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OCT 25 1991

NOTE TO: Joseph J. Holonich, Sectin Leader
Systems Engineering and Special Projects Section
Repository Licensing and Quality Assurance
Project Directorate

FROM: Robert D. Carlson, Project Manager
Systems Engineering and Special Projects Section
Repository Licensing and Quality Assurance
Project Directorate

SUBJECT: TRIP REPORT FROM THE OCTOBER 8-10, 1991, NUCLEAR WASTE TECHNICAL REVIEW BOARD MEETING ON EVALUATION OF RANGES OF THERMAL LOADING FOR HIGH-LEVEL WASTE DISPOSAL IN GEOLOGIC REPOSITORIES

On October 8-10, 1991, I attended a full board meeting of the Nuclear Waste Technical Review Board (NWTRB) in Las Vegas, Nevada. The purpose of the meeting was to evaluate the ranges of thermal loading for high-level waste (HLW) disposal in geologic repositories. I and other members of the U.S. Nuclear Regulatory Commission (NRC) attended the meeting as observers only.

The briefings were given by the U.S. Department of Energy (DOE), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SLN), various contractors and university professors, and members from the international community. A schedule of topics and responsible briefers for each subject is found in Enclosure 1. The material provided during the briefings is provided in Enclosure 2.

The briefings were divided into six major areas, which were: international views on the thermal loading rationale for the design of a HLW repository; the repository and thermal loading concept for Yucca Mountain; uncertainties associated with high and low thermal loading; enhancements and other considerations associated with higher and lower thermal loading; implications of higher and lower thermal loading; and thermal loading issues and round-table discussions. Briefings in each area were presented to the members of the NWTRB, with the floor being open for general discussion and questions from the meeting participants at the conclusion of each presentation.

The international presentations began with Mr. Nils Rydell of Sweden, representing the Swedish National Board for Spent Nuclear Fuel. He indicated that Sweden was planning on use of warm or cool disposal techniques for their HLW. Since the Swedish government has placed no requirements for future HLW retrievability, they are proposing to horizontally emplace all HLW canisters. Their rationale is that this method is more feasible from a cost and space (i.e., underground area used for disposal of HLW) standpoint.

NH16.1
108.22
WM-1

Sweden has recently changed the design of its HLW canisters, and now proposes to use steel encased containers with copper lining. Bentonite would be used as a filler material inside of the canister because of its good swelling properties at temperatures below 100 degrees centigrade, thus acting as a good barrier to moisture. Moisture is a primary concern, since Sweden is limited to placement of their geologic repository in fractured, saturated rock. Tests are being conducted to determine if the canister can maintain its structural integrity for up to 1 million years.

Mr. Klaus Kuhn of Germany briefed second, representing Company for Radiation and Environmental Research/Institute for Underground Storage. He stated that Germany currently reprocesses its expended fuel in France at La Hague, and has the HLW shipped back to Germany for vitrification. Germany has no plans for surface storage, and will only be utilizing a deep geologic repository (800-1100 meters subsurface) for all low, intermediate, and high level waste disposal. They will be using salt as the host rock for their repository, and use hot disposal techniques for their canisters. As with Sweden, the German government has placed no requirement for future retrievability of the disposed waste, and therefore will also use horizontal emplacement methods for their canisters.

Mr. Gary Simmons of Canada was the final international representative briefing the NWTRB, representing the Atomic Energy of Canada, Ltd. He indicated that Canada's sole source of spent fuel was from their CANDU reactors, thus necessitating a vast underground area for their geologic repository because of the sheer volume of HLW generated by this process. Plutonic rock will be the host formation for the Canadian repository, located in a saturated environment 500-1000 meters subsurface. All HLW will be vitrified and cooled prior to disposal (i.e., kept below 100 degrees centigrade). Three types of materials are being considered for canister use for disposal of HLW. These are, in preferential order: titanium; oxygen free copper; and iron based stainless steel. Further testing will have to be conducted before selecting a canister material.

After the international representatives concluded their briefings on thermal loading rationale for the design of a HLW repository within their respective countries, the NWTRB then began reviewing the technical aspects of thermal loading for a U.S. HLW repository. The first set of presenters discussed the thermal loading concept for Yucca Mountain. This entailed a historical perspective of the U.S. program, evolution of the repository concept at Yucca Mountain, repository design considerations, and technical considerations involved in determining thermal loading.

The next set of briefings was devoted to uncertainties associated with high and low thermal loading. This encompassed geomechanical, hydrogeologic, mineralogical, waste form degradation and materials, and biological resource uncertainties. The presenters then briefed the group on enhancements and other considerations associated with higher and lower thermal loading. This area covered repository/waste package design enhancements, repository testing considerations, near-field environment testing considerations, engineered barrier concepts, preclosure thermal enhancements, geologic heat pipes, and an overview of preclosure ventilation options.

The final portion of the NWTRB meeting was dedicated to implications of higher and lower thermal loading. This covered performance assessment considerations, HLW system comparative costs, regulatory and legislative considerations, and conceptual considerations for total system performance. Afterwards, a round-table discussion on thermal loading issues occurred. This provided a forum for participants to reach conclusions on the risks and uncertainties associated with high versus low thermal loading. Details of each of the aforementioned briefings pertaining to thermal loading can be found in Enclosure 2.

/s/

Robert D. Carlson, Project Manager
Systems Engineering and Special
Projects Section
Repository Licensing and Quality
Assurance Project Directorate

Enclosures (2): As stated

DISTRIBUTION w/c Enclosures

CNWRA
LPDR
BJYoungblood, HLWM
On-Site Reps
NMSS R/F
ACNW
JLinehan, HLWM
RCarlson, HLPD
HLPD R/F
PDR
RBallard, HLGE
LSS
Central File
MFederline, H[illegible]

OFC :HLPD	:HLPD	:HLPD	:	:	:
NAME:RCarlson/d	:JHolonich	:JLinehan	:	:	:
Date:10/25/91	:10/[illegible]/91	:10/[illegible]/91	:	:	:

NWTRB Trip Report OFFICIAL RECORD COPY

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

Agenda

Full Board Meeting

Evaluation of Ranges of Thermal Loading for High-level Waste Disposal in Geologic Repositories

October 8, 1991

St. Tropez Hotel
Monte Carlo Ballroom II & III
455 E. Harmon Avenue
Las Vegas, Nevada 89109
702/369-5400

8:30 A.M. **Welcome**
Don U. Deere, Chairman, Nuclear Waste Technical Review Board

Opening remarks
Carl Gertz, Department of Energy (DOE)/Yucca Mountain Site Characterization Project Office (YMPO)

8:45 A.M. **Strategic implications of heat in a high-level radioactive waste repository**
Larry Ramspott, Lawrence Livermore National Laboratory (LLNL)

International views on the Thermal Loading Rationale for the Design of a HLW Repository

9:15 A.M. **The Swedish geologic repository**
Nils Rydell, National Board for Spent Nuclear Fuel (SKN)

10:00 A.M. BREAK

over

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

10:15 A.M.	**The German geologic repository** Klaus Kühn, Company for Radiation and Environmental Research/Institute for Underground Storage (GFS/IFT)
11:00 A.M.	**The Canadian geologic repository** Gary Simmons, Atomic Energy of Canada, Ltd. (AECL)
11:45 P.M.	**LUNCH**

The Repository and Thermal Loading Concept for Yucca Mountain

1:00 P.M.	**Historical perspective of the U.S. program** Carl Gertz, DOE/YMPO
1:30 P.M.	**Evolution of the repository concept for a potential repository at Yucca Mountain** Michael Voegele, Science Applications International Corporation (SAIC)
3:00 P.M.	**BREAK**
3:15 P.M.	**Repository design considerations** Tom Blejwas, Sandia National Laboratories (SNL)
3:45 P.M.	**Technical considerations involved in determining thermal loading** — Thermal Design Considerations — Temperature changes over time Eric Ryder, SNL
5:15 P.M.	**ADJOURN**

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

Agenda

Full Board Meeting

Evaluation of Ranges of Thermal Loading for High-level Waste Disposal in Geologic Repositories

October 9, 1991

St. Tropez Hotel
Monte Carlo Ballroom II & III
455 E. Harmon Avenue
Las Vegas, Nevada 89109
702/369-5400

Uncertainties Associated with High and Low Thermal Loading
(During this session, the following questions will be addressed for both high and low thermal loading concepts, in the areas listed below.

What are the potential problems?
What is the significance of each of the potential problems?
What uncertainties are associated with each potential problem?
Can these uncertainties be resolved?
How much time and what costs are associated with resolving these uncertainties?
Will there be residual uncertainties?

8:30 A.M.	**Opening Remarks and Introduction** Warner North, NWTRB
8:40 A.M.	**Introduction of the following presenters** Mike Cloninger, DOE
8:45 A.M.	**Geomechanical uncertainties** Larry Costin, SNL

over

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

9:15 A.M.	**Hydrogeologic uncertainties** Thomas Buscheck, Lawrence Livermore National Laboratory (LLNL)
10:00 A.M.	**Geomechanical uncertainties** Brian Viani, LLNL
10:15 A.M.	**BREAK**
10:30 A.M.	**Mineralogical uncertainties** David Bish, LANL
11:00 A.M.	**Waste form degradation and materials uncertainties** Gregory Gdowski, LLNL
11:30 P.M.	**Biological resource concerns** Kent Ostler, EG&G Energy Measurements, Inc.
12:00 noon	**LUNCH**

Enhancements and Other Considerations Associated with Higher and Lower Thermal Loading

1:10 P.M.	**Introductory remarks** Dennis Price, NWTRB
1:15 P.M.	**Introduction of the following presenters** Mike Cloninger, DOE
1:20 P.M.	**Repository/waste package design enhancements** Tom Blejwas, SNL
1:35 P.M.	**Repository testing considerations** Tom Blejwas, SNL

2:05 P.M.	**Near-field environment testing considerations** Wunan Lin, LLNL
2:25 P.M.	**Waste form and materials testing considerations** Gregory Gdowski, LLNL
2:35 P.M.	**BREAK**
2:50 P.M.	**Introduction of speakers** Dennis Price, NWTRB
2:55 P.M.	**Candidate Engineered Barrier Concept** Peter Stevens-Guille, Ontario Hydro, Canada.
3:30 P.M.	**Preclosure thermal enhancements** George Danko, University of Nevada
4:00 P.M.	**Geologic heat pipes — State-of-the-art review** Herb Rosenberg, TRW/Ballistic Missile Office
4:30 P.M.	**An overview of preclosure ventilation options** Antony Ivan Smith, Tunneling Technical Corporation Gary Sandquist, University of Utah
5:00	**ADJOURN**

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

Agenda

Full Board Meeting

Evaluation of Ranges of Thermal Loading for High-level Waste Disposal in Geologic Repositories

October 10, 1991

**St. Tropez Hotel
Monte Carlo Ballroom II & III
455 E. Harmon Avenue
Las Vegas, Nevada 89109
702/369-5400**

Implications of Higher and Lower Thermal Loading

8:30 A.M.	**Opening remarks** John Cantlon, NWTRB
8:45 A.M.	**Performance assessment considerations** — Time-temperature profiles — Waste package integrity — Near-field effects — Overall performance Bob Shaw, Robbin McGuire, Ben Ross, Nick Apted, Dan Bullin Electric Power Research Institute (EPRI)
10:15 A.M.	**BREAK**
10:30 A.M.	**Introduction** Mike Cloninger, DOE

over

10:35 A.M. **High-level waste system comparative costs**
— Repository costs
— Transportation costs
— Storage costs
David Jones, Roy F. Weston Inc.

11:05 A.M. **Regulatory and legislative considerations**
— Human health and safety (i.e., preclosure)
— Licensing considerations
— Legislative implications
Michael Lugo, SAIC

11:35 A.M. **Conceptual considerations for total system performance**
Michael Voegele, SAIC

12:05 P.M. Summary
Mike Cloninger, DOE

12:10 P.M. LUNCH

The Thermal Loading Issue, Round-Table Discussion, Conclusions and Comments

(This session will provide an opportunity for participants to reach conclusions on the risks and uncertainties associated with high vs. low thermal loading and other factors that should be considered in determining the thermal loading for a repository.)

1:30 P.M. **Opening remarks and round-table discussion**
Clarence Allen, NWTRB, Moderator

1:35 P.M. Round-table discussion

ADJOURN

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

EVALUATION OF RANGES OF THERMAL LOADING FOR HIGH-LEVEL WASTE DISPOSAL

October 8-10, 1991
Las Vegas, NV

Tuesday, October 8, 1991

8:30	Welcome Opening Remarks	D. Deere, NWTRB C. Gertz, DOE
8:45	Strategic implications of heat in a high-level radioactive waste repository	L. Ramspott, LLNL

OVERVIEW SESSION

THERMAL LOADING RATIONALE FOR THE DESIGN OF A HLW REPOSITORY

9:15	The Swedish geologic repository	N. Rydell, SKN
10:00	Break (15 min.)	
10:15	The German geologic repository	K. Kuhn, GFS/IFT
11:00	The Canadian geologic repository	G. Simmons, AEC
11:45	LUNCH (1 hr. 15 min.)	

THE REPOSITORY AND THERMAL LOADING CONCEPT FOR YUCCA MOUNTAIN

1:00	Historical Perspective of U.S. Program	C. Gertz, DOE
1:30	History of Evolution of Repository Concept for a Potential Repository at Yucca Mountain	M. Voegele, SAIC
3:00	BREAK (15 min.)	
3:15	Repository Design Considerations	T. Blejwas, SNL

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING
(continued)

REPOSITORY THERMAL DESIGN

3:45	Technical Considerations o Thermal Design Considerations o Temperature Changes Over Time	E. Ryder, SNL
5:15	ADJOURN	

Wednesday, October 9, 1991

UNCERTAINTIES ASSOCIATED WITH HIGH AND LOW THERMAL LOADING

o During this session, the following questions will be asked for both high and low thermal loading concepts, in the areas listed below. An attempt will be made to quantify the answers.

Questions

1. What are the potential problems?
2. What is the significance of each of the potential problems?
3. What are the uncertainties associated with the potential problems?
4. Can these uncertainties be resolved?
5. What are the time and cost risks associated with the resolution?
6. Will there be residual uncertainties?

8:30	Opening Remarks	W. North, NWTRB
8:40	Introduction	M. Cloninger, DOE
8:45	Geomechanical Uncertainties	L. Costin, SNL
9:15	Hydrogeologic Uncertainties	T. Buscheck, LLNL
10:00	Geochemical Uncertainties	B. Viani, LLNL
10:15	BREAK (15 min.)	
10:30	Mineralogical Uncertainties	D. Bish, LANL

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING
(continued)

UNCERTAINTIES ASSOCIATED WITH HIGH AND LOW THERMAL LOADING (cont'd)

11:00	Waste Form Degradation and Materials Uncertainties	G. Gdowski, LLNL
11:30	Biological Resource Concerns	K. Ostler, EG&G
12:00	LUNCH (1 hr. 15 min.)	

IMPLICATIONS OF HIGHER AND LOWER THERMAL LOADING

1:15	Introduction	M. Cloninger, DOE
1:20	Repository Design Enhancements	T. Blejwas, SNL
1:35	Repository Testing Considerations	T. Blejwas, SNL
2:05	Near-Field Environment Testing Considerations	W. Lin, LLNL
2:25	Waste Form and Materials Testing Considerations	G. Gdowski, LLNL
2:35	Candidate Engineered Barrier Concept	P. Stevens-Guille, Ontario Hydro
3:05	BREAK (15 min.)	
3:20	Preclosure Thermal Enhancements	G. Danko, UNR
3:50	Geologic Heat Pipes o State-of the-art review geologic heat pipes	H. Rosenburg, TRW
4:20	Overview of Preclosure Ventilation Options	A. Ivans-Smith, Tunneling Tech. Corp./ G. Sandquist, U. of Utah
4:50	ADJOURN	

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING
(continued)

Thursday, October 10, 1991

IMPLICATIONS OF HIGHER AND LOWER THERMAL LOADING (cont'd)

8:30	Opening Remarks	NWTRB
8:45	Performance Assessment Considerations o Time-temperature profiles o Waste package integrity o Near-field effect o Overall performance	McGuire/Ross Apted/Bullin/ Shaw, EPRI
10:15	Break (15 min.)	
10:30	Introduction to Continued DOE Implications Discussions	M. Cloninger, DOE
10:35	HLW System Comparative Costs o Repository Costs o Transportation Costs o Storage Costs	D. Jones, Weston
11:05	Regulatory and Legislative Considerations Regarding Thermal Loading o Human health and safety (i.e. preclosure) o Licensing considerations o Legislative implications	M. Lugo, SAIC
11:35	Conceptual Considerations for Total System Performance	M. Voegele, SAIC
12:05	Summary	M. Cloninger, DOE
12:10	LUNCH (1 hour 15 min.)	

THE THERMAL LOADING ISSUE, ROUNDTABLE DISCUSSION, CONCLUSIONS AND COMMENTS

1:25	Opening Remarks	NWTRB
1:35	Discussion	ALL
5:00	ADJOURN	

NRC Form 8–C
(4–79)
NRCM 0240

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U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: SUMMARY

PRESENTER: MICHAEL O. CLONINGER

PRESENTER'S TITLE AND ORGANIZATION: CHIEF, FIELD ENGINEERING BRANCH
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7900

OCTOBER 8 - 10, 1991

Summary of DOE Presentations

- MGDS has evolved to meet:
  - Established policy
  - Regulated requirements
  - Defined constraints and goals
- Development has focused on a reference case which resulted in a thermal loading of 57 Kw/acre
- Uncertainties exist which need to be resolved during site characterization and reflected in establishment of constraints
- Reference case appears feasible but both higher and lower thermal loadings will be investigated
- Design enhancements which could reduce uncertainties will be investigated

An Overview of Pre-Closure Ventilation Options

A presentation to
United States Nuclear Waste Technical Review Board
Las Vegas, Nevada. October 1991

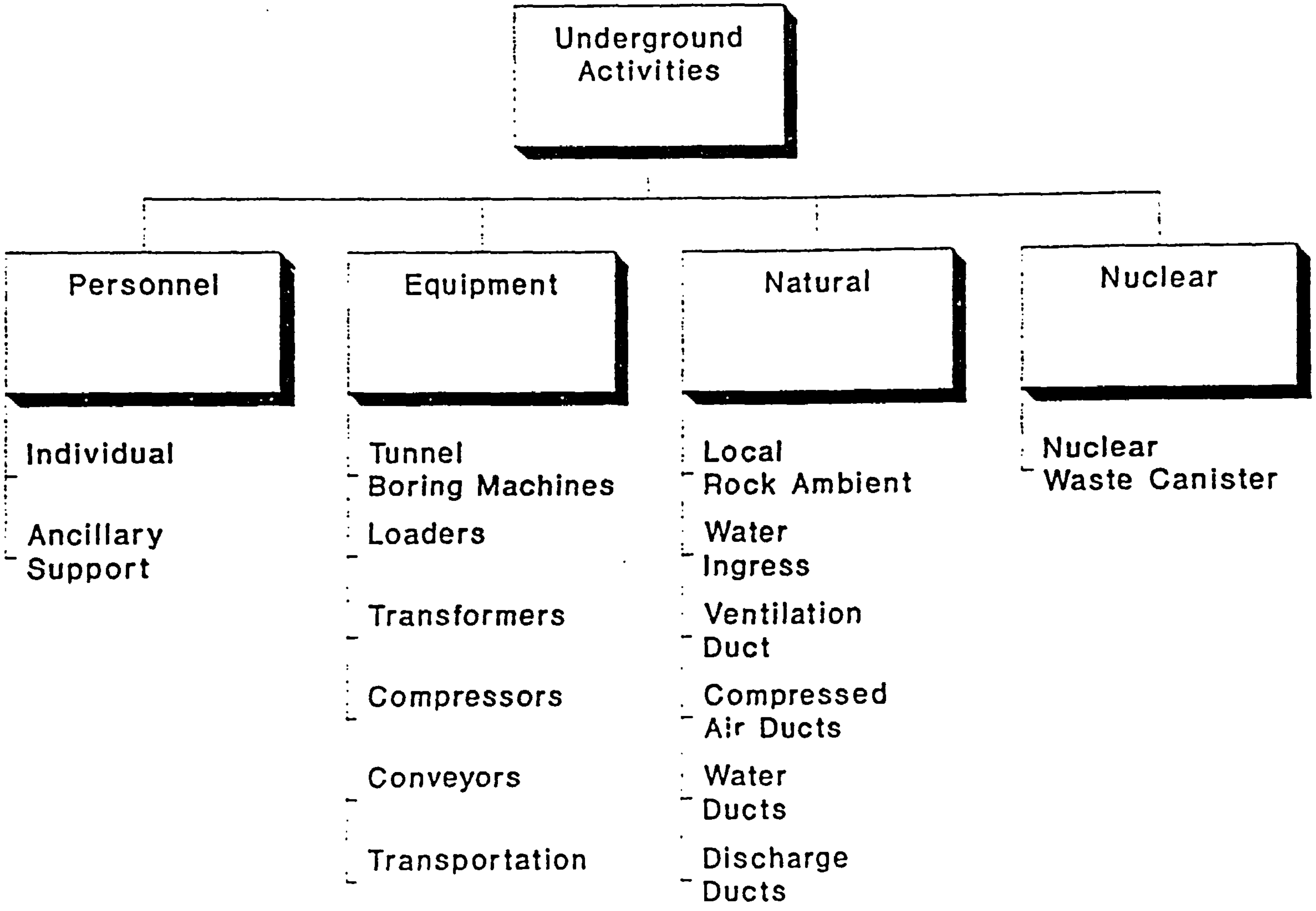
Antony Ivan Smith-Tunneling Technolgy Corporation.
Dr. Gary Sandquist-Director of Nuclear Engineering,
University of Utah.

Ventilation Requirements

- Major Underground Activities
  - Construction Operations
    - Portal Excavation
    - Access Ramps
    - Underground Excavation
    - Emplacement Tunnels
  - Emplacement Operations
    - Site Preparation
    - Waste Transportation
    - Canister Installation
    - Emergency Removal
  - Pre-Closure Operations
    - Maintenance
    - Monitoring
    - Emergency Removal
  - Post-Closure Operations
    - Back Filling

Fig 002

Heat Sources



Underground Activities

- Personnel
  - Individual
  - Ancillary Support
- Equipment
  - Tunnel Boring Machines
  - Loaders
  - Transformers
  - Compressors
  - Conveyors
  - Transportation
- Natural
  - Local Rock Ambient
  - Water Ingress
  - Ventilation Duct
  - Compressed Air Ducts
  - Water Ducts
  - Discharge Ducts
- Nuclear
  - Nuclear Waste Canister

Fig 003

Construction Operations

Minimum System Requirements

Description	Projected Units	Air Volume
Personnel	200 cfm • 150 men	30,000 cfm
Equipment, Diesel	100 cfm • 1000 HP	100,000 cfm
Tunnels	at 60 ft/min	
22 foot Main Tunnels		44,000 cfm
18 foot Emplacement		15.000 cfm
		15,000 cfm
		15,000 cfm
		15,000 cfm
		15,000 cfm
		15,000 cfm

	Total Minimum	264,000 cfm

Federal Register CFR-30

An Example of Ventilation Requirements
for Underground Operations

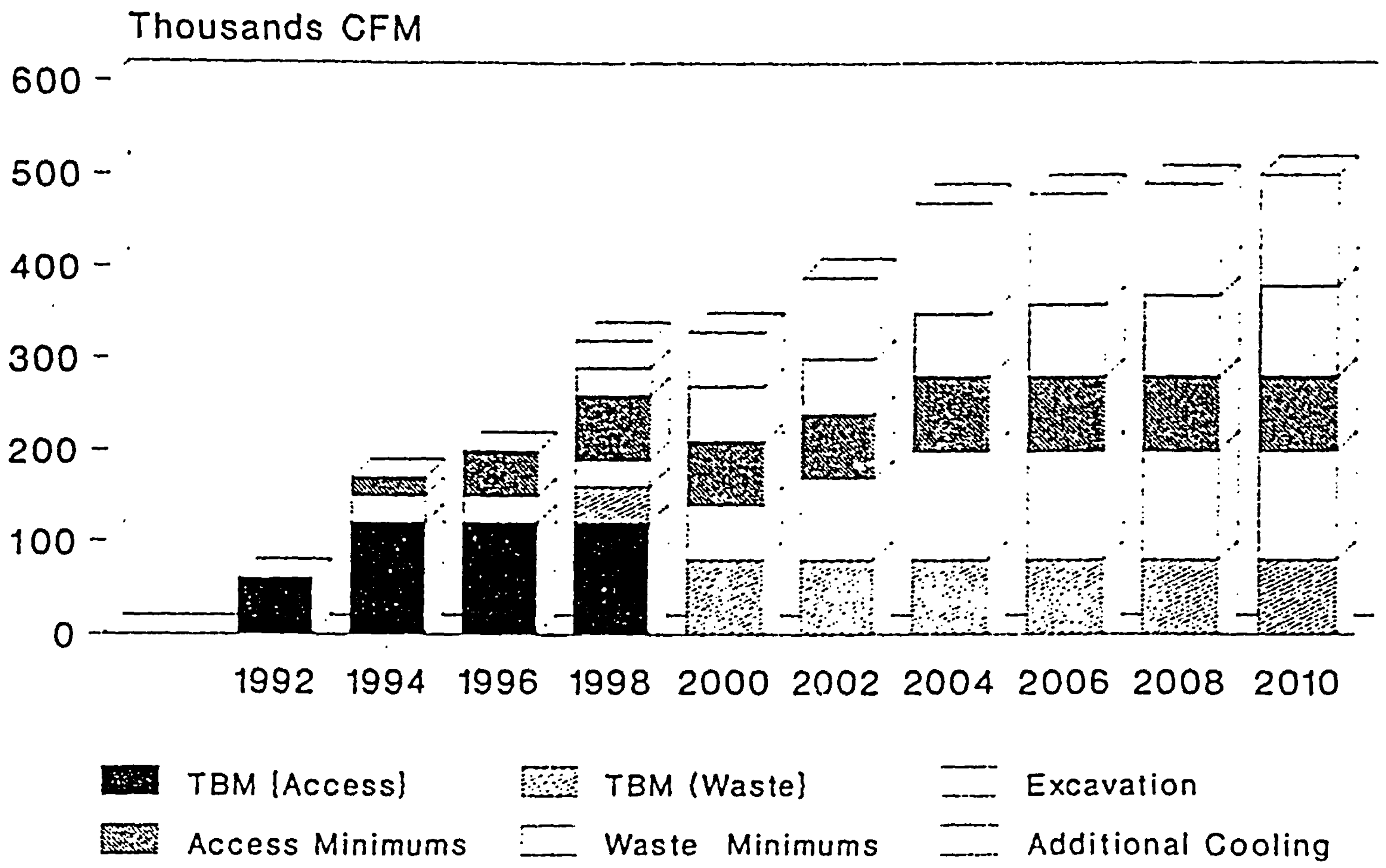
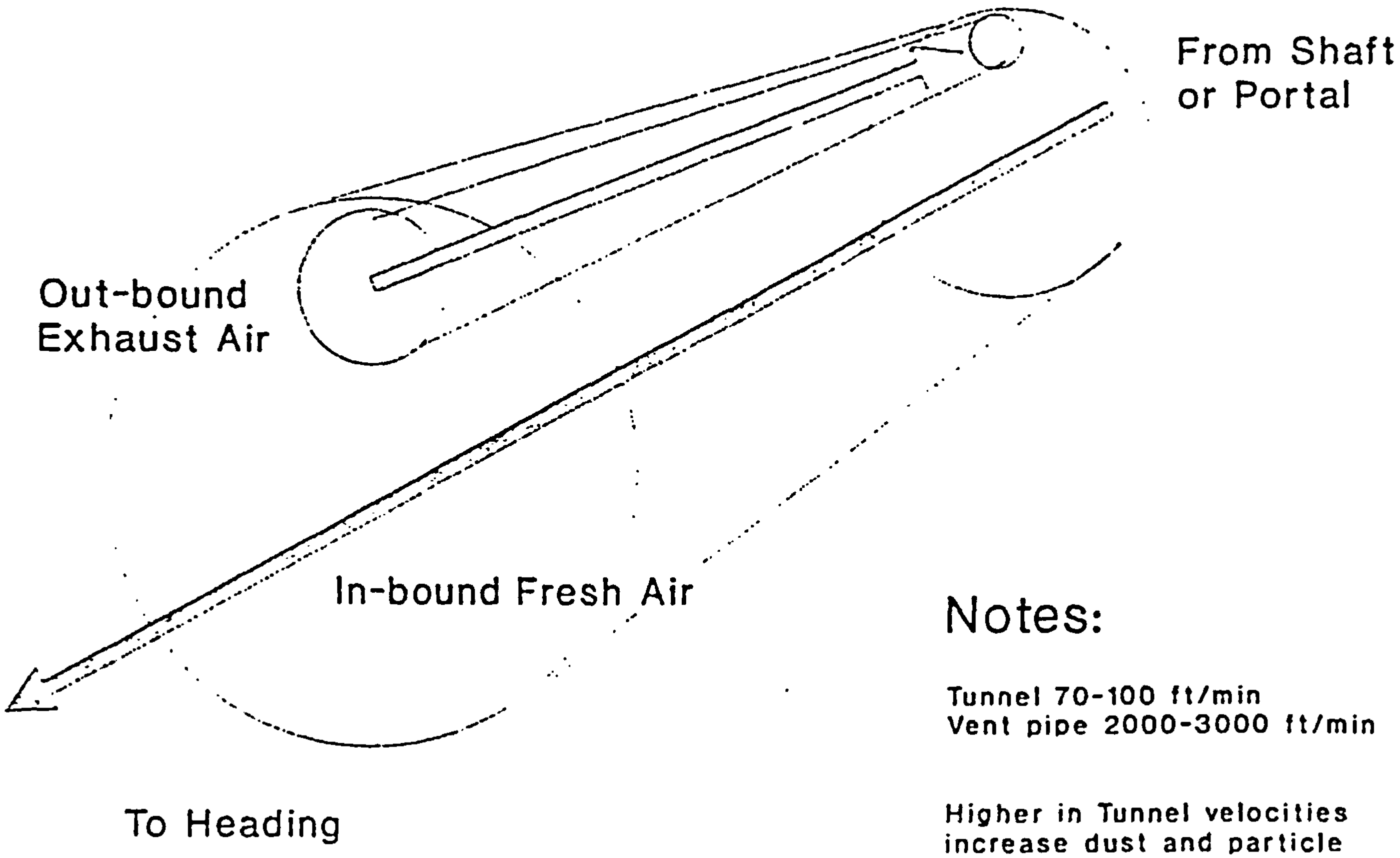


Fig.05

Typical TBM Bored Tunnel

18 to 22 foot



Notes:

Tunnel 70-100 ft/min
Vent pipe 2000-3000 ft/min

Higher in Tunnel velocities increase dust and particle problems.

Heat from the vent tube is passed back to in-bound air.

