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MEETING NOTES

TO: Distribution

DATE: November 15, 1993

FROM: Philip Nixon

MEMO #: SP307:111693:01

PROJECT #: Solar Pond IM/IRA

ATTENDANCE:

Harlan Ainscough, CDH
Arturo Duran, EPA
Mark Austin, EG&G
Phil Nixon, ES
Phil Kearns, DOE/KMI
Frazer Lockhart, DOE
Richard Henry, ES
Andy Ledford, EG&G
Joe Sheffel, CDH
Bob Segris, DOE
Alan MacGregor, ERM

DISTRIBUTION:

Attendees
L. Benson
A. Conklin
P. Breen
H. Heidkamp
K. Cutter
D. Myers
S. Stenseng
A. Fricke
R. Stegen
T. Kuykendall
T. Evans
B. Cropper
C. Montes
B. Wallace, EG&G (Admin. Record) (2)
K. Ruger, EG&G
K. London, EG&G
R. Wilkinson
Steve Howard, DOD/SMS
Jim Hartman, DOE
Helen Belencan, DOE
Ernie O'Tool, DOE/MMES
Steve Paris, EG&G
Steve Cook

SUBJECT: Weekly Status Meeting

1.) COCs/PRGs

Phil Nixon presented the questions that ES was asked to address at the November 9, 1993 team meeting and summarized the proposed resolution strategies.

A.) Should the historical data drive the selection for organic contaminants of concern that were not detected in the recent RFI/RI? It was agreed that the historical data is suspicious. Joe Sheffel of CDH suggested that a risk screening could be performed to determine the primary organic risk drivers. Amy Conklin acknowledged this approach, but stated that the modified PRG approach was originally developed to prevent a very time-consuming risk screening analysis. It was agreed that those organic constituents that were detected in vadose zone soils by historical data would be retained as PCOCs if they have been detected in the surface soils during the RFI/RI program, and/or they may exceed their readjusted PRGs.

B.) Should the 95% upper confidence limit (UCL) or maximum values be used to determine if a PCOC is a COC? ES proposed to use the upper confidence limit of the arithmetic mean and retain the maximum values for mapping the areal extent of those constituents that have PRGs which exceed the 95% UCL. Those constituents whose 95% UCL does <u>not</u> exceed their readjusted PRG but whose max value exceeds the readjusted PRG will also be mapped to locate possible "hot spot" areas. These PCOCs (or values) will not be used, however, to evaluate potential site risks. Joe Sheffel stated that CDH uses maximum values to determine if a site requires that an action be taken. Maximum values are less applicable to OU4 because it has already been determined that an action will be taken. It was agreed that the 95% UCLs can be used.

The overall methodology that has been agreed upon is as follows:

Calculate the 95% UCL for PCOCs

↓

Compare the 95% UCL to the modified PRG

↓

If the 95% UCL is less than modified PRG,
then the entire PCOC data set is not mapped;
possible hot spots will be identified

↓

If the 95% UCL is greater than the modified PRG,
then the PCOC will be considered a COC and will be mapped.

↓

The maximum measured concentration of each COC in each sampling location will be mapped to determine the areal extent of contamination. Possible hot spots due to both PCOCs and identified COCs will be mapped to verify the area(s) of concern.

Leigh Benson stated that the Gilbert methodology compares maximum values to the 97% upper tolerance limit (UTL) on background values. The 95% UTL is used generally for non-parametric data. The 95% UCL is used for parametric data or for data for which no distribution has been determined.

It was agreed that the IM/IRA-decision document would include the statistical methodology and results in addition to the COC/PRG methodologies and results.

It was agreed that the background data to be compared to the 95% UCLs and the readjusted PRGs would be calculated as the arithmetic mean plus two standard deviations. This is consistent with CDH guidance.

Joe Sheffel agreed with the previous team decision to remove any Tentatively Identified Compounds (TICs) from the PCOC list. He also concurred with the previous agreement that a qualitative assessment of the ecological risks would be satisfactory and that it was appropriate for the human health PRGs to drive the closure/remediation.

ES will prepare a non-contoured plot of all the PCOCs to identify where the PCOCs were identified at concentrations that exceeded background concentrations or the detection limits.

Leigh Benson indicated that the Rocky Creek background plutonium concentration was determined to be an error and correctly specified it as 0.1 pCi/g. In addition, the background vadose zone concentrations for inorganic analytes are generally higher than the surface soil concentrations. Harlan Ainscough indicated that this information increases his comfort with respect to the surficial soil background data.

2.) Corrective Action Management Units (CAMU)

It was discussed that the CAMU concept would likely be required to consolidate Building 788 debris and soils from the hillside within the Solar Evaporation Pond closure. Harlan Ainscough indicated that the mixture rule applies to the liners since they were part of the containment system and were in contact with the waste. Therefore, the CDH considers those materials to be hazardous waste. Concrete rubble from Building 788 was not part of a primary containment system and has the potential to be decontaminated. A rinsate sample may be used to demonstrate that the rubble is not contaminated. **Harlan Ainscough will discuss whether non-hazardous debris could be used as stabilizing/backfill material with the solid waste group.**

Harlan Ainscough indicated that collapsing the berms into the Solar Evaporation Ponds would not constitute placement because materials can be moved within the confines of the hazardous waste management unit. This, however, does not hold true for contaminated hillside soils that are outside the confines of the Solar Evaporation Ponds. The CAMU concept will have to be implemented to consolidate hillside soils into the Solar Evaporation Ponds during closure.

Phil Nixon asked whether the liners could be left in place to act as a barrier in the event that contaminated soils were consolidated under an engineered cover. The liners would act as a barrier to contaminant migration since the engineered cover would prevent the build-up of a liquid head. **Harlan will investigate this question further through his resources at CDH.**

3.) Schedule Status

Andy Ledford presented a copy of the EG&G project working schedule to the team for informational and planning purposes. Some of the schedule slip in the first milestone activity has been reduced by correcting logic ties in the schedule activities.

4. Isopleth Maps

Phil Nixon presented maps showing the areal extent of contamination based on the comparison of the 95% UCL data to the PRGs. In general, the north hillside surface soils have concentrations that exceed the PRGs for primarily cadmium, beryllium, americium-241, and plutonium. Vadose zone hillside soils have concentrations of plutonium, barium and mercury that exceed the PRGs at locations in the vicinity of the Solar Evaporation Ponds. There are vadose zone concentrations of uranium-235, americium-241, plutonium, barium, and cadmium beneath the Solar Evaporation Ponds that exceed the PRGs.

Arturo Duran questioned that if surface soils are excavated, would the newly exposed vadose zone soils need to meet the PRGs established for surface soils? It was agreed that the newly exposed surface soils would not to be less than or equal to the PRG concentrations. Therefore, during excavation, soils may have to be removed until the PRG concentration for surface soils is achieved.

It was agreed that the first soil sample beneath the liner should be considered a surface sample.

The background concentration of uranium-235 is in question as to whether its activity is reflective of natural isotopic distribution. **ES will provide an analysis to determine if the background U-235 activity is reflective of the natural uranium isotopic distribution.**

5.) Building 788 D&D.

It was confirmed that the removal of Building 788 (including its NEPA documentation) would not be included as a component of the OU4 IM/IRA.

6.) ARARs

Phil Nixon presented a list of the identified ARARs and requested comments by the next team meeting. Arturo Duran suggested that the hazardous waste designating ARAR be applicable to each of the alternatives, and questioned whether the NRC regulations should be a To-Be-Considered (TBCs) document? It was agreed that EG&G operating procedures should not be included on the list. Randy Ogg questioned whether all of the TBCs needed to be considered (primarily flood plain requirements). **The team was asked to review and comment on the list for discussion at the next team meeting.**

It was discussed that while it is certainly advantageous to comply with all the ARARs identified for the project, the final ARAR compliance is not required until the final action. Therefore, the IM/IRA should comply with the ARARs to the maximum extent practicable. However, it was agreed that the closure requirements for a hazardous waste management unit should be complied with for the IM/IRA.

7.) RFI/RI Drilling Status

Richard Henry reported that work in the 207B North Pond was completed, and the holes were patched. Three holes have been completed in 207B North. All locations in 207-B North and 207-B Center have been surveyed. The drill rig is currently waiting to begin work in 207B Center until ice is removed. Samples are being prepared for transport to the laboratory.

8.) Remedial Alternatives

There were no early comments on the portions of the IM/IRA Part I and Part III that were submitted at the previous team meeting for information and early review. **Comments are requested at the next team meeting.**

Phil Nixon stated that ES was preparing matrix tables for the detailed evaluation of alternatives. The target is to present these at the November 30, 1993 team meeting to initiate the selection of an alternative.

9.) Issue Resolution Methodology

Arturo Duran indicated that the EPA did not wish to extend or lengthen the IAG dispute resolution process by adding another step in the process. The team generally agreed that the intended purpose of the "Star Chamber" was to provide an informal forum for technical experts and decision makers to discuss and resolve the issues prior to the formal IAG dispute resolution forum.

ES will remove from the methodology document the names from the "Star Chamber" as the group will be identified on a case-by-case basis.

A "Star Chamber" type meeting between CDH/EPA/and DOE was suggested to discuss the liner issue, the CAMU issues, and what mechanism is appropriate to formally designate the future land use determination. **Steve Howard will discuss this meeting with Frazer Lockhart.**

[redacted].) Waste Handling/Disposal

Mark Austin led a discussion to determine the assumptions that would be made to estimate a cost for waste disposal. The assumptions will include:

a.) material excavation and loading into standard site wooden crates

b.) temporary storage of crates at the construction site

c.) loading and shipping crates via truck to the onsite railroad loading dock

d.) loading railcars

e.) train transport by rail to Envirocare

f.) disposal at Envirocare in Utah.

Philip Nixon, Project Manager

OPERABLE UNIT 4/SOLAR EVAPORATION PONDS

NOVEMBER 23, 1993

AGENDA

ERMA GRAPHICS CAPABILITIES-ES (8:00-8:30)

COMMENTS ON ARARS TABLE (8:30-8:45)

COMMENTS ON "PART I AND PART III" OF IM/IRA DD (8:45-9:00)

URANIUM 235 BACKGROUND CRITERIA-ES (9:00-9:15)

DISTRIBUTION OF HANFORD BARRIER DOCUMENT (9:15-9:30)

BREAK (9:30-9:45)

NEPA STATUS-ES (9:45-10:00)

SCHEDULE UPDATE-A. LEDFORD (10:00-10:15)

PHASE I RFI/RI DRILLING STATUS-R. OGG (10:15-10:30)

NEXT WEEKS AGENDA (10:30-10:45)

NEW ISSUES (10:45-11:00)

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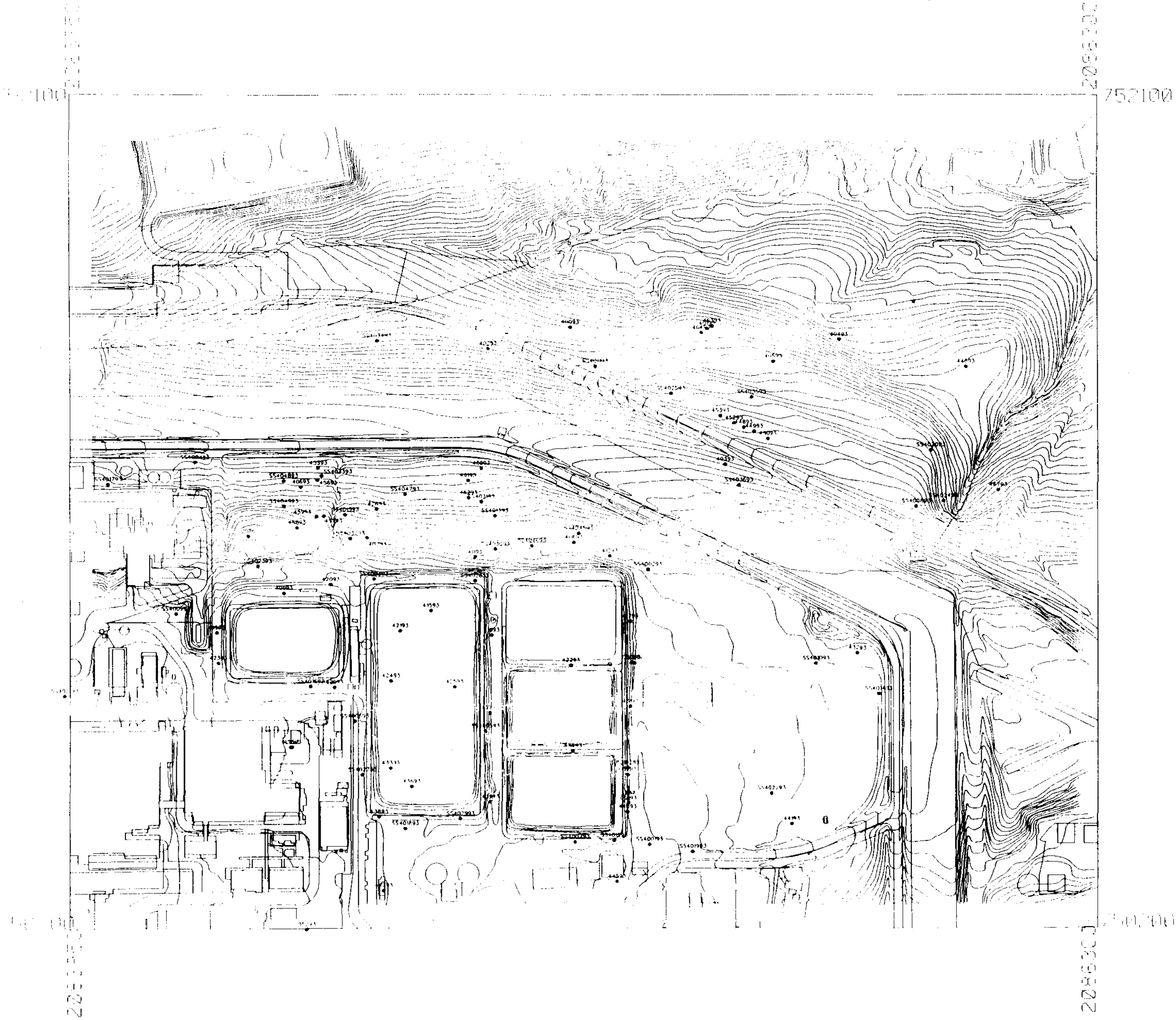

Attachment 2
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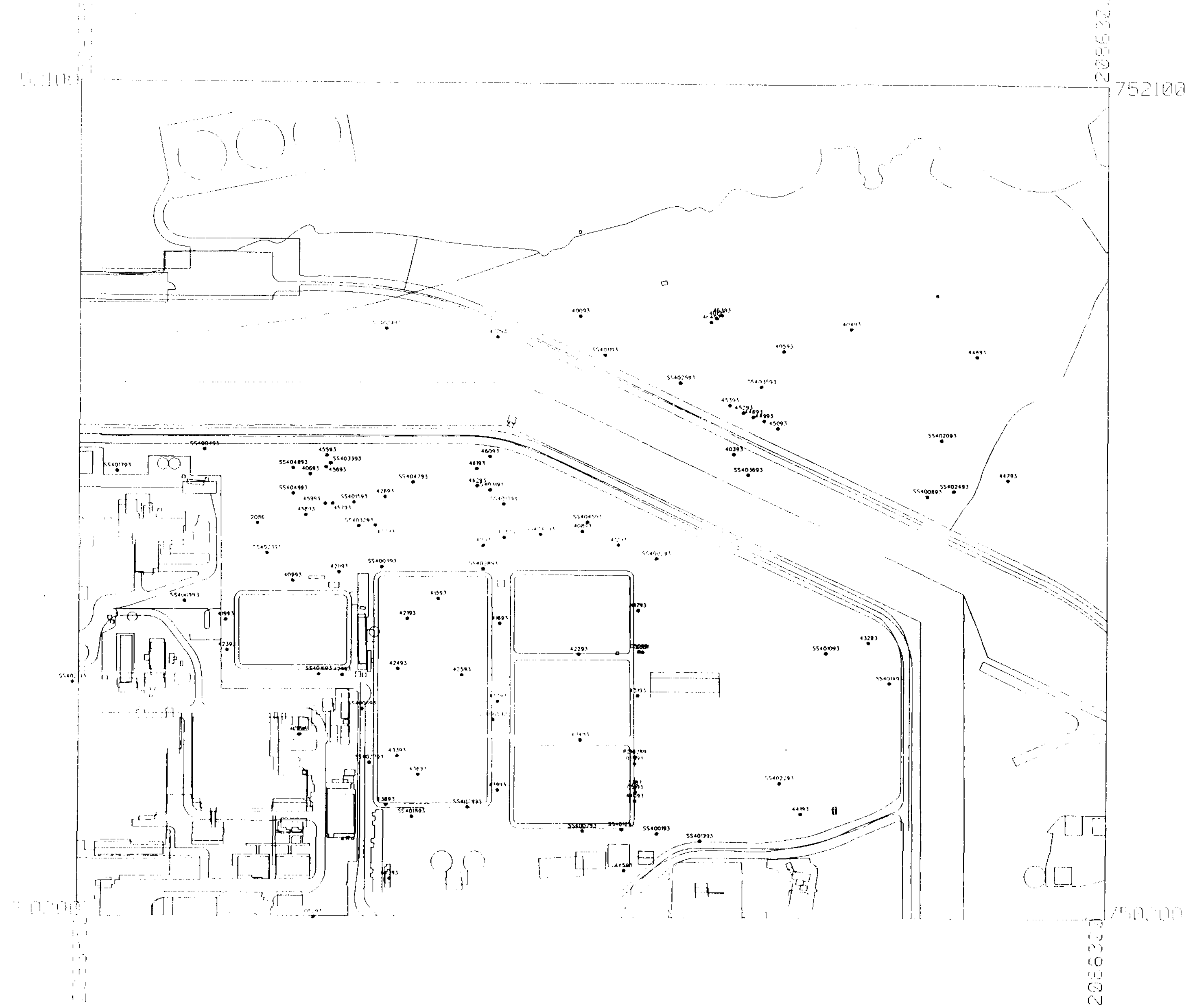

INTERNAL DRAFT

URANIUM BACKGROUND AND PHASE I CONCENTRATIONS

TYPICAL URANIUM ISOTOPIC ABUNDANCES (gram of isotope per 100 grams of uranium)[1]			
ISOTOPE	NATURAL	TYPICAL COMMERCIAL FEED ENRICHMENT	TYPICAL DEPLETED
U-234	0.0057	0.03	0.0005
U-235	0.7204	2.96	0.25
U-238	99.2739	97.01	99.75

(1) *The Health Physics and Radiological Health Handbook*; Bernard Shleien, editor; Scinta, Inc.; Silver Spring, MD; 1992.

ASSUMPTION: These isotopic abundance values are in units of grams of each of the uranium isotopes per 100 grams of uranium. For the purposes of this calculation, it was assumed that the overall mass percentage of each of the uranium isotopes with respect to each other remains the same for the OU-4 soils. In other words, U-234 accounts for 0.0057%, U-235 for 0.7204% and U-238 for 99.2739% of the natural uranium background.

STATISTICS TAKEN FROM THE OU-4 PCOC CALCULATIONS				
RADIONUCLIDE	SURFICIAL SOIL (pCi/g)		VADOSE SOIL (pCi/g)	
	95% UCL (Background)	95% UCL (All Data)	95% UCL (Background)	95% UCL (All Data)
U-234	0.17	2.5	0	2.92
U-235	0.07	0.17	0.1	0.2
U-238	1.25	1.86	0.62	1.75

Per The Health Physics and Radiological Health Handbook, the specific activity of the three isotopes in question are:

RADIONUCLIDE	SPECIFIC ACTIVITY (TBq/g)	SPECIFIC ACTIVITY (pCi/g)
U-234	2.31E-4	6.24E9
U-235	8.00E-8	2.16E6
U-238	1.24E-8	3.35E5

Specific Activity is defined as the relationship between the mass of a particular radioisotope and the activity associated with that mass. From this information we can now calculate the mass percentages for each of the three uranium isotopes. The following equation was utilized to calculate the grams of each of the uranium isotopes per gram of the OU-4 soils:

$$g_{isotope}/g_{soil} = 95\%\ \text{UCL Concentration}\ (\text{pCi}/g_{soil})/\text{Specific Activity}\ (\text{pCi}/g_{isotope})$$

For example:

$$g_{U\text{-}234}/g_{soil} = [0.17\ \text{pCi}/g_{soil}]/6.24\text{E}9\ \text{pCi}/g_{U\text{-}234}$$

$$= 2.72\text{E-}11\ g_{U\text{-}234}/g_{soil}$$

The calculated mass values for each of the 95% UCL quantities is as follows:

RADIONUCLIDE	SURFICIAL SOIL ($g_{isotope}/g_{soil}$)		VADOSE SOIL ($g_{isotope}/g_{soil}$)	
	95% UCL (Background)	95% UCL (All Data)	95% UCL (Background)	95% UCL (All Data)
U-234	2.72E-11	4.01E-10	0[1]	4.68E-10
U-235	3.24E-8	7.87E-8	4.63E-8	9.26E-8
U-238	3.73E-6	5.55E-6	1.85E-6	5.22E-6

(1) The vadose soil background mass for U-234 was not calculated as the reported background value is 0 pCi/g.

As we are going to compare this data to the naturally occurring mass percentages of the uranium isotopes, we must now normalize the above data. To accomplish this, we must first compute the total grams of uranium isotope per gram of OU-4 soil:

$$\text{U-234}\ (g_{isotope}/g_{soil}) + \text{U-235}\ (g_{isotope}/g_{soil}) + \text{U-238}\ (g_{isotope}/g_{soil}) = g_{uranium}\ \text{isotopes}/g_{soil}$$

Next, we must calculate the percentage each of the uranium isotopes contributes to the total quantity:

$$\frac{\text{U-234 } (g_{isotope}/g_{soil})}{g_{uranium} \text{ isotopes}/g_{soil}}$$

An example of this process is provided below:

<u>Surficial Soil ($g_{isotope}/g_{soil}$)</u>

U-234	2.72E-11
U-235	3.24E-8
U-238	3.73E-6
	3.76E-6

$$\frac{\text{2.72E-11 U-234 } (g_{isotope}/g_{soil})}{\text{3.76E-6 } g_{uranium} \text{ isotopes}/g_{soil}} = \text{7.23E-6 \%}$$

The following table provides the uranium isotopic mass percentage calculations for each of the uranium isotopes:

RADIONUCLIDE	SURFICIAL SOIL (%)		VADOSE SOIL (%)	
	95% UCL (Background)	95% UCL (All Data)	95% UCL (Background)	95% UCL (All Data)
U-234	7.23E-4	7.12E-3	0	8.81E-3
U-235	8.61E-1	1.40E0	2.44E0	1.74E0
U-238	9.91E+1	9.86E+1	9.76E+1	9.82E+1

We can now calculate the ratio of U-234 and U-235 to U-238. This is accomplished in the following manner:

$$\frac{\text{Naturally Occurring U-234 Percentage}}{\text{Naturally Occurring U-238 Percentage}} = \text{Ratio of U-234 to U-238}$$

For example:

$$\frac{\text{0.0057 \% (Naturally Occurring U-234 Percentage)}}{\text{99.2739 \% (Naturally Occurring U-238 Percentage)}} = \text{5.74E-5 (Ratio of U-234 to U-238)}$$

The following table presents the ratios of U-234 and U-235 to U-238 for each of the scenarios in question:

ISOTOPE	SURFICIAL SOIL (ratio)		VADOSE SOIL (ratio)		NATURALLY OCCURRING URANIUM
	95% UCL (Background)	95% UCL (All Data)	95% UCL (Background)	95% UCL (All Data)	REFERENCE, *THE HEALTH PHYSICS AND RADIOLOGICAL HEALTH HANDBOOK*
U-234	7.30E-6	7.22E-5	0	8.97E-5	5.74E-5
U-235	8.69E-3	1.42E-2	2.5E-2	1.77E-2	7.26E-3

For the purposes of additional clarification, the inverse of each is provided in the following table:

ISOTOPE	SURFICIAL SOIL (ratio)		VADOSE SOIL (ratio)		NATURALLY OCCURRING URANIUM
	95% UCL (Background)	95% UCL (All Data)	95% UCL (Background)	95% UCL (All Data)	REFERENCE, *THE HEALTH PHYSICS AND RADIOLOGICAL HEALTH HANDBOOK*
U-234	1.37E5	1.39E4	0	1.11E4	1.74E4
U-235	1.15E2	7.04E1	4.0E1	5.65E1	1.38E2

R. T. Ogg

WHC-EP-0650

UC-702

Permanent Isolation Surface Barrier: Functional Performance

N. R. Wing

Date Published
October 1993

Prepared for the U.S. Department of Energy
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N. Richard Wing N. Richard Wing 9/7/93

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R. T. Ogg

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N. R. Wing

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RL Program/Project	[X]	[]	RK Stewart	[signature]	9/27/
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Other Program/Project PNL	[X]	[]	GW Gee	[signature]	9/30/93

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transpiration recycle any excess water back to the atmosphere. The fine-soil layer also provides the medium for establishing plants that are necessary for transpiration to take place. The coarser materials placed directly below the fine-soil layer create a capillary break that inhibits the downward percolation of water through the barrier. The placement of fine soils directly over the underlying coarser materials also creates a favorable environment that encourages plants and animals to limit their natural biological activities to the upper, fine soil portion of the barrier, thereby reducing biointrusion into the lower layers. The coarser materials also help to deter inadvertent human intruders from digging deeper into the barrier profile. Low-permeability layers, placed in the barrier profile below the capillary break, also are used in the protective barriers. The purpose of the low-permeability layers is (1) to divert away from the waste zone any percolating water that gets through the capillary break and (2) to limit the upward movement of noxious gases from the waste zone. The coarse materials located above the low-permeability layers also serve as a drainage medium to channel any percolating water to the edges of the barrier.

