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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

June 9, 1997
For Immediate Release

Frank Randall
External Affairs

Repository Performance and Uncertainties: How will the engineered and natural barriers respond?

Repository system performance and uncertainties about the engineered and natural barriers at Yucca Mountain headline the Board's summer meeting in Las Vegas, Nevada, June 25-26, 1997. The meeting will begin at 8:00 a.m. both days and is open to the public. It will be held at the Crowne Plaza, 4255 S. Paradise Road, Las Vegas, Nevada 89109; Tel: 702-369-4400; Fax: 702-369-3770.

On Wednesday, June 25, Department of Energy (DOE) representatives will update the Board on the high-level nuclear waste management program and the viability assessment for Yucca Mountain. A representative of the state of Nevada also will comment on the viability assessment. The remainder of the morning will be devoted to system performance and uncertainties associated with the repository design and the engineered barrier system. Presenters will speak on the DOE waste containment and isolation strategy, waste package performance, repository design and operations, waste package design and materials, and the behavior of cementatious materials in a potential repository.

The afternoon session will focus on repository performance and uncertainties in the natural barrier system. Presentations will include a performance assessment view of the natural barriers, the unsaturated zone expert elicitation project, infiltration and the unsaturated zone model, the views of outside experts on the elicitation process, and lessons learned from expert elicitation.

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On Thursday, June 26, presentations on the natural barrier system will continue. Subjects include saturated zone flow and transport, projected plans and costs of site-characterization work through license application, performance confirmation after licensing, development of projected costs for repository construction and operation, the east-west tunnel crossing the potential repository block, and other scientific activities at Yucca Mountain.

Telephone: 703-235-4473 Fax: 703-235-4495

Ample time is scheduled for questions and comments from the public. To ensure that everyone wishing to speak is provided time to do so, the Board encourages those who have comments to sign the *Public Comment Register,* which will be located at the sign-in table. Although a speaking time limit may have to be set, written comments of any length may be submitted for the record.

Transcripts of the meeting will be available via e-mail, on computer disk, or on a library-loan basis in paper format from Davonya Barnes, Board staff, beginning July 24, 1997. For more information, contact Frank Randall, External Affairs, (PLEASE NOTE OUR NEW ADDRESS) 2300 Clarendon Boulevard, Suite 1300, Arlington, Virginia 22201-3367; (Tel) 703-235-4473; (Fax) 703-235-4495; (E-mail) info@nwtrb.gov.

The Nuclear Waste Technical Review Board was created by Congress in the Nuclear Waste Policy Amendments Act of 1987 to evaluate the technical and scientific validity of activities undertaken by the DOE in its program to manage the disposal of the nation's spent nuclear fuel and defense high-level waste.

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There are two major corrections:

1. David Stahl, "Waste Package Design and Materials"
   Slide #10, last line under the first bullet
   ......, 80-110 μm/yr (not mm/yr)

2. Richard Snell, "Repository Design and Operations"
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The New York Times

Doubt Cast on Prime Site As Nuclear Waste Dump

Study Aids Opponents of Nevada Burial

By MATTHEW L. WALD

YUCCA MOUNTAIN, Nev. — For more than a decade, this mountain in the heart of the desolate Nevada desert has been promoted as the best spot to bury the country's mounting pile of nuclear waste.

But a recent discovery by Federal researchers has cast doubt on the plan, providing ammunition for those who have long attacked the notion of creating a permanent nuclear waste dump at this site 100 miles northwest of Las Vegas.

The researchers have found that rainwater, which could dissolve nuclear waste, has seeped from the top of the mountain 800 feet into its innards, where the high-level waste would be stored, in just 40 years — much faster than scientists had expected.

The finding, made by Energy Department researchers studying the site in a recently completed tunnel, raises the possibility that radiation would be spread into the environment much sooner than they had anticipated.

The State of Nevada argues that the discovery of the rainwater, which seeps through what are called fast-flow paths, presumed to be cracks in the rocks extending down from the surface, disqualifies the site.

But others, including those in the nuclear industry, say that the volume of water is minimal, no matter how fast it travels, and that the cracks might help, by concentrating the water flow in just a few spots, which builders of the burial caves would be able to avoid.

Scientists have always known that water would travel through the rock, but they had believed that the water would take hundreds or thousands of years to travel deep into the mountain, which would have sharply limited how fast radiation could spread.

The wastes would be dangerously radioactive for hundreds of thousands of years, physicists say, and would most likely reach humans through water, flowing underground through the wastes and eventually reaching the surface through springs or wells.

Scientists outside the Government and many environmentalists have doubts about Yucca Mountain, and question whether enough can be known about any site to predict with confidence today how waste would behave thousands of years from now. But Federal officials have assumed for years that the proper way to handle nuclear waste is to bury it, and since Congress picked Yucca Mountain as the leading candidate as a burial site, the Energy Department has spent more than $2.4 billion studying the mountain. If a repository here is approved, the department would be in charge of building it.

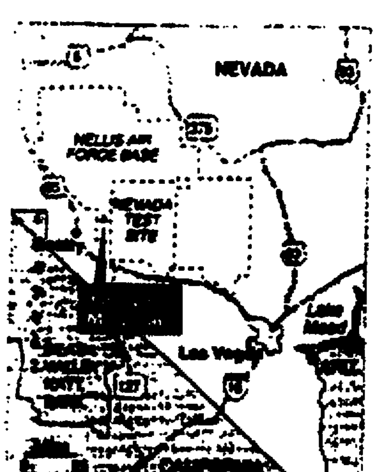
In a recent tour through the chilly, dusty tunnel, Susan B. Jones, the assistant manager for scientific programs on the project, said the evidence found so far was "not really enough to answer the question, but it raises questions."

"If we could figure out where and why it's happening, that would be helpful," Ms. Jones said of the fast water seepage. "We're not particularly sure right now."

Ms. Jones said the department would continue its evaluation of the site and was planning to issue an interim report, or "viability assessment," in September 1998. A final decision on the site's suitability is still years away.

Climate was one reason Congress gave, more than a decade ago, for choosing Yucca Mountain as the leading candidate for the country's permanent nuclear waste storage. The area gets about six inches of rain a year, most of it evaporating before it seeps into the mountain. Because the area is so dry, it is sparsely settled, presenting a generally for-

In 40 years, rainwater has seeped from the top of Yucca M[...] high-level nuclear waste, which could be dissolved by w[...]



The New York Times

Rainwater could cause problems at a Yucca Mountain dump site.

Jeffrey Hedge for The New York Times

…r has seeped from the top of Yucca Mountain in the Nevada desert to a site 800 feet down where the Government wants to store …aste, which could be dissolved by water. Scientists recently conducted tests in a tunnel at the site, 100 miles from Las Vegas.

Can any site be deemed forever safe for the storage of nuclear waste?

…bidding landscape, with place names to match. Yucca sits between Little Skull Mountain, just to the east, and the Funeral Mountains, one of the ranges adjacent to Death Valley, to the west.

Once Congress picked Yucca Mountain as a candidate for a nuclear dump, the Energy Department took on the task of evaluating the site. The most important part of the job, experts say, is understanding how water flows through the mountain because this helps scientists predict how waste will behave over the next 10,000 or 100,000 years.

By studying rock samples from the tunnel, which is at the level of the proposed site, the researchers have gained some idea how water travels from the mountaintop to where the waste would be stored. But they still are not sure how water travels from that level to the next 1,300 feet down to the water table. At that level the rock is saturated with water, which then flows horizontally over wide areas, eventually reaching wells and springs, and then humans. The water table rises and falls over long periods, but Government scientists say that in the last 2 million years it has not risen more than 300 feet above its current level.

The clue that rainwater reached the repository level in mere decades was fallout from nuclear bomb tests, which was found in the tunnel in the form of chlorine-36. Although Yucca Mountain is at the edge of the Nevada Test Site, where the Government has detonated hundreds of bombs, the researchers say the chlorine-36 was not from those tests, but from nuclear tests conducted around the world over in the past few decades.

In addition to finding 40-year-old rainwater, the researchers also found water that fell as rain 5,000 to 20,000 years ago. That is what they had hoped to find to support the choice of Yucca Mountain, indicating that it took thousands of years for rainwater to travel that far.

At Los Alamos National Laboratory, part of the Energy Department, Dr. Andrew V. Wolfsberg, a hydrologist who is part of the team that discovered the chlorine-36, said the discovery would not doom the selection of Yucca Mountain. Even if the water was moving more quickly than expected, Dr. Wolfsberg said, it was not enough water to spread much waste.

And Steven P. Kraft of the Nuclear Energy Institute, the trade association of the nuclear utilities, argued that even with the discovery, the mountain was still very dry.

"We're not talking about a faucet in your house that's running at 45 gallons per minute," Mr. Kraft said. "These are minuscule amounts dripping through the cracks."

But Steve Frishman, technical policy coordinator of Nevada's Agency for Nuclear Projects, said Federal officials had long maintained that the mere existence of fast-flowing water would disqualify a site. And Mr. Frishman argued that the area was likely to get more rain over time, increasing the dangers.

"This area is about as dry as it has ever been or ever will be," Mr. Frishman said, pointing out that scientists predict that glaciers will once again cover large parts of North America in the next few thousand years, and that when that happens, rainfall here will be much heavier.

If the repository is built, water filtering down from above for the first few hundred years would be held at bay by the heat given off by the wastes, and so there would no danger of it corroding the waste and carrying it away at that point. Mr. Frishman said the water in the rock would behave like coffee in a percolator, turning to steam and bubbling up, then recondensing into water.

But as the radiation in the waste died down, the heat would, too, and the water would return. Over centuries or millennia, the water would make the containers holding the waste corrode, and then slowly dissolve the radioactive material, carrying some of it into the environment.

If the repository is built, the Energy Department says it would want to choose a packaging system for the waste that will corrode as slowly as possible. One test now under way in the tunnel is to heat blocks of rock and see how the water behaves and whether the rock chemistry changes, so that an appropriate packaging can be found.

The tunnel is huge, 25 feet in diameter, which the designers say was needed to assure adequate ventilation. But they acknowledged that even though the tunnel was built for study purposes, it is big enough to be a driveway for a repository.

The Energy Department plans to publish an environmental impact statement in 1999 and submit a site recommendation to the President in mid-2001. In 2002, the department would submit to the Nuclear Regulatory Commission, the agency that monitors civilian reactors, an application for a license to build the repository. If all goes well, it would begin accepting waste in 2010.

But holding to any schedule is unlikely. The 1982 Nuclear Waste Policy Act established the Federal Government's responsibility for finding a repository for the high-level waste from nuclear weapons plants and civilian power plants. The law called for opening a repository 16 years later, which would have meant in 1998. Although the official schedule now is for opening the site in 13 years, many experts think that Yucca Mountain is still at least 16 years away from opening, if, in fact, the site can be shown to be suitable.

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Agenda

Summer Board Meeting

Crowne Plaza
4255 S. Paradise Road
Las Vegas, NV 89109
Tel: 702-369-4400
Fax: 702-369-3770

June 25-26, 1997

Ballroom A & B

Wednesday, June 25

8:00 a.m.	**Welcome and introductory remarks** Jared Cohon, chair Nuclear Waste Technical Review Board (NWTRB)
8:10 a.m.	**Status of the program and the viability assessment (VA)** Lake Barrett, acting director Office of Civilian Radioactive Waste Management (OCRWM)
8:25 a.m.	*Questions/discussion*
8:40 a.m.	**VA - description of the products and schedule for completion** Steve Brocoum, OCRWM
8:55 a.m.	*Questions/discussion*
9:10 a.m.	**Comments on VA from the state of Nevada** Bob Loux, state of Nevada
9:25 a.m.	*Questions/discussion*
9:40 a.m.	**Break (15 min)**

PERFORMANCE AND UNCERTAINTIES OF THE REPOSITORY DESIGN AND THE ENGINEERED BARRIER SYSTEM:

9:55 a.m.	**Session introduction** Dan Bullen, NWTRB

June 25 - continued

1:35 p.m.	**Performance assessment viewpoint on the natural barriers** Abe Van Luik, DOE • Key technical issues and remaining problem areas for total system performance assessment–viability assessment (TSPA-VA). • Significant enhancements/changes for TSPA-VA.
1:50 p.m.	*Questions/discussion*
2:05 p.m.	**The process and objectives of the unsaturated zone expert elicitation project** Kevin Coppersmith, Geomatrix
2:15 p.m.	*Questions/discussion*
2:25 p.m.	**Infiltration, the unsaturated zone model, and expert elicitation results** Bo Bodvarsson, M&O (Lawrence Berkeley National Laboratory)
2:45 p.m.	*Questions/discussion*
2:55 p.m.	**Break (15 min)**
3:10 p.m.	**Expert viewpoint on the process and results** Shlomo Neuman, University of Arizona
3:35 p.m.	*Questions/discussion*
3:50 p.m.	**Expert viewpoint on the process and results** Gaylon Campbell, Washington State University
4:15 p.m.	*Questions/discussion*
4:30 p.m.	**Lessons learned from the expert elicitation** Bob Andrews (M&O) and Bo Bodvarsson (M&O) • Who are the intended customers of this information? • How will this elicited information be used in TSPA-VA?
4:40 p.m.	*Questions/discussion*
5:00 p.m.	**Questions/comments from the public**
5:30 p.m.	**Adjourn until Thursday 8:00 a.m.**

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9:55 a.m.	**Session introduction** Dan Bullen, NWTRB

June 25 - continued

10:00 a.m.	**The OCRWM waste containment and isolation strategy** Jean Younker, M&O (TRW Environmental Safety Systems, Inc.) • Review of the OCRWM/management and operating contractor (M&O) waste containment and isolation strategy. • How does it take into account the large uncertainty in the percolation flux?
10:20 a.m.	*Questions/discussion*
10:30 a.m.	**Performance assessment viewpoint on the waste package performance** Bob Andrews, M&O (INTERA) • Major issues and uncertainties in predicting the in-drift environment and waste package performance
10:45 a.m.	*Questions/discussion*
10:55 a.m.	**Repository design and operations** Richard Snell, M&O (TRW Environmental Safety Systems, Inc.) • Review of the present design and operations of the proposed repository. • How will the large uncertainty in the percolation flux impact this design? • What are the alternative design concepts?
11:15 a.m.	*Questions/discussion*
11:30 a.m.	**Waste package design and materials** Dave Stahl, M&O (B&W Fuel Company) • Major issues and uncertainties with the waste package design
11:45 a.m.	*Questions/discussion*
11:55 a.m.	**Behavior of cementatious materials** Della Roy, Penn State University • Major issues and uncertainties on the near field environment due to use of cementatious materials
12:20 p.m.	*Questions/discussion*
12:30 p.m.	**LUNCH (1 hour)**

REPOSITORY PERFORMANCE AND UNCERTAINTIES IN THE NATURAL SYSTEM

1:30 p.m.	**Session introduction** Debra Knopman, NWTRB

June 25 - continued

1:35 p.m.	**Performance assessment viewpoint on the natural barriers** Abe Van Luik, DOE • Key technical issues and remaining problem areas for total system performance assessment–viability assessment (TSPA-VA). • Significant enhancements/changes for TSPA-VA.
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Thursday, June 26

8:00 a.m.	**Session introduction** Priscilla Nelson, NWTRB
8:05 a.m.	**Saturated zone flow and transport** Dwight Hoxie, USGS • How YMP is addressing remaining uncertainties of the saturated zone that are important for TSPA
8:30	*Questions/discussion*
8:50 a.m.	**Projected plans and costs of additional work through license application (post-VA)** Jean Younker, M&O
9:05	*Questions/discussion*
9:15 a.m.	**Performance confirmation after licensing** Richard Wagner, M&O
9:30	*Questions/discussion*
9:45 a.m.	**Plan for developing projected costs of repository construction and operation** Mitch Brodsky, DOE
10:00	*Questions/discussion*
10:15 a.m.	**Break (15 min)**
10:30 a.m.	**East-west tunnel crossing the repository block, planned studies and their objectives** Mike Voegele, M&O (Science Applications International Corporation)
10:45	*Questions/discussion*
11:00 a.m.	**Update on scientific activities at Yucca Mountain** Larry Hayes, M&O (TRW Environmental Safety Systems, Inc.)
11:30	*Questions/discussion*
12:00	**Comments from the public**
12:45 p.m.	**Closing comments** Jared Cohon, NWTRB
1:00 p.m.	**Adjourn**

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

STATUS OF THE CIVILIAN RADIOACTIVE WASTE
MANAGEMENT PROGRAM
BY
LAKE H. BARRETT, ACTING DIRECTOR
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
U.S. DEPARTMENT OF ENERGY
JUNE 25, 1997

Introduction

Chairman Cohon and Members of the Board:

Thank you for the opportunity to speak with you today and provide my perspective on the status of the Civilian Radioactive Waste Management Program and our plans for the coming year. When Dan Dreyfus spoke with you last October, the Program was in the early stages of implementing the revised Program Plan published in June 1996. Congress endorsed this plan in the 1997 Appropriations Act, and the President's 1998 budget request for the Program supports its continued implementation. With adequate funding, we will complete the viability assessment of the Yucca Mountain site next year and maintain momentum toward geologic disposal as set forth in the Nuclear Waste Policy Act of 1982, as amended.

Congress is once again considering legislation to address the near-term management of spent fuel. The Senate has passed a bill, similar to legislation that it passed last year, siting an interim storage facility on the Nevada Test Site, with alternate siting provisions if the President, upon consideration of the viability assessment, determines that the site is not suitable. The House is considering legislation that would direct the Department to begin waste acceptance at an interim storage facility on the Nevada Test Site by January 2000, irrespective of the viability assessment. As you are aware, the Administration opposes the peremptory siting of an interim storage facility near Yucca Mountain before the viability assessment has been completed. The Administration believes that a decision on the siting of an interim storage facility should be based on objective, science-based criteria and should be informed by the viability assessment of Yucca Mountain. Consequently, the President has stated that he would veto either bill, if presented in their current form.

Despite its opposition to the current legislation, the Administration remains committed to resolving the complex and important issue of nuclear waste management. Secretary Peña has stated his willingness to work cooperatively with Congress on nuclear waste disposal issues. Whatever the outcome, the Federal Government's longstanding commitment to permanent geologic disposal should remain the centerpiece of the Nation's high-level radioactive waste management policy.

The near-term management of commercial spent fuel remains an important issue to utilities and others. On December 17, 1996, the Department formally notified Standard Contract holders that it would be unable to begin accepting their spent nuclear fuel at either a repository or an interim storage facility by January 31, 1998. Legal action was subsequently taken by the utilities, and the case is still being considered by the court. In the interim, the Department is proceeding with the following dual-track approach to address the anticipated delay in accepting spent fuel:

- First, we have begun a process with contract holders to determine what actions under the standard contract would be appropriate to address the anticipated delay.
- Second, the Secretary has committed the Department to continuing discussions simultaneously with representatives of the utilities, States, and other stakeholders to seek mutually-agreeable solutions to the delay.

On June 3, 1997, the Department notified contract holders of its preliminary determination that the delay is unavoidable pursuant to the terms of the contract. While the Department believes, based on the contract, that it is not obligated to provide financial remedy for the delay, it recognizes that such delay may result in hardship to certain contract holders. Therefore, the Department is willing to consider utility proposals to amend individual contracts to mitigate the impacts of the delay in accepting spent fuel.

Viability Assessment

Over the past several years, the Yucca Mountain Project has focused on addressing major unresolved technical issues. This will permit us, by 1998, to provide the four components of the viability assessment required by the 1997 Appropriations Act. While the viability assessment is not one of the decision points defined in the Nuclear Waste Policy Act, its completion is expected to be significant to the development of a repository. The viability assessment will give policy makers key information regarding the prospects for geologic disposal at Yucca Mountain to justify continued funding of the Program. The viability assessment also serves as an important management tool for the Program. The development of the components will help integrate the ongoing activities and the assembled information will guide the completion of site characterization by identifying those areas where additional scientific and technical work is required to evaluate the site and prepare a defensible, complete, cost-effective, and timely license application. General agreement between the Program and its overseers and regulators on these remaining activities is central to the continuation of the geologic disposal program. This is especially important in an ever tightening Federal budgetary situation where so much emphasis has been placed upon balancing the budget and reducing the Department's discretionary funding allocations.

The presentations later today and tomorrow by staff and contractors from the Yucca Mountain Site Characterization Office will provide the Board further details regarding the activities that support the viability assessment. I will be here and look forward to hearing the Board's views on our plans and approaches so that we can appropriately address these concerns as we complete the components of the viability assessment.

Updating the Regulatory Framework

In its most recent report, the Board notes that the regulations governing spent fuel disposal should be updated because they are too detailed and were enacted too early in the repository development process. We agree. Our revised Program Plan recognized the need to update these regulations to reflect policy changes since the enactment of the Nuclear Waste Policy Act, the realities of the budget constraints on the Program, and, in particular, the technical understanding gained in more than a decade of site investigations. We have considered these factors in the proposed amendments to our siting guidelines. It is similarly important that these factors be considered by the U.S. Environmental Protection Agency (EPA) and the U.S. Nuclear Regulatory Commission (NRC), respectively, in developing radiation protection standards and revising the licensing criteria for a repository at Yucca Mountain. The Department believes that the resulting regulations and the licensing process should focus on issues central to protecting public health and safety and the environment, and not require a degree of proof that is beyond what science and engineering can reasonably provide.

In December 1996, we published a notice of proposed rulemaking to revise our repository siting guidelines as they would be applied in evaluating the suitability of the Yucca Mountain site. The approach we propose focuses on overall system performance as the basis for decisions about site suitability and repository development. The suitability decision need not and should not depend on individual attributes of the site outside the context of an assessment of the performance of the proposed engineered repository. The public comment period on the proposed rule ended May 16, 1997. We are presently evaluating all the comments, including those from the Board.

Recent Developments

I am pleased to report that we have continued to make significant progress since the Board's last meeting. The speakers who follow me will describe our progress in performance assessment, engineering design, and site characterization.

We completed excavation of the 7,900-meter (five-mile) loop of the exploratory studies facility at Yucca Mountain on April 25, 1997. From this point forward, work in this facility will focus primarily on thermal and hydrologic testing, and confirming our understanding of the rock where the repository would be constructed. In August 1996, we completed initial construction of the Northern Ghost Dance Fault Alcove. This alcove is the first of two that provide access to the

Ghost Dance fault, a major geologic feature of the repository setting. Testing in these alcoves will help to determine the flow properties and chemistry of water in the fault zone.

The Board has recommended accelerated excavation of an east-west drift to obtain information on the area west of the current exploratory studies facility. We agree with the Board and are conducting the detailed planning for an additional small-diameter, exploratory drift to the west of the main tunnel. This excavation will help to improve our understanding of the rock characteristics and hydrologic processes that are important to the design, construction, and performance of a repository at Yucca Mountain.

Over the last year, we continued work on the critical elements of a repository and waste package design, and on obtaining the information needed as input to the design process. Repository design activities addressed thermal management; performance confirmation design; waste handling emplacement and retrieval; development of systems, structures, and components important to safety that have little or no regulatory precedent; and design basis event analyses. Waste package design activities addressed criticality analysis methodology development; preliminary thermal, structural and shielding analyses; containment barrier fabrication; closure feasibility analyses; and conceptual invert design and material selection. These efforts will support preliminary designs for components of an engineered barrier system that contributes to isolation and retardation of radionuclides.

Waste Acceptance, Storage, and Transportation

Our Waste Acceptance, Storage, and Transportation Project is focused on the planning and long lead time activities that must precede the removal of spent nuclear fuel from reactor sites, once a Federal facility becomes available. These activities are consistent with the Administration's policy on siting an interim storage facility.

During the past year, we developed a market-driven approach that will rely on maximum use of private industry capabilities, expertise, and experience to provide the necessary services and equipment required to accept and transport commercial spent nuclear fuel to a Federal facility. We are presently working to establish a competitive procurement process to award fixed-price, multi-year, performance-based contracts.

To address long lead time requirements related to centralized storage, we completed a non-site-specific design for a centralized interim storage facility and submitted a topical safety analysis report for this design to the NRC staff on May 1, 1997. The staff docketed the topical safety analysis report on June 10, 1997, after completing an acceptance review. We believe that the staff's complete review of this report will reduce the time required for subsequent preparation and staff review of a license application.

Conclusion

Through implementation of our revised plan, we have focused the Program on the key issues and maintained the momentum of the repository program. Within the next 15 months, we will complete the viability assessment which will serve as a significant benchmark for the Program. The products associated with the viability assessment will provide all parties, including the Board, with a better understanding of geologic disposal at Yucca Mountain and the significance of the data then available. It will also help inform the ongoing revisions to the regulatory framework and guide the completion of site characterization. We intend to keep you apprised of our progress and look forward to a constructive dialogue as we carry out our mutual responsibilities.

Thank you for the opportunity to brief the Board. I would be happy to answer any questions you may have.

YUCCA
MOUNTAIN
PROJECT

Viability Assessment: Products and Schedule

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Dr. Stephan J. Brocoum
Assistant Manager for Licensing
Yucca Mountain Site Characterization Office

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

Outline

- Overview of Viability Assessment (VA)
- Description of Products/Schedule
- Challenges

Viability Assessment

"The completion of the constituent elements of the viability assessment constitute a logical convergence at which the Program can make a measurably improved appraisal of the prospects for geological disposal at the Yucca Mountain site. The assessment is an interim step in the process leading to a site recommendation to the President..." **

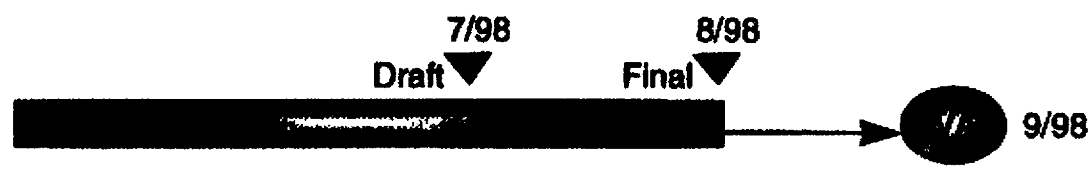
***** From the FY98 Budget of the United States Government, Appendix, p. 475***

Viability Assessment
(Continued)

- The VA consists of
  - Preliminary design concept for critical elements of repository/waste package
  - Total system performance assessment describing the probable behavior of the repository based on data available
  - Plan and cost estimate for completing the license application (LA)
  - Cost estimate to construct and operate the repository

Preliminary Design Concept

- Design bases
- Description of key site features
- Description of the design
  - Repository
  - Engineered Barrier System
- Design alternatives
- Design evolution



Total System Performance Assessment

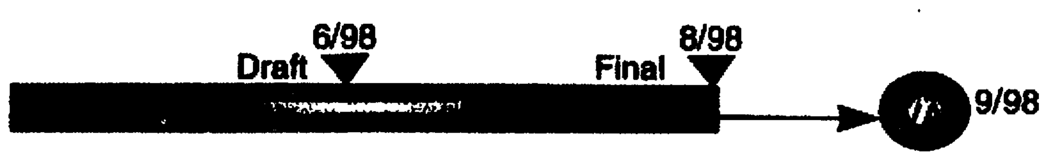
- TSPA methodology
- Assumptions used
- System/subsystem descriptions
  - Site
  - Design
  - Process models
- Evaluation of undisturbed performance
- Evaluation of disturbed performance

Plan and Cost Estimate to LA

- Overall strategy for LA development
- Work to be conducted between VA and LA
  - Site testing
  - Design
  - Total System Performance Assessment
  - Regulatory activities
  - Other
- Cost and schedule for that work
- Description of Performance Confirmation Program

Cost Estimate to Construct and Operate

- Assumptions used
- Repository life-cycle schedule
  - From LA to closure
- Estimating techniques
- Repository life-cycle cost summary
- Additional cost details

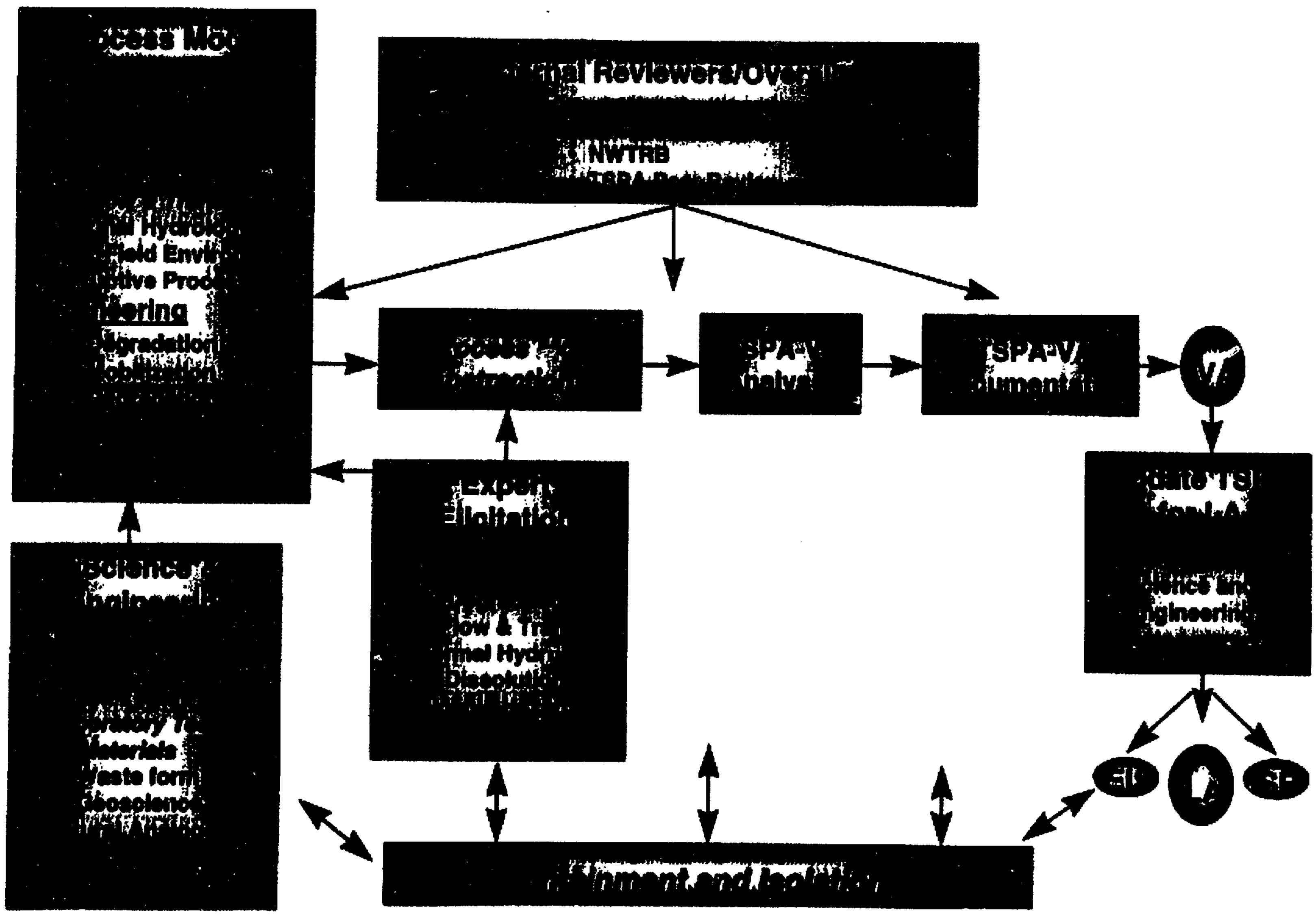


Challenges

- Differentiating the VA from a formal decision
  - VA is not equivalent to the site recommendation
- Ensuring integration among VA products
- Moving ahead in the absence of an EPA standard
- Incorporating current understanding of site conditions
- Appropriately assessing EBS design options under consideration

