks were installed to monitor the natural moisture gradients and provide detail near the very fine sand interface, where elevated moisture contents at or near saturation were anticipated.

Calibration of the soil moisture blocks was rather limited and produced mixed results (refer to Appendix G). Soil moisture block data generated in this study to derive the soil water suction and/or to infer soil water contents should be used cautiously only as an indicator of large relative changes in soil suction and/or moisture content.

5.3 Soil Pore-Water Samplers

Soil pore-water samplers were installed at three locations below the waste zone to collect leachate samples from the unsaturated zone (Figure 3.2). The soil pore-water samplers selected for use in this study were TIMCO's^(a) Teflon Vacuum Pressure Lysimeters (Morrison 1983). These pore-water samplers consist of 6-cm outside dia polyvinylchloride (PVC) tubing blanked on both ends, with a 10.2-cm-long porous Teflon section near the middle. Vacuum-pressure and sample evacuation tubes made of Nalgene were extended to the surface through a 6-cm-dia PVC access tube. Soil pore-water samples were collected by creating a vacuum within the sampler; when the soil-water tension became less than the sampler vacuum, the pressure gradient drove soil pore-water from the surrounding soil through the porous Teflon section and into the sample collection chamber. Once a sufficient amount of sample accumulated in the sampler, a pressure was applied and the sample was forced to the surface through the evacuation tube.

5.4 Geophysical Logging and Drainage Water Sampling Well

A 10.2-cm-dia aluminum tube was installed to provide access to the deepest portion of the lysimeter (Figure 3.2). This access tube permitted sampling of drainage water that accumulated in the bottom of the lysimeter and provided access for neutron probe and gross gamma-ray probe logging.

5.4.1 Neutron Probe Logging

Neutron soil moisture probes were used to measure the volumetric water content of the soil by correlating the hydrogen count to the water content. Fast neutrons emitted by the probe are slowed (thermalized) through elastic collisions with hydrogen atoms. A detector tube in the probe counts the slow neutrons (Gardner 1965; Greacen 1981; Morrison 1983). Three different neutron probes have been used to collect soil moisture data in the lysimeters. Appendix H discusses the calibration of these probes.

5.4.2 Gross Gamma-Ray Logging

The PNL gross gamma-ray logging system and the WHC sodium iodide (NaI) spectral gamma-ray logging system were used at the GWTF.

The PNL gross gamma-ray logging system was used to measure the intensity of gamma radiation in the surrounding soils. This system consists primarily of a Gearhart-Owen^(b) gamma-ray probe with a 1.9-cm (0.75 in.)-round by 6.4-cm (2.5 in.)-long thallium-doped sodium iodide [NaI(Tl)] detector. This system was field-checked annually; however, it was not formally calibrated until after its use in this study (PNL 1993; Brodeur and Koizumi 1989).

(a) TIMCO Manufacturing, Inc., Prairie du Sac, Wisconsin.

(b) Gearhart-Owen Industries, Inc., Fort Worth, Texas.

The WHC NaI spectral gamma-ray logging system uses a 6.4-cm by 20.3-cm (2.5-in. x 8-in.) NaI crystal with a 1024 multichannel analyzer (MCA). Oretch's Masestro software is used to support the MCA. Calibration was performed in the DOE borehole model standards that reside near the Hanford Meteorological Station (Steele and George 1986). Formal calibration has not been documented at this time.

5.4.3 Drainage Water Sampling

Drainage water that accumulated in the bottom of the lysimeters was pumped from the lowest part (sump) of the lysimeter bottom using a stainless steel and Teflon positive displacement pump (Hydrostar)^(a).

(a) Instrumentation NW, Redmond, Washington.

6.0 Baseline Data

Baseline data collected for the GWTF include physical analyses of the soils used in backfilling the lysimeters and measurement of the initial conditions at each lysimeter.

6.1 Soil Properties

Samples of the two lysimeter soils were analyzed for water retention characteristics, hydraulic conductivities, and particle size distributions. These samples were collected from stockpiles of the soils taken from the AP-Tank Farm spoil pile. Six randomly located samples were collected from the stockpiles of coarse sand and numbered 1-1 through 1-6, and three samples were collected from the stockpiles of very fine sand and numbered 2-1 through 2-3. Each sample consisted of approximately 12 kg of soil. All samples were collected on December 19, 1984. Standard laboratory procedures (Klute 1965; Richards 1965; ASTM 1972) were used to conduct particle size, water potential, and hydraulic conductivity analyses. Average particle size curves for the two soils are provided in Figure 6.1. The power function model used by Brooks and Corey (1964; 1966) and Campbell (1974) describe the water retention curves. These are shown as water potential as a function of water content in Figure 6.2 for the very fine sand and in Figure 6.3 for the coarse sand. The Burdine (1953) model has been used to predict the unsaturated hydraulic conductivity curve based on measured values of saturated hydraulic conductivity. Conductivity as a function of water content is shown in Figures 6.2 and 6.3 for the two soils. The results of these physical soil analyses are presented in Appendix I.

6.2 Initial Lysimeter Conditions

The initial moisture and density conditions of each lysimeter were measured via samples collected during the backfilling process, and shortly after backfilling via neutron moisture probe logging. Figures 6.4 and 6.5 illustrate the initial moisture profiles as measured via samples and neutron probe for the A-1 and B-1 lysimeters, respectively. The density profile measured during the backfilling of each lysimeter is shown in Figures 6.6 and 6.7.

Figure 6.1. Average Particle Size Distributions of the Coarse Sand and Very Fine Sand.

Very Fine Sand

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(\frac{\psi_e}{\psi} \right)^{1/b}$$

Very Fine Sand

$$\frac{K}{K_s} = \left(\frac{\psi_e}{\psi} \right)^{2+3/b}$$

S9408064.2

Figure 6.2. Water Potential and Hydraulic Conductivity Curves for the Very Fine Sand.

Figure 6.3. Water Potential and Hydraulic Conductivity Curves for the Coarse Sand.

Figure 6.4. Initial Moisture Contents in the A-1 Lysimeter.

Figure 6.5. Initial Moisture Contents in the B-1 Lysimeter.

Figure 6.6. Dry Bulk Density Profile in the A-1 Lysimeter as Measured During Backfilling.

Figure 6.7. Dry Bulk Density Profile in the B-1 Lysimeter as Measured During Backfilling.

7.0 Monitoring Results

Routine soil physics monitoring and leachate collection activities were conducted between March 1985 and January 1989. Soil temperature and soil moisture block resistance were continuously recorded (every 12 hours) from each lysimeter using a data logger. Soil moisture contents were measured using a neutron probe approximately every 2 weeks. Gamma-ray logging and leachate collection activities were conducted on an irregular basis. After January 1989, the lysimeters were placed on a maintenance budget for annual collection and disposal of drainage water. This section presents a compilation of these data and provides a brief discussion of the results.

7.1 Soil Temperature and Moisture Block Resistance

Thermocouple readings and soil moisture block resistance was measured on preset 12-hour cycles via a Campbell Scientific CR-21X data logger. These data were stored on magnetic tapes, which were manually recovered from the field. The tapes were read using office computer equipment and the data were transferred to permanent storage in the project's computerized data base. Malfunctioning of the data logger resulted in the occasional loss of data. The longest hiatus in the data occurred between September 1986 and March 1987, and no data are available after May 1988. The moisture block data have not yet been reduced or interpreted, largely due to lack of confidence in the calibration curves (Appendix G). Thus, these data are not reported or discussed further in this report.

Temperature profiles over each 3-month period are provided in Appendix J for the A-1 lysimeter and Appendix K for the B-1 lysimeter. Semiannual temperature profiles through September 30, 1987 are provided in Figures 7.1 for the A-1 lysimeter and Figure 7.2 for the B-1 lysimeter.

7.2 Soil Moisture Contents

Soil moisture contents were measured approximately every 2 weeks using a neutron soil moisture probe. These data were collected from March 29, 1985 to January 30, 1989 for the A-1 lysimeter and from September 13, 1985 to January 30, 1989 for the B-1 lysimeter. These data were recorded as raw counts in a controlled notebook and manually entered into the project's computerized data base. Computer software was used to calculate the moisture contents from the raw counts/standard count ratio using the calibration curves derived in Appendix H. The calculated soil moisture content profiles over each 3-month period are provided in Appendix L for the A-1 lysimeter and Appendix M for the B-1 lysimeter. Semiannual soil moisture profiles through September 30, 1987 are provided in Figures 7.3 and 7.4 for the A-1 and B-1 lysimeters, respectively.

7.3 Water Balance

The change in water storage, over a given time, is equal to the precipitation minus transpiration, evaporation, drainage, and runoff. For this study, runoff was assumed to be zero, due to the high

Figure 7.2. Selected Soil Temperature Profiles for the B-1 Lysimeter Through September 30, 1987.

Figure 7.3. Selected Soil Moisture Content Profiles for the A-1 Lysimeter Through September 30, 1987.

Figure 7.4. Selected Soil Moisture Content Profiles for the B-1 Lysimeter Through September 30, 1987.

infiltration capacity of the gravel surface cover and the caisson lip, which protruded above the ground surface. The surface of the lysimeters was to be kept free of vegetation, thus eliminating the transpiration term. However, vegetation was observed to occasionally invade the lysimeters and was removed during routine data collection activities. After routine monitoring efforts ended in January 1991, the vegetation was no longer removed, and transpiration likely played a more important role.

The total amount of water contained (stored) within each lysimeter was calculated by determining the area under the moisture profile curves using the trapezoid method. This water storage (calculated as cm of water) is tabulated in Table 7.1 for the A-1 and B-1 lysimeters, respectively. These tables also list the amounts of precipitation and drainage water removed from the bottom of the lysimeters. The difference between precipitation and the storage-plus-drainage terms is assumed to represent a combination of evaporation and transpiration.

Figure 7.5 illustrates the precipitation, water storage, and drainage history of the two lysimeters. The A-1 lysimeter appears to have reached equilibrium or steady-state conditions in April 1987, approximately 2 years after it was backfilled. This corresponds to the first drainage recovered from the lysimeter. More significant amounts of drainage were recovered starting in January 1988, approximately 1 month after a significant precipitation event at the beginning of the 1987/88 water year.^(a) The rate of drainage (i.e., the water flux) through the A-1 lysimeter after equilibrium was reached can be estimated at approximately 5.7 cm/yr based on the slope of the accumulative drainage curve (Figure 7.5). This corresponds well with the 6.4 cm of water recovered from the A-1 lysimeter during the 1987/88 water year (the only full water year recorded after equilibrium was reached) (Table 7.1). Comparison of the annual precipitation (12.7 cm/year) to the annual drainage collected after the A-1 lysimeter reached steady state (6.4 cm/year), suggests that the annual water flux through the A-1 lysimeter was on the order of one-half of the annual precipitation. A range of 115 to 210 L (3.7 to 6.7 cm) of drainage per year was found (Appendix A).

Dudziak (1988) simulated the water balance of the A-1 lysimeter during its first 21 months (March 1985 through December 1986) using the UNSAT-H soil water flow model (Fayer et al. 1986) and found that the flow model was capable of reproducing the measured moisture content data within $0.03 \text{ cm}^3/\text{cm}^3$. The drainage during this period (3 L [0.093 cm]) agreed within 0.002 cm of water. However, this was before the lysimeter had reached equilibrium.

The B-1 lysimeter appears to have approached equilibrium about the same time as the A-1 lysimeter (April 1987). However, its steady-state water storage level appears to be ~7% lower than that of the A-1 lysimeter. The B-1 lysimeter also displays a slight decreasing trend in its storage value after April 1987, while the A-1 lysimeter's storage value remains relatively flat. The discrepancy in the steady-state value for water storage between the two lysimeters might be accounted for by differences in the neutron probe calibrations for these soils, or slight differences in the soil conditions (e.g., grain size, packing). The decreasing trend in the B-1 lysimeter may reflect the invasion of vegetation and increased plant cover observed at this lysimeter but not at the A-1 lysimeter. Although vegetation was removed from the lysimeters during routine data collection, its presence undoubtedly enhanced evapotranspiration.

(a) A water year, as used in this report, runs from October 1 to September 30.

Table 7.1. Water Balance through January 1989.

Date	Precipitation (cm Water)**	Lysimeter A-1					Lysimeter B-1		
		Water in Storage (cm Water)	Change in Storage (cm Water)	Drainage Water Removed (L)	Drainage Water Removed (cm Water)	Net Loss = Evapo- transpiration (cm Water)	Water in Storage (cm Water)	Change in Storage (cm Water)	Drainage Water Removed (cm Water)
3/22/85		Lysimeter A-1 Operational							
9/16/85							Lysimeter B-1 Operational		
3/85 to 9/85 Totals	3.52	69.6	4.5	0.0	0.0	-0.9	65.4		
1985/86 Water Year Totals	25.96	87.0	17.4	0.0	0.0	8.5	80.4	15.0	0.0
1986/87 Water Year Totals	14.5	94.2	7.2	22.0	0.7	6.6	85.4	5.0	0.0
1987/88 Water Year Totals	12.7	97.0	2.7	200.0	6.4	3.6	87.9	2.5	0.0
10/88 - 1/89 Totals	6.17	95.6	-1.3	91.0	2.9	4.6	86.2	-1.6	0.0

**Mike Fayer's "official picks" selected from tipping rain gage, regular rain gage, and weighing lysimeter data from the BWTF.

Figure 7.5. Precipitation, Water Storage, and Drainage History for the A-1 and B-1 Lysimeters, through January 1989.

7.4 Gross Gamma-Ray Logging

PNL's gross gamma-ray logging system was run three times in the A-1 lysimeter and twice in the B-1 lysimeter between June 25, 1985 and April 25, 1986. These data were recorded via an analog chart recorder. The resulting charts were then digitized and the data stored in the computerized data base. Note that the very fine sand displays a higher natural gross gamma-ray signature than the coarse sand. The waste zone is easily recognized by its much higher gamma-ray count rate. No discernible changes were observed in the intensity or location of gamma-emitting radionuclides in the waste zone. These gross gamma-ray logs are provided in Appendix N.

On April 27, 1994, the WHC NaI spectral logging system was run in both lysimeters and produced a gross gamma log and a series of four gamma-ray spectra for each lysimeter. The gamma-ray spectra were produced at four depths: 4.5 m, 5.1 m (adjacent to waste zone), 5.7 m, and 7.5 m. The gross gamma log and the gamma-ray spectra at the waste zone in the A-1 lysimeter are shown in Figures 7.6 and 7.7, respectively. The gross gamma log and the gamma-ray spectra at the waste zone in the B-1 lysimeter are shown in Figures 7.8 and 7.9, respectively. Note that both ^{60}Co and ^{137}Cs were observed in the waste zone of the A-1 lysimeter, while only ^{137}Cs was detected in the waste zone of the B-1 lysimeter. Again, no discernible movement of the anthropogenic radionuclides was observed.

7.5 Leachate Data

Leachate samples were collected from both the soil pore-water samplers and the drainage water sampling well. These samples were analyzed in the 3720 Laboratory (300 Area) for pH, Eh, IC, ICP, TOC, and radionuclides. A list of analytes measured is provided in Table 7.2.

7.5.1 Soil Pore-Water Samples

Leachate held in soil pores surrounding the soil pore-water samplers was collected using vacuum/pressure hand pumps and 100-ml sample bottles. Only three attempts (March 26-27, 1986; November 5, 1986; and March 26, 1987) were made to pull samples from these pore-water samplers (Table 7.3). Sample collection was successful only from the 6.5-m-deep soil pore-water sampler in the A-1 lysimeter, the only pore-water sampler for which the surrounding silica flour was installed in a saturated condition. Attempts to pull samples from the remaining pore-water samplers were unsuccessful because the samplers failed to retain a vacuum. It is believed that installation of dry silica flour around these pore-water samplers failed to produce a good coupling between the silica sand and the porous Teflon membrane. Thus, when a vacuum was applied it quickly unsaturated the porous membrane and exceeded its bubbling pressure. An attempt to resaturate the porous Teflon membrane and to saturate the silica flour by adding distilled water to the sampler was unsuccessful. Table 7.4 summarizes the analytical results from the three soil pore-water samples.

The chemical composition of the pore-water vacuum squeezed from sediments about 1.3 m below the waste forms does not show evidence of any radionuclide release and transport from at least 1.3 m through the first three years.

Project: LYSIMETERS
Borehole: LYSIMETER A1
No Corrections Applied

Log Date Depth Range
Apr 27, 1994 0 - 24'

Figure 7.6. Gross Gamma-Ray Log for the A-1 Lysimeter (April 27, 1994).

Figure 7.7. Gamma-Ray Spectra Adjacent to the Waste Zone in the A-1 Lysimeter (April 27, 1994)

Project: LYSIMETERS
Borehole: LYSIMETER B1
No Corrections Applied

Log Date Depth Range
Apr 27, 1994 0 - 24'

Figure 7.8. Gross Gamma-Ray Log for the B-1 Lysimeter (April 27, 1994)

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS. LIVETIME = 113.40 SECONDS
 DATA COLLECTED AT 11:26:56 ON 27-APR-94
 10000.00

Figure 7.9. Gamma-Ray Spectra Adjacent to the Waste Zone in the B-1 Lysimeter (April 27, 1994)

Table 7.2. List of Target Analytes for the Leachate Samples.

Metals

Al
B
Ba
Ca
Cd
Cr
Cu
Fe
K
Mg
Mn
Mo
Na
P
Pb
Si
Sr
Zn
Zr

Anions

Cl
CO₃
F
HCO₃
NO₂
NO₃
PO₄
SO₄

Others

Total Organic Carbon
Total Inorganic Carbon
pH
Eh
Gamma-emitting Radionuclides
Gross alpha and beta

Table 7.3. List of Soil Pore-Water Sampling Events.

Date	Sample Volume (mL) Removed					
	Lysimeter A-1 Pore-Water Samplers			Lysimeter A-1 Pore-Water Samplers		
	5.3 m	5.7 m	6.5 m	5.3 m	5.7 m	6.5 m
3/22/85	Lysimeter A-1 Backfilling Complete			Lysimeter B-1 Backfilling Complete		
9/16/83						
3/26/86	0	0	20			
	1500 ^(a)	1500 ^(a)				
3/27/86	155 ^(b)	165 ^(b)	6 ^(b)	0	0	0
11/5/86	(c)	(c)	~ 25	(c)	(c)	(c)
3/26/87	0	0	~ 2	0	0	0

(a) Distilled water added to saturate porous cup.