The following preliminary performance objectives have been established for permanent isolation surface barriers:

- Function in a semiarid-to-subhumid climate
- Limit the recharge of water through the waste to the water table to near-zero amounts (0.05 cm/yr, which is equivalent to 1.6 x 10^{-9} cm/sec)

EXECUTIVE SUMMARY

This document presents the functional performance parameters for permanent isolation surface barriers. Permanent isolation surface barriers have been proposed for use at the Hanford Site (and elsewhere) to isolate and dispose of certain types of waste in place. Much of the waste that would be disposed of using in-place isolation techniques is located in subsurface structures, such as solid waste burial grounds, tanks, vaults, and cribs. Unless protected in some way, the wastes could be transported to the accessible environment via transport pathways, such as water infiltration, biointrusion, wind and water erosion, human interference, and/or gaseous release.

Permanent isolation surface barriers have been proposed to protect wastes disposed of in place from the transport pathways identified. The barrier consists of a variety of different materials (e.g., fine soil, sand, gravel, riprap, asphalt, etc.) placed in layers to form an above-grade mound directly over the waste zone. Surface markers, used to inform future generations of the nature and hazards of the buried wastes, are being considered for placement around the periphery of the waste sites. In addition, throughout the protective barrier, subsurface markers could be placed to warn any inadvertent human intruders of the dangers of the wastes below.

The protective barrier design consists of a fine-soil layer overlying other layers of coarser materials such as sands, gravels, and basalt riprap. Each of these layers serves a distinct purpose. The fine-soil layer acts as a medium in which moisture is stored until the processes of evaporation and

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ACKNOWLEDGEMENTS

The work conducted by members of the Hanford Site Permanent Isolation Surface Barrier Development Program has made the preparation of this document possible. In addition, several members of the team have significantly contributed to the preparation of various sections of this document. I appreciate the professional approach, team spirit, and cooperation displayed by the individuals on the barrier development team.

LIST OF FIGURES

CONTENTS

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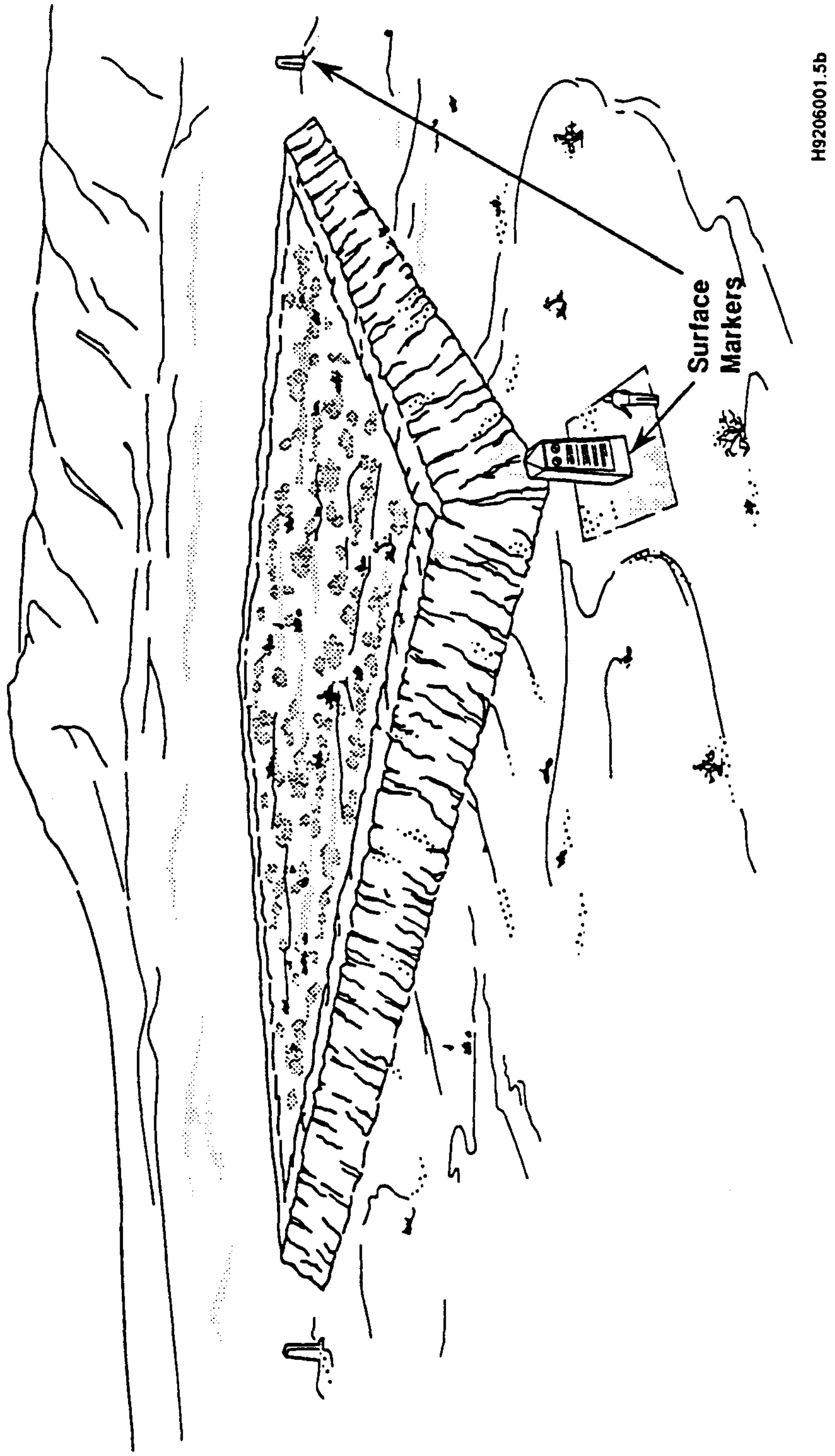
ACRONYMS

AGTP	Admix Gravel Test Plot
AILF	Animal Intrusion Lysimeter Facility
BDP	Barrier Development Program
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FLTF	Field Lysimeter Test Facility
FY	fiscal year
GCL	geosynthetic clay liners
HDW-EIS	Hanford Defense Waste-Environmental Impact Statement
HMS	Hanford Meteorological Station
MSL	mean sea level
PNL	Pacific Northwest Laboratory
RCRA	*Resource Conservation and Recovery Act of 1976*
ROD	record of decision
STLF	Small-Tube Lysimeter Facility
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
WHC	Westinghouse Hanford Company

Figure 1-1. Conceptual Permanent Isolation Surface Barrier and Warning Marker System.



PERMANENT ISOLATION SURFACE BARRIER: FUNCTIONAL PERFORMANCE

1.0 INTRODUCTION

1.1 THE IN-PLACE REMEDIATION ALTERNATIVE

The exhumation and treatment of wastes may not always be the preferred alternative in the remediation of a waste site. In-place disposal alternatives, under certain circumstances, may be the most desirable alternative to use in the protection of human health and the environment. The implementation of an in-place disposal alternative probably will require some type of protective covering that will provide long-term isolation of the wastes from the accessible environment. (It should also be noted that even if the wastes are exhumed and treated, a long-term barrier may still be needed to dispose of the wastes adequately.) Currently, no "proven" long-term barrier is available. The Hanford Site Permanent Isolation Surface Barrier Development Program (BDP) was organized to develop the technology needed to provide a long-term surface barrier capability for the Hanford Site. The permanent isolation barrier technology also could be used at other sites.

Permanent isolation barriers use engineered layers of natural materials to create an integrated structure with redundant protective features. Drawings of conceptual permanent isolation barriers are shown in Figures 1-1 and 1-2. The natural construction materials (e.g., fine soil, sand, gravel, riprap, asphalt) have been selected to optimize barrier performance and longevity. The objective of current designs is to use natural materials to develop a maintenance-free permanent isolation barrier that isolates wastes for a minimum of 1,000 yr by limiting water drainage to near-zero amounts; reducing the likelihood of plant, animal, and human intrusion; controlling the exhalation of noxious gases; and minimizing erosion-related problems.

1.2 THE NEED FOR PERMANENT ISOLATION SURFACE BARRIERS

Permanent isolation barriers were identified in the *Hanford Waste Management Plan* (DOE-RL 1987) and the *Final Environmental Impact Statement for the Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes* (HDW-EIS) (DOE-RL 1988) as integral components in the final disposal schemes for the following wastes:

- Single-shell tank wastes
- Transuranic-contaminated soil sites
- Pre-1970 buried suspect transuranic-contaminated solid wastes
- Grouted low-activity and low-level wastes from double-shell tanks.

In addition to the waste types identified above, other forms of waste may require a permanent isolation barrier. These other forms of waste include decommissioned facilities, low-level waste sites, and hazardous waste sites. In addition, barrier systems have been identified as integral components of the large-scale remediation approach to cleaning up the Hanford Site.

Existing short-term barrier designs currently are available [U.S. Environmental Protection Agency (EPA) 1982, 1990]. In general, the design life of these covers is for relatively short periods--such as the 30-yr post-closure period specified by the *Resource Conservation and Recovery Act of 1976* (RCRA). The performance of barriers during this relatively short period can be monitored, and maintenance activities can be performed to correct any problems that might be encountered. However, some waste management situations make it desirable to isolate wastes for much longer than the 30-yr post-closure period (i.e., up to or beyond a millennium). For these waste management situations, the relatively short-term (i.e., RCRA) designs might not be satisfactory. For example, many synthetic construction materials that might be effective for decades (e.g., geosynthetics) cannot be relied on to perform satisfactorily (or even exist) more than 1,000 yr. Consequently, a need arises for a long-term, permanent isolation barrier. The objective of the work being conducted by the BDP is to develop and assess the performance of permanent isolation barriers.

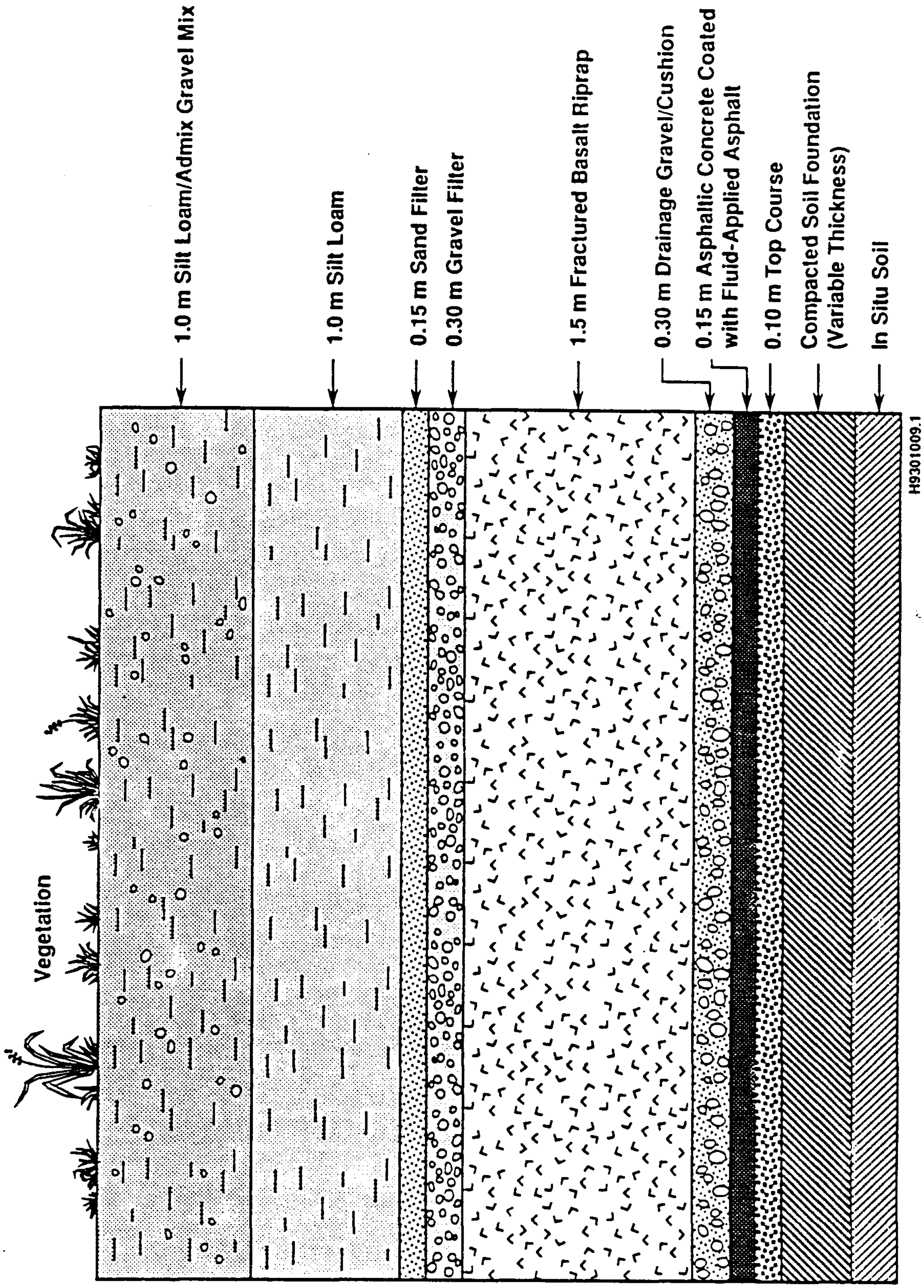
The development, testing, and evaluation of permanent isolation barriers is critical to support the Hanford Site mission of environmental restoration. Currently, no "proven" long-term barrier is available. The development of protective barriers is necessary to meet three key long-term *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) milestones (EPA et al. 1992). A barrier (final cover) is needed to support the following:

- Milestone M-08-00, "Initiate Full-Scale Tank Farm Closure Demonstration Project," by June 2004
- Milestone M-09-01, "Complete Preparation of Supplemental EIS," by June 2002
- Milestone M-09-00, "Complete Closure of All 149 Single-Shell Tanks," by June 2018.

The development of protective barriers is consistent with the HDW-EIS. The U.S. Department of Energy's (DOE) Record of Decision (ROD) for the HDW-EIS was issued on April 8, 1988 (U.S. Federal Register 1988). In the ROD, DOE stated that the decision on how certain types of waste are to be disposed of was being deferred until additional development and evaluation activities had been conducted. One of these activities identified in the ROD is the demonstration of barrier performance by "instrumented field tests and modeling."

In addition, it is assumed that a barrier will be needed to support future *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), and RCRA actions will be needed to protect human health and the environment. For example, in the *Low-Level Burial Grounds Dangerous Waste Permit Application* (DOE-RL 1989), the following statement is made.

Figure 1-2. Typical Barrier Cross Section.



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> If the radiological performance assessment indicates that the RCRA-compliant covers proposed in this permit application do not meet long-term DOE-RL (U.S. Department of Energy Richland Operations Office) objectives, an enhanced cover design will be developed and proposed in an amended closure plan. The DOE-sponsored research for the development of enhanced cover designs for the Hanford Site is in progress...

The DOE-sponsored research program developing enhanced cover designs is the BDP.

- Limit the exhalation of noxious gases
- Minimize erosion-related problems
- Meet or exceed RCRA cover performance requirements
- Isolate wastes for a minimum of 1,000 yr
- Be regulatorily and publicly acceptable.

2.2.2 Barrier Development Program Goal

The objectives previously noted have provided the basis for formulating a barrier development program and for evaluating the adequacy of various barrier designs. These objectives also have been used in the preparation of a statement (provided below) that summarizes the goals of the BDP.

The BDP goal is to provide defensible evidence that final barrier design(s) will control water infiltration; plant and animal intrusion; and wind and water erosion for a minimum of 1,000 yr and protect human health and the environment in accordance with applicable or relevant and appropriate requirements. Warning marker system conceptual designs will be provided to inform inadvertent human intruders in case institutional control is lost.

Evidence of barrier performance will be obtained by conducting laboratory experiments, field tests, computer modeling, and other studies that establish confidence in the barrier's ability to meet its 1,000-yr-plus design life. The stability and performance of natural analogs that have existed for millennia and reconstruction of climate changes during the past 10,000 yr will establish bounding conditions of possible future changes and serve to focus experimental designs and increase confidence in the barrier's ability to meet its design life.

2.2.3 Methods of Verifying Barrier Performance

As previously alluded to in the BDP's goal statement, three different types of activities are being used to acquire the information and experience necessary to design permanent isolation barriers and to assess their performance over the intended design life. These three types of activities include (1) field tests and experiments, (2) computer simulation models, and (3) natural analogs (Figure 2-1).

2.2.3.1 Field Tests and Experiments. Field tests and experiments enable scientists and engineers to test various barrier components using actual barrier construction materials. These tests are designed to be conducted under ambient climatic conditions as well as under conditions simulating a change in climate (i.e., wetter climate). In this manner, components of the permanent isolation barrier can be tested under the range of conditions that are expected to be encountered during the barrier's design life. The results of the field tests and experiments are used to develop final barrier designs.

2.0 METHODOLOGY FOR BARRIER DEVELOPMENT

2.1 ORGANIZATION

The Operations and Engineering Contractor for the DOE's Hanford Site, Westinghouse Hanford Company (WHC), and DOE's Research and Development Contractor for the Hanford Site, Pacific Northwest Laboratory (PNL), are jointly developing and testing permanent isolation surface barriers. A multiyear program (the BDP) has been organized to develop, test, and evaluate various barrier designs. A team of engineers and scientists from WHC and PNL are directing the performance of tests and experiments to design and assess the effectiveness of permanent isolation surface barriers. The Hanford Site's Architect/Engineering Contractor, Kaiser Engineers Hanford Company (KEH), also has played an important role in developing definitive designs and construction specifications to support various projects. In addition to the work being performed by Hanford Site contractors, outside contractors, universities, and consultants are used by the BDP to perform specific tasks and to provide independent technical peer reviews. The engineers and scientists in the BDP at the Hanford Site also interface with barrier researchers from other DOE sites as well as with individuals from around the world.

2.2 APPROACH

As previously discussed, protective barriers have been identified as integral components in the final disposal of certain types of waste at the Hanford Site. The approach being taken to develop, test, and verify the performance of permanent isolation barriers is described in the following subsections.

2.2.1 Preliminary Performance Objectives

To aid in the development of protective barriers, a preliminary set of performance objectives for the barriers has been defined. These objectives are intended to be broad enough to encompass the various regulatory requirements for the types of wastes anticipated to be disposed of using barriers at the Hanford Site (and elsewhere). The following list provides a summary of the preliminary performance objectives established for the development of permanent isolation barriers.

- Function in a semiarid to subhumid climate
- Limit the recharge of water through the waste to the water table to near-zero amounts [0.05 cm of water per year (1.6×10^{-9} cm/sec) was the design objective selected based on preliminary performance assessments that supported the preparation of the HDW-EIS]
- Be maintenance free
- Minimize the likelihood of plant, animal, and human intrusion

2.2.3.2 Computer Simulation Models. Computer simulation models are being developed for use in assessing the performance of permanent isolation barriers over their intended design life. The collection of field and laboratory data (mentioned previously) is necessary to generate the information required to test the computer models. Many of the field and laboratory tests and experiments mentioned in this document are designed to quantitatively evaluate the performance of protective barriers. The field and laboratory data will be compared with the predictions of the computer simulation models. Modifications and refinements of the models will be made, as needed, so that the natural processes taking place in the barrier are accurately simulated. Once tested, the computer models become particularly effective tools for predicting barrier performance (1) over periods of time much longer than can be tested in the field and (2) under environmental conditions representative of anticipated future regional climates.

While the models are being developed they can be used to perform sensitivity analyses to gain insights into the design, testing, and performance of various barrier systems and components. An example of the use of the models in this type of application is presented in Section 3.3.1.

2.2.3.3 Natural Analog Study Tasks. Insights into permanent isolation barrier performance can be obtained by studying analogous natural objects or structures constructed by humans. For example, many of the borrow pits at the Hanford Site have relatively fine materials overlying coarser materials. This layering sequence, which closely resembles the permanent isolation barrier, is primarily caused by the deposition of waterborne materials during catastrophic floods that occurred about 13,000 yr ago. Because these materials have remained relatively unchanged over such long periods of time, the materials can serve as functional models for the performance of and changes expected to occur to permanent isolation barriers for extended periods of time.

Similarly, constructed mounds used to protect tombs or to make temple platforms are known to have existed for hundreds to thousands of years. Many of these ancient mounds have survived extremely well and are still intact. The BDP has studied the mounds to gain insights that would enable current design efforts to produce a similarly durable and functional structure. The ability to study ancient constructed mounds and other analogs is particularly effective for predicting barrier performance with regard to physical stability and maintenance requirements.

Studies of other barrier analogs have been conducted, planned, or considered to provide insights into how the barrier can best be designed to accomplish the design objectives. For example, studies of asphalt durability are planned to be performed on asphalt specimens from museum collections that range in age from 150 to 5,000 yr. Desert pavements and other surface rock formations have served as analogs for developing erosion-control practices and for measuring the effects of such practices on soil water balance. The ability of plants to reestablish themselves following perturbations such as range fires can be predicted from studies of plant community dynamics on the soils that will be used for barrier construction. The potential for biointrusion of layered barriers can be judged from measurements of plant-root and animal burrow distribution in analogous layered sediments. Furthermore, the potential effects of future shifts in climate can be deduced by comparing the parameters of interest at separate locations that exhibit spatial

Figure 2-1. Methods of Verifying Barrier Performance.