Schematic of Presentations to Follow

Conceptual TSPA Logic



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Studies

Status of DOE's Evolving Waste Containment and Isolation Strategy

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Dr. Jean L. Younker
Manager, Regulatory Operations
Management and Operating Contractor
Las Vegas, Nevada

U.S. Department of Energy
Office of Civilian Radioactive

June 25-26, 1997

Background: 1996 Update to the Top-Level Strategy for Yucca Mountain

- Briefed to NWTRB in July 1996 and draft "Highlights" distributed
- Basis for 1996 update to the top-level strategy from 1988 Site Characterization Plan
  - Improved site understanding
  - Larger, more robust waste package design with increased attention to thermal loading
  - Improved performance predictions
  - Evolving regulatory framework: dose vs. release

Utility of Waste Containment and Isolation Strategy

- Provides framework for combining natural and engineered components of the repository in a system that will meet performance requirements
- Serves as a useful guide for improving design and prioritizing site testing to enhance confidence in performance

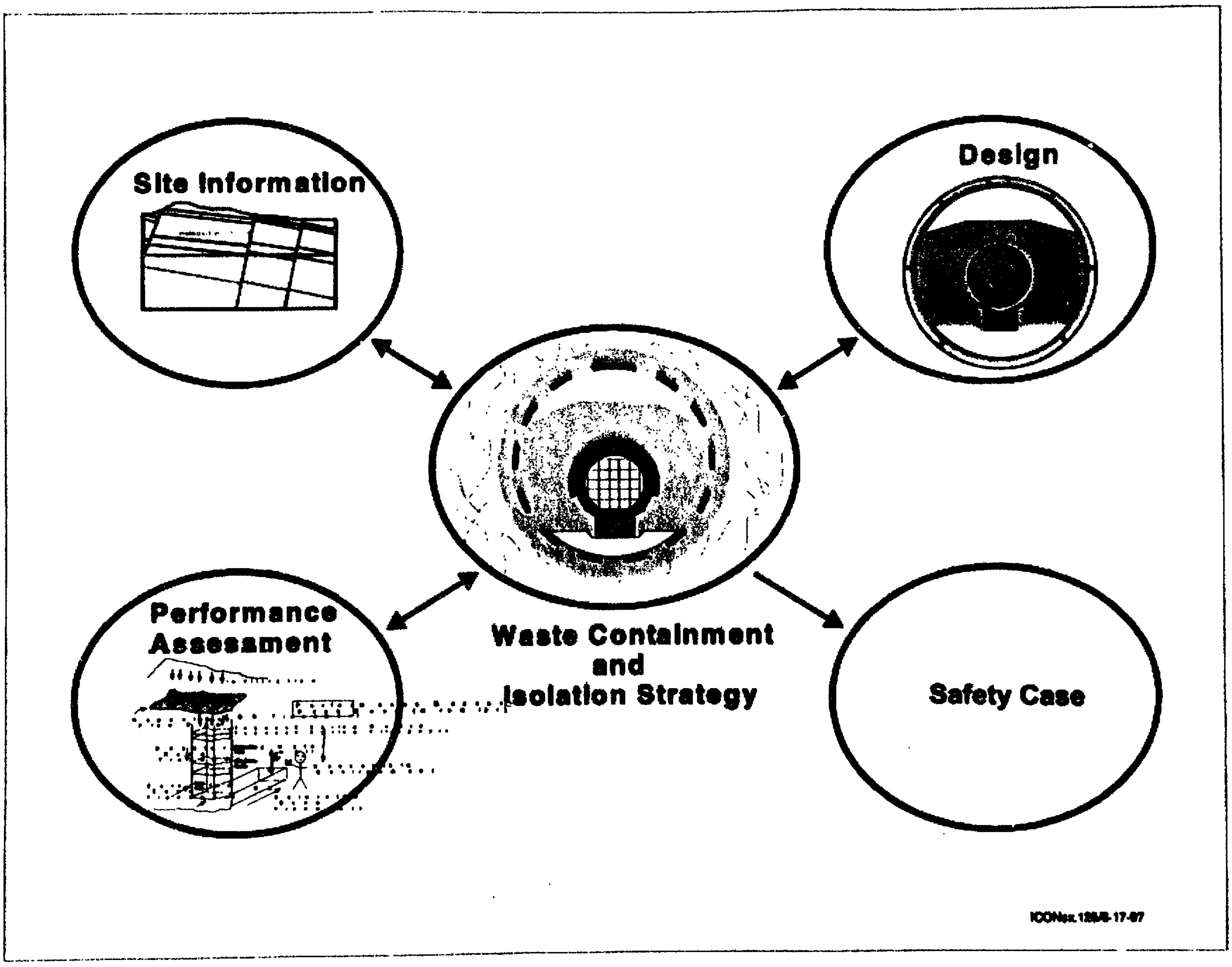
Current Concept of Waste Containment and Isolation Strategy

Approach

- Identify site and design features that, when considered in combination, are sufficient to meet performance requirements
  - Iterations of design and performance assessment have identified design options
  - Performance assessment models updated on basis of improved site and engineering understanding

Current Concept of Waste Containment and Isolation Strategy
(Continued)

- Select a subset of site/design features to develop a cost-effective repository system design that meets/exceeds performance requirements
- Develop safety case based on this design
- Iterate, as necessary, to incorporate new site and design information



Site Information
Design
Performance Assessment
Waste Containment and Isolation Strategy
Safety Case

Postclosure Repository System: Safety Case

- Prevent/delay radionuclide releases
- Mitigate transport after release
- Utilize 10 CFR 60 concept of multiple barriers: conservatism, redundancy, margin
  - Engineered barriers to compensate for uncertainties in natural barrier performance
  - Natural barriers to compensate for uncertainties in engineered barrier performance

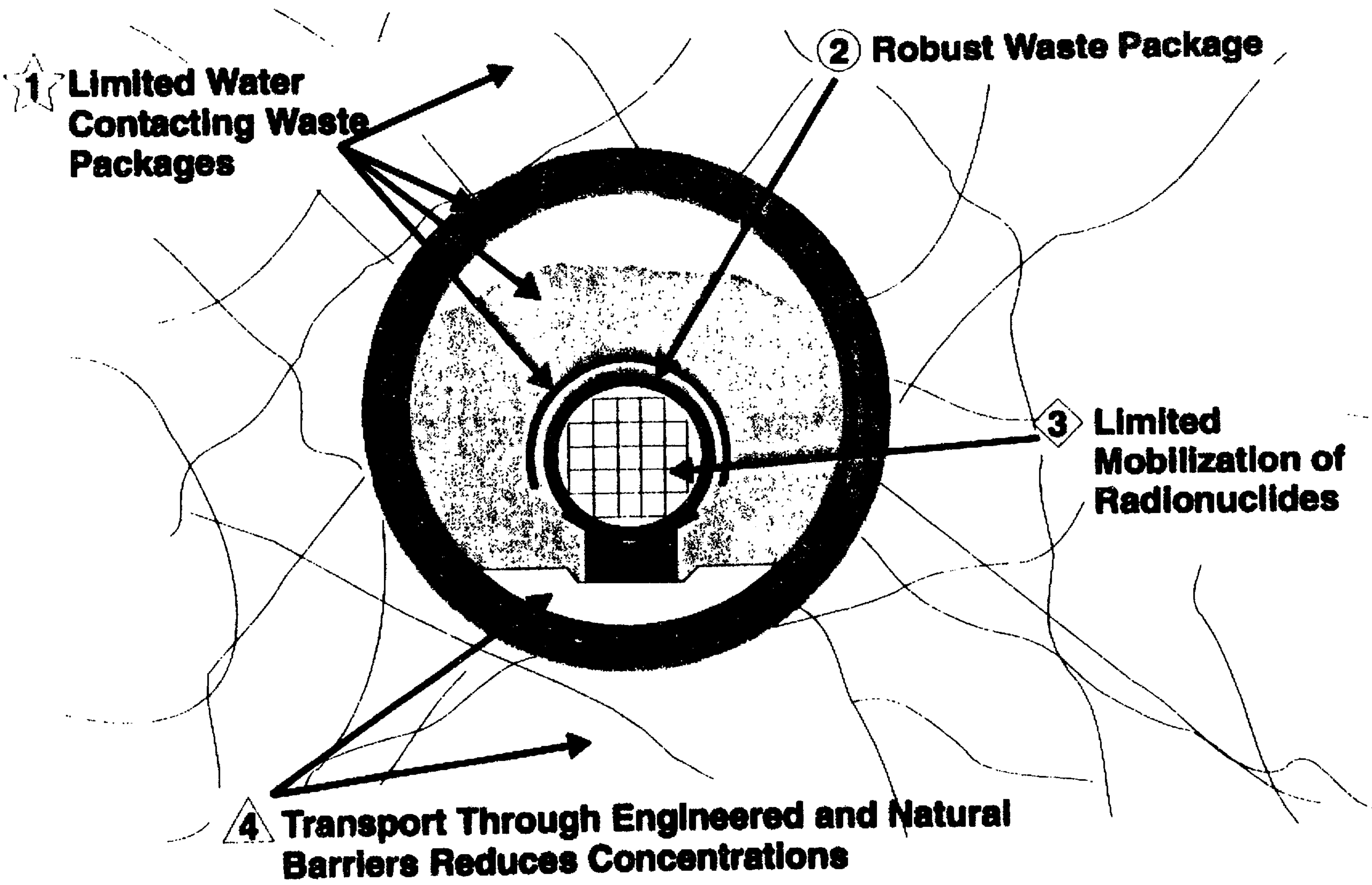
Operating Without an EPA Standard

- **Utilize interim performance standard**
  - **Requirement: expected annual dose to an average individual in a critical group living 20 km from the repository shall not exceed**
    - » 25 mrem from all pathways and all radionuclides during the first 10,000 years after closure
  - **Goal: provide sufficient defense in depth to ensure repository will satisfy requirement**
    - » Conduct analyses beyond 10,000 years to gain insight into longer-term performance
    - » For this period, the expected annual dose to an individual in a critical group living 20 km from the repository should be below the 10,000 year requirement

Evolving Waste Containment and Isolation Strategy

1. Limited water contacting waste packages
2. Robust waste packages
3. Limited mobilization of radionuclides from the waste form
4. Radionuclide concentrations reduced during transport through engineered and natural barriers

Evolving Waste Containment and Isolation Strategy



Refinement of Strategy: Improved Site Understanding

- **Recent evidence for higher percolation flux and better definition of heterogeneities**
  - **Average percolation flux through potential repository host rock from 1 to 10 mm/yr**
  - **Seepage into repository drifts is likely to be less than that, and will be variable in space and time**
  - **Thermal effects may redistribute moisture with slow return to ambient conditions over several thousand years (depends on percolation flux)**
  - **Degree of reduction in radionuclide concentrations during transport likely to remain uncertain**

Refinement of Strategy
(Continued)

- Selection of site/design features depends on their expected contribution to performance and related uncertainties
- Improved understanding of moisture conditions and better definition of spatial and temporal variability
  - Used as input to sensitivity analyses on total system performance
  - Sensitivities allow refinement of site and design features included in strategy

☆1 Limited Water Contacting Waste Packages

Natural barriers

- Semi-arid, unsaturated-zone setting limits net infiltration
- Diversion of some downward percolating flux above repository is likely

Engineered barriers

- Drift wall provides capillary barrier against seepage under certain flow conditions
- Heat from waste reduces available moisture for some time period
- *Engineered diversion of seepage entering drifts may be feasible*

② Robust Waste Packages

- **Use of corrosion-resistant inner barrier and corrosion-allowance outer barrier prolongs life of packages**
- **Galvanic processes may offer protection to inner barrier**
- ***Potential for use of ceramic coating on waste packages may prolong life***
- **Use of backfill**
  - ***May offer mechanical protection for diversion system and packages***
  - **Could limit advective flow to waste packages**

◇3 Radionuclide Mobilization

- For some radionuclides, solubilities limit mobilization
- Cladding reduces waste form surface area exposed
- Long containment time limits alteration of waste forms
- Limiting impact of engineered materials on water chemistry may be useful to reduce mobilization

⚠ Radionuclide Transport Through Engineered and Natural Barriers

Engineered barriers

- ***Potential for additives to material beneath waste package (invert) to delay transport***
- **Use of backfill reduces potential for advective flow**

Natural barriers

- **Matrix diffusion in both unsaturated and saturated zones reduces concentrations**
- **Sorption will be effective for some radionuclides**
- **Concentrations will be reduced when UZ flow reaches water table**
- **Mixing and dispersion during transport lead to dilution**
- **Additional mixing occurs at point of water withdrawal**

Analyses of Disruptive Processes and Events

- Early site screening considered the probability of significant disruptive processes and events
- Current approach is to analyze features/events/processes on basis of likelihood and potential effects
- Total system performance assessment is used to evaluate consequences for limited number of features/events/processes

Summary

- Development of Waste Containment and Isolation Strategy provides an iterative basis for establishing the safety case
  - Accommodates evolving understanding of site processes and conditions
  - Allows systematic evaluation of design features to determine their performance benefits
  - Provides flexibility to deal with uncertain regulatory framework

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Assessment of Engineered Barrier System Performance Issues in TSPA-VA

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Robert W. Andrews
Manager, M&O Performance Assessment
Management and Operating Contractor

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

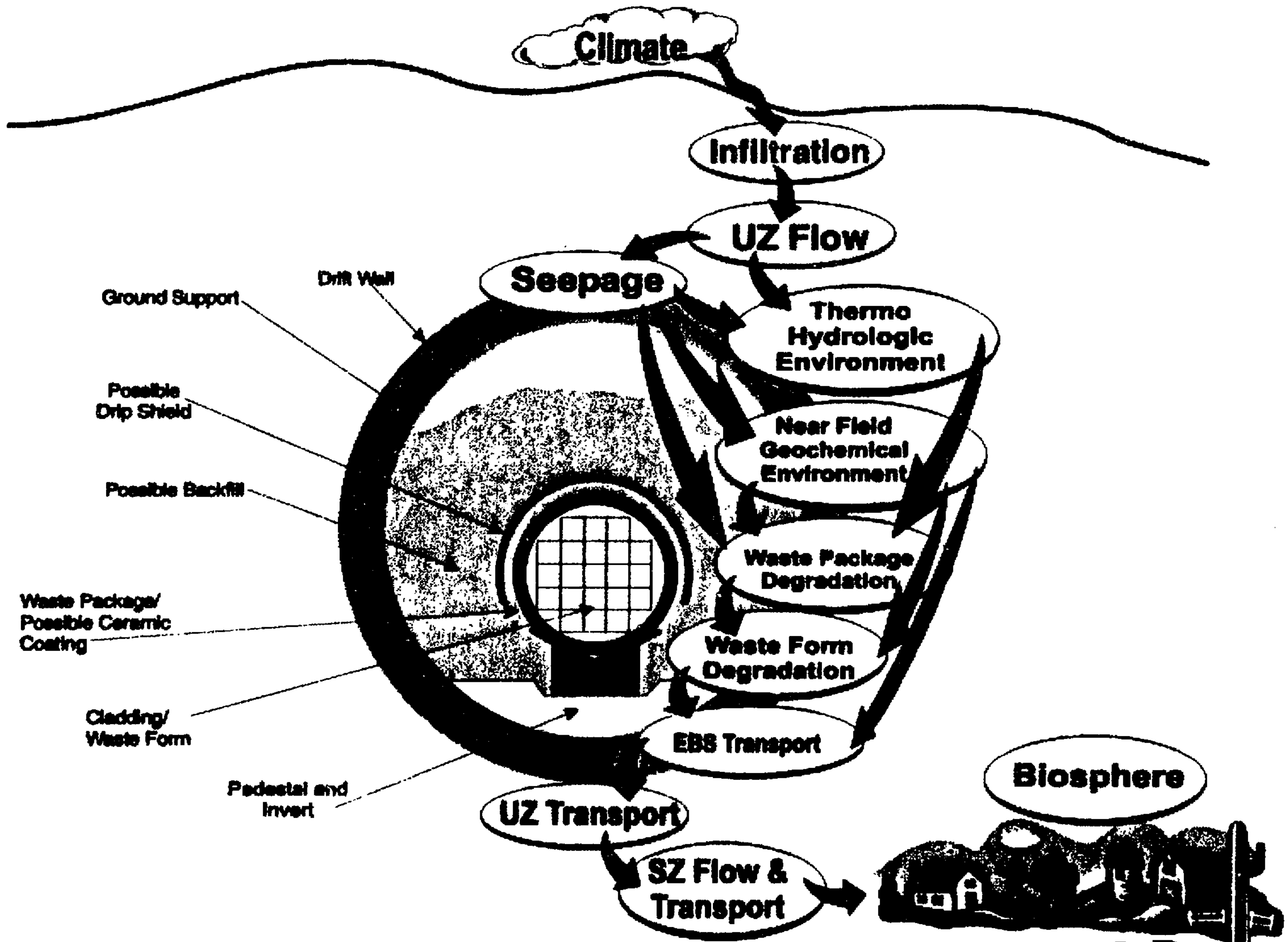
Outline

- Approach to TSPA-VA
- Schematic of Engineered Barrier System (EBS)
- Components of EBS in TSPA-VA
- Key Information Required from EBS Models
- Key Issues Associated with EBS Models
- Methods to Address Key EBS issues
- Conclusions

Approach to TSPA-VA

- Integrate site and design information and models to predict potential long-term consequences of radioactive waste disposal at Yucca Mountain
- Evaluate expected performance for the reference design using representative models and parameters
- Evaluate significance (i.e., sensitivity) of alternative models on performance
- Consider reasonable ranges in parameter values in uncertainty analysis (treat variability as stochastic process)
- Evaluate performance benefits of alternative defense-in-depth designs

Models for Total System Performance Assessment



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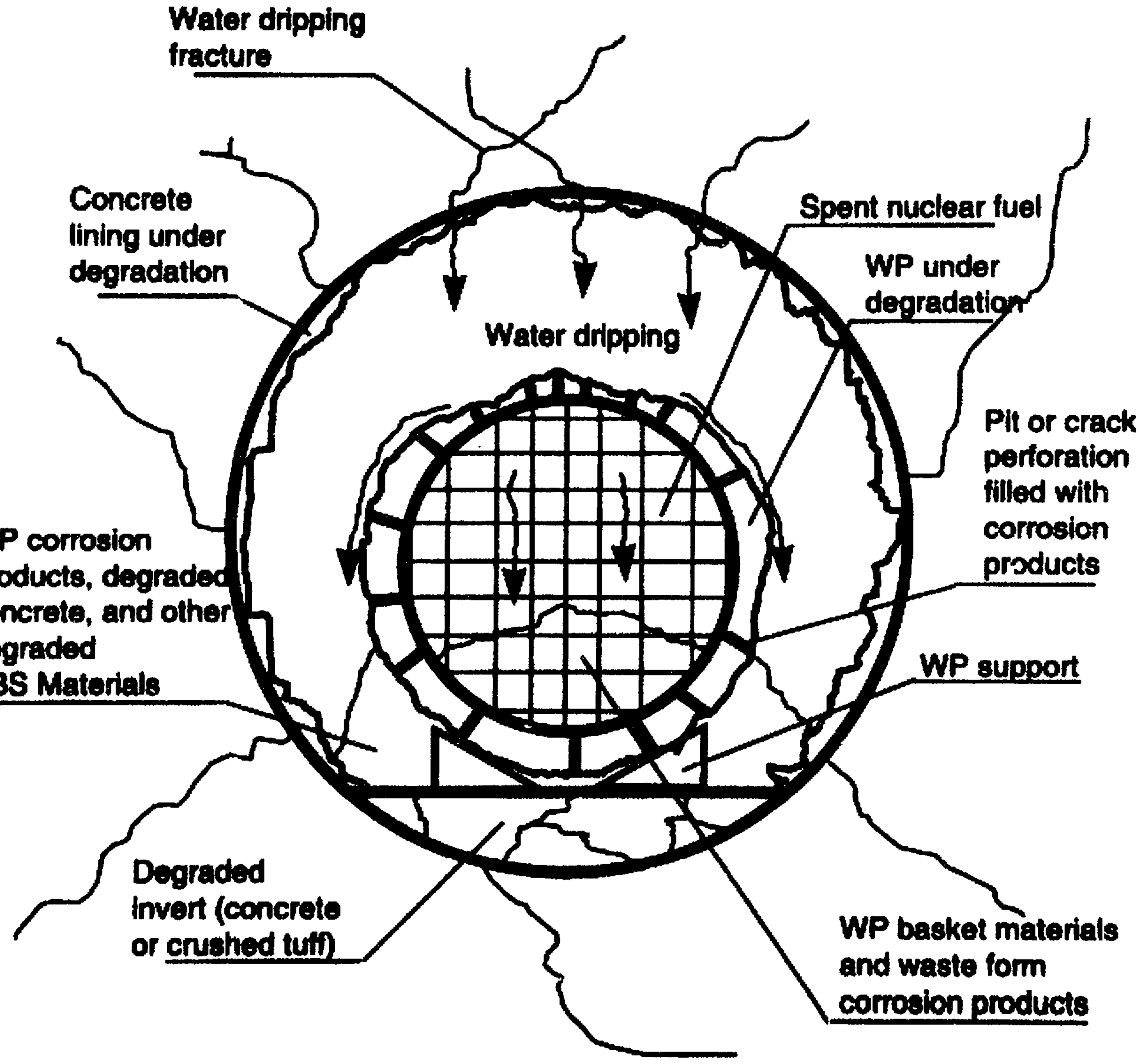
Schematic of Significant EBS Components



Key Engineering Components Affecting Predictions of Long-Term Waste Containment & Isolation

	Significance	KTI	WCIS
• Near-Field Thermohydrology	●	✓	✓
• Near-Field Thermochemistry	•	✓	✓
• Possible Drip Shield Integrity	•		
• Waste Package Degradation	●	✓	✓
- possible ceramic coating	•		
- corrosion-allowance material	•		
- galvanic protection	●		
- corrosion-resistant material	●		
• Cladding Degradation	●	✓	✓
• Waste Form Degradation	•	✓	✓
• Radionuclide Mobilization	●	✓	✓
• EBS Radionuclide Transport	●	✓	✓

Key Information Required from EBS Models

Model	Key Information
Near-Field Thermohydrology	Relative humidity (x,y,t) Temperature (x,y,t) Liquid saturation (x,y,t) Liquid flux (x,y,t)
Near-Field Thermochemistry	Key geochemical constituents (x,y,t) (e.g. pH, Eh, pO_2, pCO_2, Cl) – waste package – waste form – backfill/invert
Drip Shield Integrity	Time of return to "ambient" in drift liquid flux (x,y)

Key Information Required from EBS Models
(Continued)

Model	Key Information
Waste Package Degradation	Time of initial "pit" (x,y) Rate of pitting (x,y,t)
Cladding Degradation	Time of initial "pin hole" (x,y) Rate of "unzipping" (x,y,t)
Waste Form Degradation	Waste form surface in contact with water (x,y,t) Degradation rate (x,y,t,env.)
Radionuclide Mobilization	Form of radionuclides released Radionuclide solubility (t,env.)
EBS Transport	Colloid concentration Retardation in EBS (t) Advection/diffusion through EBS (t)

Near-Field Thermohydrologic Model Issues

Issues	Approach to Address
Pre-emplacement hydrogeology	
Percolation flux	Range of reasonable percolation fluxes derived from UZ flow model and expert elicitation
Matrix / fracture properties	Range of reasonable "calibrated" alternative conceptual models considered
Seepage flux	Variability derived by drift-scale models and expert elicitation
Thermal design	Reference VA design is focus, but options carried

Near-Field Thermohydrologic Model Issues
(Continued)

Issues	Approach to Address
Thermal load variability	Analyses for three "representative" thermal outputs – High (18 kW/WP) – Med (10 kW/WP) – Low (2 kW/WP)
Thermohydrologic characteristics of backfill and invert	Use laboratory and literature data with uncertainty
"Validity"of thermohydrolgic model	Range of reasonable models considered on-going testing to increase confidence)

Near-Field Thermochemical Model Issues

Issues	Approach to Address
Pre-emplacement hydrochemistry	Reasonable range of bulk compositions based on model of water-rock interactions (dominantly J-13)
Perturbed hydrochemistry during thermal phase	Sensitivity study of alteration of aqueous geochemistry
Hydrochemical reaction with liner	Model prediction of range of key geochemical parameters that impact waste package degradation

Near-Field Thermochemical Model Issues

(Continued)

Issues	Approach to Address
Hydrochemical reaction with waste package	Model prediction of range of key geochemical parameters that impact waste form degradation or radionuclide solubility
Hydrochemical reaction with waste form	Model prediction of range of key geochemical parameters that impact radionuclide solubility
Hydrochemical reaction with invert	Model prediction of range of key geochemical parameters that impact radionuclide retardation

Waste Package Degradation Model Issues

Issues	Approach to Address
Waste package design	Reference design is focus, but options carried
Percent of package surface in contact with seep	Dependent on probability of seep and degradation model of dripshield and/or ceramic coating derived from literature and expert elicitation
Degradation rate of corrosion-allowance material	Rate model based on literature, lab data and expert elicitations as a function of key environmental parameters (RH, T, pH, Cl....). Variability treated stochastically

Waste Package Degradation Model Issues

(Continued)

Issues	Approach to Address
Enhanced degradation rate at welds or by MIC	Rate increase from expert elicitation
Galvanic protection of corrosion-resistant material	Variable degrees of galvanic protection (e.g. throwing power) derived from expert elicitation. Variability treated stochastically
Degradation rate of corrosion-resistant material	Rate model a function of environment derived from laboratory and literature data and expert elicitation. Variability treated stochastically

Waste Form Degradation Model Issues

Issues	Approach to Address
Cladding degradation rate	Degradation model tied to mechanistic (lab- and empirical-based) data and industry information
Waste form surface in contact with water film	Derived from cladding degradation and "unzipping," laboratory information on surface area expansion and model results on in-package hydrology (saturation, RH)
Water film thickness	Derived from model results of in-package hydrology
Waste form degradation rate	Functional relationship (dependent on chemistry, temperature, burn-up) derived from laboratory data

Radionuclide Mobilization Model Issues

Issues	Approach to Address
Form of radionuclides released from waste form (including colloids)	Derived from laboratory and literature data
Solubility of radionuclides	Derived from laboratory data with functional relationships

EBS Transport Model Issues

Issues	Approach to Address
Effective diffusion through degraded waste package	Diffusion dependent on lab-derived diffusion coefficients and predicted waste package degradation
Advection through waste package	Use models relating advective flux to in-drift seepage and pit distribution
Radionuclide retardation in degraded waste package/invert materials	Changes in geochemistry used to define change in solubility and sorptive properties derived from laboratory data

EBS Transport Model Issues
(Continued)

Issues	Approach to Address
Diffusion through degraded invert	Use liquid saturation in degraded invert combined with laboratory data on effective diffusion coefficient
Advection through degraded invert	Derived from seepage flux in drift-scale flow model

Conclusions

- Previous TSPA studies have been used to identify significance of key issues in EBS models to predicted performance
- Currently addressing these issues within the TSPA-VA
- Expert elicitation will assist in quantifying uncertainty and variability in some key aspects of the waste package degradation model
- Additional testing and model development and substantiation will occur between VA and LA

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Studies

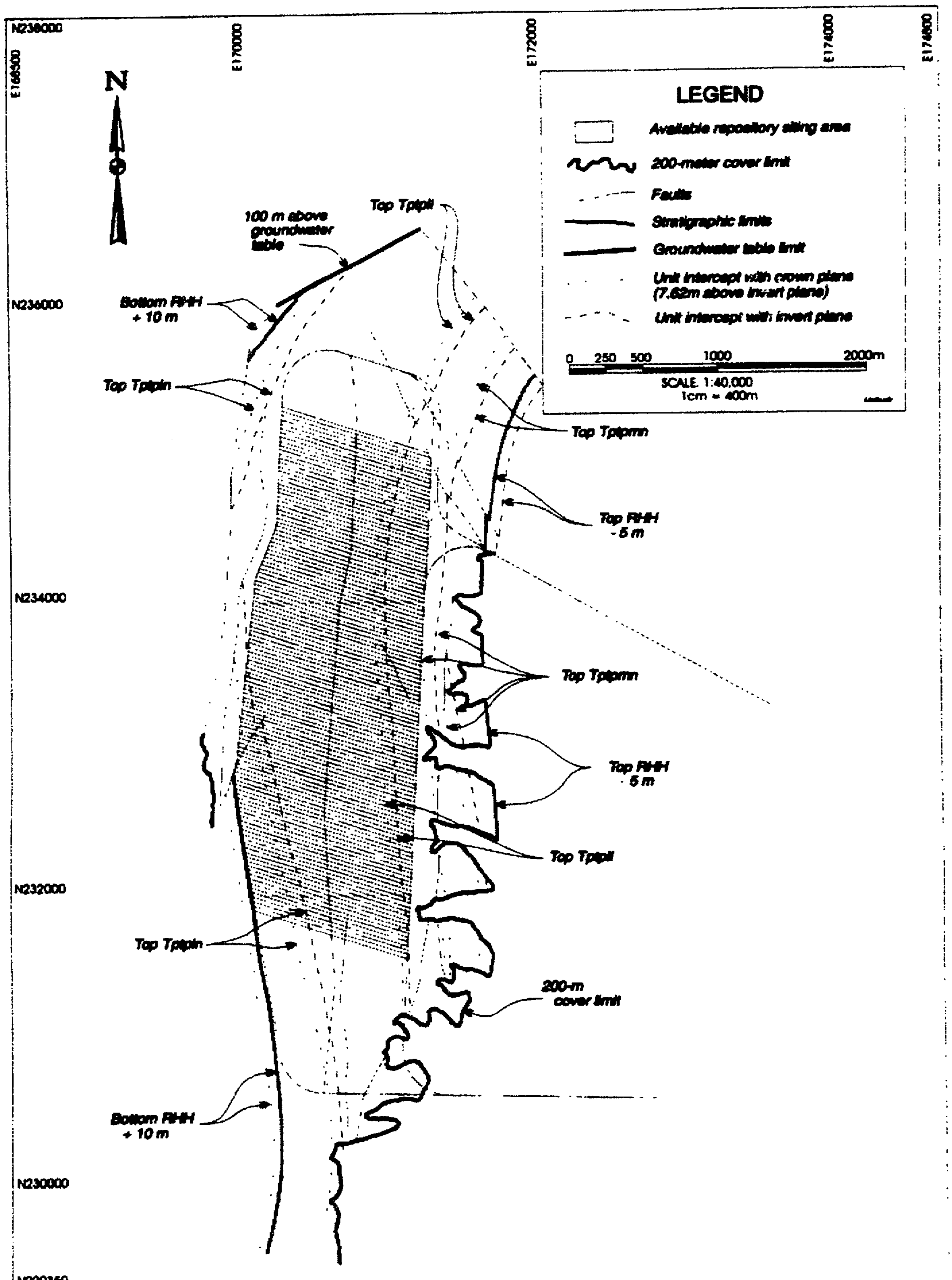
Repository Design and Operations

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Richard D. Snell
Operations Manager, Engineering and Integration
Management and Operating Contractor
Las Vegas, Nevada