(b) Recovered water not analyzed.

(c) Only a few drops collected. Not analyzed.

The stable chemicals Ca, Mg, Zn, NO₃ and SO₄ appear at higher concentrations than in uncontaminated Hanford groundwaters and saturation extracts formed by wetting Hanford sediments to saturation and squeezing out the resultant solution (Serne et al. 1993). The elevated concentrations of Ca and Mg may be a result of release from the cementitious waste forms or the silica flour/bentonite packed around the suction candles. The grout waste forms contain large amounts of Na, which is known to leach rapidly from PSW grout (Serne et al. 1987); thus it is likely that Na concentrations would be elevated if the grout waste forms were controlling the suction candle extracts' chemistry. On the other hand, the high SO₄ concentrations would appear to be caused by sulfate release from the grouts.

The zinc found at elevated concentrations may come from the paint used to coat the galvanized steel caissons. The high nitrate may result from leaching the sediments used to fill the lysimeters. The AP-Tank Farm soils are contaminated with NO₃ either from NO₂ gas emissions or past NO₃ spills/leaks.

The three data points available are too few to quantify or to establish conclusively that grout leachates are impacting the pore-water 1.3 m below waste emplacement after 2 to 3 years. There are no indications that radionuclides have reached the suction candles 1.3 m below the waste forms.

7.5.2 Drainage Water Samples

Leachate from the bottom of the A-1 lysimeter was collected using a stainless steel Hydrostar positive displacement hand-operated pump. Table 7.5 lists various sampling events and volumes of water recovered from the bottom of the A-1 lysimeter. No water was ever recovered from the bottom of the B-1 lysimeter. Table 7.6 summarizes the analytical results from these samples. The chemical composition of the drainage collected approximately 2.5 m below the zone of waste form emplacement

Table 7.4. Summary of Analytical Results of Pore-Water Samples from the 6.5-m-deep Pore-Water Sampler in the A-1 Lysimeter.

		Sampling Date		
		3-26-86	11-5-86	3-26-87
pH		7.79	7.79	---
Eh	mv	355	347	---
Al	mg/L	<0.03	<0.03	<0.03
Ba	mg/L	0.047	0.153	0.130
Ca	mg/L	117	150	142
Cd	mg/L	<0.004	0.009	<0.004
Cr	mg/L	<0.02	<0.02	<0.02
Cu	mg/L	0.014	0.008	<0.004
Fe	mg/L	0.005	0.038	0.011
K	mg/L	4.4	9.3	0.5
Mg	mg/L	21.7	42.60	40.00
Mn	mg/L	0.01	0.042	0.030
Mo	mg/L	<0.01	<0.01	<0.01
Na	mg/L	37.5	43	41.1
P	mg/L	<0.1	<0.1	<0.1
as PO ₄	mg/L	<0.31	<0.31	<0.31
Pb	mg/L	<0.06	<0.06	<0.06
Si	mg/L	19.3	9.5	10.9
Sr	mg/L	0.531	0.785	0.700
Zn	mg/L	0.148	1.390	1.940
Zr	mg/L	<0.008	<0.008	<0.008
F ⁻	mg/L	0.3	0.7	0.7
Cl ⁻	mg/L	15	14	19
NO ₂ ⁻	mg/L	<0.2	<0.2	<0.2
NO ₃ ⁻	mg/L	50	111.0	24.0
SO ₄ ⁻²	mg/L	290	158	490
HCO ₃ ⁻	mg/L	166.5	68.20	---
CO ₃ ⁻²	mg/L	12.6	0.00	---
OH ⁻	mg/L	0	0.00	0
B	mg/L	0.031	0.043	0.040
as H ₃ BO ₃	mg/L	0.177	0.246	0.23
PO ₄ ⁻³	mg/L	<2.0	<2.0	<2.0
TOC	mg/L	6	---	---
Total Alkalinity ^(a)	mg/L	94.5	34	---
P-Alkalinity ^(a)	mg/L	0	0	0
IC	mg/L	29.9	---	---
Cations	meq/L	9.39	13.13	12.21
Anions	meq/L	10.49	6.70	11.17
⁵¹ Cr	pCi/L	<700	<800	---
⁵⁴ Mn	pCi/L	<520	<1280	---
⁵⁹ Fe	pCi/L	<1000	<1900	---
⁶⁰ Co	pCi/L	<480	<1750	---
¹⁰³ Ru	pCi/L	<790	<960	---
¹³⁷ Cs	pCi/L	<480	<1150	---

--- Data not available.

(a) Alkalinity as CO₃²⁻

Table 7.5. List of Drainage Water Sampling Events and Volumes Recovered from the A-1 Lysimeter.

<u>Date</u>	<u>Volume Recovered (liters)</u>	<u>Volume Recovered (cm)</u>
11-5-86	3	0.1
3-26-87	8	0.3
9-21-87	11	0.4
1-5-88	79	2.5
2-18-88	42	1.3
4-15-88	41	1.3
6-23-88	38	1.2
10-24-88	56	1.8
11-10-88	9.7	0.3
12-2-88	7.6	0.2
1-17-89	16.7	0.5
7-20-90	180	5.7
10-17-91	163	5.2
11-12-92	65	2.1

Table 7.6. Summary of Analytical Results from Drainage Water Collected at the Bottom of the A-1 Lysimeter.

		Sampling Dates								
		11-5-86	11-5-86	3-26-87	9-21-87	9-21-87	1-5-88	1-5-88	2-18-88	4-15-88
pH		8.08	7.98	—	7.67	7.64	7.75	7.78	7.89	7.65
Eh		346	350	—	382	384	420	419	438	340
Al	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.11	0.08
Ba	mg/L	0.127	0.146	0.070	0.480	0.460	0.118	0.117	0.109	0.051
Ca	mg/L	152.0	156.0	191.0	144.0	148.0	129.0	130.0	130.0	123.0
Cd	mg/L	0.006	0.005	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cr	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cu	mg/L	0.011	<0.004	<0.004	0.010	0.013	<.005	<.005	<.005	<.005
Fe	mg/L	0.013	<0.005	<0.005	0.025	0.031	<.005	<.005	<.005	0.048
K	mg/L	8.8	7.2	8.8	9.8	9.5	8.8	9.0	10.3	8.6
Mg	mg/L	38.50	43.00	36.00	37.60	37.10	33.00	33.60	30.70	29.90
Mn	mg/L	0.033	0.033	0.030	0.018	0.023	0.005	0.006	0.005	0.005
Mo	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Na	mg/L	48	43	68.90	39.90	39.40	43.60	43.90	46.00	51
P	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.14	0.20
as PO ₄	mg/L	<0.31	<0.31	<0.31	<0.31	<0.31	<0.31	<0.31	0.42	0.60
Pb	mg/L	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Si	mg/L	15.2	15.0	30.7	11.4	11.5	15.0	15.2	14.9	14.4
Sr	mg/L	0.762	0.300	0.850	0.598	0.600	0.663	0.655	0.597	0.576
Zn	mg/L	0.942	4.080	0.300	3.610	3.150	0.890	0.920	1.140	1.030
Zr	mg/L	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
F	mg/L	0.7	0.9	0.7	0.7	0.7	0.2	0.1	0.3	0.3
Cl ⁻	mg/L	13	15	12	10	10.90	10.60	10.00	9.30	9.66
NO ₂ ⁻	mg/L	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NO ₃ ⁻	mg/L	110.0	118.0	98.0	99.0	96.00	93.00	98.00	95.60	93.4
SO ₄ ²⁻	mg/L	158	170	140	117	125.00	106.00	102.00	102.00	113
HCO ₃ ⁻	mg/L	110.2	108.65	78.87	322.76	298.79	322.84	408.86	319.87	358.89
CO ₃ ²⁻	mg/L	0	0	0	0	0	0.00	0.00	0.00	0.00
OH ⁻	mg/L	0	0	0	0	0	0.00	0.00	0.00	0.00
B	mg/L	0.044	0.210	<0.01	0.048	0.046	0.054	0.055	0.057	0.051
as H ₃ BO ₃	mg/L	0.25	1.18	0.00	0.27	0.26	0.31	0.31	0.33	0.29
PO ₄ ³⁻	mg/L	<2.0	0.4	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Total	mg/L	131	70	52	179	167	184	224	177	198
Alkalinity ^(a)										
P-Alkalinity ^(a)		0	0	0	0	0	0	0	0	0
IC	mg/L	75.8	93.6	—	89.1	84.4	—	—	—	77.1
TOC	mg/L	—	8.4	—	5.5	6.0				82.8
Cations	meq/L	13.09	13.40	15.75	12.29	12.42	11.30	11.42	11.30	11.06
Anions	meq/L	7.34	8.27	6.61	10.33	10.07	10.15	11.46	9.84	10.75
⁵¹ Cr	pCi/L	<800	<800	<250	<1300	<6200	<3070	—	<300	<100
⁵⁴ Mn	pCi/L	<1280	<1280	<160	<760	120	<360	—	<30	<30
⁵⁹ Fe	pCi/L	<1900	<1900	<500	<1240	<1180	432	—	<30	<15
⁶⁰ Co	pCi/L	<1750	<1750	<400	<840	<700	<360	—	<35	<20
¹⁰³ Ru	pCi/L	<960	<960	<200	<720	<730	<300	—	<30	<30
¹³⁷ Cs	pCi/L	<1150	<1150	<380	<690	<250	540	—	132	88

— Data not available.

(a) Alkalinity as CO₃²⁻

Table 7.6. (contd)

		Sampling Date						
		6-23-88	11-10-88	12-2-88	1-17-89	7-20-90	10-17-91	11-12-92
pH		8.23	8.40	8.34	8.43	7.38	7.87	7.7
Eh		379.00	278.00	296.00	385.00	297	278	—
Al	mg/L	0.135	0.050	0.088	<0.03	<0.3	<1	<1
Ba	mg/L	0.099	0.112	0.115	0.107	0.22	<0.1	0.20
Ca	mg/L	123.000	120.000	130.000	137.000	255	225	240
Cd	mg/L	<0.004	<0.004	<0.004	<0.004	<0.01	<0.1	<0.1
Cr	mg/L	<0.020	<0.020	<0.020	<0.020	<0.01	<0.1	<0.1
Cu	mg/L	<0.004	<0.004	<0.004	<0.004	<0.01	<0.1	<0.1
Fe	mg/L	0.024	0.700	0.032	<0.005	<0.01	<1.0	2.2
K	mg/L	9.200	11.100	10.800	8.800	12	<20	<20
Mg	mg/L	28.200	29.000	29.000	26.400	58.3	53.6	59.8
Mn	mg/L	0.005	0.009	0.006	0.005	0.01	<0.1	<0.1
Mo	mg/L	—	—	—	—	—	—	—
Na	mg/L	46.700	48.000	49.000	45.700	7.42	69.2	74.8
P	mg/L	0.170	0.083	0.131	0.104	<0.1	<1.0	<1.0
as PO ₄	mg/L	0.521	0.256	0.400	0.319	<0.3	<3.0	<3.0
Pb	mg/L	<0.060	<0.060	<0.060	<0.060	<0.1	<1.0	<1.0
Si	mg/L	14.300	14.000	14.000	13.000	13.4	11.8	10.4
Sr	mg/L	0.540	0.564	0.565	0.544	1.2	1.1	1.1
Zn	mg/L	0.799	0.417	1.770	1.060	1.5	1.6	<0.5
Zr	mg/L	—	—	—	—	—	—	—
F ⁻	mg/L	0.258*	0.263	0.275	0.266	0.01*	—	—
Cl ⁻	mg/L	9.500	9.000	9.000	9.300	105	113	132
NO ₂ ⁻	mg/L	<0.300	<0.300	<0.300	<0.300	<0.3	<0.3	<0.3
NO ₃ ⁻	mg/L	95.800	106.000	110.000	111.000	490	522	593
SO ₄ ⁻²	mg/L	118.000	110.000	108.000	102.000	150	145	145
HCO ₃ ⁻	mg/L	207.400	356.850	393.450	372.100	390	254	186
CO ₃ ⁻²	mg/L	0.000	0.000	0.000	0.000	0.0	0.0	0.0
OH ⁻	mg/L	0.000	0.000	0.000	0.000	0.0	0.0	0.0
B	mg/L	0.055	0.062	0.063	0.058	0.05	0.2	0.3
as H ₃ BO ₃	mg/L	0.314	0.355	0.360	0.332	0.30	1.2	1.8
PO ₄ ⁻³	mg/L	<0.400	<0.400	<0.400	<0.400	<0.4	<0.4	<0.4
Total Alkalinity ^(a)	mg/L	102.000	175.500	193.500	183.000	195	127	93
P-Alkalinity ^(a)	mg/L	0.000	0.000	0.000	0.000	0.0	0.0	0.0
IC	mg/L	72.280	68.280	82.480	77.0	67	—	—
TOC	mg/L	8.1	6.8	8.2	3.3	14	7.1	10.3
Cations	mg/L	10.737	10.759	11.293	11.234	21.1	18.7	20.2
Anions	mg/L	7.686	10.120	10.743	10.292	20.4	18.8	19.4
⁵¹ Cr	pCi/L	—	—	—	—	—	—	—
⁵⁴ Mn	pCi/L	—	—	—	—	—	—	—
⁵⁹ Fe	pCi/L	—	—	—	—	—	—	—
⁶⁰ Co	pCi/L	<186	32	83	<60	<800	—	—
¹⁰³ Ru	pCi/L	—	—	—	—	—	—	355
¹³⁷ Cs	pCi/L	<160	22	115	93	<640	—	440
Li	mg/L	0.014	0.013	0.014	0.011	<0.05	<0.5	<0.5

— Data not available.

(a) Alkalinity as CO₃⁻²

shows a distinct increase in total dissolved solids between January 1989 and July 1990. This is the exact point at which frequent soil physics monitoring and drainage collection activities ceased, and only sporadic activities to collect drainage from the A-1 lysimeter began.

Before the project was placed on a maintenance-only schedule (January 1989), the drainage chemistry was very similar to the suction candle extract chemistry. The same constituents (Ca, Mg, Zn, NO₃ and SO₄) at about the same concentrations were present at elevated concentrations.

The July 1990 drainage sample and the final two drainages (see Table 7.6) show abrupt increases in Ca, Mg, Na, Cl, and NO₃ and a slight increase in SO₄. The large increase in Cl is especially puzzling because neither the grout waste forms nor the sediments have known sources of Cl. The radionuclide measurements of the drainage waters show no consistent patterns. All results are below detection limits or very low (<500 pCi/L). The detection limits for the various isotopes varied in each sample depending on the volume and length of time counted.

Of the isotopes present in the PSW liquid wastes or spiked into the liquids before grouting, we would expect ¹³⁷Cs to leach most rapidly (Serne et al. 1987, 1989) but the sediment between the waste forms and the drain would be expected to readily adsorb Cs. Thus, it is not surprising that no significant breakthrough of radionuclides was observed in the 8 years that data were collected.

The elevated Ca, Mg, Na, and SO₄ found in drainage might indicate that some leaching of major constituents in the PSW grout has occurred, and these constituents have traveled through the sediments to the drain. On the other hand, impurities in the bentonite and silica flour could be the source of Ca and Mg. Ion exchange reactions between these alkaline-earth divalent cations and adsorbed Na naturally present on the sediments could be the source of the elevated Na concentrations in the drainage. There is no dramatic imprint in the drainage data to conclusively show that the grout leached significantly during the 8 years for which monitoring results are available. Starting in February 1988, lysimeter drainage was analyzed for total alpha-total beta radioactivity using a liquid scintillation detector. An uncontaminated Hanford groundwater sample was used as a background sample to compare the drainage water count rates. The average background count rate of 63.4 ± 5.9 cpm/ml (2σ) equates to an activity of about 2860 pCi/L. The net difference between count rates for the drainage and background groundwater samples is shown in Table 7.7.

In Table 7-7, the column marked Net Difference shows the observed count rate of the drainage sample minus the count rate of the uncontaminated groundwater. The uncertainty represents one standard deviation. There is no trend in the data. All results except for the June 23, 1988 drainage sample suggest that the drainage is indistinguishable from background. The June 23, 1988 sample suggests a slight release of activity. All the other samples show activities within the uncertainty of background measurements.

Uncontaminated groundwater at the Hanford Site contains low but measurable activity from ²³⁸U, ²³²Th parent/daughter decay chains, and ⁴⁰K, but at concentrations considerably lower (tens of pCi/L) than detection limits possible with the screening instrument used on the drainage samples. All that can be concluded is that there has not been significant leaching and subsequent transport of any alpha and beta isotopes from the grouts to the drain in the A-1 lysimeter.

Table 7.7. Total Alpha/Beta Results for Drainage Water

Sample Date	Net Difference cpm/mL	Absolute Activity pCi/L
2/18/88	3.4 ± 6.3	≤ 3100
4/15/88	-1.4 ± 6.5	≤ 2820
6/23/88	23.9 ± 7.2	≤ 4000
10/24/88	7.7 ± 8.8	≤ 3280
11/11/88	4.4 ± 7.8	≤ 3130
12/5/88	5.6 ± 7.7	≤ 3180
1/24/89	---	---
7/20/90	-1.7 ± 6.4	≤ 2880
10/17/91	2.7 ± 9.1	≤ 2940
11/12/91	8.6 ± 11.4	≤ 2990

8.0 Discussion and Conclusions

The GWTF was designed to test the leaching and migration rates of grout-solidified low-level radioactive wastes generated by Hanford Site operations. Only two of the four 8-m-deep by 2-m-dia closed bottom lysimeters were ever completed for their intended purpose. These two lysimeters, designated A-1 and B-1, were backfilled with a two-layer soil profile representative of the proposed grout disposal site. The A-1 lysimeter was backfilled in March 1985, with a grout-solidified phosphate/sulfate waste from N Reactor decontamination and ion exchange resin regeneration. The B-1 lysimeter was backfilled in September 1985, and received a grout-solidified simulated CRW representative of waste generated from fuel reprocessing operations at the head end of the PUREX plant. Routine monitoring of soil physics instrumentation and leachate collection activities were conducted for over 3 years, ending in January 1989.

Soil physics data and water balance evaluations suggest that the A-1 lysimeter did not reach equilibrium/steady state conditions relative to meteoric water flux until April 1987, 2 years after it was backfilled. The B-1 lysimeter appears to have approached equilibrium at about the same time, but at a lower water storage level (~7% lower than the A-1 lysimeter). The B-1 lysimeter also displayed a slight decreasing trend in water storage, while the A-1 lysimeter remained relatively flat.