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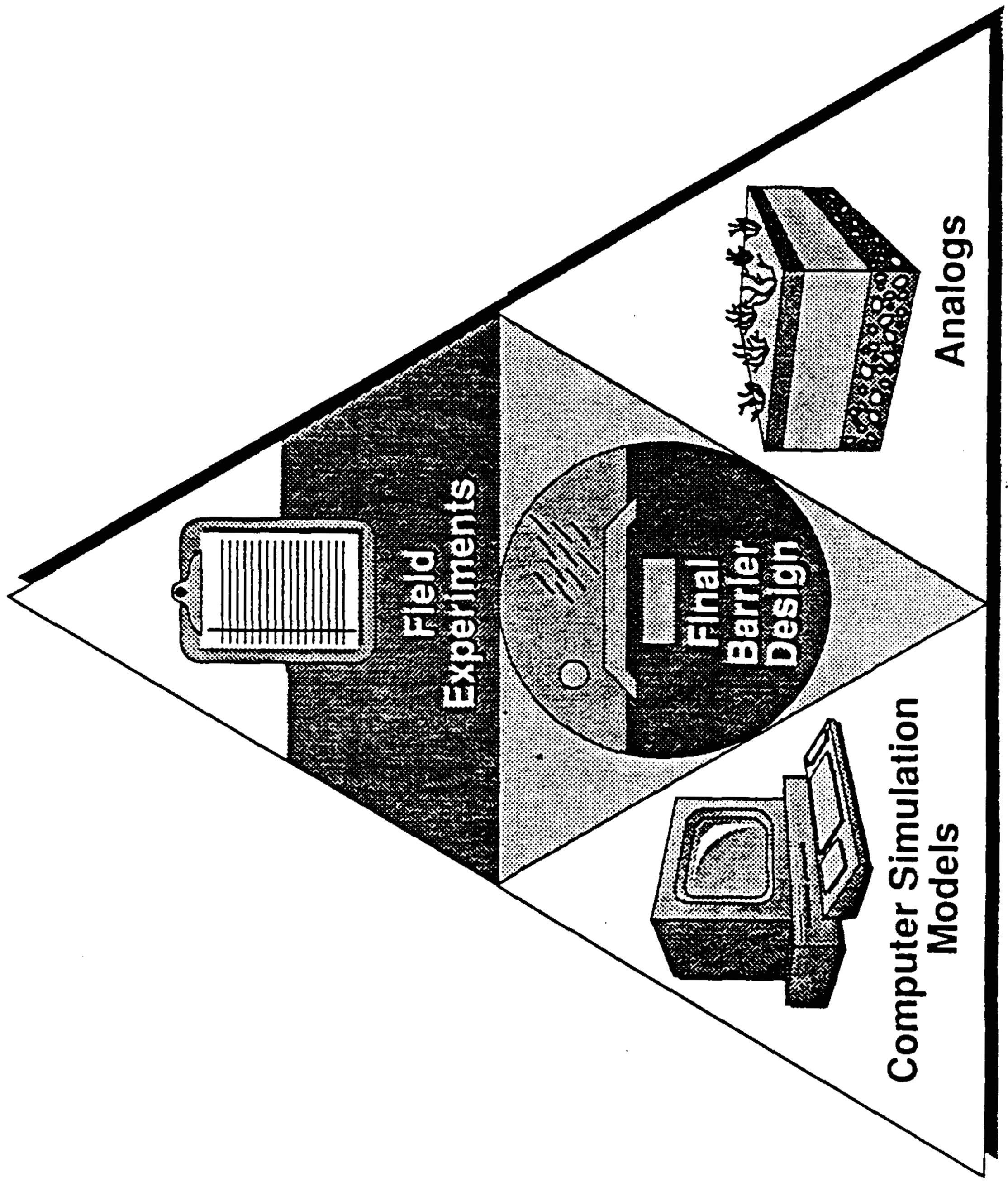
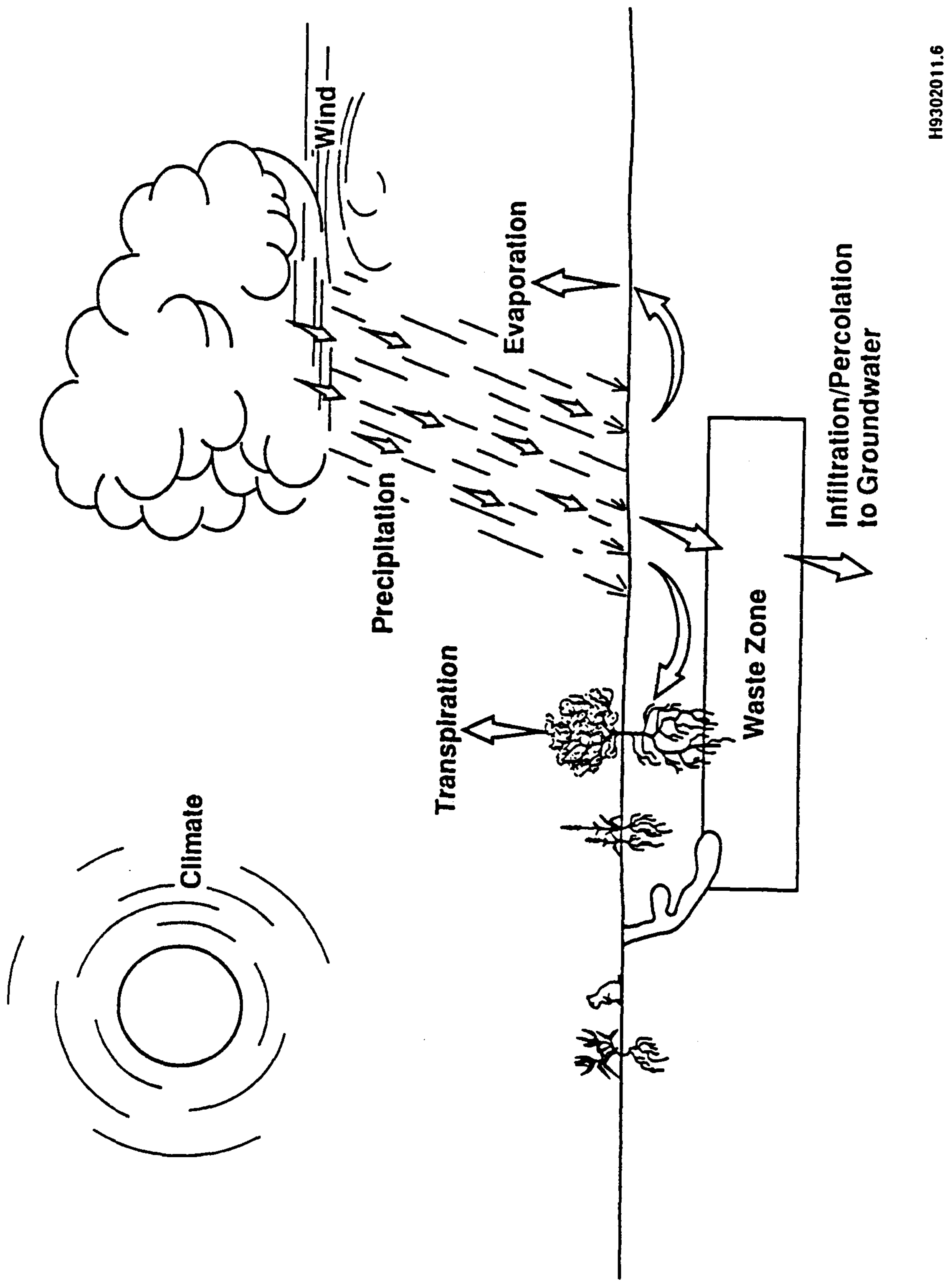


Figure 3-1. Potential Problems of the Current Waste Management Situation.



3.0 FUNCTIONAL REQUIREMENTS FOR THE BARRIER

As discussed in Sections 1.0 and 2.0 of this document, certain types of waste at the Hanford Site (and elsewhere) may be disposed of using in-place stabilization techniques. Much of the waste that would be disposed of by in-place stabilization currently is located in relatively shallow subsurface structures such as solid waste burial grounds, tanks, vaults, and cribs. Unless protected in some way, the wastes could be transported to the accessible environment via the following pathways (Figure 3-1).

- Water infiltration is the infiltration and percolation of water through the waste zone resulting in the leaching and subsequent transport of mobile radionuclides and other contaminants to the water table.

- Biointrusion is the penetration of deep-rooting plants and burrowing animals into the waste zone below. The deep-rooting plants could draw radionuclides and other contaminants into its root system and subsequently translocate the contaminants to the above-grade portion of the plant. The contaminants in the above-grade portion of the plant could then be dispersed by animals that eat the plants or by wind. Animals burrowing directly into the waste zone could contact contaminants and subsequently bring them to the earth's surface as part of the soil castings. Erodible loose soil cast to the surface by burrowing animals could contribute to accelerated erosion of the fine-soil surface layer. In addition, the presence of animal burrows may provide preferential pathways for infiltrating water to gain access to the waste zone.

- Wind and water erosion the removal of the surface soils at a waste site as a result of erosive forces. Erosion-related problems could provide a direct pathway for contaminant transport if the erosive forces are strong enough to remove the surface soils and expose the buried wastes to the accessible environment. A more probable scenario is for wind and water erosion to reduce the thickness of soils overlying a waste zone so another transport pathway (i.e., water infiltration) becomes a more serious concern.

- Human interference is the inadvertent or intentional intrusion of humans into the waste sites (assuming institutional control is lost) and subsequent dispersion of contaminants. A basic assumption is that the barrier will not be required to be designed to deter the intentional human intruder.

- Gaseous release is the diffusion of noxious gases from the waste zone to the accessible environment.

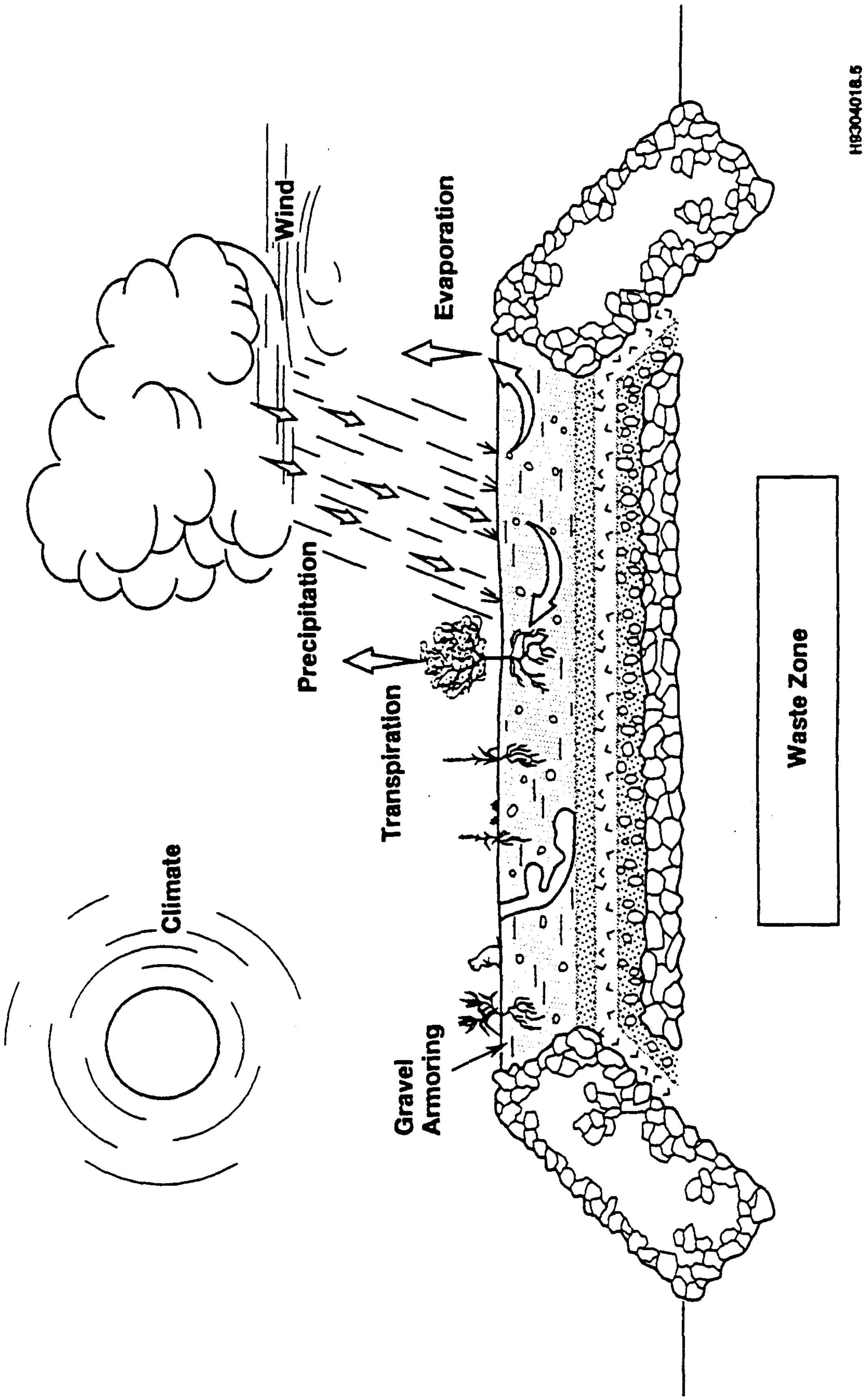
Engineered barriers have been proposed to protect wastes disposed of "in place" from the transport pathways identified previously (Figure 3-2). The protective barrier consists of a variety of different materials (e.g., fine soil, sand, gravel, riprap, asphalt, etc.) placed in layers to form an above-grade mound directly over the waste zone. Surface markers are being considered for placement around the periphery of the waste sites to inform future generations of the nature and hazards of the buried wastes. In addition, throughout the protective barrier, subsurface markers could be placed to warn any inadvertent human intruders of the dangers of the wastes below (Figure 3-3). (Please refer to Section 3.4 for a more in-depth discussion of the human intrusion issue.)

The protective barrier design consists of a fine-soil layer overlying other layers of coarser materials such as sands, gravels, and basalt riprap. Each of these layers serves a distinct purpose. The fine-soil layer acts as a medium in which moisture is stored until the processes of evaporation and transpiration recycle any excess water back to the atmosphere. The fine-soil layer also provides the medium for establishing plants that are necessary for transpiration to take place. The coarser materials placed directly below the fine-soil layer create a capillary break that inhibits the downward percolation of water through the barrier (see Section 3.1.3). The placement of the silt loam directly over the underlying coarser materials also creates an environment that encourages plants and animals to limit their natural biological activities to the upper, fine soil portion of the barrier, thereby reducing biointrusion into the lower layers. The coarser materials also will help to deter inadvertent human intruders from digging deeper into the barrier profile. Low-permeability layers, placed in the barrier profile below the capillary break, will also be used in the protective barriers. The purpose of the low-permeability layers is (1) to divert away from the waste zone any percolating water that gets through the capillary break and (2) to limit the upward movement of noxious gases from the waste zone. The coarse materials located above the low-permeability layers also serve as a drainage medium to channel any percolating water to the edges of the barrier.

As discussed previously, the following preliminary performance objectives have been established for protective barriers:

- Function in a semiarid-to-subhumid climate
- Limit the recharge of water through the waste to the water table to near-zero amounts (0.05 cm/yr, which is equivalent to 1.6×10^{-9} cm/sec)
- Be maintenance free
- Minimize the likelihood of plant, animal, and human intrusion
- Isolate waste for a minimum of 1,000 yr
- Minimize erosion-related problems
- Meet or exceed RCRA cover performance requirements
- Limit the exhalation of noxious gases
- Be regulatorily and publicly acceptable.

Figure 3-2. Functional Performance of Barriers.



Because the barrier needs to perform for at least 1,000 yr without maintenance, natural construction materials (e.g., fine soil, sand, gravel, cobble, crushed basalt riprap, asphalt, etc.) have been selected to optimize barrier performance and longevity. Most of these natural construction materials are available in large quantities on the Hanford Site and are known to have existed in place for thousands of years or longer (e.g., basalt). In contrast to the natural construction materials, the ability of synthetic construction materials to survive and function properly for 1,000 yr is not known. Because of this uncertainty, synthetic construction materials are not relied upon in current designs to perform satisfactorily (or even exist) through centuries or millennia.

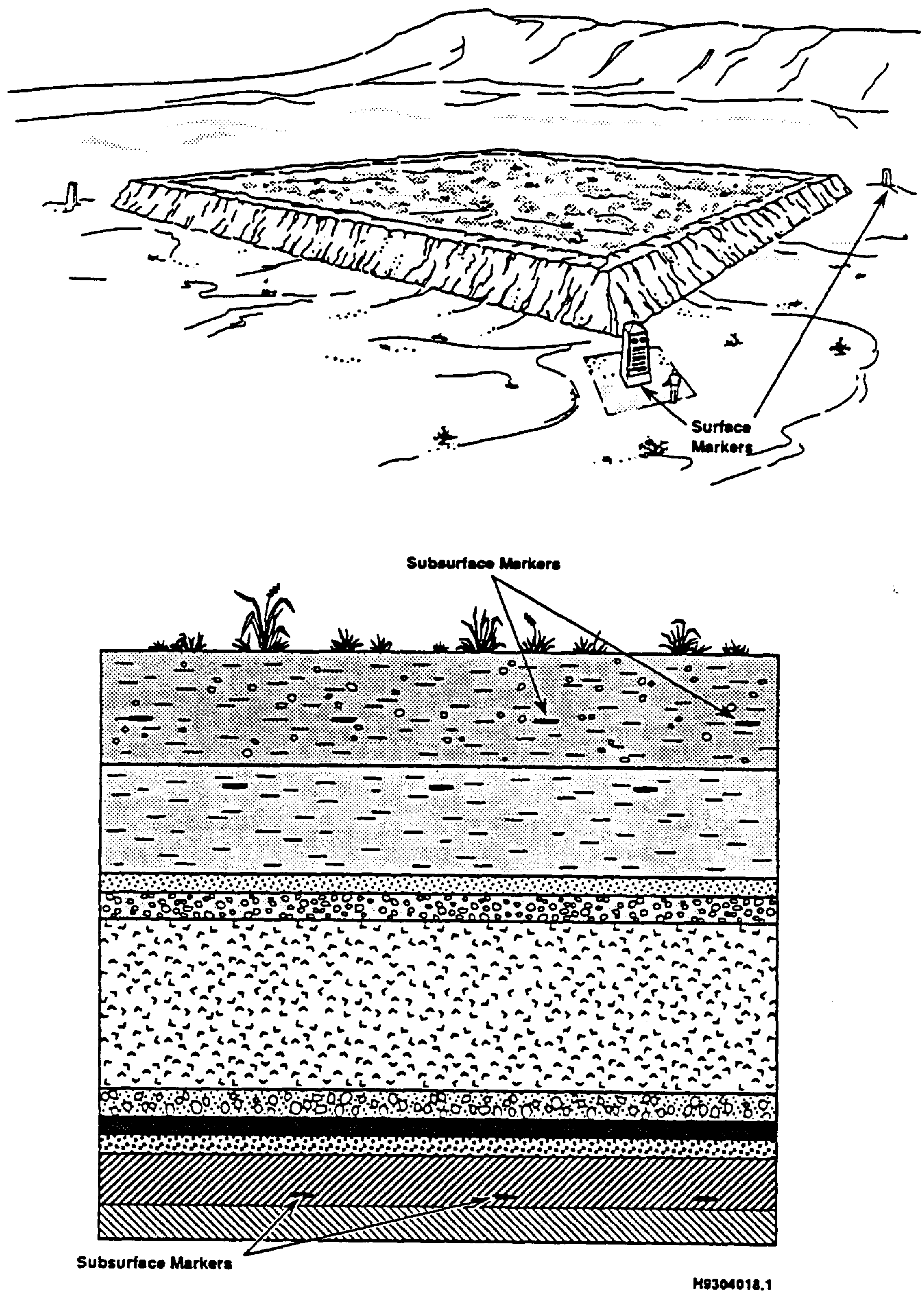
The need for a maintenance-free barrier that lasts for a minimum of 1,000 yr necessitates the use of passive systems for achieving the preliminary performance objectives. Active systems are impractical because they require human involvement to operate, monitor, and maintain. For example, the use of an active leachate collection and removal system requires monitoring the collection of leachate and removing it from the collection system via a sump pump or similar device. The various components of the leachate collection and removal system would need to be maintained periodically as well. This level of human activity over extremely long periods of time is impractical and would mean passing on this generation's legacy of waste to future generations -- an undesirable option.

The permanent isolation barrier is intended to remain functional throughout its design life with minimum or no human intervention. Consequently, in designing a permanent isolation barrier, it is important to understand the natural processes that are expected to act on the barrier during its design life. An understanding of how the natural processes affect barrier performance enables a design to be developed that passively meets performance objectives.

In the following sections, the natural processes acting on the permanent isolation barrier, as well as the engineered features of the barrier that have been designed to protect buried wastes from the natural processes, are discussed. Specifically, the document will provide a description of how various barrier components are used to protect buried wastes from water infiltration, biointrusion, wind and water erosion, human intrusion, and the release of noxious gases. Insights that have been acquired from BDP tasks conducted to date have been incorporated into the design of the barrier and are presented in the following discussions.

The permanent isolation barrier design uses a number of components integrated into a simple and constructible structure. The barrier concept presented in this document is for above-grade (mounded barrier) applications to existing waste sites. However, many of the barrier components described herein also are relevant and applicable to at-grade barriers at new waste disposal sites (Figure 3-4).

Figure 3-3. The Placement of Surface and Subsurface Markers.



3.1 WATER INFILTRATION AND PERCOLATION CONTROL

The control of water infiltration and percolation through the barrier depends on the amount of water available. The amount of water available depends on the climate. Because of the long timeframe during which permanent isolation barriers must function, the climatic conditions acting on the barrier may change. Section 3.1.1 discusses the projected changes in climate. These climate changes are considered when designing barrier features to control the infiltration and percolation of water through the barrier.