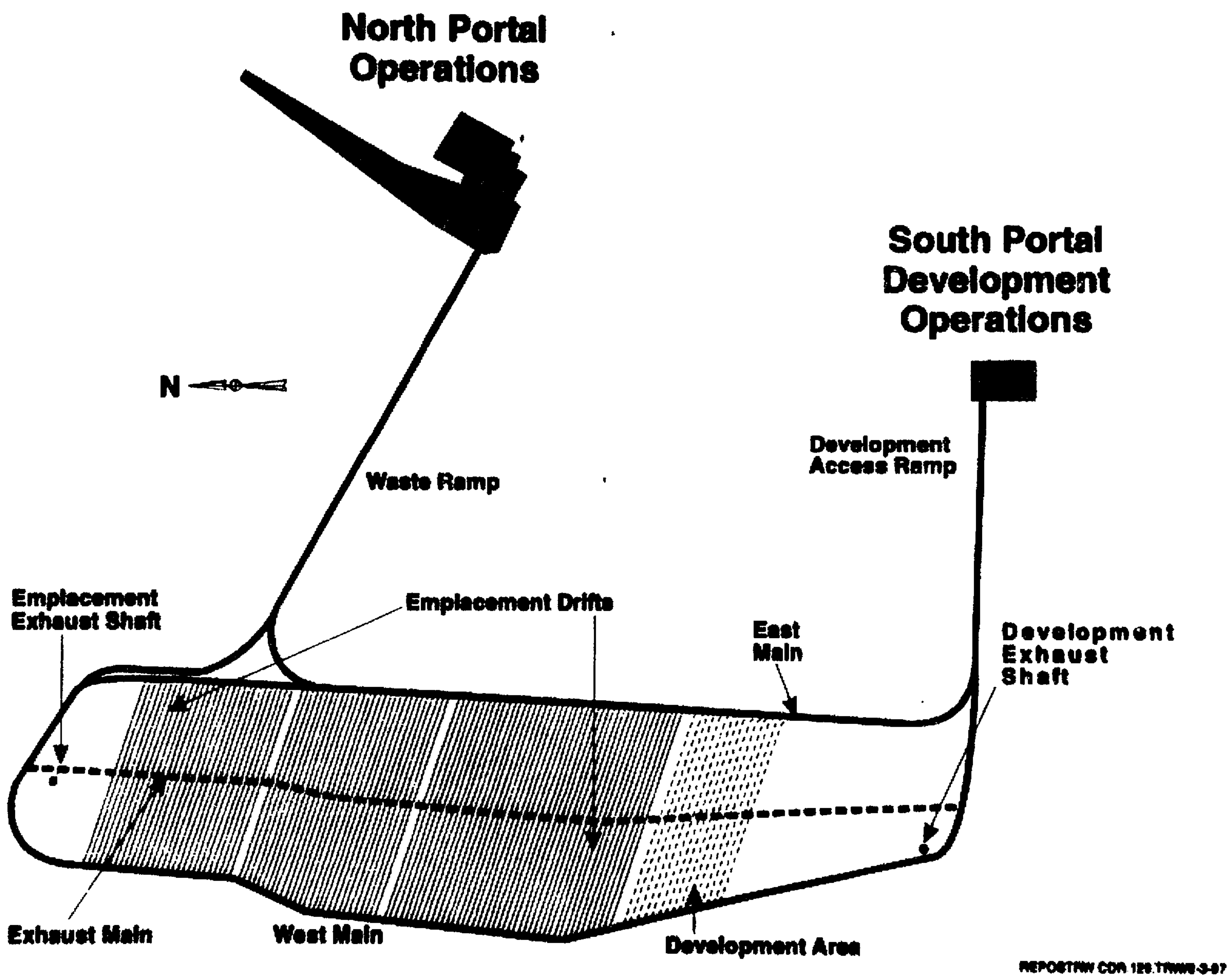
U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

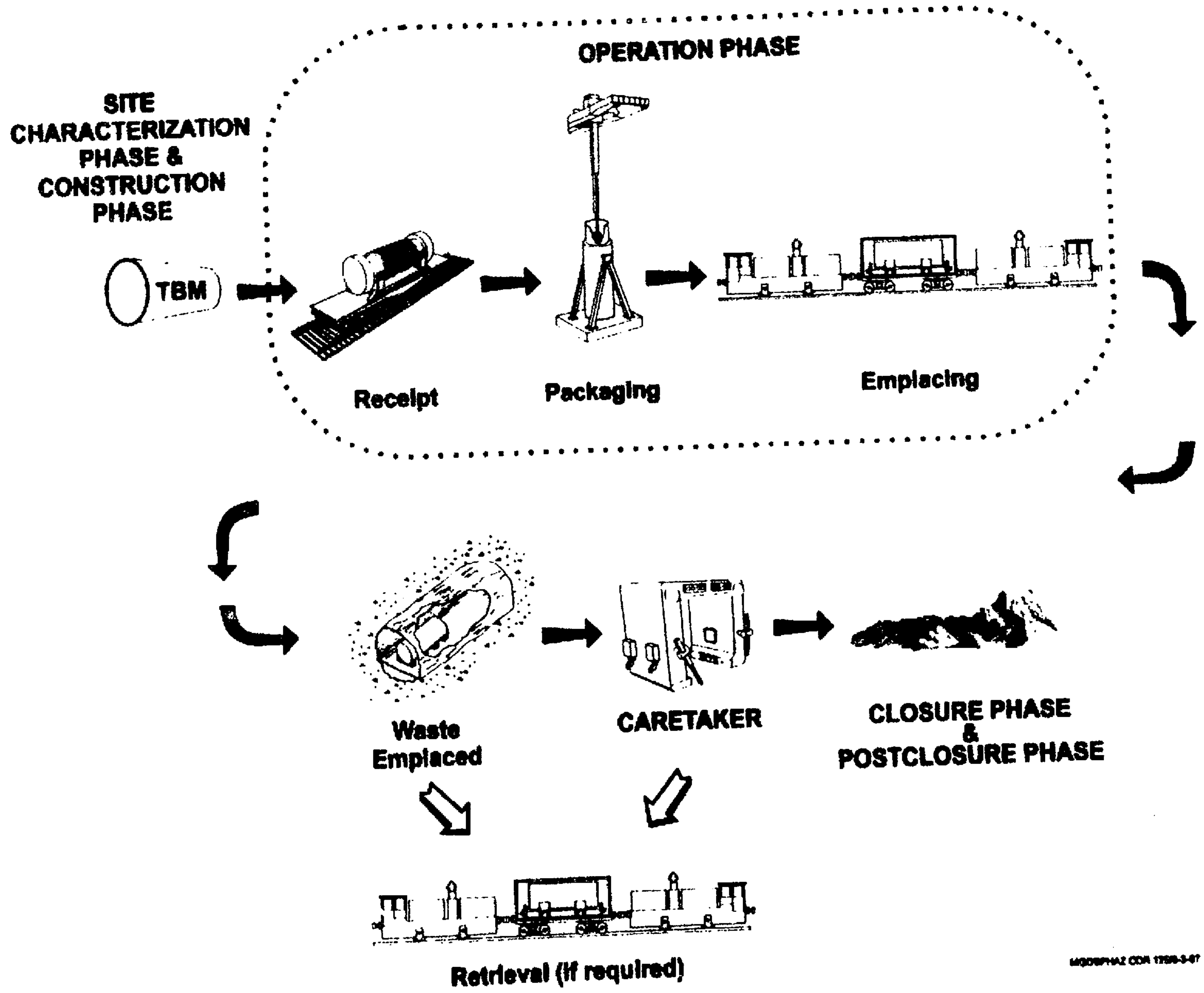


Available repository siting area

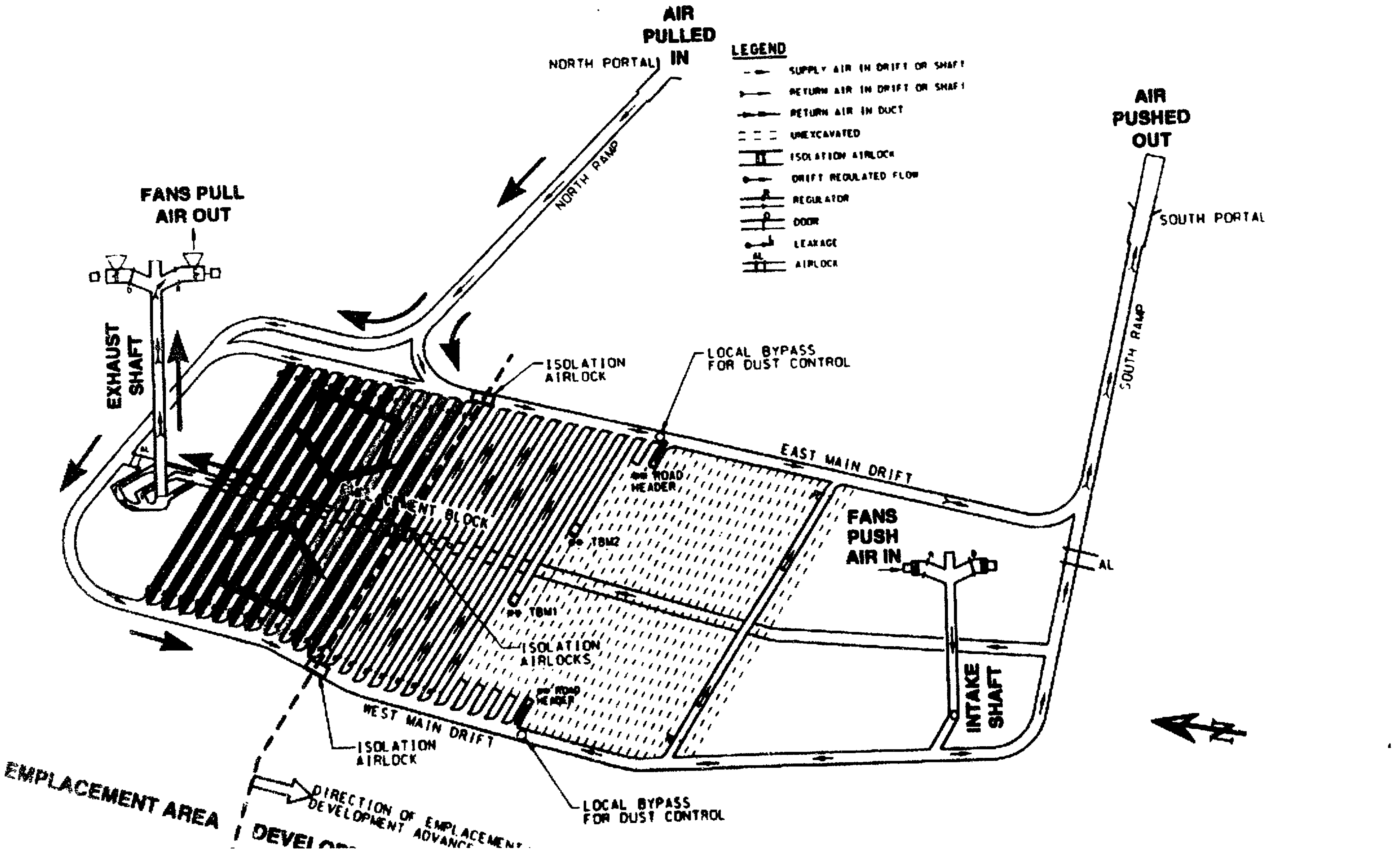
Repository Operations Areas



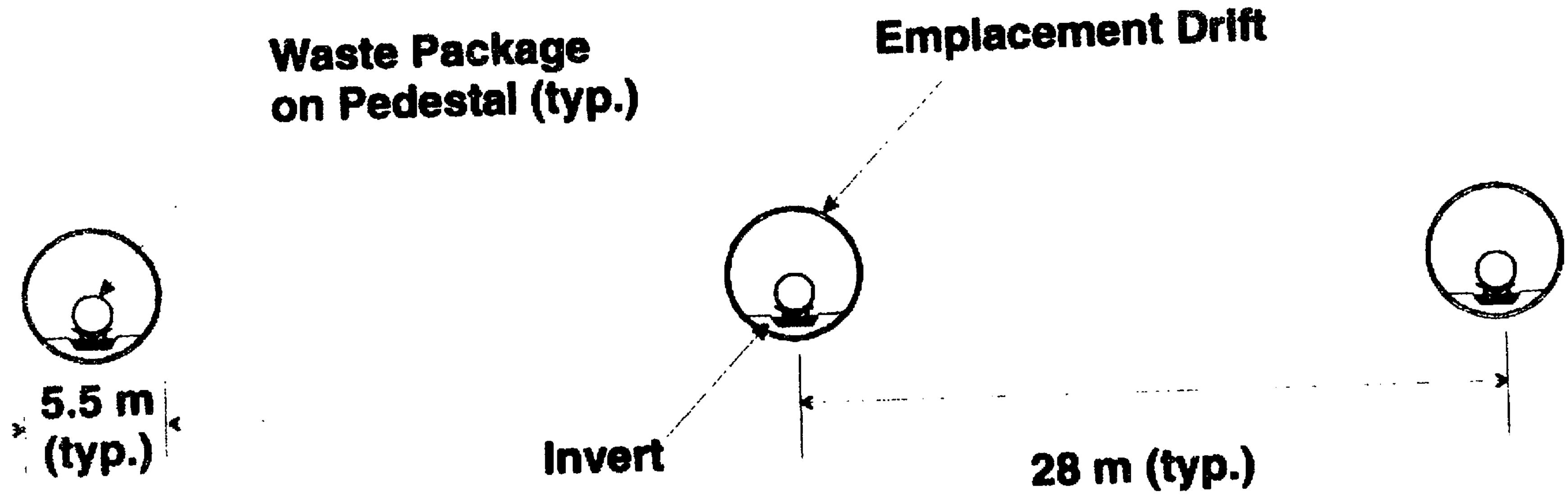
Base Repository Operations



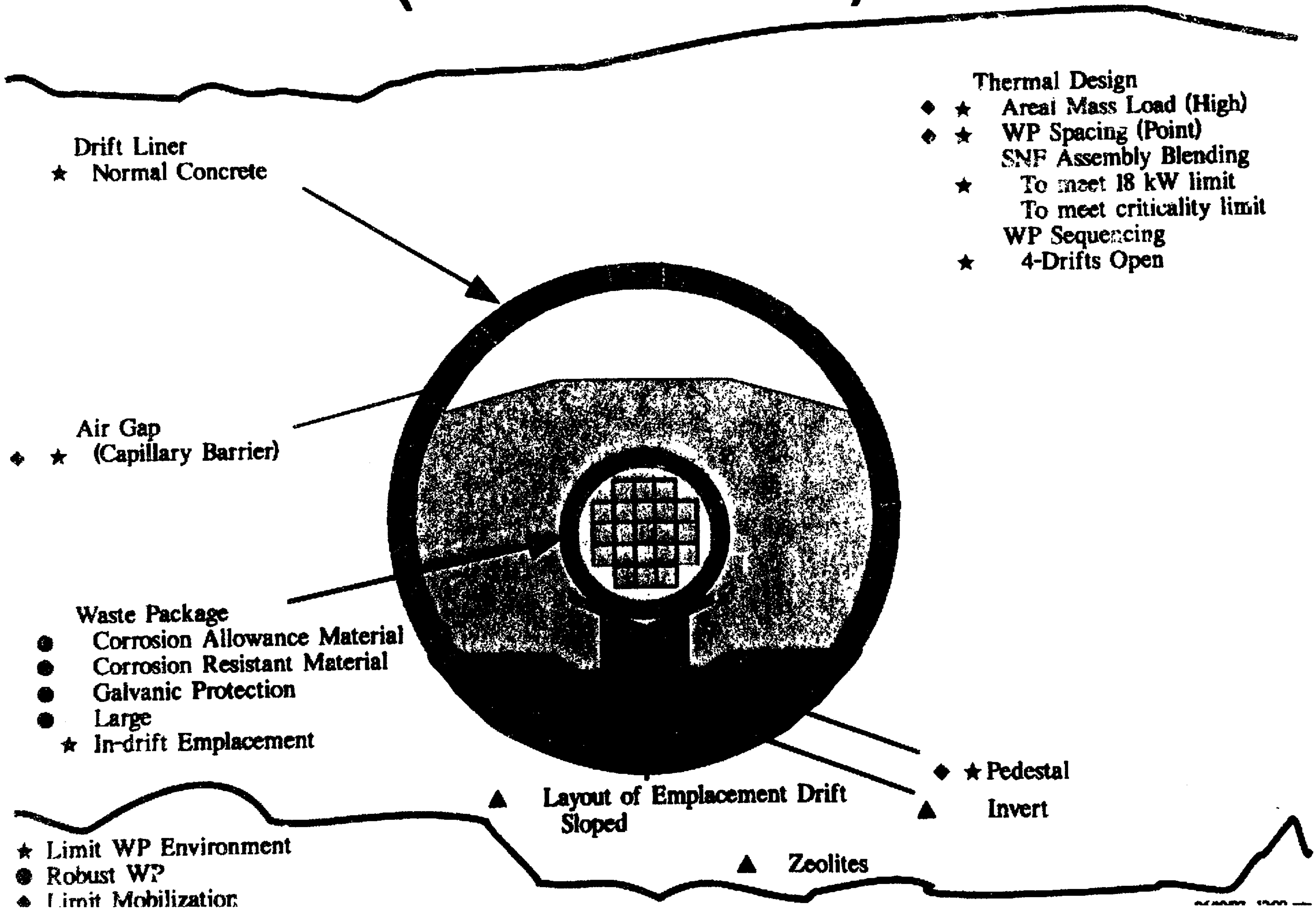
Typical Ventilation Balance



Partial Repository Section



Design Options for Waste Isolation
(Reference Case)



Engineered Barrier System (EBS)

- What must the EBS do?
  - Work in concert with the natural barriers so the repository meets performance requirements
  - Be configured to provide "Defense-in-Depth"
  - Be explainable and defendable by analysis and test for NRC licensing

Engineered Barrier System (EBS)
(Continued)

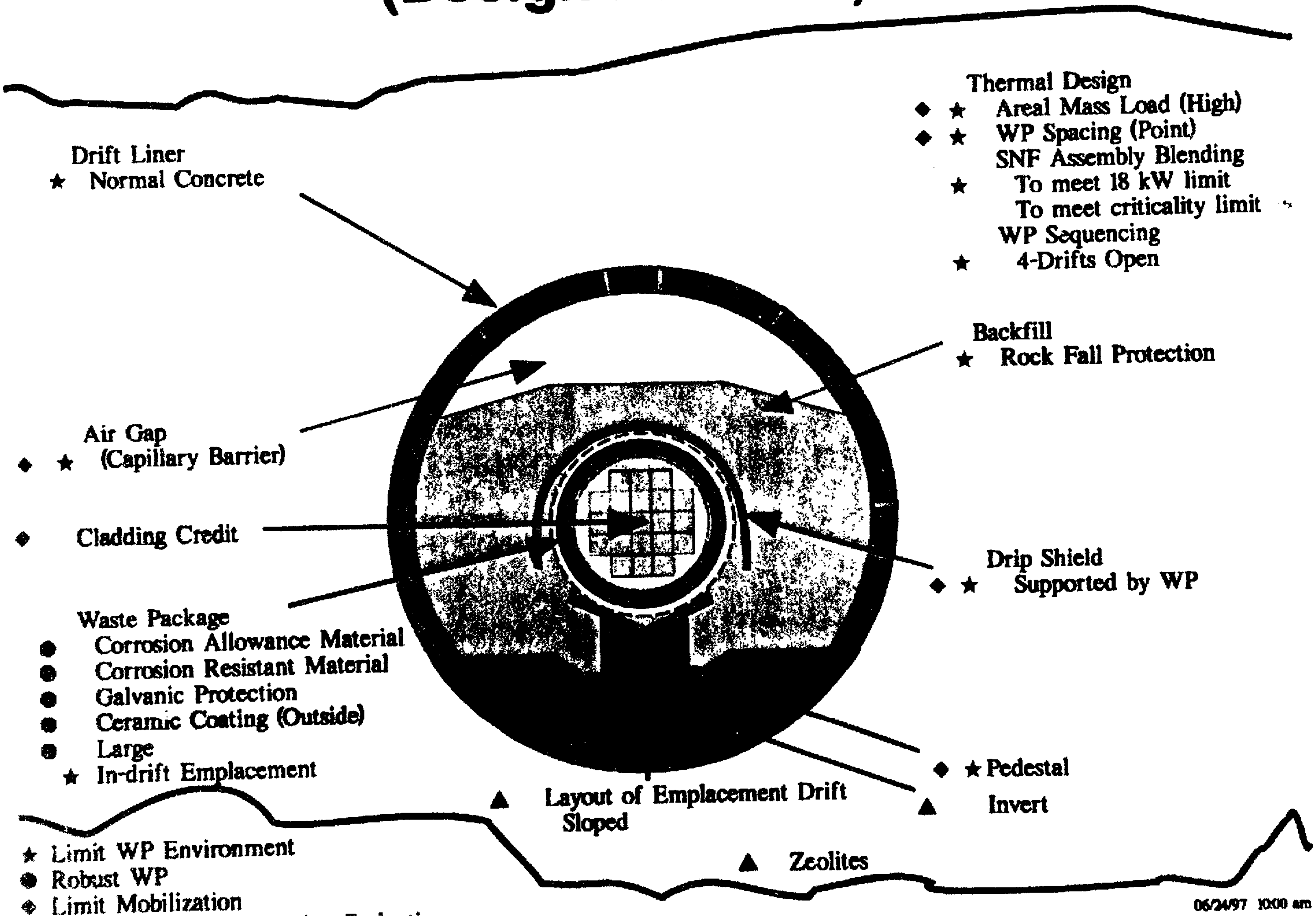
- **What is the strategy for developing the EBS?**
  - Develop a set of operating and bounding conditions which are expected over the life of the Repository (e.g., water quantities and flow conditions in the mountain)
  - Identify, and characterize, a family of EBS design features that could be employed in the repository
  - Use Performance Assessment (PA) sensitivity studies to perform evaluations of the overall performance of the repository (using combinations of the EBS features) against the performance requirements

Engineered Barrier System (EBS)

(Continued)

- Evaluate percolation flux -- current considerations
  - Percolation flux (1 -15 mm/yr; 6 ± mm/yr average)
  - Climate changes (30 mm/yr)
  - Variability in percolation flux distribution; focused flows
  - Episodic behavior
- Evaluate seepage into emplacement drifts
- Develop EBS features and evaluate performance/cost
  - Includes interactions between site, PA, and design, and is an iterative process

Design Options for Waste Isolation
(Design Features)



EBS Performance Over Time

- Other (non-CRWMS) test and empirical data
- Natural analogs
- Effective use of test programs
- Laboratory Materials Tests
- Drift Scale Test (In-Drift; Near Field)
- Performance Confirmation program data
  - Emplacement Drift Liner
  - Waste Package/EBS
  - In-Drift Environment
  - Near-Field Environment
  - Far-Field Environment

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Studies

Waste Package Design and Materials

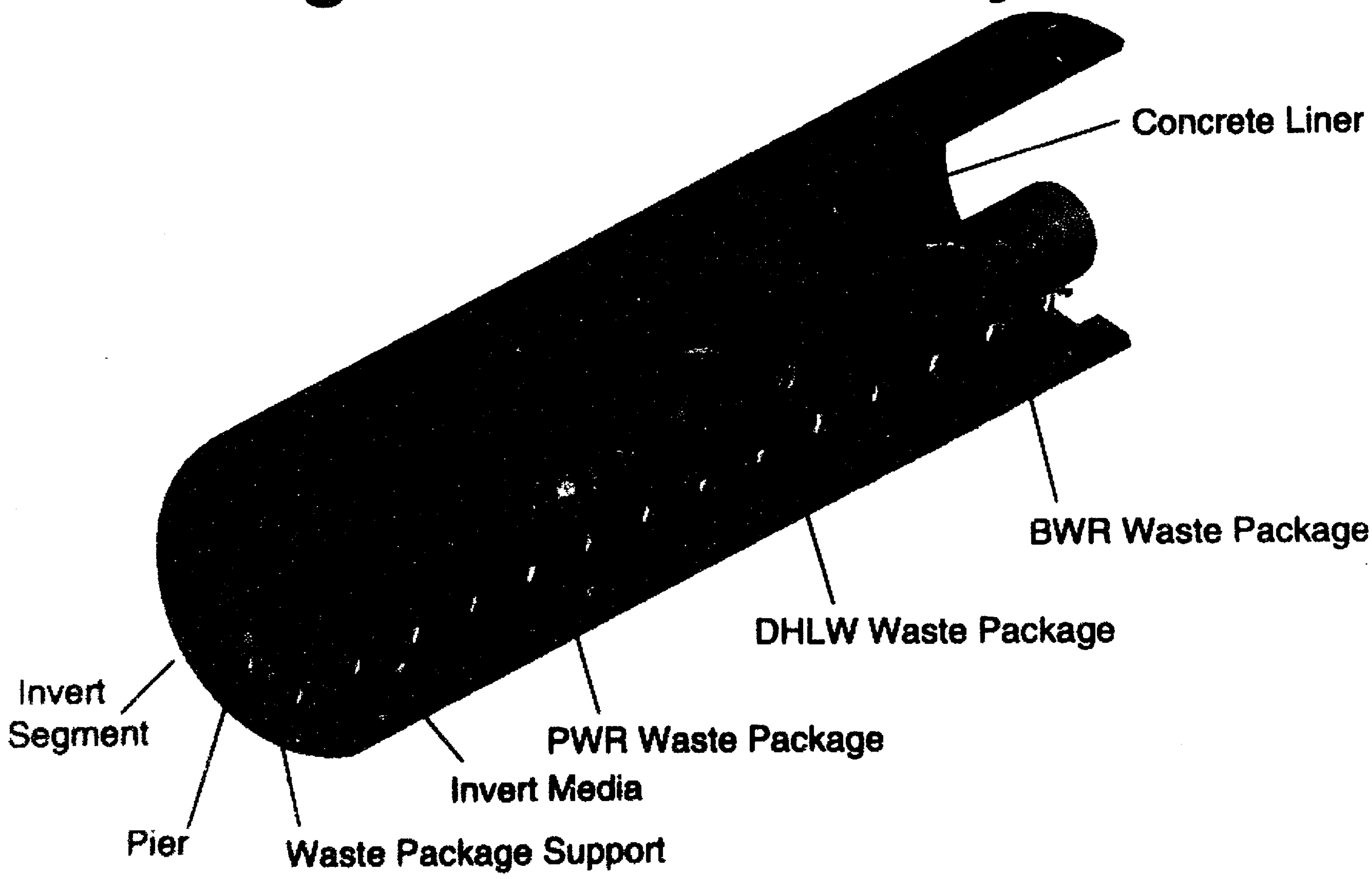
Presented to:
Nuclear Waste Technical Review Board

Presented by:
David Stahl, Ph.D.
Manager, Waste Package Materials Department
Management and Operating Contractor

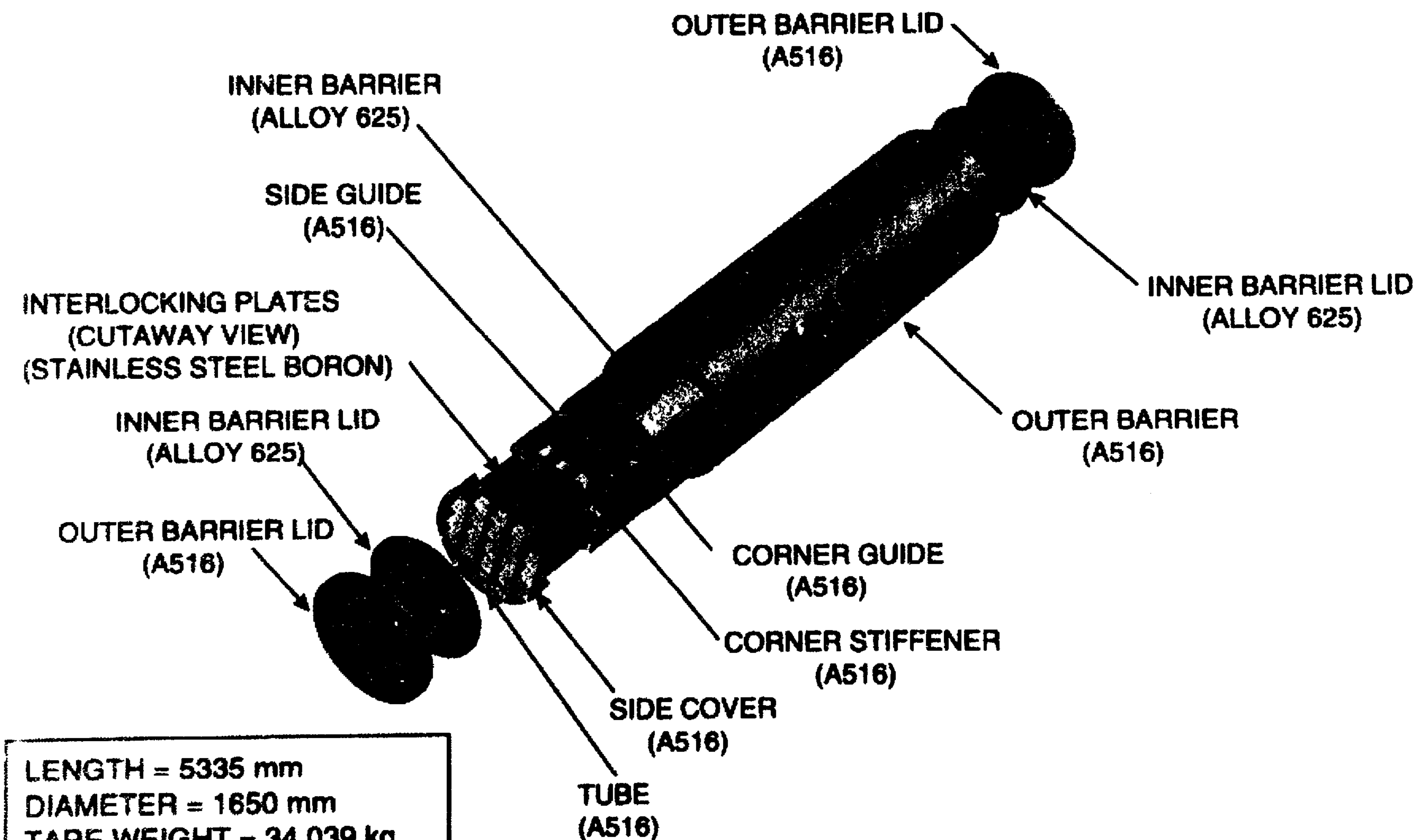
U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