Fig.06

Alternate Concept

Separate Ventilation Tunnel

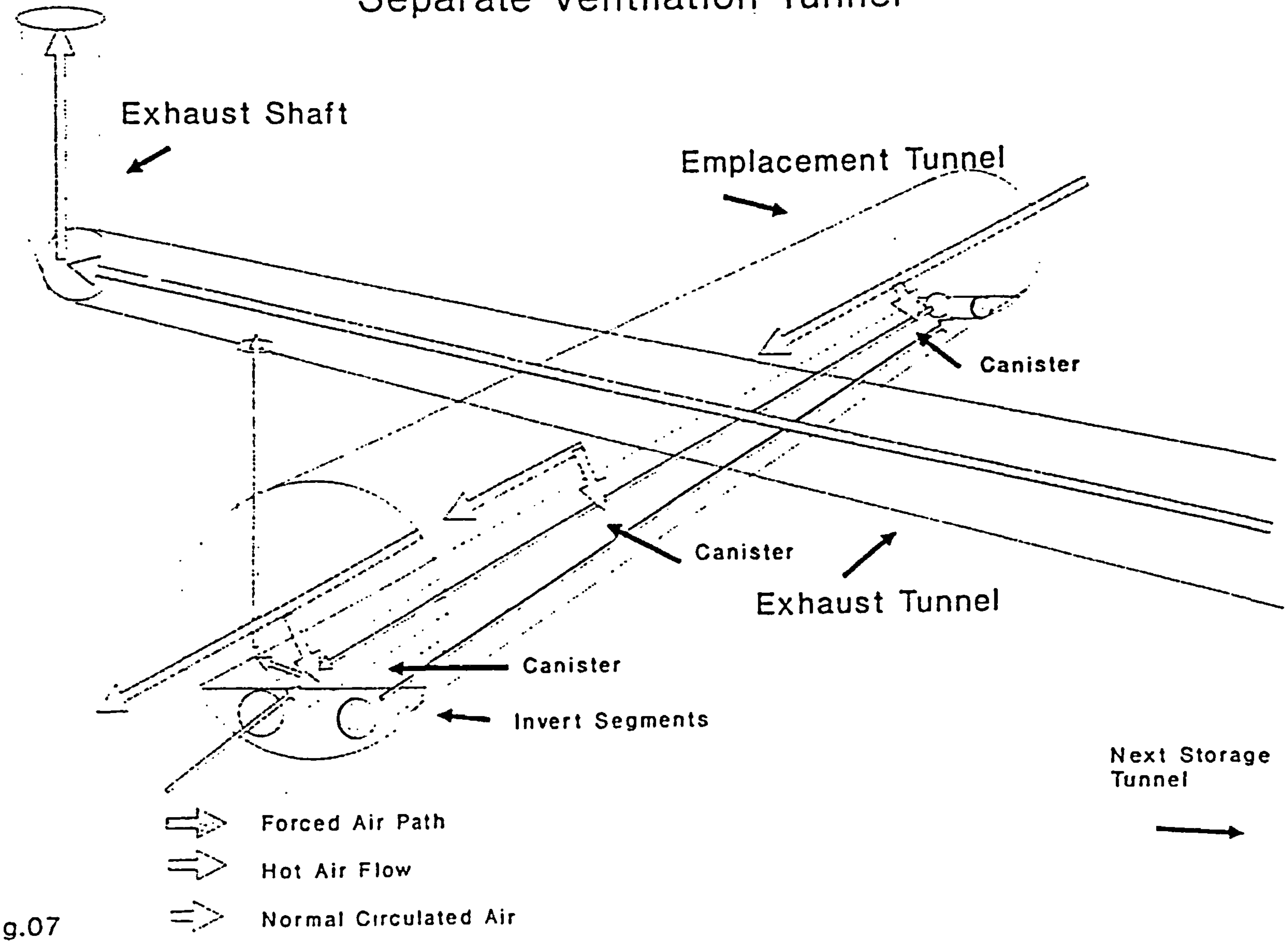


Fig.07

MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA, RENO

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PRECLOSURE THERMAL ENHANCEMENTS

PRESENTER: DR. GEORGE DANKO

PRESENTER'S TITLE AND ORGANIZATION: ASSOCIATE PROFESSOR
MINING ENGINEERING DEPARTMENT
MACKAY SCHOOL OF MINES,
UNIVERSITY OF NEVADA, RENO
RENO, NV. 89557

PRESENTER'S TELEPHONE NUMBER: (702) 784-4284

OCTOBER 8-10, 1991

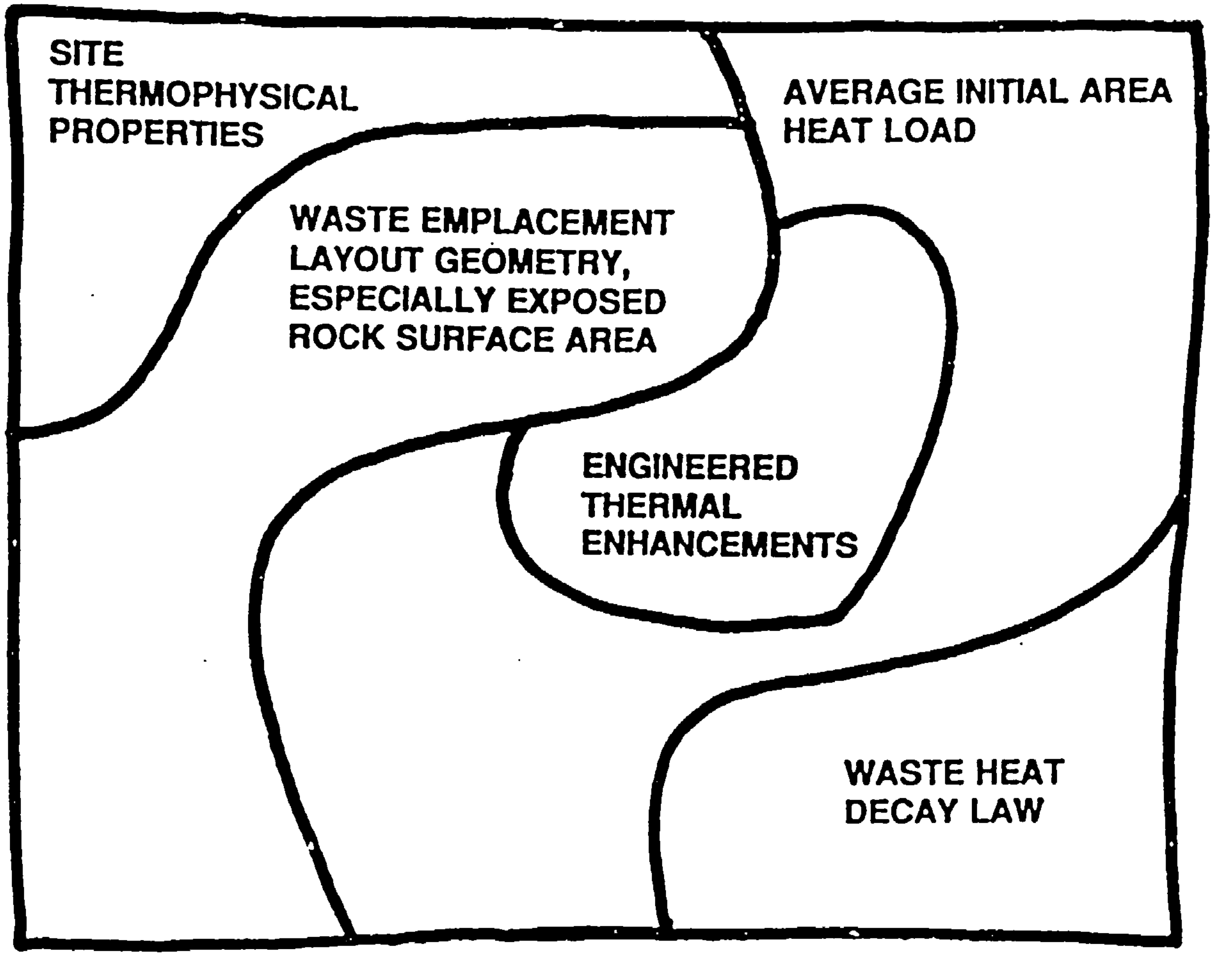
OUTLINE

- * PROBLEM DEFINITION RELATIVE TO HEAT LOAD AND RESULTING PROCESSES
- * DESCRIPTION OF REPOSITORY THERMAL ENHANCEMENT
- * CONCEPTUAL THERMAL ENHANCEMENT CONFIGURATION EXAMPLES
- * IMPACTS OF THERMAL ENHANCEMENT UPON REPOSITORY THERMAL PERFORMANCE
- * CONCLUSIONS, AND QUESTIONS TO BE ANSWERED

DEFINITION OF PRECLOSURE THERMAL ENHANCEMENT

PROMOTION OF HEAT REJECTION INTO THE GEOLOGICAL ROCK MASS AND/OR ENVIRONMENT OF THE REPOSITORY BY ENGINEERED HEAT TRANSPORT TECHNIQUES AND/OR DEVICES

REPOSITORY THERMAL ENGINEERING AS A JIGSAW PUZZLE



SITE THERMOPHYSICAL PROPERTIES

AVERAGE INITIAL AREA HEAT LOAD

WASTE EMPLACEMENT LAYOUT GEOMETRY, ESPECIALLY EXPOSED ROCK SURFACE AREA

ENGINEERED THERMAL ENHANCEMENTS

WASTE HEAT DECAY LAW

THESE ELEMENTS INFLUENCE REPOSITORY TEMPERATURES AND HEAT FLOWS

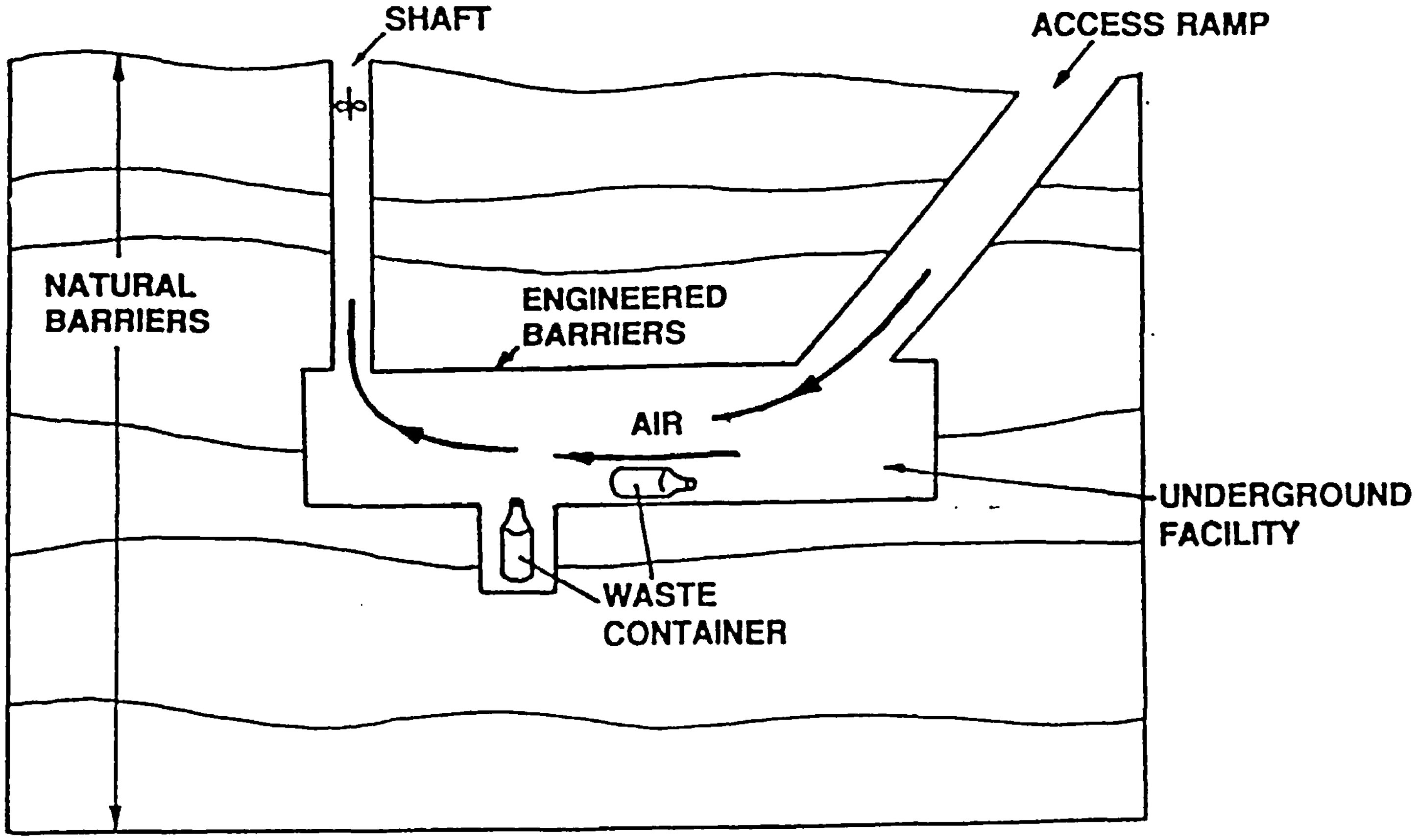
FACTORS INFLUENCING REPOSITORY TEMPERATURES AND HEAT FLOWS

1. SITE THERMOPHYSICAL PROPERTIES
2. AVERAGE INITIAL AREA HEAT LOAD
3. WASTE EMPLACEMENT LAYOUT GEOMETRY, ESPECIALLY EXPOSED ROCK SURFACE AREA
4. WASTE AGE – HEAT DECAY LAW
5. ENGINEERED THERMAL ENHANCEMENTS

ELEMENTS OF PRECLOSURE THERMAL ENHANCEMENT

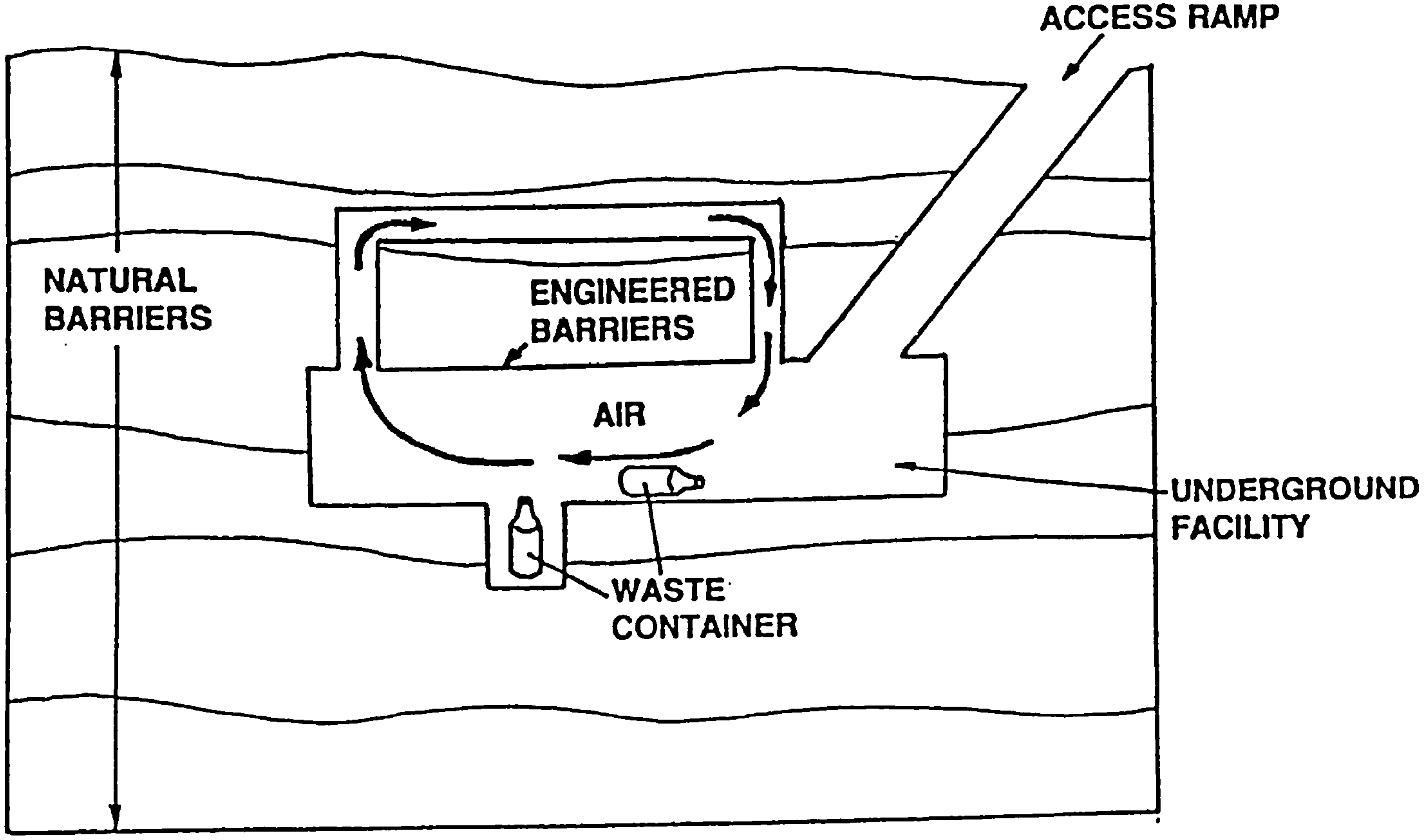
1. OPEN-LOOP REPOSITORY AIR COOLING BY VENTILATION
2. CLOSED-LOOP CONTROLLED AIR RECIRCULATION
3. CLOSED-LOOP NATURAL AIR CONVECTION
4. PROMOTION OF HEAT TRANSFER WITHIN THE ROCK

OPEN-LOOP REPOSITORY AIR COOLING BY VENTILATION



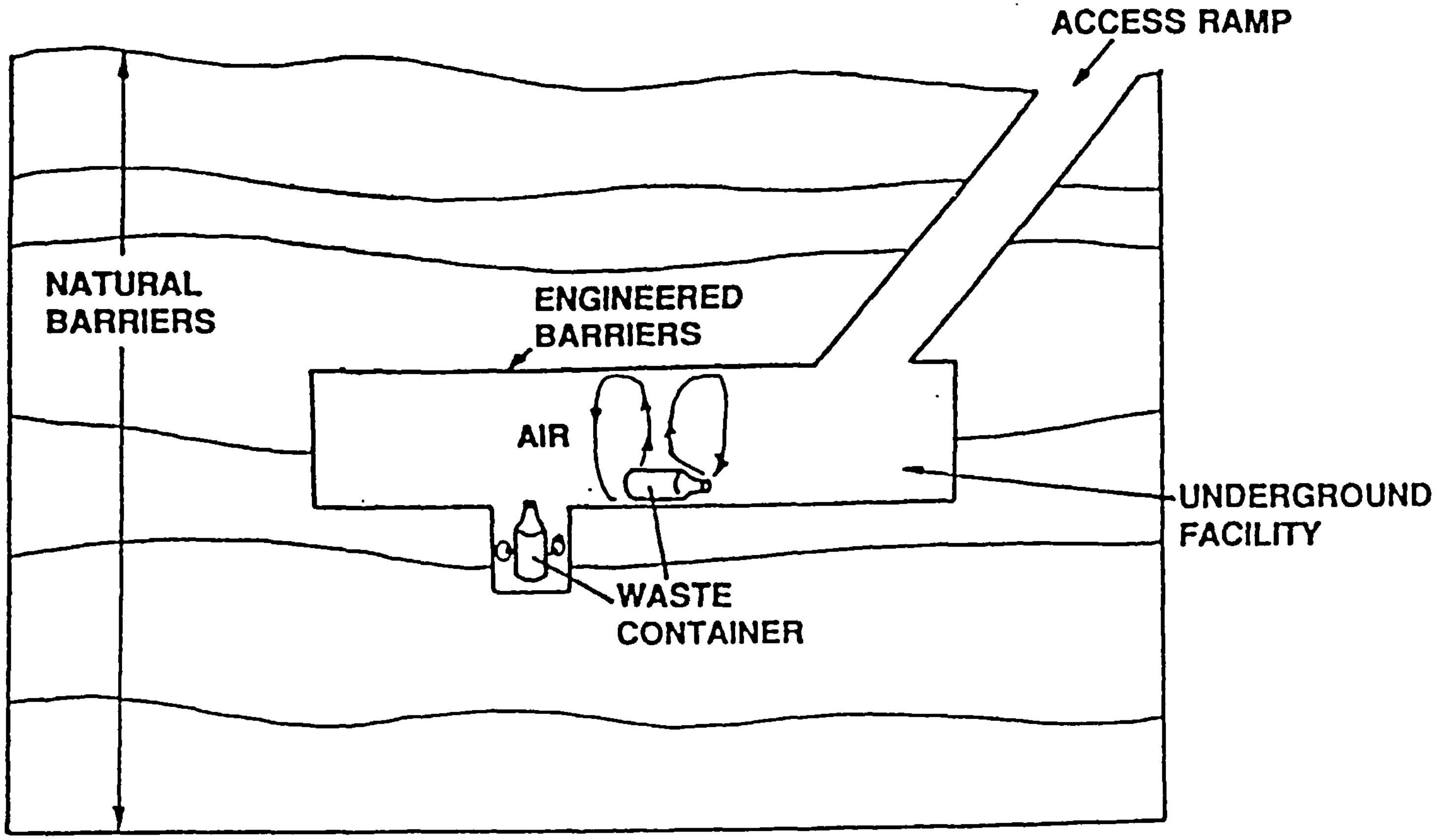
THERMAL ENHANCEMENT: CONTAINER-TO-AIR (CTA)

CLOSED-LOOP CONTROLLED AIR RECIRCULATION



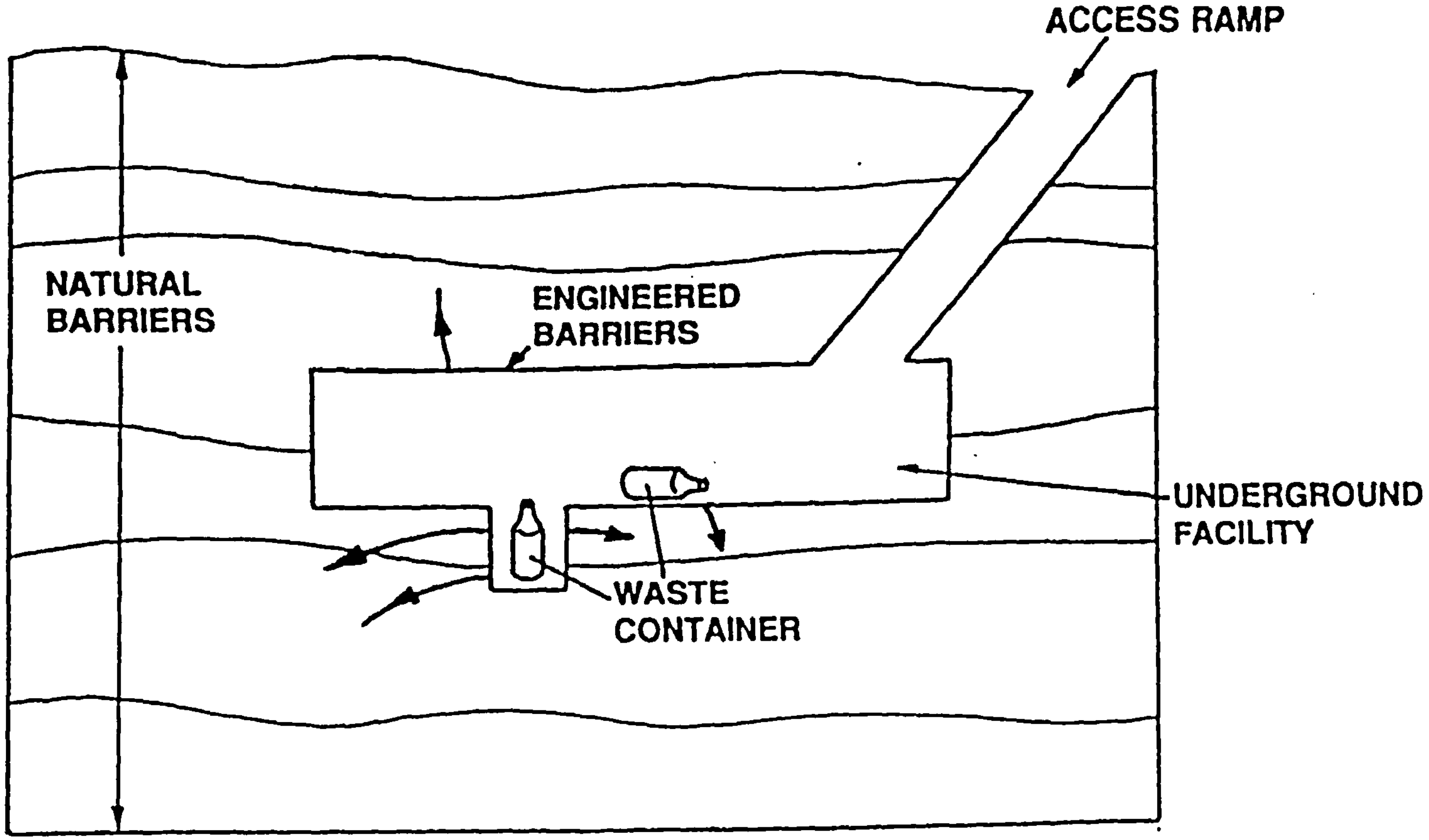
THERMAL ENHANCEMENT: CONTAINER-TO-AIR (CTA)
AIR-TO-ROCK (ATR)

CLOSED-LOOP NATURAL AIR CONVECTION



THERMAL ENHANCEMENT: CONTAINER-TO-AIR (CTA)
AIR-TO-ROCK (ATR)

PROMOTION OF HEAT TRANSFER WITHIN THE ROCK

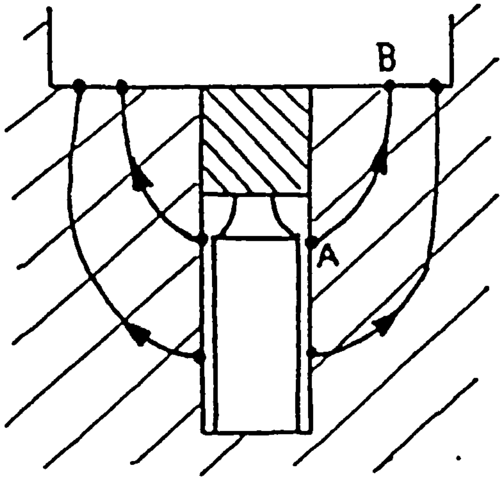


THERMAL ENHANCEMENT: ROCK-TO-ROCK (RTR)

AN IMPORTANT ELEMENT: ROCK-TO-ROCK THERMAL ENHANCEMENT

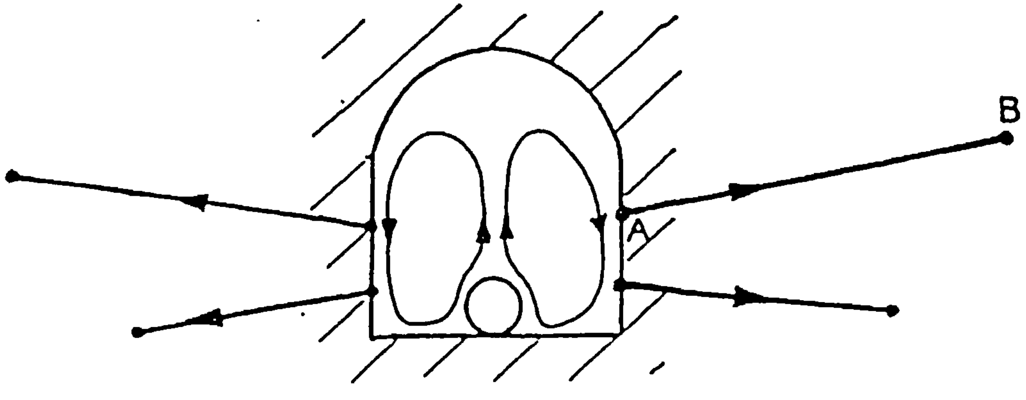
GOALS:

* TO REMOVE HEAT FROM THE EMPLACEMENT CAVITY TOWARDS THE DRIFT SURFACE



A & B ARE BOTH
WITHIN THE ROCK

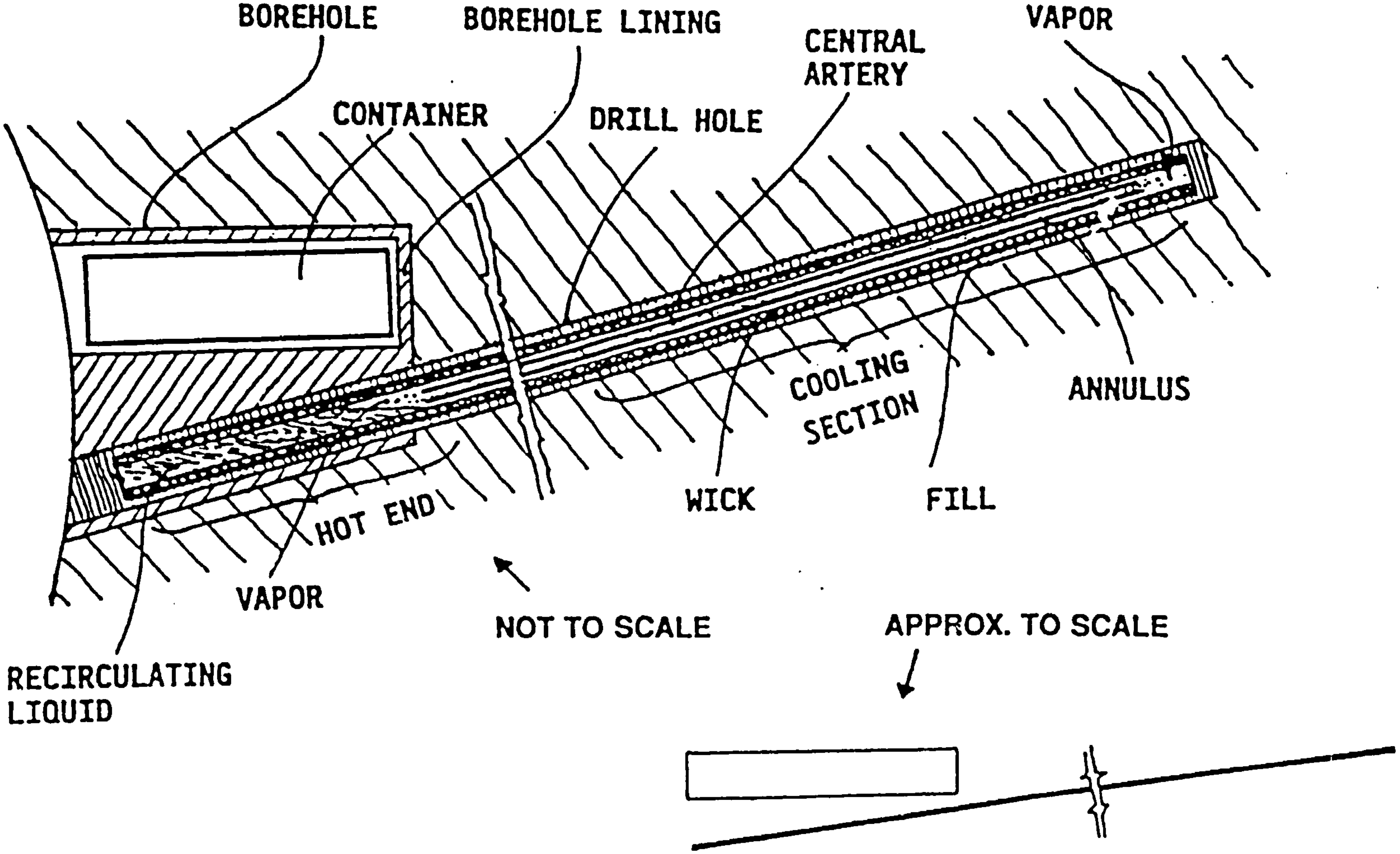
* TO REJECT HEAT TOWARDS THE PILLAR AREA