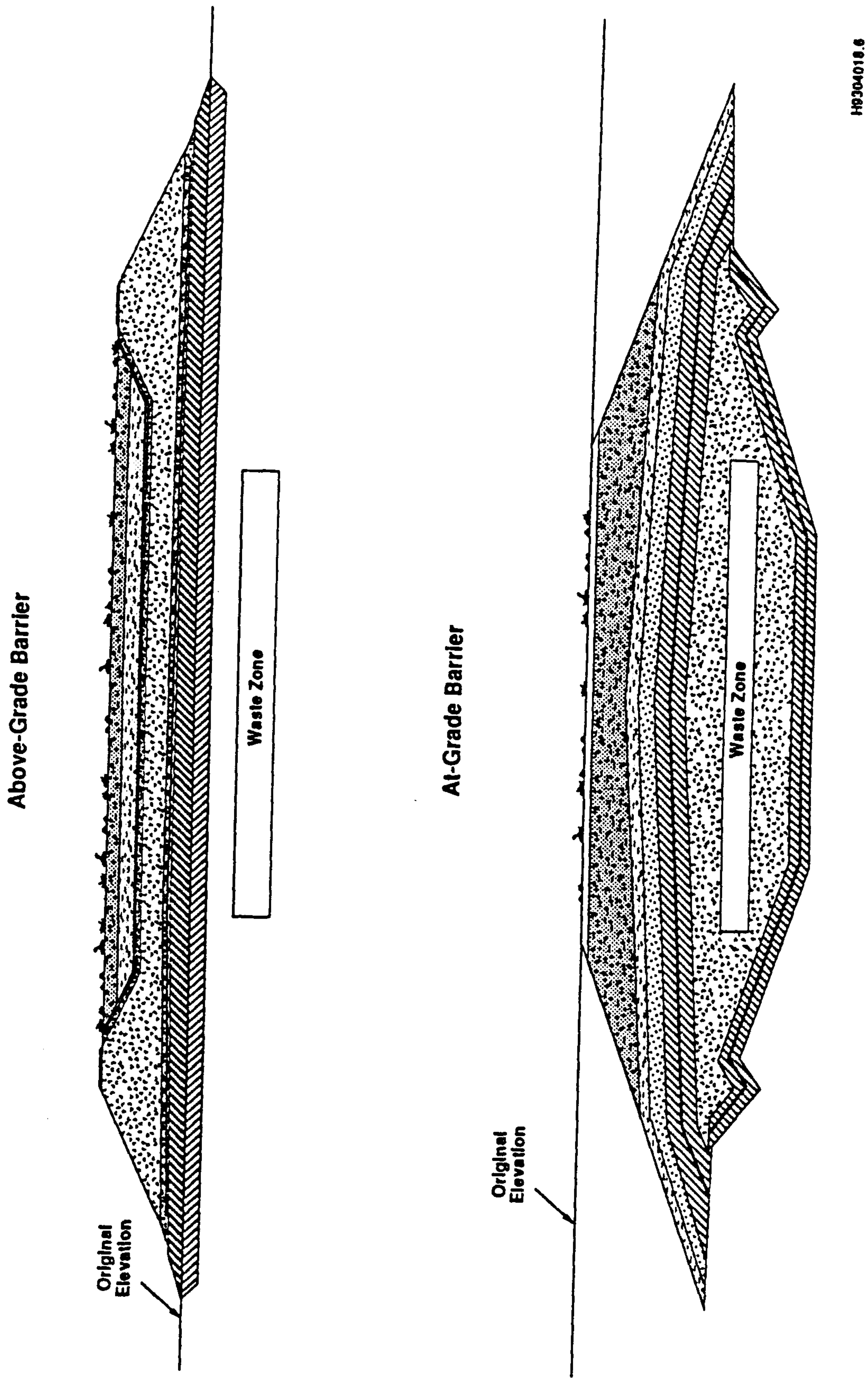
3.1.1 Projections of Long-Term Climate Change

Climate will have a profound influence on the performance of permanent isolation barriers being developed at the Hanford Site in south-central Washington. For example, soil water movement will be influenced by changes in precipitation, temperature, and vegetation. Climatically induced changes in plant and animal communities will affect the potential for biointrusion. Surface stability will be impacted by changes in precipitation and wind patterns. The following paragraphs provide the best information available at this time on the parameters that should be considered in designing a permanent isolation barrier to control water infiltration and percolation. A task within the BDP, the "Long-Term Climate Change Effects Task," has been established to obtain probabilistic projections of long-term variability in the Pasco Basin climate that can be input to analyses of water balance, biointrusion, and erosion of protective barriers (Petersen et al. 1993). As information from this task becomes available, it is incorporated into barrier designs.

3.1.1.1 General Description of the Hanford Site. Stone et al. (1983) summarize the present climate for the Hanford Site. The climate for the site is greatly influenced by being in the rainshadow of the Cascade Mountains. The Hanford Meteorological Station (HMS) is situated on a plateau at an elevation of about 213 m (700 ft) above mean sea level (MSL). The plateau slopes downward toward the Columbia River, which is located approximately 16 km (10 mi) to the north at an elevation of roughly 107 m (350 ft) above MSL. The plateau also slopes upward to the foothills of Rattlesnake Mountain located approximately 16 km (10 mi) to the south.

3.1.1.2 Amount of Precipitation at the Hanford Site. The amount of precipitation collected at the HMS averages 15.9 cm (6.25 in.) annually. The months November through January contribute 44 percent of this total, while the months July through September contribute only 13 percent. On average, there are only two occurrences per year of 24-hour precipitation events of 1.3 cm (0.50 in.) or more. In addition, there have been only two 24-hour precipitation events in the entire 35 yr of record (1946-1980) that have accumulated 5.0 cm (2.0 in.) or more. One of these high-intensity precipitation events was the record storm of October 1-2, 1957, in which rainfall totalled 2.74 cm (1.08 in.) in 3 hours, 4.27 cm (1.68 in.) in 6 hours, and 4.78 cm (1.88 in.) in 12 hours. Based on extreme-value analysis of Hanford Site climatological records from 1947 through 1969, the 60-minute, 100-yr storm would result in 2.06 cm (0.81 in.) of precipitation and the 60-minute, 1,000-yr storm would result in 2.82 cm (1.11 in.). [No records have been kept for time periods less than 60 minutes. However, the rain gauge

Figure 3-4. Above-Grade and At-Grade Barrier Designs.



3.1.1.5 Past Climatic Extremes. A synthesis of evidence for past climatic extremes for the Hanford Site region (summarized in Wing and Gee 1990, pp. 47) suggests that the climate between 8,000 and 5,400 yr ago was characterized by 30 to 40 percent lower precipitation and temperatures that were about 1.94 °C (3.5 °F) higher than present. Evidence suggests that the interval between 5,400 and 4,500 yr ago was cooler than the previous interval, but was still dry. During the interval between 4,500 and 3,900 yr ago, precipitation was 25 percent to 30 percent higher than present, and temperatures were similar as those today. High precipitation continued from 3,900 yr ago up to about 2,400 yr ago, but under colder conditions than currently exist. During the last 2,400 yr, the climate has been more like the present than during any of the previous periods. Such ranges suggest that the use of three times the average annual precipitation in the field studies and barrier designs would more than bound what is known about long-term average conditions that have occurred in the last 8,000 to 10,000 yr, although more information is needed about (1) individual storm events, (2) the possibility of entering a new ice age within the next 10,000 yr, and (3) the possibility of a trace-gas induced "super-interglacial" period within the next 500 yr.

3.1.1.6 Designing a Barrier for Water Infiltration and Percolation Control. Based on the climatological conditions and projections discussed previously, three methods are described for controlling the infiltration and percolation of water through a protective barrier: (1) engineering the barrier surface to maximize runoff while at the same time minimizing erosion, (2) incorporating a capillary break (or capillary barrier) within the integrated barrier system, and (3) incorporating a low-permeability, umbrella-like layer within the barrier profile to shed any infiltrating/percolating water away from the waste zone.

3.1.2 Runoff

The surface of the protective barrier can be engineered with a slight slope or crown to maximize the runoff of meteoric water and, in turn, reduce the amount of precipitation available for infiltration and percolation. The amount of water available for infiltration and percolation is a function of the amount of precipitation that falls on the barrier surface, minus the amount of water that runs off of the barrier surface and away from the structure. The engineering of the barrier surface is being optimized such that the runoff of water from the barrier surface is maximized and the erosion of the fine soil is minimized. (The barrier design features being considered to control erosion are discussed in Section 3.3.) Tests are being conducted to address these issues (Walters et al. 1990). Insights gained from the water erosion tests are being incorporated into barrier designs.

3.1.3 Capillary Barrier

The protective barrier will be designed and constructed with a fine-soil layer overlying a layer of coarser materials (e.g., sands and/or gravels). The differences in textures between the barrier materials at this interface provide a capillary barrier for percolating water (Figure 3-5).

chart for June 12, 1969 shows that 1.40 cm (0.55 in.) of precipitation was collected during a 20-minute period. In addition, an afternoon thunderstorm on June 29, 1991 dumped 1.12 cm (0.44 in.) of rain at the HMS in only 10 minute.] A 24-hour maximum accumulation for a 100-yr return period is 5.05 cm (1.99 in.) and the 1,000-yr return is 6.81 cm (2.68 in.).

About 38 percent of all precipitation is in the form of snow during December through February. However, only one of four winters is expected to accumulate as much as 15.2 cm (6 in.) of snow on the ground. The average seasonal number of days with 15.2 cm (6 in.) or more of snow on the ground is four, although the 1964-1965 winter had 35 days--32 of which were consecutive. That same winter also provided one of the greatest depths of snow accumulation recorded--30.7 cm (12.1 in.) of snow occurring in December 1964. The record for the greatest depth of snow accumulation is 62.2 cm (24.5 in.) which occurred in February 1916. However, the winter seasonal snowfall of 1992-1993 (December through February) totalled 133.6 cm (52.6 in.), surpassing all other winter snowfall records, including the winter of 1915-1916, by 22.9 cm (9.0 in.). February 1993 contributed 31.5 cm (12.4 in.) to that record winter accumulation with 25.7 cm (10.2 in.) falling February 18 and 19, setting a new record for 24-hr snowfall.

3.1.1.3 Temperatures at the Hanford Site. The average monthly temperature at the HMS is 11.7 °C (53.0 °F). However, temperatures at the Hanford Site are colder in the winter [the January monthly average is -1.5 °C (29.3 °F)] and warmer in the summer [the July monthly average is 24.7 °C (76.4 °F)] than would be the case without the Cascade Mountains, which separate the Hanford Site from the more moderate climate of the Pacific Ocean coastal areas. Other mountain ranges to the north and east shield the area from many of the arctic surges that affect the northern Plains at the same latitude; half of all winters are free of temperatures as low as -17.8 °C (0 °F). Although temperatures reach 32.2 °C (90 °F) or above an average of 55 days a year, minimum temperatures of 21.1 °C (70 °F) or above occur only an average of 8 days per year. The unusual cool nights are caused by cool gravity winds originating from the Cascade Mountains.

3.1.1.4 Winds at the Hanford Site. Hourly average wind speeds at five different elevations for the HMS have been collected and summarized for 1946 through 1980 (Stone et al. 1983). The Cascade Mountains serve as a source of gravity winds, which are mostly important in the summer and have considerable diurnal range of speed. Although gravity winds occur with regularity in summer, they are seldom strong unless reinforced by frontal activity. June, the month of highest average speed, has fewer instances of hourly averages exceeding 13.9 m/s (31 mph) than December, which has the lowest average speed. Because of topographic channelling, the prevailing wind direction is either WNW or NW in every month of the year. However, the strongest speeds are from the SSW, SW, and WSW. When extreme-value analysis of peak gusts is performed on data from 1945 through 1980 [collected at an elevation of 15.2 m (50 ft) at the HMS], the 100-yr return period for a peak wind gust can be estimated to be 38 m/s (85 mph). The maximum gust recorded in the data set was measured in January 1972 at 35.8 m/s (80 mph). The 1,000-yr peak gust is estimated to be 44 m/s (99 mph).

In an unsaturated system, the capillary pressures are much less than atmospheric pressure. For significant quantities of water to flow into and through the coarser sublayers, the water pressure must be raised to nearly equal atmospheric pressure. The overlying fine-textured soils must become nearly saturated for the water pressure to approach atmospheric pressure and allow water to flow into the sublayers. This resistance to drainage increases the storage capacity of the overlying fine-textured soil. Keeping the water in the fine-textured layer provides time for the processes of evaporation and transpiration to remove it.

The critical component of the capillary barrier is the fine-soil layer. The fine-soil layer must be able to retain infiltrating precipitation until the processes of evaporation and transpiration can recycle the water back to the atmosphere. The results of preliminary computer simulation model runs suggested that for Hanford Site conditions, a layer of suitable fine soils at least 1.5 m (4.9 ft) thick should be used in the design of the barrier. The effectiveness of this 1.5-m (4.9-ft) thick fine-soil layer has been demonstrated in lysimeter studies conducted by the BDP (discussed later in this subsection). A large deposit of fine soils that possess suitable moisture retention characteristics has been located on the Hanford Site. The fine-soil site, known as the McGee Ranch, was characterized during the spring of 1986. The results of the characterization indicate that a substantial quantity of suitable fine soils exists at the McGee Ranch site (Last et al. 1987).

The removal of water from a barrier's fine-soil layer is increased significantly by the presence of vegetation. Following the construction of a barrier, desired stands of vegetation on the barrier surface will be engineered and cultivated. However, during a barrier's design life there may be periods when the engineered vegetative cover is disturbed by range fires, drought, disease, or some other phenomenon. Because of the design objective to create a maintenance-free barrier, it may not always be possible to revegetate the barrier surface with the desired plant species. In these circumstances, it may be a long time before a climax community of vegetation reestablishes itself on the barrier surface. Although the presence of vegetation on the barrier surface is ideal, the results of lysimeter tests (presented in the following paragraphs of this section) provide interesting evidence that the capillary barrier concept performs very effectively, even in the absence of vegetation.

The capillary barrier concept has been tested for several years at the Field Lysimeter Test Facility (FLTF) (Figures 3-6 and 3-7). Results from these tests indicate that the capillary barrier functions as designed. During the first 3 yr of testing, twice the annual average precipitation (320 mm or 2X) was added to lysimeters simulating a wetter climate. During the next 2 yr, three times the annual average precipitation (480 mm or 3X) was added to the same lysimeters. During this entire 5-yr testing period, water losses by evaporation and transpiration exceeded water gains by precipitation and irrigation--even for the lysimeters receiving treatments representative of wetter climatic conditions. It also should be noted that these results were observed for both vegetated and unvegetated lysimeters. Even though the vegetated lysimeters were most effective at removing soil moisture, even the

Figure 3-5. Capillary Barrier Concept.

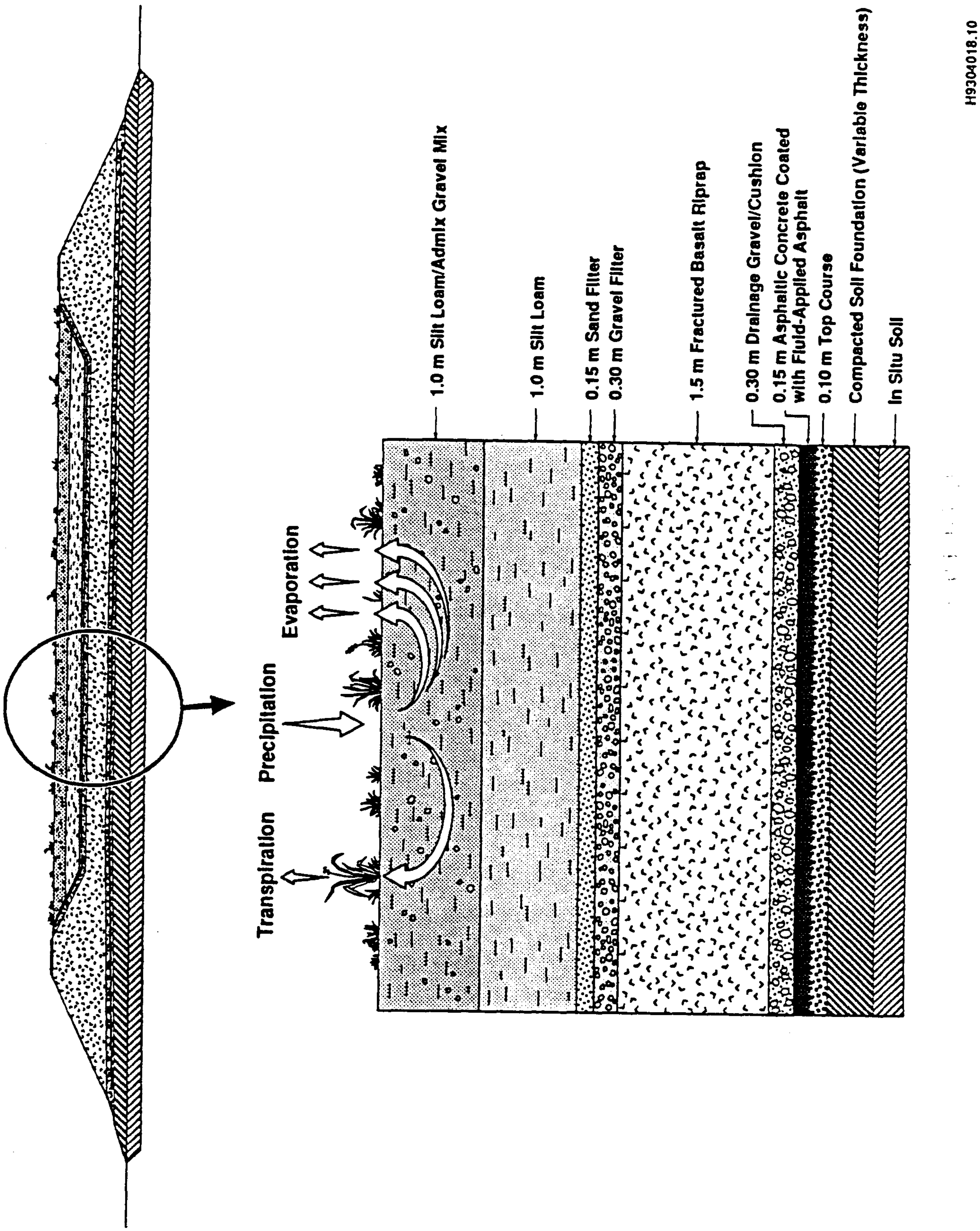


Figure 3-7. The Field Lysimeter Test Facility: Experimental Design.

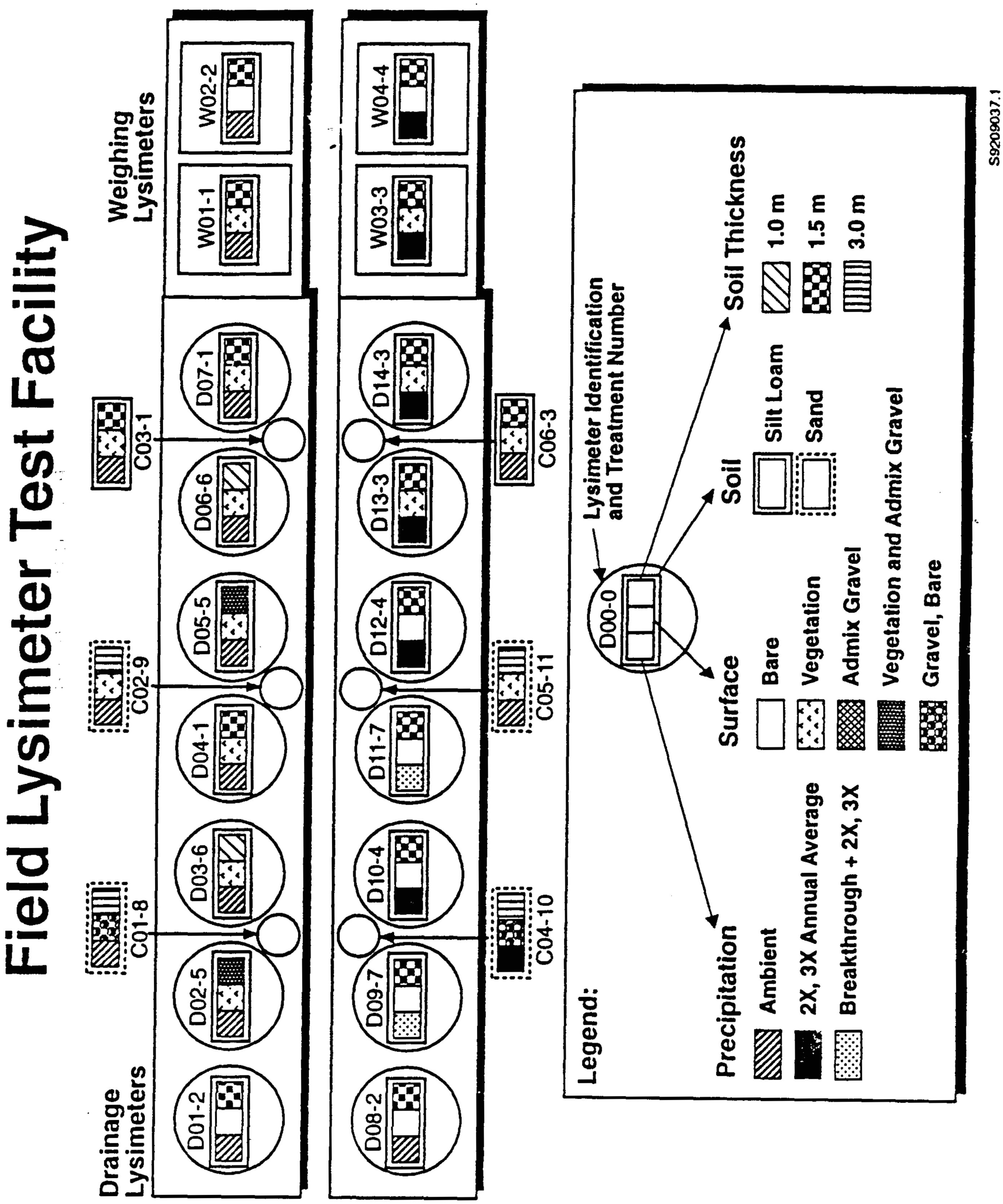
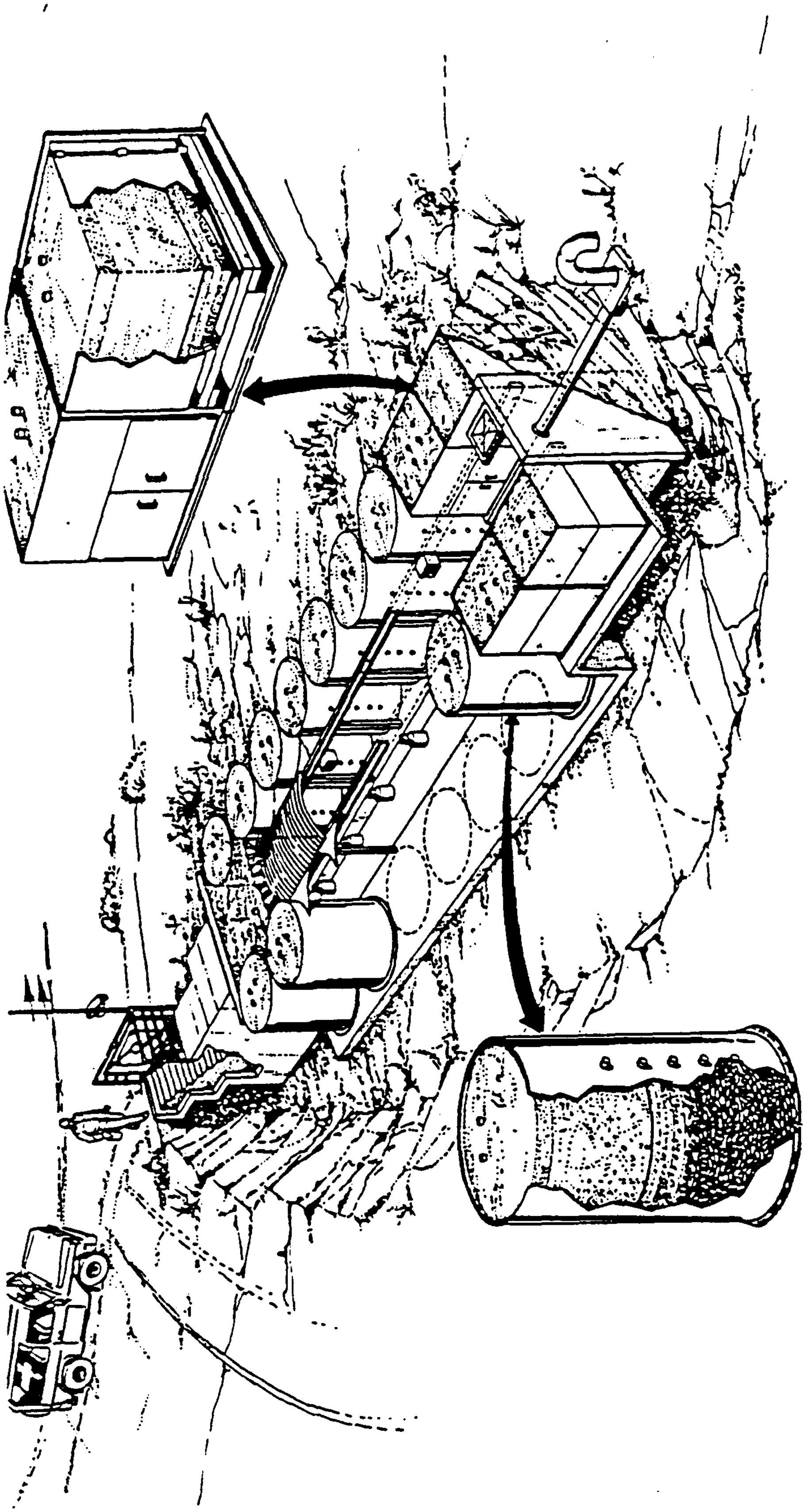


Figure 3-6. The Field Lysimeter Test Facility: Artist's Conception.



the atmosphere. Unless checked in some way, the water would be free to migrate down through the barrier and into the waste zone below. In addition, coarse-textured, sparsely vegetated side slopes will allow significant water infiltration. (Please refer to Section 3.1.5 for a more detailed discussion of water infiltration through side-slope materials.) As a means of restricting the percolating water from gaining access to the waste zone, a low-permeability component is strategically placed within the barrier profile below the capillary barrier to divert percolating water away from the buried waste. This diversion barrier is constructed of a material(s) with low permeability such as asphalt.