Engineered Barrier System



21-PWR UCF Disposal Container



LENGTH = 5335 mm
DIAMETER = 1650 mm
TARE WEIGHT = 34,039 kg
LOADED WEIGHT = 50,423 kg

Materials Considerations in Waste Package Designs

- Corrosion-allowance outer barrier materials
  - Predictable slow degradation
  - Tolerant to handling and service loads
  - Radiolysis protection
  - Galvanic protection
  - Acceptable strength
  - Fabricability
- Corrosion-resistant inner barrier materials
  - Long-term corrosion resistance
  - Predictable performance
  - ceptable strength
  - ıbricability

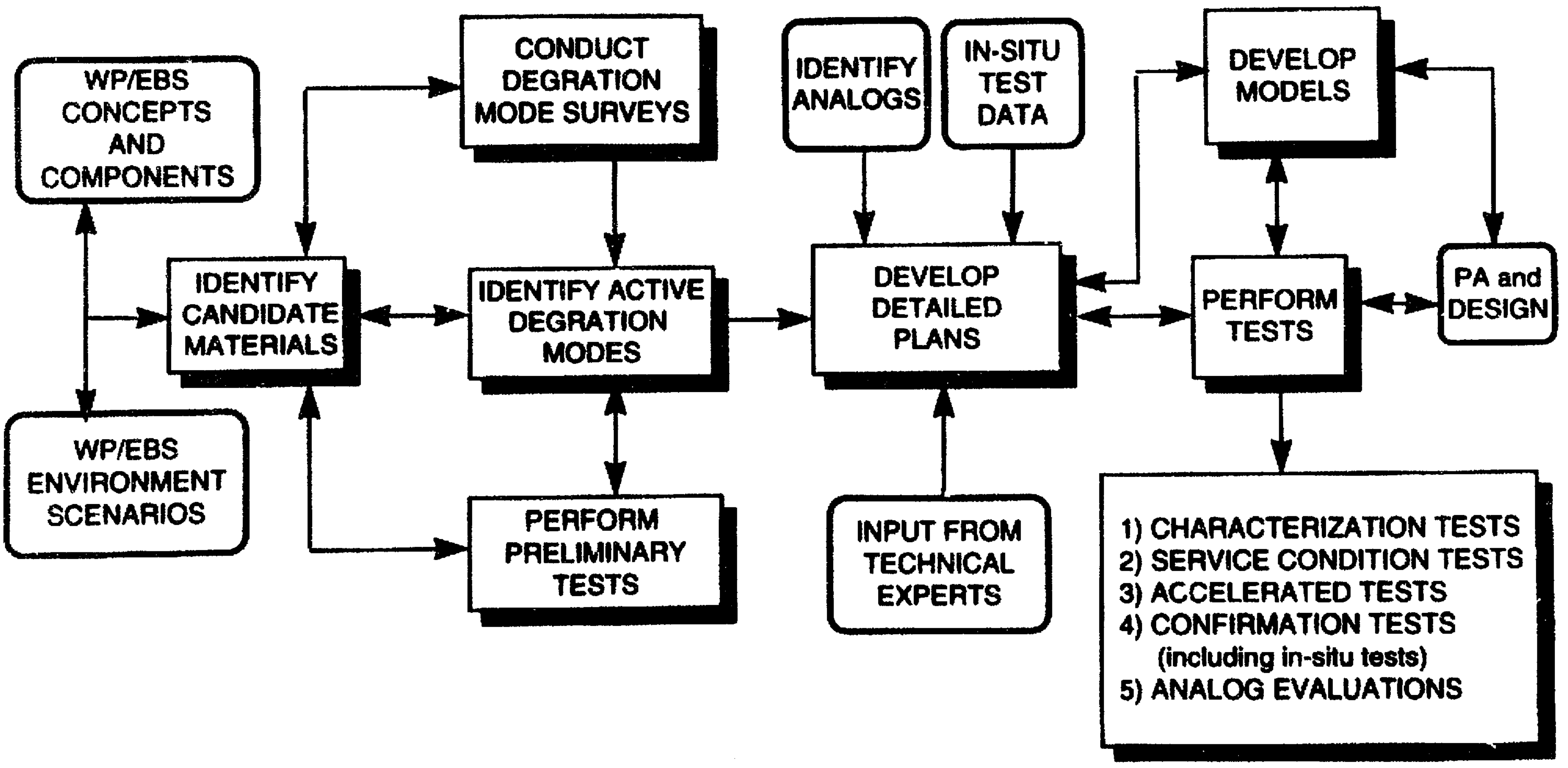
Environment Assumptions for Waste Package Materials Testing

- Assumed Water Contact Mode Scenario:
  - Early hot, dry conditions followed by cooler, more humid conditions with potential for dripping of concentrated groundwater onto waste packages
- Existing test conditions include water chemistry which ranges from 10X to 1000X J-13 and pH ranges from 2 to 12 and temperatures of 60 and 90°C
- Higher water seepage flux may reduce concentration of ionic species of water contacting the packages
  - However corrosion degradation is more closely coupled to local conditions at the surface of the waste package
- Test environments include controlled and equilibrated relative humidity, water line and complete submersion
  - Drip testing is scheduled to begin in FY 1998

Container Materials in Corrosion Test Program

- Corrosion-Allowance Materials
  - Carbon steel - cast (ASTM A27) and wrought (ASTM A516)
  - Low alloy (2.25 Cr - 1 Mo) steel
- Intermediate Corrosion-Resistant Materials
  - Copper-nickel (70/30) alloy
  - Nickel-copper (70/30 - Monel 400) alloy
- Corrosion-Resistant Materials
  - Nickel-rich alloys (Alloy G-3, G-30, 825)
  - Nickel-base alloys (Alloy 625, C-4, C-22)
  - Titanium alloys (Ti-Grade 12, Ti-Grade 16)
- Other Materials
  - Type 304/316 stainless steel with and without boron
  - Zircaloy (to be added to support Navy testing)
  - Ceramic coatings (alumina, titania, alumina-magnesia)

Waste Package Materials Test Strategy



Waste Package Materials Studies

- Engineered Barrier Materials
  - Container materials testing
    - » Long-term corrosion
    - » Humid air corrosion
    - » Crack growth
    - » Electrochemical potential
    - » Microbiologically-influenced corrosion
- Basket materials corrosion
  - Ceramic materials testing
  - Other engineered barrier materials testing
  - Degradation and abstraction modeling
- Waste Form Materials
  - Spent fuel testing
  - High-level waste glass testing
  - Degradation and abstraction modeling

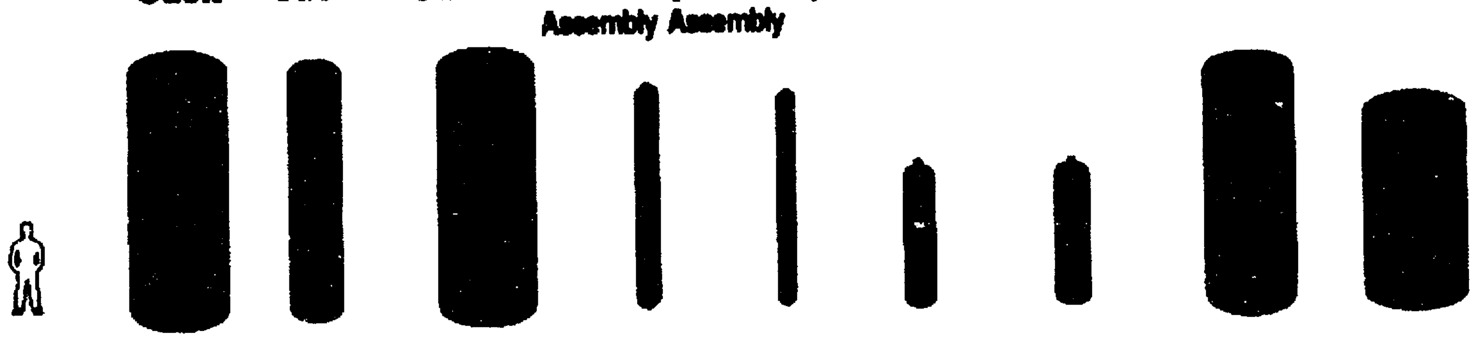
Results of Near-Term Materials Studies

(Continued)

- Microbiologically Influenced Corrosion
  - Tests with carbon steel at room temperature in a range of microbes showed that corrosion rate was about five times that of the abiotic case
- Basket Material Testing
  - Examination of boron-stainless steel from the scoping tests indicated that the metal borides were more corrosion resistant than the stainless steel matrix which will be confirmed utilizing ongoing electrochemical tests
- Ceramic Material Testing
  - Drops testing of coated steel at up to 2 m using a 100 kg simulated tuff rock did not produce visible coating damage while greater loads produced some flaking of the coating

Receipt

Representative Waste Form Data



	Received		Transferred					Emplaced	
	Rail Cask	Truck Cask	SNF Canister	PWR Assy Assembly	BWR Assy Assembly	DOE SNF	DHLW Canister	SNF DC	DHLW DC 5
Loaded Weight (tons)	105	25	31	0.9	0.4	2.0	1.1	53	39
Peak Units per Year	420	140	460	4,900	8,300	103	800	370	160

BWR	Boiling Water Reactor
DC	Disposal Container
DC 5	5 Pack DOE Center
DHLW	Defense High-Level Waste
PWR	Pressurized Water Reactor
SNF	Spent Nuclear Fuel

Results of Near-Term Materials Studies

(Continued)

- Engineered Barrier System Materials Testing
  - Short-term (1 mo) concrete tests revealed that significant chemical and microstructural alteration occurred
- Waste Form Testing
  - Thermogravimetric spent fuel oxidation tests to establish oxidation kinetics and spent fuel and HLW glass unsaturated drip condition tests are ongoing to establish dissolution and release information for PA
  - Scoping tests are underway to establish the geometry and conditions for colloid and rodlet unsaturated tests
- Materials Modeling
  - Significant progress has been made in both container materials, particularly in describing the interaction between the inner and outer containers, and waste form modeling, and interaction meetings were held with PA

Uncertainties in Materials Performance

- Durability of corrosion-allowance material including pitting and microbiologically influenced corrosion
- Preferential attack of welds
- Effectiveness of galvanic protection
- Durability of corrosion-resistant material including localized and microbiologically influenced corrosion
- Extrapolation of degradation rates to long times

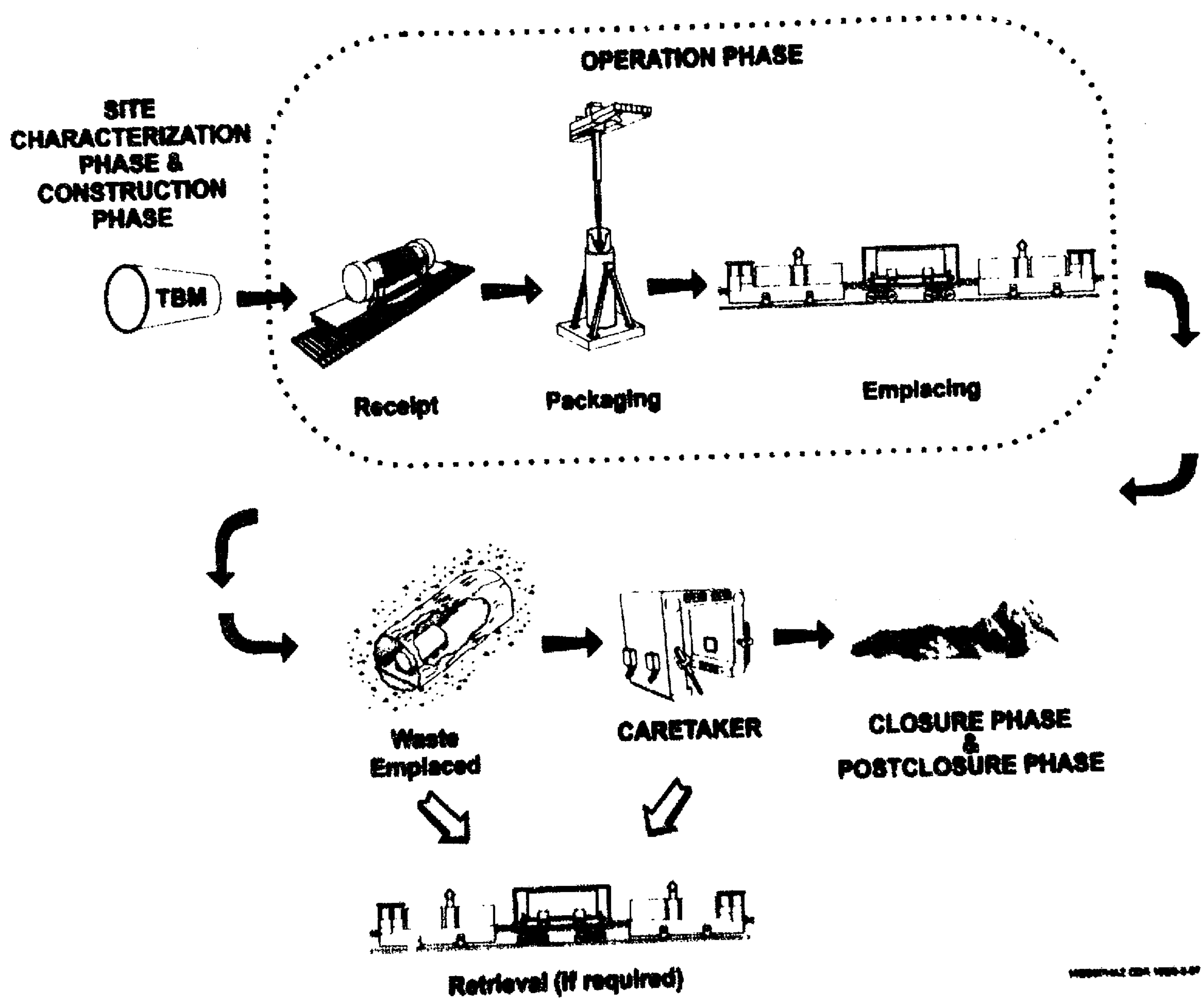
Methods of Treating Uncertainties

Uncertainties	Samples in long-term tests	Bounding environments	Various temperatures	Mechanistic models	Analogs
Durability of corrosion-allowance material	X	X	X		X
Preferential attack at welds	X	X	X		
Effectiveness of galvanic protection	X	X	X		
Durability of corrosion-resistant material	X	X	X	X	
Extrapolation of degradation rates to long times				X	X

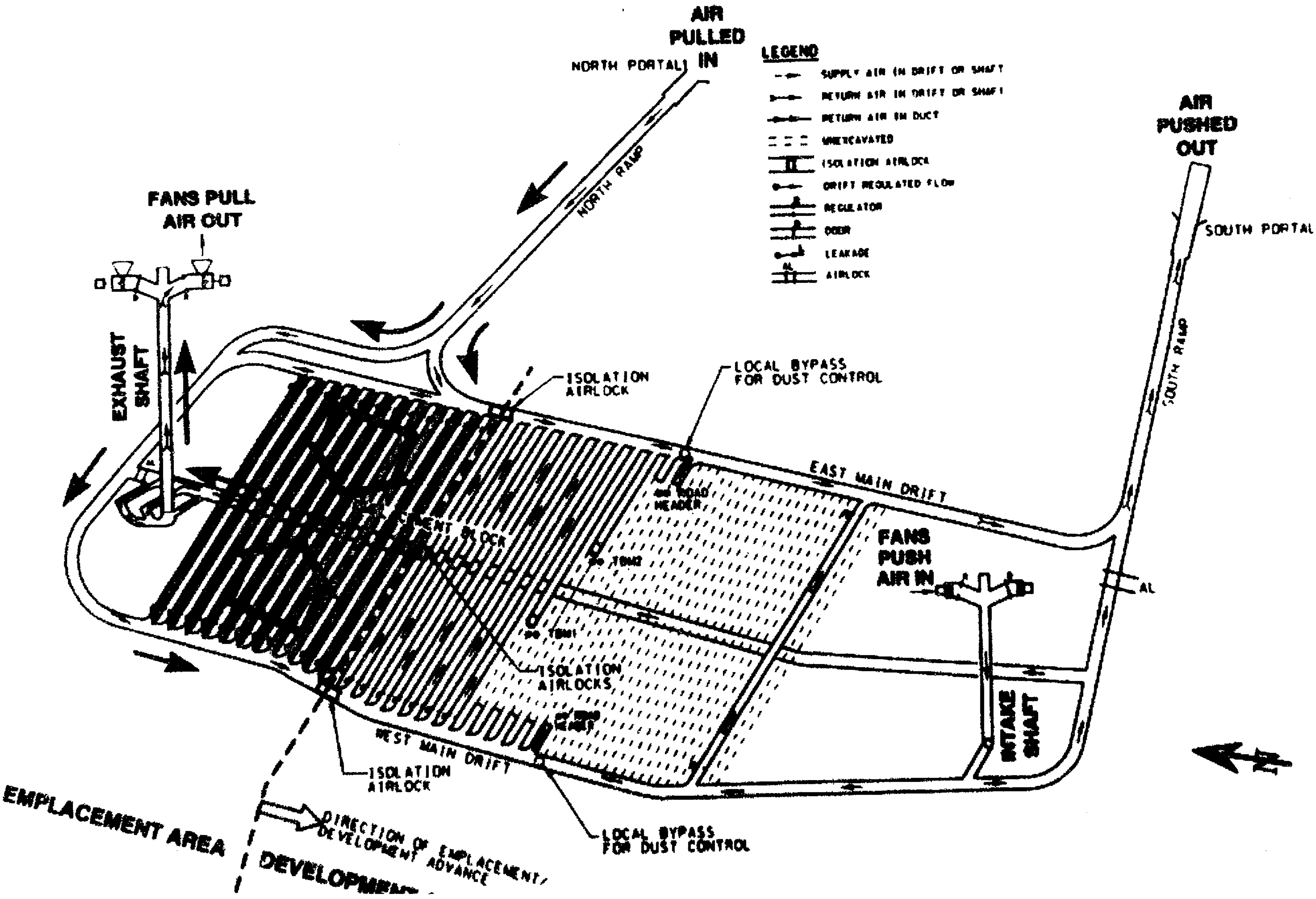
Interactions of Program Activities

- Frequent interface meetings with the design team on material test results and latest design considerations
- Frequent meetings with performance assessment on model inputs and the test results during the model abstraction process
- Input from the experts on the Nuclear Waste Technical Review Board, the Repository Consulting Board, the TSPA Peer Review Panel and the Waste Package Degradation Expert Elicitation Panel
- The overall objective of these interactions is to ensure that the testing and modeling efforts are consistent with design and performance assessment needs

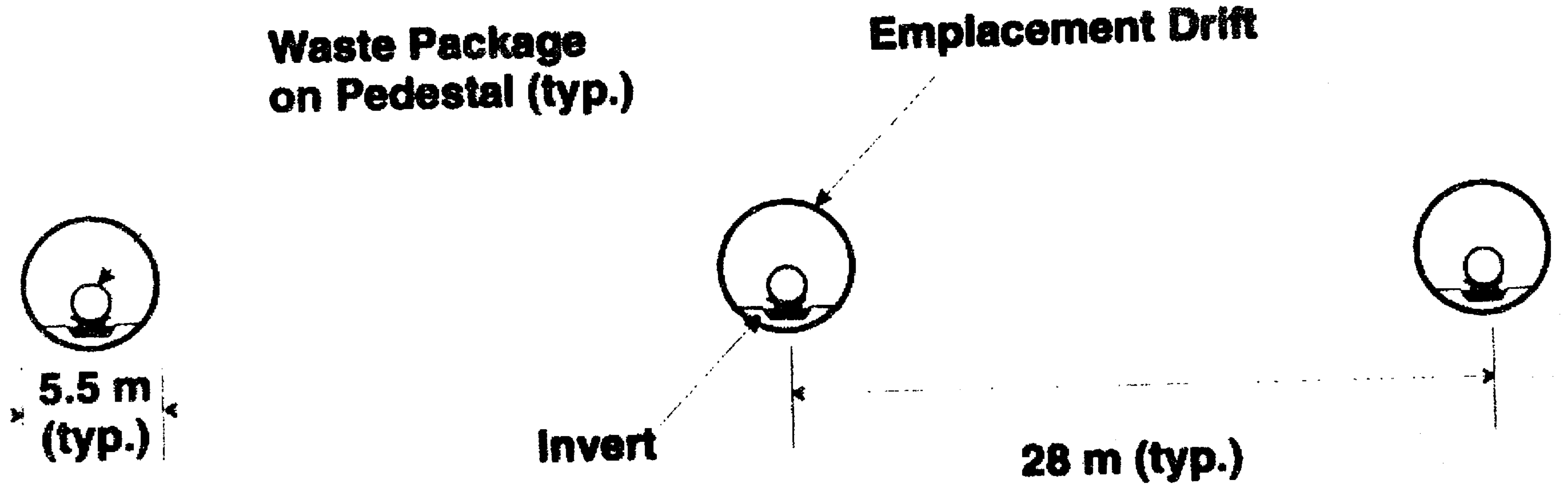
Base Repository Operations



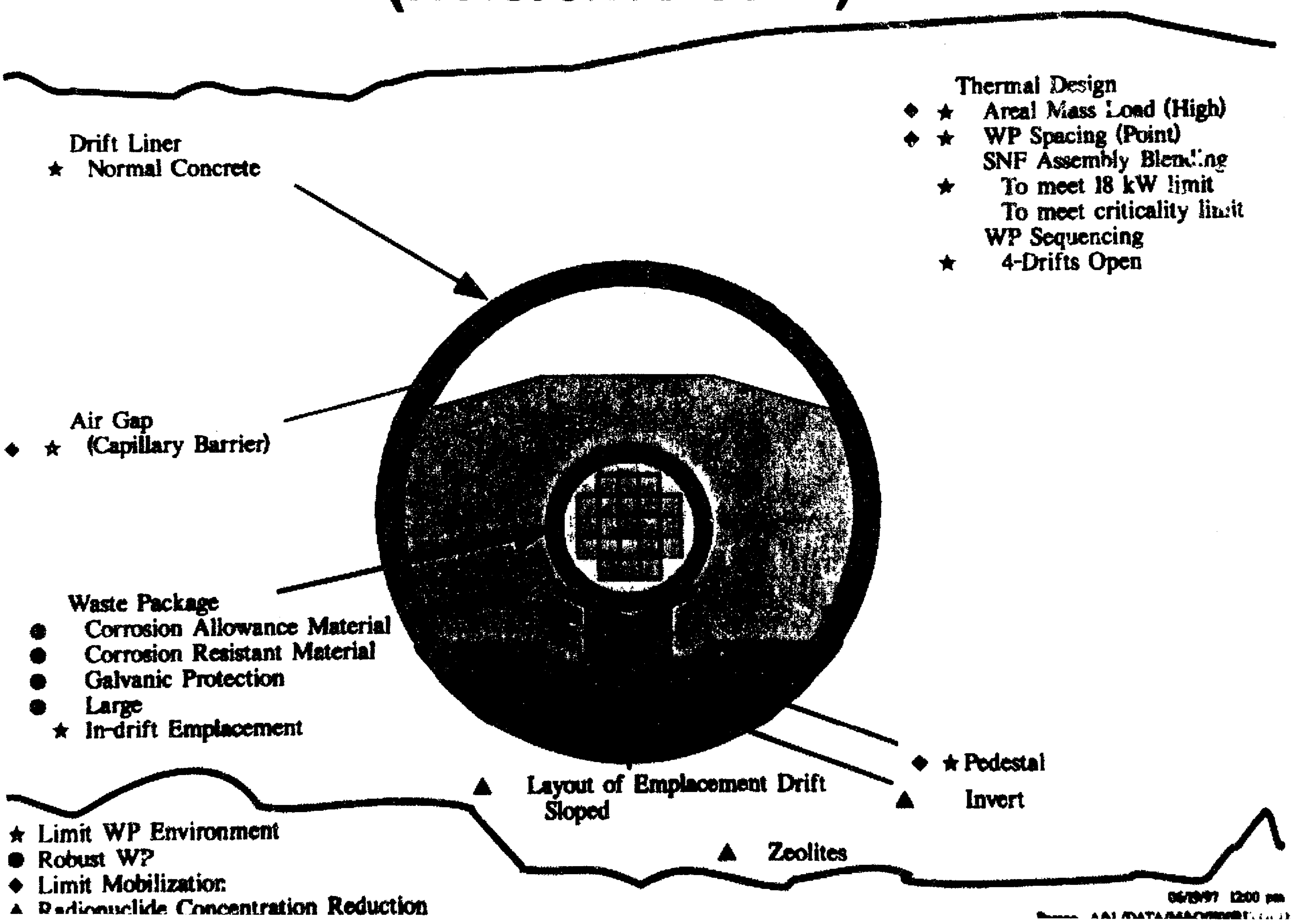
Typical Ventilation Balance



Partial Repository Section



Design Options for Waste Isolation
(Reference Case)



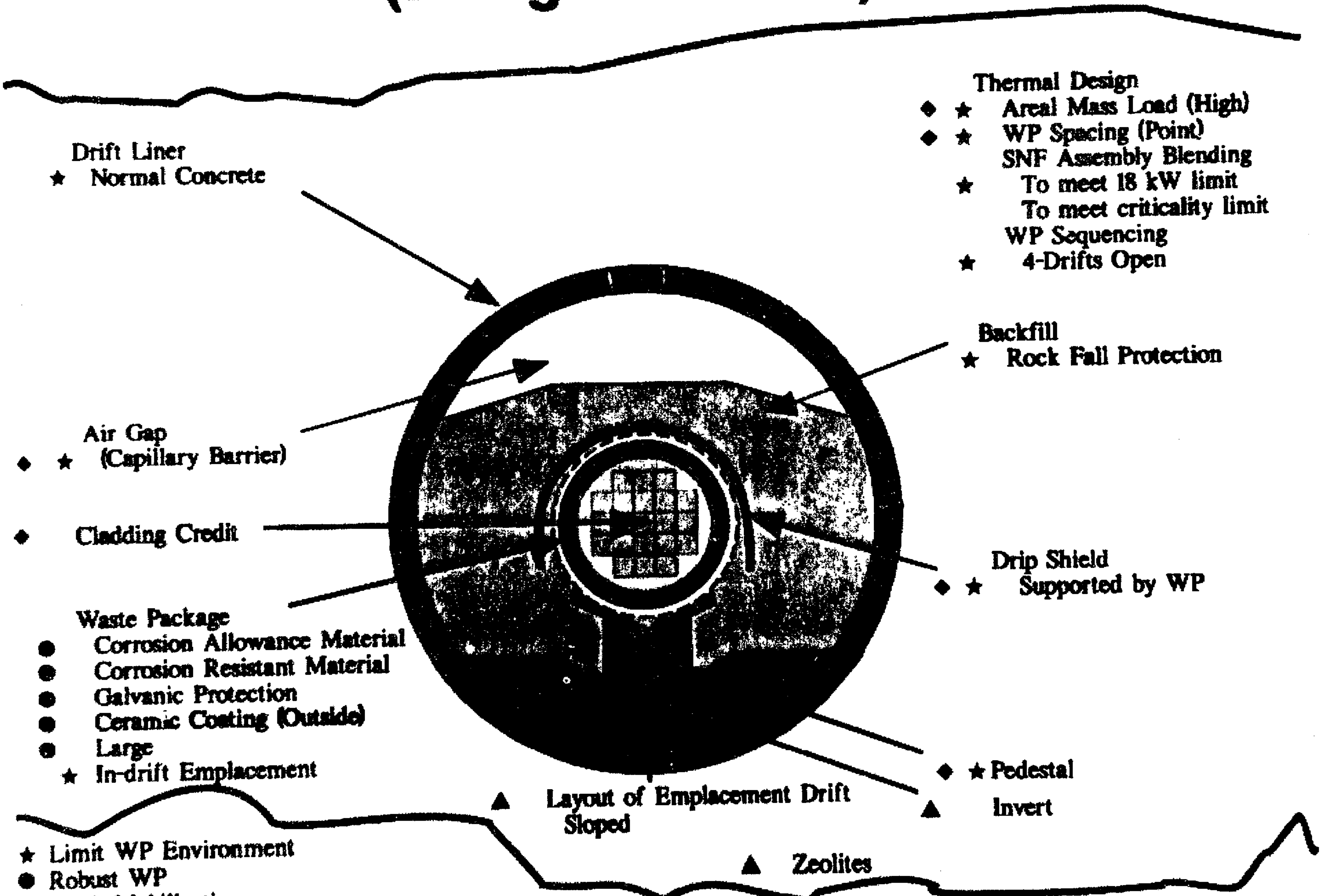
Engineered Barrier System (EBS)

- **What must the EBS do?**
  - Work in concert with the natural barriers so the repository meets performance requirements
  - Be configured to provide "Defense-in-Depth"
  - Be explainable and defendable by analysis and test for NRC licensing

Engineered Barrier System (EBS)
(Continued)

- **What is the strategy for developing the EBS?**
  - Develop a set of operating and bounding conditions which are expected over the life of the Repository (e.g., water quantities and flow conditions in the mountain)
  - Identify, and characterize, a family of EBS design features that could be employed in the repository
  - Use Performance Assessment (PA) sensitivity studies to perform evaluations of the overall performance of the repository (using combinations of the EBS features) against the performance requirements

Design Options for Waste Isolation
(Design Features)



★ Limit WP Environment
● Robust WP
◆ Limit Mobilization
▲ Radionuclide Concentration Reduction

06/24/97 10:00 am
Path: A&L/DATA/M&O/EIS/GPD

EBS Performance Over Time

- Other (non-CRWMS) test and empirical data
- Natural analogs
- Effective use of test programs
- Laboratory Materials Tests
- Drift Scale Test (In-Drift; Near Field)
- Performance Confirmation program data
  - Emplacement Drift Liner
  - Waste Package/EBS
  - In-Drift Environment
  - Near-Field Environment
  - Far-Field Environment