Comparison of the annual precipitation (12.7 cm/year) to the annual drainage collected after the A-1 lysimeter reached steady state (6.4 cm/year) suggests that the annual water flux through the A-1 lysimeter was on the order of one half of the annual precipitation. This scale of annual water flux was heavily influenced by the presence of a relatively vegetation-free gravel cover. The cumulative drainage through January 1989 was approximately 10 cm, which is equal to only about 4% of the pore column volume of the lysimeter (assuming a porosity of 30%). The cumulative drainage through November 12, 1992 was approximately 23 cm, which is only about 9% of the pore column volume. Thus, the leaching driving force has been small.

Laboratory analyses of both soil-pore-water samples and drainage samples found no conclusive evidence of a breakthrough of contaminants over the 8.5 years of monitoring since the PSW waste forms were emplaced.

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Appendix A

Occurrence Report and Estimate of B-1 Lysimeter Drainage

OCCURRENCE REPORT

Name of Facility: 300 Area North Lysimeter Facility

Name of Laboratory Site or Organization: PACIFIC NORTHWEST LABORATORY

Facility Manager: Title: Telephone No.:
JW Falco Manager, Earth & Environmental Sciences (509) 376-8432
Center

Originator: Title: Telephone No.:
RL Skaggs Manager, Geosciences Department (509) 376-8319

1. OCCURRENCE REPORT NUMBER: PNL-91-0018-300GPF

2. STATUS AND REPORT DATE:	Date	3. OCCURRENCE CATEGORY
☐ Notification Report	<u>01/25/91</u>	☐ Emergency
☒ 10-Day	<u>02/08/91</u>	☐ Unusual Occurrence
☒ Final	<u>02/08/91</u>	☒ Off-Normal

4. DIVISION OR PROJECT:
a) Contractor Organization: Earth & Environmental Sciences Center
b) DOE Program Office: ☐ CE ☐ DP ☒ ER ☐ EM ☐ FE ☐ NE
☐ RW

5. FACILITY, SYSTEM, BLDG. OR EQUIPMENT: 300 Area North Lysimeter Facility

6. PLANT AREA: 300 Area

7. DATE & TIME OCCURRENCE DISCOVERED: 01/25/91, 1530 hrs.

8. DATE & TIME OCCURRENCE CATEGORIZED: 01/25/91, 1536 hrs.

9. DATE & TIME OF DOE PROGRAM NOTIFICATION: N/A

10. DATE & TIME OF OTHER NOTIFICATIONS: DOE-RL, 01/25/91, 1700 hrs.

11. SUBJECT OR TITLE OF OCCURRENCE: Apparent release of radiotraced simulated waste from lysimeter.

12. DESCRIPTION OF OCCURRENCE: At a meeting that ended at approximately 1530 hrs. on 1/25/91, it was concluded that drainage from a buried lysimeter in the 300 Area North lysimeter facility has probably leaked into the underlying sediments. The lysimeter contains radiotraced simulated solidified neutralized cladding removal wastes. It is estimated that over a three year period, as much as 300 liters of drainage may have leaked. The maximum concentration of contaminants in the sediments is estimated to be 6×10^{-5} microcuries/ml to 1.3×10^{-4} microcuries/ml of ^{99}Tc .

13. OPERATING CONDITIONS OF FACILITY AT TIME OF OCCURRENCE: Normal

14. IMMEDIATE ACTIONS TAKEN AND RESULTS: A waterproof lid has been placed over the lysimeter.

Occurrence
Report Number: PNL-91-0018-300GPF
Report Date: 02/08/91

15. CAUSE:

Direct Cause: Design ☐ Material ☒ Personnel ☐
Procedure ☐ Other ☐

EXPLAIN: Welded metal bottom has apparently lost its water tightness. We speculate that welds were compromised when construction persons dumped gravel from surface to bottom of facility (8 m) using front end loader instead of hand packing.

Contributing cause(s): Design ☐ Material ☐ Personnel ☐
Procedure ☒ Other ☐

EXPLAIN: The procedure may not have explicitly required hand packing of the bottom layer.

Root Cause: Procedure ☐ Training ☐ Management ☒
Personnel ☐ Design ☐ Material ☐

EXPLAIN: Management did not ensure adequate installation procedures were prepared and communicated to appropriate staff.

-
16. DESCRIPTION OF CAUSE: Without exhuming the contents of the lysimeter we can only speculate that the probable cause for the lysimeter to not collect recharge water is that the welded bottom plate was compromised during filling the lysimeter. The facility was water tight (tested for several days) just prior to filling. A staff member recalls that the construction workers dropped a load of gravel from the surface into the empty lysimeter (≥ 8 m). It would have been more appropriate to hand pack the gravel. Subsequent layers of soil and grout wastes were hand packed as instructed.

-
17. EVALUATION: (By Facility Manager) The action taken to minimize future drainage is appropriate. The facility has been awaiting decommissioning funds for the past two years, thus, there is no loss of data or impact on program. Environmental consequences appear to be minimal. The lysimeter is no longer in operation and a decommissioning plan has been prepared. Further evaluation will be conducted when decommissioning activities begin.

-
18. IS FURTHER EVALUATION REQUIRED? Yes ☐ No ☒
IF YES, BEFORE FURTHER OPERATION? Yes ☐ No ☐
IF YES, BY WHOM?
WHEN?

-
19. CORRECTIVE ACTION: A waterproof lid has been placed over the lysimeter surface to preclude future precipitation from entering the soil column. New lysimeter installations will include instructions and training on backfilling the site.
Taken: ☒ Recommended: ☐ To be supplied: ☐
-

Occurrence
Report Number: PNL-91-0018-300GPF
Report Date: 02/08/91

20. **IMPACT ON ENVIRONMENT, SAFETY & HEALTH, SECURITY AND QUALITY ASSURANCE:**
The estimated amounts of radionuclides that may have leaked should have a minimal impact on the environment. If radionuclides have in fact migrated outside the lysimeter they are in the unsaturated sediments above the water table. Upon reaching the water table the nuclides would be significantly diluted and would likely be undetected in any down gradient monitoring wells. Upon reaching the Columbia River the radionuclides would be further diluted.
-
21. **PROGRAMMATIC IMPACT:** None. Hanford Grout Project has not been funding lysimeter operation for several years and has been planning to exhume sediments and buried grouts to properly decommission facility.
-
22. **IMPACT UPON CODES AND STANDARDS:** None
-
23. **FINAL EVALUATION AND LESSONS LEARNED:** In future construction of lysimeters involving simulated wastes, procedures must be established and followed to ensure that the integrity of the lysimeter bottom is not compromised subsequent to testing for water tightness.
-
24. **SIMILAR OCCURRENCE REPORT NUMBERS:** None
-

Occurrence
Report Number: PNL-91-0018-300GPF
Report Date: 02/08/91

25. SIGNATURES:

Approved by:
Originator

RL Skaggs Date: 2/8/91
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Geosciences Department

Facility Manager

JW Falco Date: 2/8/91
JW Falco, Manager
Earth & Environmental Sciences Center

GR Hoenes Date: 2/8/91
GR Hoenes, Manager
Laboratory Safety Department

RR King Date: 2-8-91
RR King, Manager
Technical Services Department

TD Chikalla Date: 2-8-91
for TD Chikalla, Director
Facilities & Operations

Others Signatures:
DOE Facility
Representative

JJ Sutey Date: 2/11/91
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Research & Development Division

DOE Program Manager

HC Field Date: _____
HC Field, ER-65

Authorized Derivative
Classifier

RR King Date: 2-8-91
RR King
[] Classified [X] Unclassified

Occurrence
Report Number: PNL-91-0018-300GPF
Report Date: 02/08/91

DOE FACILITY REPRESENTATIVE'S INPUT

26. DOE FACILITY REPRESENTATIVE INPUT: acceptable.

27. Entered by: David K. Jones Date: 02/08/91
Name of DOE Facility Representative

Battelle

Pacific Northwest Laboratories

Project Number HGTP

Internal Distribution

Date January 25, 1991

To Distribution

From J. H. Westsik, Jr. *Joe*

Subject Release from Grout Lysimeter

CR Allen
PA Scott
RJ Serne
File/LB

Jeff Serne has performed calculations indicating that a lysimeter used by the Hanford Grout Technology Program has leaked reportable concentrations of technetium to the environment. The pertinent numbers are listed below.

<u>Limit</u>	<u>Serne</u>	<u>Westsik</u>
$1 \times 10^{-4} \mu\text{Ci/mL}$	$1.3 \times 10^{-4} \mu\text{Ci/mL}$	$6 \times 10^{-5} \mu\text{Ci/mL}$

Jeff's calculations include two worst-case assumptions:

1. The quantity released the first year is the same as for the following three years. This neglects the decrease in release rates that would be expected as a diffusion profile develops in the test materials in the lysimeters.
2. The minimum quantity of solution collected in a neighboring lysimeter during any of the last three "lysimeter" years was ~100 liters. The contaminants leached from the test specimens during each of the past three years were assumed to leach into this minimum volume.

My calculations include the decrease in release rate over time and use the actual volumes of accumulated liquid in the neighboring lysimeter (211, 169, and ~100 liters). The maximum concentration still occurs in the first year that drainable liquids would have been collected; the concentration is lower because a relatively large volume of liquid (211 liters) was collected that first year.

While Jeff's calculations are probably conservative, I cannot assure that my calculations are. Only by actually measuring the concentrations in the soil can we be certain.

Therefore, I recommend that we should report this potential release to the occurrence officer.

Date January 5, 1991
To Joe Westsik
From R. Jeff Serne *Jeff Serne*
Subject Estimate of Lysimeter Drainage Composition

Enclosed is my estimate of the worst-case chemical composition of drainage that apparently has leaked out of one of the Hanford Grout Technology lysimeters over the past three years. This particular lysimeter contains radiotracred simulated neutralized cladding removal wastes (CRW). On November 13, 1990, we placed a watertight plywood-composite shingle lid over the lysimeter, so drainage should be significantly reduced in the future.

The CRW lysimeter was activated on September 12, 1985, when 24 one-half liter sized "pucks" of CRW grout were buried at a depth of ~5.1 meters inside lysimeter B-1, which was then backfilled with sediments from the AP Tank Farm. The sloping drain in the gravel bed at the bottom of the lysimeter is at a depth of ~8.2 meters. Thus, approximately 3.1 meters of sediment (and gravel) lies below the waste forms (see Figure 1). The water table under the lysimeter site is ~18 meters from ground surface, or about 10 meters further below the bottom of the lysimeter.

I have discussed what could have happened to compromise the lysimeter integrity with George Last, the original task manager. Prior to loading the lysimeter, the bottom welds were hydrostatically tested for several days without leaking any water. George suspects that the lysimeter was damaged when the construction crew dumped the gravel into the empty lysimeter from the surface using a front end loader bucket. The gravel fell the full 8 meters onto the bottom end plate. It is not known whether a similar procedure was used to fill lysimeter A-1, which contains phosphate/sulfate (PSW) grout and is working correctly. The instructions to the construction workers are in storage, but it is known that they properly installed the sediments and waste forms by hand in thin lifts.

To estimate the concentration of contaminants that could be in the drainage water that has probably escaped the lysimeter, I used drainage times and volumes from the neighboring PSW lysimeter and estimates of mass leached from the 24 "pucks" based on laboratory leach tests conducted on smaller CRW test specimens, and on mass-transport by effective diffusion theory, theory nearly always invoked when describing leaching from cementitious solid waste forms (Bernard et al. 1982, Croney 1985, Dayal et al. 1983, Godbee et al. 1980, Habayeb 1985, Matsuzuru and Ito 1978, and Sambell et al. 1982). Once contaminants leach from the grout "pucks," they probably travel through the AP Tank Farm sediment the 3 meters to the gravel and then must travel outside the lysimeter through 10 meters of unsaturated sediment to reach the groundwater. For the case in which I consider adsorption, I factored in only the 3 meters of sediment inside the lysimeter and used the very simple constant distribution (K_d or R_d) approach to account for sediment adsorption [see Freeze and Cherry (1979), Serne and Muller (1987) and Serne and Wood (1990) for details, assumptions and limitations to using the simplistic constant R_d sorption/transport model]. Estimating transport outside the lysimeter within the 10-meter vadose zone above the water table is beyond the scope of my capabilities. It can be safely stated that travel times through the 10 meters would be at least 10 years, and some (perhaps significant) dilution with natural recharge water is certain.

Estimate of Drainage Lost Through Leaky Bottom Welds

The neighboring PSW lysimeter (lysimeter A-1) was started March 21, 1985. It is very similar in construction to the CRW lysimeter, although the type of waste solidified in the 24 "pucks" differs. The drainage history of lysimeter A-1 is listed in Table 1.

Based on data from other studies of lysimeters that are adjacent to the grout lysimeters, we have learned that the delay time from when January rain/snow occurs and when it reaches the bottom drain (once the lysimeter is in a steady-state condition) is such that a drainage year is September to the following August (i.e., the precipitation from a given year starts draining in

TABLE 1. Drainage History of Lysimeter A-1

<u>Date</u>	<u>Volume Drained (liters)</u>	<u>Total Liters for Drainage Year</u>
3/21/85 (start)		
3/26/86	bottom moist but no drainage	
11/5/86	3	
3/26/87	8	11
9/21/87	11	
1/5/88	79	
2/18/88	42	
4/15/88	41	
6/23/88	38	211
10/24/88	56	
11/11/88	10	
12/2/88	8	
1/24/89	17	169
7/20/90	180	~100+

September of the first year and drains through August of the following year). We also found that lysimeters filled in late summer (such as lysimeter B-1, which was filled 9/12/85) take 1 additional year to start draining because the sediment used to repack the lysimeter gets extremely dry during the summer while it sits in a pile at the surface. Thus, lysimeter B-1 would be expected to start draining one drainage year later than lysimeter A-1.

Lysimeter A-1 started significant drainage in the September 1987 to August 1988 year, so I estimate that lysimeter B-1 should have first produced significant drainage in the year September 1988 to August 1989. We would thus be in the second quarter of the third drainage year, and two full drainage years would have passed. The amount of drainage each year is a function of the preceding year's precipitation. Table 1 shows a range of about 115 to 210 liters draining each year.

For estimating a worst-case concentration, I will assume that all the contaminants that leach from the grout pucks in 1 year dissolve into 100 liters of drainage. For estimating the worst-case mass leached from the pucks, I will assume that lysimeter B-1 actually drained for the past 3 years (as opposed to the past 2 years, which is more likely). I also assume that

Joe Westsik
January 5, 1991
Page 4

once leached, the contaminants reach the drain without further attenuation (adsorption). To account for the possibility of adsorption, I have also provided an estimate of the delay in contaminants reaching the drain (assuming a linear breakthrough).

The worst-case calculation of drainage lost suggests that about 300 liters of drainage has escaped lysimeter B-1. A value of 100 L/yr will be used to calculate worst-case concentrations of contaminants released at the grout surfaces and available at the drains when adsorption does not occur.

Estimate of Mass of Contaminants Released from Grout

The total inventory of radionuclides added to the simulated CRW grout pucks is known. The major inorganic constituents of concern are nitrate, fluoride, and ammonium. Their respective concentrations in cured CRW grout were measured after total dissolution.

Table 2 lists the activities (in curies/puck) and concentrations (in wt% or g/puck) for the radionuclides and potentially regulated major constituents, respectively.

TABLE 2. Inventory of Constituents in CRW Grout Pucks

<u>Constituent</u>	<u>Ci/puck (A_0)</u>	<u>% wt</u>	<u>g/puck (A_0)</u>
^{14}C	2.5×10^{-5}		
^{90}Sr	1.0×10^{-4}		
^{99}Tc	2.5×10^{-5}		
^{137}Cs	5.0×10^{-5}		
^{238}Pu	2.7×10^{-4}		
^{241}Am	2.5×10^{-4}		
F		4.08	32.3
NH_4		0.50	4.0
NO_3		0.21	1.7

Using diffusion-controlled mass transport theory and laboratory data on effective diffusion coefficients for CRW grout^(a), the following equation and assumptions quantify the mass or activity released per year per puck. The simple diffusion-controlled equation to estimate release is

$$\Sigma a_n = 2 \frac{S}{V} A_0 \sqrt{\frac{D_e \cdot t}{\pi}} \quad (1)$$

where

Σa_n = cumulative mass leached over n leach intervals

S = the geometric surface area of the puck (cm²)

V = the geometric volume of the puck (cm³)

A_0 = original inventory of contaminant in puck

D_e = effective diffusion coefficient (cm²/s)

t = total time of leaching (s).

The pucks are right cylinders with a radius of 5.4 cm and a length of 5.4 cm. The volume ($V = \pi r^2 l$) is 494.7 cm³ and the surface area is $S = 2\pi r(r + l) = 366.4$ cm². The S/V ratio is thus 0.741 cm⁻¹. The A_0 values for the radionuclides are given in Table 2. For the inorganic constituents, the grout bulk density (ρ_b) was assumed to be 1.6 g/cm³ so the grams/puck could be calculated from

$$A_0 = \frac{(\rho_b) \cdot V \cdot \text{wt}\%}{100}$$

The results are shown in the third column of Table 2.

Diffusion coefficients determined in laboratory experiments^(a) for similar CRW samples leached in Hanford groundwater are shown in Table 3.

When diffusion controls leaching, the largest amount of mass released is released at the beginning of the test. Thus, a worst case would assume that the CRW pucks leach each year at the "fast" rate that occurs in the first year (there are 3.156×10^7 s/yr).

(a) 1987 draft report, Pacific Northwest Laboratory, Richland, Washington.

TABLE 3. Effective Diffusion Coefficients (cm²/s)

Constituent	D _e	
¹⁴ C	2 x 10 ⁻¹³	
⁹⁰ Sr	1 x 10 ⁻¹¹	
⁹⁹ Tc	2 x 10 ⁻¹¹	
¹²⁹ I	7 x 10 ⁻⁸	
¹³⁷ Cs	4 x 10 ⁻¹⁵	
²³⁸ Pu	2 x 10 ⁻¹⁶	
²⁴¹ Am	6 x 10 ⁻¹⁶	
F	2 x 10 ⁻¹²	
NH ₄	6.5 x 10 ⁻⁹	(Value for Na assume NH ₄ ≈ Na)
NO ₃	2 x 10 ⁻⁹	

Combining the constants and fixed variables ($2 \cdot S/V \cdot \sqrt{t/\pi}$), I calculate a value of 4.7×10^3 . Equation 1 is thus reduced to

$$\Sigma a_n = 4.7 \times 10^3 A_0 \sqrt{D_e}$$

Table 4 lists the values for Σa_n determined for each constituent based on A_0 and D_e values found in Tables 2 and 3, respectively.