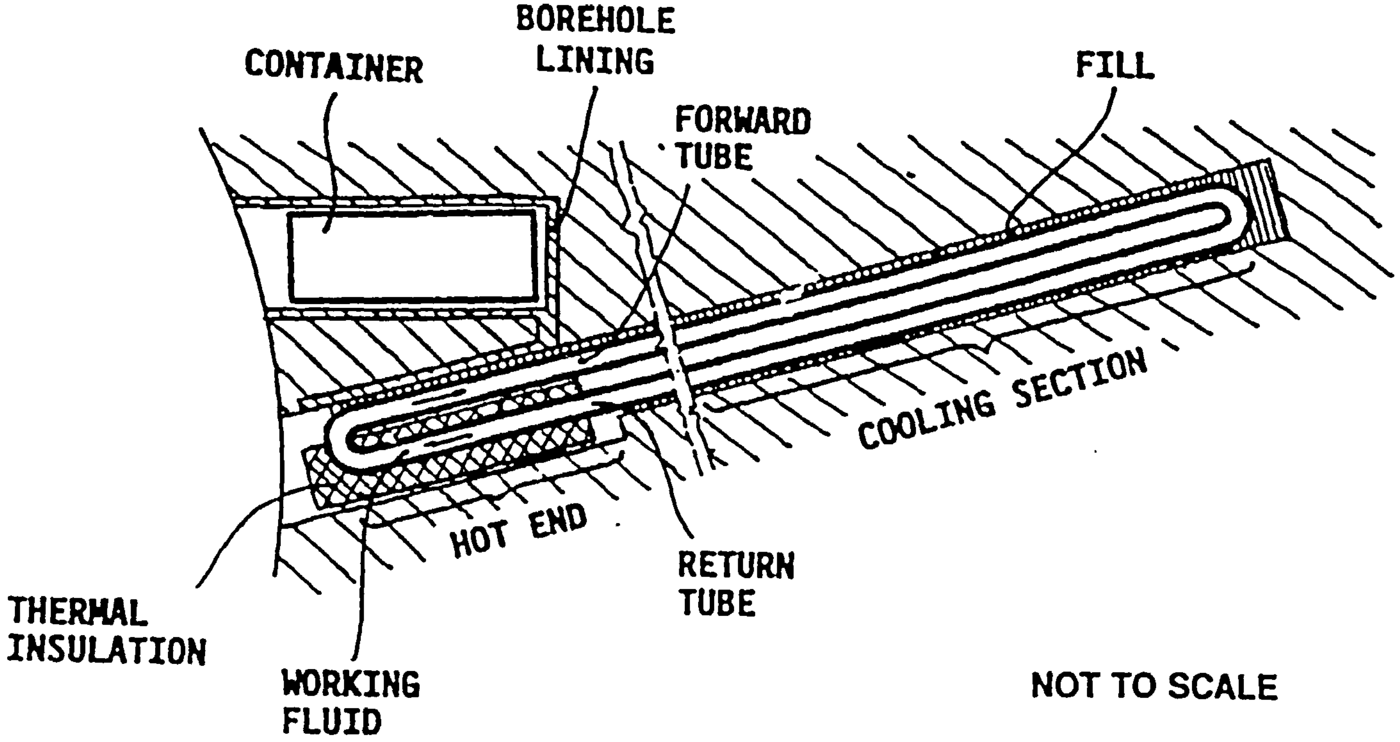
ROCK-TO-ROCK THERMAL ENHANCEMENT TECHNIQUES

1. HEAT PIPES
2. THERMAL SYPHONS
3. HEAT-SUPERCONDUCTOR RODS
4. ACTIVE OR PASSIVE HEAT PUMPS

HEAT PIPE


BOREHOLE
BOREHOLE LINING
CENTRAL ARTERY
VAPOR
CONTAINER
DRILL HOLE
COOLING SECTION
ANNULUS
WICK
FILL
HOT END
VAPOR
RECIRCULATING LIQUID
NOT TO SCALE
APPROX. TO SCALE

THERMAL SYPHON

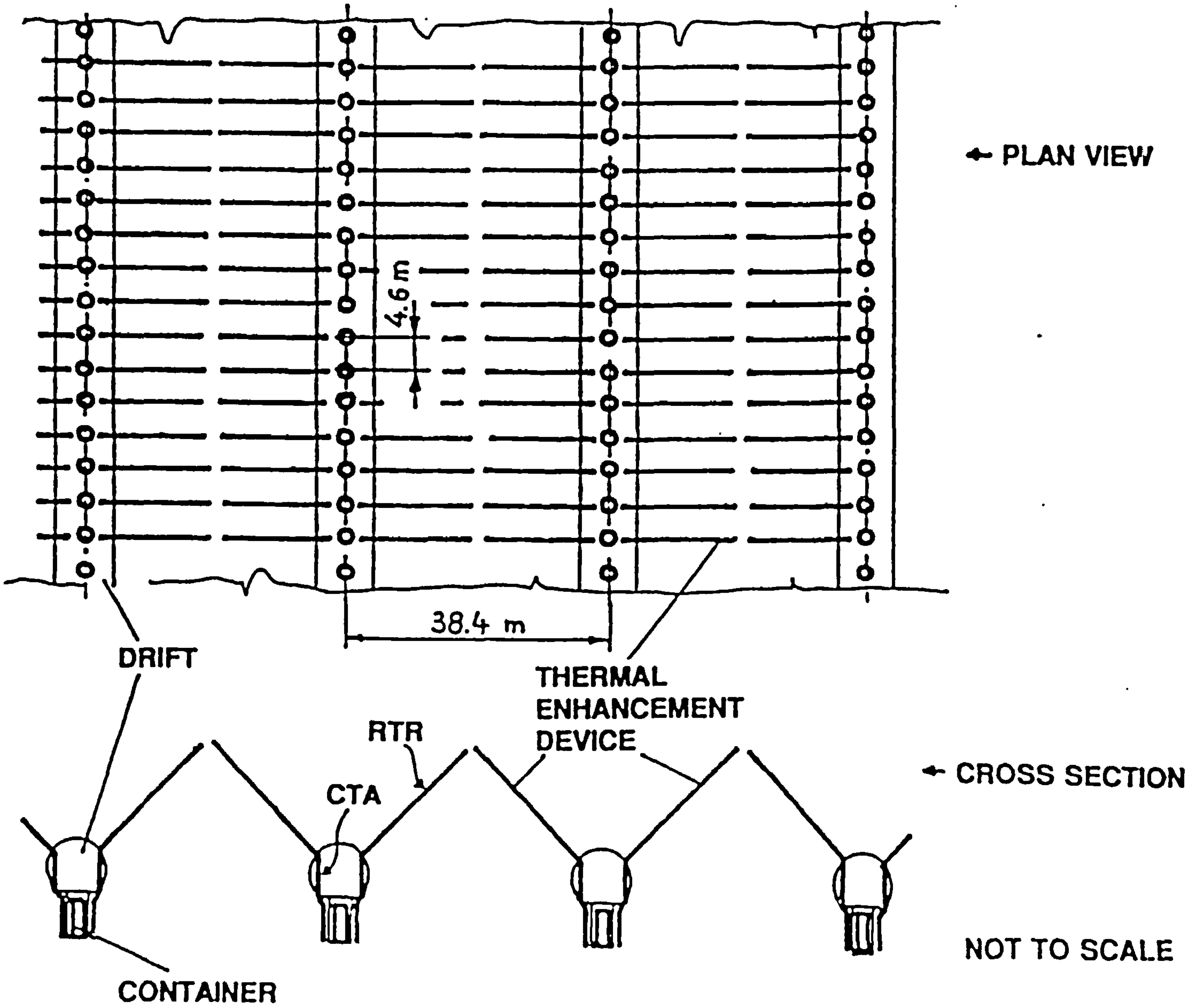


NOT TO SCALE

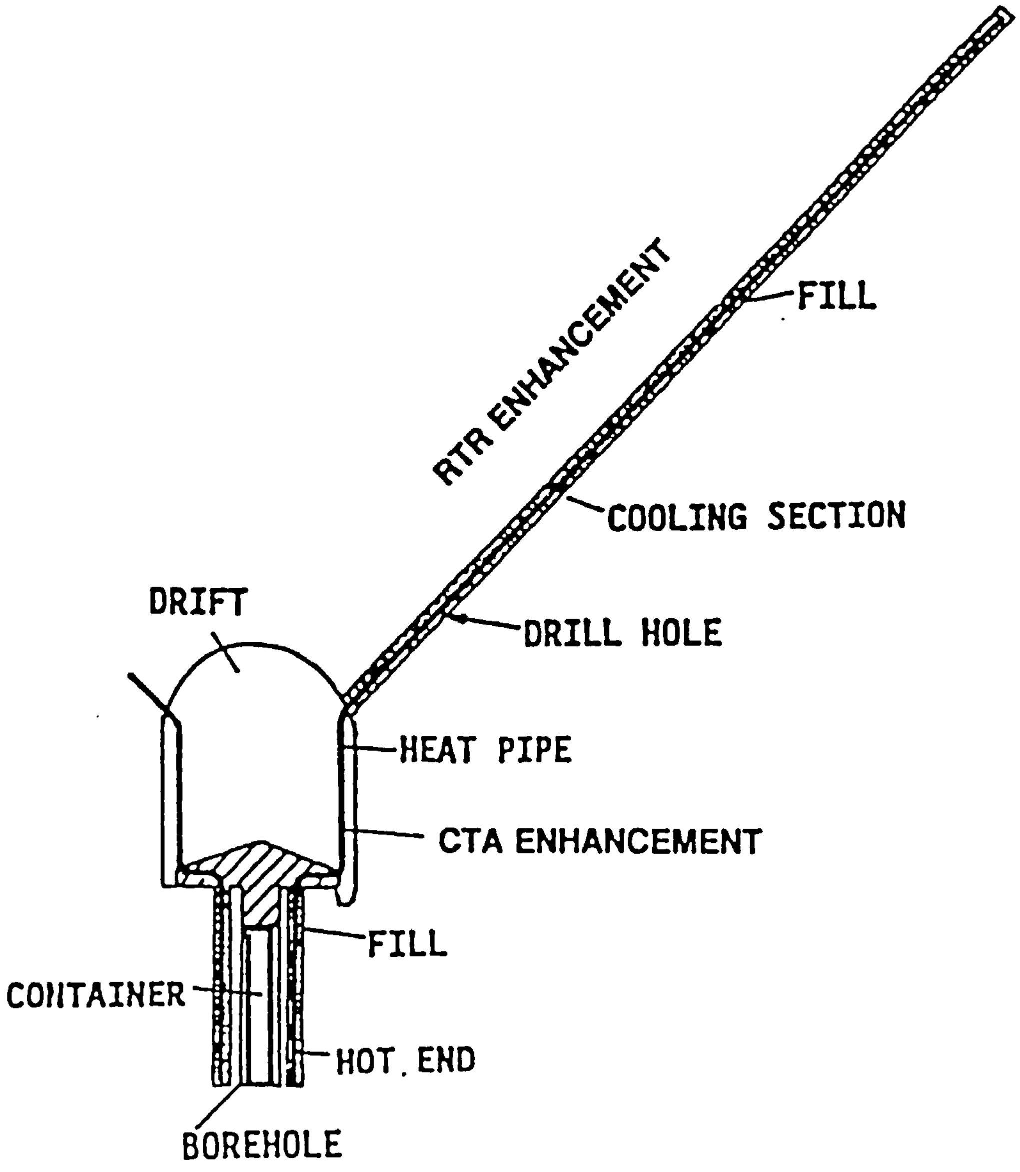
CONCEPTUAL THERMAL ENHANCEMENT CONFIGURATION EXAMPLES

1. SHORT VERTICAL EMPLACEMENT WITH CTA AND RTR ENHANCEMENT
2. SHORT HORIZONTAL EMPLACEMENT WITH RTR ENHANCEMENT
3. DRIFT EMPLACEMENT WITH RTR, CTA AND ATR ENHANCEMENT
4. HIGH-DENSITY VERTICAL EMPLACEMENT WITH CTA AND RTR ENHANCEMENT

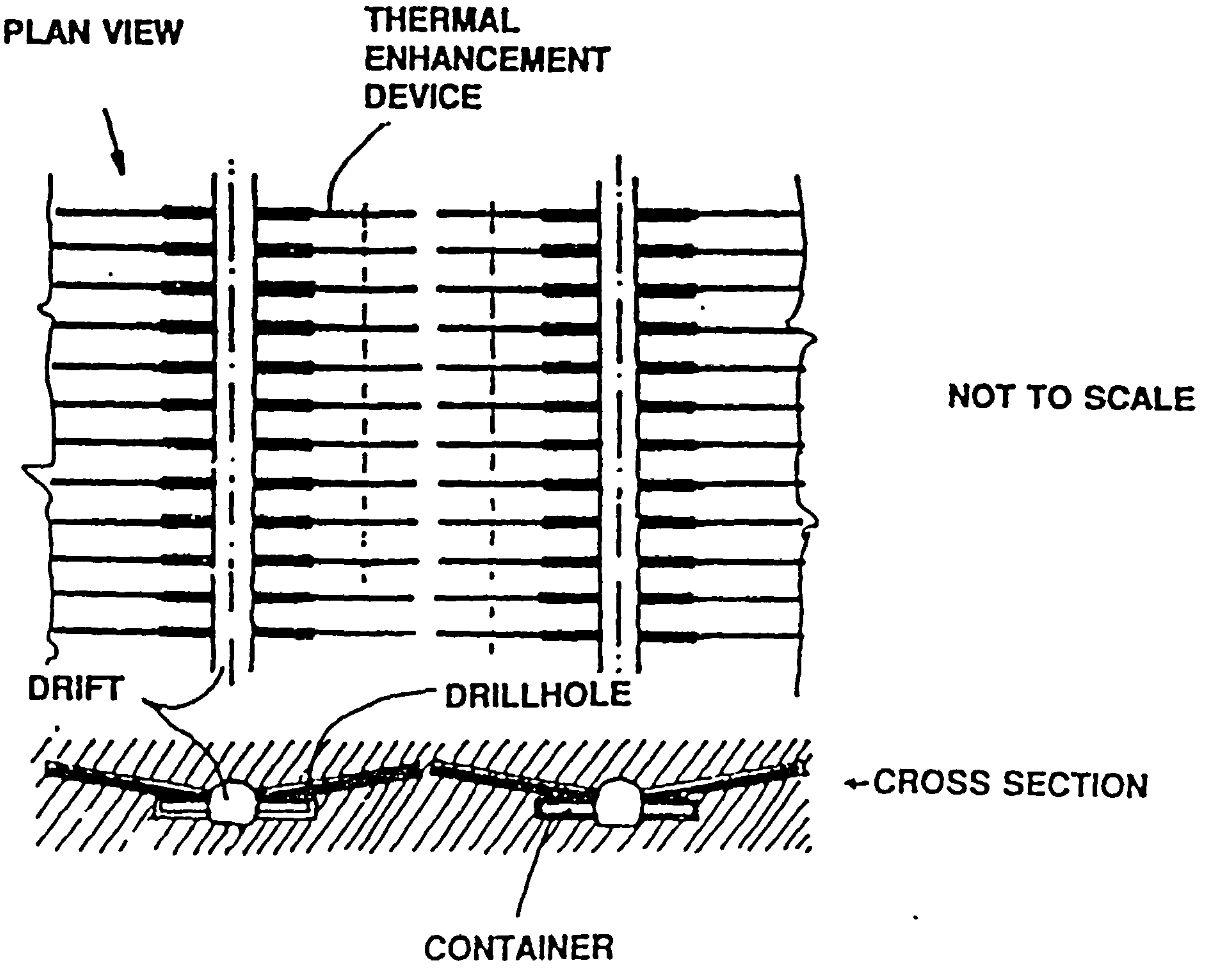
SHORT VERTICAL EMPLACEMENT WITH CTA AND RTR ENHANCEMENT



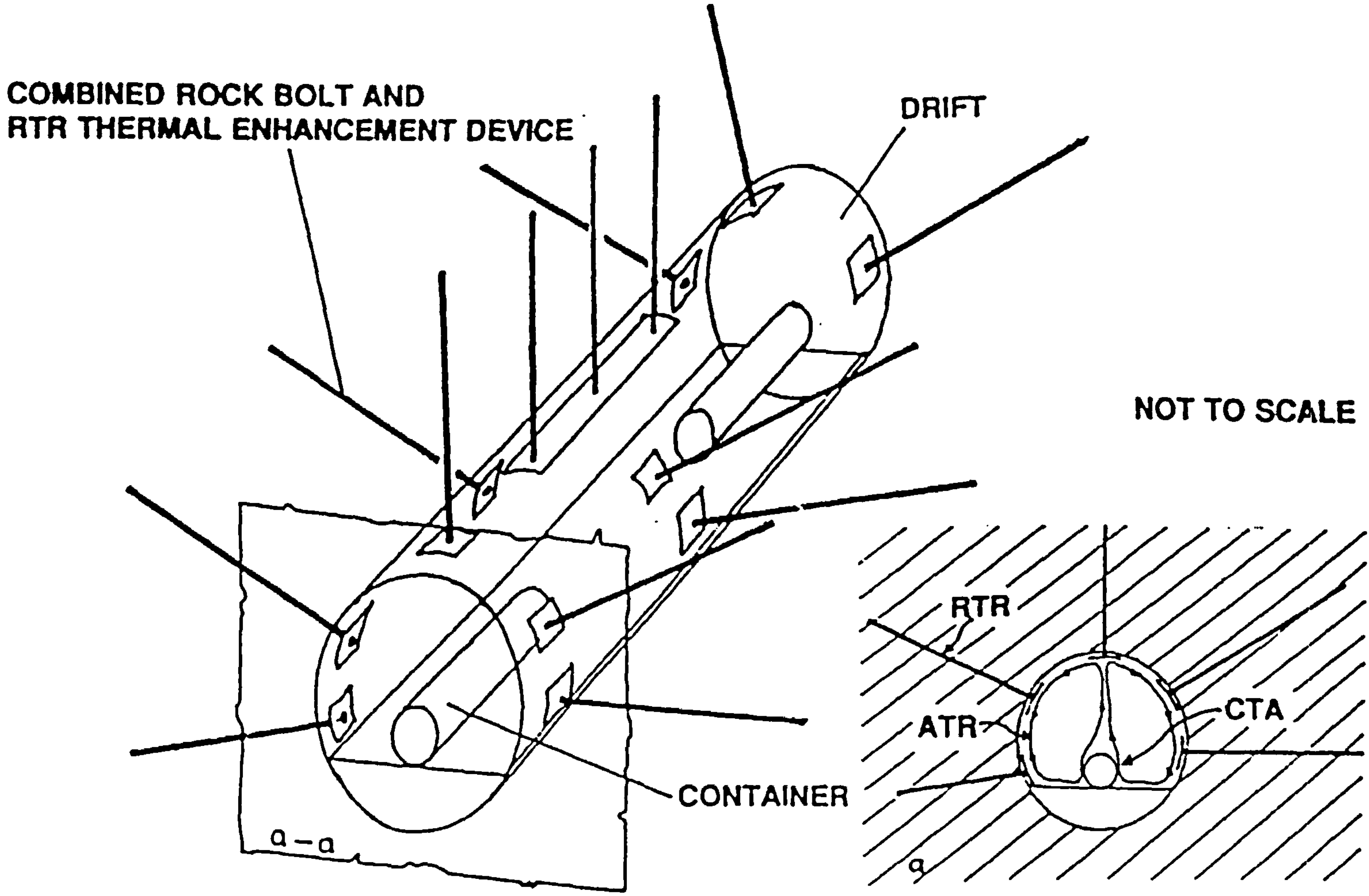
THERMAL ENHANCEMENT CONNECTION



SHORT HORIZONTAL EMPLACEMENT WITH RTR ENHANCEMENT

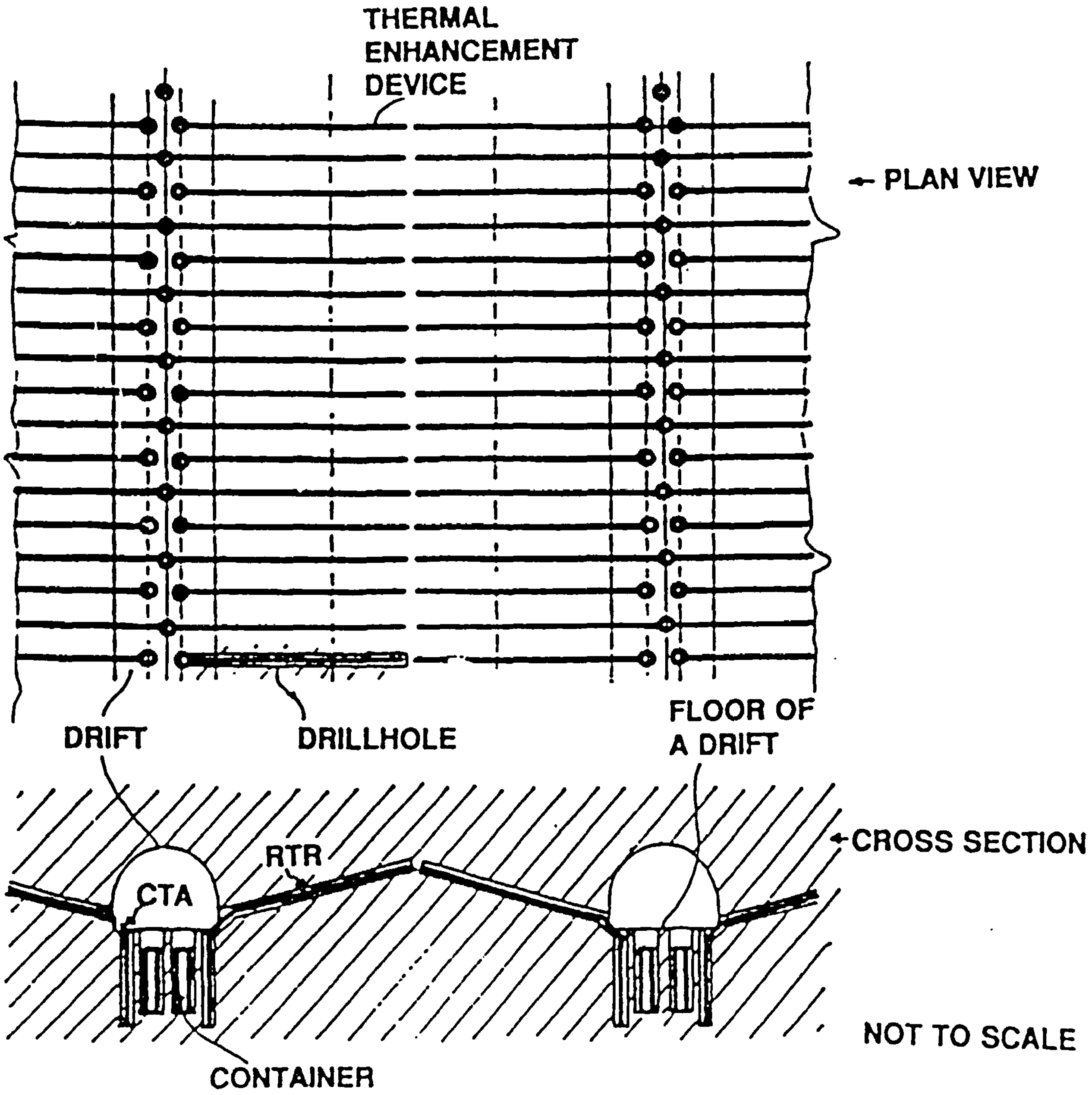


DRIFT EMPLACEMENT WITH RTR, CTA AND ATR ENHANCEMENT



INCREASED CONDUCTION PLUS CONVECTION

HIGH-DENSITY VERTICAL EMPLACEMENT WITH CTA AND RTR ENHANCEMENT



IMPACTS OF THERMAL ENHANCEMENT UPON REPOSITORY THERMAL PERFORMANCE

1 DECREASE IN HOT-SPOT ROCK, AND CONTAINER SURFACE TEMPERATURES

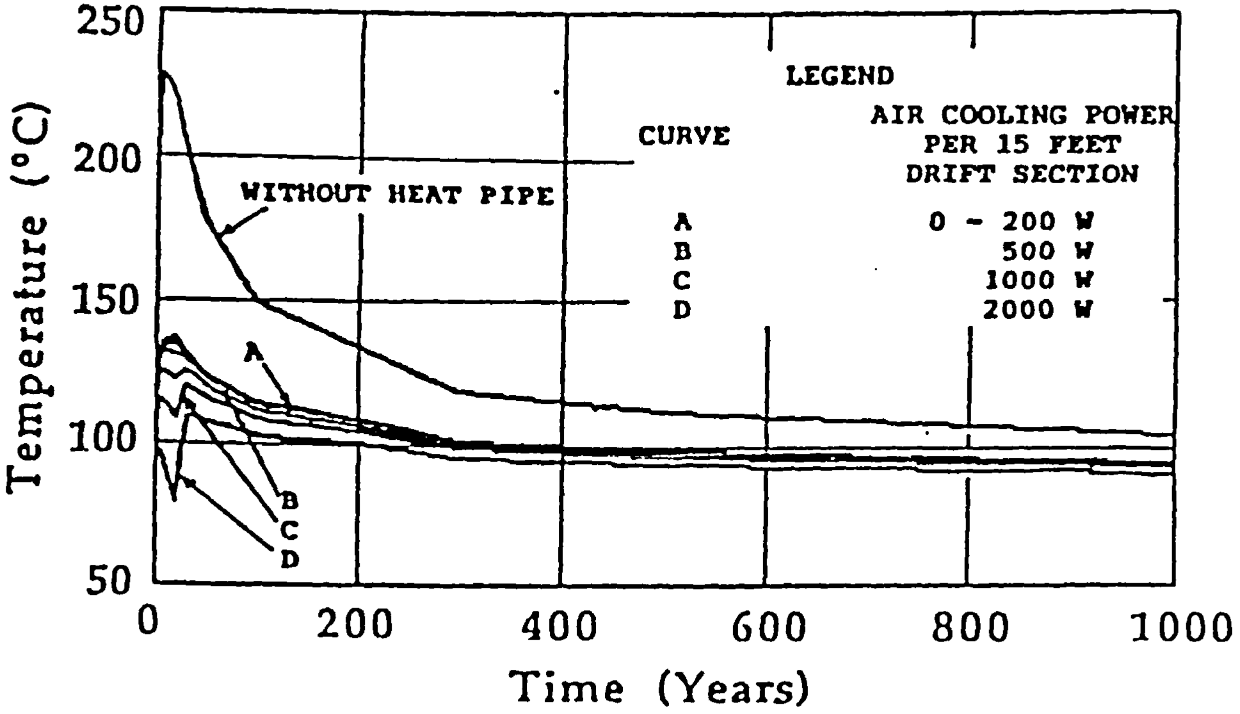
2 DECREASE IN THERMAL GRADIENTS AROUND THE EMPLACEMENT AREA AND DRIFTS

3 PROMOTION OF ROCK DRYING

4 REDISTRIBUTION OF IN SITU AND THERMAL STRESSES

DECREASE IN HOT-SPOT ROCK TEMPERATURES

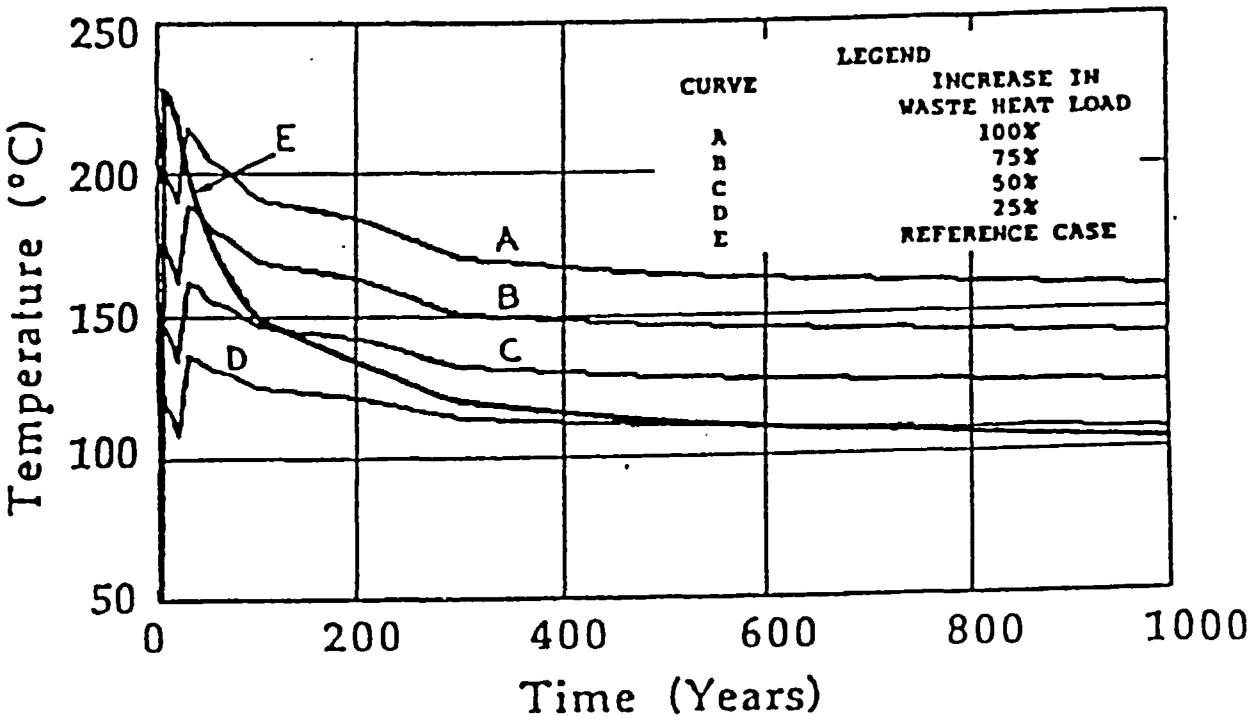
SHORT VERTICAL EMPLACEMENT, CONVENTIONAL CONTAINER ARRANGEMENT, AND NORMAL HEAT LOAD



CONTAINER BOREHOLE TEMPERATURE USING HEAT PIPES AND VARIABLE COOLING BY VENTILATION

DECREASE IN HOT-SPOT ROCK TEMPERATURES AND PROMOTION OF ROCK DRYING

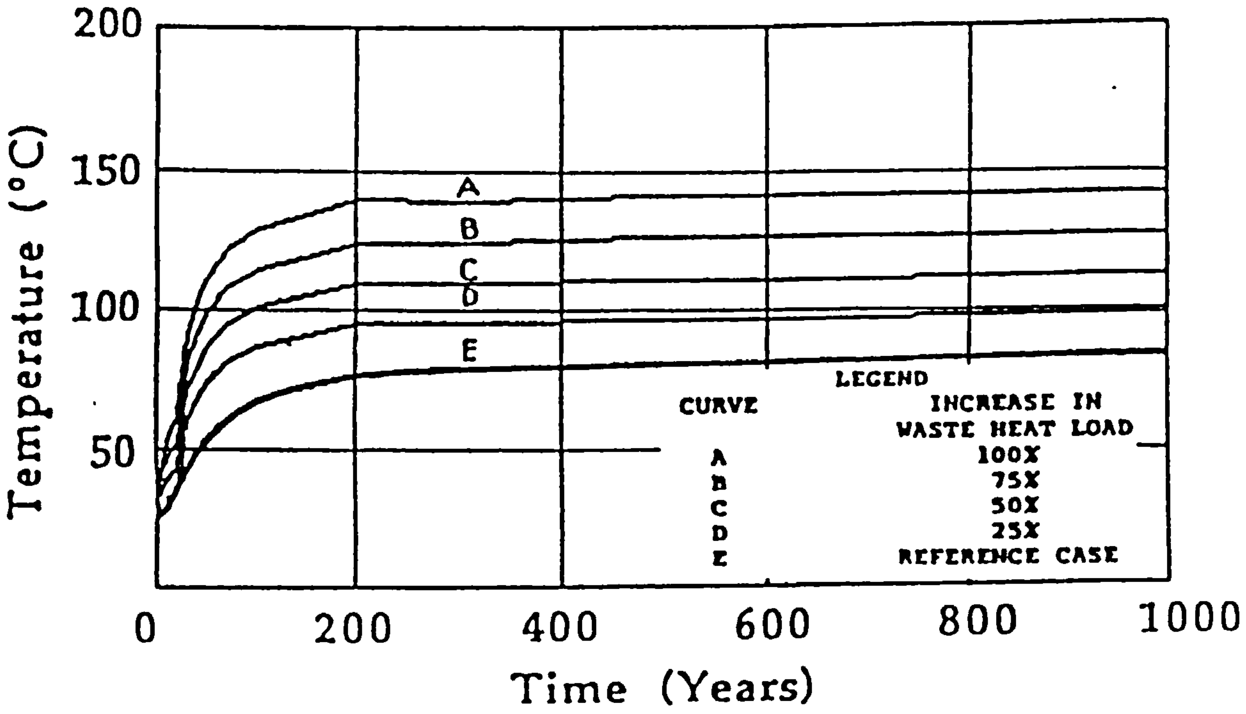
SHORT VERTICAL EMPLACEMENT, CONVENTIONAL CONTAINER ARRANGEMENT, AND INCREASED WASTE MASS



CONTAINER BOREHOLE TEMPERATURE USING HEAT PIPES

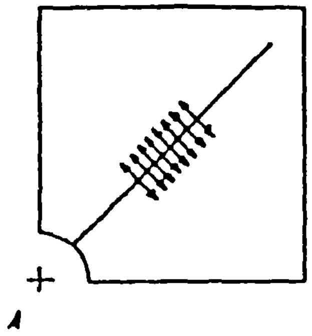
PROMOTION OF ROCK DRYING

SHORT VERTICAL EMPLACEMENT, CONVENTIONAL CONTAINER ARRANGEMENT, AND INCREASED WASTE MASS

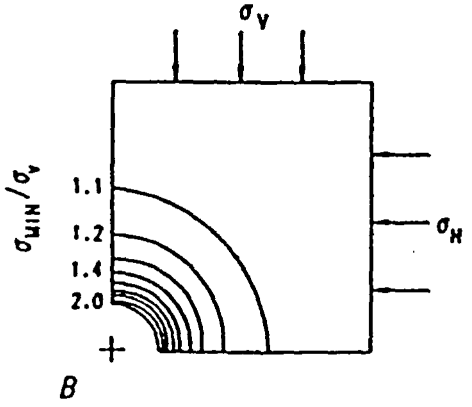


ROCK TEMPERATURE VARIATION AT 30 m DISTANCE FROM THE CENTER OF THE CONTAINER

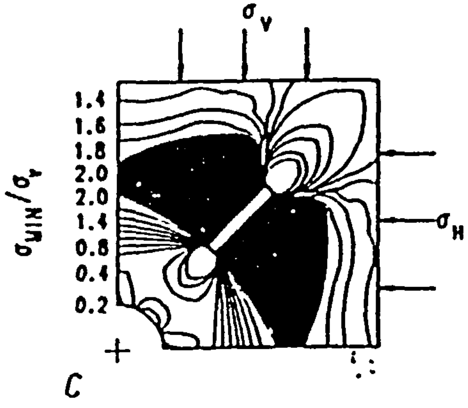
ACTIVE STRESS REDISTRIBUTION USING HEAT PIPES ORIENTED AT 45 DEGREES



COMPRESSION BY
THERMAL EXPANSION



ORIGINAL STRESS FIELD



STRESS REDISTRIBUTION

CONCLUSIONS

- THERMAL ENHANCEMENT CAN SIGNIFICANTLY IMPROVE TEMPERATURE DISTRIBUTION BOTH IN THE EMPLACEMENT AND THE PILLAR AREA,
- A VARIETY OF CONVENTIONAL TECHNOLOGY CAN BE USED, ESPECIALLY VENTILATION, HEAT PIPES, AND THE COMBINATION OF THE TWO,
- THERMAL ENHANCEMENT CAN BE APPLIED TO EITHER CAVITY, OR DRIFT EMPLACEMENT,
- EITHER HOT, OR COOL CONCEPT CAN BE SUPPORTED BY THERMAL ENHANCEMENT,
- ADDITIONAL ADVANTAGES CAN BE ACHIEVED, SUCH AS INCREASED DRYING, A FAVORABLE STRESS REDISTRIBUTION AROUND THE EMPLACEMENT DRIFT, AND REDUCED EMPLACEMENT AREA, OR INCREASED WASTE MASS.