YUCCA
MOUNTAIN
PROJECT

Waste Package Design and Materials

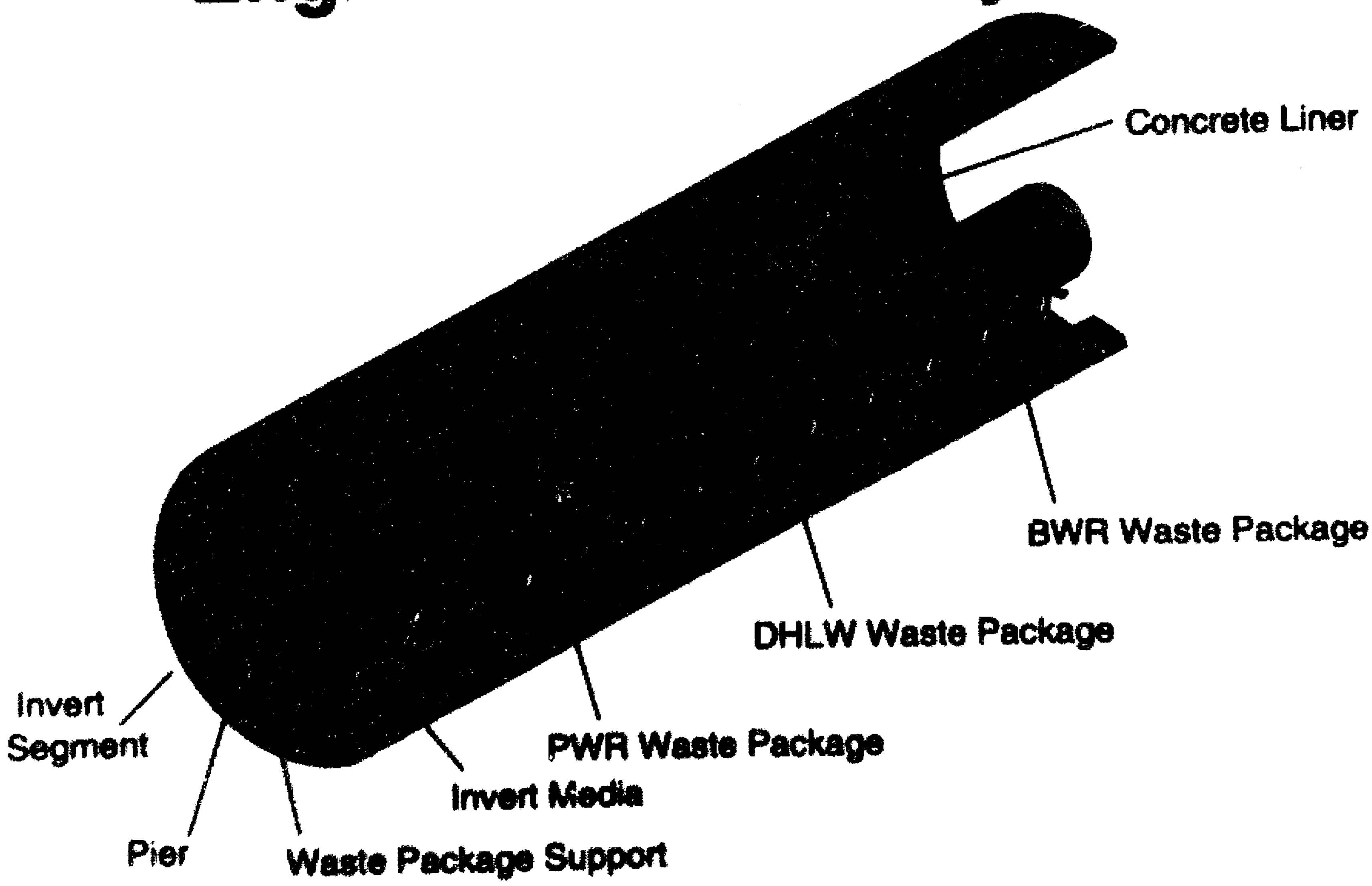
Presented to:
Nuclear Waste Technical Review Board

Presented by:
David Stahl, Ph.D.
Manager, Waste Package Materials Department
Management and Operating Contractor

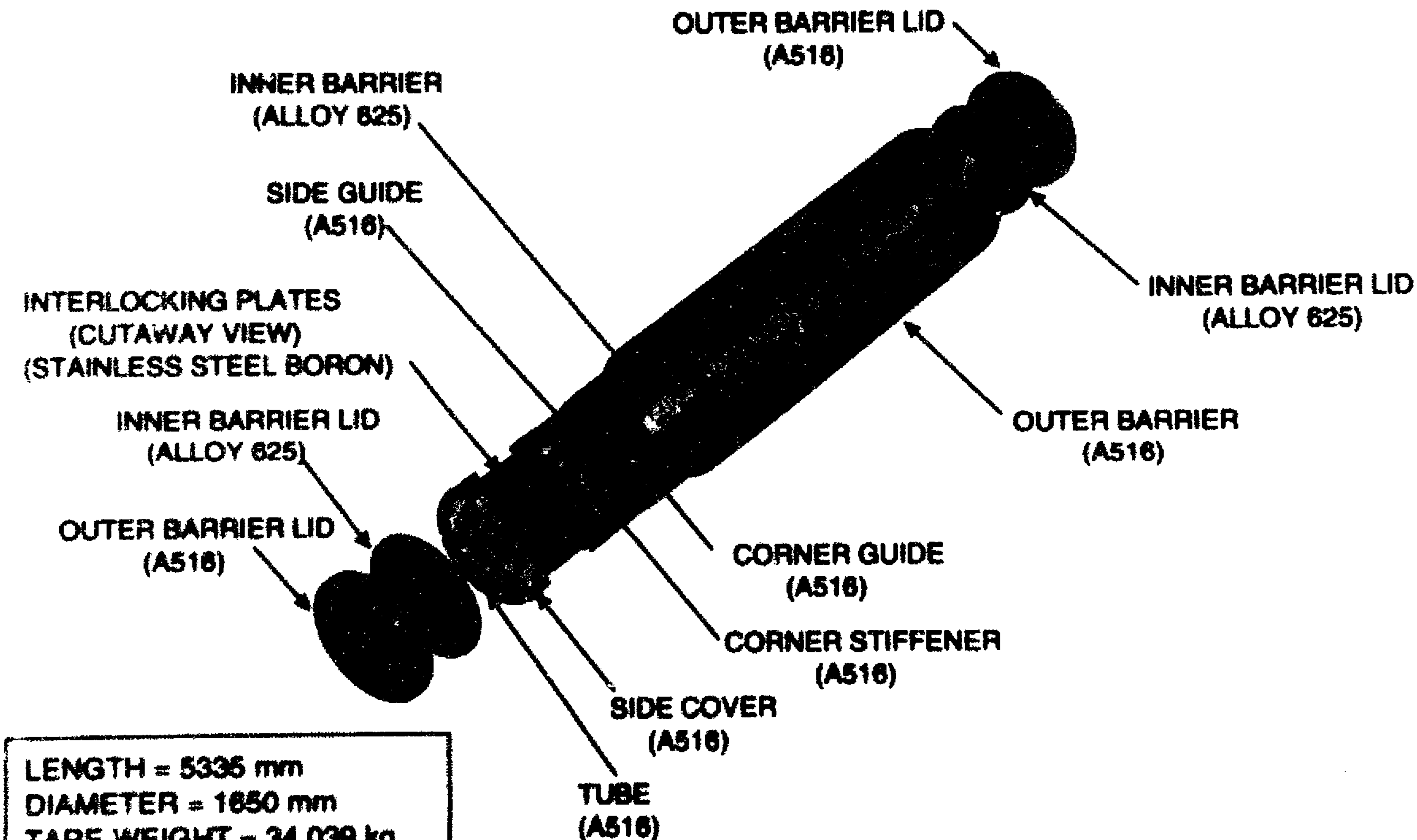
U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

Engineered Barrier System



21-PWR UCF Disposal Container



LENGTH = 5335 mm
DIAMETER = 1650 mm
TARE WEIGHT = 34,039 kg
LOADED WEIGHT = 50,423 kg

Materials Considerations in Waste Package Designs

- **Corrosion-allowance outer barrier materials**
  - Predictable slow degradation
  - Tolerant to handling and service loads
  - Radiolysis protection
  - Galvanic protection
  - Acceptable strength
  - Fabricability
- **Corrosion-resistant inner barrier materials**
  - Long-term corrosion resistance
  - Predictable performance
  - Acceptable strength
  - Fabricability

Materials Considerations in Waste Package Designs
(Continued)

- Basket Materials
  - Long-term performance of neutron absorber material
  - Predictable performance of structural materials
  - Acceptable thermal conductivity
  - Fabricability
- EBS Materials
  - Compatible with other waste package materials
  - Ability to retard radionuclide migration in the long term when the waste package has degraded

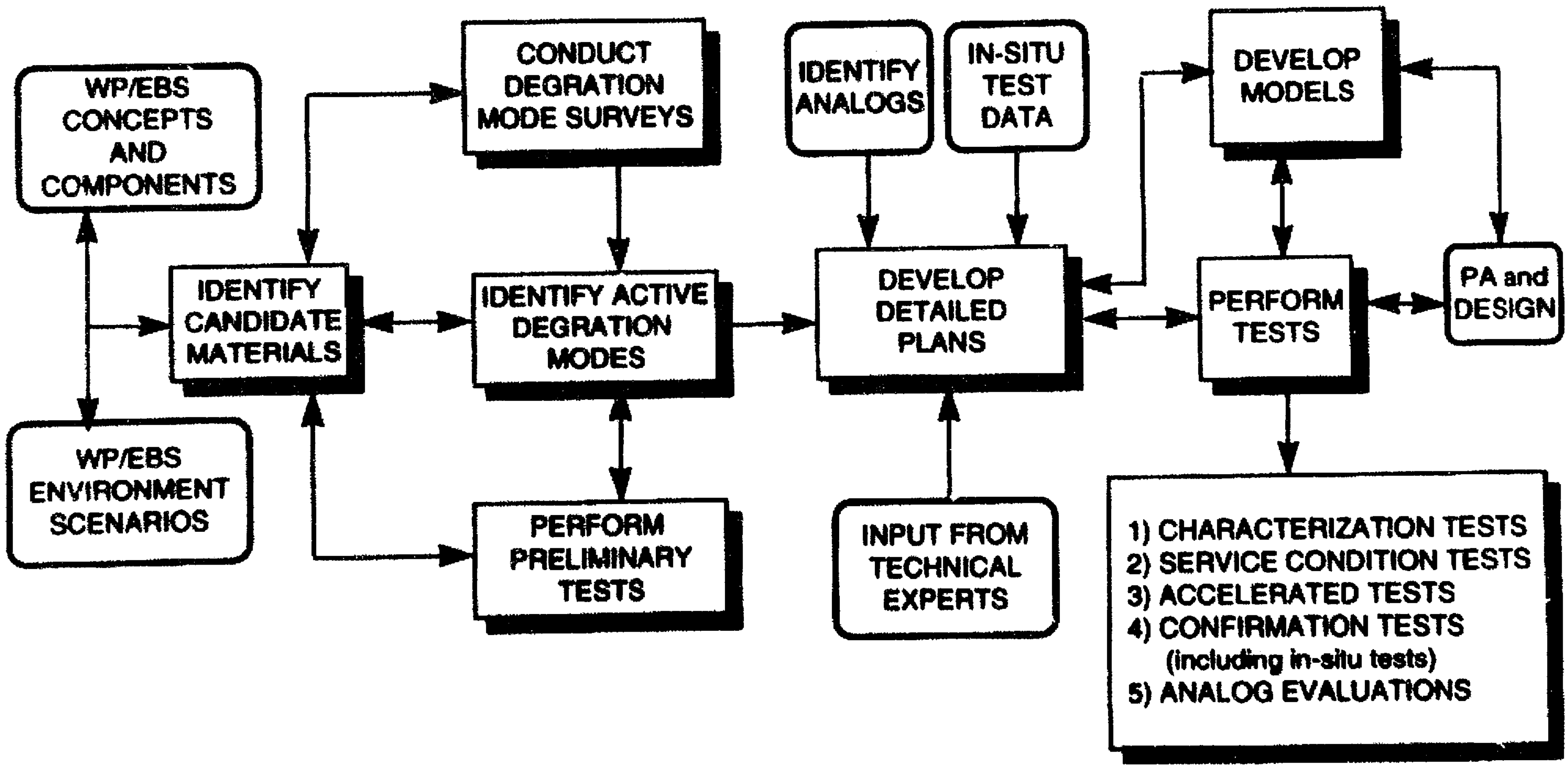
Environment Assumptions for Waste Package Materials Testing

- Assumed Water Contact Mode Scenario:
  - Early hot, dry conditions followed by cooler, more humid conditions with potential for dripping of concentrated groundwater onto waste packages
- Existing test conditions include water chemistry which ranges from 10X to 1000X J-13 and pH ranges from 2 to 12 and temperatures of 60 and 90°C
- Higher water seepage flux may reduce concentration of ionic species of water contacting the packages
  - However corrosion degradation is more closely coupled to local conditions at the surface of the waste package
- Test environments include controlled and equilibrated relative humidity, water line and complete submersion
  - Drip testing is scheduled to begin in FY 1998

Container Materials in Corrosion Test Program

- Corrosion-Allowance Materials
  - Carbon steel - cast (ASTM A27) and wrought (ASTM A516)
  - Low alloy (2.25 Cr - 1 Mo) steel
- Intermediate Corrosion-Resistant Materials
  - Copper-nickel (70/30) alloy
  - Nickel-copper (70/30 - Monel 400) alloy
- Corrosion-Resistant Materials
  - Nickel-rich alloys (Alloy G-3, G-30, 825)
  - Nickel-base alloys (Alloy 625, C-4, C-22)
  - Titanium alloys (Ti-Grade 12, Ti-Grade 16)
- Other Materials
  - Type 304/316 stainless steel with and without boron
  - Zircaloy (to be added to support Navy testing)
  - Ceramic coatings (alumina, titania, alumina-magnesia)

Waste Package Materials Test Strategy



Waste Package Materials Studies

- Engineered Barrier Materials
  - Container materials testing
    - » Long-term corrosion
    - » Humid air corrosion
    - » Crack growth
    - » Electrochemical potential
    - » Microbiologically-influenced corrosion
- Basket materials corrosion
  - Ceramic materials testing
  - Other engineered barrier materials testing
  - Degradation and abstraction modeling
- Waste Form Materials
  - Spent fuel testing
  - High-level waste glass testing
  - Degradation and abstraction modeling

Results of Near-Term Materials Studies

- Long-Term Corrosion Test Facility
  - First six-month test completed March 1997 and preliminary analysis of specimens indicated that aqueous corrosion rates are in the range of expected values, 80-110 mm/yr (3-4 mpy)
- Humid Air Corrosion Tests
  - For clean surfaces the critical RH is greater than 85% while that for surfaces with oxide or salt films is significantly reduced
- Crack Growth Testing
  - Cracking confirmed in Alloy 825 under broad range of environmental conditions while only limited cracking found in Alloy C-4
- Electrochemical Potential Testing
  - Alloys 825, G-3, G-30 and C-4 suffered pitting/crevice corrosion in acidic brines while C-22 and titanium did not

Results of Near-Term Materials Studies

(Continued)

- Microbiologically Influenced Corrosion
  - Tests with carbon steel at room temperature in a range of microbes showed that corrosion rate was about five times that of the abiotic case
- Basket Material Testing
  - Examination of boron-stainless steel from the scoping tests indicated that the metal borides were more corrosion resistant than the stainless steel matrix which will be confirmed utilizing ongoing electrochemical tests
- Ceramic Material Testing
  - Drops testing of coated steel at up to 2 m using a 100 kg simulated tuff rock did not produce visible coating damage while greater loads produced some flaking of the coating

Results of Near-Term Materials Studies

(Continued)

- **Engineered Barrier System Materials Testing**
  - Short-term (1 mo) concrete tests revealed that significant chemical and microstructural alteration occurred
- **Waste Form Testing**
  - Thermogravimetric spent fuel oxidation tests to establish oxidation kinetics and spent fuel and HLW glass unsaturated drip condition tests are ongoing to establish dissolution and release information for PA
  - Scoping tests are underway to establish the geometry and conditions for colloid and rodlet unsaturated tests
- **Materials Modeling**
  - Significant progress has been made in both container materials, particularly in describing the interaction between the inner and outer containers, and waste form modeling, and interaction meetings were held with PA

Uncertainties in Materials Performance

- Durability of corrosion-allowance material including pitting and microbiologically influenced corrosion
- Preferential attack of welds
- Effectiveness of galvanic protection
- Durability of corrosion-resistant material including localized and microbiologically influenced corrosion
- Extrapolation of degradation rates to long times

Methods of Treating Uncertainties

Uncertainties	Samples in long-term tests	Bounding environments	Various temperatures	Mechanistic models	Analogs
Durability of corrosion-allowance material	X	X	X		X
Preferential attack at welds	X	X	X		
Effectiveness of galvanic protection	X	X	X		
Durability of corrosion-resistant material	X	X	X	X	
Extrapolation of degradation rates to long times				X	X

Interactions of Program Activities

- Frequent interface meetings with the design team on material test results and latest design considerations
- Frequent meetings with performance assessment on model inputs and the test results during the model abstraction process
- Input from the experts on the Nuclear Waste Technical Review Board, the Repository Consulting Board, the TSPA Peer Review Panel and the Waste Package Degradation Expert Elicitation Panel
- The overall objective of these interactions is to ensure that the testing and modeling efforts are consistent with design and performance assessment needs

BEHAVIOR OF CEMENTITIOUS MATERIALS IN A REPOSITORY ENVIRONMENT

Della M. Roy
Materials Research Laboratory
The Pennsylvania State University

For Presentation to:
U. S. Nuclear Waste Technical Review Board
Meeting, June 25, 1997, Las Vegas

Needed Knowledge for Cementitious Materials in Tuff Repository Environment

Physical/mechanical properties in
- thermal environment
- durability

Shorter term and through post-closure period

Interaction with host rock

Interaction with waste package

pH control

Concrete carbonation

Other durability issues

Tailoring cementitious materials for optimium performance (knowledge needed for assurance).

TABLE I

BULK CHEMICAL COMPOSITION OF GROUTS

Oxide	Grout (wt %) 82-22	84-12
SiO_2	64.16	61.98
Al_2O_3	4.50	4.19
Fe_2O_3	2.74	1.10
CaO	25.88	27.52
MgO	1.83	4.65
MnO	0.12	0.17
Na_2O	0.10	0.10
K_2O	0.48	0.27
P_2O_5	0.11	0.02
Total	99.92	100.00

TABLE II

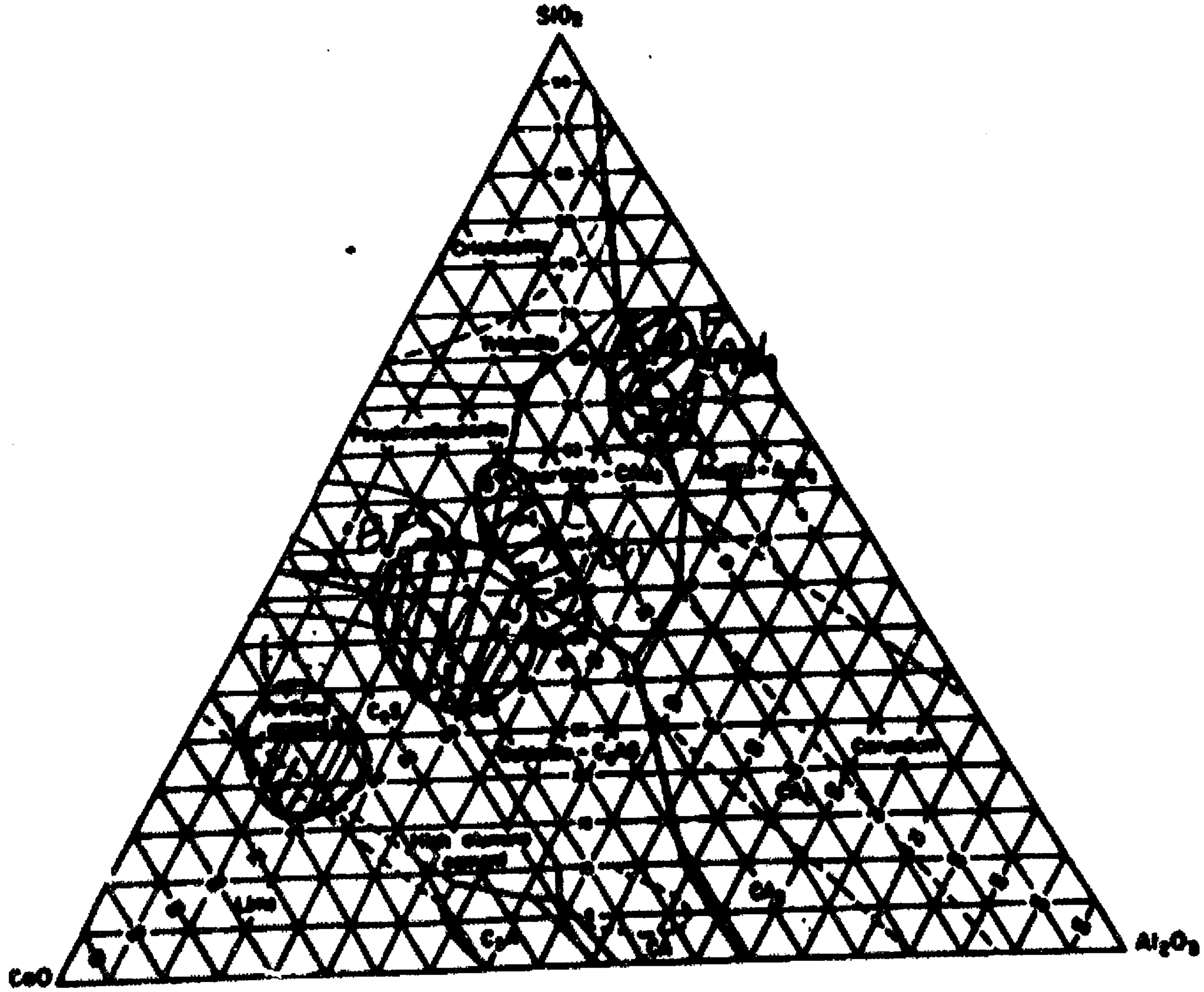
BULK CHEMICAL COMPOSITIONS OF GROUTS WITHOUT SAND AGGREGATE

Oxide	Grout (wt %) 82-22	84-12
SiO_2	38.60	48.45
Al_2O_3	7.74	5.44
Fe_2O_3	4.72	1.59
CaO	44.59	37.69
MgO	3.14	6.05
MnO	0.04	0.22
Na_2O	0.15	0.13
K_2O	0.83	0.40
P_2O_5	0.15	0.04
Total	99.99	100.01

APPLICATION AREAS

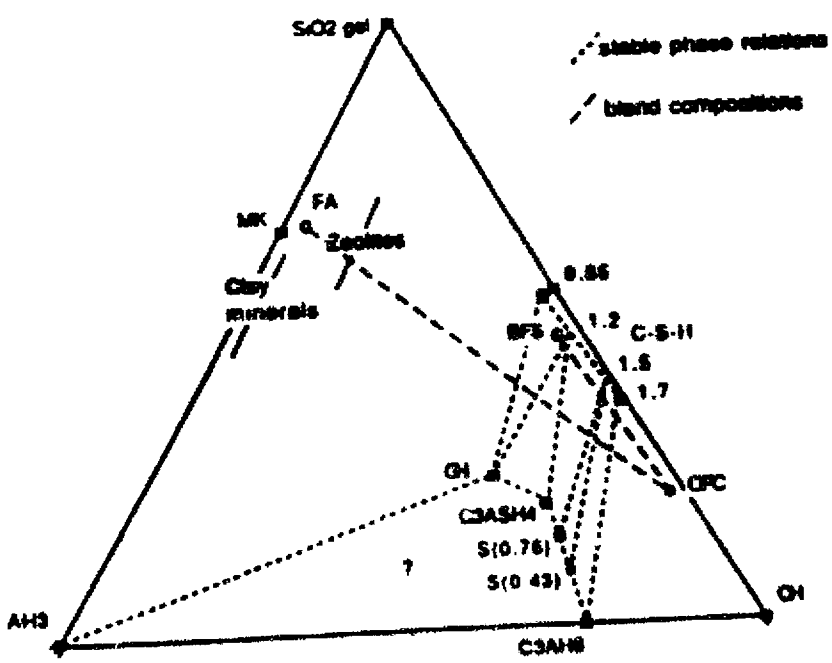
Application	Desirable Characts.
Matrix Mat.	Potential to condition *E*h and pH. Resistance to aggressive disposal conditions.

The System CaO-SiO_2-Al_2O_3

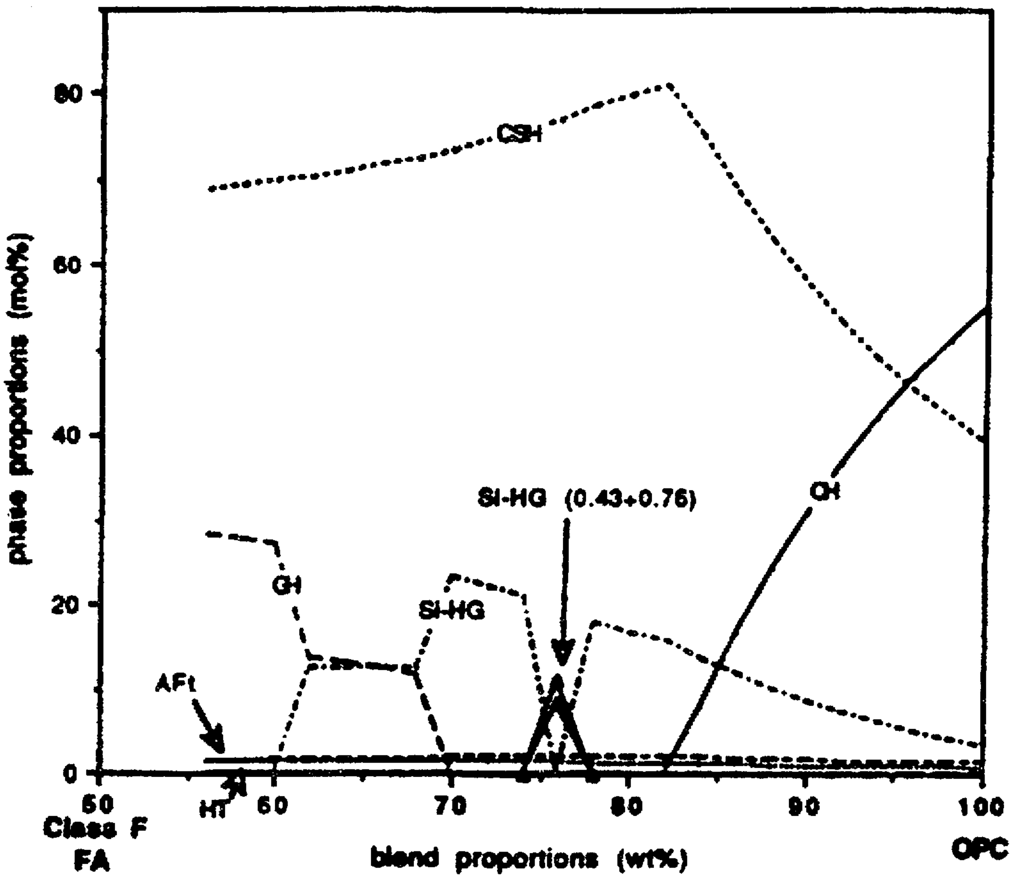


Phase	Constitution	Notes
<u>Crystalline</u>		
Ettringite	$C_3A.3C\bar{S}.32H$ $3CaO.Al_2O_3.3CaSO_4.32H_2O$	Potential substitution of Fe for Al, and various anions for S.
Monosulphate	$C_3A.C\bar{S}.12H$ $3CaO.Al_2O_3.CaSO_4.12H_2O$	As above.
Hydrogarnet	C_3AH_6 $3CaO.Al_2O_3.6H_2O$- $3CaO\ Al_2O_3.SiO_2\ 4H_2O$	Potential substitution of Fe for Al and SiO_2 for H_2O.
Portlandite	$Ca(OH)_2$ CH	-
Hydrotalcite	$4MgO.Al_2O_3.10H_2O$	Potential substitution of various anions for $(OH)_2$.
<u>Amorphous</u> C-S-H	$(0.9\text{-}1.7)\ CaO\ SiO_2.xH_2O$	Ca/Si ratio ~1.7 in OPC, but less in siliceous blends. Anion sorption increases with increasing Ca/Si ratio. Converse for cations.

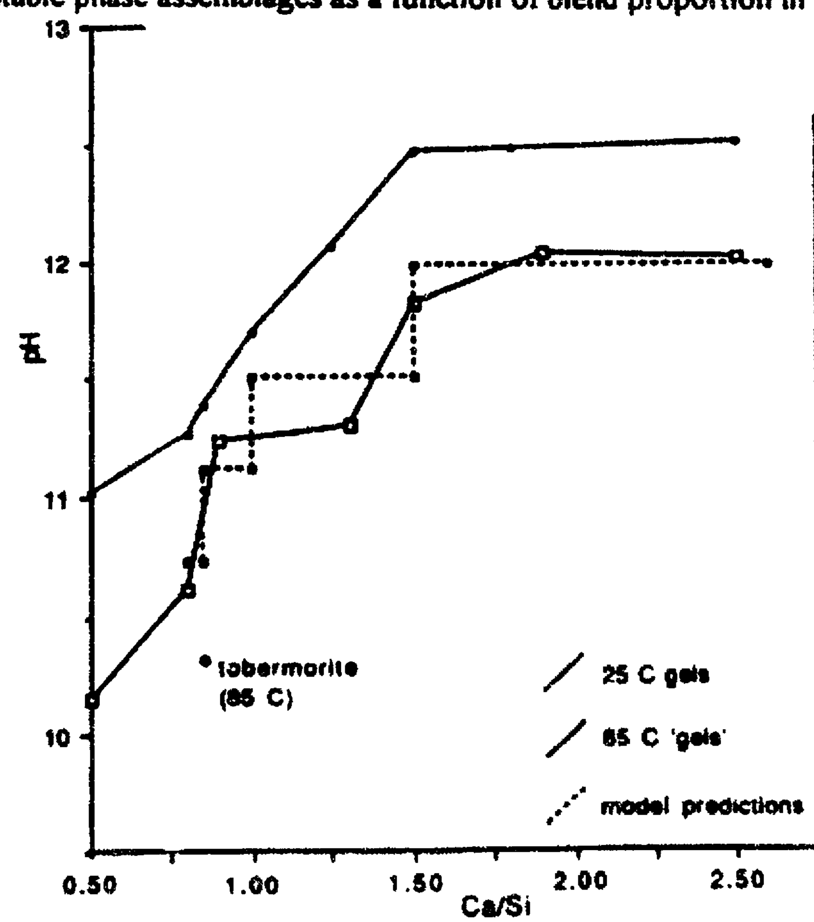
Cement hydrate phases. composition and properties.