TABLE 4. Mass/Activity Released Per Puck Per Year

Constituent	Quantity Released
¹⁴ C	5.3 x 10 ⁻⁸ Ci
⁹⁰ Sr	1.5 x 10 ⁻⁶ Ci
⁹⁹ Tc	5.3 x 10 ⁻⁷ Ci
¹³⁷ Cs	1.5 x 10 ⁻⁸ Ci
²³⁸ Pu	1.8 x 10 ⁻⁸ Ci
²⁴¹ Am	2.9 x 10 ⁻⁸ Ci
F	0.217 g
NH ₄	1.52 g
NO ₃	0.353 g

There are 24 pucks in lysimeter B-1, so the total release per year would be values from Table 4 multiplied by 24.

Estimate of Worst-Case Concentrations

The mass/activity released per year would be dissolved in the water that percolates through the lysimeter. The low estimate of drainage is 100 L/yr. The highest potential concentrations are shown in Table 5 (concentrations based on values from Table 3 multiplied by 24 and divided by 100 L).

One would find these concentrations in the drainage if there were no adsorption in the sediments below the waste forms but above the leaking drain. A more realistic approach would consider that the constituents ^{90}Sr , ^{137}Cs , ^{238}Pu , ^{241}Am and NH_4 would exhibit significant adsorption tendencies. I will address this issue in the last section.

Estimate of Total Activity or Mass That May Have Been Released

The concentrations shown in Table 5 are one way of presenting the data. One should recall that the 24 pucks constitute only 12 liters [$\sim 20,000$ g (~ 44 pounds)] of solid waste with small amounts of contaminants. If I assume the lysimeter has been draining for 3 years, the total activity/mass released are the values in Table 4 multiplied by 72 (3 years x 24 pucks). The results are shown in Table 6.

TABLE 5. Worst-Case Concentrations of Contaminants in Drainage

<u>Constituent</u>	<u>Concentration</u>	<u>Convenient Regulatory Units</u>
^{14}C	1.3×10^{-8} Ci/L	1.3×10^{-5} $\mu\text{Ci/mL}$
^{90}Sr	3.6×10^{-7} Ci/L	3.6×10^{-4} $\mu\text{Ci/mL}$
^{99}Tc	1.3×10^{-7} Ci/L	1.3×10^{-4} $\mu\text{Ci/mL}$
^{137}Cs	3.6×10^{-9} Ci/L	3.6×10^{-6} $\mu\text{Ci/mL}$
^{238}Pu	4.3×10^{-9} Ci/L	4.3×10^{-6} $\mu\text{Ci/mL}$
^{241}Am	7.0×10^{-9} Ci/L	7.0×10^{-6} $\mu\text{Ci/mL}$
F	5.2×10^{-2} g/L	52 mg/L
NH_4	3.6×10^{-1} g/L	360 mg/L
NO_3	8.5×10^{-2} g/L	85 mg/L

TABLE 6. Estimate of Maximum Mass/Activity Possibly Released to Date

Constituent	Mass-Activity	Estimate
^{14}C	$4.2 \times 10^{-6} \text{ Ci}$	$4.2 \mu\text{Ci}$
^{90}Sr	$1.1 \times 10^{-4} \text{ Ci}$	$110 \mu\text{Ci}$
^{99}Tc	$4.2 \times 10^{-5} \text{ Ci}$	$42 \mu\text{Ci}$
^{137}Cs	$1.1 \times 10^{-6} \text{ Ci}$	$1.1 \mu\text{Ci}$
^{238}Pu	$1.3 \times 10^{-6} \text{ Ci}$	$1.3 \mu\text{Ci}$
^{241}Am	$2.1 \times 10^{-6} \text{ Ci}$	$2.1 \mu\text{Ci}$
F	15.6 g	35 g as NaF
NH_4	109.4 g	103 g as NH_3
NO_3	25.4 g	35 g as NaNO_3

Accounting for Adsorption

The 3 meters of sediment below the grouts probably adsorb many of the contaminants, which would significantly delay the arrival time of the contaminants to the leaky drain. Using the distribution coefficient concept that treats adsorption as an ideal ion exchange process, the breakthrough curve concentration (the ratio of effluent to influent concentration in the feed source) versus time for contaminants to reach the drain would look like Figure 2 for a constant yearly release of material from the grout. Distribution coefficient theory suggests that a concentration equal to 50% of the source concentration (Table 5 values) will reach the drain at a time equal to $(1 + \rho_b/\theta K_d)$ times the travel time for water. We are assuming that the recharge water reaches the drain 1 year after it enters the lysimeter. The typical bulk density (ρ_b) for Hanford sediments is 1.5 g/cm^3 and the typical porosity (θ) is 0.40. Distribution coefficients for ^{90}Sr , ^{137}Cs , ^{238}Pu , ^{241}Am and NH_4 in Hanford sediments contacted with grout leachates are estimated in Table 7 from data reviewed in Serne and Wood (1990) and from specific values measured on CRW grout leachate.

The problem lies in quantifying the shape of the breakthrough curve shown in Figure 2 (see curves 1, 2, and 3). Theory demands that the 50% breakthrough point be invariant, but the shape at low percentage breakthrough (early data such as that occurring now) and high percentage

TABLE 7. K_d Values for Adsorption

<u>Constituents</u>	<u>K_d (mL/g)</u>
^{14}C , ^{99}Tc , F, NO_3	0
^{90}Sr	20
^{137}Cs	50
^{241}Am , ^{238}Pu	100
NH_4	5

breakthrough is highly dependent upon hydrologic and chemical processes that control dispersion. I have no knowledge of which dispersion values to use, so to be conservative I will linearize the breakthrough curve to allow a worst-case estimate of concentrations in the early part of the release curve [see curve #4 (dashed line) in Figure 2]. Clearly, curve #4 shows higher breakthrough at early times compared to more "normal" curves; thus, the estimates of concentrations in drainage with sorption considered should be biased to higher values to assure we don't underestimate concentrations released.

Using the retardation equation, bulk density, porosity and K_d values from Table 7, I calculate that the 50% breakthrough time for adsorbing constituents would be as shown in Table 8. Furthermore, the linearized breakthrough curve allows me to determine how much breakthrough occurs each year. Assuming that we are experiencing the third year of breakthrough, I can estimate the current concentrations of contaminants in the drainage, the concentrations from the first 2 years, and the concentrations for any future year if drainage is allowed to continue.

Table 9 estimates the current concentrations in drainage when adsorption is considered.

SUMMARY

It appears that lysimeter B-1 is leaking waters into the Hanford sediment from the welds at the bottom of the lysimeter. Approximately 300 liters of drainage may have leaked. If we ignore adsorption, the maximum concentrations of key constituents in the drainage are those shown in Table 5. If we

TABLE 8. Time to Reach 50% Breakthrough

<u>Constituent</u>	<u>Time (yr)</u>	<u>Linearized Breakthrough (%/yr)</u>
^{90}Sr	76	0.658
^{137}Cs	190	0.263
^{241}Am , ^{238}Pu	380	0.132
NH_4	20	2.5
^{14}C , ^{99}Tc , F, NO_3	1	100

TABLE 9. Estimate of Concentrations When Considering Adsorption

<u>Constituent</u>	<u>Concentration</u>
^{14}C	$1.3 \times 10^{-5} \mu\text{Ci/mL}$
^{90}Sr	$7.1 \times 10^{-6} \mu\text{Ci/mL}$ (increases by $2.4 \times 10^{-6} \mu\text{Ci/mL/yr}$)
^{99}Tc	$1.3 \times 10^{-4} \mu\text{Ci/mL}$
^{137}Cs	$2.8 \times 10^{-8} \mu\text{Ci/mL}$ (increases by $9.5 \times 10^{-9} \mu\text{Ci/mL/yr}$)
^{238}Pu	$1.7 \times 10^{-8} \mu\text{Ci/mL}$ (increases by $5.7 \times 10^{-9} \mu\text{Ci/mL/yr}$)
^{241}Am	$2.8 \times 10^{-8} \mu\text{Ci/mL}$ (increases by $9.2 \times 10^{-9} \mu\text{Ci/mL/yr}$)
F	52 mg/L
NH_4	27 mg/L
NO_3	85 mg/L

consider that adsorption occurs in the sediments between the buried wastes and drains, then the estimates of drainage concentrations listed in Table 9 are appropriate.

We placed a cover over the lysimeter on November 13, 1990 so that future drainage should be low during the next year and negligible in future years.

FIGURE 2. Breakthrough Curves for a Constant Source Release into Sediment Column

FIGURE 1. Lysimeter Construction Details

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Appendix B

Environmental Evaluation

ENVIRONMENTAL EVALUATION
HANFORD GROUT LYSIMETER FACILITY
PROJECT#: B-475

PACIFIC NORTHWEST LABORATORY
OPERATED BY
BATTELLE MEMORIAL INSTITUTE
FOR
U.S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
RICHLAND, WASHINGTON

Prepared by:

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Date:

6/6/84

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DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
ENVIRONMENTAL EVALUATION

PROJECT NUMBER B-475
HANFORD GROUT LYSIMETER FACILITY

JUNE, 1984

BATTELLE
PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

ENVIRONMENTAL EVALUATION HANFORD GROUT LYSIMETER FACILITY (HGLF)

A. SUMMARY

The Hanford Grout Lysimeter Facility (HGLF) will be constructed to test the leaching and migration of radioactive and nonradioactive tracers embedded in a solidification agent (grout) under actual burial conditions in Hanford soil. Three different water treatment rates will be used: natural precipitation, 4 times and 8 times natural precipitation.

Six lysimeters will be assembled. Each unit will measure 6 feet in diameter, 25 feet deep. Their construction and instrumentation will be performed during June-July, 1984 by J. A. Jones Construction Company and/or their subcontractor. The routine monitoring will be performed by Battelle staff over a 5.5 year period beginning in November 1984. The total estimated project cost will be approximately \$200,000.

The only anticipated environmental impact from this project will be a temporary nuisance-type local dust problem during the construction phase. This will not be a detriment to the environment. The results of dose calculations indicate that dose rates from the grouted waste cans will be quite low when the cans are covered by a meter or more of earth. Dose rates at or near the surface of the individual cans are not high enough to preclude their handling. The facility area will be fenced, posted as a radiation zone and operated under a radiation work procedure.

B. DESCRIPTION OF THE PROPOSED ACTION

The proposed action is to have the J. A. Jones Construction Company and/or their subcontractor excavate large diameter boreholes on the Hanford Reservation for the purpose of constructing lysimeters for the Hanford Grout Lysimeter Facility (HGLF). The study at this facility involves the continuous monitoring of the leaching and migration of both radioactive and nonradioactive tracers after their solidification in a grout and their placement in the lysimeters. The location of this excavation/construction is in the NW 1/4 of Section 28, Township 11N, Range 28E. Figure 1 shows the location of the HGLF area.

The proposed facility will consist of six lysimeters, each being a large diameter borehole lined in a vertical fashion with a watertight, sealed steel liner (caisson) of welded steel pipe with a welded steel bottom or other suitable material. The lysimeters will be 6 feet in diameter, 25 feet deep and arranged in three sets of two. The layout of the project is shown in Figure 2. A detailed drawing of one of the lysimeters is shown in Figure 3. Small drum-like blocks composed of a solidification agent (grout) and quantities of either radioactive or nonradioactive tracers will be placed in each lysimeter.

The waste forms used in this study will consist of the sulfate-type Hanford facility waste. The preliminary solidification agent (grout) to be used is a mixture of: cement (40%), fly ash (40%) and clay (20%). The radioactive composition and quantity of the hot-waste form blocks are listed in Table 1 and Table 2. The cold-waste form blocks will contain similar quantities of nonradioactive tracers. Three lysimeters will contain three hot-waste form

blocks each while the remaining lysimeters will contain three cold-waste form blocks each. Each block is about the size of a 2 gallon paint can.

Instrumentation will be installed inside each lysimeter as the caissons are filled with specially selected and compacted soils and the waste-forms. Instrumentation includes thermocouples, heat dissipating fiberglass blocks, suction candles, access tubes, scintillation and pumping devices. Additionally, an irrigation system will be used for four of the six lysimeters. This system, which will use ground water from a nearby well, is already set up from a current lysimeter facility in the immediate vicinity.

J. A. Jones Construction Company and/or their subcontractor will drill the six boreholes to a sufficient size to accommodate the 6 foot diameter, 25 foot deep caissons of welded steel pipe with a welded steel bottom or other suitable material. They will install the caissons. If temporary casings are used during the drilling process, these will be removed when the caissons are installed.

The caissons will be installed such that no part of them will protrude above ground level. J. A. Jones Construction Company and/or their subcontractor will cover the caissons with 1/2-inch plywood caps during the construction phase for safety reasons, and grade the immediate areas to blend with the surrounding terrain grade so as to provide reasonable access to the caissons and so that no severe puddling or subsidence will occur around the covered caissons. In addition, they will collect duplicate 1 quart soil samples, during the drilling process, at 5 foot depth intervals and/or where sediment changes occur.

After the six boreholes are drilled and the caissons are emplaced, J. A. Jones Construction Company and/or their subcontractor will complete the construction of the lysimeters. They will backfill the caissons with specially selected Hanford soil, install all instrumentation and waste-forms and connect the irrigation systems to the appropriate lysimeters.

Operations will consist of monitoring, by Battelle staff, the leaching and migration of radioactive and nonradioactive tracers in the lysimeters. Monitoring will be performed on a routine basis. As shown in Figure 2, the lysimeters will be arranged in three sets of two. Each set will contain one hot waste-form and one cold waste-form setup. Each set will also have a different water treatment (irrigation) rate. Set 1 will have no irrigation, thus a natural precipitation rate; set 2 will have irrigation at four times the natural precipitation rate; set 3 will be at eight times the natural precipitation rate.

Construction is planned for June-July, 1984 and operation will span the period of November, 1984 through at least November, 1989.

The cost of the proposed action will be a total of approximately \$200,000 over a 5.5 year period.

C. PURPOSE OF PROPOSED ACTION

The purpose of this HGLF is to test the leaching and migration rates of radioactive and nonradioactive tracers embedded in a solidification agent (grout) under actual burial conditions in Hanford soil. Radioactive and nonradioactive waste-forms will be encapsulated in grouts using identical

formulations, mixing equipment and procedures. After curing, both radioactive and nonradioactive grout waste-forms will be tested under identical conditions. The two data sets, one for radioactive and one for nonradioactive waste-forms, will be compared and any differences explained. This study will provide information for future burial operations.

D. ANTICIPATED ENVIRONMENTAL IMPACTS

The attached checklist, Exhibit 1, has been examined for any anticipated impacts that potentially could result from the proposed action. The items marked "yes" on the checklist are further described below:

No. 1 (a):

The only potential impact expected from this project will be a temporary dust problem during the construction stage and from lysimeter removal, if removal is necessary. This will be more of a nuisance-type problem rather than a detriment to the environment.

Other potential impacts will be mitigated through optimum use of design engineering, as exemplified below. No other environmental impacts are expected to result from this study. Exhibit 2 details the calculated dose rates from the radioactive waste-forms at the HGLF. The results of these calculations show that the dose rates from the grouted waste cans will be quite low when the cans are covered by a meter or more of earth. Dose rates at or near the surface of the individual cans are not high enough to preclude their handling.

Mitigating Measures

The following mitigating measures will be performed during construction, operation or site restoration of this project:

- o Vegetation will be kept from growing on the facility area to prevent any radionuclide uptake.
- o No radionuclides are expected to migrate from the buried waste to surface soils; however, the site will be closely monitored to detect any migration.
- o The facility area will be designated a radiation zone and operated under a radiation work procedure.
- o All contaminated soil/backfill will be removed and disposed of as radioactive waste according to proper procedures.
- o Contaminated lysimeters/caissons will either be decontaminated or removed and buried in the 200 Area burial ground according to proper procedures.
- o Once the study at the HGLF is completed, the original excavated soil will be backfilled into the caissons or into the boreholes if the caissons are dismantled.

E. CONCLUSIONS

It is concluded that the only environmental impact resulting from the

proposed HGLF is the generation of slight dust during facility construction. This will be more of a nuisance-type problem rather than a detriment to the environment. Calculations show that the dose rates from the grouted waste cans will be quite low when the cans are covered by a meter or more of earth. Dose rates at or near the surface of the individual cans are not sufficiently high enough to preclude their handling.

It is concluded that this EE presents an adequate description of the proposed action and the resulting environmental impacts. It is also concluded that no further environmental documentation is required.

TABLE 1. Waste Form Composition

	<u>Ci/l</u>
Co - 60	33.0
Co - 58	2.50
Fe - 59	5.00
Cr - 51	3.90
Mn - 54	2.80
Ru - 103	0.60
Pu	0.14

Note: Maximum composition will not exceed 10 times these concentrations.

TABLE 2. Optional Waste Form Composition

	<u>Ci/l</u>
Co - 60	33.0
Co - 58	2.50
Fe - 59	5.00
Cr - 51	3.90
Mn - 54	2.80
Ru - 103	0.60
Pu	0.14
Cs - 137	33.0
Sr - 90	33.0

Note: Maximum composition will not exceed 10 times these concentrations.

Figure 1. Location Map of Hanford Grout Lysimeter Facility (HGLF)

Figure 2. Hanford Grout Lysimeter Facility (HGLF) Layout and Cut-away Views

Scale: 1" = 1.5 meters

Figure 3. Enlarged Cut-away View of "Composite" Lysimeter

Exhibit 1

ENVIRONMENTAL EVALUATION CHECKLISTENVIRONMENTAL IMPACTS

(Explanations of all "yes" answers are required)

CONSTRUCTION		OPERATION	
Yes	No	Yes	No

(1) Air. Will the Project:(a) Violate State/County Emissions Standards?
(Particulates, Opacity, Dust, etc.)Slight
Dust
XX(b) Violate Ambient Air Quality Standards?
(CO, Hydrocarbons, Particulates, etc.)XX(c) Release Hazardous Air Pollutants?
(Asbestos, Beryllium, Mercury, etc.)XX

(d) Release Airborne Radioactivity?