Two types of asphalt have been used in tests being conducted by the BDP. Based on recommendations supported by laboratory test results, lysimeter studies at the Small-Tube Lysimeter Facility (STLF) have used two asphalt formulations: (1) hot rubberized asphalt and (2) an admixture of cationic asphalt emulsion and concrete sand containing 24-wt% residual thick asphalt. These asphalt formulations have been very effective in limiting percolation (Freeman et al. 1989). A third type of asphalt, asphaltic concrete with ~8% asphalt, also is being evaluated for use in barrier designs. The advantage of this third asphalt formulation is its high mechanical strength.

Compacted clay layers will be used sparingly, if at all, in permanent isolation barriers at the Hanford Site. This reticence to use compacted clay layers is caused primarily by the hot, arid climatic conditions at the Hanford Site. The construction of compacted clay layers requires relatively close control of moisture content and/or compactive energy imparted to the clay to achieve the desired degree of impermeability. The level of control required to achieve the desired low hydraulic conductivities may be difficult to realize and maintain during the Hanford Site's hot, dry summers and for the extremely large barriers planned for the Hanford Site's disposal needs. In addition, concerns have been raised regarding the potential for desiccation cracking of clay layers in arid sites following construction.

Geosynthetic clay liners (GCLs) may provide an effective alternative to the compacted clay layers. GCLs are easy to install and because they are placed in an unhydrated condition, the problems associated with drying and desiccation cracking during construction are minimized.

A particularly promising application of GCLs is their use in tandem with an asphalt layer to form a composite low-permeability layer. The composite layer concept has been shown to provide much lower permeabilities than one layer alone (Daniel and Trautwein 1991). One concept currently being considered is to place a GCL directly on top of an asphalt layer. Any cracks or holes that may develop (but are not expected) in the asphalt would be "plugged" by hydrated clay from the GCL above. Another composite layer concept currently being considered is the application of a layer(s) of hot rubberized asphalt directly on top of a layer(s) of asphaltic concrete.

Additional research and testing needs to be conducted to verify the effectiveness of these concepts. In addition, the physical properties of the various types of asphalt being considered for use in permanent isolation barriers need to be understood. These physical properties include large-scale permeability and the stress-strain relationships associated with 3-dimensional deformation. Another area requiring further study pertains to the longevity soil water stored in the unvegetated lysimeters decreased during the 5-yr test period. It should be emphasized that no drainage was collected from any of these lysimeters.

The capillary barrier concept does have its limits, however. During the commencement of the sixth year of testing, drainage was observed (during the unusually wet winter of 1992-1993) from several unvegetated lysimeters receiving supplemental precipitation. The routine supplemental irrigation treatments when combined with the unusually large amount of precipitation received during that winter resulted in greater than 3X (>520 mm) precipitation being added to the subject lysimeters. The net result was that the storage capacity of the fine-soil reservoir was exceeded and the unvegetated lysimeters began draining. The lysimeters with vegetation did not drain even though they received the same amount of moisture (520 mm).

Because of earlier tests conducted on two of the lysimeters at the FLTF, some understanding existed of the limits of the capillary barrier's performance. In two of the drainage lysimeters at the FLTF, enough water was added to force water to break through the capillary barrier. As expected, it was determined that water does not pass through the capillary barrier in the liquid phase until the soil approaches saturation and pore pressure approaches zero. Once breached, the capillary barriers in the lysimeters drained only slowly until they reached a stable water content, resulting in a storage of over 500 mm -- almost twice as high as that normally held by that soil against gravity (~250 mm) (Campbell et al. 1989).

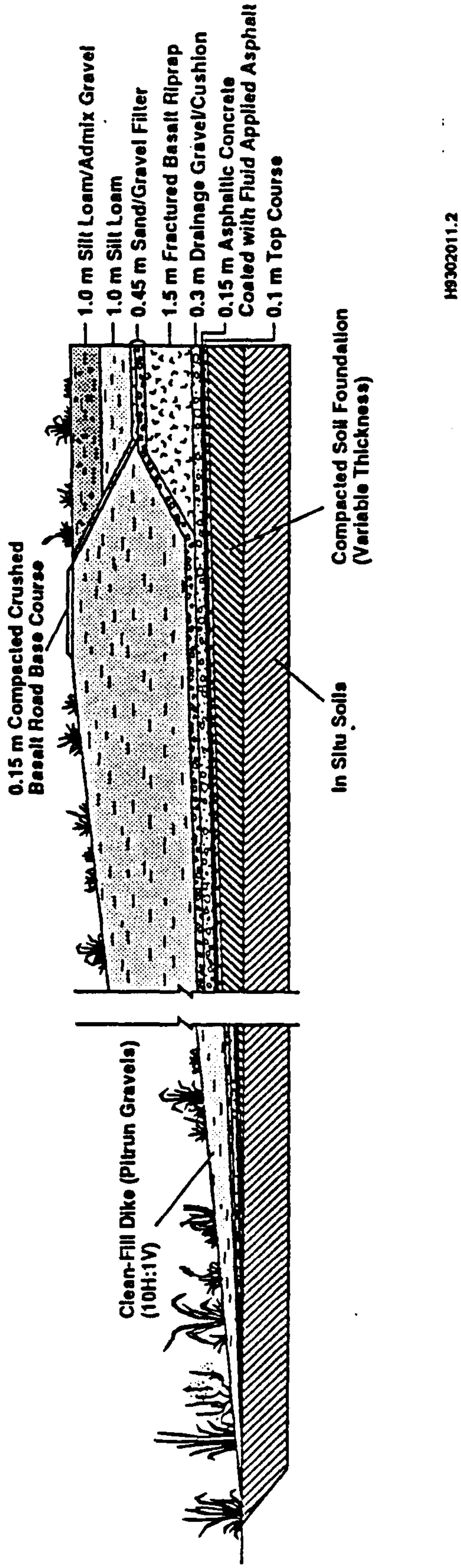
The observations at the FLTF indicate that both vegetated and unvegetated barrier systems are able to store and evapotranspire at least three times the annual average precipitation--simulating the upper bound of projected climate changes at the Hanford Site during the next 1,000 yr. Vegetated barrier systems are able to accommodate even greater amounts of precipitation because of the water extraction capabilities of plants--thereby providing increased storage capacity. For those infrequent occasions when the moisture retention capabilities of the fine-soil layer are exceeded, the low-permeability layers located lower in the barrier profile will provide another barrier to water infiltration. (A more in-depth discussion of the low-permeability layers is provided in Section 3.1.4.)

Future activities at the FLTF and elsewhere will address other water infiltration control issues. For example, issues regarding vapor-phase transport past the capillary break will be addressed. In addition, a prototype barrier planned for construction in the near future will enable tests to be performed to determine the effectiveness of the capillary barrier on a much larger scale than that provided by lysimeters.

3.1.4 Low-Permeability Layers

The basic premise of the capillary barrier concept is that most, if not all of the meteoric water that infiltrates the barrier surface can be returned to the atmosphere by surface evaporation and plant transpiration. However, for periods of unusually heavy, intense, and/or prolonged precipitation, the water-holding capacity of the fine soils may be exceeded, thereby allowing water to break through the capillary barrier before it can be recycled back to

Figure 3-8. Barrier Side Slope: Clean-Fill Dike Concept.



of asphalt as a low-permeability component. The asphaltic layers need to be durable enough to provide the level of impermeability needed over the design life of the permanent isolation barriers. Asphalt longevity studies were initiated in 1992.

The low-permeability layers, in concert with (1) the engineered surface that maximizes runoff and (2) the capillary barrier, which blocks the downward movement of percolating water, is expected to perform in such a way that near-zero drainage rates through the barrier can be achieved.

3.1.5 Edge Effects

The term "edge effects," used in this context, refers to the influence of the barrier side slope and toe on the overall performance of the barrier. The side slopes and toes of permanent isolation barriers are generally designed and constructed with materials and such that long-term stability can be achieved and water accumulation can be controlled. Two radically different side slope designs are being considered by the BDP: (1) a relatively flat apron of clean-fill materials (commonly called a clean-fill dike) (Figure 3-8) and (2) a relatively steep embankment of fractured basalt riprap (Figure 3-9).

The clean-fill dike concept uses readily available borrow materials (such as pitrun gravels) to create a relatively flat apron around the periphery of the barrier. This relatively flat apron provides a more gentle transition from the shoulder of the barrier to the surrounding environment than does the steep side slope.

A clean-fill dike side slope is desirable for several reasons. First, it is aesthetically appealing and tends to blend in with the surrounding environment. Second, the pitrun gravels used to create the clean-fill dike will probably provide a relatively erosion-resistant surface. Third, the pitrun gravels used in construction of the clean-fill dike will probably support the growth of vegetation. Vegetation already has been described as a desirable barrier feature for the removal of undesirable, excess water from waste sites. Fourth, the pitrun gravels used in the design of the clean-fill dike side slope may be more effective in transmitting runoff water further away from the waste zone than the fractured basalt riprap used in the other side-slope design configuration.

A disadvantage of the clean-fill dike concept is that its gentle slope could significantly increase the surface area, or footprint, of the barrier. If significantly more construction materials are needed to create the gently sloping apron, the costs of the clean-fill dike concept may also be greater than for a steeper side slope, despite the fact that the unit cost of pitrun gravels is considerably less expensive than for fractured basalt riprap. (An engineering evaluation should be performed to assess the cost effectiveness of these concepts.) The subtle blending of the barrier with the surrounding topography may also pose some challenging human intrusion design considerations and tradeoffs (please refer to Section 3.4).

The steep side slope design uses fractured basalt riprap, which consists of relatively large angular rocks. The angularity of the riprap provides many interlocking surfaces between adjacent rocks, enabling a relatively steep, yet stable, side slope to be created. A steep, rocky side slope provides several desirable design features. First, steeper side slopes help to minimize the total surface area of the barrier. Second, the steep, rocky side slope clearly delineates the boundaries of the surface barrier. Third, the basalt riprap is an effective erosion control feature (please refer to Section 3.3.2).

However, in addition to its positive features, the limitations of a riprap side slope also must be understood and considered. For example, the procurement of basalt riprap at the Hanford Site can be quite expensive and difficult to obtain. Costs associated with drilling, blasting, crushing, screening, and hauling the basalt riprap from the quarry to the barrier construction site can be significant. In addition, cultural resource and other environmental concerns associated with basalt outcrops must be considered. In certain circumstances, these cultural and environmental concerns can prohibit the procurement of basalt riprap from specific locations.

Another potential problem with basalt riprap is that in some circumstances, it can encourage the invasion and establishment of deep-rooted perennial plants. These deep-rooted plants could encroach into undesirable locations of the barrier or the waste zone. Potential remedies for this problem include burying the riprap side slopes beneath clean-fill dikes that provide soils that promote favorable plant growth, or using a choked-rock design to fill in the interstices of the outermost riprap surfaces.

In addition, fractured basalt riprap has many relatively large pore spaces between adjacent rocks. Consequently, surface water that comes into contact with the fractured basalt side-slope materials will readily drain through the pore spaces between rocks and onto the native soils over which the barrier has been constructed. Hence, the basalt riprap will do little to divert the movement of any infiltrating water.

The control of water infiltration at the periphery of the barrier is a significant design feature that must be considered for both clean-fill dike and fractured basalt side slopes. As discussed previously in this document, protective barriers are designed with sloped fine-soil surfaces and low-permeability subsurface components. Consequently, water will be channeled to the side slopes and toe of the barrier. As a result of this channeling, a significant amount of water could accumulate at the periphery of the barrier. This accumulation of water poses two major design considerations: (1) What effect does the additional water have on side slope stability and erosion? and (2) How can the additional water be kept from contacting buried wastes? The response to the first design consideration is addressed in Sections 3.1.6 and 3.2.2.2. The response to the second design consideration is addressed in the following four sections (3.1.5.1 to 3.1.5.4) of this document.

3.1.5.1 Barrier Overhang. Because water running on and off the barrier is being concentrated into a relatively localized area at the side slope and toe, the amount of water available for recharge at the periphery of the barrier may be significantly higher than at other locations of the barrier that receive only ambient precipitation. The use of sufficient "barrier overhang" is one

Figure 3-9. Barrier Side Slope: Fractured Basalt Riprap Concept.

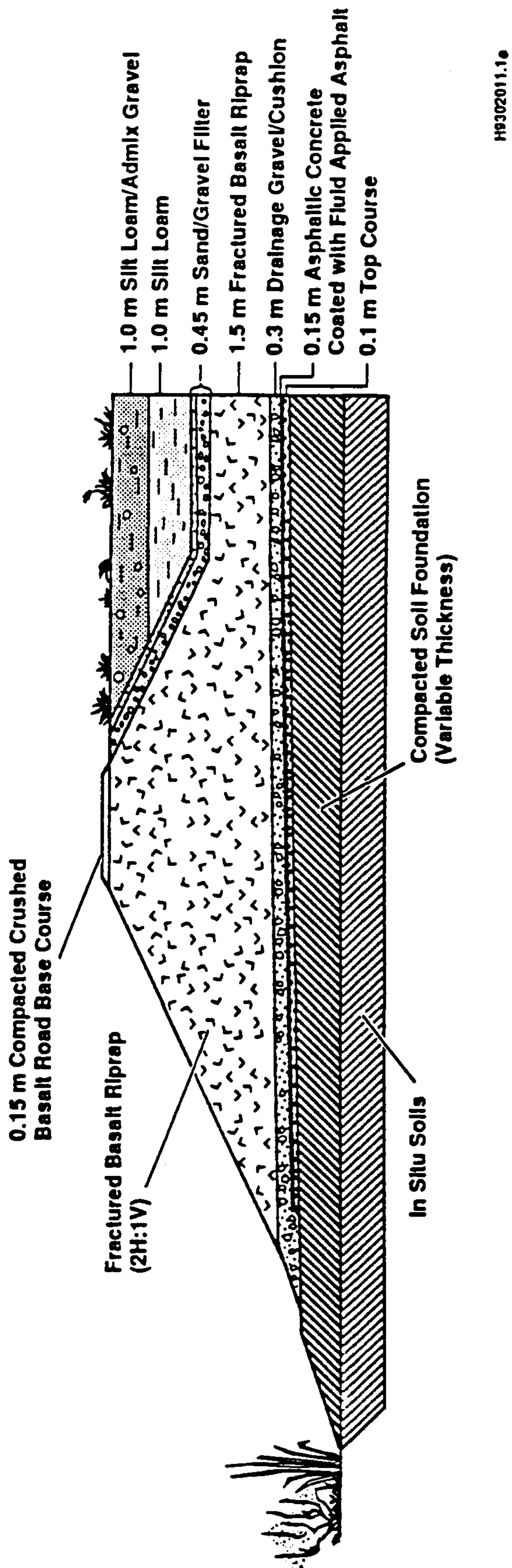
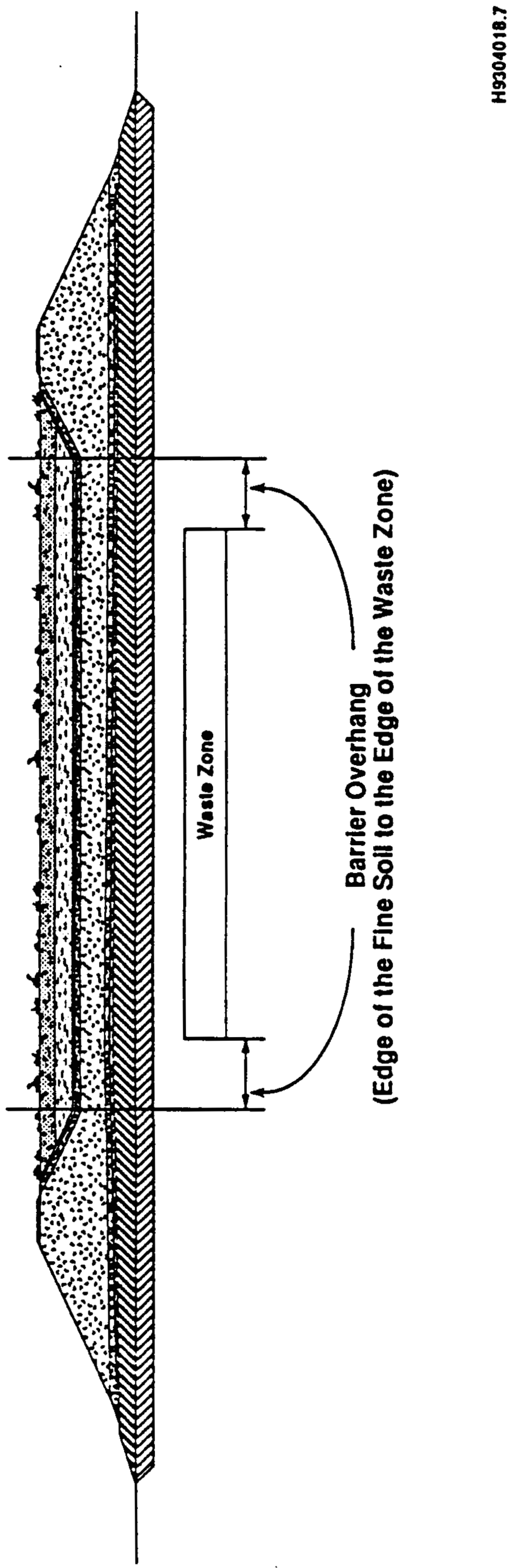


Figure 3-10. Barrier Overhang.



technique being employed to manage the excess water and inhibit it from contacting wastes buried under the barrier.

"Barrier overhang" is the terminology used to describe the projection of the functional barrier surface (outer edge of the fine-soil layer--Figure 3-10) beyond the perimeter of the waste zone. Barrier designs use overhang to control the lateral flow of water from the toe of the barrier (where water accumulates) to the waste zone (Figure 3-11). If the barrier overhang is great enough, the amount of water (if any) that gains access to the waste zone via lateral flow would be sufficiently low to minimize the possibilities of contaminant leaching and subsequent transport.

Two-dimensional computer simulation models have been used to optimize the amount of barrier overhang needed (Fayer 1987). Enough overhang is required to control the lateral flow of water into the waste zone. However, considering cost, it is also desirous to minimize the size (and therefore the cost) of the barrier. The computer simulation models are being used to optimize the amount of overhang needed while maintaining the cost of protective barriers at a minimum. Using simulated conditions, preliminary modeling results suggest that edge effects associated with water accumulation at the toe of the barrier are minimized with a 10-m barrier overhang (Fayer 1987). This result was for a situation where the waste was as deep as 14 m, and the surrounding sediments were sand. If the surrounding sediments were finer textured (like silt), the barrier overhang would have to be increased.

3.1.5.2 Asphalt or Grout Curtains. As an additional means of restricting the lateral flow of accumulated water from the toe of a barrier to the waste zone, asphalt or grout curtains could be designed and constructed (Figure 3-12). The asphalt or grout curtains would consist of a vertical ring or band of low-permeability materials that completely encircles a waste site. The curtain would be constructed such that runoff water from the barrier would be diverted onto the side of the curtain opposite the waste zone. In this manner, the curtain would serve as a barrier between the water and the waste.

The incorporation of low-permeability asphalt or grout curtains into permanent isolation barrier designs could be used to reduce the amount of barrier overhang required. An engineering evaluation should be performed to determine the cost effectiveness of this concept.

3.1.5.3 Barrier Toe Design. The barrier must be designed so that the accumulation of water under the side slope and at the toe of the barrier is not allowed to travel indiscriminately via overland or subsurface flow into adjacent waste sites. Designs such as the ones illustrated in Figure 3-8 and Figure 3-9 will be tested on the prototype barrier. The low-permeability asphalt layer is extended beneath the side slopes to the toe of the barrier. Water that percolates through the relatively porous side slope materials and comes into contact with the asphalt layer will be channeled to the toe of the barrier. The accumulation of water at the toe is expected to enhance the establishment of plants in this region. Plants are known to be very effective in extracting or mining water from soils via the process of transpiration.

Figure 3-12. Asphalt or Grout Curtains.

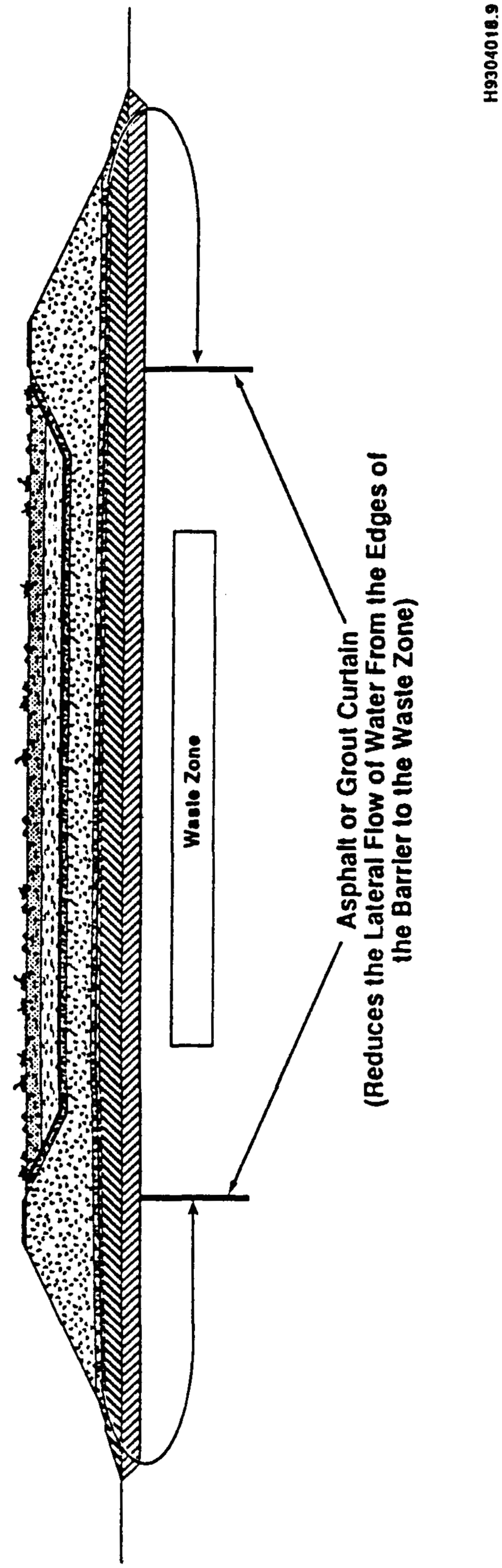


Figure 3-11. Lateral Flow of Water from the Barrier Edge to the Waste Zone.