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: **REPOSITORY DESIGN ENHANCEMENTS**

PRESENTER: **DR. THOMAS E. BLEJWAS**

PRESENTER'S TITLE AND ORGANIZATION:
TECHNICAL PROJECT OFFICER,
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 844-9160

OCTOBER 8 - 10, 1991

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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OCTOBER 8 - 10, 1991

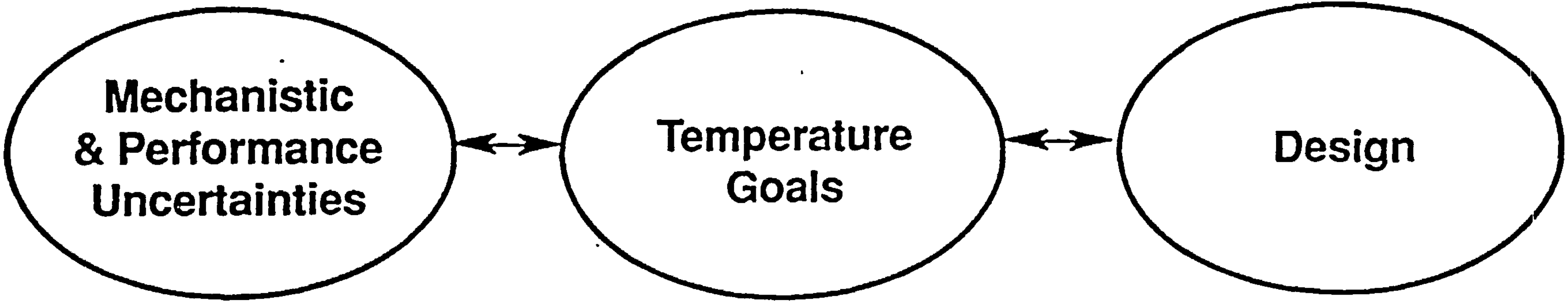
Outline

- Design goal
- Design trade-offs
- Plans
- Conclusion

Design Goal

Design a repository system that meets performance objectives with an acceptable level of uncertainty

Uncertainties

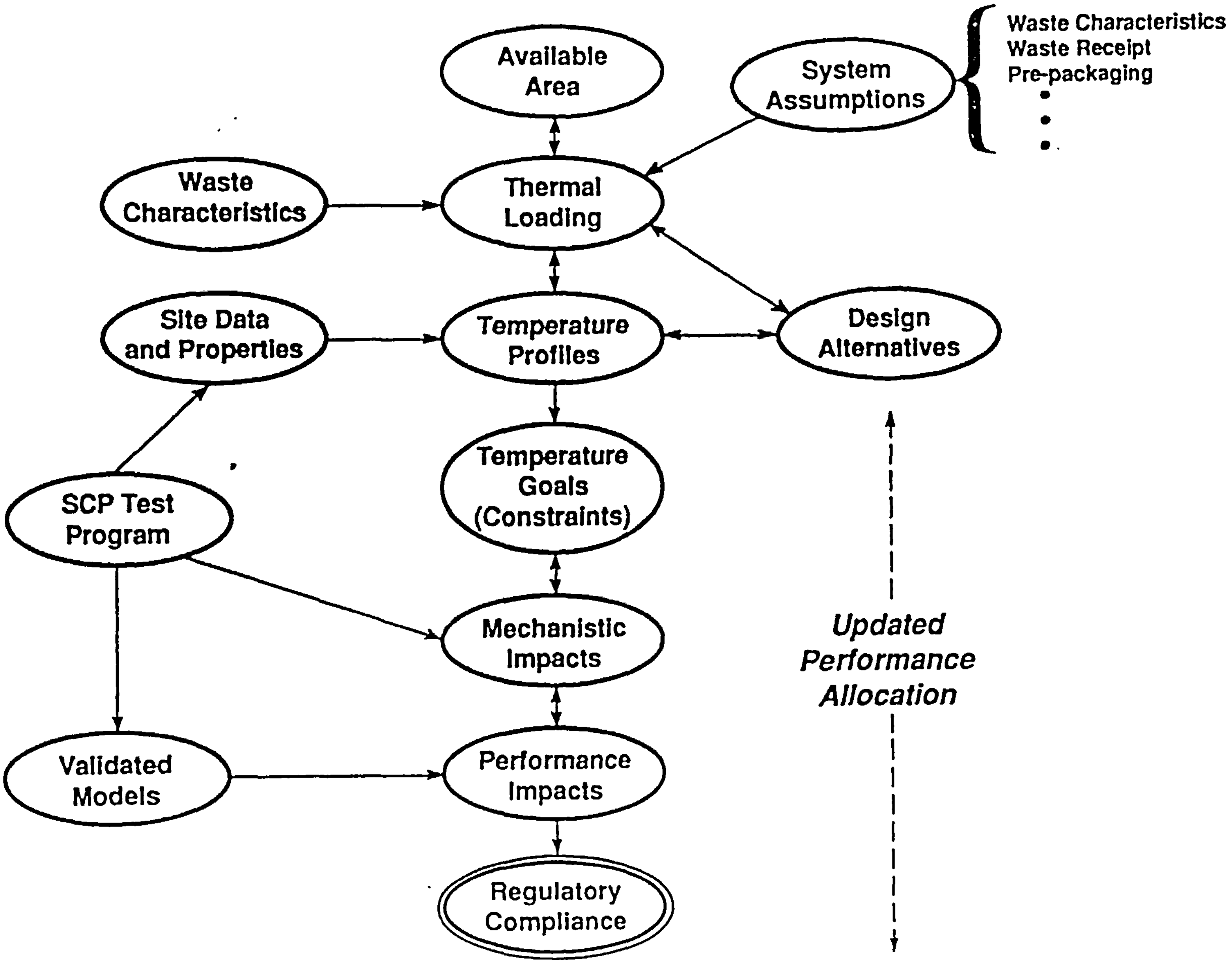


Mechanistic & Performance Uncertainties

Temperature Goals

Design

Planned Approach



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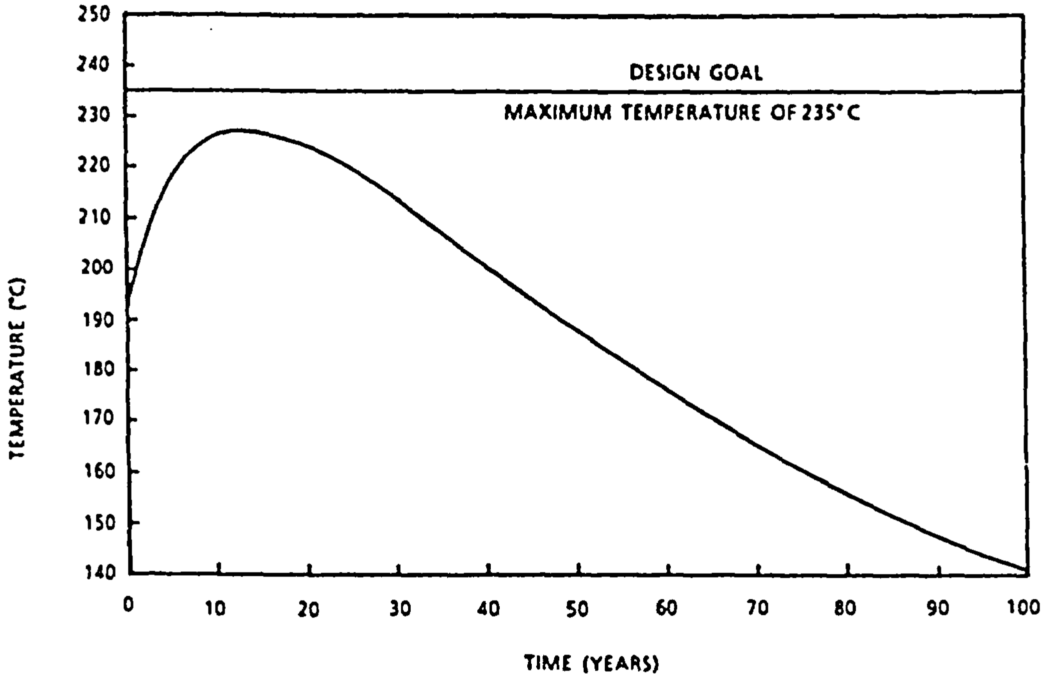
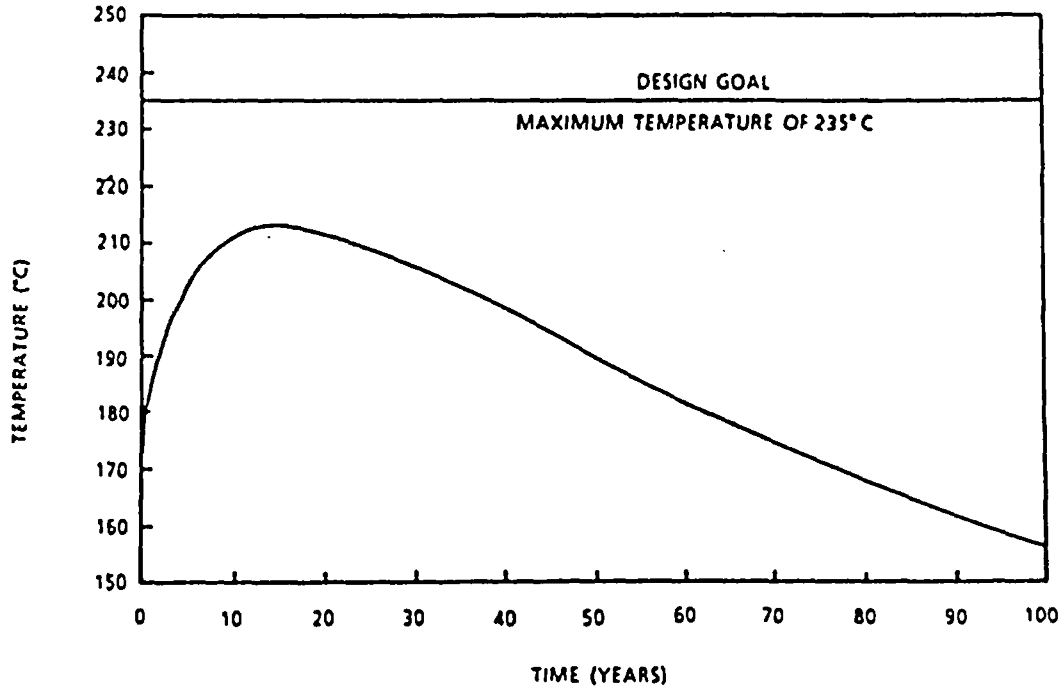
Design Trade-offs

Hotter	Design Elements	Colder
Larger waste volume in smaller area	Spacing (area-volume--flexibility)	Smaller waste volume in larger area
Early emplacement	Schedule	Delayed emplacement
Separate spent fuel and defense waste	Layout	Comingled waste
Limited ventilation	Ventilation	Extensive drift ventilation
Backfill early	Backfill	No backfill
• • •	• • •	• • •

Predicted Temperatures For Emplacement Boreholes



Borehole Wall Temperature - Vertical Emplacement

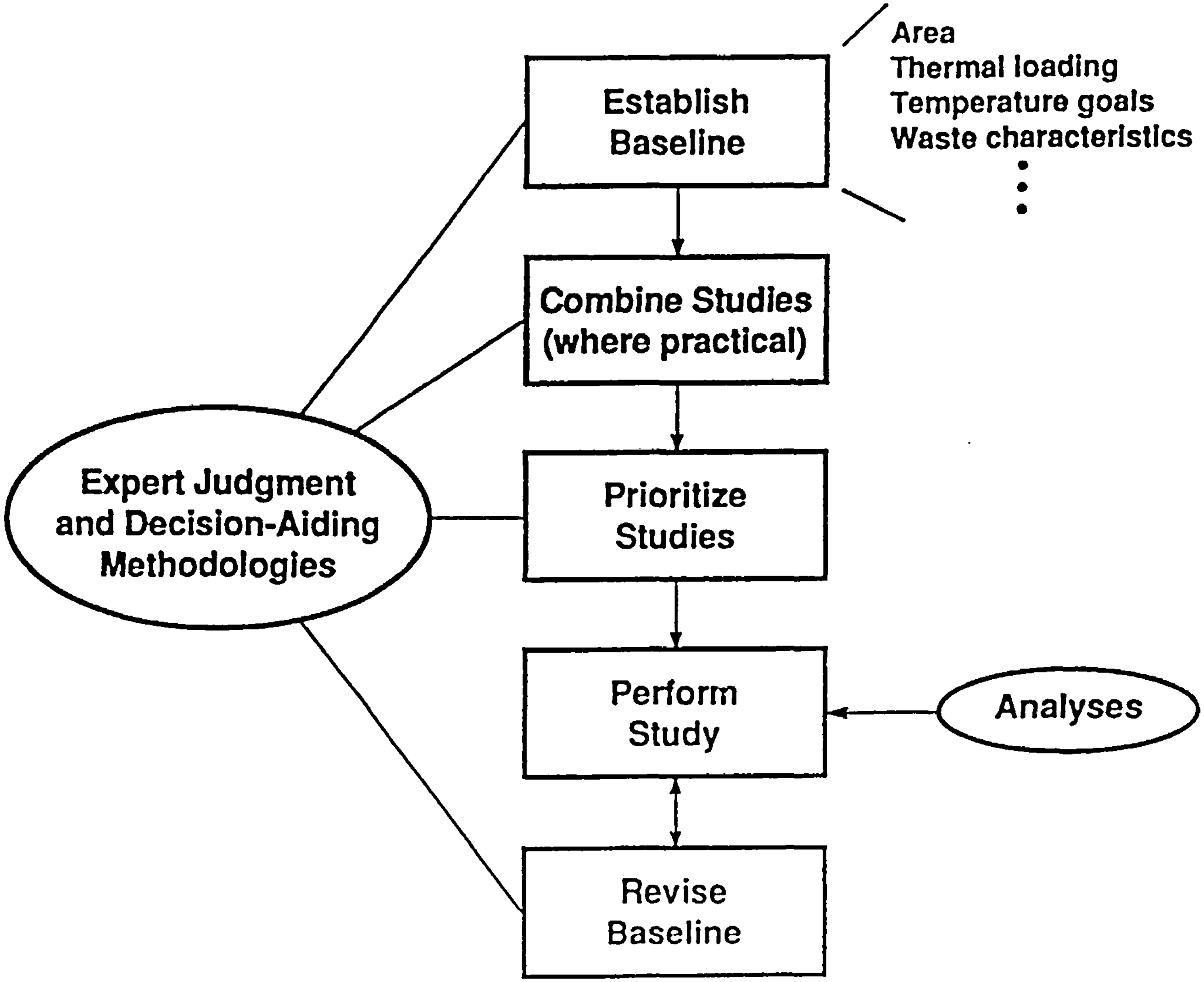


Borehole Wall Temperature - Horizontal Emplacement

Proposed Actions

- Perform mechanistic studies where appropriate
- Update temperature goals recognizing
  - Uncertainties in impacts & benefits
  - Prudence of early conservatism
  - Improved understanding of mechanisms
  - Improved performance models
- Develop boundaries of design alternatives
- Perform design studies

Design Studies



Establish Baseline

Area
Thermal loading
Temperature goals
Waste characteristics
•
•
•

Combine Studies (where practical)

Prioritize Studies

Perform Study

Analyses

Revise Baseline

Expert Judgment and Decision-Aiding Methodologies

Conclusions

- Appropriate temperature constraints are necessary in the design process
- Design trade-offs will include consideration of (higher/lower) temperatures
- Trade-offs will be performed during ACD

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PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: **WASTE FORM AND MATERIALS TESTING CONSIDERATIONS**

PRESENTER: DR. GREGORY E. GDOWSKI

PRESENTER'S TITLE AND ORGANIZATION: CHEMICAL ENGINEER
KMI/LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 423-3486

OCTOBER 8 - 10, 1991

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OCTOBER 8 - 10, 1991

Outline of Presentation

- Introduction
- Low thermal loading testing considerations
- High thermal loading testing considerations
- Other testing considerations
- Summary

Thermal Loading Temperature Scenarios

- Low thermal loading
  - Temperature always remains below boiling
- High thermal loading
  - Temperature initially above boiling but eventually will be below boiling

Low Thermal Loading Testing Considerations

Low temperature testing

- Degradation of container materials and Zircaloy cladding
- Hydride precipitation and reorientation in Zircaloy cladding
- Oxidation and dissolution of UO_2 fuel pellets
- Hydration and dissolution of borosilicate glass

High temperature testing

- Accelerated testing
  - Must ensure that mechanisms of degradation do not change with temperature

High Thermal Loading Testing Considerations

High temperature testing

- Aging and oxidation of container materials
- Other degradation modes of container materials
- Creep/stress rupture of Zircaloy cladding
- Hydrogen effects in Zircaloy cladding
- Oxidation of UO_2 fuel pellets
- Hydration of borosilicate glass
- Accelerated testing

High Thermal Loading Testing Considerations

Low temperature testing

- Low thermal loading testing
- Tests on materials modified by high temperature processes
  - Dissolution of U_3O_8 / UO_3
  - Dissolution of hydrated borosilicate glass
  - Degradation resistance of oxidized and aged container materials

Other Testing Considerations

- Backfill/container material interaction
- Waste package component interaction
- Final closure

Summary

- Degradation phenomena and concerns have been identified for both high and low thermal loading scenarios
- Testing is required to characterize and model the degradation modes of materials and waste forms
- Testing should proceed simultaneously with engineered barrier system design

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PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

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Outline

- Potentially affected experiments
- Effects of lower/higher thermal loadings
- Conclusions

Potentially Affected Experiments

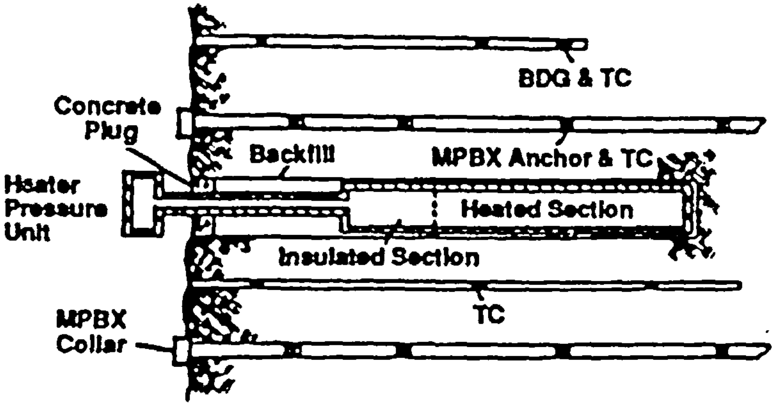
Field

- Heater experiments
- Heated block
- Thermal stress measurements
- Heated room experiment

Laboratory

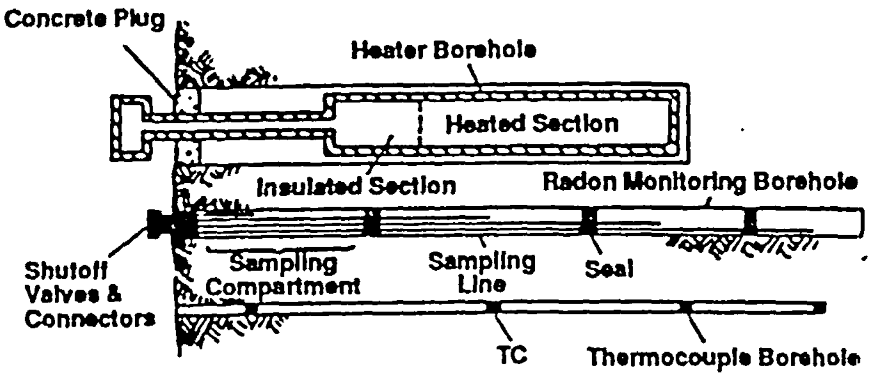
- Thermal properties
- Thermal expansion
- Other temperature-dependent properties
- Other laboratory experiments

Typical Layout of Heater and Instrumentation



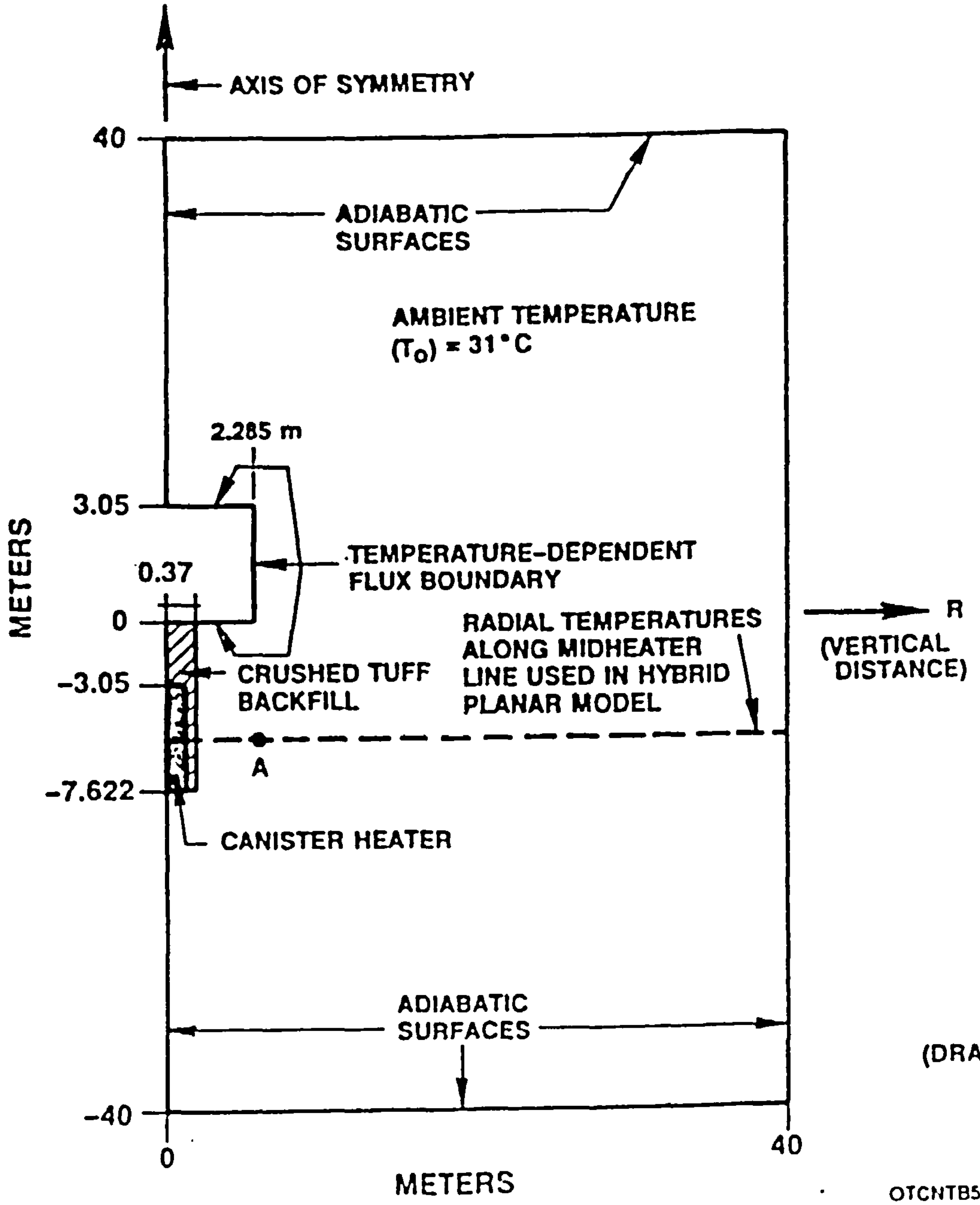
Section A - A

Typical Layout of Radon-Monitoring Borehole



Section B - B

Axisymmetric Thermal Model



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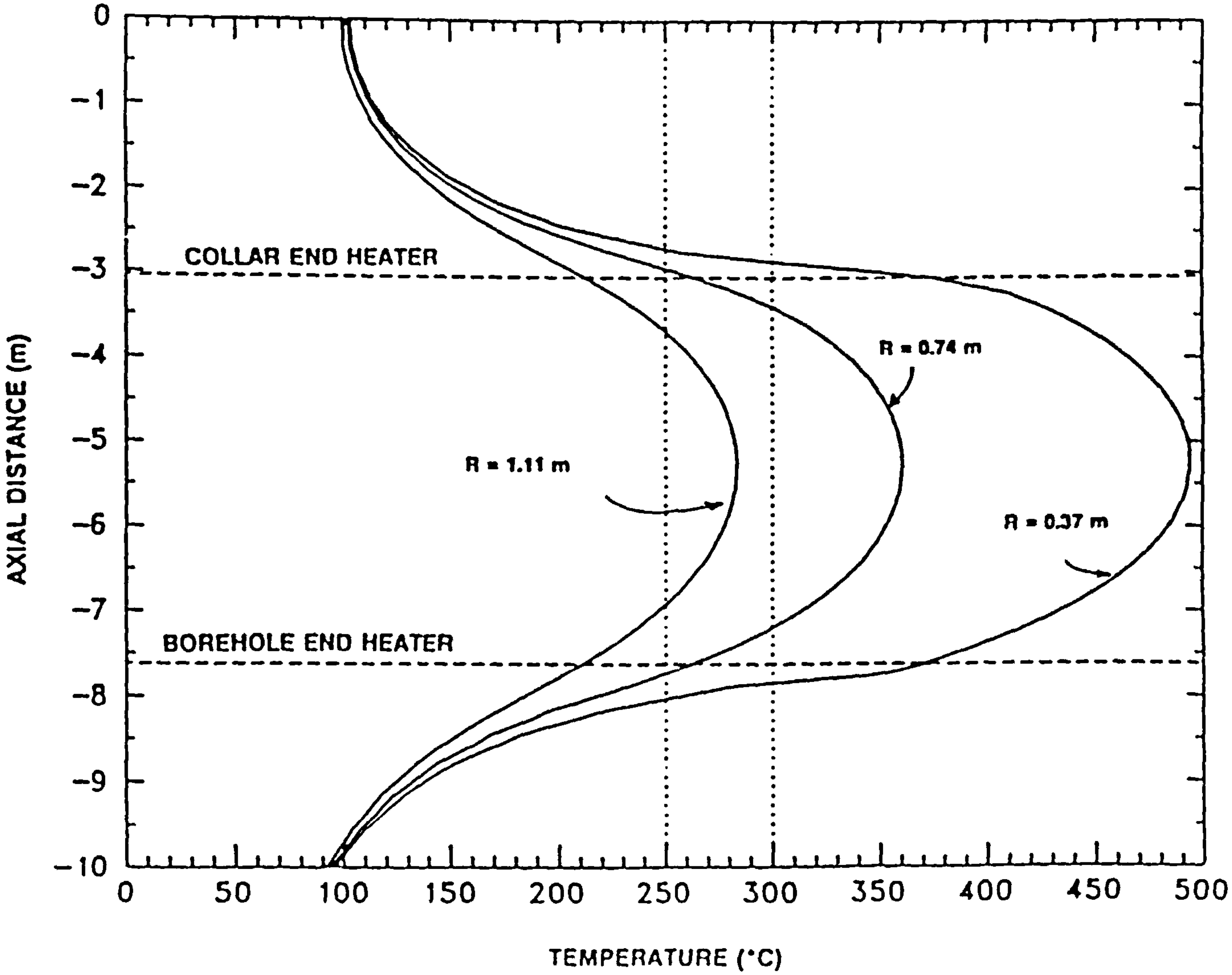
OTCNTB5P 125 NWTRN/10 8.10 91

Axial Temperature Profiles After 30 Mo of Heating for the Axisymmetric Model at Selected Radial Distances (R)