XX

(e) Cause any other atmospheric disturbance?

XX

(f) Require PSD or other permits?

XX(2) Water. Will the Project?(a) Violate State Water Quality Standards?
(COD, BOD, TOC, DO, TDS, pH, temperature, etc.)XX(b) Require NPDES⁽¹⁾ or Corps of Engineers Permits?XX(c) Require shoreline modifications (Hydraulic
Modification Permit⁽²⁾)?XX(d) Increase volume of sewage or process waste
for disposal?XX

(e) Effect ground water?

XX

(f) Effect any source of drinking water?

XX

(g) Discharge radioactive waste water?

XX

(h) Discharge hazardous water pollutants?

XX(i) Require an Oil or Chemical Spill Control
and Prevention Plan?XX

(1) NPDES--National Pollution Discharge Elimination System.
 (2) Obtained by RL as a matter of comity.

CONSTRUCTION		OPERATION	
Yes	No	Yes	No

(3) Land Use. Will the Project:

(a) Conflict with existing zoning or land use plans?	___	<u>X</u>	___	<u>X</u>
(b) Be located on wetlands or the 100 year or 500 year floodplain?	___	<u>X</u>	___	<u>X</u>
(c) Contribute to volumes of solid waste for disposal				
i. Nonradioactive?	___	<u>X</u>	___	<u>X</u>
ii. Hazardous?	___	<u>X</u>	___	<u>X</u>
iii. Radioactive?	___	<u>X</u>	___	<u>X</u>
(d) Require licensing as a hazardous waste storage, treatment or disposal site?	___	<u>X</u>	___	<u>X</u>
(e) Cause erosion?	___	<u>X</u>	___	<u>X</u>
(f) Be located on ALE ⁽³⁾ ?	___	<u>X</u>	___	<u>X</u>
(g) Conflict with NERP ⁽⁴⁾ activities?	___	<u>X</u>	___	<u>X</u>
(h) Require installation of wells?	___	<u>X</u>	___	<u>X</u>

(4) General. Will the Project:

(a) Increase noise levels?	___	<u>X</u>	___	<u>X</u>
(b) Impact archaeological or historic sites?	___	<u>X</u>	___	<u>X</u>
(c) Require use of carcinogens, pesticides or toxic substances?	___	<u>X</u>	___	<u>X</u>
(d) Impact wildlife or habitat?	___	<u>X</u>	___	<u>X</u>
(e) Effect endangered species or critical habitat?	___	<u>X</u>	___	<u>X</u>
(f) Require long-term commitment of nonrenewable resources?	___	<u>X</u>	___	<u>X</u>
(g) Require new utilities or modifications to existing utilities?	___	<u>X</u>	___	<u>X</u>
(h) Increase offsite radiation dose?	___	<u>X</u>	___	<u>X</u>
(i) Impair recreation?	___	<u>X</u>	___	<u>X</u>
(j) Require modifications to the site-wide Environmental Surveillance Program?	___	<u>X</u>	___	

(3) ALE--Arid Lands Ecology Reserve; contact Dr. L. E. Rogers, PNL.

(4) NERP--National Environmental Research Park, contact Dr. W. H. Rickard, PNL.

Project Number _____

Internal Distribution

Date: May 17, 1984
To: George Last
From: Kathryn A. Hawley *Kathryn*
Subject: Calculated Dose Rates for Hanford
Grout Lysimeter Study

G. A. Bruno
W. D. McCormack
B. A. Napier
R. G. Schreckhise
File/LB

Radiation dose rates have been calculated for the waste-filled canisters proposed for this special study. Calculations were performed for two compositions of waste, two concentrations, and seven shielding configurations. The attached report describes the calculations performed, the models and other assumptions used, and presents the results of the calculations.

KAH:ncv

Attachment

ATTACHMENT 1

HANFORD GROUT LYSIMETER STUDY

CALCULATED DOSE RATES

For the calculations, it was assumed that the solidified waste would be packaged in paint-can sized containers; each can holding approximately two gallons of material. In all calculations the can was treated as a right cylinder with a diameter of 20.06 cm (7.9 inches) and a length of 24.1 cm (9.5 inches). The can was presumed to be constructed of steel with a 0.16-cm (0.063 inch) wall thickness. The solidification agents used to contain the waste were estimated to have a density of 2.4 gm/cm^3 ; the soil used to cover the cans was estimated to have a density of 1.8 gm/cm^3 .

For all dose rate calculations, the computer code ISOSHL (Engle 1966) was used. This code uses point-kernel methodology to calculate dose rates from selected exposure geometries considering different shielding materials. ISOSHL considers only photons as contributing to the dose rate, but does include bremsstrahlung gammas generated by betas interacting with the waste and shielding material. The exposure geometry used as a basis for calculating dose rates from the grouted waste is shown in Figure 1.

Figure 1. Exposure Geometry for the Grouted Waste Cans

The radionuclide concentration and total content of the cans for each waste type are shown in Table 1. Dose rates for cans with radionuclide inventories up to ten times the amount in Table 1 were also figured.

Table 1. Radionuclide Contents of Grouted Waste Cans

<u>Nuclide</u>	<u>Waste Form 1 Composition (μCi/L)</u>	<u>Can Contents (Ci)</u>	<u>Optional Waste Form 2 Composi- tion (μCi/L)</u>	<u>Can Contents (Ci)</u>
^{60}Co	33.0	2.5E-04	33.0	2.5E-04
^{58}Co	2.50	1.9E-05	2.50	1.9E-05
^{59}Fe	5.00	3.8E-05	5.00	3.8E-05
^{51}Cr	3.90	2.9E-05	3.90	2.9E-05
^{54}Mn	2.80	2.1E-05	2.80	2.1E-05
^{103}Ru	0.60	4.5E-06	0.60	4.5E-06
^{239}Pu (a)	0.14	1.1E-06	0.14	1.1E-06
^{137}Cs (b)	-	-	33.0	2.5E-04
^{90}Sr	-	-	33.0	2.5E-04

(a) Reported as plutonium in data base.

** (b) Reported as cesium-139 in data base.

Dose Rates from Unshielded Waste Cans

For each waste type, calculations were performed to determine dose rates from the unshielded cans. Calculations were performed for two configurations: the surface of the can and 0.15 meters from the surface. Table 2 lists the dose rates for these configurations.

Table 2. Dose Rates from Unshielded Waste Cans (mR/hr)

<u>Point of Exposure</u>	<u>Waste Form 1</u>	<u>10 x Concentration Waste Form 1</u>	<u>Waste Form 2</u>	<u>10 x Concentration Waste Form 2</u>
Surface	24	240	29	290
15 cm from Surface	3.3	33	3.9	39

** Note: Data base (Table 2 of text) had a typographical error which has been corrected. The correct nuclide designation is ^{137}Cs .

Dose Rates from Shielded Waste Cans

Each lysimeter will contain three waste cans arranged in the geometry shown in Figure 2. Dose rates were calculated at one meter above the ground surface for a single waste can buried under 0.5, 1, 2, 3, 4, or 5 meters of soil. The total dose rate at one meter above the lysimeter is approximately three times the value calculated for the single waste can. The dose rates are listed in Tables 3 and 4.

Lysimeter (6' diameter)

Top View

Side View

Figure 2. Waste Can Geometry

Table 3. Dose Rates One Meter Above Ground From Grouted Waste Form 1 (mR/hr)

<u>Shielding</u>	<u>Waste Form 1 (Single Can)</u>	<u>10 x Waste Form 1 (Single Can)</u>	<u>Waste Form 1 (Three Cans)</u>	<u>10 x Waste Form 1 (Three Cans)</u>
0.5 m soil	1.5×10^{-3}	1.5×10^{-2}	4.5×10^{-3}	4.5×10^{-2}
1 m soil	7.5×10^{-6}	7.5×10^{-5}	2.3×10^{-5}	2.3×10^{-4}
2 m soil	1.9×10^{-10}	1.9×10^{-9}	5.7×10^{-10}	5.7×10^{-9}
3 m soil	5.4×10^{-15}	5.4×10^{-14}	1.6×10^{-14}	1.6×10^{-13}
4 m soil	1.8×10^{-19}	1.8×10^{-18}	5.4×10^{-19}	5.4×10^{-18}
5 m soil	7.3×10^{-24}	7.3×10^{-23}	2.2×10^{-23}	2.2×10^{-22}

Table 4. Dose Rates One Meter Above Ground From Grouted Waste Form 2 (mR/hr)

<u>Shielding</u>	Waste Form 2 (Single Can)	10 x Waste Form 2 (Single Can)	Waste Form 2 (Three Cans)	10 x Waste Form 2 (Three Cans)
0.5 m soil	1.6×10^{-3}	1.6×10^{-2}	4.8×10^{-3}	4.8×10^{-2}
1 m soil	7.6×10^{-6}	7.6×10^{-5}	2.3×10^{-5}	2.3×10^{-4}
2 m soil	1.9×10^{-10}	1.9×10^{-9}	5.7×10^{-10}	5.7×10^{-9}
3 m soil	5.4×10^{-15}	5.4×10^{-14}	1.6×10^{-14}	1.6×10^{-13}
4 m soil	1.8×10^{-19}	1.8×10^{-18}	5.4×10^{-19}	5.4×10^{-18}
5 m soil	7.3×10^{-24}	7.3×10^{-23}	2.2×10^{-23}	2.2×10^{-22}

Conclusion

The preceding calculations indicated that dose rates from the grouted waste cans will be quite low when the cans are covered by a meter or more of earth. The dose rates at or near the surface of the individual cans are substantially higher. However, they are not sufficiently high to preclude handling.

Dose rates for other concentrations of the grouted waste can be computed from the data provided in this report if the relative concentrations of the nuclides remain constant. If the concentrations were to be scaled up or down by some multiplicative factor (e.g., the inventory was doubled), the dose rates could be multiplied by the same factor. This procedure would be valid only if the geometry and shielding remained unchanged. Any alteration in these factors would require new calculations to be made.

References

Engle, R. L., J. Greenborg, and M. M. Hendrickson. 1966. ISOSHLD - A Computer Code for General Purpose Isotope Shielding Analysis. BNWL-236, Pacific Northwest Laboratory, Richland, Washington.

ATTACHMENT 2

DOCUMENTATION OF HANFORD GROUT LYSIMETER STUDY DOSE CALCULATION

Facility Name: Hanford Grout Lysimeter Study

Releases: None

Meteorological Conditions: NA

Dispersion Model: NA

X/Q: NA

Release Height: NA

Population Distribution: NA

Computer Code: ISOSHL D

Files Addressed: File 9 (ISOSHL D Photon Production Library,
ISOSHL D Beta End Point Library, and Photon
Attenuation Library for 20 shield materials)

Appendix C

Physical Analyses of 241-AP Tank Farm Soil Samples

Internal Distribution
GW Gee
LL Wendell
Project File
File/LB

Date April 23, 1984
To A. E. Reisenauer
From P. R. Heller *FRH*
Subject Physical Analysis for Grout Study

2. Last ✓

The following is a brief report of the characterization work done on 6 samples in March 1984

Soil Materials and Sampling

Table 1 lists the materials characterized in this study:

TABLE 1. Materials Characterized

<u>Log Number</u>	<u>Elevation</u>	
	<u>Feet</u>	<u>Meter</u>
241-AP-1	630	192
241-AP-2	<i>644</i> 638	194
241-AP-3	664	196
241-AP-4	655	200
241-AP-5	658	201
241-AP-6	665	203

These samples were taken at the various levels listed in Table 1 by digging in the east wall of the excavation for 241 AP Tank farms. These samples were all analyzed for hydraulic conductivity, particle size and water retention.

Methods of Analysis

Particle Size

Particle size was determined on two separate bases. The particles larger than 2 mm were determined by dry sieve analysis using sieve sizes of 3 in., 2 in., 1 in., 3/4 in., 1/2 in., No. 4 and No. 10 mesh (Tyler numbers). For all samples, sand, silt and clay distribution was determined based on only the less than 2-mm-sized particles from each large sample. The samples were analyzed for a complete distribution curve, except for dispersion of the sample, by ASTM procedure D 422. Sample dispersion was done using an ultrasonic homogenizer for more complete dispersion of the particles. Table 2 presents the results of the particle size analysis.

TABLE 2. Particle Size Analysis

Sample	Hydrometer Analysis (based on <2 mm size)		
	% Sand	% Silt	% Clay
241-AP-1	98	2	0
241-AP-2	91	6	3
241-AP-3	97	2	1
241-AP-4	98	2	0
241-AP-5	27	64	9
241-AP-6	66	27	7

Dry Sieve Analysis

Percentage Less Than

Sample	3 in.	2 in.	1 in.	3/4 in.	1/2 in.	4.75 mm	2.0 mm
241-AP-1	100	100	98.98	97.55	96.18	90.89	62.37
241-AP-2	100	100	100	100	100	100	99.99
241-AP-3	100	100	100	100	100	99.89	99.32
241-AP-4	100	100	94.06	90.96	87.31	80.26	67.92
241-AP-5	100	100	100	100	99.92	99.92	99.92
241-AP-6	100	100	100	100	97.49	99.23	98.62

Hydraulic Conductivity

Hydraulic conductivity of each of the samples was determined using a falling water head method of analysis (Klute 1965). In this method, the sample is placed in a container and enclosed with lids having an inflow valve at one end and an outflow valve at the other end. The inflow valve is connected to a standpipe of a known cross-sectional area and height. The sample is saturated before any test runs are done. An initial head in the standpipe is recorded and water is allowed to flow from the standpipe through the sample for a given length of time. The ending head level in the standpipe is recorded. The hydraulic conductivity is determined using the following equation

$$K = (a/L/At) \ln(H_1/H_2)$$

where a = cross-sectional area of the standpipe

L = length of the sample

A = cross-sectional area of the sample

t = time for the hydraulic head difference to decrease from H₁ to H₂.

The hydraulic conductivity values were determined on an average of five falling head runs over a period of several minutes or several hours, depending on the flow rate, and at room temperature (22 ± 2 C). Table 3 lists the hydraulic conductivities.

TABLE 3. Hydraulic Conductivity

Sample	Hydraulic Conductivity cm/sec
241-AP-1	2.55 E-03 ×
241-AP-2	5.97 E-04
241-AP-3	8.10 E-04
241-AP-4	2.25 E-03
241-AP-5	3.00 E-05
241-AP-6	1.37 E-05

Water Retention

Water retention characteristics were measured using three different techniques depending on the applied pressure. For pressures in the very wet range, 0 cm to 100 cm, hanging water columns were used. For the 100 cm to 500 cm pressure range Tempe cells (Soil Moisture Equipment Corporation, Sant Barbara, California) were used and for the drier range, 100 cm to 15,300 cm pressure, pressure plate extractors (Soil Moisture Equipment Corporation, Sant Barbara, California) were used.

For the hanging water columns the sample was packed to a predetermined density in a buchner funnel which was connected to an outflow tube. A graduated cylinder was used for measuring the outflow. The samples were allowed to remain saturated 48 hours before the excess water was drained at 0 cm pressure. The pressure head was increased slowly until it reached 100 cm, see Table 4. After reaching equilibrium at 100 cm pressure, the samples were weighed and oven dried to determine moisture content.

Tempe cells were used to determine the water retention characteristics at 100 cm and 500 cm pressure head. The samples were packed into cells 3 cm x 5.4 cm (height x diameter) and placed over a porous ceramic plate. Each cell was individually sealed with end cups. Pressure was applied across the top of the cell, first at 100 cm pressure, then 500 cm pressure. At the end of the run the samples were weighed and oven dried to determine moisture content.

Water retention characteristics were measured at 100 cm, 1000 cm, and 15,300 cm pressure using a pressure plate extractor. Equilibrium water contents were

obtained by packing the samples in containing rings on a porous ceramic plate where they were saturated and pressure drained in the extractor. Water contents were determined in the same manner as the other methods.

Each sample in each of the three methods was packed to the same density to allow comparison of the volumetric water content. The 100 cm values for each method was averaged to determine that point (100 cm) on the drainage curve.