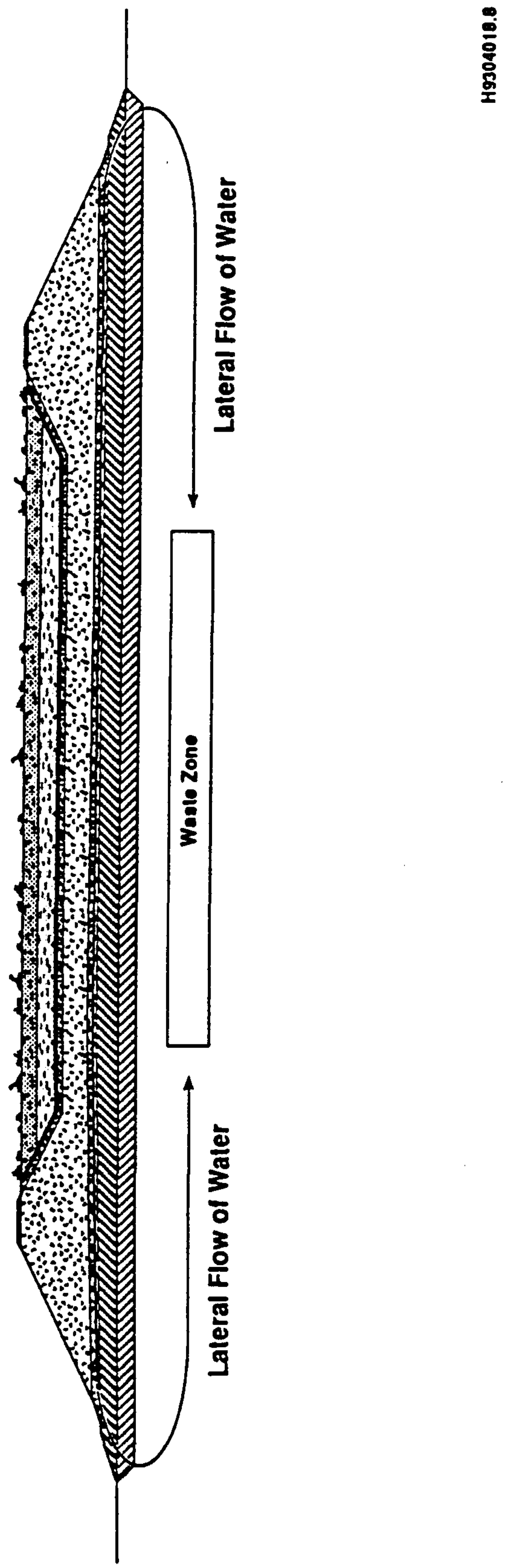
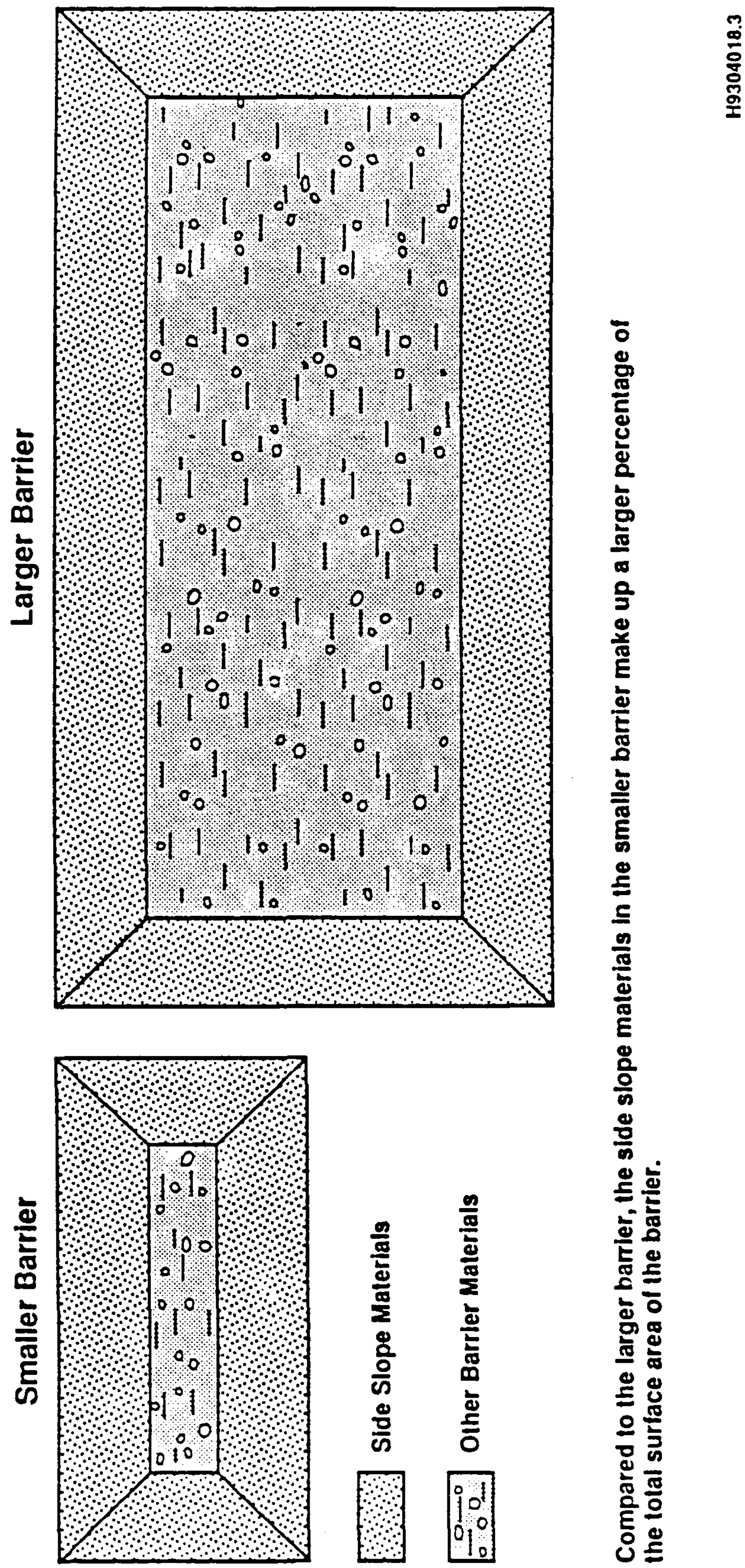


Figure 3-13. The Impact of Edge Effects as a Function of Barrier Size.



The distance of the toe of the barrier from the waste zone will need to be designed with considerations of barrier overhang. Enough barrier overhang will be needed to minimize the lateral migration of the accumulated water backto the waste zone. In addition, enough barrier overhang will need to be provided to assure that plant roots are far enough away from the waste zone so that biointrusion does not become a concern.

The effectiveness of the two side slope/toe design concepts presented will be evaluated as part of the testing and monitoring activities planned for the prototype barrier. Based on their performance, the side slope/toe designs will be adopted or modified, as necessary.

3.1.5.4 Barrier Size. The extent to which side slopes influence barrier performance is dependent on the size of the barrier. Generally, larger barriers minimize the adverse impacts associated with edge effects. Calculating the following ratio clarifies the impact of the edge effects:

$$\text{Edge Effect Ratio} = \frac{\text{Total Surface Area of the Side Slope Portion of Barrier}}{\text{Total Surface Area of the Entire Barrier.}}$$

For a smaller barrier, the edge effect ratio would be greater than for a larger barrier because the side slope materials make up a greater percentage of the barrier's total surface area (Figure 3-13). Consequently, the larger the barrier, the more edge effects are minimized.

3.1.6 Physical Stability

Protective barriers must be able to function as designed after experiencing potentially disruptive events that may be expected to occur during the design life of the barrier. These potentially disruptive events may be the result of (1) natural phenomena such as earthquakes and tornados, or (2) the physical, chemical, and radiological characteristics of the various types of waste being disposed of.

An assessment is needed, and is planned to be conducted in the near future, to identify those extreme potentially disruptive natural events that are likely to affect protective barriers at the Hanford Site based on a probabilistic evaluation. Those disruptive events determined to have a reasonable probability of occurring during the design life of the barrier will be assessed to determine their consequences on the performance of the protective barrier. Specifically, an assessment will be made of earthquakes, high-intensity precipitation events, tornados and other high-wind conditions, the deposition of volcanic ash, and any other possible naturally occurring disruptive events that could act on the barrier.

The performance of permanent isolation barriers also may be adversely affected by the physical, chemical, and radiological characteristics of certain types of waste. Of specific concern are (1) the magnitude of subsidence events occurring below the barrier and (2) the volumes, concentrations, and types of gases that could be generated by the waste. (For a discussion of the control of gaseous releases, please refer to Section 3.5.)

3.2.1.1 Plant Roots and the Capillary Break Interface. Plant roots need water to survive. Because the capillary barrier is expected to be effective in keeping water from moving past the fine-soil/sand interface, the plant-available water below the capillary barrier is expected to be limited enough so that plant root growth will not be sustained.

This phenomenon has been observed in a clear-tube lysimeter at the FLTF. In the fall of 1988, a deep-rooting sagebrush was planted in the surface soils of the clear-tube lysimeter. As the sagebrush matured, the root system of the plant developed into a network that penetrated the fine-soil layer. However, as the roots reached the textural interface between the fine soils and the coarser sands below, their growth was stopped. The roots next to the inside wall of the clear-tube lysimeter were observed to penetrate just a few millimeters into the sand. No plant roots were observed to penetrate past the sand layer and into the graded filter.

The plant lived for more than three yr within the lysimeter but appeared stressed by late 1991 and died in 1992. During its 3-yr life, while the lysimeter was subject to 2 yr of 2X precipitation and 1 yr of 3X precipitation, no water was observed to move below the fine-soil layer. In this lysimeter, the capillary barrier was effective in keeping plant roots from moving past the fine-soil/sand interface, even under conditions simulating a wetter climate.

However, as mentioned previously, the capillary barrier concept does have its limits. During the winter of 1992/1993, when record snowfalls were recorded at the Hanford Site, the storage capacity of the fine-soil reservoir was exceeded. The routine supplemental irrigation treatments, when combined with the unusually large amount of precipitation received during that winter, resulted in greater than 3X (>520 mm) precipitation being added to the clear-tube lysimeter. The net result was that the moisture in the lysimeter wetted the sand and began draining past the capillary barrier. The sublayer filter material and riprap materials were visibly wetted but no drainage occurred from the base of the lysimeter. [The lysimeters with vegetation did not drain even though they received the same amount of moisture (520 mm). It is reasonable to assume that, had the sagebrush been living during the winter of 1992/1993, the storage capacity of the soil would not have been exceeded and the underlying graded filter materials would have remained dry.]

In March of 1993, following the unusually wet winter, another sagebrush was planted in the clear-tube lysimeter. By early June the roots of the sagebrush grew past the fine soil/sand interface and into the graded filter -- following the water that had percolated past the capillary barrier. By July, the soils in the subject clear-tube lysimeter were dried out by the combined effects of surface evaporation and plant transpiration. As a result, the moisture content in the soils of the lysimeter has been reduced such that the effectiveness of the capillary barrier has been restored. The plant roots that penetrated below the capillary barrier probably will not be able to survive as the plant-available water continues to be depleted. It will be interesting to observe how this lysimeter performs over the next few years. Is the capillary barrier restored to its original effectiveness? Do the plant roots below the capillary barrier die as expected? Do the plant roots that have penetrated the capillary barrier (even if they are dead) provide a preferential pathway for moisture drainage? Destructive sampling of large

The maximum allowable subsidence that a barrier can withstand and still remain functional needs to be determined. Although the use of subsidence control measures (e.g., dynamic compaction and in situ grouting) is expected to reduce significantly the magnitude of subsidence experienced; for certain types of waste, subsidence events cannot be expected to be reduced to zero. Consequently, there is a need to determine the magnitude of subsidence that a barrier is capable of withstanding and still function as designed.

Field and laboratory tests will be performed to determine the barrier's ability to withstand subsidence events of various magnitudes. As appropriate, computer simulation models also may be used in the assessment. The results of the tests and modeling will be used to formulate barrier design standards and waste acceptance criteria. For a permanent isolation barrier to be employed, end users would be required to provide waste forms that comply with the established barrier design standards and waste acceptance criteria for subsidence.

The final permanent isolation barrier design will need to provide some measure of assurance that it can survive and function as designed following the potentially disruptive events discussed previously. Studies to ensure that current barrier designs will provide the level of physical stability needed have not yet been conducted but are scheduled for the future. Any permanent isolation barrier design modifications that are needed because of the results of the studies will be incorporated into future designs, as applicable.

3.2 BIOINTRUSION CONTROL

Protective barriers must be designed to protect wastes from the intrusion of deep-rooting plants and burrowing animals. The protective barrier design configurations being considered to control these potential problem areas are discussed in the following subsections.

3.2.1 Plant-Root Intrusion Control

Barrier designs are intended to control plant roots from the following:

- Disrupting the textural break interface between the fine-soil layer and the coarser materials below
- Disturbing the low-permeability layers
- Penetrating into the waste zone beneath the protective barrier.

The control of plant-root intrusion is accomplished primarily by the materials used to construct protective barriers (e.g., fine soil, sand, gravel, cobble, basalt riprap, and asphalt). These barrier construction materials are expected to provide an effective deterrent to plant-root intrusion.

The following paragraphs will discuss what can be done to mitigate these potential problems.

3.2.2.1 Burrowing Animals and the Disruption of Critical Barrier Interfaces. As discussed previously, it is recommended that the fine-soil layer that serves as a water retention medium be at least 1.5 m (4.9 ft) thick. Current designs use a fine-soil layer 2.0 m (6.6 ft) thick. Because the fine-soil layer is placed directly over a coarser sandy layer to create the capillary break, an animal would have to burrow down 2 m (6.6 ft) before contacting the capillary break interface. The results of a literature survey show that virtually all animals that currently inhabit or are expected to inhabit the Hanford Site during the design life of the permanent isolation barriers normally do not have a need to burrow deeper than 1 m (3.3 ft) (Gano and States 1982). Favorable biological conditions (i.e., food, shelter, moisture, soil temperature, etc.) for most of the animals are found within the top 0.5 to 1 m (1.6 to 3.3 ft) of the earth's surface. Because there is no need or incentive for these animals to burrow deeper than 2 m (6.6 ft) and because the layers below the fine soil are "hostile" (e.g., dry, sterile, composed of large rocks, etc.), the animals probably will not expend the additional energy required to dig deeper into the barrier profile.

There are animals on the Hanford Site, however, that are known to have burrowed deeper than 2 m (6.6 ft), particularly the Western harvester ant. If burrowing animals such as ants were to penetrate the top fine-soil layer of the barrier, they probably would be deterred by the highly compacted asphalt layers.

3.2.2.2 Burrowing Animals and Their Ability To Penetrate into Buried Wastes. As was the case for plant-root intrusion, the thickness of the barrier in addition to the resistance offered by the low-permeability layer (asphaltic concrete mix) and the basalt layers (crushed and fractured layers) are expected to further discourage animals from burrowing through the barrier and into the waste zone.

3.2.2.3 Burrowing Animals and the Creation of Preferential Pathways for Water Infiltration. Tests have been conducted to assess the impact of burrowing animals on the infiltration and percolation of water through protective barriers (Cadwell et al. 1989, Landeen et al. 1990, Landeen 1990, Landeen 1991). During the early years of the BDP, concerns were raised that the presence of animal burrows may provide preferential conduits through which infiltrating water could bypass the fine-soil layer of the permanent isolation barrier and subsequently migrate deeper into the barrier and possibly into the waste zone below. The results of the tests that have been conducted (for both small and large mammals) have provided somewhat contrasting results.

An Animal Intrusion Lysimeter Facility (AILF) was constructed in FY 1988 to assess the effects of small-mammal burrows on the infiltration of meteoric water through protective barriers. The AILF, located adjacent to the HMS, consists of two outer boxes buried in the ground such that the top of each of the boxes is flush with the original grade. These outer boxes serve as receptacles for six animal intrusion lysimeters; three lysimeters are housed in each outer box (Figure 3-14). Each of the lysimeters has been engineered structurally so that it can be lifted out of the outer boxes with a crane.

vegetated lysimeters and observations on the prototype barrier will further define the ability of the capillary barrier to resist root penetrations. As the information from this and other lysimeters and studies becomes available, it will be incorporated into future barrier designs as needed.

3.2.1.2 Plant Roots and the Low-Permeability Layers. The textural break at the capillary interface between the fine soil and sand layers is expected to substantially limit root penetration into the lower portion of the barrier profile. However, if plant roots are able to penetrate through the fine-soil layers, the coarser materials used in the lower portions of the barrier profile will provide an additional deterrent to plant-root intrusion. As an example, the use of gravels and fractured basalt below the capillary break will probably discourage plant-root intrusion by limiting plant-available water. Consequently, it is not expected that plant roots will come into direct contact with the low-permeability layers that lie beneath the sands, gravels, and fractured basalt. However, should the plant roots come into direct contact with the low-permeability materials, the compacted asphalt is expected to limit root penetration deeper into the barrier profile. Previous work performed by PNL, using asphalt layers on uranium mill tailing sites, indicated that compacted asphalt emulsion layers are effective in preventing root intrusion (Baker et al. 1984). Tests have been conducted at the STLF to verify the effectiveness of asphalt layers in preventing root intrusion under Hanford Site conditions.

3.2.1.3 Plant Roots and the Waste Zone below the Barrier. In addition to the barrier construction materials and the properties derived from their placement (textural break, coarse materials, and compacted asphalt layers), the sheer thickness of the protective barrier is anticipated to exceed the maximum rooting depths of most plants expected to grow on the barrier. The thickness of current permanent isolation barrier designs is around 5 m (16.4 ft). The thickness of the barrier, in addition to the thickness of the overburden materials backfilled over the waste zone before barrier construction, provide a substantial buffer between the barrier's surface and the upper portions of the buried wastes. Root intrusion tests are an ongoing task in the BDP. Results from these tests will be incorporated into future designs.

3.2.2 Burrowing Animal Intrusion Control

As with plant root intrusion, the intrusion of burrowing animals could adversely affect barrier performance in the following ways:

- The disruption of critical barrier interfaces
- The penetration into and transport of contaminants from the waste zone
- The creation of preferential pathways for water to migrate deeper into the barrier profile
- The deposition of loose soil castings on the barrier surface with potential for accelerated soil erosion (barrier degradation).

The side walls of the lysimeters also have been engineered such that they can be disassembled.

The lysimeters at the AILF were designed such that a series of 3- to 4-month long tests could be conducted at the facility. The following description illustrates how the lysimeters in the facility are used to assess the effects of animal intrusion on the infiltration of water through a protective barrier. Each of the animal intrusion lysimeters is filled with soil excavated from McGee Ranch. (McGee Ranch is the borrow pit site that has been established for obtaining fine soils with which to construct protective barriers). Small-burrowing mammals, common to the Hanford Site, are introduced into the lysimeters and allowed to burrow for a 3- to 4-month period of time. During this 3- to 4-month period, supplemental precipitation is added to three of the six lysimeters using a rainfall simulator (rainulator). The supplemental precipitation is applied once a month at a rate equivalent to a 100-yr storm event at the Hanford Site (0.55 in. [0.14 cm] of water -- it takes the rainulator 13 minutes to apply this amount. See Section 3.1.1.2 for a discussion of the 100-yr storm).

Soil moisture samples are taken at the beginning of the experiment as well as at the conclusion of the 3- to 4-month testing period. Throughout the duration of the test, soil moisture measurements also are taken with a neutron moisture probe. These neutron moisture probe measurements, along with the soil moisture samples taken at the beginning and end of a testing period, enable a determination to be made of the changes in the soil moisture content throughout the barrier profile.

At the conclusion of the testing period, the burrowing animals are released and the burrow networks throughout the lysimeters are mapped. The changes in soil moisture content can then be correlated with the burrow networks created by the small mammals.

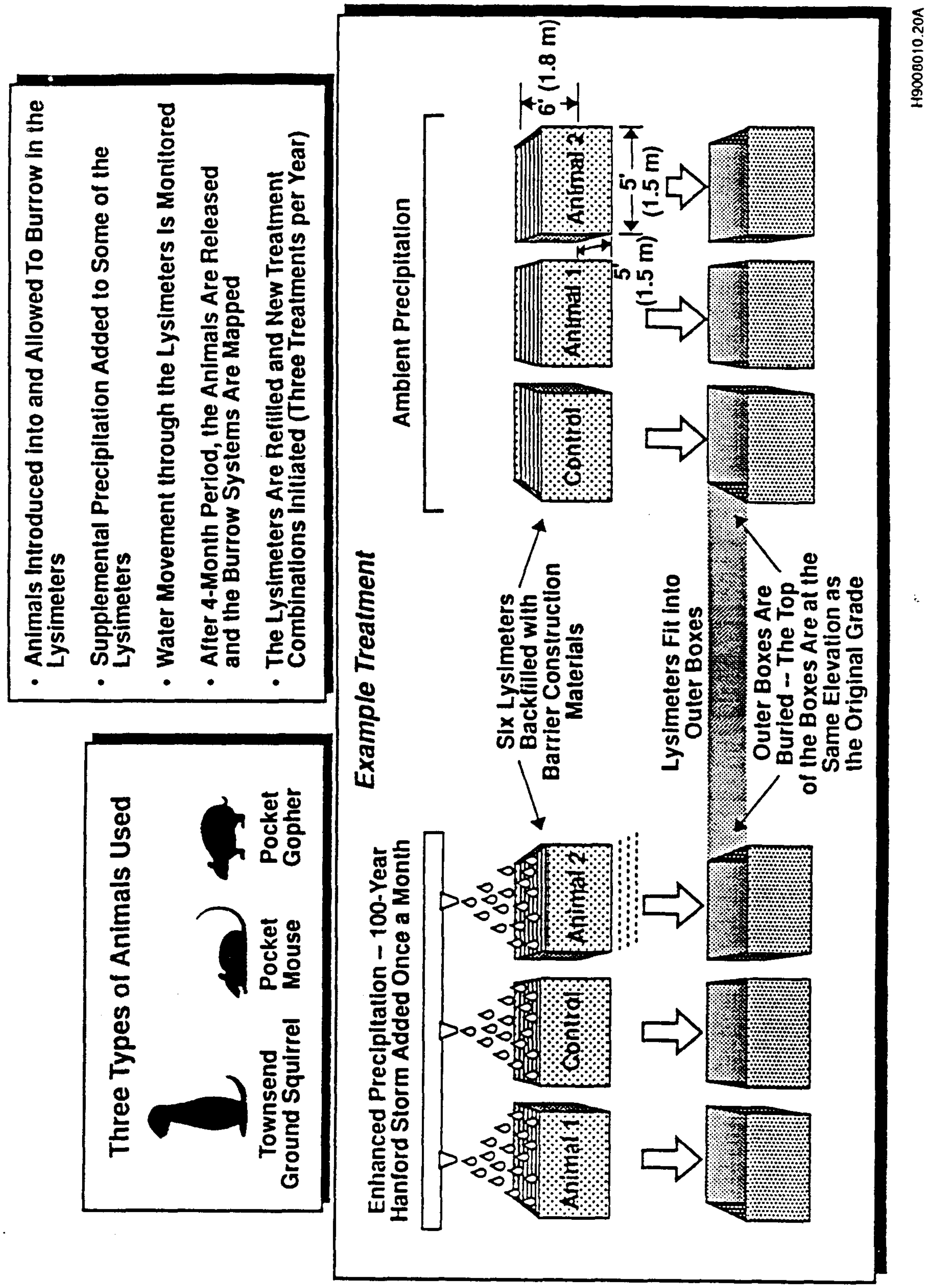
The following trends have been observed from the tests conducted to date with small mammals at the AILF (Landeen 1991).