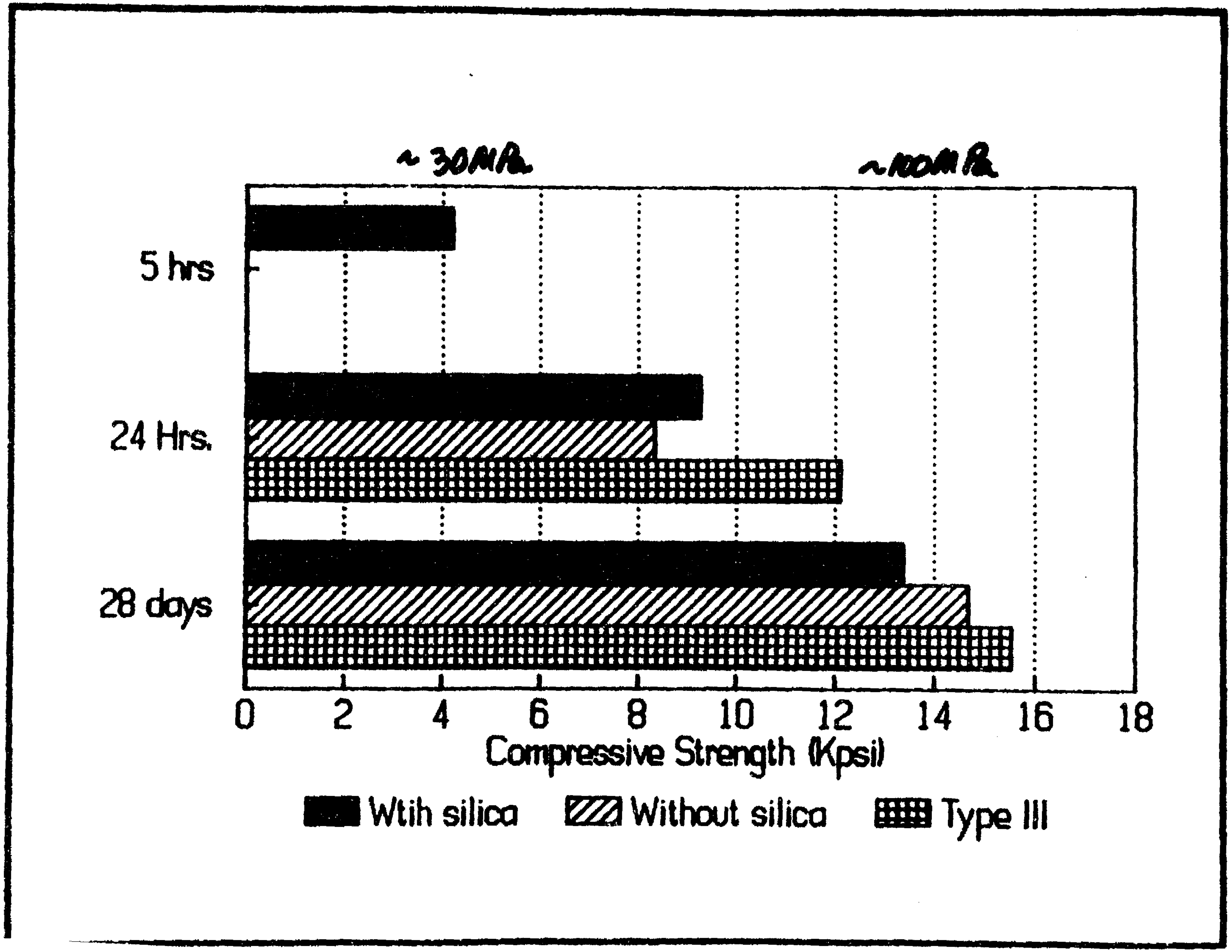
Phase relations in the water saturated portion of the C-A-S system at 25ºC

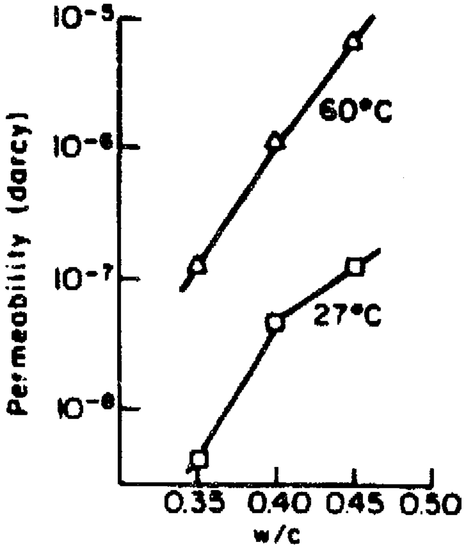


Predicted stable phase assemblages as a function of blend proportion in an example

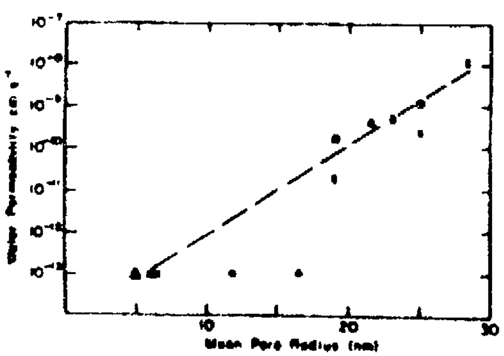


pH as a function of Ca/Si ratio in the C-S-H system


~30MPa
~100MPa
5 hrs
24 Hrs.
28 days
0
2
4
6
8
10
12
14
16
18
Compressive Strength (Kpsi)
Wtih silica
Without silica
Type III



Relationship between permeability and w/c

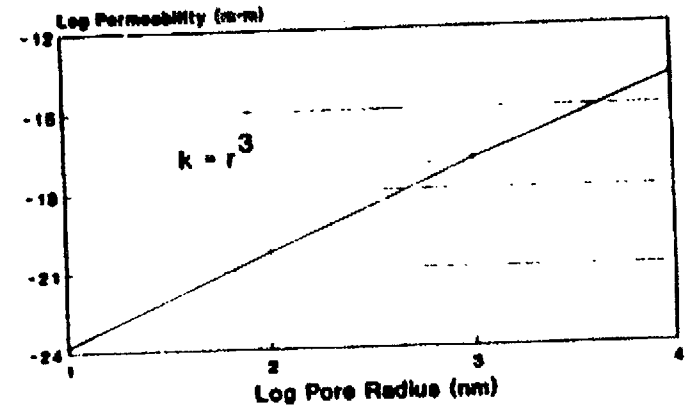


Water permeability vs.mean pore radius of pastes

PENNSTATE

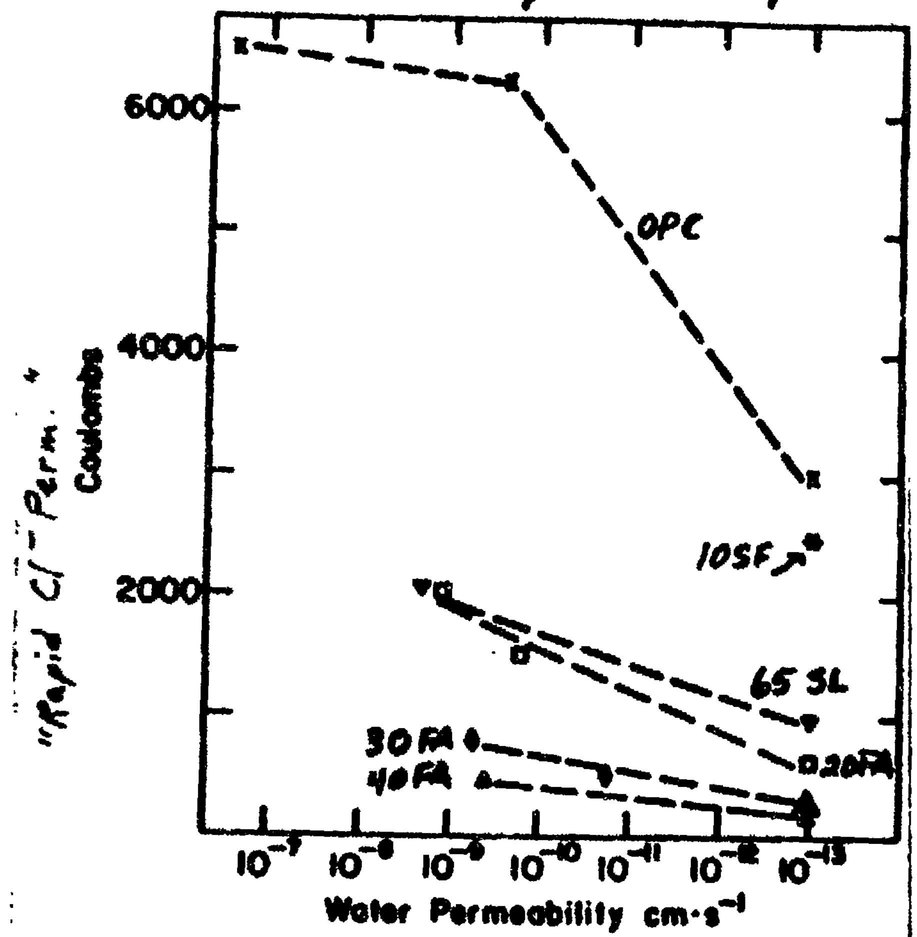
PERMEABILITY vs. POROSITY

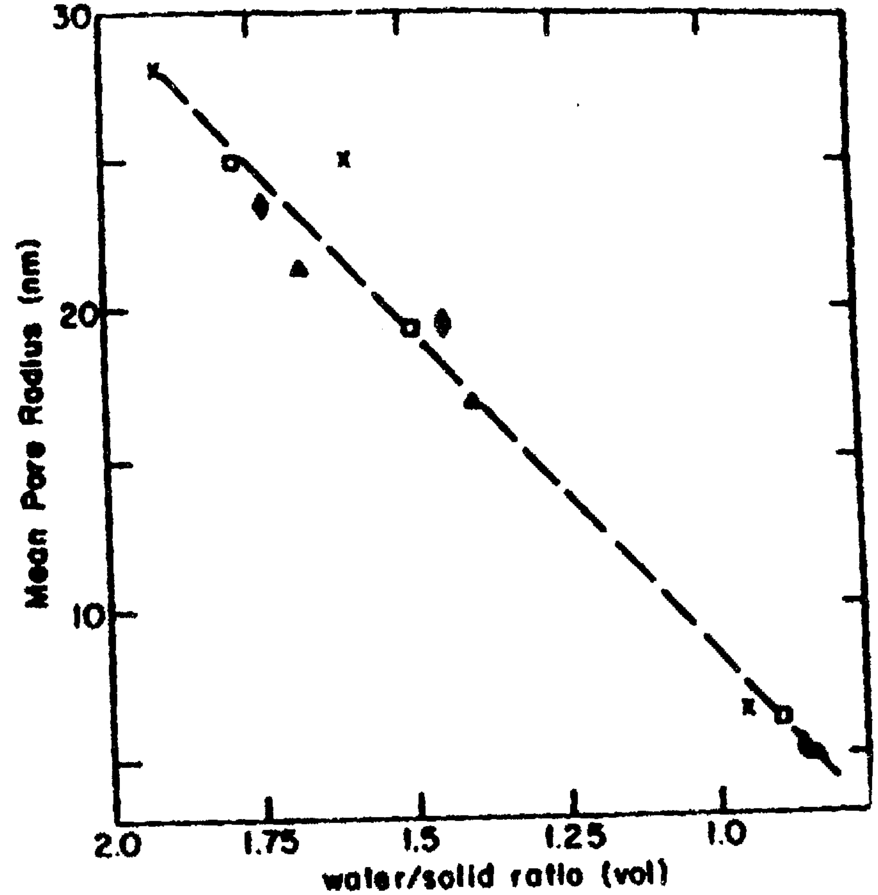
OPC pastes



(Atkinson and Hearne, 1984)

Cl "Diffusion/Permeability"

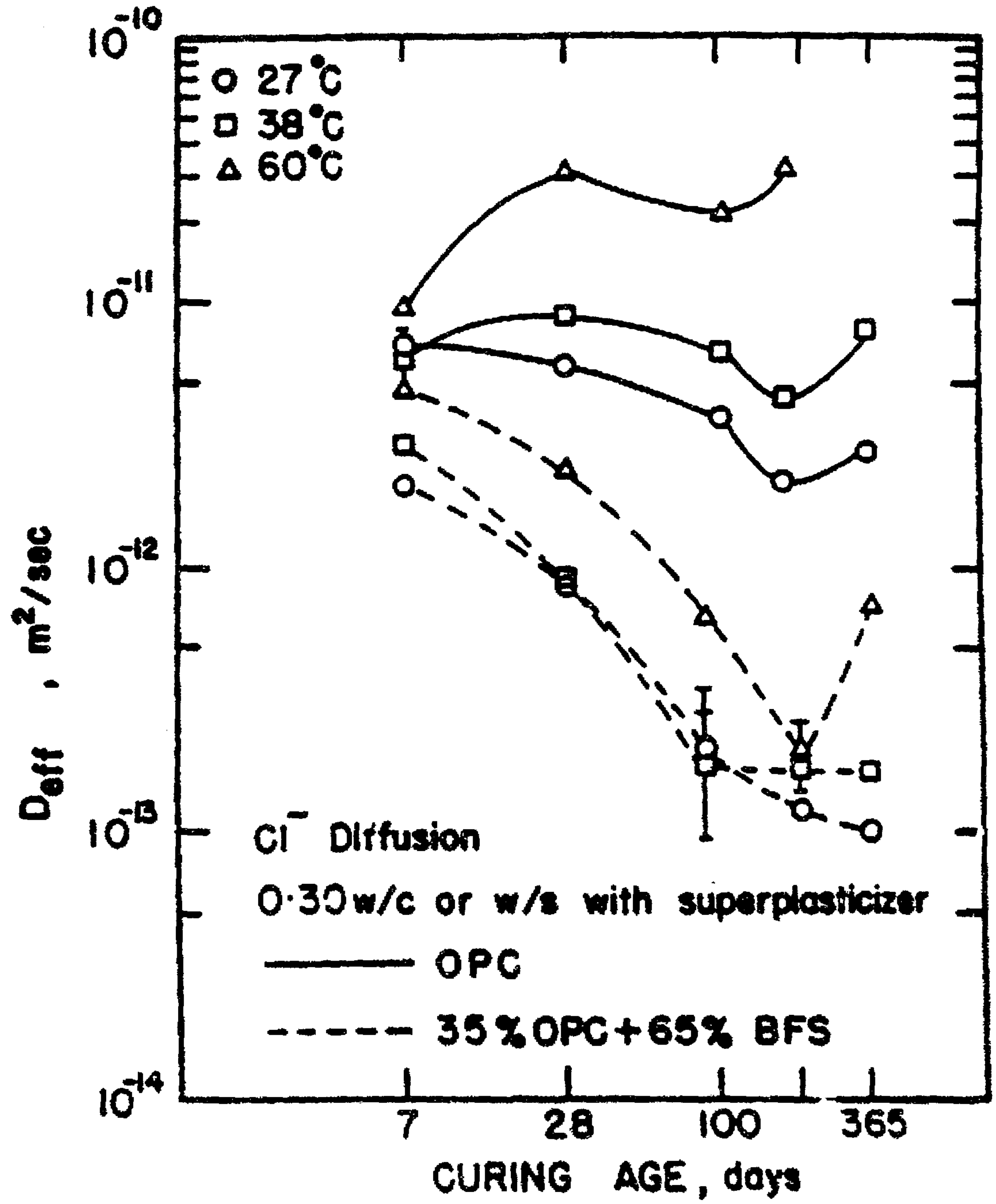




(includes OPC, SLAG, SF, FA)

PENNSTATE

EFFECTIVE DIFFUSIVITY OF Cl^- IONS IN OPC vs. SLAG CEMENTS



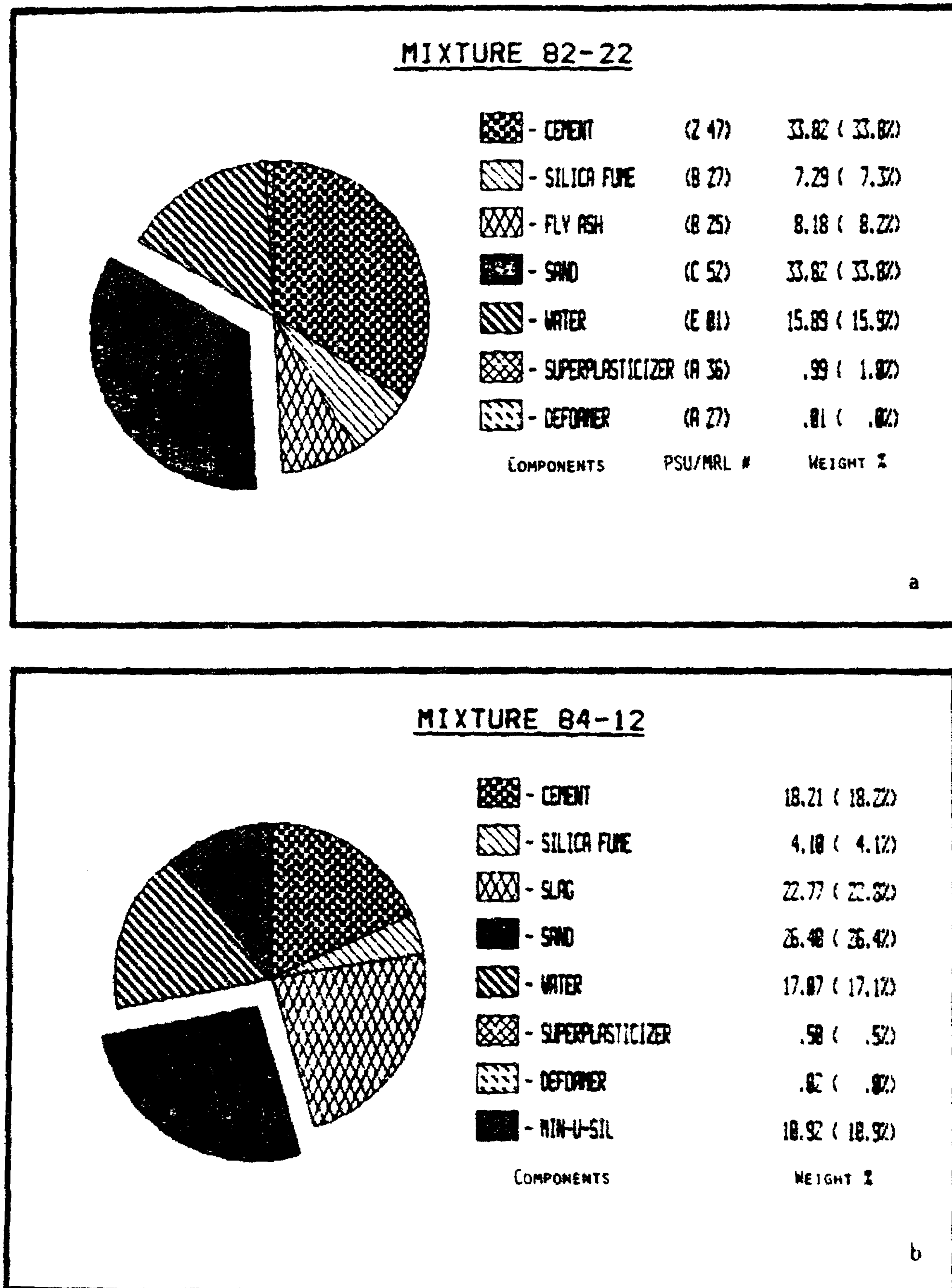


Fig. 1. Schematic representation of (a) 82-22 mortar and (b) 84-12 grout compositions

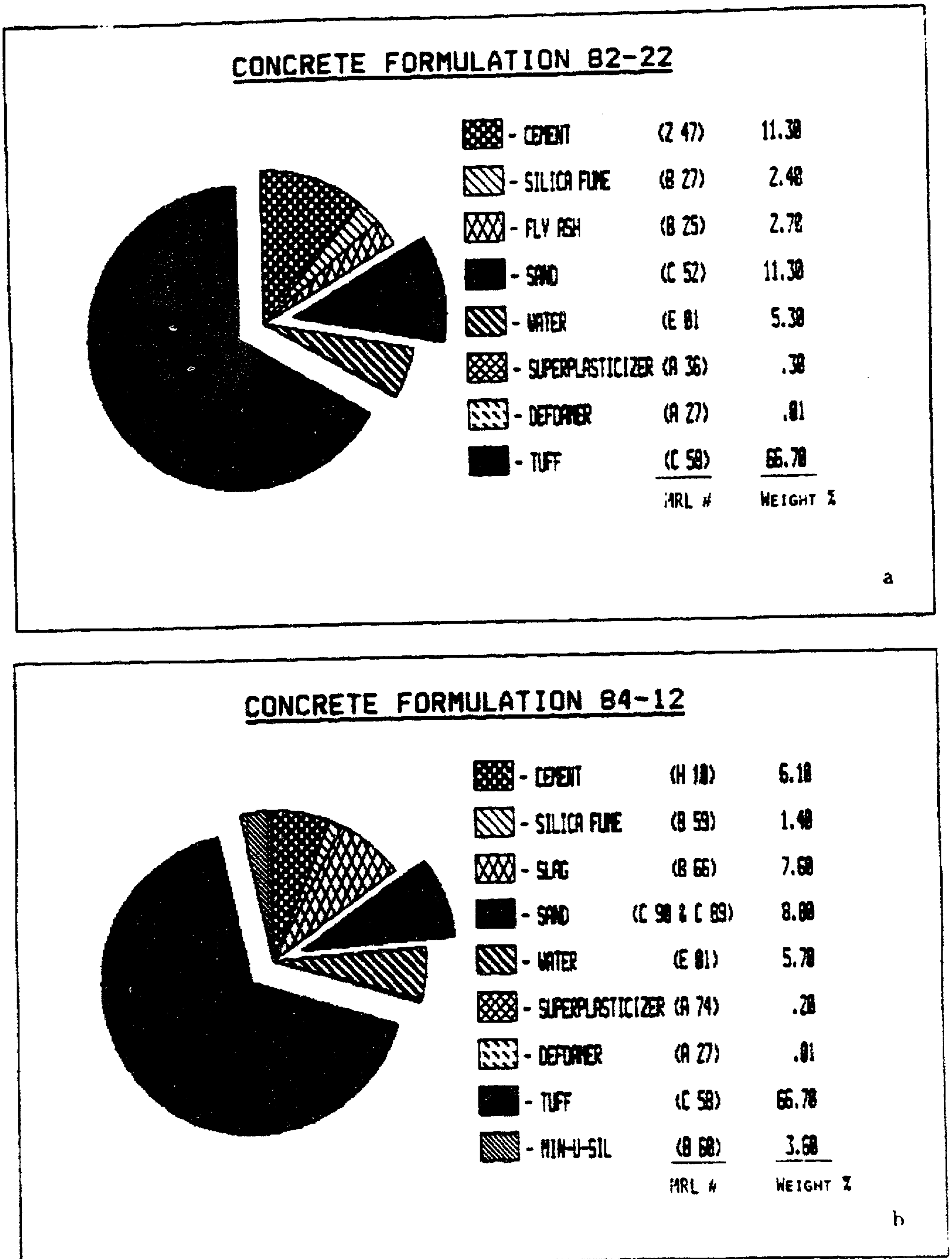


Fig. 2. Schematic representation of "artificial" concrete formulation based upon (a) 82-22 and (b) 84-12.

TABLE I

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MgO	1.83	4.65
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TABLE II

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MgO	3.14	6.05
MnO	0.04	0.22
Na_2O	0.15	0.13
K_2O	0.83	0.40
P_2O_5	0.18	0.04
Total	99.99	100.01

Table 10. Water Permeabilities (Darcy) of Nonexpansive and Expansive Mortars

	Nonexpansive				Expansive			
	Curing Temperature (°C)							
Curing Time	38		60		38		60	
(days)	82-19	82-20	82-19	82-20	82-22	82-31	82-22	82-31
7	$<10^{-8}$	1.9×10^{-7}	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$
14	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	--	--	--	--
28	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	$<10^{-8}$	5.5×10^{-7}

Table 14. Unconfined Compressive Strength (MPa) of Mixture 82-22

Curing Time	Curing Temperature (°C)		
(days)	38	60	90
7	103.31(1)*	--	119.5(3) [8.79]
28	127.6(3) [5.58]	137.3(1)	114.0(3) [3.75]
56	112.6(2) [9.21]	--	113.2(2) [12.42]
90	88.5(2) [6.72]	--	103.4(1)
180	130.95(2) [2.78]	130.71(3) [8.29]	--
360	62.4(2) [8.77]	60.4(2) [2.91]	124.0(1)
720	122.0(1)	--	--

*Number of samples tested in ( ); one standard deviation, 1σ, in [ ].

TABLE 2--UNCONFINED COMPRESSIVE STRENGTHS (MPa) OF 82-22 SAMPLES HEATED AT 150 C AND 300 C

Heating Time	HYDROTHERMAL HEATING		"DRY" HEATING		
	Temperatures				
	150°C	300°C	150°C	300°C	38°C
7 days**	111 ± 12	112 ± 8	79 ± 10	37*	
28 days**	119 ± 3	95 ± 7	114 ± 2	44 ± 2	
28 days+	91	51			
Curing Time					
56 days++					110 ± 6

*visible cracks existed on each specimen.
**pre-curing at 38°C for 28 days prior to heating.
+precured at 38°C in $Ca(OH)_2$ solution for 900 days.
++baseline data specimens cured a total of 56 days at 38°C in $Ca(OH)_2$ solution.

TABLE 5--PERMEABILITY OF "DRY" AND "WET" THERMALLY TREATED 82-22 GROUT SAMPLES (Darcy)*

	"DRY" HEATED		HYDROTHERMALLY HEATED	
	150°	300°	150°	300°
7 days	3.7×10^{-6}	5.7×10^{-4}	8×10^{-7}	1.2×10^{-5}
28 days	5.8×10^{-6}	1.6×10^{-3}	1.5×10^{-6}	1.0×10^{-5}
900 days		---	$<1.0 \times 10^{-8}$	4.8×10^{-6}

*1 darcy = 10^{-3} cm/sec

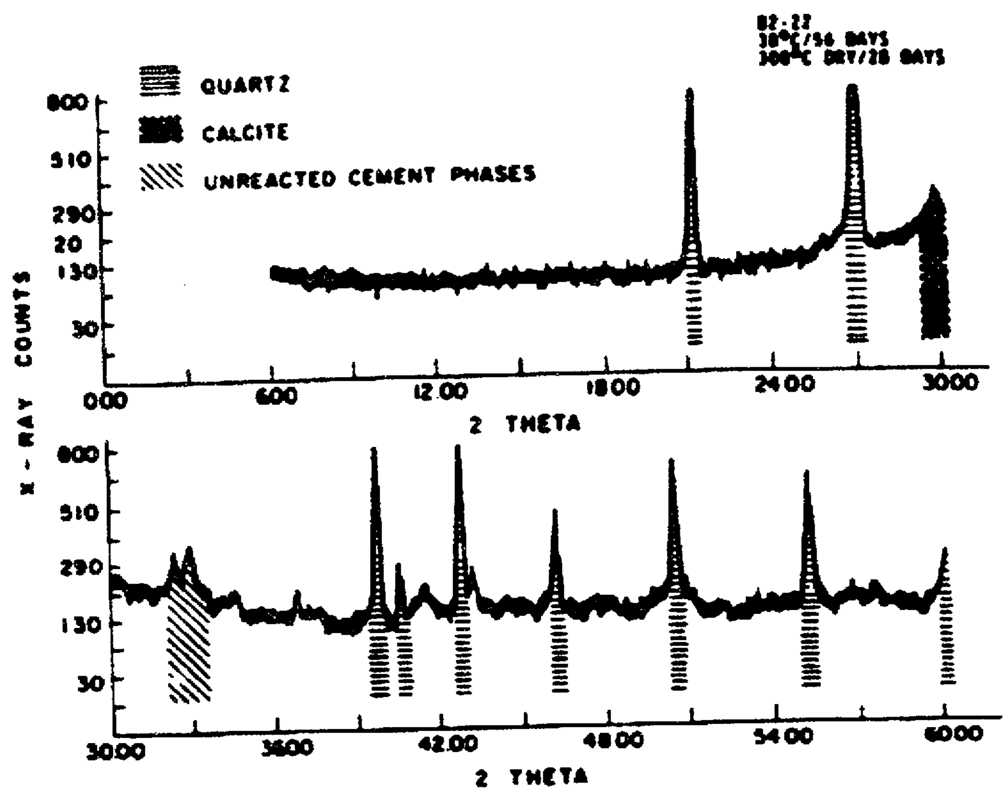


Fig. 4--X-ray diffractogram identifying all major phases (82-22 300 C for 28 days of "dry" heating)