PRH:pd

TABLE 4. Water Retention Characteristics as Measured by Various Methods

Sample	Pressure Plate (columetric H ₂ O Outlet)			Tempe Cells	
	100 cm	1,000 cm	15,300 cm	100 cm	500 cm
241-AP-1	0.03	0.03	0.02	0.05	0.04
241-AP-2	0.12	0.11	0.07	0.14	0.11
241-AP-3	0.06	0.06	0.05	0.07	0.07
241-AP-4	0.05	0.04	0.04	0.07	0.03
241-AP-5	0.31	0.16	0.07	0.28	0.23
241-AP-6	0.24	0.12	0.08	0.34	0.21

Sample	Hanging H ₂ O Columns										
	Sat	2 cm	4 cm	5 cm	6 cm	8 cm	10 cm	15 cm	20 cm	50 cm	100 cm
241-AP-1	0.417	0.414	0.405		0.373	0.326	0.268		0.122	0.058	0.046
241-AP-2	0.521	0.520	0.517		0.516	0.514	0.505		0.477	0.231	0.157
241-AP-3	0.436	0.435	0.432		0.428	0.425	0.418		0.292	0.099	
241-AP-4	0.454	0.453	0.449		0.445	0.428	0.405		0.206	0.127	0.079
241-AP-5	0.428			0.425			0.422	0.419	0.416	0.403	0.397
241-AP-6	0.417			0.414			0.410	0.409	0.406	0.388	0.375

↑
PORTAL

241-AP-1

241-AP-2

3.2% moisture by weight (assuming density of 1.7 g/cc)

Appendix D

Hydrostatic Testing of Lysimeter Caissons

Hydrostatic Test Data

Date	Elapsed Time (days)	Depth to Water (ft)				Depth to Water (m)			
		A1	A2	B1	B2	A1	A2	B1	B2
12/14/84	0	-22.89	-23.32	-23.04	-23.64	-6.98	-7.11	-7.02	-7.21
12/17/84	3	-23.00	-21.20	-23.00	-24.00				
12/18/84	4	-22.98	-23.33	-23.11	-23.70	-7.01	-7.11	-7.04	-7.22
12/19/84	5	-22.97	-23.33	-23.11	-23.73	-7.00	-7.11	-7.04	-7.23
12/26/84	12	-22.98	-23.37	-23.11	-23.73	-7.01	-7.12	-7.04	-7.23
12/27/84	13	-22.99	-23.36	-23.13	-23.73	-7.01	-7.12	-7.05	-7.23
12/28/84	14	-23.00	-23.35	-23.13	-23.74	-7.01	-7.12	-7.05	-7.24
1/2/85	19	-23.02	-23.36	-23.15	-23.74	-7.01	-7.12	-7.05	-7.24
1/11/85	28	-23.04	-23.37	-23.17	-23.78	-7.02	-7.12	-7.06	-7.25
1/18/85	35	-23.05	-23.38	-23.18	-23.79	-7.02	-7.13	-7.07	-7.25
1/25/85	42	-23.05	-23.34	-23.19	-23.80	-7.03		-7.07	-7.25
2/22/85	70	-23.10	-23.21	-23.20	-23.83	-7.04		-7.07	-7.26

REGRESSION RESULTS

Slope (m/d)

-0.00072 -0.00049 -0.00061 -0.00067

Y Intercept (m)

-6.99620 -7.11045 -7.03899 -7.22259

Calculated Rate of Change (cm/month)

-2.23 -1.52 -1.89 -2.08

Meteorologic Data (12/14/84 to 2/22/85)

Date	Air Temp.		Solar Rad ly/d	Wind Spd kph	Cloud Cover tenth	Prec. cm	PET
	Max C	Min C					Penman cm/day
1/26/85	0.56	-2.22	36.00	0.97	10.00	0.00	0.031
1/27/85	-0.56	-3.33	57.00	1.93	10.00	0.00	0.034
1/28/85	0.56	-5.00	104.00	2.74	8.90	0.00	0.065
1/29/85	1.67	-6.67	200.00	4.51	5.40	0.00	0.104
1/30/85	-2.78	-11.67	211.00	3.22	5.50	0.00	0.079
1/31/85	-2.78	-10.00	208.00	5.31	0.70	0.00	0.070
2/1/85	-5.56	-10.00	70.00	5.63	10.00	0.66	0.051
2/2/85	-5.56	-15.56	177.00	3.22	8.50	0.00	0.068
2/3/85	-7.22	-18.33	235.00	2.57	0.20	0.00	0.044
2/4/85	-11.67	-20.00	186.00	2.90	10.00	0.00	0.052
2/5/85	-6.11	-13.33	161.00	2.90	9.60	0.03	0.072
2/6/85	-7.22	-17.22	125.00	2.90	9.90	0.08	0.036
2/7/85	-4.44	-12.78	109.00	5.47	8.50	0.69	0.028
2/8/85	-3.33	-8.33	100.00	4.18	10.00	0.30	0.035
2/9/85	-2.78	-15.00	194.00	4.99	8.10	0.18	0.061
2/10/85	6.11	-10.00	248.00	10.62	9.00	0.00	0.182
2/11/85	9.44	1.67	154.00	11.42	9.70	0.15	0.230
2/12/85	7.78	-2.22	263.00	3.70	1.60	0.00	0.135
2/13/85	3.89	-3.89	259.00	5.79	6.90	0.00	0.158
2/14/85	3.33	-2.78	191.00	3.70	9.50	0.00	0.131
2/15/85	9.44	-3.89	274.00	6.60	3.30	0.00	0.180
2/16/85	8.33	-2.78	268.00	4.02	7.30	0.00	0.198
2/17/85	7.78	-5.56	262.00	3.06	8.10	0.00	0.159
2/18/85	5.56	-4.44	267.00	4.18	6.90	0.00	0.145
2/19/85	1.67	-2.22	87.00	4.18	10.00	0.00	0.062
2/20/85	10.56	-5.00	253.00	6.11	5.30	0.00	0.175
2/21/85	5.00	-1.67	40.00	3.22	9.70	0.00	0.044
2/22/85	15.56	4.44	297.00	10.46	9.00	0.00	0.435
AVERAGE	-0.30	-7.20	113.25	4.44	8.38	0.05	0.075
TOTAL						3.78	5.307

Notes:

Data is from disk2:[d39994]hms1984.dat and hms1985.dat

Wind speed is from 7 ft. (2.1m)

Created with PROMET V. 1.1 for input to UNSAT-H Version 2.0

PET values created by FAOPET V. 1.0

Curtsey of Michael J. Fayer (personal communication)

Meteorologic Data (12/14/84 to 2/22/85)

Date	Air Temp.		Solar Rad ly/d	Wind Spd kph	Cloud Cover tenth	Prec. cm	PET
	Max C	Min C					Penman cm/day
12/14/84	8.33	-5.00	52.00	13.84	9.90	0.00	0.145
12/15/84	2.78	-4.44	95.00	4.51	9.30	0.00	0.092
12/16/84	0.56	-6.11	99.00	4.83	9.60	0.00	0.086
12/17/84	-3.89	-13.33	57.00	10.30	10.00	0.46	0.077
12/18/84	-6.67	-18.89	116.00	6.11	0.00	0.00	0.034
12/19/84	-8.89	-19.44	153.00	3.86	8.00	0.00	0.053
12/20/84	-11.67	-18.33	44.00	2.09	10.00	0.05	0.021
12/21/84	-9.44	-17.78	64.00	1.93	10.00	0.00	0.026
12/22/84	8.89	-12.78	132.00	8.05	8.90	0.00	0.117
12/23/84	11.11	0.56	93.00	8.21	7.50	0.00	0.173
12/24/84	3.89	-3.89	124.00	3.22	8.90	0.00	0.092
12/25/84	1.67	-1.67	52.00	6.92	10.00	0.00	0.088
12/26/84	2.22	-2.22	91.00	4.02	8.60	0.00	0.054
12/27/84	6.67	-3.33	83.00	9.49	7.90	0.00	0.110
12/28/84	5.00	-5.00	136.00	6.44	3.30	0.00	0.072
12/29/84	4.44	-6.67	76.00	12.71	10.00	0.33	0.159
12/30/84	-5.00	-13.89	67.00	5.15	10.00	0.00	0.039
12/31/84	-7.22	-16.11	167.00	2.90	0.60	0.00	0.025
1/1/85	-8.33	-15.00	52.00	3.70	10.00	0.00	0.030
1/2/85	-5.56	-12.78	137.00	4.51	1.80	0.00	0.025
1/3/85	-5.00	-15.00	89.00	2.74	8.90	0.00	0.030
1/4/85	-6.11	-9.44	36.00	2.09	10.00	0.00	0.016
1/5/85	-5.00	-7.78	42.00	2.57	10.00	0.00	0.027
1/6/85	-3.89	-6.11	37.00	3.54	10.00	0.00	0.037
1/7/85	-2.78	-7.78	76.00	2.25	10.00	0.00	0.042
1/8/85	-2.22	-9.44	68.00	4.18	10.00	0.00	0.029
1/9/85	-2.78	-5.56	37.00	3.86	10.00	0.00	0.037
1/10/85	-2.78	-4.44	36.00	3.54	10.00	0.00	0.039
1/11/85	-2.22	-3.89	28.00	3.38	10.00	0.00	0.040
1/12/85	-2.22	-3.89	45.00	1.45	10.00	0.00	0.035
1/13/85	-2.22	-3.89	52.00	2.90	10.00	0.00	0.050
1/14/85	-0.56	-3.89	92.00	3.54	9.90	0.00	0.076
1/15/85	-1.67	-3.89	35.00	3.22	10.00	0.00	0.031
1/16/85	-1.11	-3.33	49.00	3.70	10.00	0.00	0.049
1/17/85	-2.22	-2.78	37.00	2.90	10.00	0.00	0.031
1/18/85	-2.22	-3.33	37.00	2.41	10.00	0.00	0.020
1/19/85	-1.67	-3.33	33.00	1.93	10.00	0.18	0.016
1/20/85	0.00	-1.67	49.00	1.61	10.00	0.66	0.019
1/21/85	-0.56	-1.67	67.00	4.02	10.00	0.00	0.025
1/22/85	0.00	-1.11	52.00	2.41	10.00	0.03	0.025
1/23/85	0.00	-1.67	53.00	1.45	10.00	0.00	0.025
1/24/85	0.00	-1.67	34.00	0.32	10.00	0.00	0.011
1/25/85	0.00	-1.67	31.00	2.09	10.00	0.00	0.022

Appendix E

Procedure to Backfill Lysimeters and Install Instrumentation

HANFORD GROUT LYSIMETERS
PROCEDURE TO INSTALL INSTRUMENTATION

REVISION 1

July 19, 1985

APPROVED: G. V. Last
G. V. Last, Task Manager

July 30, 1985
Date

The following procedures apply to each of four lysimeters illustrated in figure 1. Figure 2 illustrates the cross sectional and plan view details of these lysimeters.

1) BOTTOM - Set one 8.2 meter (26' 10.8") length of 7.4cm (2.9") ID. thin wall aluminum tubing into the deepest part of the lysimeter. The bottom 20.3cm (8") of the tube shall be slotted such that there are four 3.8cm x .32cm (1.5" x 1/8") horizontal cuts per round and one round per 2.5cm (1"). Temporarily brace tube to remain vertical while backfilling*.

2) Evenly lay 1 to 3cm (1/4" to 1") gravel in the lysimeter until a depth of 10cm (4 inches) at the caisson wall is reached. Depth from surface should equal 7.7m (25' 3.6"). Place one layer of an inert geotextile fabric on the surface of the gravels.

3) Lay 10cm (4") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 7.6m (24' 11.2").

4) 7.6 METERS - Place appropriate moisture block and thermocouple pair on surface of backfill, offset away from aluminum tube 15cm (6") from center, see plan view in figure 2. All moisture blocks and thermocouples are attached to a single wiring harness and are labeled according to depth. Hold excess wiring harness up in center of caisson while backfilling*. Handpack around sensors a minimum of 5cm (2").

5) Lay 1 meter (3' 3.4") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Run wiring harness up through center of lysimeter. See figure 2. Final depth from surface: 6.6m (21' 7.9").

6) 6.6 METERS - Place suction candle (PVC) tube recessed into the surface of backfill in center of lysimeter such

that the center of the bottom filter portion is 6.49m (21' 3.5") below the top of the caisson. Saturate the porous filter portions prior to installation. Slip a thin wall 15cm (6") ID tube sleeve over the suction candle tube and center it on the surface of the backfill. Temporarily brace the suction candle (PVC) tube to remain vertical during backfilling*.

7) Handpack silica sand into the tube sleeve around the porous filter to a thickness equal to or slightly greater than 22cm (8.7"). Lay 22cm (8.7") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Slide the sleeve up the suction candle tube, and repack the silica sand. Final depth from surface: 6.4m (21').

8) Hold the tube sleeve above the backfill, and lay 12cm (4.7") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 6.27m (20' 6.9").

9) Center the tube sleeve around the suction candle tube, and handpack bentonite into the tube sleeve to a thickness equal to or slightly greater than 15cm (5.9"). Lay 15cm (5.9") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Slide the sleeve up the suction candle tube, and repack the bentonite. Final depth from surface: 6.1m (20').

10) Hold the tube sleeve above the backfill, and lay 12cm (4.7") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 6.0m (19' 8.2").

11) Center the tube sleeve around the suction candle tube, and handpack silica sand into the tube sleeve around the porous filter to a thickness equal to or slightly greater than 22cm (8.7"). Lay 22cm (8.7") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Slide the sleeve up the suction candle tube, and repack the silica sand. Final depth from surface: 5.78m (18' 11.6").

12) Hold the tube sleeve above the backfill, and lay 11cm (4.3") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 5.67m (18' 7.2").

13) 5.67 METERS - Place the appropriate thermocouple on the surface of the backfill, offset 15 cm (6") from center away from the aluminum tube. Handpack around sensors a minimum of 5cm (2").

14) Center the tube sleeve around the suction candle tube,

and handpack bentonite into the tube sleeve to a thickness equal to or slightly greater than 15cm (6"). Lay 15cm (6") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Slide the sleeve up the suction candle tube, and repack the bentonite. Final depth from surface: 5.52m (18' 1.3").

15) Hold the tube sleeve above the backfill, and lay 11cm (4.3") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 5.41m (17' 9").

16) Center the tube sleeve around the suction candle tube, and handpack silica sand into the tube sleeve around the porous filter to a thickness equal to or slightly greater than 22cm (8.7"). Lay 11cm (4.3") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 5.3m (17' 4.7").

17) 5.3 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

18) Lay 20cm (7.9") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Slide the sleeve up and off the suction candle tube, and repack the silica sand. Final depth from surface: 5.1m (16' 8.8").

19) 5.1 METERS - Place the 3 appropriate moisture block and thermocouple pairs on the surface of the backfill, 120 degrees apart and 50cm (1' 7.7") from the center, as shown in figure 2. Place waste form sleeves recessed 10cm (4") into the backfill in their pre-determined positions. Refer to the Waste Form Installation Procedures. Handpack around sensors and sleeves a minimum of 5cm (2").

20) Lay 30cm (1') of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 4.8m (15' 9").

21) 4.8 METERS - Place waste forms inside sleeves, pull coverings and sleeves and fill in voids with stockpiled soil 1**, leveling to the above final depth. Refer to the Waste Form Installation Procedures.

22) 4.8 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

23) Lay 30cm (1') of stockpiled soil 1** in the lysimeter,

tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 4.5m (14' 9.2").

24) 4.5 METERS - Place the appropriate thermocouple on the surface of the backfill, offset 15cm (6") from center away from the aluminum tube. Handpack around sensors a minimum of 5cm (2").

25) Lay 30cm (1') of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 4.2m (13' 9.4").

26) 4.2 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

27) Lay 20cm (7.9") of stockpiled soil 1** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 4.0m (13' 1.5").

28) 4.0 METERS - Lay 20cm (7.9") of stockpiled soil 2** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 3.8m (12' 5.6").

29) 3.8 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

30) Lay 30cm (1') of stockpiled soil 2** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 3.5m (11' 5.8").

31) 3.5 METERS - Place the appropriate thermocouple on the surface of the backfill, offset 15cm (6") from center away from the aluminum tube. Handpack around sensors a minimum of 5cm (2").

32) Lay 30cm (1') of stockpiled soil 2** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 3.2m (11' 6").

33) 3.2 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

34) Lay 80cm (2' 7.5") of stockpiled soil 2** in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 2.4m (7' 10.5").

35) 2.4 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

36) Lay 70cm (2.3') of stockpiled soil in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Handpack bentonite around the suction candle string aluminum tube and caisson walls to a thickness of at least 4cm (1.5") for the top 20cm (between depths of 1.9 and 1.7m (6' 2.8" to 5' 6.9")). Final depth from surface: 1.7m (5' 6.9").

37) Lay 50cm (1' 7.7") of stockpiled soil in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 1.2m (3' 11.3").

38) 1.2 METERS - Place appropriate moisture block and thermocouple on surface of the backfill, offset 15cm (6") from center away from aluminum tube. Handpack around sensors a minimum of 5cm (2").

39) Lay 60cm (1' 11.6") of stockpiled soil in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 0.6m (1' 11.6").

40) 0.6 METERS - Place the appropriate thermocouple on the surface of the backfill, offset 15cm (6") from center away from the aluminum tube. Handpack around sensors a minimum of 5cm (2").

41) Lay 30cm (1') of stockpiled soil in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Final depth from surface: 0.3m (1 foot).

42) 0.3 METERS - Place the appropriate thermocouple on the surface of the backfill, offset 15cm (6") from center away from the aluminum tube. Handpack around sensors a minimum of 5cm (2").

43) Lay 10cm (4") of stockpiled soil in the lysimeter, tamping during backfilling* to a bulk density of 1.6 to 1.7 g/cc. Handpack bentonite around suction candle string, wiring harness, aluminum tube, and caisson walls to a thickness of at least 4cm (1.5") for the top 20cm (between depths 0.4m and 0.2m (1' 3.8" to 7.9")). Final depth from surface: 20cm (8").

44) Run wiring harness through side of caisson at 10cm (4") depth.

45) Lay 20cm (8") of 1 to 3cm (1/4" to 1") gravel to a finished depth of 0m.

GENERAL NOTES:

- * - Backfilling is to be done in 30cm (1 foot) lifts.
- ** - Soil 1 is a fine silty soil. Soil 2 is a coarse sand.

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Figure 1. Plan view of the Hanford Grout Lysimeter Facility.

Figure 2. Cross section and plan view details of lysimeters.

Appendix F

Procedure to Install Waste Forms

HANFORD GROUT LYSIMETERS
PROCEDURE TO INSTALL WASTE FORMS

REVISION 1

July 22, 1985

APPROVED:

G. V. Last

G. V. Last, Task Manager

July 30, 1985
Date

The following procedures apply to the B1 lysimeter of the Hanford Grout Lysimeter Facility.

PREPARATION

Reference: Hanford Grout Lysimeters - Procedure to Install Instrumentation (steps 19 and 20).

- 1) Place waste form sleeves in their designated places (see figure 1) with their lower ends at a depth of 5.2 m (17' 0.7").

Twenty-four radioactive waste forms containing Cladding Removal Waste (CRW) are to be placed in the B1 lysimeter. Twelve sleeves approx. 12cm (4.7") ID by 45cm (17.7") in length are to be placed in accordance with the arrangement illustrated in figure 1. These sleeves should be made of thin plastic (Plexiglass) tubing.

It should be noted again that these sleeves will have to be recessed into the backfill 10cm (4") at the time they are placed into position, putting their lower end at a depth of 5.2 m (17' 0.7").

- 2) Backfill around the waste form sleeves with stockpiled soil 1 and the required instruments to a finished depth from surface of 4.8 m (15' 9").

WASTE FORM INSTALLATION
(Requires RWP)

Reference: Hanford Grout Lysimeter Procedure to Install Instrumentation (step 21)

- 1) Cover immediate area around waste form sleeves with plastic, leaving sleeves open for free access.

2) Lower, via a plastic bucket and rope, one double plastic "filter bag-out" bag (containing the necessary waste forms and backfill soil) into the Bl lysimeter.

Twelve "bag-out" bags will be needed, each holding 4.0 liters of soil 1, a "craft knife", a 30cm long stick, and two 0.5 liter CRW waste forms. The 4.0 liters of soil 1 shall be contained within two labeled plastic bags. Bag "A" shall contain 1.5 liters of soil and bag "B" shall contain 2.5 liters.