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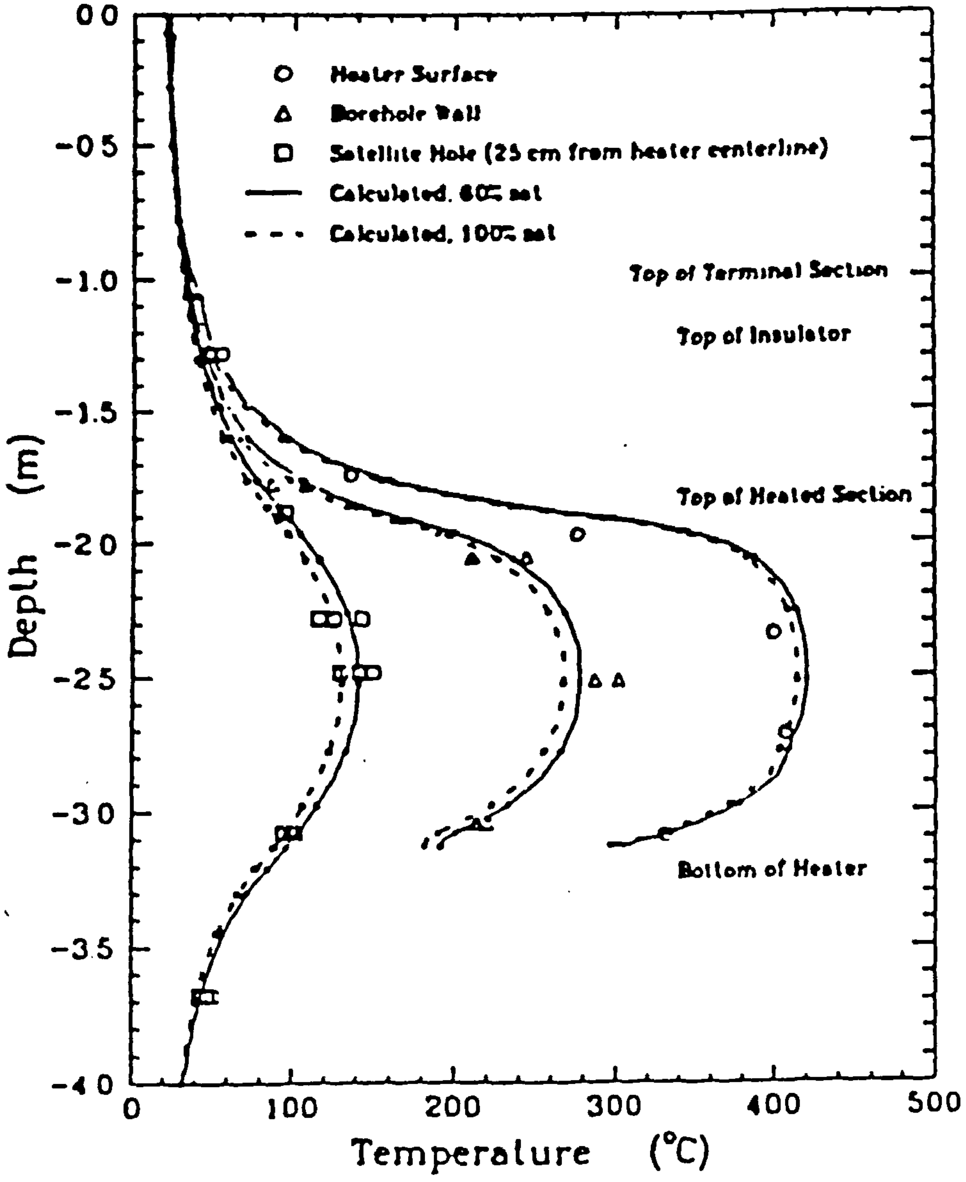
Comparison of Measured and Calculated Temperature Profiles for the Welded Tuff Small-Diameter Heater Experiment



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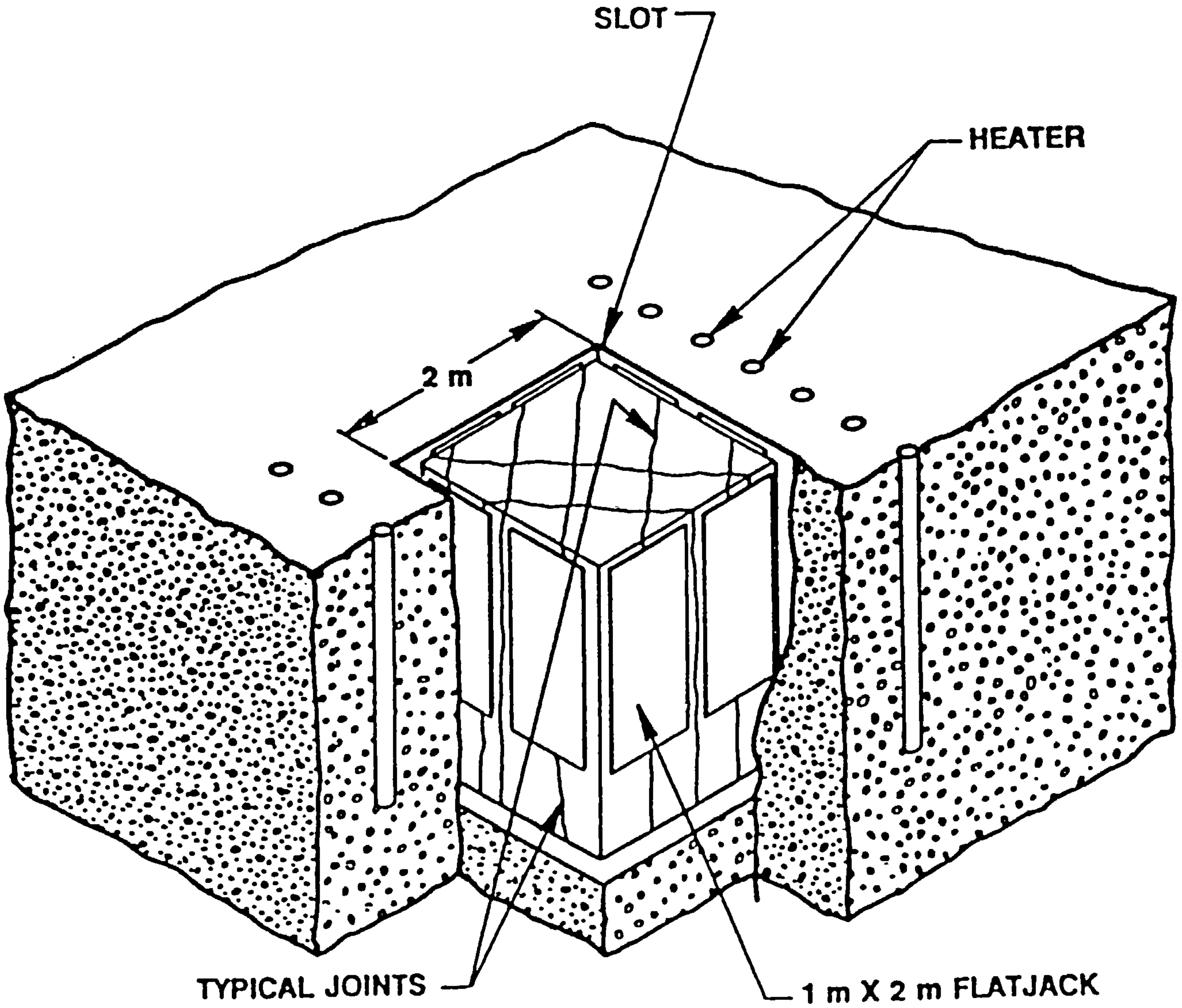
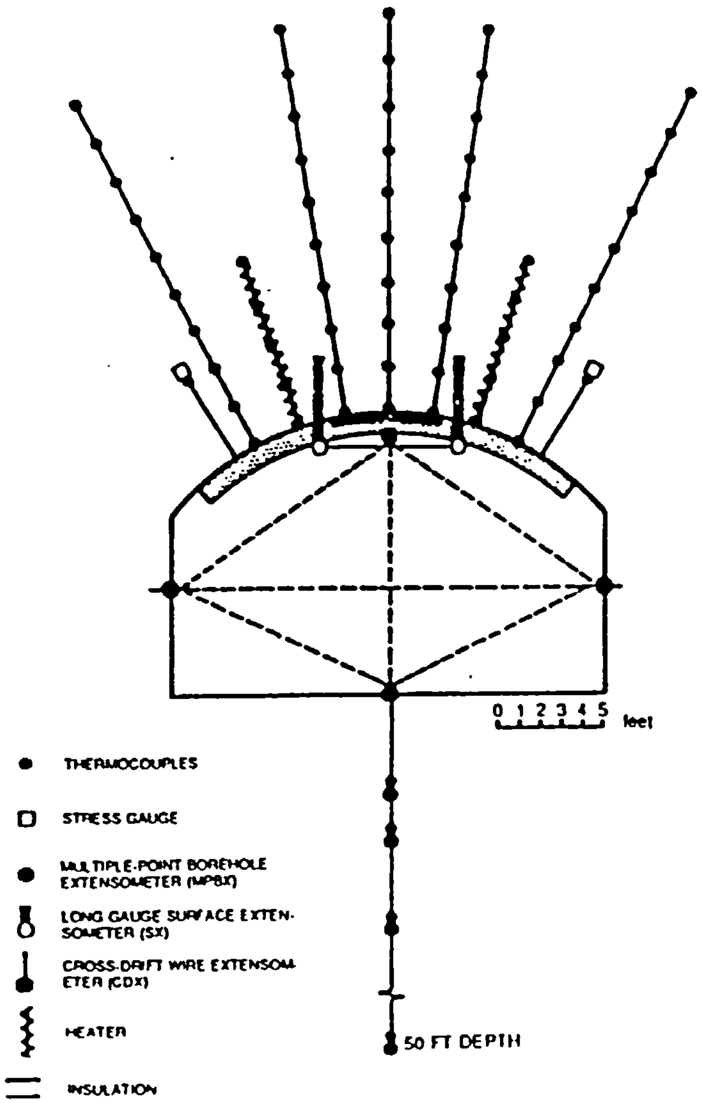
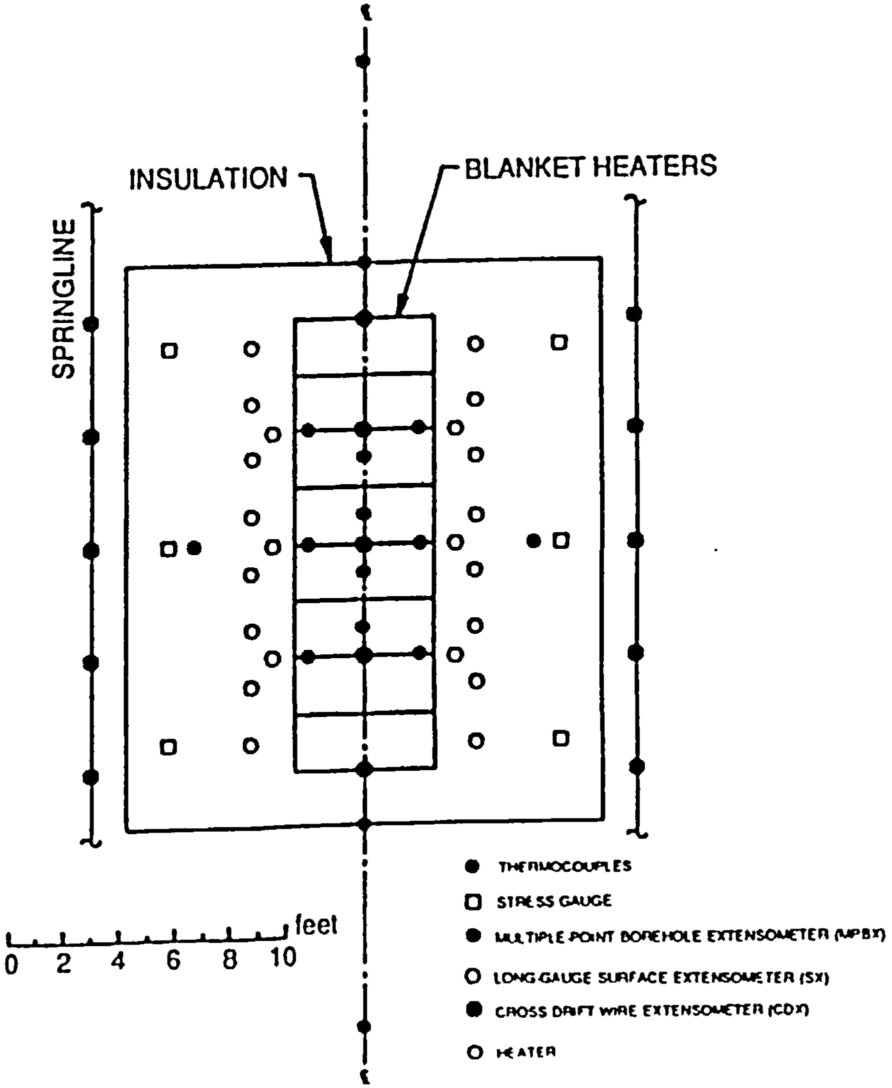
G-Tunnel Heated Block Experiment



Prototype Thermal Stress Test Layout: Section View



Prototype Thermal Stress Test Layout: Plan View



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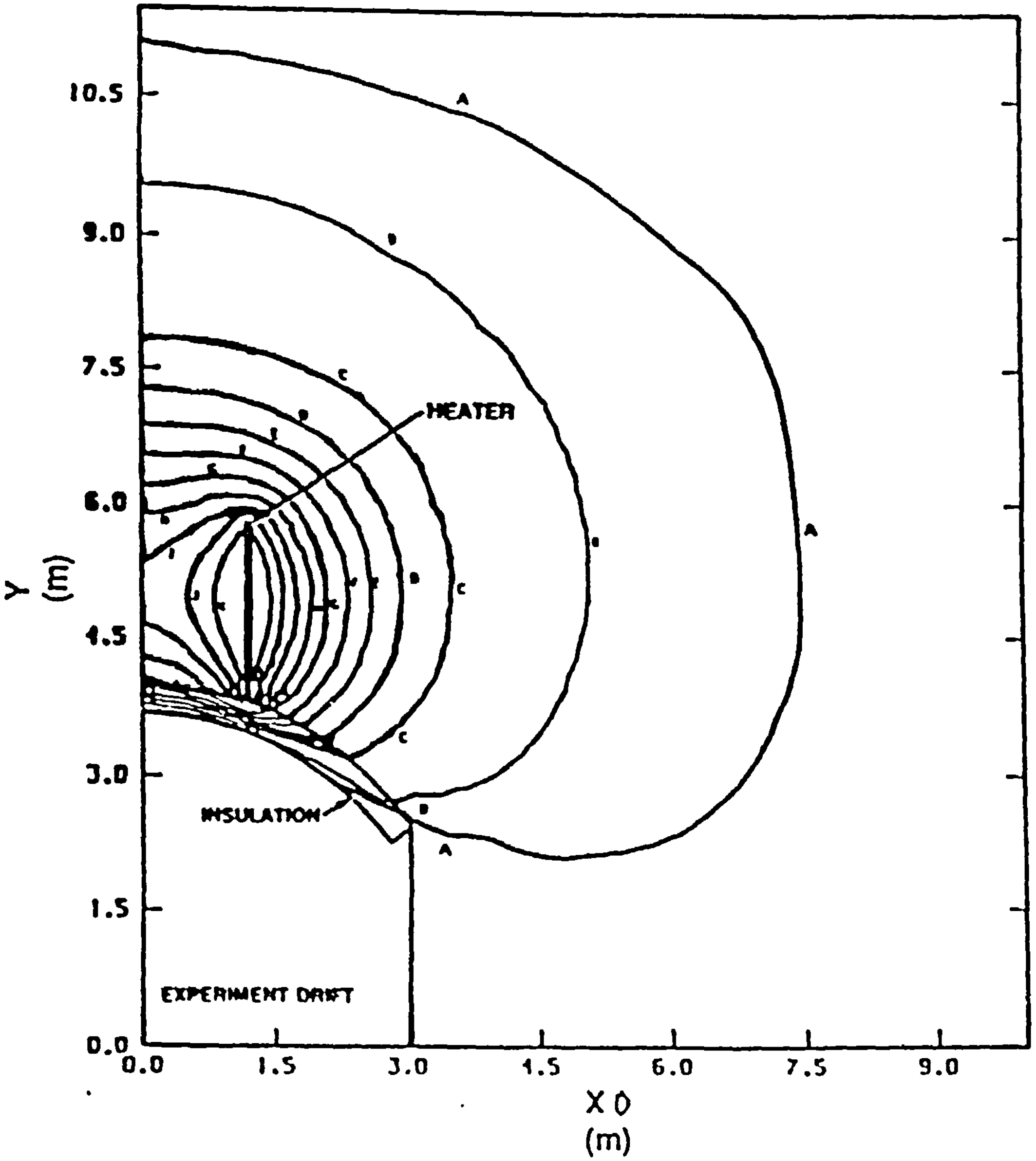
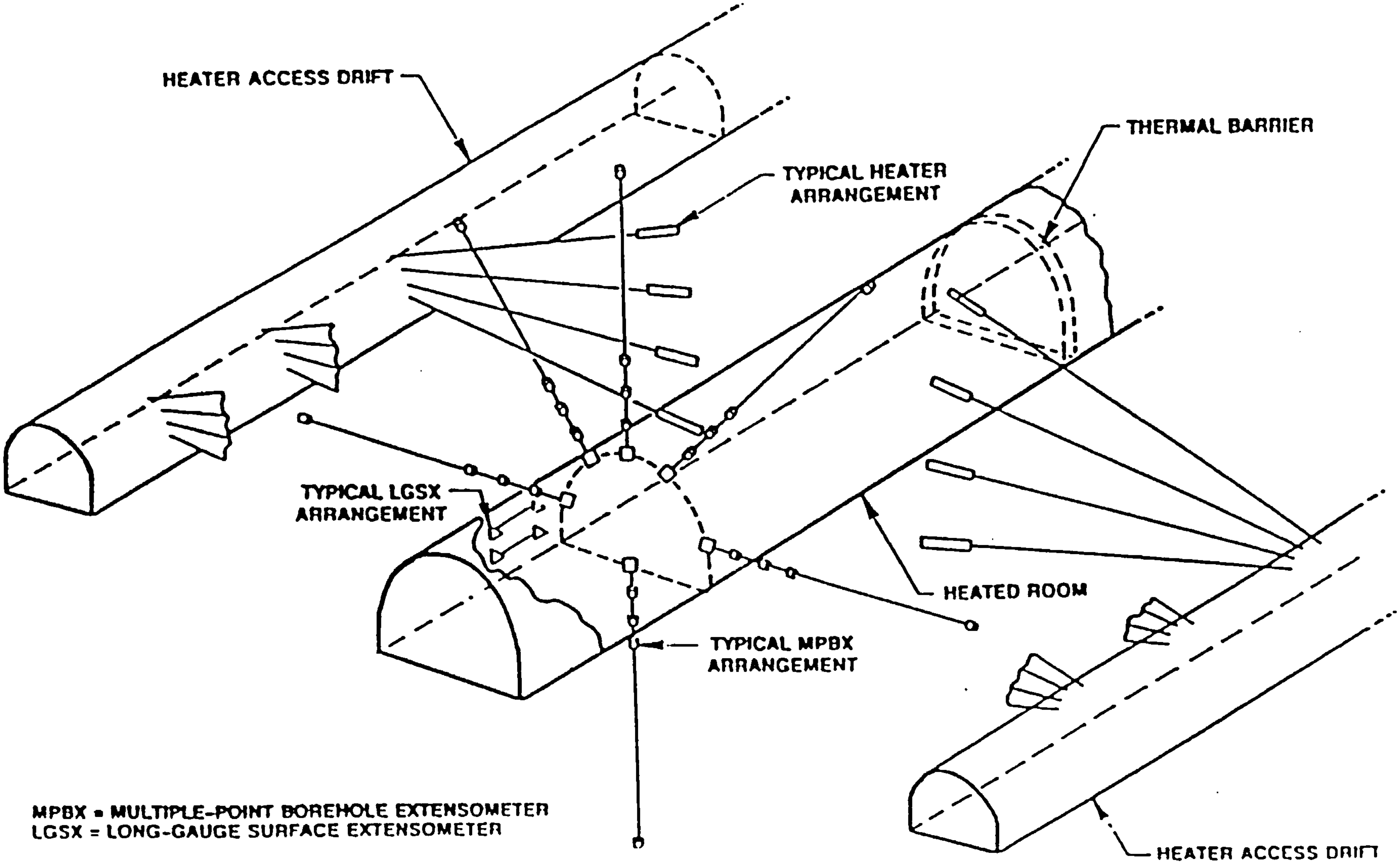
Temperature Contours at 90 Days of Heating



Temperature (°C)
A = 23
B = 40
C = 60
D = 120
E = 160
F = 200
G = 240
H = 280
I = 320
J = 360
K = 400

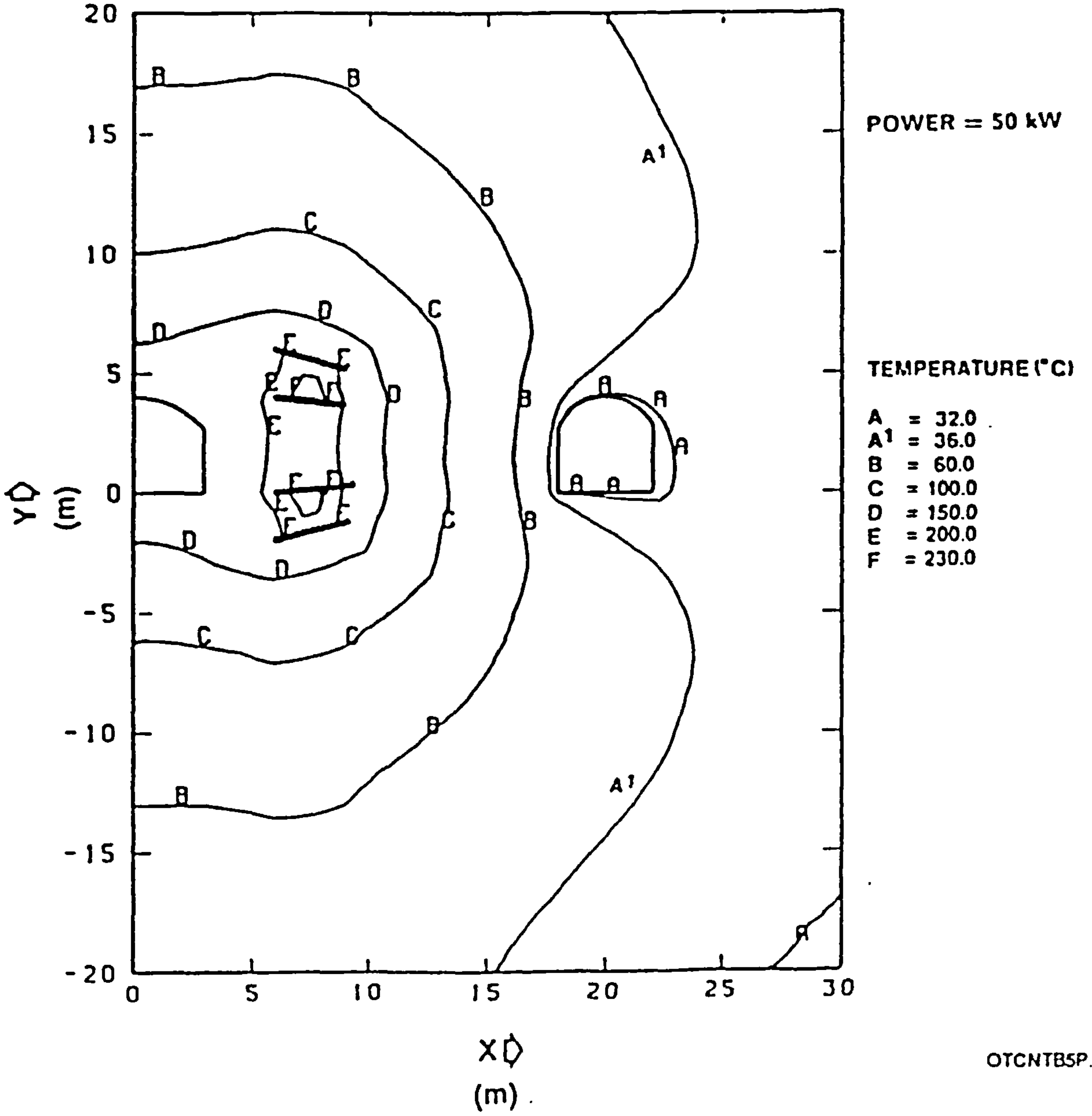
Conceptual Arrangement of Heated Room Test



MPBX = MULTIPLE-POINT BOREHOLE EXTENSOMETER
LGSX = LONG-GAUGE SURFACE EXTENSOMETER

OTCNTBSP.125 NWTRN/10-8,10-91

Temperature Contour Plot: 40 Mo



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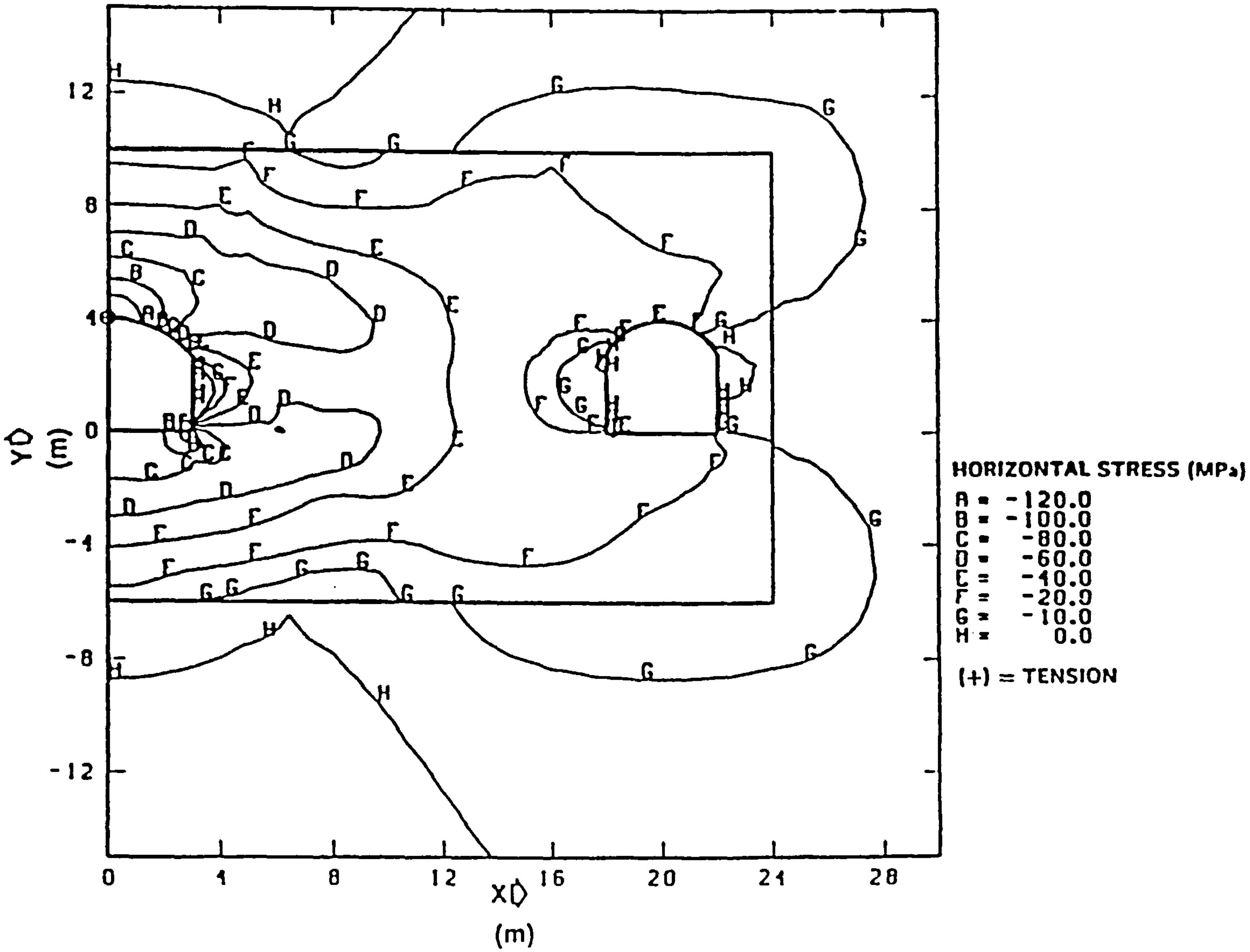
Horizontal Stress Contours at 40 Mo



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Effects of Lower Thermal Loading

A Little Lower

- All field experiments conducted
- Temperature ranges lower for lab tests
- Instrumentation problems reduced
- Time required lower for thermomechanical tests

Effects of Lower Thermal Loading

A Lot Lower

- Elimination of some or most field thermal-mechanical experiments
- Reduction in lab-properties tests

Effects of Higher Thermal Loading

- Slightly modify some field experiments
- Expand the range of some lab-properties tests

Conclusions

- Thermal loading can be accommodated with possible Δ to testing program
- Present plans accommodate a wide temperature range

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: WASTE FORM DEGRADATION AND MATERIALS UNCERTAINTIES

PRESENTER: DR. GREGORY E. GDOWSKI

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OCTOBER 8 - 10, 1991

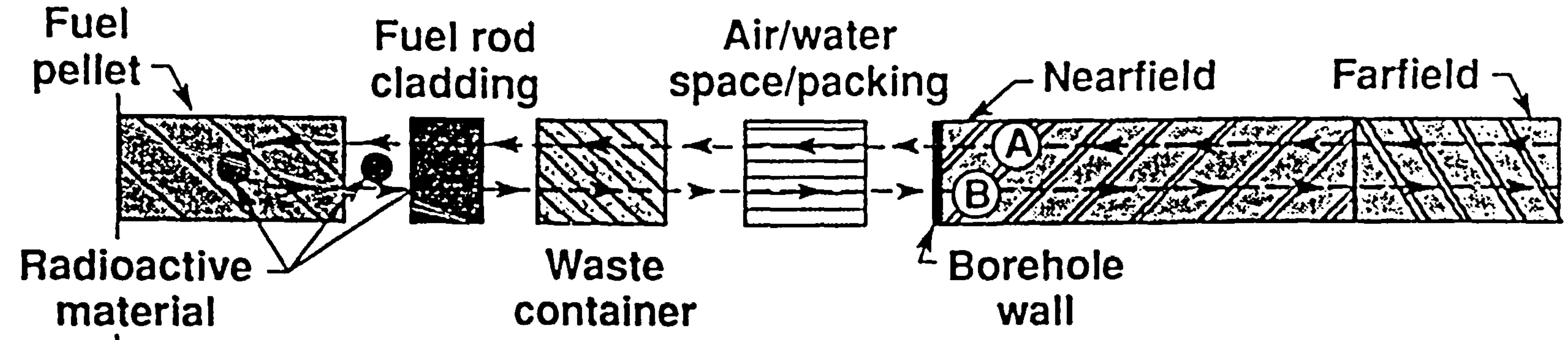
Outline of Presentation

- Introduction
- Container materials
  - Metallic alloys
- Waste form
  - Spent Fuel
    - * Zircaloy cladding
    - * Fuel pellets
  - Borosilicate glass
    - * Pour canister
    - * Glass
- Summary

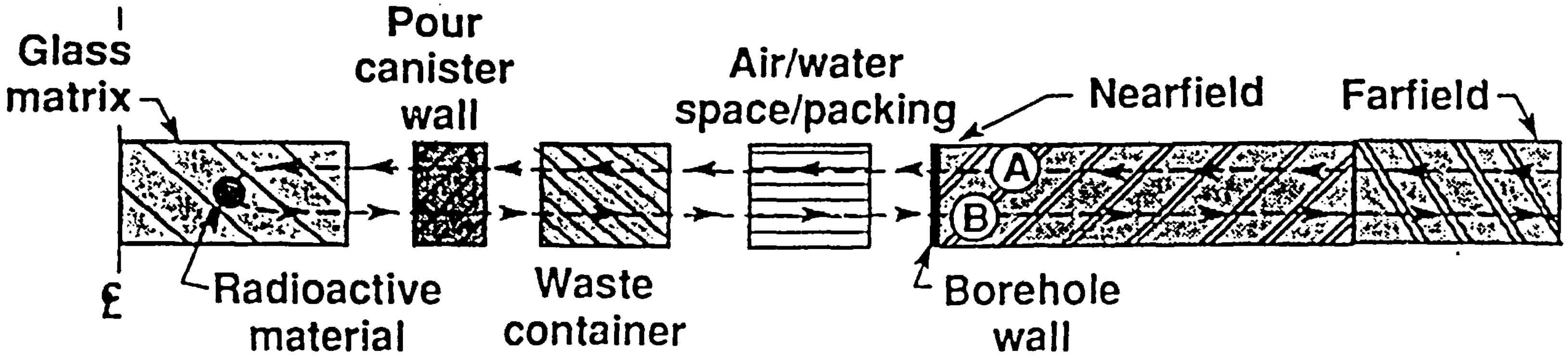
Temperature Regions

- High temperature region
  - Material dependent
  - Microstructural changes
  - Accelerated oxidation (corrosion)
- Above boiling region
  - Dominated by gas phase phenomena
  - Temperature definition is complicated by presence of hygroscopic salts, pores, and crevices
- Below boiling region
  - Dominated by aqueous phenomena
  - Temperature definition is complicated by presence of hygroscopic salts, pores, and crevices