- During the summer months, more water is lost from plots with animal burrows than from the control plots (no animal burrows).
- During the winter months, both the plots with animal burrows and the control plots gain water.
- There is no indication of water infiltration below ~1 m (36 in.) even though burrow depths always exceed ~1.2 m (48 in.).

The lack of significant water infiltration at depth and the overall water loss in the lysimeter plots is occurring despite the following worst-case conditions:

- No vegetative cover (no water loss through transpiration)
- No water runoff (all incipient precipitation is contained)
- The burrow densities in the lysimeters are greater than the burrow densities found in "natural" settings

Figure 3-14. Animal Intrusion Lysimeter Facility: Experimental Design.



vicinity of badger burrows after the 1989 growing season than in nearby locations away from burrows. Studies are currently underway to determine whether the preferential drying occurs in soils beneath the burrows in the absence of vegetation.

Other observations were made with the large-mammal burrows. These observations were summarized by Cadwell and others in the document edited by Wing and Gee 1990.

The FY 1989 annual characterization of existing marked badger burrows indicated that abandoned burrows are only temporary surface features that soon fill with soil and organic debris. Many of the badger burrows also connect with small-mammal burrows. The small mammals appear to be instrumental in filling the larger burrows by casting soil into the openings. More importantly, the smaller burrows provide an opportunity for runoff that enters large burrows to drain.

From the results of the testing performed to date, the presence of small-mammal burrows does not appear to have a significant effect on the deep percolation of water through the barrier. Large mammals do appear to cause increased deep penetration of water in the fine-soil layer, but it was observed that much of this water was removed later. The current barrier design does not include design features to reduce the hazards of deep water penetration through large-mammal burrows because there has been no demonstrated need based on work conducted to date.

3.2.2.4 Burrowing Animals and the Deposition of Loose Soil Castings on the Barrier Surface. The soils excavated by burrowing animals and deposited on the surface of a protective barrier are thought to be more susceptible to accelerated erosion than the surrounding soils that have not been disturbed by animal activity. A discussion of this issue is provide below in the section pertaining to wind erosion of the barrier surface (Section 3.3.1).

3.3 WIND AND WATER EROSION CONTROL

Protective barriers are being designed to minimize the effects of wind and water erosion of the surface cover, side slopes, and toe of a protective barrier. In addition, designs for stabilizing the areas surrounding the protective barriers are being considered to minimize the deposition of wind-blown materials from these areas onto the surface of the barrier.

3.3.1 Barrier Surface

Throughout the majority of its design life, vegetation will be growing on the surface of the protective barrier. The presence of vegetation on the barrier surface will significantly reduce the amount of fine soil lost from the barrier by wind and water erosion. However, to protect the barrier surface during periods of time when the vegetative cover is disturbed by range fires, drought, disease, or some other phenomenon, surface gravels will be admixed into the surface of the protective barrier.

- Extreme rainfall events applied frequently (three 100-yr storm events in 3 months)
- Animals burrow deeper in the lysimeters than in "natural" settings.

Three preliminary conclusions have been drawn from the tests conducted to date at the AILF. Overall water loss appears to be enhanced by (1) a combination of soil turnover and subsequent drying, (2) ventilation effects from open burrows, and (3) high ambient temperatures.

Similar water loss results have been observed for experiments conducted on existing large-mammal burrows found in a natural setting on the Arid Land Ecology Reserve at the Hanford Site. The large-mammal burrows studied were excavated by coyotes and badgers in search of prey. The soils into which the burrows were excavated consist of a silt loam similar to the sediments found at the McGee Ranch.

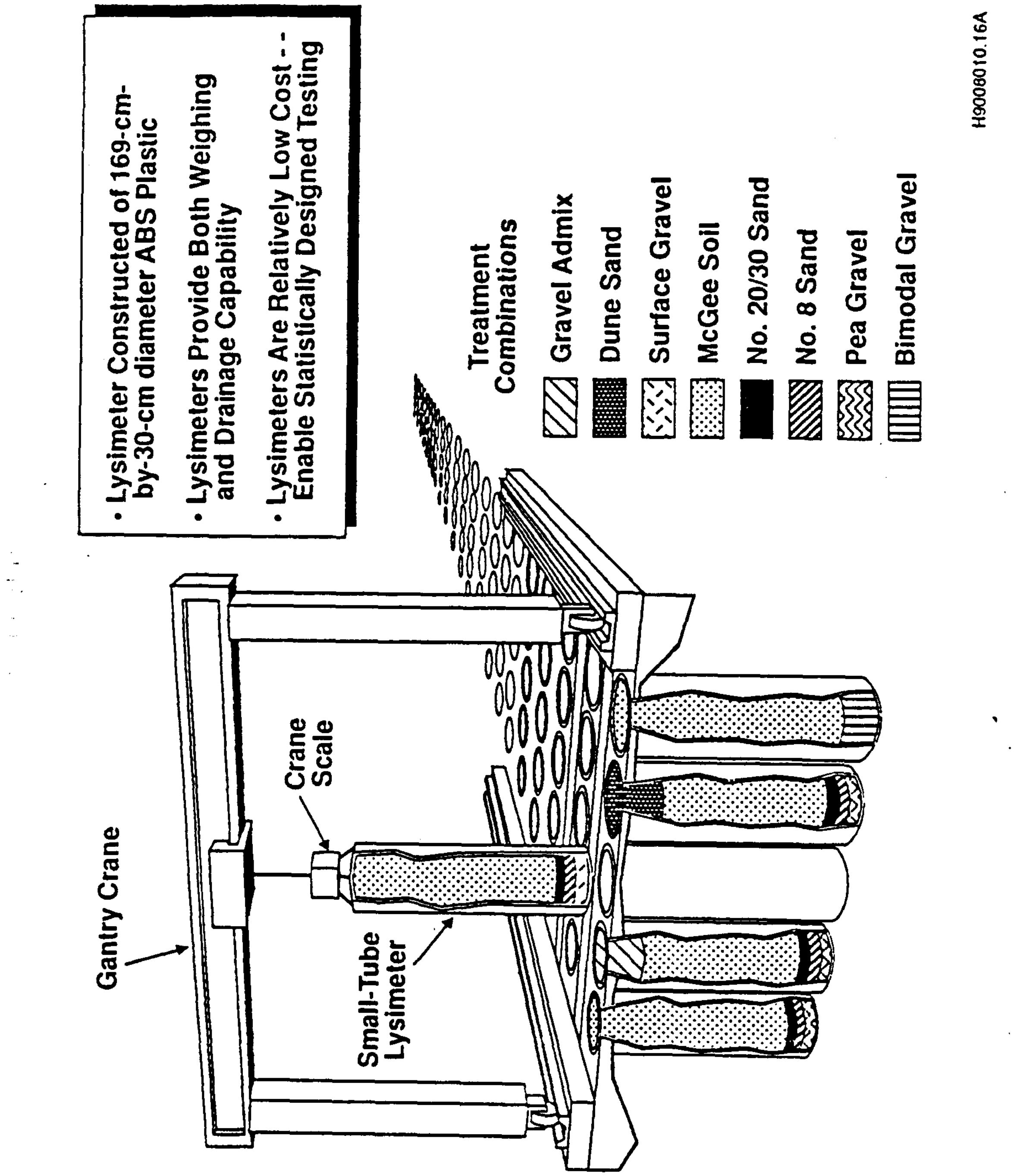
One of the studies conducted with the large-mammal burrows demonstrated that the burrows are very effective in rapidly accumulating runoff water as it moves across the soil surface via overland flow. Cadwell and others provided the following observations (Cadwell 1991).

> Studies...were conducted to quantify the amount of runoff entering badger burrows. A runoff generator was used to apply water along the slope above badger burrows. Results from these studies showed that burrows intercept a considerably greater amount of runoff than expected based solely on the surface area of the burrow. Thus, it seems clear that runoff may either be funneled into burrows, or there may be increased infiltration in the soil around burrow openings or both.

Neutron probe access tubes were installed around the periphery of several of the large-mammal burrows as well as in nondisturbed areas adjacent to the burrows. The effects of large-mammal burrows on water infiltration and percolation were studied by comparing the moisture contents of the soils around the burrows with the "control" plots (the nondisturbed areas adjacent to the burrows). In some cases, supplemental precipitation was added to the burrows being studied as well as to the "control" plots. The researchers provided the following observations from the tests that were conducted (Cadwell 1991).

> Observations made with simulated rainfall in previous years showed that large burrows dug by coyotes and badgers can divert surface water deep into barrier soils. Measurements made in FY 1989 and FY 1990 document that under natural rainfall, precipitation penetrates deep beneath and around badger burrows. However, the water is subsequently withdrawn...In disturbed soils near burrows, the vigorous growth of invading plant species may result in the preferential extraction of water through plant transpiration. Enhanced evaporation from the soil surfaces exposed by burrowing may also preferentially remove soil water near burrows. Our data showed that the soil beneath burrows in mid-summer was actually drier than in adjacent areas away from burrows. Vegetation sampling showed that plant densities (mustards) were significantly greater in the

Figure 3-15. Small-Tube Lysimeter Facility: Experimental Design.



The amount of gravel used to stabilize the surface of the protective barrier is a critical design consideration. If too much gravel is mixed into or spread onto the fine-soil surface, plant transpiration and surface evaporation could be significantly reduced, thereby increasing the potential for water drainage through the barrier. Conversely, if too little gravel is used, the ability of the gravel admix to reduce wind and water erosion may be severely limited.

The range of surface-gravel concentrations and sizes over which protective barriers perform best is being determined in the BDP by using computer simulation models as well as field and laboratory tests (Fayer et al. 1985; Waugh 1989; Hoover et al. 1990; Ligotke and Klopfer 1990; and Ligotke 1993).

Computer simulation models have been used to estimate the optimum amount of gravel that should be used. The computer models simulate the relative sensitivity of barrier performance (with respect to water infiltration) to the amount of gravel admixed into or spread onto the fine-soil surface (Fayer 1985). The range over which the simulations predict the barrier to perform best have then been tested in the field.

At the STLF, the water storage and evapotranspiration in a permanent isolation barrier were determined to be significantly affected by the types of materials used on the barrier surface. The lysimeters at the STLF have been backfilled with materials to test how various erosion control surface treatments affect soil moisture balance (Figure 3-15). Relyea et al. (1989) reported the following:

> The surface treatments include bare soil, gravel admix, gravel mulch, and dune sand with and without vegetation and with ambient and twice normal precipitation. . . . Initial results suggest that there is less evapotranspiration and greater storage in the gravel-mulch and dune-sand treatments than in the bare soil and gravel-admix treatments. Vegetation appears to decrease the storage and increase the evapotranspiration for the precipitation treatments and all surface treatments.

Drainage has occurred only in irrigated gravel- and sand-covered lysimeters. Because of the results stated above, from a water infiltration standpoint, the use of admix gravels rather than gravel mulches is recommended.

Studies conducted in the PNL Aerosol Wind Tunnel Research Facility have shown that field wind erosion stresses and surface conditions can be replicated in the wind tunnel. These studies have provided significant input for the design of protective barriers (Ligotke and Klopfer 1990; Ligotke 1993). For example, wind tunnel tests have demonstrated that admixtures and layers of 0.3- to 0.7-cm (0.12- to 0.28-in.) gravels provided superior surface protection. The best gravel admixtures reduced surface deflation rates by 96% to >99% (compared to unprotected soil). In addition, it was determined that rounded river rock and angular crushed-rock gravel provided equal surface protection, thereby expanding the possibilities of finding adequate source materials for the least expense.

During a tour of the AGTP in FY 199^ a fresh animal burrow, excavated into one of the subject admix gravel tes plots, was observed. The fine soils brought to the surface by the anima were free of gravel, indicating that the animal had burrowed deeper than 30 cm (1 ft) (the depth to which gravels had been admixed into the fine soil). A concern was raised that the unarmored fine soils cast to the surface by the burrowing animal may be more susceptible to accelerated erosion than the surrounding undisturbed soils. Because of this concern, modifications to the design of the barrier were made.

The depth to which admix gravels were mixed into the surface of the fine-soil layer was increased from 30 cm to 1 m (1 ft to 3.3 ft). The rationale for this decision was that virtually all animal burrowing activities are confined to the top 1 m (see Section 3.2.2.1). The design change is intended to assure that any soil cast to the surface by an animal burrowing within the top 1 m would be armored with the admix gravels -- a more erosion-resistant material than fine soils alone. The second design change increased the total depth of the fine-soil layer (including the admix gravel portion) from 1.5 m to 2.0 m (4.9 to 6.6 ft). Calculations demonstrated that if gravel were mixed into the top 1 m (3.3 ft) of a 1.5-m (4.9-ft) fine-soil layer, the moisture retention capabilities of the fine-soil reservoir would be significantly reduced. An additional 0.5 m (1.6 ft) of fine soil was needed to maintain the moisture retention capacity of the fine-soil reservoir at acceptable levels. Therefore, the depth of the fine-soil layer was increased from 1.5 m to 2.0 m (4.9 to 6.6 ft).

3.3.2 Barrier Side Slopes and Toe

As was mentioned in Section 3.1.5, the side slopes and toes of permanent isolation barriers are generally designed and constructed with materials and in a manner such that long-term stability can be achieved and water accumulation can be controlled. Two different side slope designs are being considered by the BDP: (1) a clean-fill dike of pitrun gravels and (2) a relatively steep embankment of fractured basalt riprap. A description of how pitrun gravels and riprap are used to control wind and water erosion is provided in the following subsections.

3.3.2.1 Pitrun Gravels and Riprap as Deterrents to Wind Erosion. As wind passes over protective barriers, turbulent gusts and eddies could be created on the upwind and downwind side slopes and toes of the protective barriers. Unless protected with materials such as pitrun gravels or riprap, these turbulent gusts and eddies could possess enough energy to scour away finer materials adjacent to the toe of the barrier. Eventually, this scouring effect could render the toe, and subsequently the side slopes of the barrier, unstable. The pitrun gravels and riprap contain large enough particles that their displacement from the effects of wind erosion is improbable. As a result, the pitrun gravels and riprap provide effective deterrents to wind erosion. In addition, the pitrun gravels used in construction of the clean fill dike will probably support the growth of vegetation. Vegetation has already been described to be a desirable barrier feature for minimizing erosional processes. The effectiveness of the side slope designs will be observed on the prototype barrier.

Wind tunnel studies also determined that erosion rates increased five times as the sand content of McGee Ranch soil was increased from 40% to 80%. The enhanced erosion is caused primarily by the sand acting as a saltating agent that abrades or scours the fine-soil surface. This finding suggests that it is prudent to minimize the amount of sand available on the barrier surface that acts as a saltating agent. Consequently, the sandy areas surrounding a permanent isolation barrier may need to be stabilized to minimize the possibility of sand being eroded from surrounding areas and deposited onto the barrier surface (see Section 3.3.3).

In addition to the wind erosion studies, other studies are being conducted to optimize the design of the barrier surface to resist water erosion (Walters et al. 1990). During their design life, permanent isolation barriers will be subjected to various hydrologic and erosional processes from rainfall and runoff generated from melting snow. For example, the barrier surface must be able to resist water erosion and the subsequent loss of fine soils resulting from rainsplash, sheetwash, rilling, or gullying. Walters et al. (1990) have noted the following:

> The loss of sediment from barrier [surface] slopes is the result of complex interactions among many variables. The amount and erosivity of runoff generated on the barrier are influenced by the form and dimension of the barrier tops. Especially important in this regard are the slope lengths, slope gradients, and slope form of the barriers, meaning whether the slopes are straight, concave, convex, or crested. Longer slopes generate more runoff, yielding deeper and potentially more erosive flows. Steeper slopes are more easily eroded. . . . Also critical to sediment yields from barriers are the types (rainfall or snowmelt) and amounts of precipitation to which the barriers are subjected. Important rainfall characteristics include raindrop size, rainfall intensity, and rainstorm duration. For snow, the critical variables are total amount and timing and rapidity of melting.

As the results of the water erosion studies become available, they are incorporated into barrier designs.

Another concern that has been evaluated in the BDP is the potential for enhanced erodibility of soils excavated from and brought to the surface of a protective barrier by burrowing animals. A preliminary estimate has been made of the cumulative volume of soils displaced through time by the burrowing activities of several common burrowing mammals indigenous to the Hanford Site. This estimate was made using an existing animal intrusion computer simulation model called BURROW. The computer model estimated that the top 100 cm (3.3 ft) of the fine-soil layer would be completely turned over by burrowing mammals in 1,500 yr.

The estimated amount of soil turnover on the barrier surface suggests that the potential for enhanced erodibility caused by the burrowing activity of animals is an important design consideration for barriers intended to function for at least 1,000 yr. Early barrier designs used a 1.5-m (49 ft) thick layer of fine soil with admix gravels incorporated into the top 30 cm (11.8 in.). Tests using this design configuration were conducted at the Admix Gravel Test Plot (AGTP) -- one of the first field tests conducted by the BDP.

than the original fine soils, could affect the establishment of desired species of vegetation on the barrier, promote deeper drainage, and reduce evaporation. In addition, if the upper, moisture-retaining layer of the barrier is too thick, moisture may percolate below the root zone where it may be difficult or impossible to evapotranspire back to the atmosphere. Another concern, discussed in Section 3.3.1, involves the deposition of sand particles on the barrier surface causing accelerated erosion of the fine-soil layer.

Large surface sand deposits in the vicinity and upwind of a protective barrier may require stabilization to reduce the amount of saltating sand flow impacting the barrier surface. This stabilization might be accomplished by spreading gravel mulches over sandy areas; however, additional study of the issue is needed before determining an appropriate solution. In addition, vegetation in the vicinity of the barrier should be re-established if disturbed during construction. This would result in a greater degree of erosion control in the surrounding areas in the critical period immediately after construction. Control over active sand deposits may not be feasible over the life span of a barrier; however, other engineering features (primarily the pea gravel admixture and the pitrun gravel or basalt sideslopes) have been included for erosion protection under worst-case climatic conditions.

3.4 HUMAN INTERFERENCE CONTROL

When institutional control is in effect, the inadvertent intrusion of humans into waste sites is considered to be an unlikely scenario because DOE will still be managing and patrolling the Hanford Site. However, if institutional control of the Site is ever lost, the threat of inadvertent human intrusion becomes a more plausible scenario. A significant amount of consideration has been given to protecting future generations (for 1,000 yr and beyond) from inadvertently contacting the buried wastes. For example, for certain types of wastes, standards have already been established to help warn the inadvertent human intruder of the dangers associated with the buried wastes. As an example, the EPA standard 40 CFR 191.14c states, "Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location." Efforts at the Hanford Site as well as at the Sandia National Laboratory have been conducted to develop, at least conceptually, a permanent warning marker system with other human interference control features (Adams and Kaplan 1986, Kaplan and Adams 1986, Guzowski et al. 1991, Hora et al. 1991, Ast et al. 1992, Givens et al. 1992).

The DOE fully intends to maintain active control of the Hanford Site (using fences, patrols, alarms, monitoring instruments, etc.) for the foreseeable future. If active control should ever cease, passive measures (i.e., those requiring no maintenance) could be developed to warn the inadvertent intruder of the potentially hazardous materials disposed beneath the barrier. These potential passive measures include recognizable warning markers, engineered features, and widely dispersed information (e.g., U.S. Geological Survey maps, libraries, and other information repositories).

3.3.2.2 Pitrun Gravels and Riprap as Deterrents to Water Erosion. As discussed in Section 3.1.5.3, the accumulation of water at the shoulder and toe of the barrier must be considered during the design of protective barriers. With the accumulation of water at the extremities of the barrier, the potential for structural instability and erosion-related problems of the barrier side slopes and toe is increased. Designs that use pitrun gravels and crushed basalt riprap have been proposed and are being engineered to accommodate the runoff water without compromising the structural stability of the barrier toe and side slopes.

The clean-fill dike concept uses pitrun gravels, which exist in abundance at the Hanford Site, to create a relatively flat apron around the periphery of the barrier. This relatively flat apron provides a more gentle transition from the shoulder of the barrier to the surrounding environment than does the relatively steeper basalt riprap side slope. As a general rule, the more gentle the side slope, the less impact erosive forces have. Because the pitrun gravels on the Hanford Site are made up of a significant portion of gravels and cobbles, it should be an excellent water erosion-resistant material.

The steep side slope design uses fractured basalt riprap. The riprap consists of relatively large angular rocks that provide many interlocking surfaces between adjacent rocks. The angularity of the riprap enables a relatively steep, yet stable side slope to be created. The fractured basalt riprap has many relatively large pore spaces between adjacent rocks. These large pore spaces allow surface water to readily drain or cascade through the rocks. As the runoff water makes its way through the rocks, much of its erosive forces are dissipated by the time it reaches the subsurface soils below the riprap. Hence, the riprap is considered to provide an effective deterrent to water erosion, too.

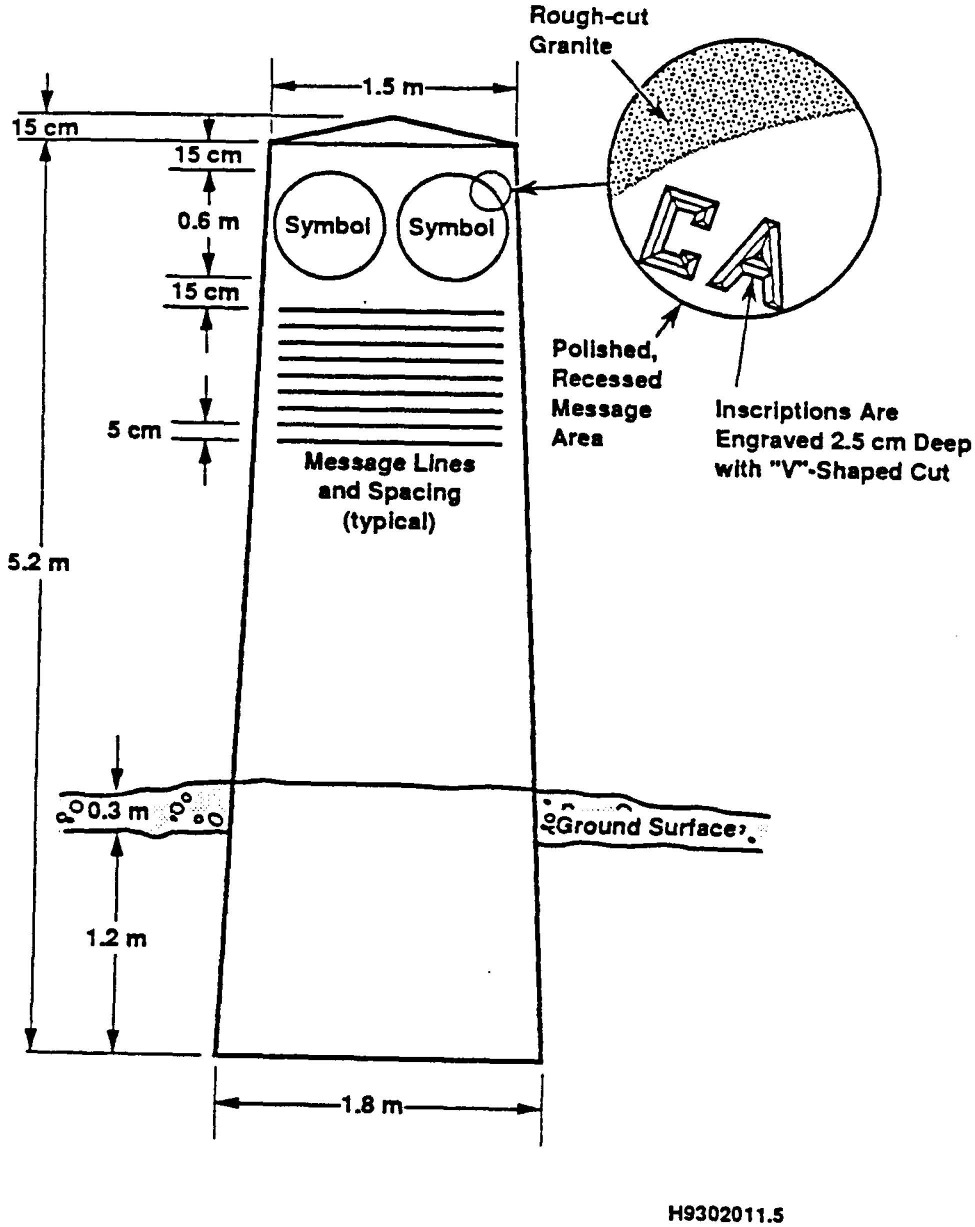
Studies on the prototype barrier are currently planned in the BDP to assess the stability of the barrier toe and side slopes under various conditions (Walters et al. 1990). These studies will provide useful data and insights into the design of protective barriers. The results of these studies will be integrated into future protective barrier designs.