3) Place the "bag-out" bag and its contents immediately adjacent to the sleeve selected for waste form installation. Adjust the contents of the bag so that it is all at one end, away from the sleeve. Open the other end just enough so that it will slip over the top of the sleeve. Slip it over the sleeve and tape it into place, sealing off the outside air. Now, working from outside of the sealed plastic bag, remove the lid and loosen the container (using the "craft knife" if necessary) from around one of the waste forms. Hold the waste form over the sleeve and turn it upside down. Using both thumbs, press down on the bottom of the waste form container, forcing the waste form to slip away from its container. Make sure the waste form falls all the way down inside the sleeve and lays flat on the bottom (if necessary use the stick to adjust the position of the waste form). Now cover the waste form with the soil from bag "A", compacting it by hand. Remove the lid and loosen the container from the remaining waste form and place it into the sleeve in the same way as the first one. Cover it with the soil in bag "B", compacting it by hand.

4) Carefully remove the tape sealing the plastic bag to the sleeve. Still working from outside the "bag-out" bag, pull the sleeve up inside. Place the used tape in the bag and seal it with new tape. Recompact the soil by hand, and remove the contaminated garbage from the lysimeter, via the rope and bucket.

5) Repeat steps 2, 3 and 4, until all the waste forms have been placed in the sleeves and the sleeves removed.

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Figure 1. Waste form configuration for the A1 and B1 lysimeters.

Appendix G

Calibration of Soil Moisture Blocks

Appendix G

Calibration of Soil Moisture Blocks

Calibration of the soil moisture blocks was conducted in three basic stages; 1) calibration of a Group of randomly selected blocks using a pressure plate, 2) calibration of the soil moisture blocks in wiring harnesses for the A-1 and B-1 lysimeters using hanging water columns, and 3) calibration of the B-1 wiring harness using a hanging water column. The calibration data were recorded via laboratory notebook and/or via data logger and stored on magnetic disk. Table G.1 presents a synopsis of the calibration data representing the equilibrium resistance at a given soil suction. A brief discussion of the calibration efforts follows.

Two groups of five moisture blocks each were calibrated in representative aliquots of the two soils using a pressure plate apparatus to extract pore-water from the soils at various pressures. The calibration intervals were: Saturated, 0.1 bar, 0.3 bars, 1.0 bars, and 3.0 bars (Table G.1). Note that some variation was found between the blocks purchased at different times (i.e., those labeled alphabetically verses those label numerically), see Figures G.1 and G.2. Note also that these blocks were not used in the soils in which these calibrations were conducted. These calibration results are provided only to demonstrate the general shape of the expected calibration curves, and the variability found between the moisture blocks.

The pressure plate calibrated moisture blocks were added to wiring harnesses for the A-1 and B-1 lysimeters along with other uncalibrated moisture blocks. All the moisture blocks in each wiring harness were then calibrated at the same time using hanging water columns. Each moisture block was placed in a representative aliquot of the soil types into which they were to be placed within the lysimeters. The only successful hanging water column calibration points were: Saturated and 0.1 bar (Table G.1). Note, however, that two of the moisture blocks (104 and 132) calibrated in the very fine sand were later actually placed in the coarse sand within the lysimeters. Four blocks calibrated in the coarse sand (B, 126, 114, and 129) were later placed in the very fine sand, and four blocks (A, C, 113, and 127) were never used.

The moisture blocks and wiring harness for the B-1 lysimeter were calibrated a second time via hanging water column just prior to installation into the B-1 lysimeter. This time all moisture blocks were calibrated in their respective soils. The hanging water column calibration points were: Saturated, 0.1 bar, and 0.2 bars (Table G.1).

Examination of the calibration data in Table G.1 indicates some discrepancy between the pressure plate calibration measurements and the hanging water column measurements for the same moisture block under similar head conditions. It should be noted that those calibrations conducted in the hanging water columns also included the wiring harness. Thus, these calibration data were considered the most representative. The calibration data (resistance [ohms] vs. soil suction [-bars]) for each soil type was plotted separately and smooth curves fitted to the log/log plot for each block. Calibration

equations were derived by breaking the plots into two segments assuming; a constant resistance for soil suction values less 0.01 bars, and a power curve function for the resistance at soil suctions > 0.01 bars. These linear segments (on a log/log plot) were fit by eye through groupings of data points, and equations derived to represent the fitted segments. Figures G.3 and G.4 provide the best available calibrations for the fiberglass moisture blocks. These calibrations must be used with extreme caution and should be used only to provide an indication of rather large relative changes in soil suction and/or moisture content.

Figure G.1. Initial Soil Moisture Block Calibration: Very Fine Sand, Pressure Plate.

Figure G.2. Initial Soil Moisture Block Calibration: Coarse Sand, Pressure Plate.

Figure G.3. Soil Moisture Block Calibration: Very Fine Sand.

Figure G.4. Soil Moisture Block Calibration: Coarse Sand.

Table G.1. Block Calibration Record, Revision 2 (9/6/94).

		Saturation - 1 cm H2O (0.001 bars)				
	Date/Time	1/17/85	2/26/85 7:55	2/26/85 8:00	2/28/85 8:00	7/3/85 10:13
	Cal. Method	Pressure Plate	Hanging Water Column	Hanging Water Column	Hanging Water Column	Hanging Water Column
	Meas. Method	CR-21	CR-21	CR-21	CR-21	ACRM II
	Data Source	Data File	Lab. Book	Data File	Lab. Book	Lab. Book
Moisture Block ID	Moisture Block Location (Lys/depth [m])	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)
COARSE SAND CALIBRATION						
B2-26	B-1/7.6		191.35	191.6	180.23	182
B2-18	B-1/5.4		166.7	167	158.4	177
B2-17A	B-1/5.1A		296.14	295.9	266.96	234
B2-17B	B-1/5.1B		16.625	185.9	179.87	199
B2-17C	B-1/5.1C		211.32	211	202.08	228
B2-16	B-1/4.8		166.35	166.3	154.77	177
B	B-1/3.8	234.6	175.27	174.9	162.37	
C	Not Used	213.6	215.24	215.2	219.78	
126	A-1/3.2	215.4	171.06	171.1	175.63	
114	A-1/3.8	362.6	196.22	196.1	190.29	
129	B-1/3.2	632.4	193.44	193.3	220.22	
A2-26	A-1/7.6		327.16	326.7	358.25	
A2-18	A-1/5.4		215.44	215.2	182.78	
A2-17A	A-1/5.1A		214.96	215	199.77	
A2-17B	A-1/5.1B		214.38	214.5	216.88	
A2-17C	A-1/5.1C		217.56	217.4	240.26	
A2-16	A-1/4.8		235.32	235.1	228.85	
132	B-1/4.2					193
VERY FINE SAND CALIBRATION						
B2-8	B-1/2.4		116.34	116.4	415.6	130
B2-4	B-1/1.2		131.72	131.8	583.35	153
127	Not Used	698.1	128.97	128.9	1329.2	
104	A-1/4.2	592.1	114.4	114.4	2213.6	
132	B-1/4.2	283.5	140.62	140.5	2212.2	
113	Not Used	328.7	128.97	129	1439.1	
A	Not Used	318.0	172.93	172.9	529.59	
A2-8	A-1/2.4		112.06	112.1	536.04	
A2-4	A-1/1.2		132.72	132.6	516.16	
129	B-1/3.2					111
B	B-1/3.8					111

BOLD: Used in final calibration.

Italic: Data suspect

Table G.1. (contd)

		102 cm H ₂ O (0.1 bars)						(0.2 bars)
Date/Time		1/29/85		3/6/85 8:00	3/13/85 8:00	3/13/85 14:40	7/22/85 10:02	8/5/85 16:05
Cal. Method		Pressure Plate		Hanging Water Column	Hanging Water Column	Hanging Water Column	Hanging Water Column	Hanging Water Column
Meas. Method		CR-21		CR-21	CR-21?	CR-21	ACRM II	ACRM II
Data Source		Lab. Book		Data File	Data File "Paula 8"/Lab Book	Lab. Book	Lab. Book	Lab. Book
Moisture Block ID	Moisture Block Location (Lys/depth [m])	Resistance (ohms)	Wt. % Water	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)	Resistance (ohms)
COARSE SAND CALIBRATION								
B2-26	B-1/7.6			977	822	792.88	918	
B2-18	B-1/5.4			1235	962	925.92	1050	
B2-17A	B-1/5.1A			1011	790	772.41	790	
B2-17B	B-1/5.1B			1245	985	945.67	1210	
B2-17C	B-1/5.1C			1328	1050	1010.9	1280	
B2-16	B-1/4.8			1110	869	835.06	1030	
B	B-1/3.8	1920	3.12	868	635	608.06		
C	Not Used	1990	3.61	925	630	606.21		
126	A-1/3.2	25040	4.8	2033	1531	1509.8		
114	A-1/3.8	14470	2.91	3372	2240	2181.2		
129	B-1/3.2	11920	3.62	2467	1750	1706.7		
A2-26	A-1/7.6			1312	1060	1052.5		
A2-18	A-1/5.4			887	630	602.35		
A2-17A	A-1/5.1A			1172	809	775.68		
A2-17B	A-1/5.1B			1089	724	697.41		
A2-17C	A-1/5.1C			1131	932	923.03		
A2-16	A-1/4.8			1258	861	835.72		
132	B-1/4.2						2010	
VERY FINE SAND CALIBRATION								
B2-8	B-1/2.4			418.2	454	429.3	373	524
B2-4	B-1/1.2			569.3	595	571.06	467	695
127	Not Used	7369	14.43	1280	1260	1248.1		
104	A-1/4.2	7110	13.26	2203	2200	2172.4		
132	B-1/4.2	5251	10.25	2011	1980	1980		
113	Not Used	4507	12.06	1348	1270	1297.4		
A	Not Used	942	11.89	523.1	493	508.14		
A2-8	A-1/2.4			527.9	556	527.94		
A2-4	A-1/1.2			511.8	552	523.83		
129	B-1/3.2						1080	1380
B	B-1/3.8						365	556

BOLD: Used in final calibration.

Italic: Data suspect

Table G.1. (contd)

		306 cm H2O (0.3 bars)			1020 cm H2O (1.0 bars)			3060 cm H2O (3.0 bars)	
Date/Time		2/5/85 8:00			2/12/85 8:00			2/20/85 9:20	
Cal. Method		Pressure Plate			Pressure Plate			Pressure Plate	
Meas. Method		CR-21			CR-21			CR-21	
Data Source		Lab. Book	Data File	Lab. Book	Lab. Book	Data File	Lab Book	Lab. Book	
Moisture Block ID	Moisture Block Location (Lys/depth [m])	Resistance (ohms)	Resistance (ohms)	Wt % Water	Resistance (ohms)	Resistance (ohms)	Wt.% Water	Resistance (ohms)	Wt % Water
COARSE SAND CALIBRATION									
B2-26	B-1/7.6								
B2-18	B-1/5.4								
B2-17A	B-1/5.1A								
B2-17B	B-1/5.1B								
B2-17C	B-1/5.1C								
B2-16	B-1/4.8								
B	B-1/3.8	5962.3	5953	3.5	93537	68520	3.48	76599	2.87
C	Not Used	6143.1	6130	3.47	26099	26050	2.95	80932	3.13
126	A-1/3.2	85547	NA	3	340400	NA	3.57	348160	2.79
114	A-1/3.8	53484	52720	3.61	239060	NA	2.88	373710	2.69
129	B-1/3.2	37031	37140	3.86	138680	NA	3.13	154960	2.96
A2-26	A-1/7.6								
A2-18	A-1/5.4								
A2-17A	A-1/5.1A								
A2-17B	A-1/5.1B								
A2-17C	A-1/5.1C								
A2-16	A-1/4.8								
132	B-1/4.2								
VERY FINE SAND CALIBRATION									
B2-8	B-1/2.4								
B2-4	B-1/1.2								
127	Not Used	24829	25090	6.93	283510	NA	5.19	387880	3.86
104	A-1/4.2	27613	27350	7.18	259400	NA	4.26	486650	4.21
132	B-1/4.2	19432	19660	6.89	212390	NA	4.59	348160	4.32
113	Not Used	13333	13800	6.24	31010	31210	4.31	431710	4.11
A	Not Used	2102.6	2127	6.62	54070	54270	4.53	74863	4.29
A2-8	A-1/2.4								
A2-4	A-1/1.2								
129	B-1/3.2								
B	B-1/3.8								

BOLD: Used in final calibration.

Italic: Data suspect

Appendix H

Calibration of Neutron Soil Moisture Probes

Appendix H

Calibration of Neutron Soil Moisture Probes

Calibration of the neutron moisture probe readings to actual field moisture contents was performed separately for each lysimeter. These calibrations were performed by correlating laboratory measured moisture contents (of samples collected during backfilling of the lysimeters) with neutron probe count ratios (count/standard count) measured shortly after backfilling each lysimeter. Calibration curves for the very fine sand of both lysimeters were fairly straight forward since a variety of moisture contents were sampled. However, the coarse sand for lysimeter A-1 was of fairly uniform moisture content and thus no correlation could be made directly from the measured values. An effort was then made to estimate the equivalent water content of the coarse soil using the following equation from Greacen (1981):

$$W_e = 0.124(+or-0.012)C + 0.015,$$

where C = clay content in g/g. Particle size analysis of the coarse sand yielded 2% clay (0.02 g/g) size particles (See Section 5.1). Assuming this percentage of clay size particles also represented the percentage of clay minerals, yielded an equivalent water content (W_e) of 2.85 volume percent at a neutron moisture count ratio of 0. Calibration for the coarse sand of lysimeter B-1 was conducted similar to that of the very fine sand of both lysimeters. The calibration curves for these soils is provided in Figures H.1 through H.4.

Three different neutron probes have been used to collect moisture profile data at the lysimeters. Therefore correlations were made between the moisture probes. This was performed by comparison of the count ratios of the different probes collected from the same lysimeters one after the other. The neutron probe used almost exclusively is designated as the H35 probe. The calibration curves between the various neutron probes is provided in Figures H.5 and H.6.

Figure H.1. Calibration of the H33 Neutron Moisture Probe in Fine Soil of the A-1 Lysimeter.

Figure H.2. Calibration of the H33 Neutron Moisture Probe in Coarse Soil of the A-2 Lysimeter.

Figure H.3. Calibration of the H35 Neutron Probe in Fine Soil of the B-1 Lysimeter.

S.H

LEGEND

- CURVE
- WT. AVERAGE 19/17/85 OF THE 3 MOISTURE CONTENT ANALYSES CLOSEST TO THE NEUTRON PROBE MEASURING POINTS, AS MEASURED ON 7/17/85.

$$\theta = 20.0(H35) - 2.47$$

$$r^2 = 0.9344$$

Figure H.4. Calibration of the H35 Neutron Moisture Probe in Coarse Soil of the B-1 Lysimeter.

Figure H.5. Calibration Between the H33 and H38 Neutron Probes.

Figure H.6. Calibration Between the H35 and H33 Neutron Probes.

Appendix I

Physical Analyses of the Two Lysimeter Soils

Figure I.1. Location of Soil Samples Collected from the Stockpiled AP Tank Farm Soils.

Battelle

Pacific Northwest Laboratories

CALCULATION WORKSHEET

Calc. No. _____

Page _____ of _____

ORIGINAL WATER CONSTANTS

SAMPLE WT. % H₂O

1-1	0.70
1-2	0.95
1-3	0.83
1-4	0.72
1-5	1.07
1-6	0.93
2-1	0.78
2-2	0.69
2-3	0.60

Title _____

Project: _____

Prepared by: _____

Date _____

Reviewed by: _____

Date _____

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
46.47							
SAMPLE A			2000.000	85.450000	2000.000	85.450	94% SAND
			1000.000	66.840000	1000.000	67.500	4% SILT
			500.000	39.490000	500.000	40.590	2% CLAY
			250.000	18.740000	250.000	19.510	SAND
			106.000	8.565000	106.000	8.780	
			75.000	6.542000	75.000	6.682	
			53.000	5.660000	53.000	5.789	
	49.13	3.8	49.130	8.177319	49.230	7.101	
	49.41	2.9	28.530	6.240585	28.530	5.703	
	49.56	2.1	15.670	4.519045	15.680	4.949	
	49.47	2.0	9.032	4.303852	9.041	3.981	
	49.59	1.7	6.402	3.658274	6.401	3.443	
	49.37	1.8	5.204	3.873467	5.208	3.120	
	49.50	1.2	4.519	2.582311	4.515	3.126	
	49.94	1.0	1.289	2.151926	1.289	2.152	

[1,0]
SAMPLE
B

			2000.000	85.450000		
			1000.000	68.150000		
			500.000	41.680000		
			250.000	20.270000		
			106.000	8.995000		
			75.000	6.822000		
			53.000	5.918000		
	49.32	2.8	49.320	6.025393		
	49.42	2.4	28.530	5.164622		
	49.57	2.5	15.680	5.379815		
	49.57	1.7	9.050	3.658274		
	49.57	1.5	6.399	3.227889		
	49.45	1.1	5.212	2.367119		
	49.42	1.7	4.511	3.658274		
	49.94	1.0	1.289	2.151926

13.13

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
46.14							
SAMPLE A			2000.000	85.960000	2000.000	85.960	97% SAND
			1000.000	59.520000	1000.000	61.070	0% SILT
			500.000	36.550000	500.000	35.500	3% CLAY
			250.000	19.420000	250.000	15.730	SAND
			106.000	2.844000	106.000	6.190	
			75.000	2.844000	75.000	4.012	
			53.000	2.735000	53.000	3.459	
	49.58	1.8	49.580	3.901170	49.560	4.118	
	49.67	2.1	28.680	4.551365	28.680	4.551	
	49.56	2.1	15.670	4.551365	15.660	4.876	
	49.60	1.5	9.056	3.250975	9.056	3.359	
	49.54	1.7	6.396	3.684439	6.403	3.359	
	49.45	1.2	5.212	2.600780	5.211	2.926	
	49.45	1.8	4.514	3.901170	4.513	3.901	
	49.81	1.5	1.286	3.250975	1.286	3.251	

[1,0]							
SAMPLE B			2000.000	85.960000			
			1000.000	62.610000			
			500.000	34.440000			
			250.000	12.030000			
			106.000	9.536000			
			75.000	5.180000			
			53.000	4.183000			
	49.53	2.0	49.530	4.334634			
	49.67	2.1	28.680	4.551365			
	49.48	2.4	15.650	5.201560			
	49.60	1.6	9.056	3.467707			
	49.65	1.4	6.410	3.034244			
	49.42	1.5	5.209	3.250975			
	49.42	1.8	4.511	3.901170			
	49.81	1.5	1.286	3.250975