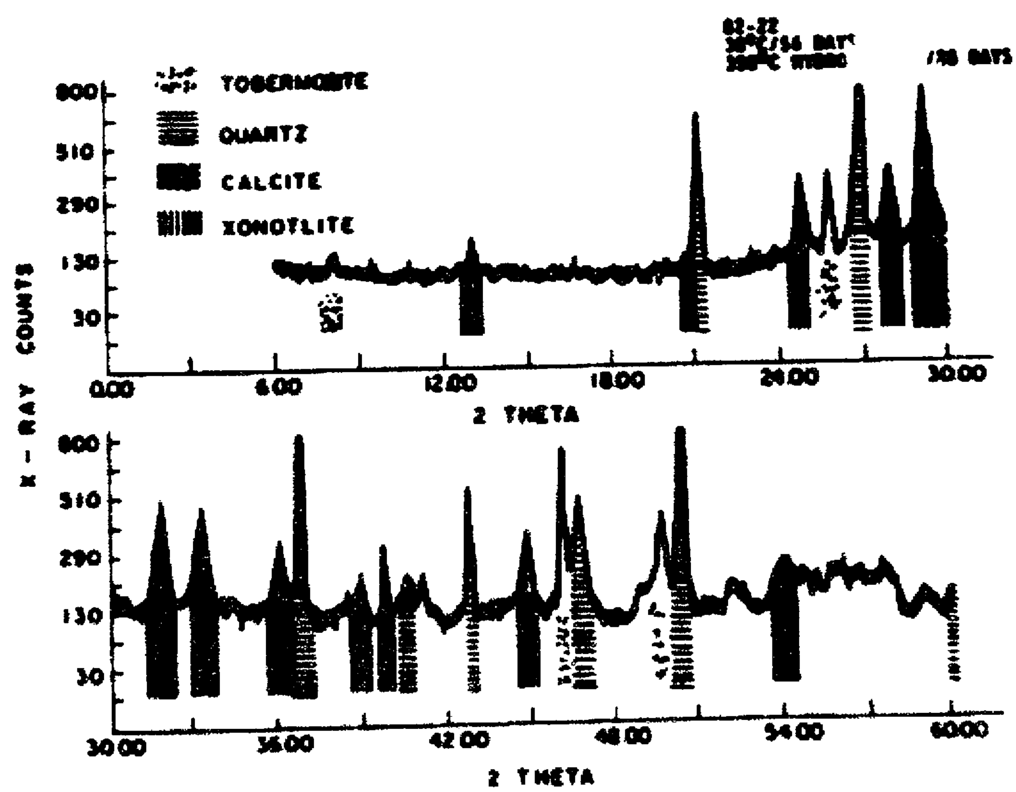
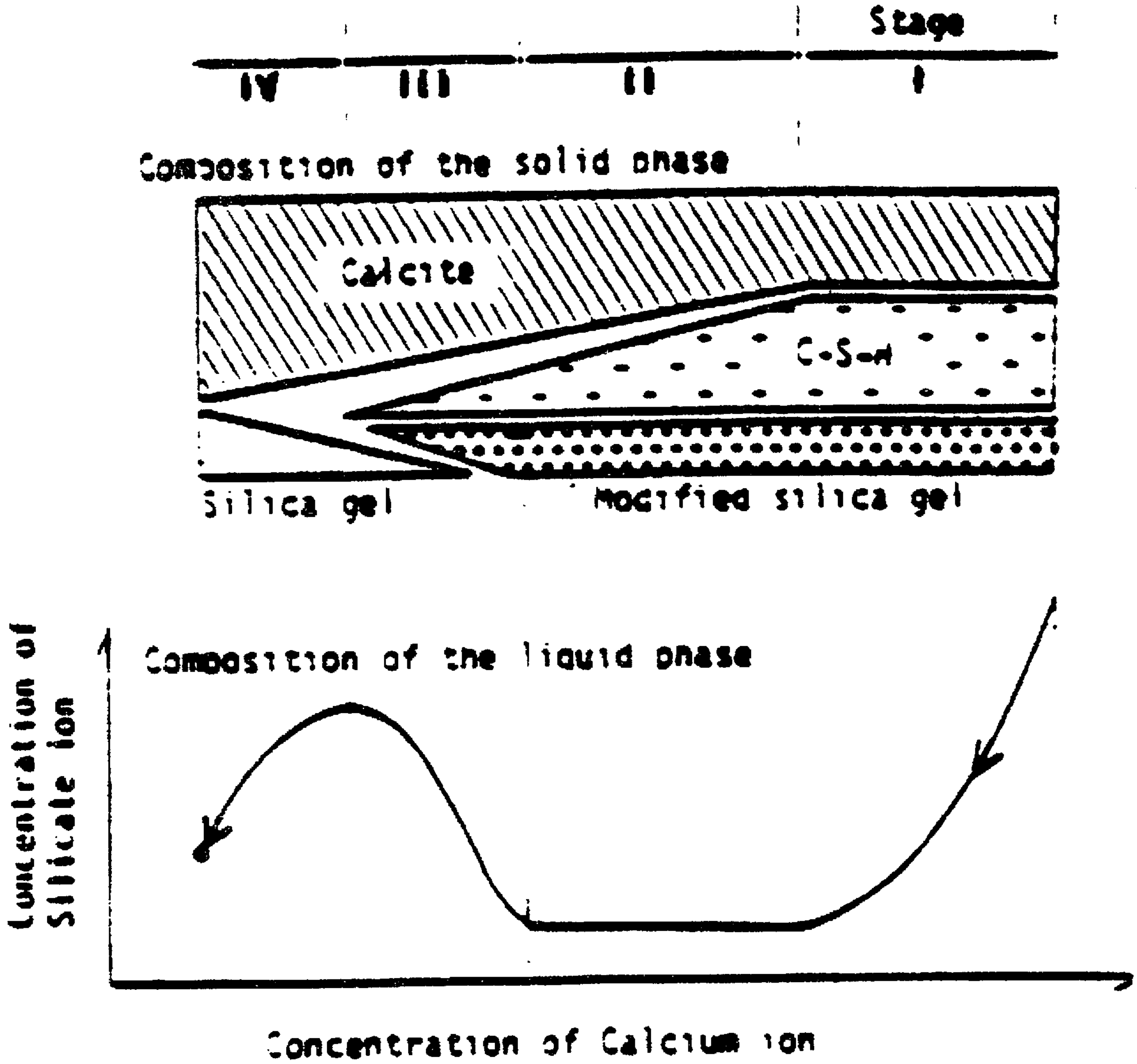


Fig. 7--X-ray diffractogram identifying all major phases (82-22 300 C for 28 days of "hydrothermal" heating)

Other Effects - Carbonation

Calculated Results of the Carbonation Reactions of the Constituents of Cement Paste.

No. of Reactions	Equations of Reactions	ΔG^0_{298} of reactions [kcal/ml]	P_{CO2} equilibrium values [atm]
1	1/5 $(5CaO \cdot 6SiO_2 \cdot 5.5H_2O)$ + (sol) + CO_2 (gas) = $CaCO_3$ (sol) + 6/5 SiO_2 (sol) + 1.1 H_2O (liq)	-11.29	$10^{-8.28}$
2	1/4 $(4CaO \cdot Al_2O_3 \cdot 19H_2O)$ (sol) + CO_2 (gas) = $CaCO_3$(sol) + 1/2 $Al(OH)_3$ (am) + $4H_2O$ (liq)	-14.70	$10^{-10.78}$
3	1/3 $(3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O)$ (sol) + CO_2 (gas) = $CaCO_3$ (sol) + $CaSO_4 \cdot 2H_2O$ (sol)	-10.26	$10^{-7.52}$
4	1/3 $(3CaO \cdot Fe_2O_3 \cdot 3CaSO_4 \cdot 32H_2O)$ + CO_2 = $CaCO_3$ + $CaSO_4 \cdot 2H_2O$ + 2/3 $Fe(OH)_3$ + 23/3 H_2O	-14.07	$10^{-10.31}$
5	$Ca(OH)_2$ (sol) + CO_2 (gas) = $CaCO_3$ (sol) + H_2O (liq)	-17.82	$10^{-13.1}$



Carbonation stages (schematic) of C-S-
prepared from solution

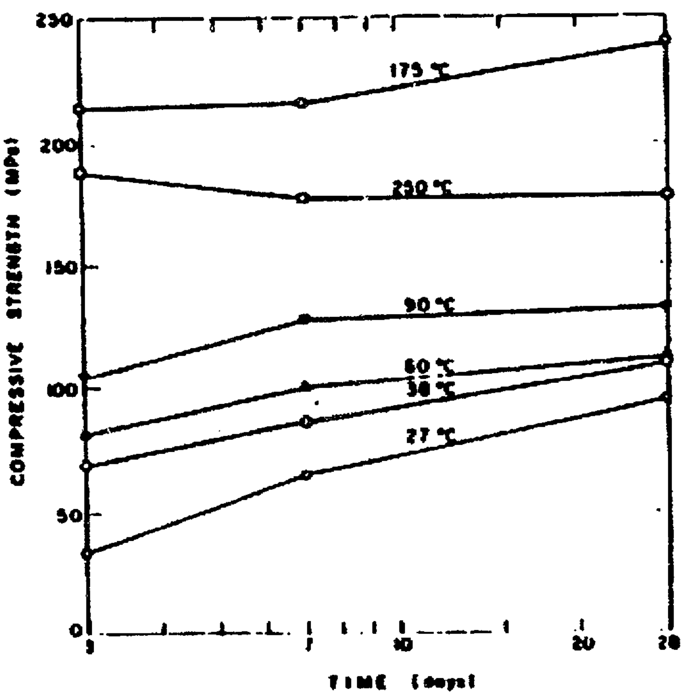


FIG. 4. Compressive strength of mortar mixtures 82-11 (top two) and 83-01 (bottom four) cured at constant temperatures from 27 to 250°C.

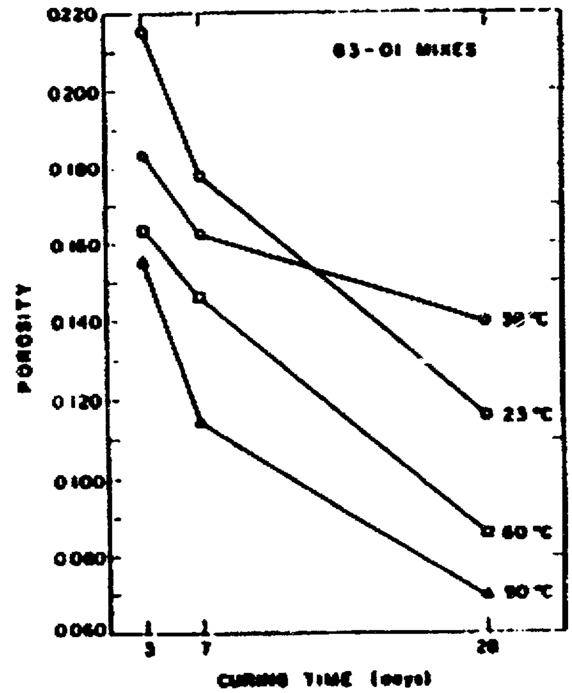
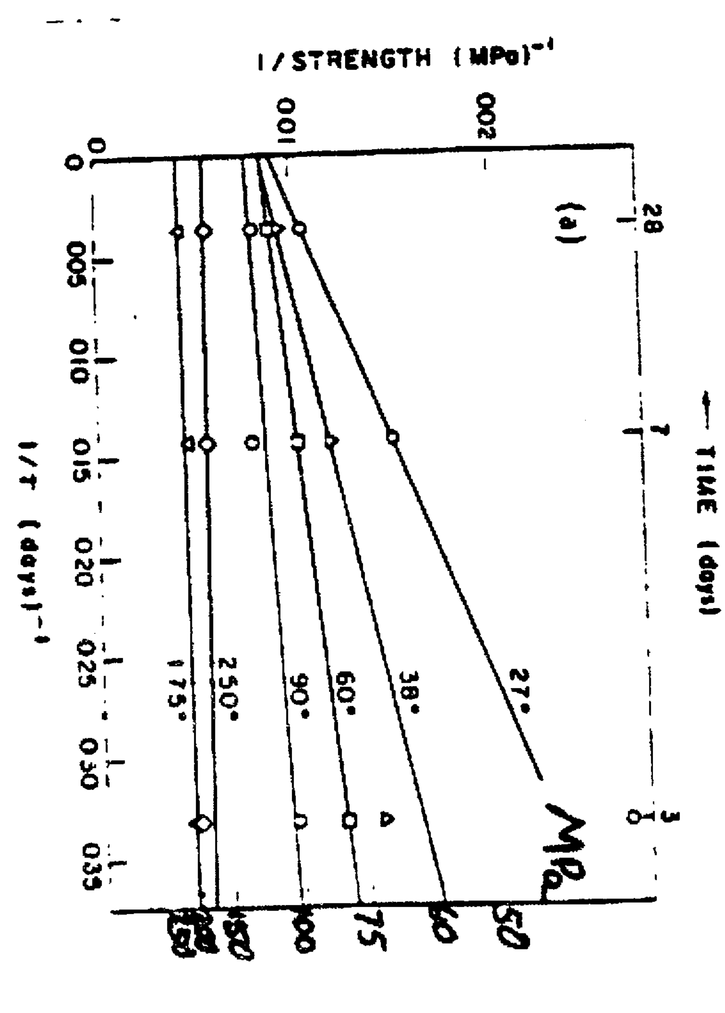


FIG. 5. Porosity (Hg porosimetry)-curing time and temperature relation for 83-01 slag-cement mixtures.



SUMMARY,

Physical constraints:

- Low permeability
- Mechanical stability
- Fine interwoven solid/pore structure

Environmental factors:

- Near equilibrium state may be attained (especially if elevated temperatures).

Summary

- Modest data base exists for concrete mechanical properties at elevated temperatures
- Potential durability appears to depend on several factors
  - — physical/mechanical properties under sustained elevated temperatures
  - — chemical compatibility of cementitious matrix with host rock; phase stability and effects on water chemistry
  - — benign effects of cementitious materials on waste package
  - — adequate matrix-aggregate bonding
- Specialized (tailored) cements/concretes appear feasible/in order

YUCCA MOUNTAIN PROJECT

studies

Assessment of Geosphere Performance Issues in TSPA-VA

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Abraham Van Luik
U.S. Department of Energy
Yucca Mountain Site Characterization Office
Las Vegas, Nevada

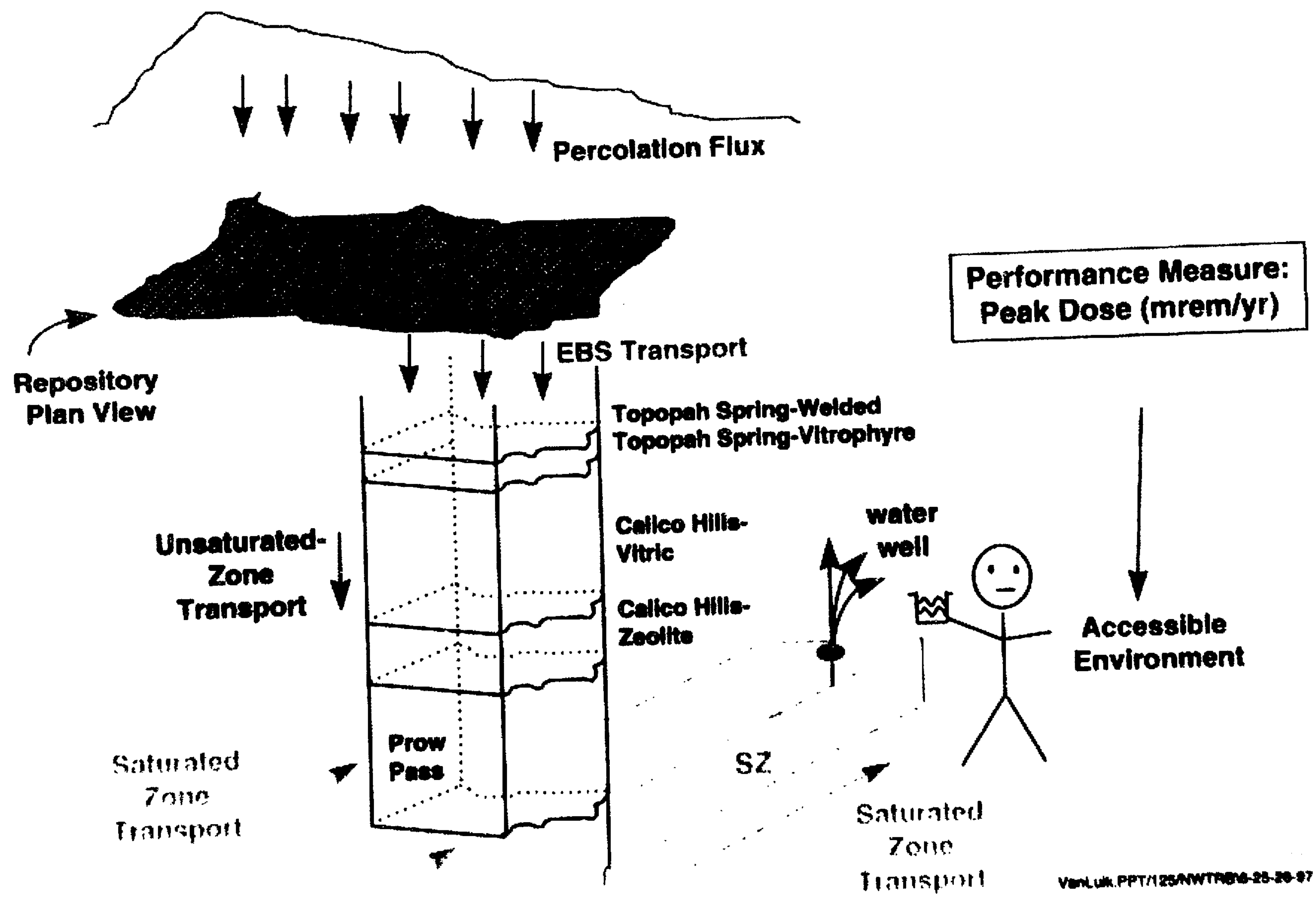
U.S. Department of Energy
Office of Civilian Radioactive Waste Management

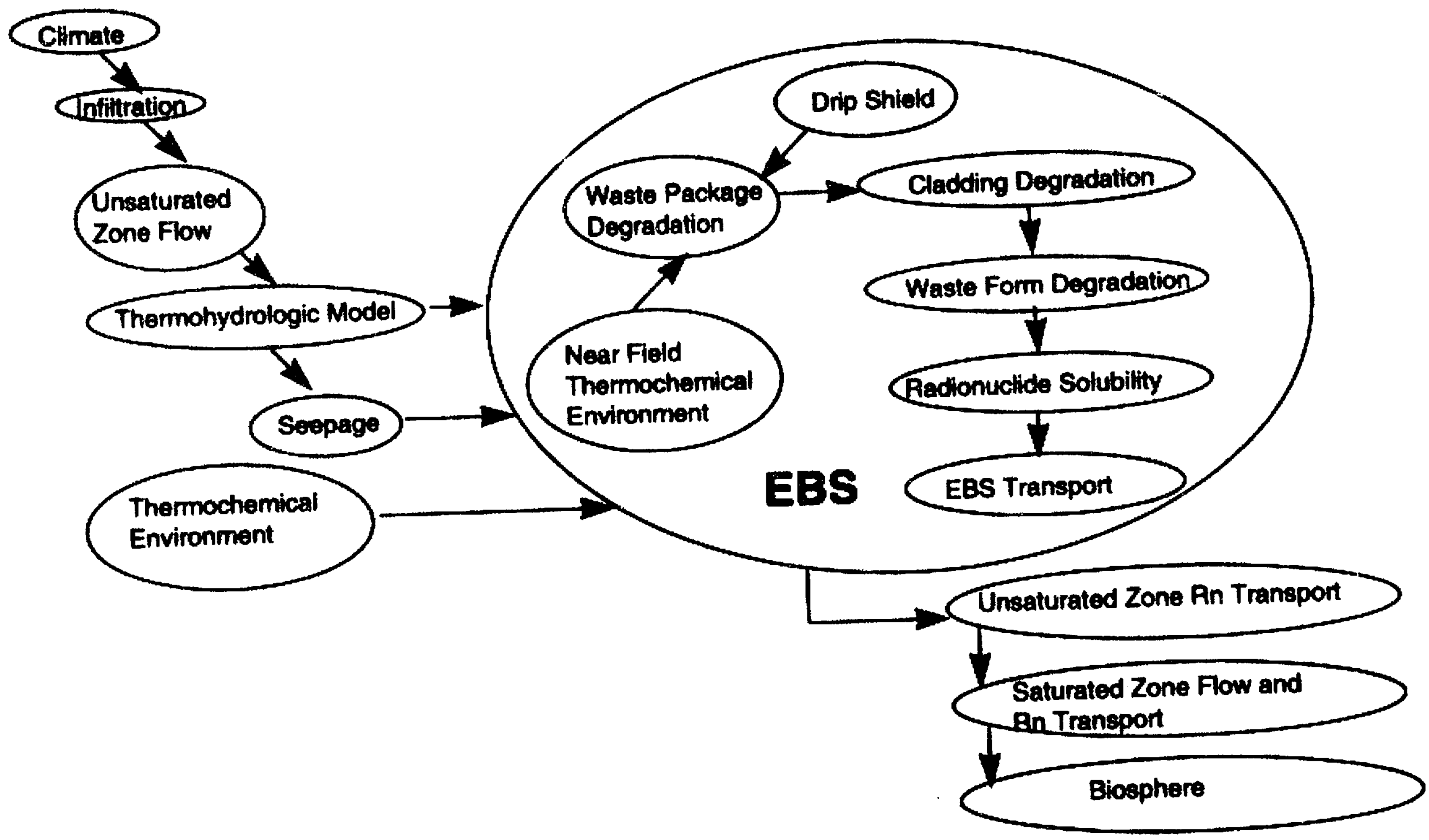
June 25-26, 1997

Outline

- Schematic of Geosphere in TSPA-VA
- Components of Geosphere
- Role of Geosphere in Waste Containment and Isolation Strategy
- Key Information Required from Geosphere Models
- Key Issues Associated with Geosphere Models
- Approach to Address Key Geosphere Model Issues in TSPA-VA
- Conclusion

Schematic of Natural System





Climate
Infiltration
Unsaturated Zone Flow
Thermohydrologic Model
Seepage
Thermochemical Environment
Drip Shield
Waste Package Degradation
Cladding Degradation
Waste Form Degradation
Near Field Thermochemical Environment
Radionuclide Solubility
EBS
EBS Transport
Unsaturated Zone Rn Transport
Saturated Zone Flow and Rn Transport
Biosphere

Key Site Components Affecting Predictions of Long-Term Waste Containment and Isolation

	Significance	KTI	WCIS
• Infiltration	●	✓	✓
• Unsaturated Zone Percolation Flux	●	✓	✓
• Seepage into Drifts	●	✓	✓
• Changes in Aqueous Flow: Thermal/Climate	●	✓	✓
• Unsaturated Zone Rn Transport	●	✓	✓
• Saturated Zone Rn Transport	●	✓	✓
• Biosphere	•		
• Disruptive Processes - Volcanism	•	✓	✓
• Disruptive Processes - Seismicity	•	✓	✓

Role of Natural Barrier System in Waste Containment and Isolation Strategy

- Provides controlled environment within which behavior of engineered components can be evaluated
- Provides remoteness from variability in surficial processes
- Provides remoteness from biosphere
- Provides reduction (by dispersion, dilution, retardation) and delay in arrival of any released radionuclides from engineered components

Key Information Required from Geosphere Models

Model	Key Information
Unsaturated Zone Flow	Percolation flux spatial/ temporal variability Fracture-matrix flux distribution Seepage flux spatial/ temporal variability
Thermohydrology	Seepage flux spatial/temporal variability Average "edge" vs "center" waste package groups In-drift relative humidity, temperature, liquid saturation

Key Information Required from Geosphere Models
(Continued)

Model	Key Information
Thermochemistry	Ambient key geochemical constituents Changed refluxing aqueous geochemistry due to thermal effects Thermally induced alteration of mineralogy
Unsaturated Zone Transport	Advective velocity distribution Mass breakthrough at the water table

Key Information Required from Geosphere Models
(Continued)

Model	Key Information
Saturated Zone Flow and Transport	Advective velocity distribution Dilution/mixing along flow path Mass breakthrough at potential receptors

Unsaturated Zone Flow Model Issues

Issues	Approach to Address
Infiltration rate	Use alternate maps including uncertainty; expert elicitation
Variability in infiltration rate	Sensitivity study to propagate surface variability to variability at depth
Effect of climate change	Derived from multiple "calibrated" UZ flow models with alternate climate/infiltration scenarios

Unsaturated Zone Flow Model Issues
(Continued)

Issues	Approach to Address
Seepage flux	Derived from drift-scale models evaluating a reasonable range of conceptual and parameter uncertainty; expert elicitation
Variability Seepage flux	Derived from drift-scale model results combined with expert elicitation

Unsaturated Zone Transport Model Issues

Issues	Approach to Address
Unsaturated zone flow model	Range of infiltration rates (best estimate and reasonable range from expert elicitation) combined with appropriate range of conceptual models and properties
Fracture-matrix coupling, matrix diffusion, fracture continuity, and fracture porosity	Sensitivity analyses to identify most significant parameters within range of calibrated models

Unsaturated Zone Transport Model Issues
(Continued)

Issues	Approach to Address
Changes in flow/transport properties by thermal/ chemical alteration	Sensitivity study to identify applicable range of effects to consider in TSPA
Retardation within fractures and matrix	Reasonable values based on mineralogic abundance. Small-scale effects tested by sensitivity study

Saturated Zone Flow and Transport Model Issues

Issues	Approach to Address
Darcy flux distribution including variability (esp. major structural features)	Incorporate alternative heterogeneous properties in sensitivity analysis
Alternative conceptual models of fracture-matrix interaction and range of effective transport properties (dispersivity, fracture/matrix sorption, matrix diffusion, and effective fracture porosity)	Sensitivity analyses combined with expert elicitation to identify applicable range of most significant parameters to include in TSPA
Effect of climate change	Identif, range of changes in flow rates and water table elevations based on regional flow model

Saturated Zone Flow and Transport Model Issues

(Continued)

Issues	Approach to Address
Effective transport properties of scale of km to 10s of km (including regional aquifer mixing)	Use regional and local scale inference to other analog systems, including natural geochemical tracers combined with expert elicitation
Mixing in well withdrawal scenarios	Alternative scenarios treated for 5-km biosphere; not an issue at 30 km due to transition from tuff to alluvial aquifer

Disruptive Features, Events, and Process Model: Signficant Issues

Issues	Approach to Address
Probability of direct volcanic eruption	Use PDF of volcanic event frequency derived from expert elicitation. Scale frequency for indirect effects
Effects and consequences of direct volcanic eruption	Review CNWRA model and incorporate reasonable ranges of effects based on expert judgment
Effects and consequences of indirect volcanic event	Develop bounded effects based on expert judgment and conduct sensitivity analyses on range of consequences

Disruptive Features, Events, and Process Model: Signficant Issues

(Continued)

Issues	Approach to Address
Probability and effects of seismic/tectonic event	Use PDFs for likelihood of occurrence derived from expert elicitation. Conduct sensitivity analyses on range of consequences
Probability and effect of human intrusion	Conduct stylized human intrusion analyses as recommended by NAS

Conclusions

- Significant issues exist regarding the confidence in models (and therefore predictions based on these models)
- Approaches have been implemented to address these issues within the TSPA for the Viability Assessment
- Additional testing and model development and substantiation will occur between VA and LA

YUCCA MOUNTAIN PROJECT

Studies

Objectives and Structure: Unsaturated Zone Flow Model Expert Elicitation (UZFMEE) Project

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Kevin J. Coppersmith
Geomatrix Consultants

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

June 25-26, 1997

Objective of Study

- The objective of the UZFMEE project was to identify and assess the uncertainties associated with certain key components of the unsaturated zone flow system at Yucca Mountain
- The assessment reviewed the data inputs, modeling approaches, and results of the unsaturated zone flow model being developed by Lawrence Berkeley National Laboratory (LBNL)

Objective of Study
(Continued)

- Focused on percolation flux (volumetric flow rate per unit cross-sectional area) at the potential repository horizon
- Two users of results: site-scale unsaturated zone flow model and Total System Performance Assessment

Uncertainty Treatment

- Major goal to capture the uncertainties in assessing unsaturated flow processes, including modeling and parameter uncertainties
- To ensure a range of perspectives, multiple individual judgments were elicited from seven members of an expert panel
- Panel members from within and outside the Yucca Mountain project represented a range of experience and expertise

Uncertainty Treatment

(Continued)

- Deliberate process followed in facilitating interactions among the experts, training them to express their uncertainties, and eliciting their interpretations
- Expert elicitation processes consistent with recent NRC and DOE guidance
- Resulting assessments and probability distributions provide a reasonable representation of the knowledge and uncertainties about key Yucca Mountain unsaturated zone issues

Steps in the UZFMEE Methodology

- Development of project plan
- Selection of the expert panel
- Data compilation and dissemination
- Meetings of the expert panel
- Elicitation of experts
- Feedback of preliminary results
- Finalization of expert assessments
- Preparation of project report

UZFMEE Panel Members

Expert	Affiliation
Gaylon S. Campbell	Washington State University
Glendon W. Gee	Battelle, Pacific Northwest National Laboratory
James W. Mercer	Geotrans, Inc.
Shlomo P. Neuman	University of Arizona
Karsten Pruess	Lawrence Berkeley National Laboratory
Daniel B. Stephens	Daniel B. Stephens & Associates
Edwin P. Weeks	U.S. Geological Survey

Meetings and Other Key Steps of the UZFMEE Project

Workshop #1 Significant Issues and Available Data (November 14-15, 1996)

- Identified issues important to TSPA-VA and for UZ site-scale model
- Summaries by PIs of data collected for Yucca Mountain

Workshop #2 Alternative Models and Interpretations (December 18-20, 1996)

- Summary of key components of UZ site-scale model
- Alternative conceptual models of fracture-matrix interaction, temporal models
- Net infiltration modeling
- Calibration

Meeting and Other Key Steps of the UZFMEE Project

(Continued)

Field trip to ESF and Yucca Mountain Vicinity

- Workshop #3 Preliminary Interpretations (February 4-5, 1997)
- Presentations by experts of preliminary interpretations: net infiltration, rock properties, major pathways, calibration uncertainties, and alternative conceptual models
- Discussion of uncertainties

Meetings and Other Key Steps of the UZFMEE Project

(Continued)

Elicitation Interviews (February 6-21, 1997)

- One-day sessions with each expert
- Interpretations documented

Feedback

- Following elicitations, feedback package prepared consisting of elicitation summaries, summary of key assessments across panel, and sensitivity analyses conducted based on expert requests

Meetings and Other Key Steps of the UZFMEE Project

(Continued)

Finalization and Documentation of Interpretations by Experts

- Multiple refinements of elicitation summaries
- Elicitation summaries describe unsaturated zone flow processes, alternative approaches to percolation flux estimation, flux estimates, seepage into drifts, etc.