Radionuclides are Isolated from the Environment by Multiple Barriers



Spent fuel barriers



HLW barriers

- Failure path: Water enters from Ⓐ, radionuclides leave at Ⓑ

Container Materials Degradation

High temperature region

- Elevated temperature (>350-500° C) phenomena
- **Considerations**
  - Precipitation of carbides, intermetallics
  - Graphitization
  - Internal oxidation
  - Accelerated oxidation
- Potential problems
  - All the considerations
- Potential benefits
  - None

Container Materials Degradation

(Continued)

Above boiling region

- Dry steam/air mixture with possible radiolysis products
- Considerations
  - Long-term aging
  - General corrosion (oxidation)
  - Episodic water contact
- Potential problems
  - Microstructural changes
  - Mineral deposition
  - Enhanced corrosion because of radiolysis products
- Potential benefits
  - Oxide layer growth
  - Residual stress relieving
  - Modeling

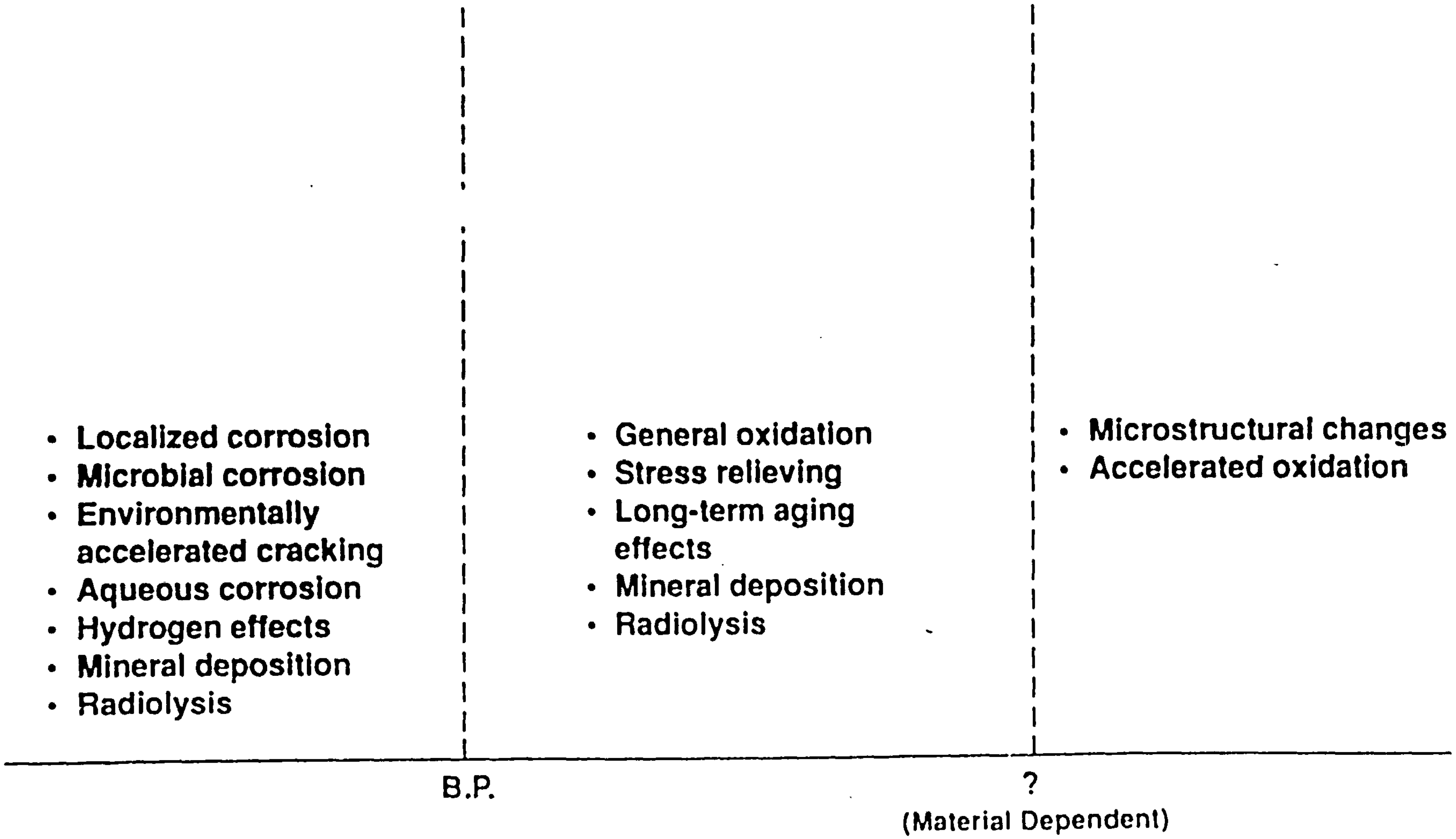
Container Materials Degradation

(Continued)

Below boiling region

- Humid air/liquid water with possible radiolysis products
- Considerations
  - General corrosion
  - Localized corrosion
  - Stress corrosion cracking
  - Microbiological corrosion
  - Hydrogen effects
  - Mineral deposition
- Potential problems
  - Corrosion processes
  - Modeling
  - Enhanced corrosion because of radiolysis products
- Potential benefits
  - Favorable water/material interaction

Temperature Regions Container Cladding



- Localized corrosion
- Microbial corrosion
- Environmentally accelerated cracking
- Aqueous corrosion
- Hydrogen effects
- Mineral deposition
- Radiolysis

- General oxidation
- Stress relieving
- Long-term aging effects
- Mineral deposition
- Radiolysis

- Microstructural changes
- Accelerated oxidation

Temperature

Zircaloy Cladding Degradation

High temperature region (>350° C)

- No container failure
  - Inert atmosphere
- Container failure
  - Dry steam/air mixture with possible radiolysis products
- Considerations
  - Creep/stress rupture (380° C)
  - Accelerated oxidation (540° C)
  - Internal oxidation (700° C)
- Potential problems
  - Creep/stress rupture
- Potential benefits
  - None

Zircaloy Cladding Degradation

(Continued)

Above boiling region

- No container failure
  - Inert atmosphere
- Container failure
  - Dry steam/air mixture with possible radiolysis products
- Considerations
  - General corrosion (oxidation)
  - Episodic water contact
  - Long-term aging
  - Radiolysis effects
- Potential problems
  - All the considerations
  - C-14 Release
- Potential Benefits
  - Above hydride precipitation temperature
  - Relieving of radiation hardening
  - Oxide layer growth
  - Modeling

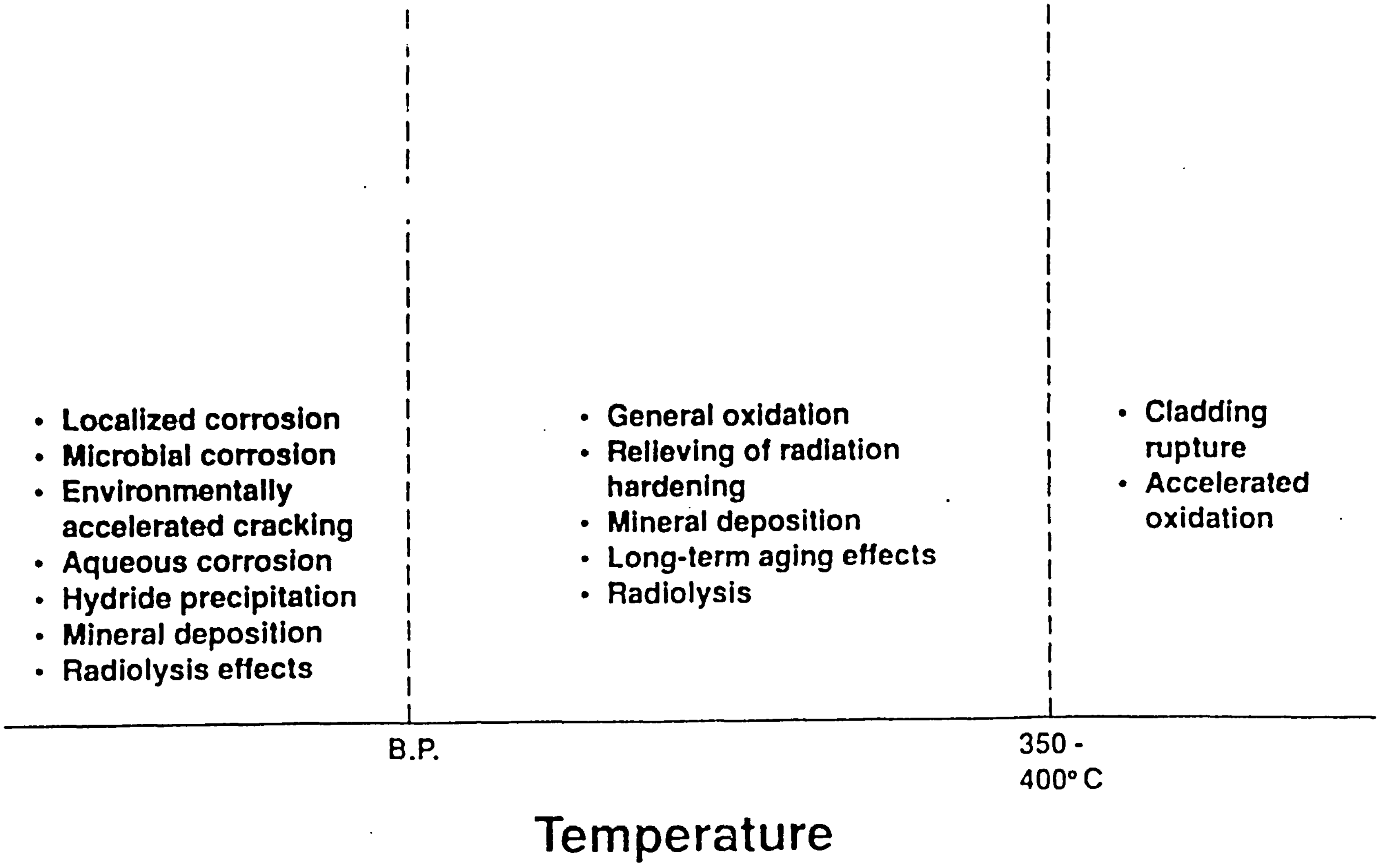
Zircaloy Cladding Degradation

(Continued)

Below boiling region

- No container failure
  - Inert atmosphere
- Container failure
  - Humid air/liquid water with possible radiolysis products
- Considerations
  - Localized corrosion
  - General corrosion
  - Stress corrosion cracking
  - Hydrogen effects
  - Microbiological corrosion
  - Mineral deposition
- Potential problems
  - All the considerations
  - Modeling
- Potential benefits
  - Favorable water/Zircaloy interaction

Temperature Regions Zircaloy Cladding



- Localized corrosion
- Microbial corrosion
- Environmentally accelerated cracking
- Aqueous corrosion
- Hydride precipitation
- Mineral deposition
- Radiolysis effects

- General oxidation
- Relieving of radiation hardening
- Mineral deposition
- Long-term aging effects
- Radiolysis

- Cladding rupture
- Accelerated oxidation

B.P.

350 -
400° C

Temperature

Fuel Pellet Degradation

Above boiling and high temperature regions

- No container/cladding failure
  - Inert atmosphere
- Container/cladding failure
  - Dry steam/air mixture with possible radiolysis products
- Considerations
  - Oxidation response

    >250° C U_3O_8/UO_3 (powder)

    <250° C $UO_{2.4}$ (fragments intact)
- Potential problems
  - Oxidation of fuel pellets and release of volatile radionuclides
- Potential benefits
  - No dissolution
  - No oxidation if no container/cladding failure

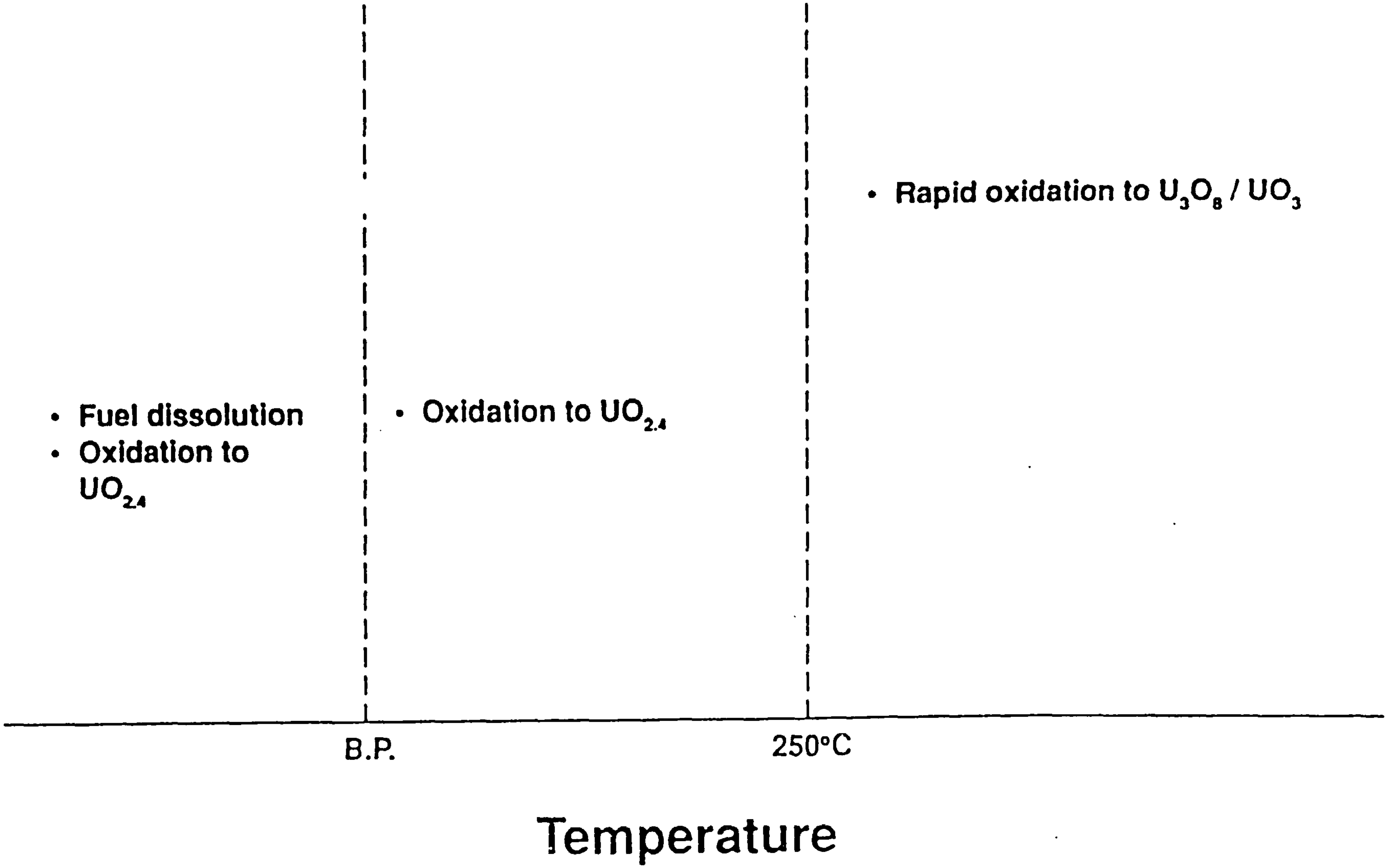
Fuel Pellet Degradation

(Continued)

Below boiling region

- No container/cladding failure
  - Inert atmosphere
- Container/cladding failure
  - Humid air/liquid water with possible radiolysis products
- Considerations
  - Oxidation response
  - Fuel dissolution
- Potential problems
  - Fuel dissolution
    - * UO_2 fragment dissolution
    - * U_3O_8/UO_3 powder dissolution
- Potential benefits
  - Favorable water/fuel pellet interaction
  - Low oxidation rates
  - No oxidation/dissolution if no container/cladding failure

Temperature Regions UO_2 Fuel Pellets



- Fuel dissolution
- Oxidation to $UO_{2.4}$

- Oxidation to $UO_{2.4}$

- Rapid oxidation to U_3O_8 / UO_3

Borosilicate Glass Degradation

Above boiling and high temperature region

- No container/canister failure
  - Inert atmosphere
- Container/canister failure
  - Dry steam/air mixture with possible radiolysis products
- Considerations
  - Devitrification above 500-600° C
  - Hydration of glass
- Potential probems
  - Hydration of glass
- Potential benefits
  - Hydration rates low in low relative humidity
  - No dissolution
  - Secondary mineral precipitation
  - No hydration if no container/canister failure

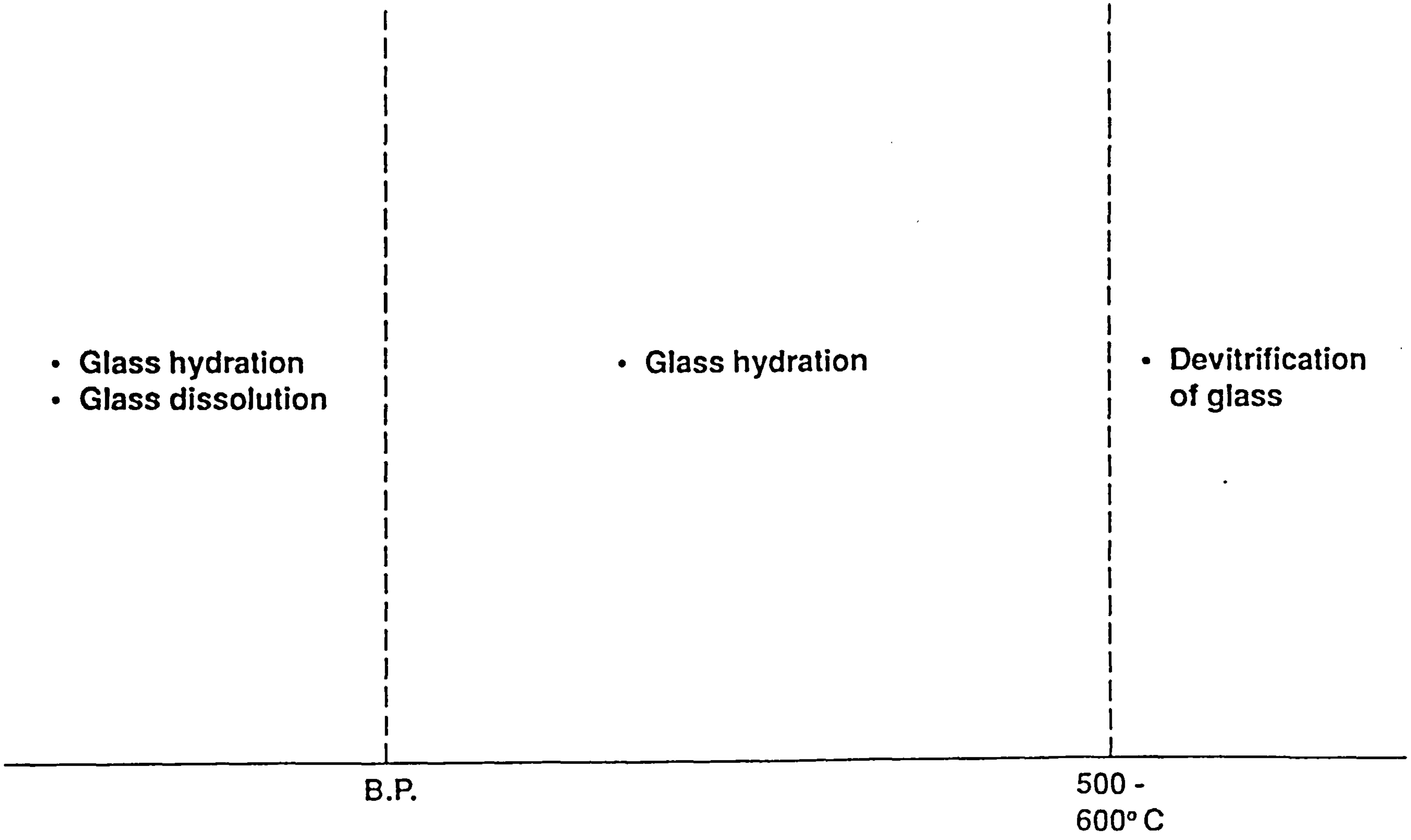
Borosilicate Glass Degradation

(Continued)

Below boiling region

- No container/canister failure
  - Inert atmosphere
- Container/canister failure
  - Humid air/liquid water with possible radiolysis products
- Considerations
  - Glass dissolution
  - Hydration of glass
- Potential problems
  - Glass dissolution
  - Hydration of glass
- Potential benefits
  - Slow hydration rates
  - Favorable water/glass interaction

Temperature Regions Borosilicate Glass



- Glass hydration
- Glass dissolution

- Glass hydration

- Devitrification of glass

B.P.

500 -
600° C

Temperature

Summary

- Based on previous experience and preliminary YMP testing certain temperature regions appear to offer advantages over other temperature regions for various waste package components when considered independently:

Container materials	above boiling
Zircaloy cladding	above boiling
UO_2 fuel pellets	below boiling
Borosilicate glass	below boiling

- Testing will be necessary to determine whether degradation modes exist under repository relevant conditions, and if they exist to determine their significance

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: BIOLOGICAL RESOURCE CONCERNS

PRESENTER: DR. W. KENT OSTLER

PRESENTER'S TITLE AND ORGANIZATION: SECTION HEAD
EG&G ENERGY MEASUREMENTS
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7474

OCTOBER 8 - 10, 1991

Presentation Outline

- Delineation of impact
- Significance of impact
- State of knowledge on significance
- Uncertainties in state of knowledge
- Resolution of uncertainties
- Residual uncertainties
- Conclusions

Delineation of Impact

Increased soil temperature

- Most probable increase is 1.0-1.5° C
- Maximum temperature increase expected is <6° C
- Increased surface temperature to be seen on 2.3-3.0 sq. mi.
- Temperature increase to begin about 1,000 years after initial emplacement
- Temperature maximum obtained 2,000-3,000 years after initial emplacement
- Temperature to gradually reduce 2,000-3,000 years after initial emplacement

Significance of Thermal Loading on Biological Resources

- Dependent on magnitude of temperature increase
  - < 2° C - minimal impact
  - 2-6° C - moderate to large impact
- Altered water mass balance
- Altered timing of biological processes
- Destabilization of system

Significance of Thermal Loading on Biological Resources

(Continued)

Altered water mass balance

- Evaporation
- Transpiration
- Available water for biological processes

Significance of Thermal Loading on Biological Resources

(Continued)

Altered timing of biological processes

- Species use environmental cues to initiate phases
- Asynchrony of processes
  - Breaking seed dormancy
  - Emergence from hibernation
  - Pollination
- Insufficient time to complete processes
  - Reduced growing season/activity period
  - Reduced resources

Significance of Thermal Loading on Biological Resources

(Continued)

Destabilization of system

- Limiting factors/threshold limits
- Enhancement of other detrimental processes
  - Decomposition of organic matter
  - Enhance pathogens/pests

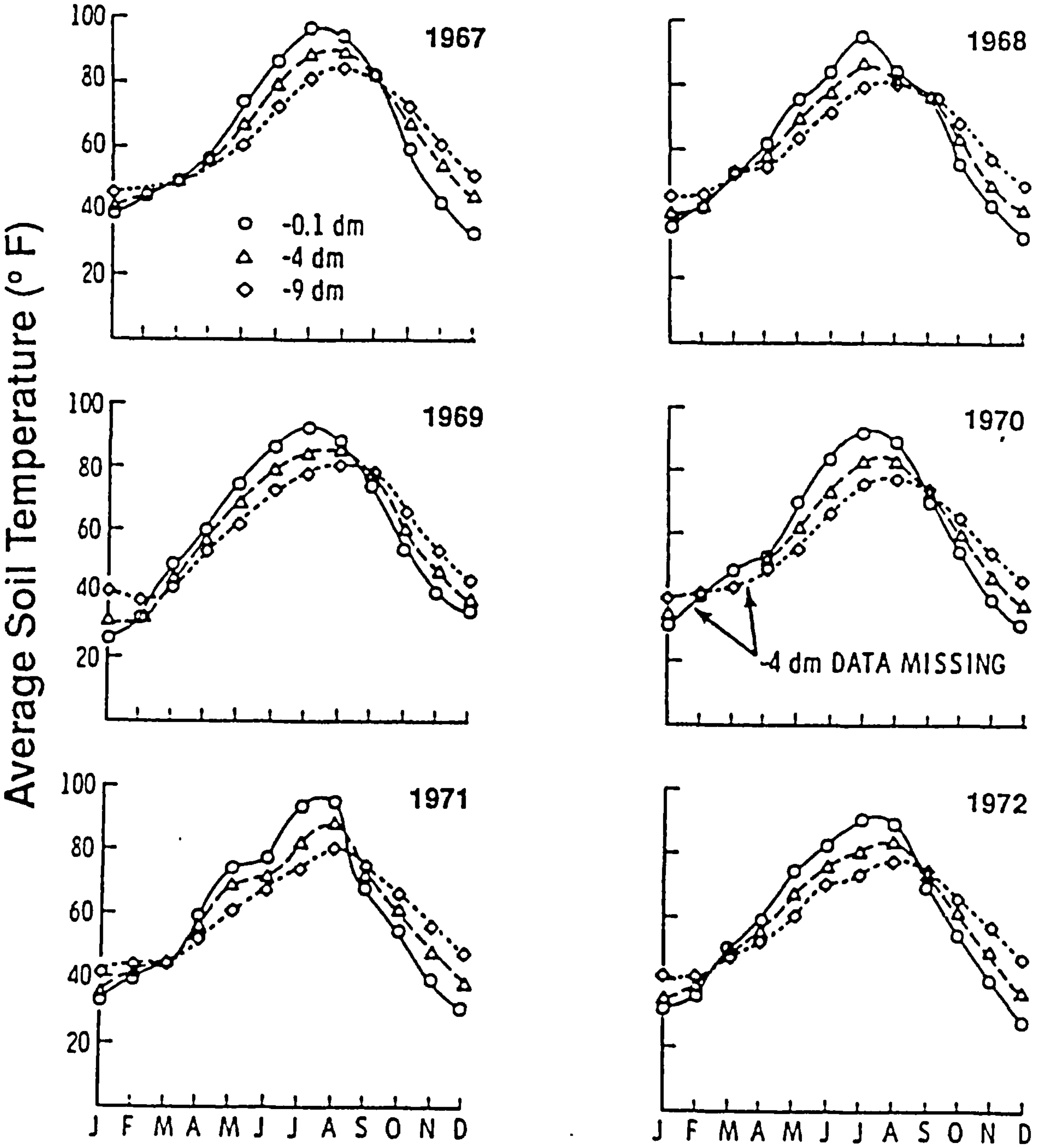
State of Knowledge on Significance of Thermal Loading on Biological Resources

- Current environment
  - Regional: seasonal variability: scale of change induced by natural vs repository
  - Site-specific: seasonal variability: scale of change induced by natural vs repository
  - Geothermal areas
- Literature review
  - Effects of increased soil temperature
  - Effects of reduced soil moisture
  - Effects of interaction between increased soil temperature and reduced soil moisture

Average Soil Temperatures Measured at Three Depths

Thomas P. O'Farrell et. al.

Ecological Monograms
Vol. 45, No. 1



Natural Variability in Soil Temperature at Yucca Mountain

Soil temperature (C°) at 45 cm	Vegetation Associations			
	Larrea-Ambrosia	*Larrea-Lycium-Grayia*	*Coleogyne*	*Lycium-Grayia*
January temp. (1991)	8.9	8.6	7.3	7.8
August temp. (1991)	30.9	30.3	28.7	28.0
Range of January temps.	8-10	7-10	6-9	6-10
Range of August temps.	30-33	29-31	26-31	26-31
Difference of September 1990-1991 temps.	-2.8	-2.7	-1.0	-1.8

Impact of Geothermal Heating on Lodgepole Pine in Yellowstone N.P. (White, 1978)

- "The actual upper limit of tolerance is probably not set by heat flow as such but by the seasonal maximum soil temperature at the root depths preferred by each form of vegetation"
- Investigated three zones: normal, mixed, stunted

Zone	Near surface heat flow (W/m^2)
Normal	1.9 - 8.4
Mixed	9.6 - 13.8
Stunted	> 20.9

Uncertainties in State of Knowledge

- Species processes
  - Change in phenology/activity periods
  - Change in biomass production/food resource
  - Available water for biological processes

- Ecosystem processes
  - Loss of species from ecosystem
  - Interaction of remaining species
  - Impact on trophic levels

- Limited or no site-specific information

Resolution of Uncertainties

- Measure existing ecosystems along latitudinal/ elevational gradients
- Measure local/regional geothermal areas
- Conduct glasshouse/small field trials
- Develop models/improve existing models

Residual Uncertainties After Completion of Studies and Modeling

- Secondary impacts
  - Indirect impacts to other trophic levels and trophic-level interfaces
  - Effects at a large scale not detectable on small scale studies
- Evolutionary scale effects
  - Genetic drift
- Climatic change

Conclusions

- High thermal loading should have an impact on biological resources
- The significance of that impact is dependent on actual level of surface temperature increase
- Surface temperature increases of 1-1.5° C over a 1,000 year period should cause minimal impacts
- High thermal loading may cause the loss of some species at the impacted area
- Biological system has tolerance for change
- Uncertainties exist on level of change and impact on the specific biological resources at Yucca Mountain
- Many of these uncertainties could be addressed through a research progam
- Some uncertainties would still exist

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: **GEOCHEMICAL UNCERTAINTIES**

PRESENTER: **DR. BRIAN E. VIANI**

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OCTOBER 8 - 10, 1991

Issues to be Addressed Regardless of Thermal Load

- Can we predict the variation in the composition of groundwater over time and space?
- Can we predict the ability of the rock matrix, fracture coatings, and introduced repository components to sorb radionuclides?
- Can we predict the effect that geochemical reactions have on hydrologic properties?