Model for Computation of Particle Size Ordinates

MPLE IGHT	Theta	C	X. Part Size	P (% <)	X. Avg	P. Avg	TEXT CLAS
45.11 SAMPLE A			2000.000	87.870000	2000.000	87.870	95% SAND
			1000.000	61.870000	1000.000	60.470	2% SILT
			500.000	33.320000	500.000	32.050	3% CLAY
			250.000	15.980000	250.000	15.430	SAND
			106.000	7.559000	106.000	7.648	
			75.000	5.697000	75.000	5.963	
			53.000	4.722000	53.000	4.977	
	49.84	2.3	49.840	5.098648	49.630	5.875	
	49.62	2.2	28.650	4.876967	24.720	5.764	
	49.46	2.0	15.640	4.433607	15.650	5.320	
	49.81	1.5	9.094	3.325205	9.092	3.658	
	49.94	1.0	6.447	2.216803	6.430	3.325	
	49.73	1.8	5.242	3.990246	5.239	4.212	
	49.81	1.5	4.547	3.325205	4.541	3.769	
	49.86	1.2	1.314	2.660164	1.312	3.325	
11.01 SAMPLE B			2000.000	87.870000			
			1000.000	59.060000			
			500.000	30.770000			
			250.000	14.870000			
			106.000	7.737000			
			75.000	6.229000			
			53.000	5.232000			
	49.41	3.0	49.410	6.650410			
	35.99	3.0	20.780	6.650410			
	43.52	2.8	15.660	6.207049			
	43.78	1.8	9.083	3.990246			
	49.67	2.0	6.412	4.433607			
	49.67	2.0	5.236	4.433607			
	49.67	1.9	4.534	4.211926			
	49.70	1.8	1.310	3.990246

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
45.7							
SAMPLE A			2000.000	86.700000	2000.000	86.700	97% SAND
			1000.000	55.270000	1000.000	57.330	0% SILT
			500.000	22.410000	500.000	25.290	3% CLAY
			250.000	8.031000	250.000	9.211	SAND
			106.000	3.786000	106.000	4.191	
			75.000	3.020000	75.000	3.337	
			53.000	2.648000	53.000	2.899	
	49.86	1.5	49.860	3.282276	49.740	4.048	
	49.73	2.0	28.710	4.376368	28.660	4.923	
	49.73	2.0	15.730	4.376368	15.680	5.470	
	49.81	1.5	9.094	3.282276	9.081	3.829	
	49.88	1.0	6.439	2.188184	6.426	3.282	
	49.81	1.5	5.250	3.282276	5.243	3.720	
	49.81	1.4	4.547	3.063457	4.544	3.939	
	49.76	1.6	1.311	3.501094	1.311	3.720	

11.0			2000.000	86.700000			
SAMPLE B			1000.000	59.390000			
			500.000	28.160000			
			250.000	10.390000			
			106.000	4.595000			
			75.000	3.654000			
			53.000	3.151000			
	49.62	2.2	49.620	4.814004			
	49.54	2.5	28.600	5.470460			
	49.41	3.0	15.620	6.564551			
	49.67	2.0	9.068	4.376368			
	49.67	2.0	6.412	4.376368			
	49.67	1.9	5.236	4.157549			
	49.73	2.2	4.540	4.814004			
	49.70	1.8	1.310	3.938731

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
48.99							
SAMPLE A			2000.000	81.040000	2000.000	81.040	96% SAND
			1000.000	54.050000	1000.000	55.630	1% SILT
			500.000	27.760000	500.000	29.640	3% CLAY
			250.000	11.330000	250.000	12.120	SAND
			106.000	5.348000	106.000	5.593	
			75.000	4.327000	75.000	4.470	
			53.000	3.940000	53.000	4.032	
49.55	2.4		49.550	4.898959	49.600	4.593	
49.50	2.6		28.580	5.307206	28.620	4.797	
49.49	2.6		15.650	5.307206	15.660	5.205	
49.52	1.2		9.059	3.874219	9.059	3.471	
49.49	2.1		6.389	4.286589	6.400	3.881	
49.70	1.3		5.239	2.653603	5.233	3.062	
49.65	1.0		4.532	2.041233	4.532	2.041	
49.59	2.0		1.307	4.082466	1.308	3.878	
11.01							
SAMPLE B			2000.000	81.040000			
			1000.000	57.200000			
			500.000	31.520000			
			250.000	12.900000			
			106.000	5.838000			
			75.000	4.613000			
			53.000	4.123000			
49.65	2.1		49.650	4.286589			
49.62	2.1		28.650	4.286589			
49.52	2.5		15.660	5.103032			
49.62	1.6		9.059	3.874219			
49.65	1.8		6.410	3.874219			
49.59	1.7		5.227	3.471094			
49.65	1.0		4.532	2.041233			
49.65	1.8		1.308	3.874219

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Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (% <)	X. Avg	P. Avg	TEXT CLAS
46.49							
SAMPLE A			2000.000	85.180000	2000.000	85.180	96% SAND
			1000.000	59.220000	1000.000	59.210	0% SILT
			500.000	30.290000	500.000	31.260	4% CLAY
			250.000	11.900000	250.000	12.560	SAND
			106.000	5.313000	106.000	5.442	
			75.000	4.216000	75.000	4.259	
			53.000	3.936000	53.000	3.872	
49.75	1.60		49.750	3.441600	49.640	4.947	
49.75	2.00		28.720	4.302000	28.630	5.700	
49.59	2.83		15.680	6.087331	15.680	6.055	
49.52	2.40		9.041	5.162401	9.041	5.378	
49.52	2.50		6.393	5.377501	6.404	4.517	
49.49	2.10		5.217	4.517100	5.220	4.302	
49.49	2.30		4.518	4.947300	4.528	4.410	
49.59	2.20		1.307	4.732200	1.308	4.517	

[1.0]
SAMPLE B

			2000.000	85.180000		
			1000.000	59.200000		
			500.000	32.220000		
			250.000	13.210000		
			106.000	5.571000		
			75.000	4.302000		
			53.000	3.807000		
49.53	3.00		43.530	6.453001		
49.42	3.30		28.530	7.098301		
49.56	2.80		15.670	6.022801		
49.52	2.60		9.041	5.592601		
49.68	1.70		6.414	3.656700		
49.54	1.90		5.222	4.086900		
49.70	1.80		4.537	3.871800		
49.65	2.00		1.308	4.302000		

PARTICLE SIZE ANALYSIS
HGLF SAMPLE 1-6

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
40.61							
SAMPLE A			2000.000	97.730000	2000.000	97.730	80% SAND
			1000.000	96.130000	1000.000	96.160	17% SILT
			500.000	90.220000	500.000	90.420	3% CLAY
			250.000	78.380000	250.000	78.380	LOAMY SAND
			106.000	41.690000	106.000	40.520	
			75.000	26.400000	75.000	26.700	
			53.000	19.820000	53.000	20.010	
	49.76	-2.0	49.760	-4.924895	48.580	6.772	
	48.08	4.5	27.760	11.081015	27.790	11.080	
	48.47	3.0	15.330	7.387343	15.330	7.757	
	48.71	2.1	8.893	5.171140	8.891	5.294	
	48.76	2.0	6.295	4.924895	6.293	5.048	
	48.86	1.5	5.150	3.693672	5.148	4.063	
	49.00	1.3	4.473	3.201182	4.465	3.447	
	49.22	1.0	1.297	2.462448	1.297	2.709	
11.07							
SAMPLE B			2000.000	97.730000			
			1000.000	96.180000			
			500.000	90.620000			
			250.000	78.380000			
			106.000	39.350000			
			75.000	26.990000			
			53.000	20.190000			
	47.40	7.5	47.400	18.468358			
	48.19	4.5	27.820	11.081015			
	48.46	3.3	15.320	8.126077			
	48.68	2.2	8.888	5.417385			
	48.73	2.1	6.291	5.171140			
	48.81	1.8	5.145	4.432406			
	48.81	1.5	4.456	3.693672			
	49.17	1.2	1.296	2.954937

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
41.45							
SAMPLE A			2000.000	95.850000	2000.000	95.850	81% SAND
			1000.000	94.310000	1000.000	94.360	15% SILT
			500.000	87.890000	500.000	87.990	4% CLAY
			250.000	75.100000	250.000	75.120	LOAMY SAND
			106.000	37.300000	106.000	37.020	
			75.000	21.350000	75.000	22.140	
			53.000	18.820000	53.000	18.940	
47.45	7.9		47.450	19.059107	47.550	18.090	
48.28	4.5		27.870	10.856454	27.910	10.620	
48.64	3.1		15.380	7.478890	15.380	7.600	
48.87	1.7		8.922	4.101327	8.925	4.463	
48.76	2.0		6.295	4.825090	6.299	4.584	
48.79	1.8		5.143	4.342581	5.143	4.343	
48.79	1.8		4.454	4.342581	4.456	4.101	
49.09	1.5		1.294	3.618818	1.294	3.619	
11.01							
SAMPLE B			2000.000	95.850000			
			1000.000	94.400000			
			500.000	88.080000			
			250.000	75.130000			
			106.000	36.740000			
			75.000	22.920000			
			53.000	19.060000			
47.64	7.1		47.640	17.129071			
48.41	4.3		27.950	10.373945			
48.64	3.2		15.380	7.720145			
48.90	2.0		8.928	4.825090			
48.82	1.8		6.303	4.342581			
48.79	1.8		5.143	4.342581			
48.84	1.6		4.458	3.860072			
49.09	1.5		1.294	3.618818

Model for Computation of Particle Size Ordinates

SAMPLE WEIGHT	Theta	C	X. Part Size	P (%)	X. Avg	P. Avg	TEXT CLAS
40.22							
SAMPLE A			2000.000	98.860000	2000.000	98.860	78% SAND
			1000.000	97.240000	1000.000	97.390	18% SILT
			500.000	91.350000	500.000	91.610	4% CLAY
			250.000	79.240000	250.000	79.280	LOAMY SAND
			106.000	42.640000	106.000	41.090	
			75.000	26.650000	75.000	26.310	
			53.000	22.200000	53.000	22.250	
47.56	7.5		47.560	18.647439	47.690	18.030	
48.41	4.4		27.950	10.939831	27.980	10.570	
48.70	3.1		15.400	7.707608	15.410	7.708	
48.90	2.2		8.928	5.469915	8.929	5.594	
48.87	1.7		6.309	4.226753	6.311	4.848	
48.91	1.2		5.156	2.983590	5.151	3.854	
48.89	1.6		4.463	3.978120	4.457	4.351	
49.11	1.4		1.294	3.480855	1.293	3.978	
11.81							
SAMPLE B			2000.000	98.860000			
			1000.000	97.540000			
			500.000	91.870000			
			250.000	79.310000			
			106.000	39.530000			
			75.000	25.960000			
			53.000	22.300000			
47.81	7.0		47.810	17.404276			
48.52	4.1		28.010	10.193933			
48.73	3.1		15.410	7.707608			
48.91	2.3		8.930	5.718548			
48.90	2.2		6.313	5.469915			
48.82	1.9		5.146	4.724018			
48.76	1.9		4.451	4.724018			
49.01	1.8		1.292	4.475385

Appendix J

Temperature Profiles of the A-1 Lysimeter

TEMPERATURE PROFILE IN LYSIMETER #1

LEGEND

— DATE-(12/13/85)
..... DATE-(12/27/85)

TEMPERATURE PROFILE IN LYSIMETER A1

TEMPERATURE PROFILE IN LYSINETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND
— DATE-(10/ 6/86)

TEMPERATURE PROFILE IN LYSIMETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(7/31/87)

TEMPERATURE PROFILE IN LYSIMETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(9/ 2/87)

TEMPERATURE PROFILE IN LYSIMETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(9/30/87)

TEMPERATURE PROFILE IN LYSINETER A1

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(11/ 5/87)

TEMPERATURE PROFILE IN LYSIMETER A1

ST.15

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(12/16/87)

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

DATE-(12/30/87)

TEMPERATURE PROFILE IN LYSIMETER #1

LEGEND

DATE- (1/12/88)

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(1/26/88)

TEMPERATURE PROFILE IN LYSIMETER A1

LEGEND

— DATE-(2/10/88)

Appendix K

Temperature Profiles of the B-1 Lysimeter

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSINETER B1

TEMPERATURE PROFILE IN LYSINETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

DATE-(7/31/87)

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE- (8/12/87)

TEMPERATURE PROFILE IN LYSIMETER B1

K.10

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(9/30/87)

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(10/20/87)

TEMPERATURE PROFILE IN LYSINETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE—(11/23/87)

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(12/16/87)

K.15

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(12/30/87)

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(1/12/88)

TEMPERATURE PROFILE IN LYSIMETER B1

TEMPERATURE PROFILE IN LYSIMETER B1

LEGEND

— DATE-(2/10/88)

Appendix L

Neutron Moisture Probe Profiles for the A-1 Lysimeter

A1 LYSIMETER

A1 LYSIMETER

LEGEND

— DATE-(4/25/85) AREA - 68.90
..... DATE-(5/8/85) AREA - 69.23
- - - DATE-(6/17/85) AREA - 70.62

A1 LYSINETER

R1 LYSIMETER

LEGEND

DATE-(11/10/85) AREA - 69.10
 DATE-(12/13/85) AREA - 73.06
 DATE-(12/27/85) AREA - 72.47

A1 LYSINETER

A1 LYSIMETER

A1 LYSIMETER

LEGEND

- DATE-(07/07/86) AREA - 87.28
- DATE-(07/18/86) AREA - 87.17
- DATE-(08/04/86) AREA - 87.93
- DATE-(08/20/86) AREA - 87.09
- DATE-(09/02/86) AREA - 87.04
- DATE-(09/16/86) AREA - 86.98

A1 LYSIMETER

A1 LYSIMETER

R1 LYSIMETER

LEGEND

—	DATE-(4/3/87)	AREA - 94.51
.....	DATE-(4/21/87)	AREA - 95.03
-----	DATE-(5/1/87)	AREA - 94.42
-----	DATE-(5/18/87)	AREA - 94.58
----	DATE-(6/3/87)	AREA - 95.77
---	DATE-(6/17/87)	AREA - 95.42
---	DATE-(7/8/87)	AREA - 95.48
.....	DATE-(7/21/87)	AREA - 94.38
-----	DATE-(7/31/87)	AREA - 94.89
-----	DATE-(8/12/87)	AREA - 95.21
----	DATE-(9/02/87)	AREA - 95.68
---	DATE-(9/18/87)	AREA - 93.41
---	DATE-(9/30/87)	AREA - 94.21
.....	DATE-(10/20/87)	AREA - 93.62
-----	DATE-(11/5/87)	AREA - 92.77
-----	DATE-(11/23/87)	AREA - 92.32
---	DATE-(12/18/87)	AREA - 96.38

A1 LYSIMETER

1117

L.12

A1 LYSIMETER

L.14

A1 LYSIMETER

L.15

A1 LYSIMETER

Appendix M

Neutron Moisture Probe Profiles for the B-1 Lysimeter

B1 LYSIMETER

B1 LYSIMETER

M.3

B1 LYSIMETER

B1 LYSIMETER

M.5

B1 LYSIMETER

B1 LYSIMETER

B1 LYSIMETER

B1 LYSIMETER

11

6'W

B1 LYSIMETER

B1 LYSIMETER

M 11

M.12

M.13

Appendix N

Gross Gamma-Ray and Septral Gamma-Ray Logs

A1 NATURAL GAMMA

Figure 30.

Nal Gamma-Ray Borehole Survey

Project: LYSIMETERS

Borehole: LYSIMETER A1

No Corrections Applied

Log Date Depth Range

Apr 27, 1994 0 - 24'

Gross Gamma

1 * 100 cps

Gross Gamma

1 * 100 cps

TYPE = --1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS, LIVETIME = 289.74 SECONDS
 DATA COLLECTED AT 13:19:05 ON 27-APR-94

COUNTS X 1000

C:\M1241103.CH SAMPLE: LYSIMETER A1 14.80 FT 300s RT
 NaI Spectral RSLN1 ENERGY KEV

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS, LIVETIME = 69.58 SECONDS
 DATA COLLECTED AT 13:12:17 ON 27-APR-94

C:\1241102.CH SAMPLE: LYSIMETER 16.70 FT 300s RT
 NaI Spectral RLSN1

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS, LIVETIME = 290.08 SECONDS
 DATA COLLECTED AT 13:05:04 ON 27-APR-94
 10000.00

C:\M1244101.CH SAMPLE: LYSIMETER A1 18.59 FT 300s RT
 NaI Spectral RLSN1

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS, LIVETIME = 297.38 SECONDS
 DATA COLLECTED AT 12:57:08 ON 27--APR--94
 10000.00E

COUNTS X 1000

9N

C:\M241100.CHSAMPLE:

LYSIMETER

24.61 FT 300s RT

NaI Spectrometer RLSN1

B1 NATURAL GAMMA

Figure 31.

Nal Gamma-Ray Borehole Survey

Project: LYSIMETERS

Borehole: LYSIMETER B1

No Corrections Applied

Log Date Depth Range

Apr 27, 1994 0 - 24'

Gross Gamma

1 * 100 cps

Gross Gamma

1 * 100 cps

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS, LIVETIME = 296.54 SECONDS
 DATA COLLECTED AT 11:42:07 ON 27-APR-94
 10000.00

C:\N1231100.CHN SAMPLE: LYSIMETER B1 14.79 FT 300s RT
 NaI Spectral RSI H1

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
 REALTIME = 300.00 SECONDS. LIVETIME = 113.40 SECONDS
 DATA COLLECTED AT 11:26:56 ON 27-APR-94
 10000.00E

COUNTS X 1000

C. 1231098.016 SAMPLE: NaI Spectral HSLM
 16.72 FT 300S RT

TYPE = -1 MCA # 01 SEGMENT # 01 SEQUENCE # 0
REALTIME = 300.00 SECONDS, LIVETIME = 297.44 SECONDS
DATA COLLECTED AT 11:34:47 ON 27-APR-94
10000.00

COUNTS X 1000

11'N

C:\M1231099.CHSAMPLE: LYSIMETER B1 24.45 FT 300s RT
HAI Spectral RLSN1

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