Documentation of procedures, assessments, and results

Key Issues Addressed By UZFMEE Panel

- Conceptual model of unsaturated zone flow system
- Net infiltration (surface water balance)
    - +Temporal issues
    - +Spatial issues
    - +Temporal and spatial average over YM block
- Lateral diversion at top of Ptn and other interfaces
- Temporal behavior of UZ flow system
- Methods used to estimate percolation flux at potential repository horizon

Key Issues Addressed By UZFMEE Panel

(Continued)

- Percolation flux
  - +Spatial and temporal average over YM block
  - +Spatial distribution
- Components of flux in fractures and matrix
- Fast-flow component of total flux
- Seepage into drifts
- Modeling issues
- Additional data collection to reduce uncertainties

Nuclear Waste Technical Review Board
Full Board Meeting

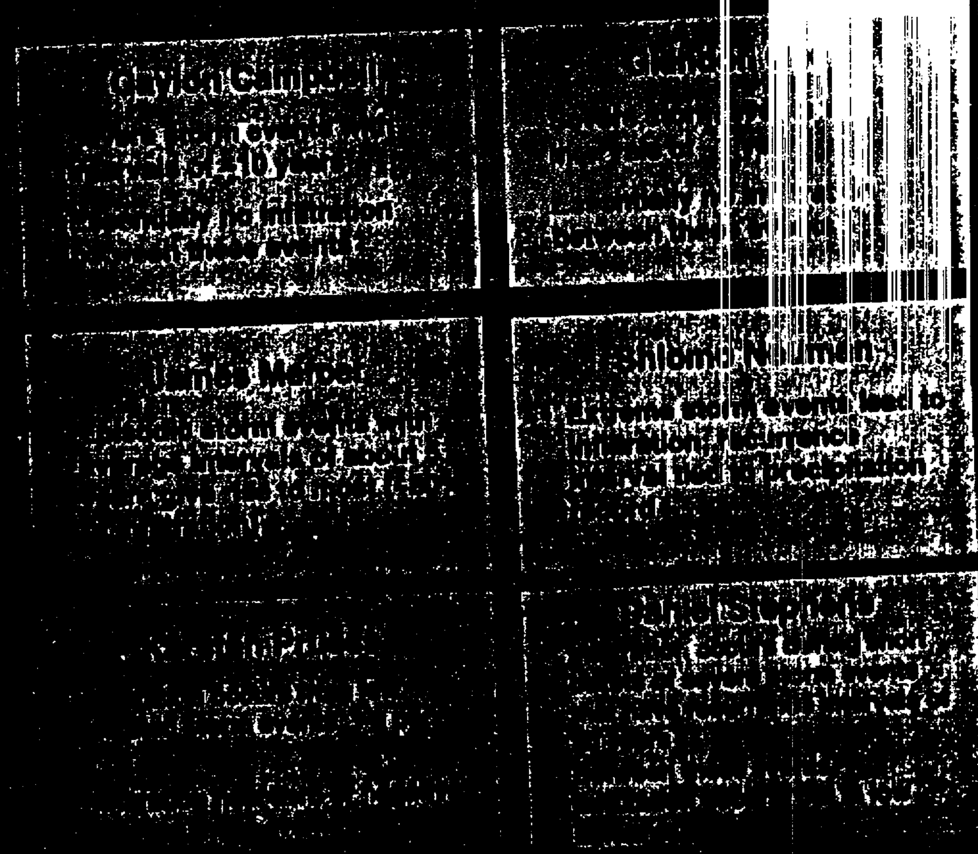
The Unsaturated Zone (UZ) Site-Scale Flow Model and Results of the UZ Expert Elicitation

June 24 and 25, 1997
Las Vegas, Nevada

Bo Bodvarsson
E.O. Lawrence Berkeley National Laboratory

pert Elicitation:

Net Infiltration: Temporal Issues



Overall Summary

- Infiltration occurs primarily during severe storm events (every 1 to 20 years)
- Essentially no infiltration between these events

Model Expert Elicitation:

Net Infiltration: Spatial Issues

Overall Summary

- Map by Flint et al. (1996) generally reasonable in large scale spatial variability
- Expect more infiltration into washes and less at ridgetops
- Several processes neglected by Flint et al. may be important, including runoff lateral flow at alluvium/bedrock contact

Gaylon Campbell

- and relative importance of various factors
- Horse-tailing faults important

Glendon Gee

- Funneling of water into faults and fractures
- area) is important process

James Mercer

Shlomo Neuman

- Expected to be heterogeneous

Daniel Stephens

Expert Elicitation

Lateral Diversion at Top of PTn or Other Interfaces?

Overall Summary

- Lateral flow exists but is limited to tens of meters up to 100m
- Likely places include the PTn, top of TSw and from Solitario Canyon

Model Expert Elicitation:

Temporal Behavior of UZ Flow System

Overall Summary

- Episodic infiltration events
- PTn dampens most pulses
- Fast flow component is not dampened by PTn

Expert Elicitation:

Method(s) Used to Estimate Percolation Flux at Repository Horizon

Overall Summary

- Net infiltration mostly
- Saturation and water potentials within PTn
- Temperature gradients
- Chemicals such as total chloride and ^{14}C
- Perched water

... Expert Elicitation:

Percolation Flux Estimate: Temporal and Spatial Average

Overall Summary

- Mean: 10.3 mm/yr
- Median: 7.2 mm/yr
- 5th percentile: 1.0 mm/yr
- 95th percentile: 30.0 mm/yr

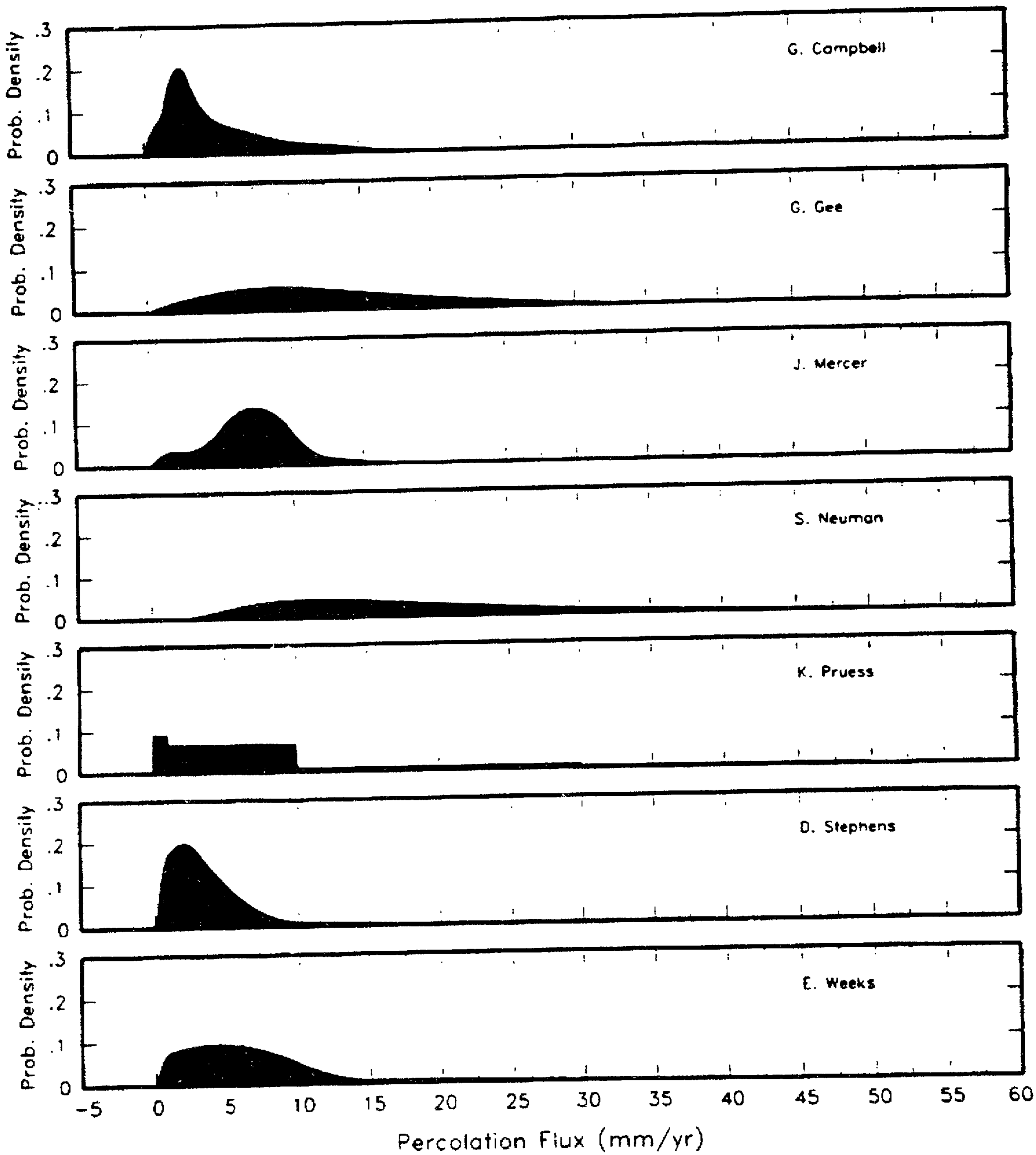


Figure 3-2a Probability density distributions for percolation flux at the repository level defined by the seven experts.

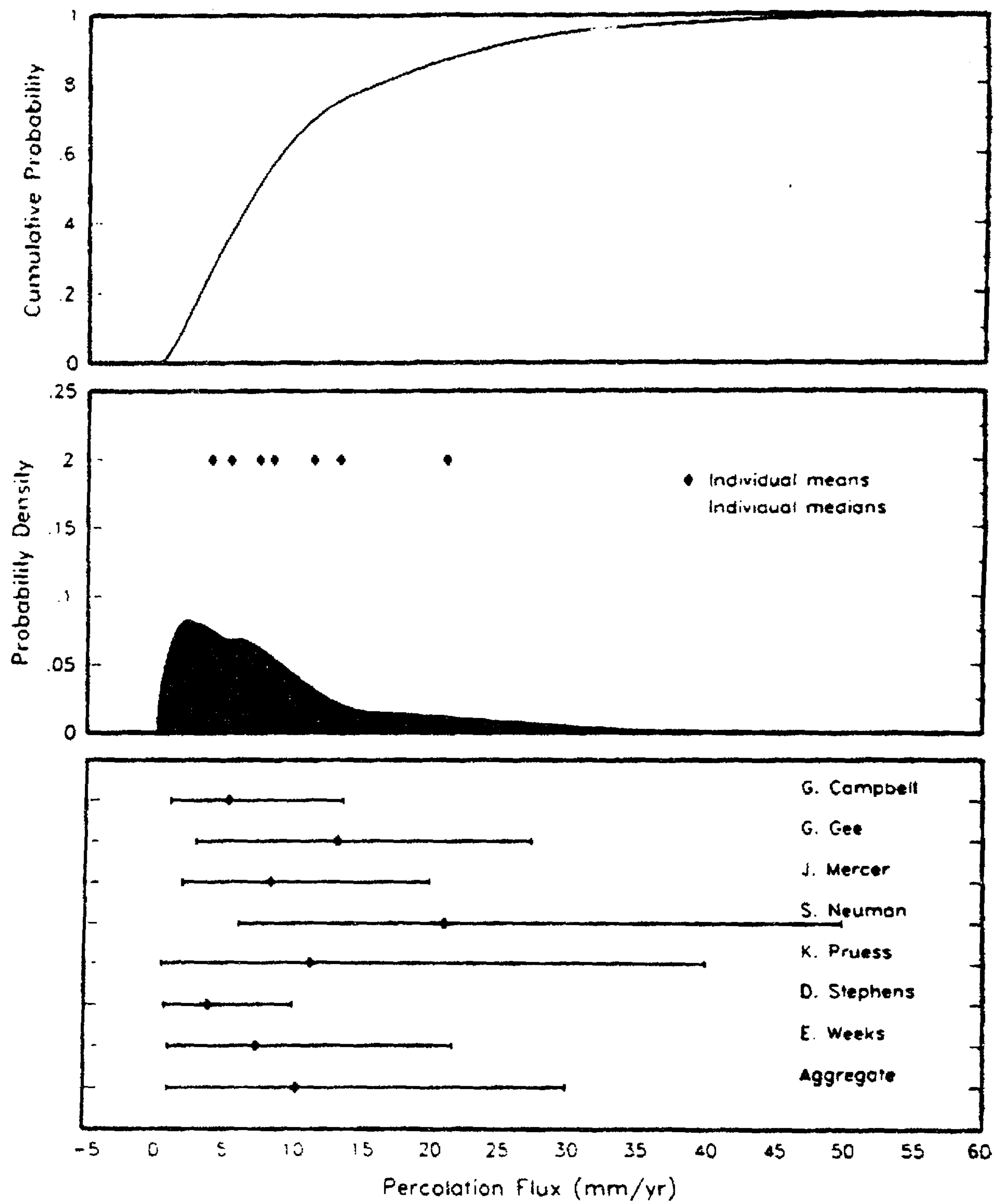


Figure 3-2b Summary of the UZFM elicitation results. Top plot: aggregate cumulative probability distribution for percolation flux across the seven expert panel members. Middle plot: corresponding probability density function for the aggregate probability distribution. Also shown are the mean and median values for the individual expert's distributions. Bottom plot: median, mean, and 5[th] to 95[th] percentile range for the seven individual expert's distributions and the aggregate distribution.

UZ Model Expert Elicitation:

Percolation Flux: Spatial Issues

Overall Summary

- Generally the same as the infiltration map, but smoother
- As predicted by LBNL model results
- Some heterogeneities in flow may develop with depth

Gaylon Campbell

- Generally same as net infiltration map, but smoother
- As predicted by LBNL model results

Glendon Gee

- Generally same as net infiltration map

James Mercer

- More uniform distribution than infiltration, because of diffusion into TSw fracture network (which contains ubiquitous fractures)

Shlomo Neuman

- Should generally correlate with infiltration map, but local lateral flow, medium heterogeneities and fast-flow channels will modify

Karsten Pruess

- Not known; may be similar to the infiltration map; or heterogeneities may develop with variability

Daniel Stephens

- Generally same as infiltration map (highs and lows generally the same locations)
- Superimposed are local highs as faults and fractures

UZ Model Expert Elicitation:

Components of Flux in TSw: Fractures versus Matrix

Summary

- ...ctures carry bulk of ... about 90%
- ... carries about - ... the flux

Gaylon Campbell
- Fractures (95% of flux) Matrix (5%)

Glendon Gee
- 90% of flux in faults/fracture
- 2-3 mm/yr occurs in matrix

James Mercer
- Most (~90%) of flux is in fracture network of TSw

Shlomo Neuman
- Maximum flux in matrix is 1.5 mm/yr; therefore, at 17 mm/yr total flux, ratio of matrix to fracture is 10% to 90%

Karsten Pruess
- Matrix conductivity is about 0.3 mm/yr; rest is in fractures
- Slow component in both fractures and matrix

Daniel Stephens
- Partitioning is uncertain (10% to 70% in fractures based on UZ model, depending on total flux); possibly most of total flux is in matrix

Edwin Weeks
- Matrix can carry 1 mm/yr; rest is in fractures [illegible]
- Small percentage (1%-10%) of total fractures are accommodating flux

UZ Model Expert Elicitation:

Components of Flux in TSw: Fast Flow versus Total Fux

- Fast flow is only 1% or so
- Fast Flow May Occur in many fractures

Gaylon Campbell
- Fast flow component is <1% of total flux

Glendon Gee
- ~5% of area is faults and fractures
- Some fractures accommodate fast flow (~150-200 mm/yr)

James Mercer
Not sure of volume that fast-flow component represents; would trust results of LBNL model

Shlomo Neuman
- Fast flow component is small part of total flux
- Area of ESF with fast paths is 0.03-2% of total area (19-1200 m² out of 64,000 m² of tunnel)

Karsten Pruess
- ... thus only a small number of fractures would be ... fast flow component

Daniel Stephens
- Fast flow component is small % of total flux

Edwin Weeks

UZ Model Expert Elicitation:

Seepage into the Drifts

Overall Summary

- Mixed opinion
- Water flow in fractures will enter drifts
- Matrix component will go around drifts
- Some believe no water will enter drifts
- Area with seeps is small or 1 to 10%

Gaylon Campbell
- Not sure under ambient conditions
- …void by providing a small …ount of ventilation

Glendon Gee
- Very unlikely based on available data, consistent with absence of seeps in ESF, even in Faults

James Mercer
- Expect seepage into drift due to film flow along wall of drift; weeps are believed to be ubiquitous, as evidenced by Cl found everywhere

Shlomo Neuman
- Full saturation not needed for seeps, therefore percent of area with seeps will be less than area with fast paths (see above)

Karsten Pruess
- Slight negative matric potential should stop matrix component; fracture component will enter drift

Daniel Stephens
- Will occur only at fractures, not matrix
- A very small part of total area (<1%) will occupy seeps

Edwin Weeks
- Matrix component will go around … fracture component will …

UZ Model Expert Elicitation:

Modeling Issues: Infiltration

Overall Summary

- 1-d modeling is limited as it neglects runoff and lateral flow
- Bucket model may not be adequate
- Need mass balance model for infiltration

Gaylon Campbell

- 1-d finite difference model for net infiltration is OK

Glendon Gee

- [illegible] modeling doesn't adequately address runoff
- Need mass balance model for infiltration
- Neutron probe data do not capture episodic nature of storm events

James Mercer

- Transient component of flow should be included

Shlomo Neuman

- One-dimensional modeling is not capable of incorporating lateral flow at bedrock-alluvium contact

Karsten Pruess

Daniel Stephens

- No confidence in Bucket model for infiltration; Maxey-Eakin not satisfactory for points within a [illegible]

Edwin Weeks

UZ Model Expert Elicitation:
UZ Modeling Issues

Overall Summary

- Dual-K model needed above PTn; ECM model adequate below that
- Fast-paths need to be modeled. and more faults added and the sensitivity evaluated
- Transient component of flow needs to be modeled
- Investigate alternative models to the continuum models. e.g. Weeps model
- Model mass balance of perched water and water table fluctuation
- Predictability of which fracture flow should be modeled as random
- Perform uncertainty and error analysis of heat flux and temperature data

Gaylon Campbell

- Dual-K needed through PTn; ECM probably OK below PTn
- Fast paths need to be represented
- Add faults and test sensitivity
- Upscaling should reasonably match measured matrix properties

Glendon Gee

James Mercer

- Dual-K above PTn, ECM probably OK below, as long as fast-flow component included
- Fast-flow component in PTn probably requires faults modeled in this unit
- Expect little fracture matrix interaction in TSw

Shlomo Neuman

- Uncertainty and error analyses of heat flux estimates and measured temperature profiles should be conducted

Karsten Pruess

- A WEEPS-type model embedded in a more complex model may be way to portray fast-flow component
- Continuum description of flow assumes volume-averaging and may miss much of localized flow [illegible]

Daniel Stephens

- Perched water balance and overall water balance including water table fluctuations should be modeled
- TOUGH2 modeling should predict key observations such as the wet spot in ESF at station 75+00

Edwin Weeks

[illegible]

UZ Model Expert Elicitation:
Additional Data Collection/Future Work

Overall Summary

- Collect water potential, water content and hydrologic property measurements in ESF
- Unsaturated conductivity measurement are a high priority
- Collect data on surface water balance
- Inject water above sealed room in the ESF to test for seepage
- Run UZ model to examine effects of higher infiltration patterns; do many "what-if" studies
- Analyze pump test data for perched water bodies to determine drainable porosity

Gaylon Campbell

[illegible]

Glendon Gee

[illegible] balance using drip line [illegible] above ESF and pan

Inject water above sealed-off room [illegible] ESF to test for seepage

Perform non-linear fit to temperature data to see if profiles show curvature

James Mercer

Run UZ model to examine the effect of higher infiltrations

Evaluate effect of more infiltration in washes

Shlomo Neuman

Extract from pumping test data in perched water bodies, information about the drainable porosity of the fracture system

Karsten Pruess

Monitoring and data collection related to net infiltration should continue

Daniel Stephens

Thoroughly study and instrument small drainage basin above repository

More unsaturated hydraulic conductivity measurements

[illegible] measurements of water [illegible] Canyon

[illegible]

UZ Model Expert Elicitation:
Additional Data Collection/Future Work

Overall Summary cont.

- Continue infiltration studies
- Thorough study of small drainage basin above the repository
- More accurate measurements of water potential in the PTn
- Infiltration study of the Solitario Canyon area
- Develop hydrographs of perched water
- Perform large-scale experiments in ESF with plastic sheets to investigate inflow
- Obtain more detailed temperature logs

Gaylon Campbell

- Water potential, water content, hydraulic properties measurements in situ in ESF
- Unsaturated conductivity measurements should be high priority
- Sfc water balance info, plant uptake, rock cover on slopes, snow, washes, rock-alluvium contact

Glendon Gee

- Mass balance using drip line sources above ESF and pan
- Inject water above sealed-off room of ESF to test for seepage
- Perform non-linear fit to temperature data to see if profiles show curvature

James Mercer

- Run UZ model to examine the effect of higher infiltrations
- Evaluate effect of more infiltration in washes

Shlomo Neuman

- Extract from pumping test data in perched water bodies, information about the drainable porosity of the fracture system

Karsten Pruess

- Monitoring and data collection related to net infiltration should continue

Daniel Stephens

- Thoroughly study and instrument small drainage basin above repository
- More unsaturated hydraulic conductivity measurements
- More accurate measurements of water potentials in PTn
- Infiltration study of Solitario Canyon

Edwin Weeks

- Large-scale experiments in the ESF; install plastic sheets on roof and walls and monitor water inflow
- Obtain temperature logs with measurements at close intervals

UZ Model Expert Elicitation

Recommendation	Action
LBNL develop a surface hydrology module for TOUGH2	Preliminary module developed during Elicitation; tested on a 2.0 cross section in Wren Wash; full evaluation in FY98 planning
Dual-K model needed above Ptn, ECM model adequate below that	UZ model has dual-K model throughout entire unsaturated zone
Fast-paths need to be modeled, and more faults added and the sensitivity evaluated	UZ model matches bomb-pulse Cl-36 data; we have added more faults
Transient component of flow needs to be modeled	We have performed sensitivity studies of transient flow
Investigate alternative models to the continuum models, e.g. Weeps model	A new activity of alternative models has been incorporated into FY98 planning
Model mass balance of perched water and water table fluctuation	Perched water mass balance is included in FY97 report
Predictability of which fracture flow should be modeled as random	Currently fracture flow is modeled using dual K continuum with all or some random fractures flowing
Perform uncertainty and error analysis of heat flux and temperature data	We have developed an analytical model for the evaluation of temperature data, that allows for uncertainty and error analysis
Run UZ model to examine effects of higher infiltration; do many "what-if" studies	We have performed some studies and the results suggest that UZ model becomes inconsistent with observed data for average percolation flux rates exceeding 20mm/yr

UZ Model Expert Elicitation:

Components of Flux in TSw: Fast Flow versus Total Flux

- Fast flow is only 1% or so
- Fast Flow May Occur in many fractures

Gaylon Campbell

Fast flow component is < 1% of total flux

Glendon Gee

area is faults and fractures

fractures

accommodate fast flow (~150-200 mm/yr)

James Mercer

Not sure of volume that fast flow component represents; would trust results of LBNL model

Shlomo Neuman

Fast flow component is small part of total flux

Area of ESF with fast paths is of total area (19-1200 m² out of 84,000 m² of tunnel)

Karsten Pruess

fast flow component

Daniel Stephens

Fast flow component is small % of total flux

UZ Model Expert Elicitation:

Lateral Diversion at Top of PTn or Other Interfaces?

Overall Summary

- Lateral flow exists but is limited to tens of meters up to 100m
- Likely places include the PTn, top of TSw and from Solitario Canyon

Gaylon Campbell
Yes, but no more than few tens of meters at bottom of PTn and top of TSw

Glendon Gee
Likely, but not on a regional-scale

James Mercer
Yes, but not much lateral diversion because of faults and [illegible]

Shlomo Neuman
Expect some degree of lateral flow and redistribution at top of PTn and top of TSw; not major
No evidence for or against lateral flow, so assume vertical

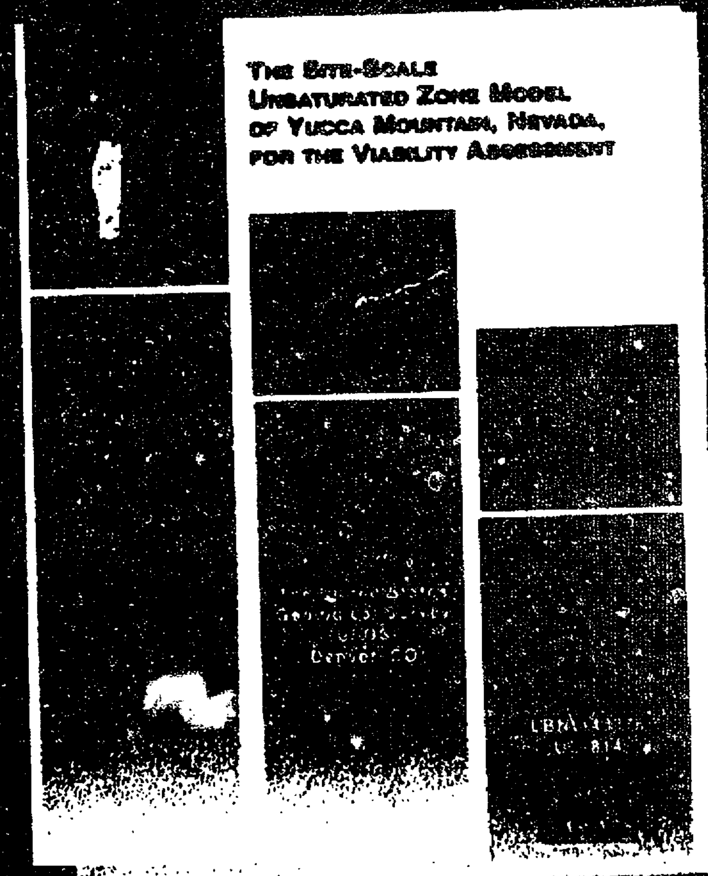
Karsten Pruess
[illegible] but will occur over scales [illegible] to 100 meters

Daniel Stephens
Yes, some degree of diversion is likely, although faults and fractures will preclude regional-scale diversion
Lateral flow from Solitario Canyon may be important contribution to perched water bodies

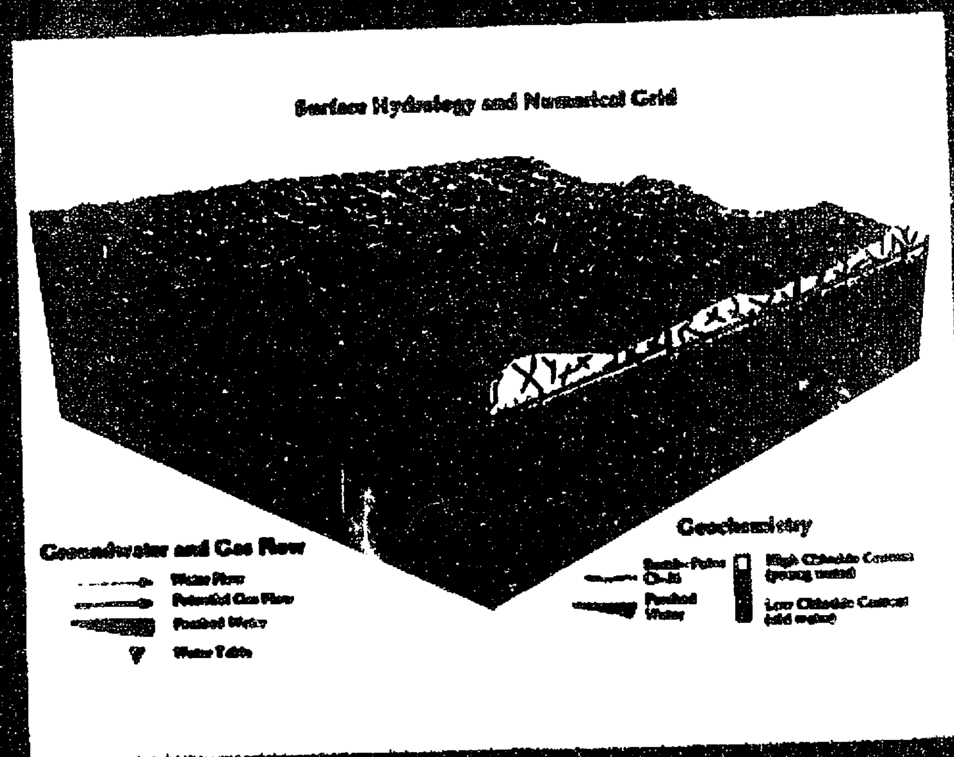
Edwin Weeks
[illegible]

... Results of UZ Site-Scale Flow Model for VA (cont.)

- Little, if any, water will seep into drifts
- Different fracture matrix interaction conceptual models lead to different calibrated hydrological properties
- Flow patterns below the repository horizon are uncertain; it is estimated that about 25% of the total flow passes through sorptive zeolitic rock
- Future climate change analysis is estimated to increase percolation flux multi-fold, and will elevate perched water levels by less than 10 meters



- Current average percolation flux is estimated to be 1-10 mm/yr in the repository area
- Current average percolation flux cannot exceed 20 mm/yr
- Geochemical evidence including total Cl, C-14 and Sr helps bound percolation flux, as does the temperature data
- Bomb-pulse Cl-36 represents only a very small fraction of total flow, and may be over-emphasized
- Over 80% of flow in TSw occurs through fractures
- Flow occurs through thousands or millions of flow channels, each carrying small amounts of water



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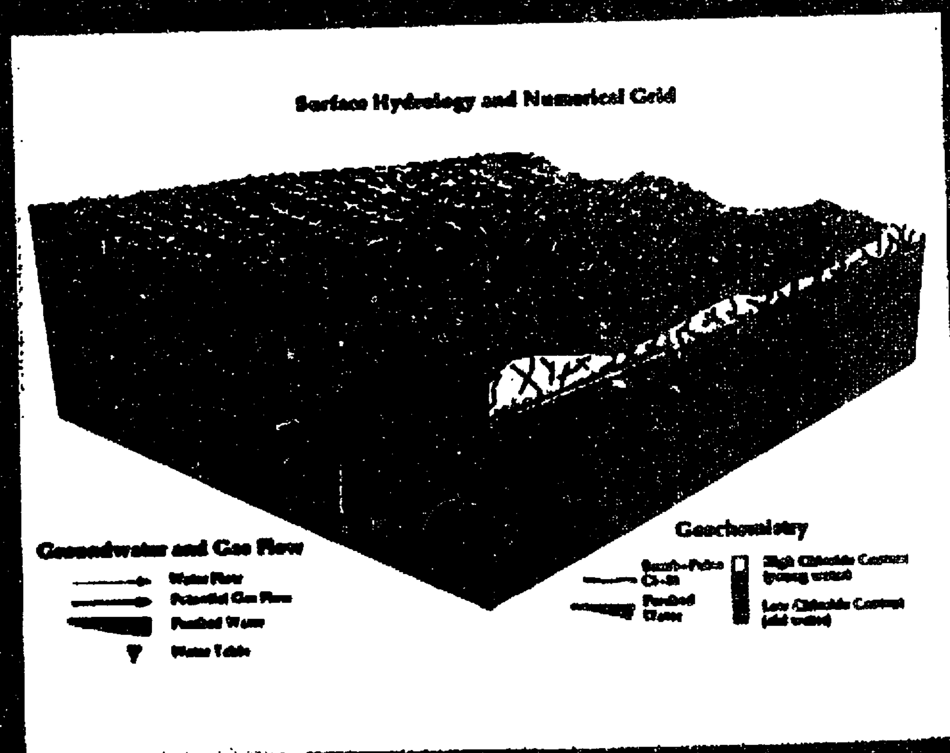

Nuclear Waste Technical Review Board

Full Board Meeting

Use of the UZ Expert Elicitation Results in the UZ Site Scale Model

June 24 and 25, 1997

Las Vegas, Nevada

Bo Bodvarsson

E.O. Lawrence Berkeley National Laboratory