3.3.3 Surface Soils Surrounding the Barrier

The existence of various geologic features in the surface soils at the Hanford Site (e.g., blowouts, dunes, etc.) suggests that the eolian processes of wind erosion and deposition have been active for millennia. The influence of these eolian processes on the soils immediately surrounding protective barriers could have an adverse effect on the performance of the barrier.

Turbulent wind gusts and eddies could erode soil and sand deposits adjacent to or upwind of a protective barrier and subsequently deposit the wind-suspended particles onto the barrier surface. If the wind-blown materials deposited on the barrier surface are coarser in texture than the fine soils used in constructing the protective barrier, the moisture retention capability of the barrier could be adversely affected. The potential for having more coarse-grained, wind-blown soil and sand on the surface of the barrier, which possess relatively poorer moisture retention characteristics

Figure 3-16. Surface Marker Design.



Passive measures will not provide absolute protection to every individual for all postulated events during the barrier's design life, nor will such measures prevent intentional intrusion. Recognition of this limitation is consistent with the history of rulemaking for the disposal of radioactive waste.

This section describes a conceptual approach for warning future generations of the dangers of the buried wastes at the Hanford Site. The approach, which has built-in redundancies, consists of using (1) offsite records, (2) surface markers, (3) subsurface markers, and (4) barrier designs. The role that each of these components plays in controlling human interference is described in the following subsections.

The ideas presented in the following subsections represent just one concept that has been considered. DOE has not yet decided on the approach that will be used to deter inadvertent human intrusion at the Hanford Site. Various warning marker designs or concepts have been proposed. The effectiveness of some aspects of these designs/concepts has been questioned by various technical peers. The warning marker issue is not one of which design/concept is "right" or "wrong." Rather, the critical concern is the assumption(s) upon which the warning marker designs/concepts are based. Without a clearly delineated set of assumptions and policies to guide the development of warning marker systems, current designs/concepts should be considered preliminary or conceptual. However, when a warning marker policy has been established, it should be uniformly and consistently applied across the Site.

3.4.1 Offsite Records

Records and other information pertaining to the type, location, and quantity of wastes disposed of at the Hanford Site will be provided to applicable offsite organizations such as municipal, county, state, and federal governments. The possession of these records by offsite organizations will provide redundant archives of records and information regarding the disposal of wastes at the Hanford Site. The multiple archives will enable waste disposal records and information to be readily accessible by future generations.

3.4.2 Surface Markers

Surface markers are large monolithic stone obelisks on which will be inscribed a message to warn potential intruders of the nature and hazards of the wastes buried at a disposal site (Figure 3-16). Preliminary designs for modern surface markers have been patterned after the characteristics of ancient surface markers (e.g., the Pyramids of Egypt; the Great Wall of China; Stonehenge; the Acropolis; and Serpent Mound, Ohio). These ancient archaeological analogs of surface markers have existed for millennia and provide valuable insights into the design of modern surface markers that are expected to last for at least 1,000 yr.

The surface markers would be placed around the periphery of the waste sites such that the markers can be seen easily and recognized. For example,

Figure 3-18. Surface Marker Placement around a Group of Waste Sites.

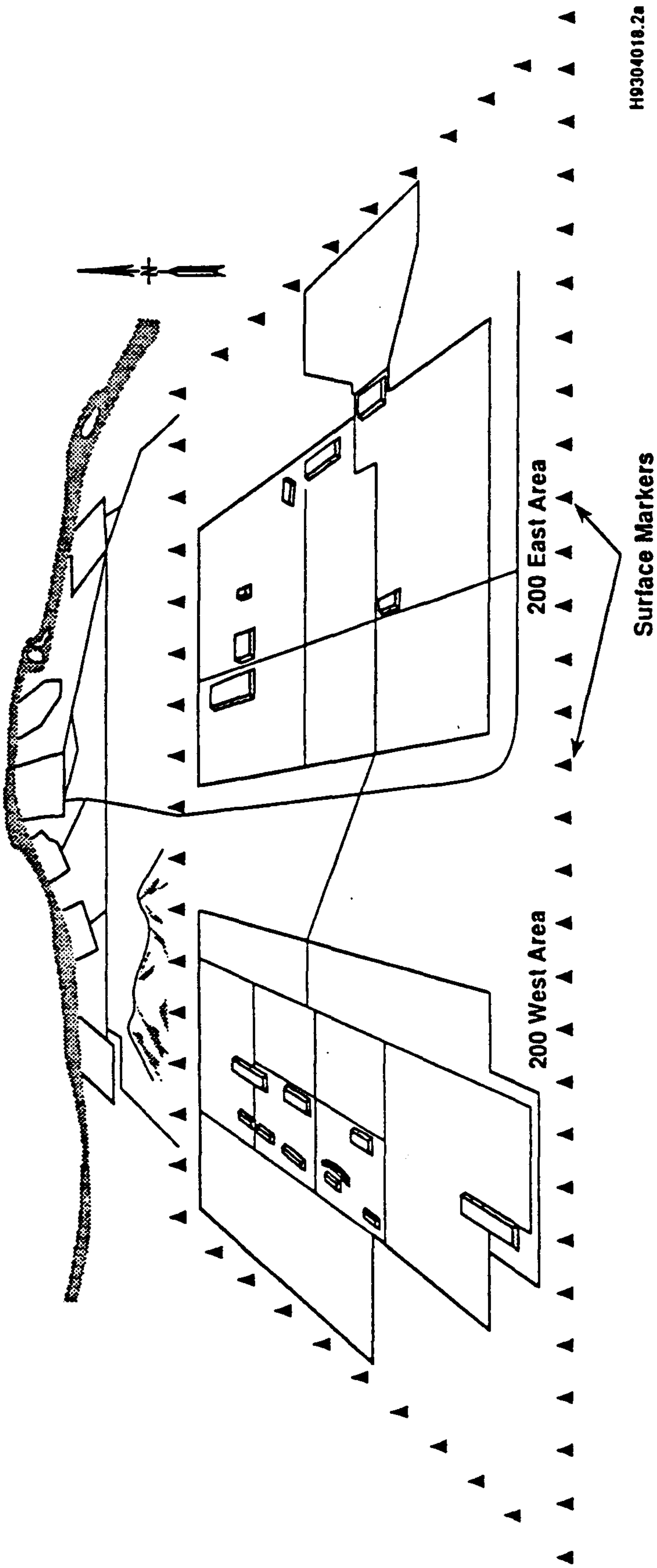


Figure 3-17. Surface Marker Placement around a Waste Site.

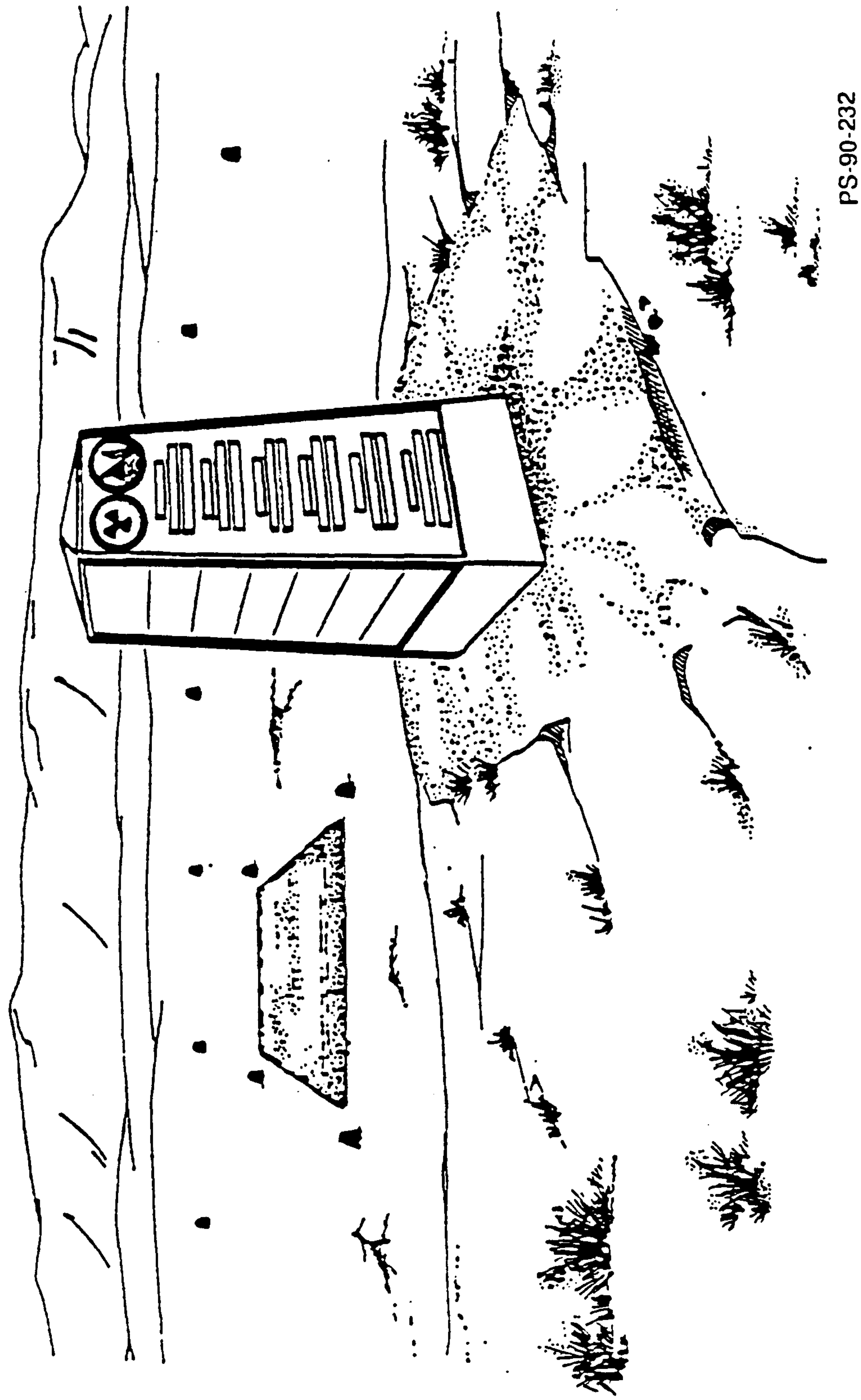


Figure 3-19. Subsurface Marker Design.

PS-90-209

the surface markers would be placed at the corners of each barrier mound (disposal block) and at any other locations necessary to clearly delineate areas where wastes have been disposed of (Figure 3-17). In addition, the surface markers would be used to delineate a marker perimeter around a group of disposal sites such as the 200 Areas at the Hanford Site (Figure 3-18). The placement of markers involves a determination of surface marker placement locations and intervals based on actual site topography and vegetative cover considerations. Field surveys will need to be conducted to locate marker placement points that offer the best visibility while optimizing placement intervals and costs. Engineered drawings will also be prepared to guide marker placement. Preliminary sketches and specifications for surface markers have been drafted (Phillips et al. 1985).

3.4.3 Subsurface Markers

A network of subsurface markers will be placed at strategic locations throughout protective barriers to provide a redundant warning system to the surface markers. Should, for whatever reason, inadvertent human intruders get past the surface markers without seeing the warning message, the intruders could dig into the protective barrier without being cognizant of the inherent dangers of the wastes buried below. The subsurface markers will provide a backup mechanism for increasing the probability that a warning message is seen and understood.

The design of subsurface markers has benefitted greatly from the examination of analogous archaeological artifacts. For example, the materials, size, and placement schemes used in the design of the subsurface markers have been patterned after the insights gained from studying buried archaeological artifacts, such as pottery, that have existed for millennia.

Current designs of subsurface warning markers use circular ceramic discs that are approximately 12.5 cm (5 in.) in diameter and 1.25 cm (1/2 in.) thick (Figure 3-19). The disks are yellow and use magenta letters and pictograms to create the warning message.

The first layer of subsurface markers is placed 0.67 m (2 ft) below the surface of the barrier; the second layer is placed 1.33 m (4 ft) below the surface of the barrier; and the third layer is placed at the original grade (Figure 3-20) (Phillips et al. 1985).

To achieve the maximum probability that at least one marker will be exposed should an intruder dig into the barrier, the subsurface markers have been strategically spaced throughout each layer. In addition to spacing within a layer, the subsurface markers in the three different layers have been staggered. The concept of staggering subsurface markers is based on the natural angle of repose of the soils used to construct the protective barriers. Unless shored in some way, the side slopes of unconsolidated soils will remain unstable during excavation activities and will tend to slough until the natural angle of repose of the soils is reached. As a result of this sloughing, the area opened up at the surface of the excavation will be much larger than the area at the bottom (or working face) of the excavation. Consequently, the opening will become wider at the surface of the barrier as the depth of the excavation into the protective barrier increases. The subsurface markers have been spaced and staggered such that if a subsurface marker were not directly in the path of the excavation, an intruder would not have to dig too deep before a subsurface marker would be uncovered due to the sloughing of soils as they reach their stable, natural angle of repose.

3.4.4 Barrier Designs

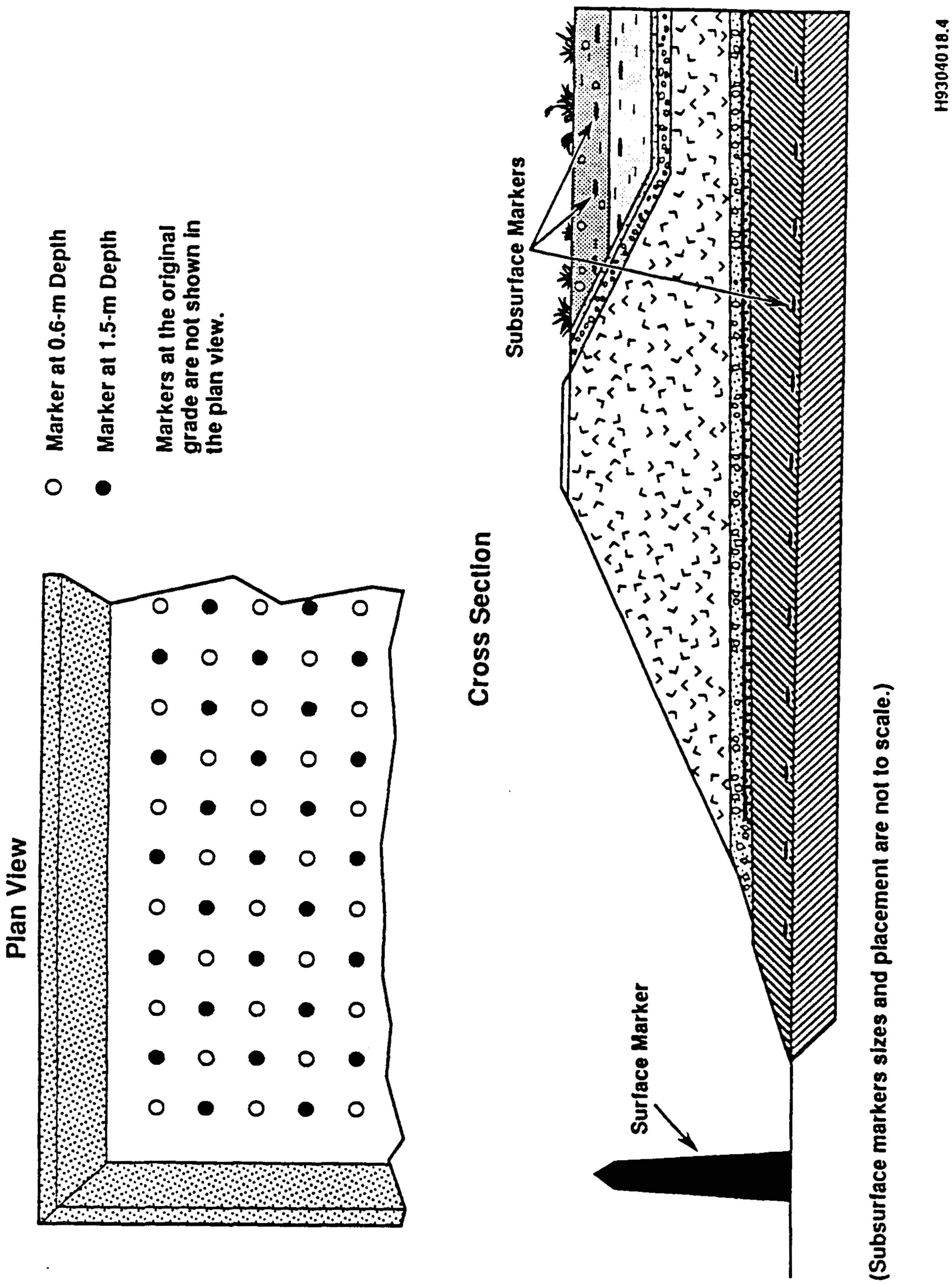
As discussed previously, two different side slope designs are being considered by the BDP: (1) a relatively gently sloping clean-fill dike of pitrun gravels and (2) a relatively steep embankment of fractured basalt riprap. The clean-fill dike provides a gentle transition from the shoulder of the barrier to the surrounding environment. In essence, the clean-fill dike concept blends the barrier into the topography of the surrounding landscape. Conversely, the steep, rocky side slope of the basalt riprap clearly delineates the boundaries of the surface barrier by providing a stark contrast with the surrounding environment.

Considering human intrusion, there are pros and cons associated with using either side slope design. A clean-fill dike side slope is aesthetically appealing because it blends in with the surrounding landscape. However, there are those who contend that if surface markers are lost for any reason, blending in the waste sites with the local topography would tend to hide the location of the waste sites, thereby making it possible for someone to "stumble" inadvertently onto the sites. Barriers that employ the basalt riprap side slopes are obviously structures that have been engineered and constructed by humans (Figure 1-1). The basalt riprap side slope designs make no attempt to blend the barrier in with the appearance of the surrounding landscape; consequently, these barriers are readily noticeable. There is some contention that the obvious barrier designs could become an attractive nuisance that draws curious individuals to the mounds. For example, the relatively flat surfaces of the barriers that contain excellent fine soils may attract future farmers to the barriers. In addition, curious individuals may think that something of value has been buried beneath the mounded soils and subsequently be attracted to excavate into it.

The best understanding at this time is that the spirit of existing regulations is not to hide the wastes, but to identify clearly and permanently mark the locations where the wastes have been buried. As discussed in the introductory remarks to Section 3.4, standards exist that state that "disposal systems shall be identified by the most permanent markers and records practicable to indicate the dangers of the wastes and their location" (40 CFR 191.14e). The presence of the permanent isolation barrier, therefore, will identify where the wastes have been disposed of and the warning system (e.g., offsite records of waste site locations and inventories, surface markers, and subsurface markers) will inform inadvertent human intruders of the dangers of the buried wastes.

Should the messages in the archives and on surface and subsurface markers be misunderstood, not seen, or ignored, the protective barrier itself will provide two additional lines of defense against human intruders. These two additional lines of defense are (1) the types of materials used to construct the protective barrier and (2) the thickness of the protective barrier.

Figure 3-20. Subsurface Marker Placement within a Barrier.



addition, radon has a very low partial pressure so gas pressure build up did not occur; hence, the cover was not disrupted by excessive pressures. The results also suggested that asphaltic layers constructed in the field with conventional equipment can perform as designed for an extended period of time (Gee et al. 1989).

The BDP will use the experience and expertise gained at Grand Junction, Colorado, and elsewhere in the design of barriers that mitigate problems associated with the release of gaseous wastes. A test plan is also being developed to address the various technical issues associated with the emanation of noxious gases that were identified previously.

The types and thickness of materials used to construct barriers will protect waste sites from most probable inadvertent human intrusion activities. Some of the barrier construction materials being used to discourage the intrusion of deep-rooting plants and burrowing animals will provide a formidable obstacle to human intruders as well. For example, the lower levels of the protective barrier consist of relatively thick layers of coarse materials such as gravels and fractured basalt riprap. These coarse materials by themselves probably will provide a substantial obstacle for human intrusion. In addition, the combined layers of barrier construction materials provide a relatively thick obstacle (approximately 5 m [6.4 ft]) for a human intruder to overcome. The types and thickness of barrier construction materials should provide an effective deterrent to all but the most determined human intrusion activities that reasonably could be expected to occur on the protective barrier.

3.5 GASEOUS RELEASE CONTROL

Depending on the type of waste being disposed of, noxious gases from the wastes could be generated and subsequently diffuse from the waste zone to the accessible environment. Unless controlled in some way, the noxious gases could pose a potential threat to human health and the environment. In addition, concerns have been raised regarding the potential for gases to be trapped under various barrier layers, particularly the low-permeability components. It is hypothesized that these gases could induce elevated pressures on the barrier components of concern. In addition, concerns have been raised regarding the accumulation of water vapor under the low-permeability components. Another concern requiring assessment is the potential harmful effects of organic vapors (solvents) on the low-permeability asphalt layers.

The potential for problems with noxious gases is not unique to the Hanford Site. As an example, uranium mill tailings sites are often challenged with the emanation of elevated concentrations of radon gas. One such site is located in Grand Junction, Colorado.

Many years ago, scientists and engineers (several of whom are currently serving on the BDP) were requested to participate in finding a solution to the elevated radon gas concentrations at the Grand Junction uranium mill tailings sites. Various barrier designs that used several different barrier construction materials were developed and tested. In general, the designs consisted of a multilayer barrier of compacted soils and gravels with a low-permeability component (asphalt or clay) incorporated into the barrier profile. In 1979, full-scale protective barriers were constructed over the uranium mill-tailing sites (Baker et al. 1984).

Nearly 8 yr after the protective barriers had been constructed, the opportunity availed itself to perform a post-mortem examination of the performance of the Grand Junction protective barriers. The results of the post mortem showed that the protective barriers that were constructed with low-permeability, asphaltic layers performed the best in inhibiting the diffusion of radon gas to the surface of the barrier. Control of radon exhalation was effective using low-permeability asphalt because radon has a short (<4 day) half-life. Restricting radon flux allows for radon decay. In

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APPENDIX A

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