Geochemical Processes Need to be Known as a Function of Temperature and $p/p^\circ_{H_2O}$ (Relative Humidity)

- Dissolution/precipitation
  - Equilibrium properties
  - Kinetic properties
- Sorption
  - Cation exchange equilibria
  - Surface complexation equilibria
  - Water adsorption equilibria

Results of Experimental and Modeling Studies of Groundwater/Repository-Rock Interaction at Elevated Temperature

- Mineral dissolution/precipitation

  Results obtained from experiment (K. Knauss) and modeling (C. Bruton) are consistent:

  1. The activity of aqueous silica is the dominant variable controlling the types of minerals expected to form or persist at elevated T
  2. Activity of silica is controlled by the least stable silica polymorph
  3. High and moderate silica activities (Si controlled by glass and cristobalite solubilities) favor zeolites (clinoptilolite and mordenite) and clays (smectite), phases with significant ion-exchange capacity

Results of Experimental and Modeling Studies of Groundwater/Repository-Rock Interaction at Elevated Temperature

(Continued)

- Mineral dissolution/precipitation (continued)

4. Low silica activities (Si controlled by quartz solubility) favor analcime and feldspars, phases without significant exchange capacity

5. Evolution of silica polymorphs is kinetically controlled

6. The phases expected to form during the reaction of groundwater and Topopah Spring tuff at elevated temperatures are those that already exist as secondary phases present in the rock, namely, zeolites and clays

Results of Experimental and Modeling Studies of Groundwater/Repository-Rock Interaction at Elevated Temperature

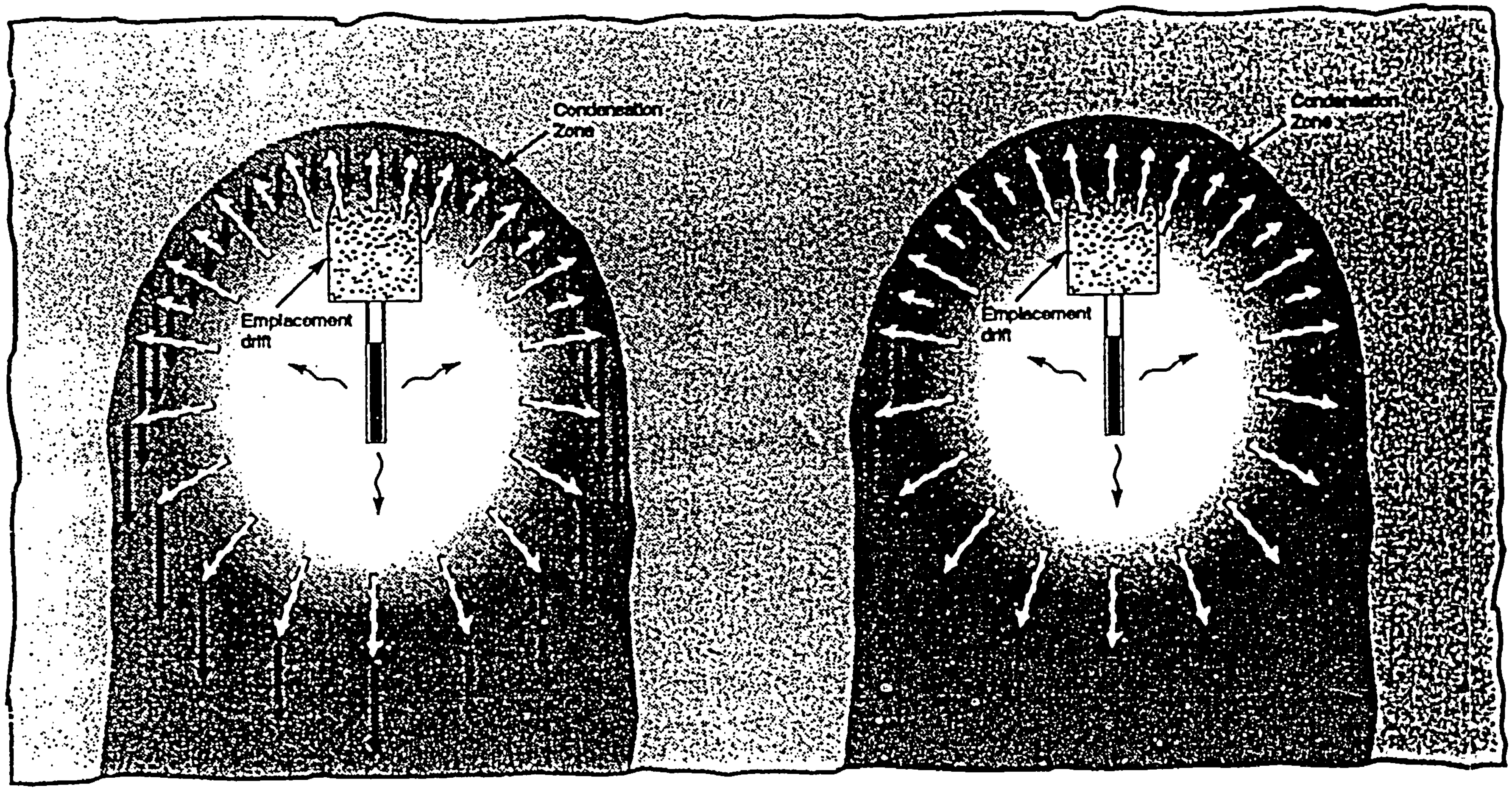
(Continued)

- Cation exchange

1. Cation exchange modeling results (LLNL) agree with experiments (LANL) for sorption of Cs and Sr from groundwater onto tuff
2. Compositions of clinoptilolite formed during hydrothermal alteration of tuff are consistent with predictions based on exchange modeling
3. Cation exchange modeling predictions suggest that cation exchange equilibria, and therefore, sorption, will be sensitive to temperature
4. Experimental data for cation exchange (and surface complexation) are lacking at elevated temperatures. Modeling results are based on estimated thermodynamic data

Glass Dissolution Features And Clinoptilolite Formed From Solution During Zeolitization Of Vitric Tuff Under Hydrothermal Conditions at 250°C

A "Hydrothermal Umbrella" is Established Along Each of the Emplacement Drifts Due to Condensate Being Shed Off of the Boiling Zone

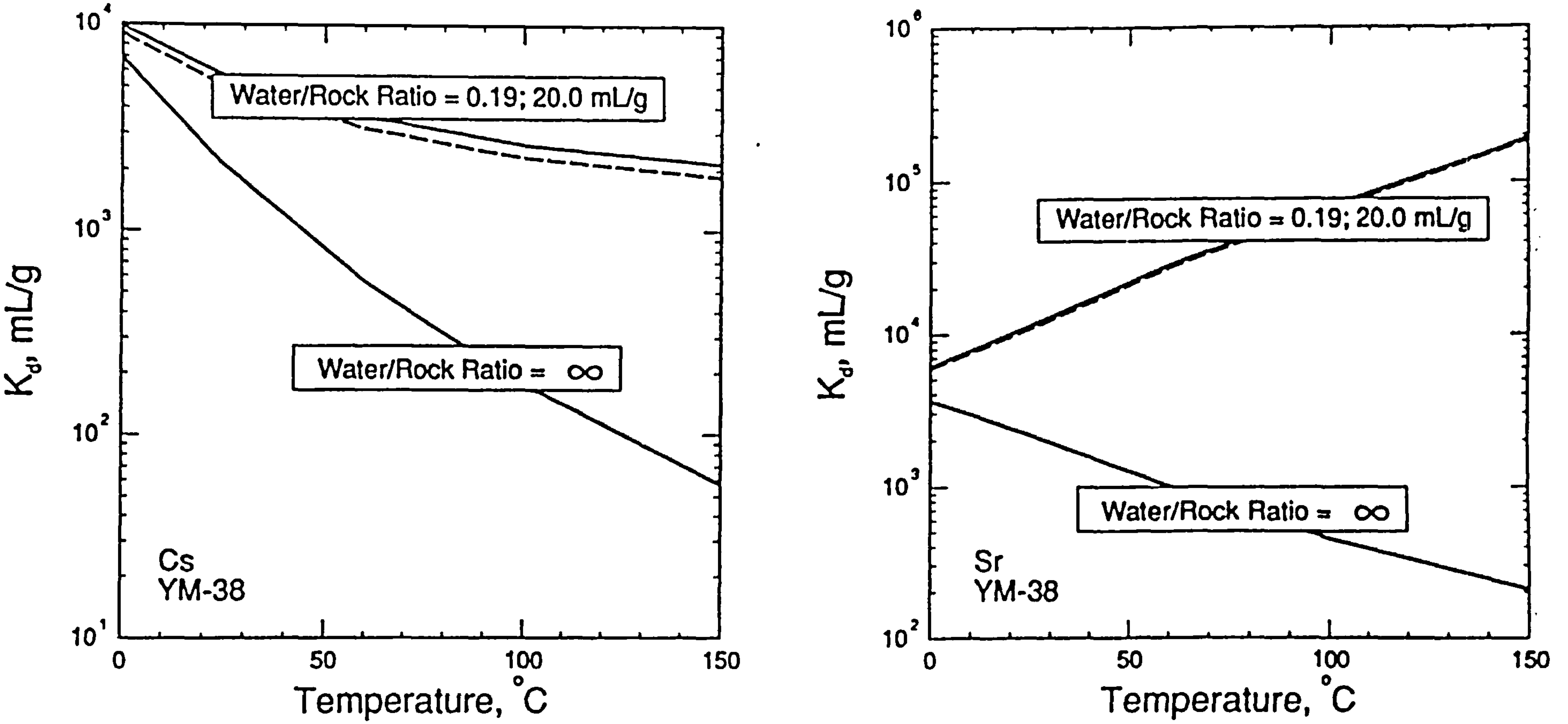


Examples of Coupled Geochemical/Hydrologic Scenarios

- Reactions accompanying the flow of condensate via a fracture network to the saturated zone
    - Dissolution of fracture minerals at point of condensation
    - Precipitation of minerals in fracture as fluid moves and cools
    - Alteration of zeolite and clay mineral exchange ion compositions along fracture

- Reactions accompanying the "refluxing" of water along the boiling isotherm
    - Dissolution of matrix and fracture minerals by condensate
    - Precipitation of secondary phases upon boiling of previously condensed fluid
    - Development of a region in which permeability and porosity have been altered

Predicted Effect of Temperature on Sorption of Cs and Sr on Calico Hills Tuff at Different Water/Rock Ratios



Water: J13; Cs and Sr concentration = 1E-11 molal
Rock: Calico Hills; Sample YM-38; 49% clinoptilolite
Model: EQ3 with 1-site Vanselow exchange model
Data: Data at 25 ° C from published isotherms; data at other temperatures are estimated
Water/rock ratio = 0.19 mL/g equivalent to fully saturated rock with 30% porosity; *matrix case*
Water/rock ratio = 20.0 mL/g equivalent to LANL batch sorption experiments
Water/rock ratio = ∞ ; *fracture case*

Concluding Comments

- There are both benefits and detriments related to the interaction of repository rock, introduced materials, and groundwater at the temperatures defined by "hot" and "cold" scenarios. Uncertainties are associated with <u>both</u> benefits and detriments
- Geochemical processes and geochemical/ hydrological scenarios are expected to be qualitatively similar over the thermal regime encompassed by the hot and cold scenarios

Concluding Comments

(Continued)

- Uncertainties associated with fundamental geochemical processes are similar for hot and cold scenarios
- Coupling geochemical processes to specific hydrological scenarios introduces greater complexities and hence, greater uncertainties

Resolution of Issues

- Existing scientific plans pertaining to the near-field environment are of wide enough scope so that the uncertainties associated with geochemical processes can be addressed

- Integration of geochemistry and hydrology must take place via analysis of specific scenarios

- Elements of a near-field geochemistry program required to resolve issues:
  - Modeling applications
  - Experimental-rock/water interaction
  - Thermodynamic and kinetic data acquisition and development
  - Model development
  - Natural analogue studies

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT:	**UNCERTAINTIES ASSOCIATED WITH HIGH AND LOW THERMAL LOADING**
PRESENTER:	MICHAEL O. CLONINGER
PRESENTER'S TITLE AND ORGANIZATION:	CHIEF, FIELD ENGINEERING BRANCH YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT LAS VEGAS, NEVADA
PRESENTER'S TELEPHONE NUMBER:	(702) 794-7900

OCTOBER 8 - 10, 1991

Uncertainties Associated with High and Low Thermal Loading

- Establishing and understanding these uncertainties is crucial to the success of the program
- Program will focus on reducing the overall uncertainty to an acceptable level
- For Yucca Mountain, reducing thermal loads may not necessarily result in reducing the overall uncertainty
- DOE considers the following presentations and subsequent discussions as the primary focus of this meeting

Uncertainties Associated With High and Low Thermal Loading

• Geomechanical Uncertainties	L. Costin, SNL
• Hydrogeologic Uncertainties	T. Buscheck, LLNL
• Geochemical Uncertainties	B. Viani, LLNL
• Mineralogical Uncertainties	D. Bish, LANL
• Waste Form Degradation and Materials Uncertainties	G. Gdowski, LLNL
• Biological Resource Concerns	K. Ostler, EG&G

Uncertainties Associated With High and Low Thermal Loading

- Presentations will address the following NWTRB questions for high versus low thermal loadings

1. What are the benefits and potential problems?
2. What is the significance of the benefits, problems?
3. What are the uncertainties associated with the potential problems?
4. Can these uncertainties be resolved?
5. How much time and money will be needed for this resolution?

Uncertainties Associated With High and Low Thermal Loading

- Resolution of uncertainties is included in the Project's current long range plan
  - The approach to resolving these uncertainties is included in SCP Study Plans and other plans
  - The currently planned budget and schedule can accommodate some variation in thermal loading
  - Major shifts to a much lower thermal loading concept may require possible revisions to the current plan

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: **IMPLICATIONS OF HIGHER AND LOWER THERMAL LOADING**

PRESENTER: MICHAEL O. CLONINGER

PRESENTER'S TITLE AND ORGANIZATION:
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OCTOBER 8 - 10, 1991

Implications of Higher and Lower Thermal Loading

- System-wide versus MGDS Implications
- Design enhancement presentations to focus more on MGDS
  - Repository enhancements to reduce geotechnical uncertainties
  - Waste packge enhancements to reduce materials/waste form uncertainties
- The focus should be on reducing uncertainties not thermal loading
- Decisions will follow system-wide studies followed by repository trade-off studies
- Current focus is on site characterization

Design Enchancements to Reduce Materials/Waste Form Uncertainties

- Higher waste package temperatures
  - Redundant barriers during thermal period
  - Corrosion and creep resistant materials

- Lower waste package temperatures
  - Design for aqueous environment
  - Corrosion allowance materials
  - Absorbent packing materials

Implications of Higher and Lower Thermal Loading

• Repository/Waste Package Design Enhancements	T. Blejwas, SNL
• Repository Testing Considerations	T. Blejwas, SNL
• Near-Field Environment Testing Considerations	W. Lin, LLNL
• Waste Form and Materials Testing Considerations	G. Gdowski, LLNL
• NWTRB Invited Presentations	

Implications of Higher and Lower Thermal Loading

Thursday

• HLW System Comparative Costs	D. Jones, Weston
• Regulatory and Legislative Considerations Regarding Thermal Loading	M. Lugo, SAIC
• Conceptual Considerations for Total System Performance	M. Voegele, SAIC
• Summary	M. Cloninger, DOE

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HYDROGEOLOGIC UNCERTAINTIES

PRESENTER: DR. THOMAS A. BUSCHECK

PRESENTER'S TITLE AND ORGANIZATION:
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OCTOBER 8 - 10, 1991

Hydrogeologic uncertainties

- Overview of Yucca Mountain hydrology
- Hydrothermal flow at the repository horizon
- Temperature profiles as a function of thermal load
- Impact of hydrothermal flow on temperature distribution
- Impact of thermal load on repository performance
- Impact of thermal load on hydrogeologic uncertainties
- Conclusions
- Appendix

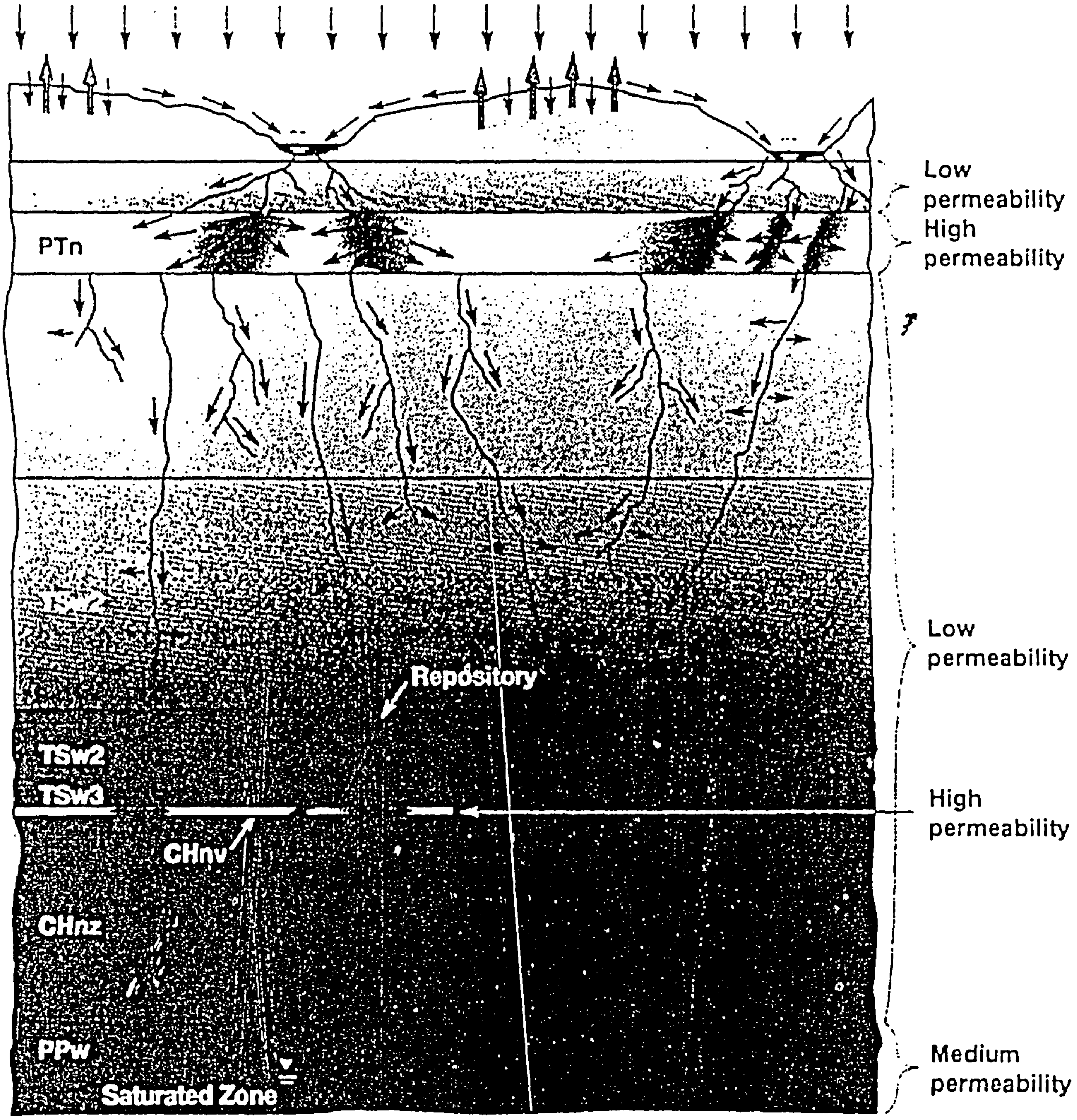
Key repository performance issues depend on hydrology

- Waste package degradation/waste form dissolution
- Radionuclide flow and transport

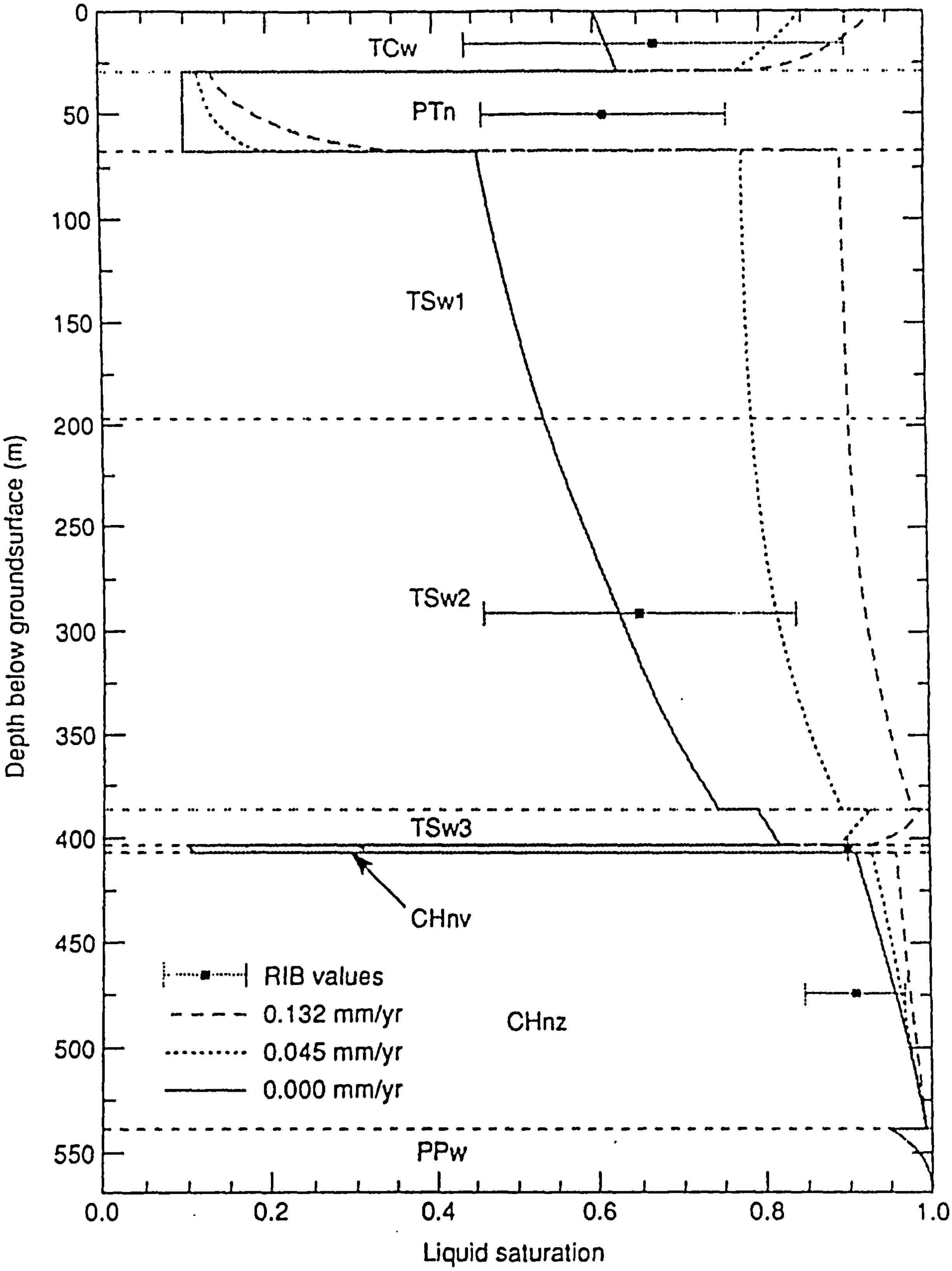
Overview of Yucca Mountain hydrology

- The key consideration is the impact of thermal load on fracture-dominated flow
  - Matrix-dominated flow will not result in significant vertical transport of radionuclides
  - Field evidence indicates fracture-dominated flow can occur to considerable depth
  - Fracture-dominated flow is only credible mechanism bringing water to waste packages and transporting radionuclides
- Boiling and dry-out greatly enhance fracture flow attenuation
  - These effects can reduce the impact of uncertainties

Episodic infiltration occurs as fracture-dominated flow in the low permeability units and matrix-dominated flow in the high permeability units



Liquid saturation profile obtained from several 1-D models of steady-state recharge flux versus saturations from the reference information base (RIB)



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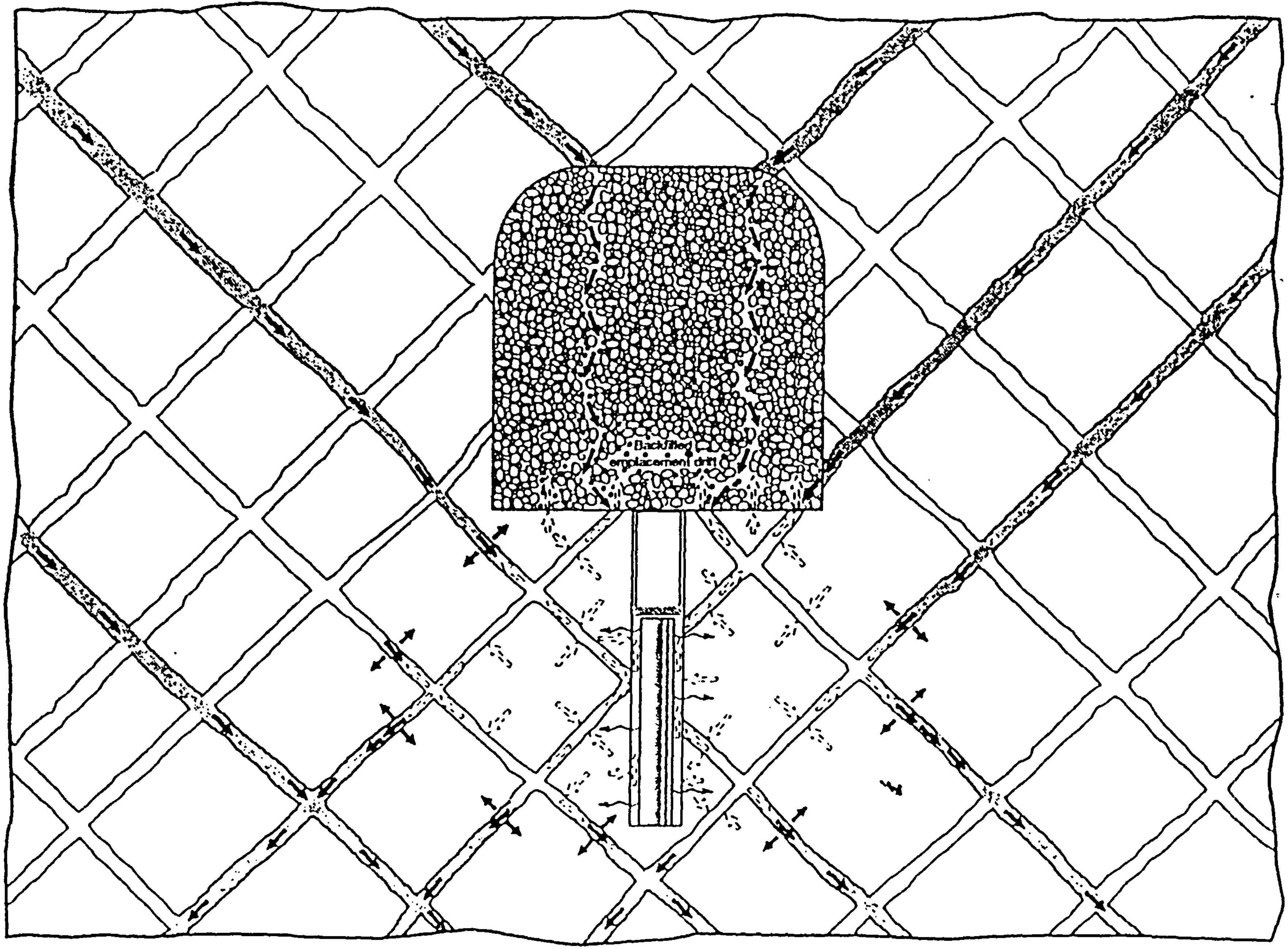
Factors mitigating liquid flow along preferential fracture pathways

- Discontinuity in fracture networks
- Liquid-phase dispersion in fracture networks
- Fracture-matrix interaction
    - For low APD's, only matrix imbibition
    - For high APD's, boiling effects and enhanced imbibition due to dry-out

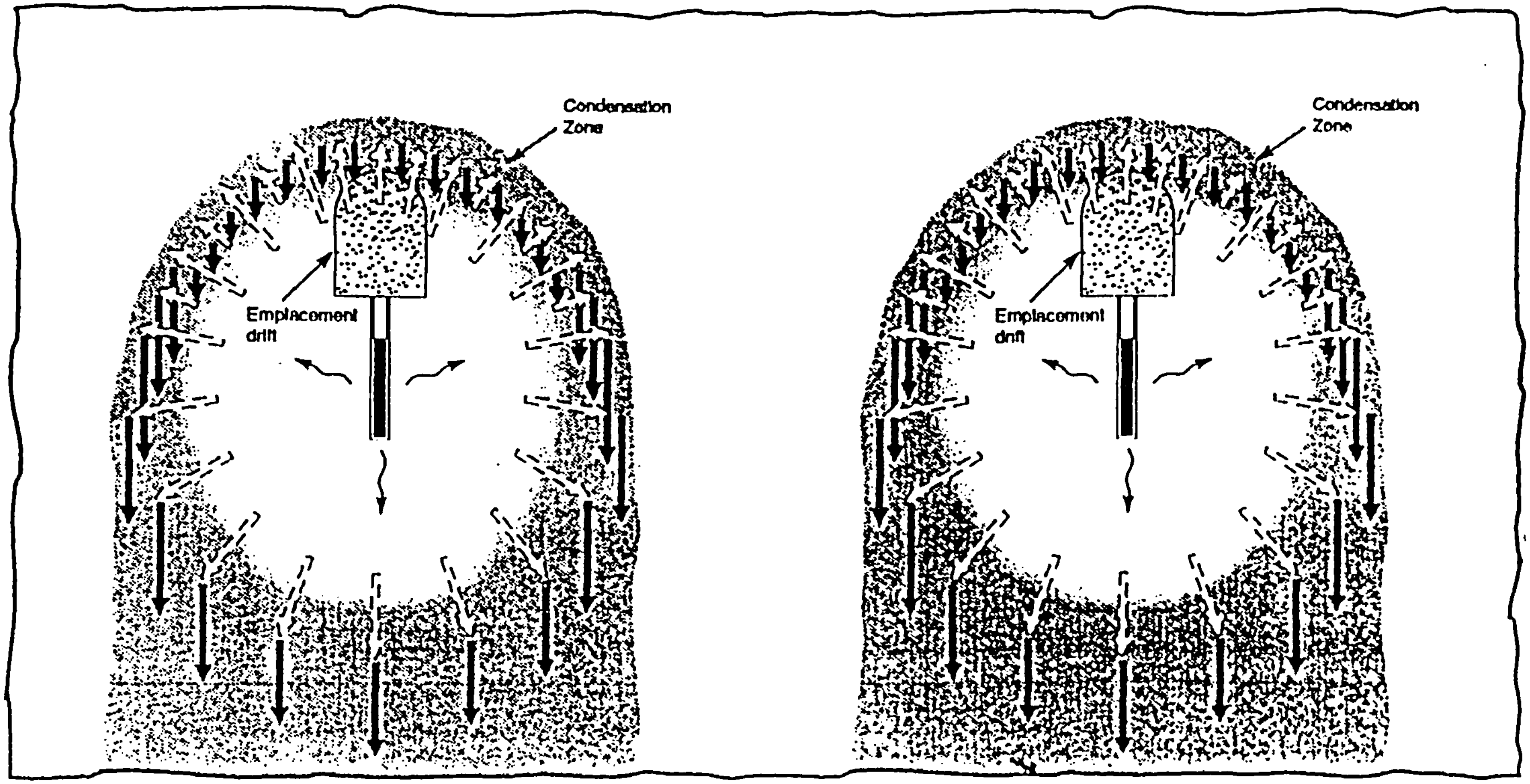
Hydrothermal flow at the repository horizon

- Unsaturated, fractured tuff promotes rock dry-out by boiling
- Volume of dry-out zone is primarily dependent on thermal load and thermal properties
- Fracture-matrix properties of host rock promote rapid condensate drainage
- Volume of dry-out zone can be enhanced by alternative emplacement configurations
- The numerical models used in this study are very conservative in predicting the dry-out volume

Under hydrothermally perturbed conditions, boiling will mitigate episodic fracture flow from reaching the waste package (for up to 1000 years for a repository heat loading rate of 57 *kw/acre*) (Buscheck and Nitao, 1991)

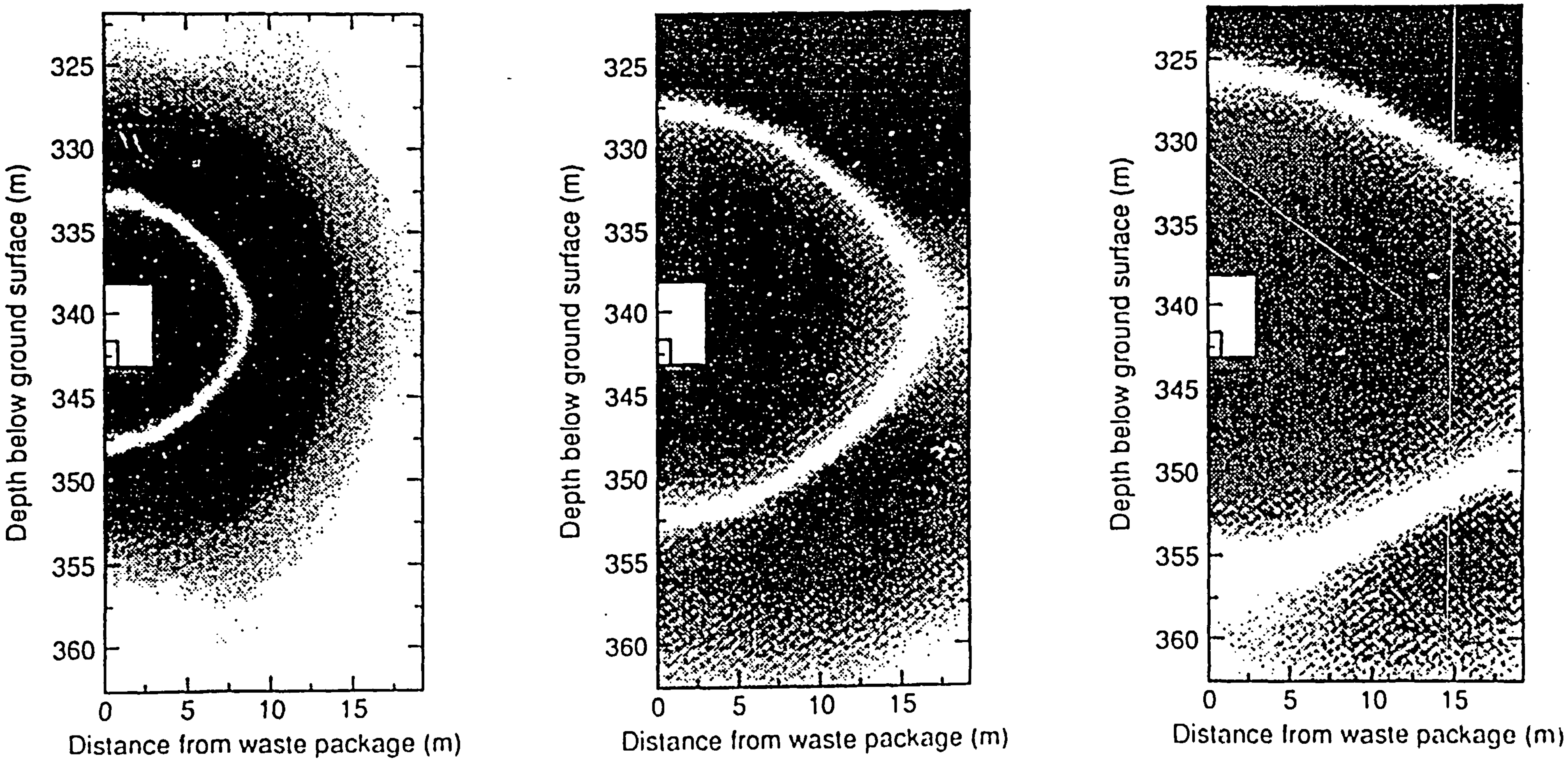


A "hydrothermal umbrella" is established along each of the emplacement drifts due to condensate being shed off of the sides of the boiling zone



The shedding of condensate between emplacement drifts will continue until the boiling zones coalesce approximately 80 years after emplacement

Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre,
a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



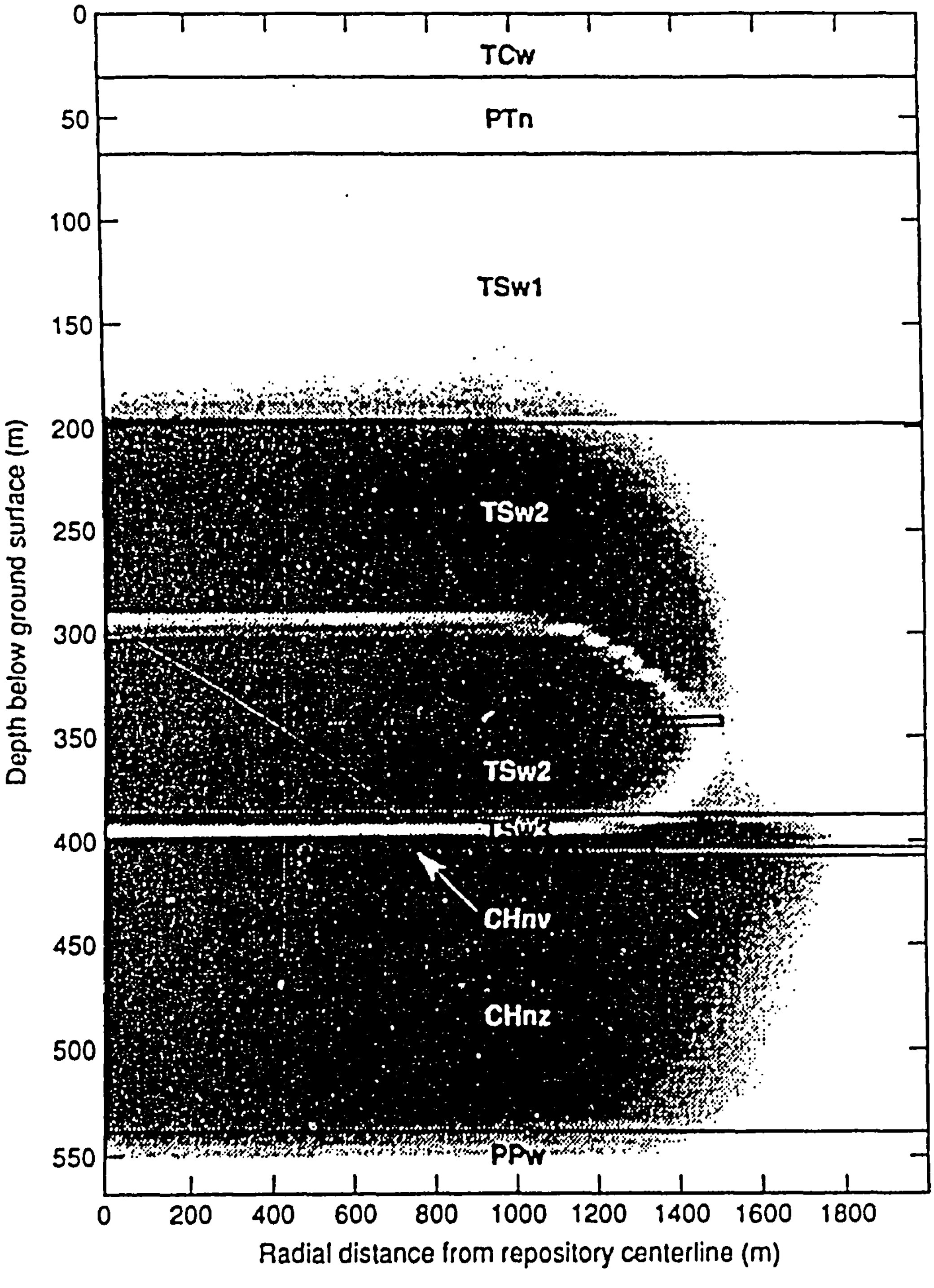
t = 30 yr

t = 60 yr

t = 100 yr

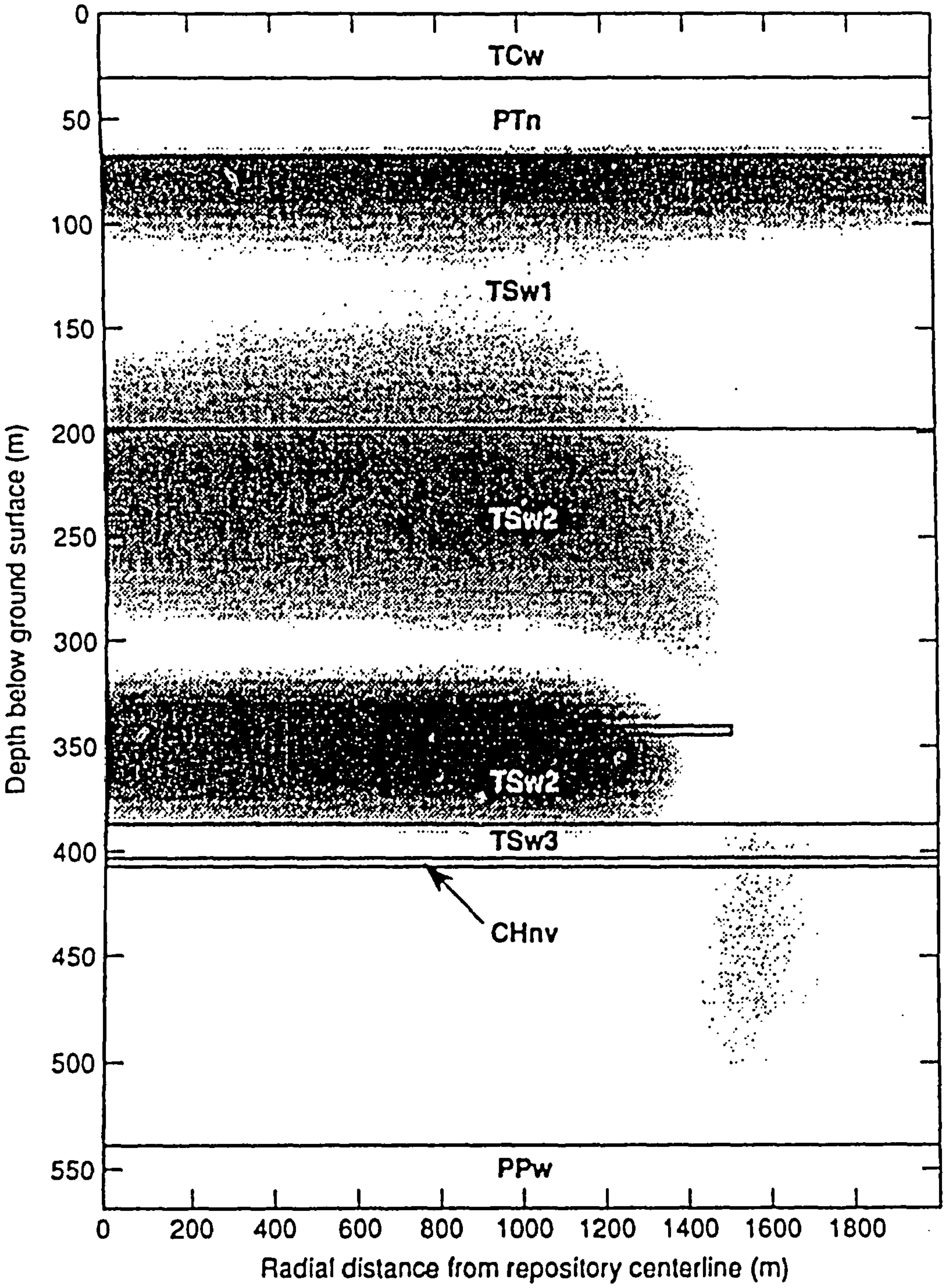
After 1000 years, boiling has resulted in a 100-m-thick dry-out zone, surrounded by a condensation zone, with condensation drainage extending to the water table

Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



Although boiling ceased after 1800 years, most of the repository remains dry 5000 years after emplacement

Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



Temperature profiles as a function of thermal load

- Thermal disturbance reaches ground surface and water table within 300 years

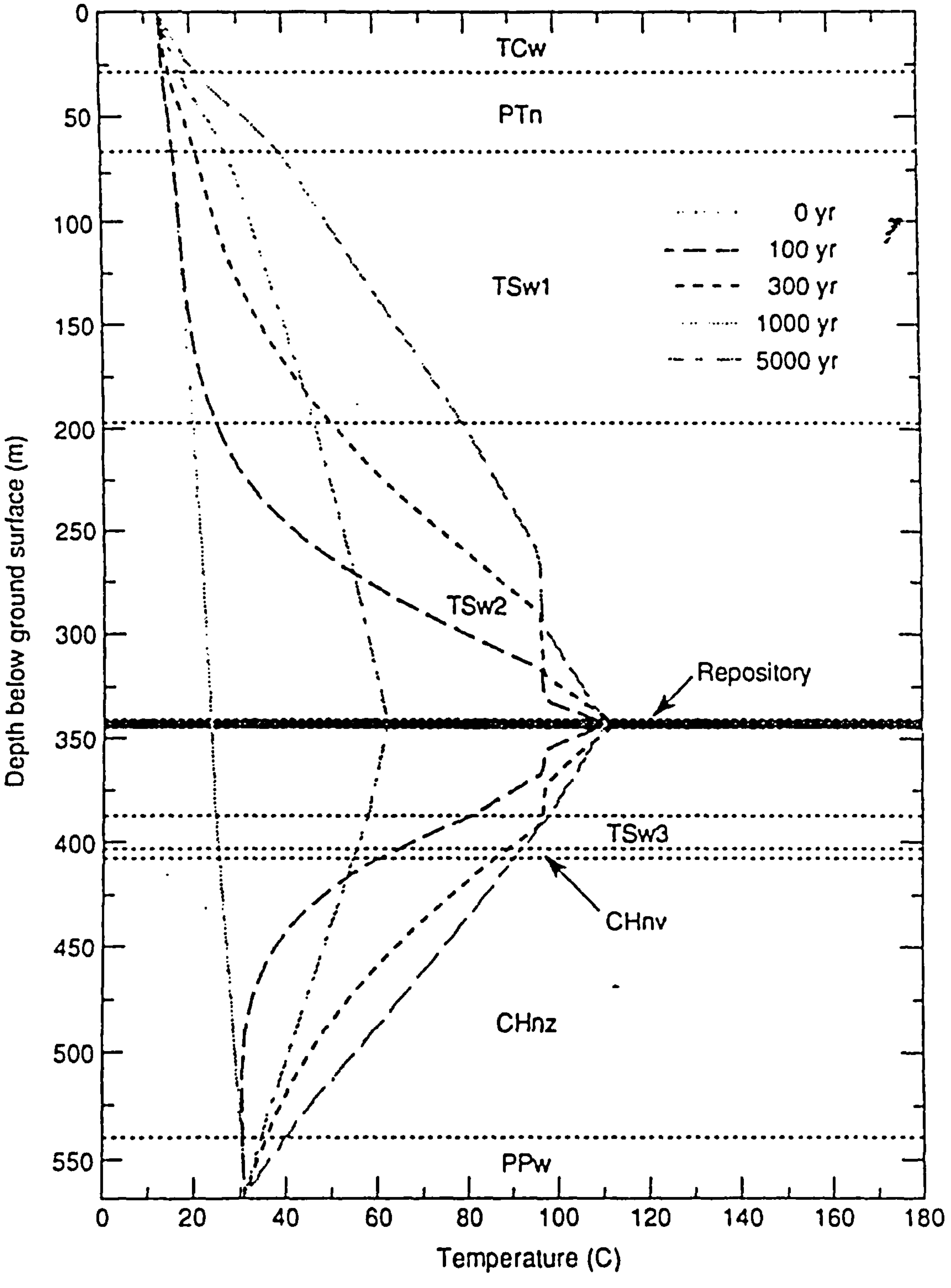
- For given fuel age, temperature rise is linear in APD

- Repository temperatures are uniform within the inner two-thirds of repository area

- The emplacement drift-scale model (which accounts for local thermal load distribution) predicts temperatures similar to those in the inner two-thirds of the repository-scale model (which averages the thermal load)

Temperature profile is flattened at boiling zone (~ 96°C) and the temperature disturbance reaches ground surface 300 years after emplacement

Temperature profile along repository centerline for 30-year-old fuel, an APD of 57 kW/acre, and a recharge flux of 0.000 mm/yr



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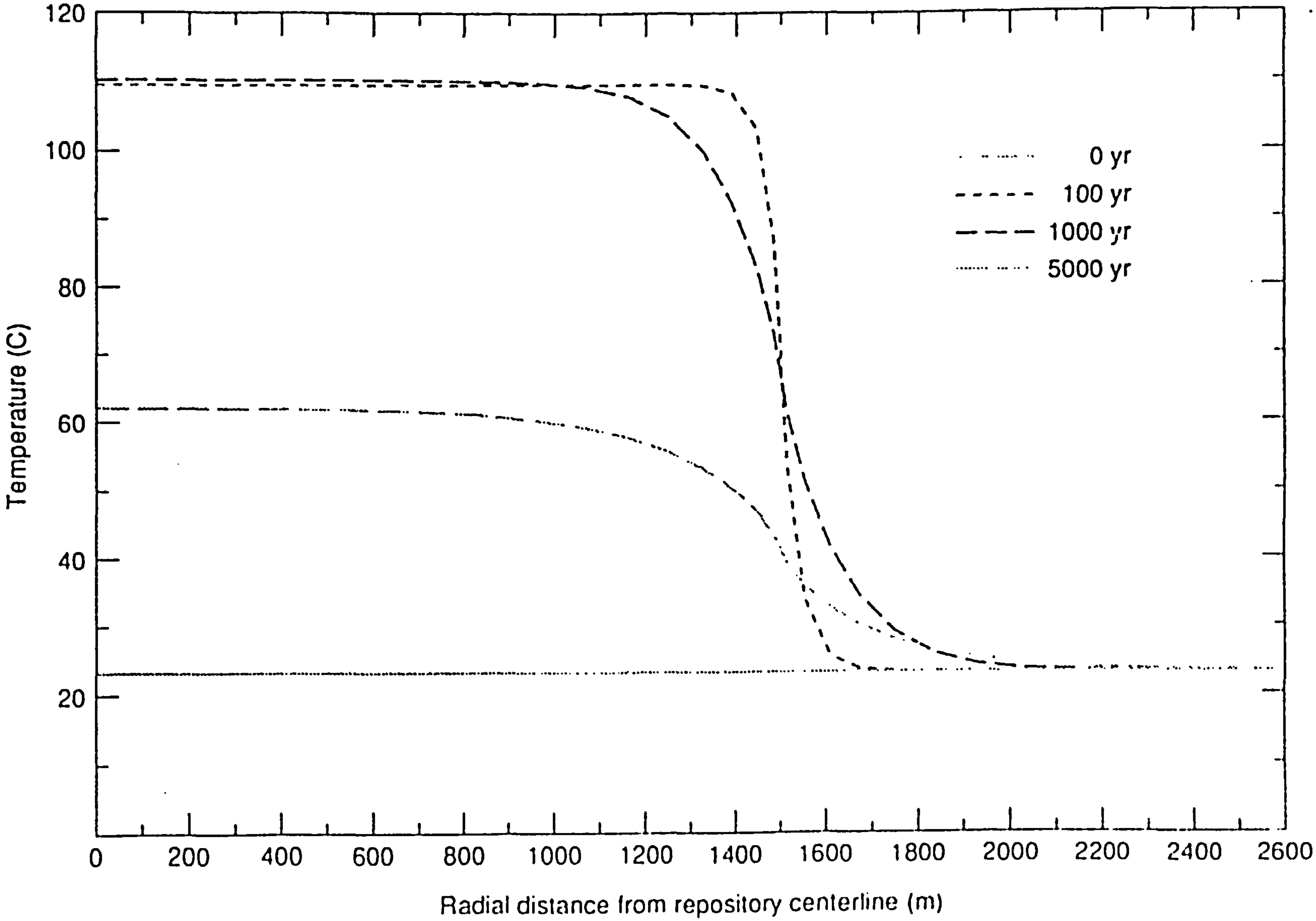
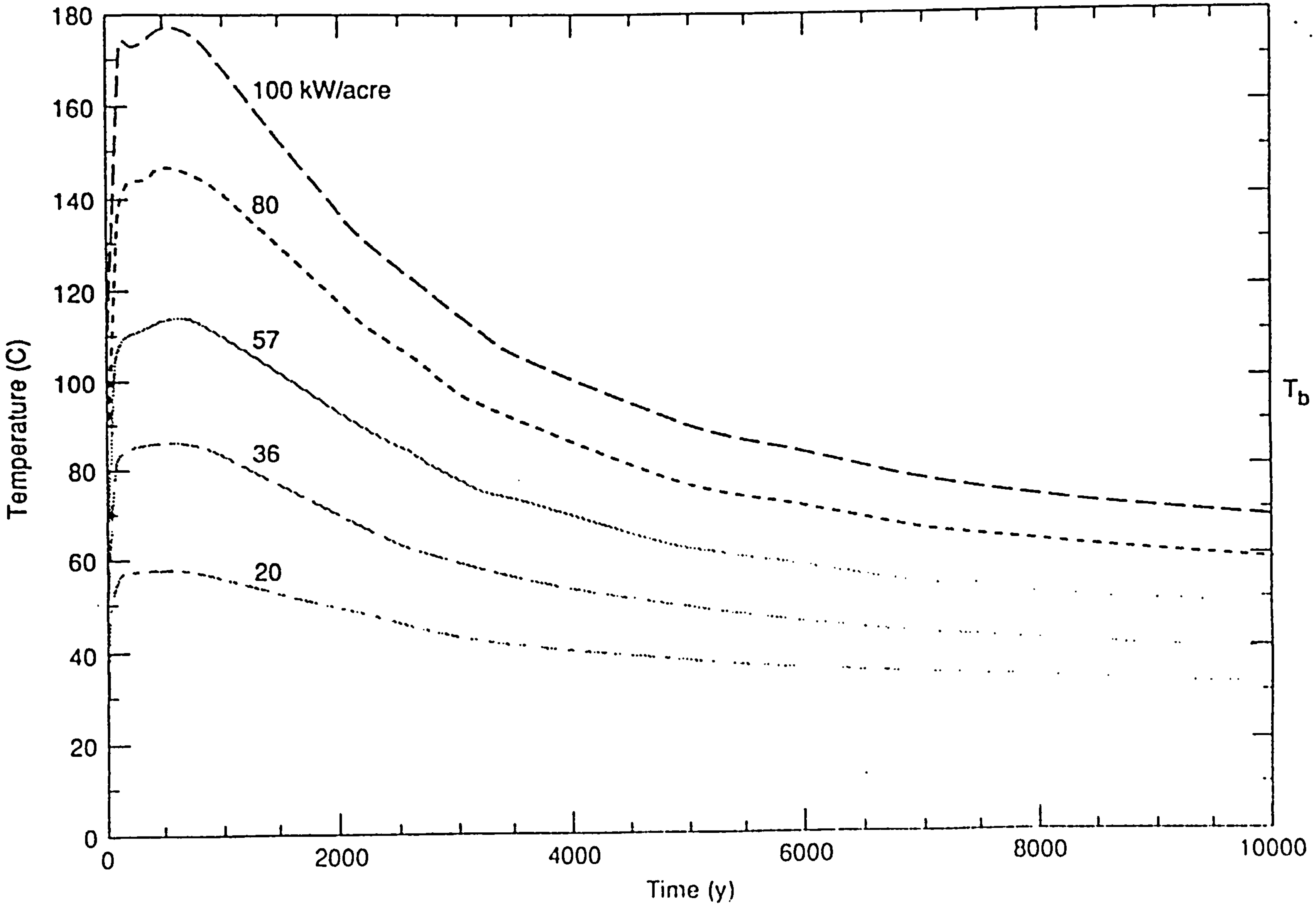
Repository temperatures are uniform within the inner two-thirds of repository

Radial temperature profile at repository horizon for 30-year-old fuel, and an APD of 57 kW/acre, and a recharge flux of 0.0 mm/yr



For a given age fuel, temperature rise is proportional to APD

Temperature history at repository center for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



Impact of hydrothermal flow on temperature field

- For 30-year-old fuel and APDs up to 100 kW/acre, heat flow around the repository is dominated by heat conduction

- Temperatures in the vicinity of the waste packages decrease modestly with increasing recharge flux

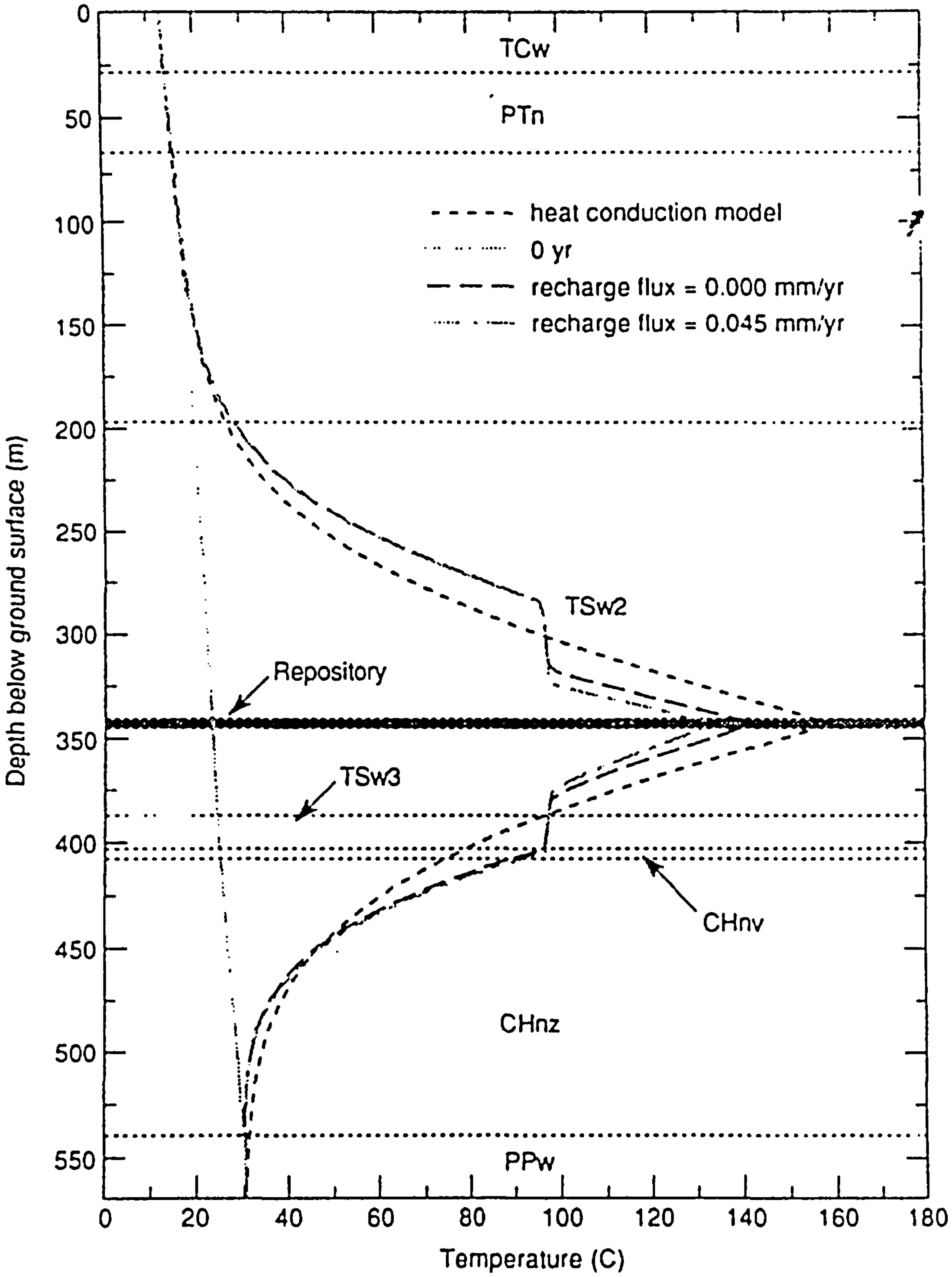
- Boiling results in lower temperatures in the vicinity of the waste packages

- Heat conduction models yield
  - conservatively high temperatures in the vicinity of the waste packages
  - conservatively low temperatures with respect to the extent of the boiling zone

- Hydrothermal models predict higher temperatures in the Calico Hills units (CHnv and CHnz)

The heat conduction model yields conservatively high temperatures near the waste packages and conservatively low temperatures with respect to the extent of boiling

Temperature profile along repository centerline for 30-yr-old fuel, and APD of 57 kW/acre predicted by the hydrothermal and heat conduction models at t = 100 yr



Impact of thermal load on repository performance

- The threshold for significant rock dry-out benefits occurs between 36 and 57 kW/acre for 30-yr-old fuel

- For low-to-medium APD's (20 to 40 kW/acre for 30-yr-old fuel) performance considerations remain with no dry-out benefits

- Substantial boiling and dry-out benefits occur for high APD's
  - Dry steam boiling conditions persist at the waste package for thousands of years
  - Rock dry-out benefits remain thousands of years after boiling ceases

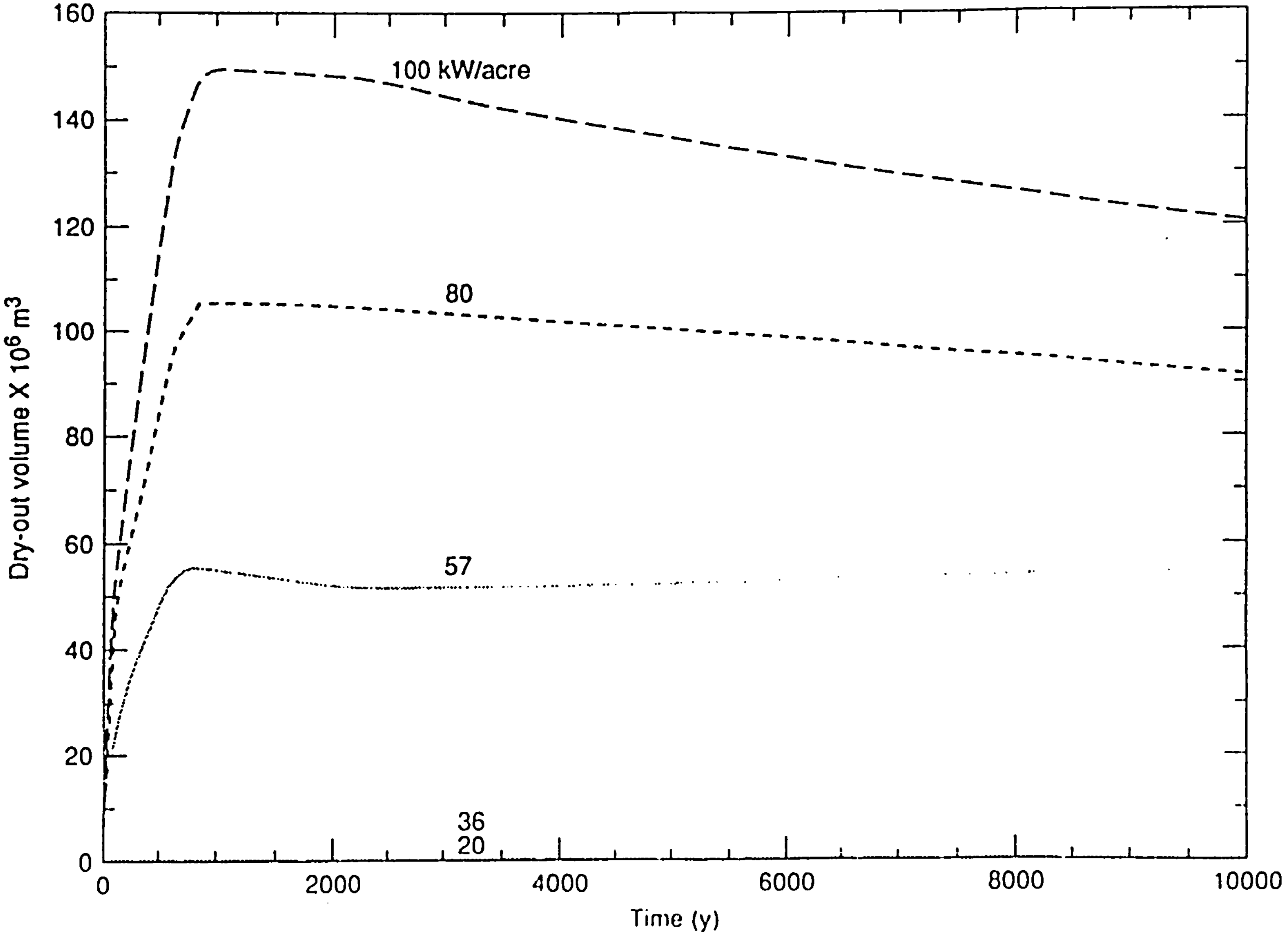
- For drift emplacement, substantial dry-out benefits are obtained with minimal impact on waste package temperatures

- Even high APD's result in minimal temperature disturbance at ground surface

- Boiling conditions and rock dry-out greatly enhance fracture flow attenuation

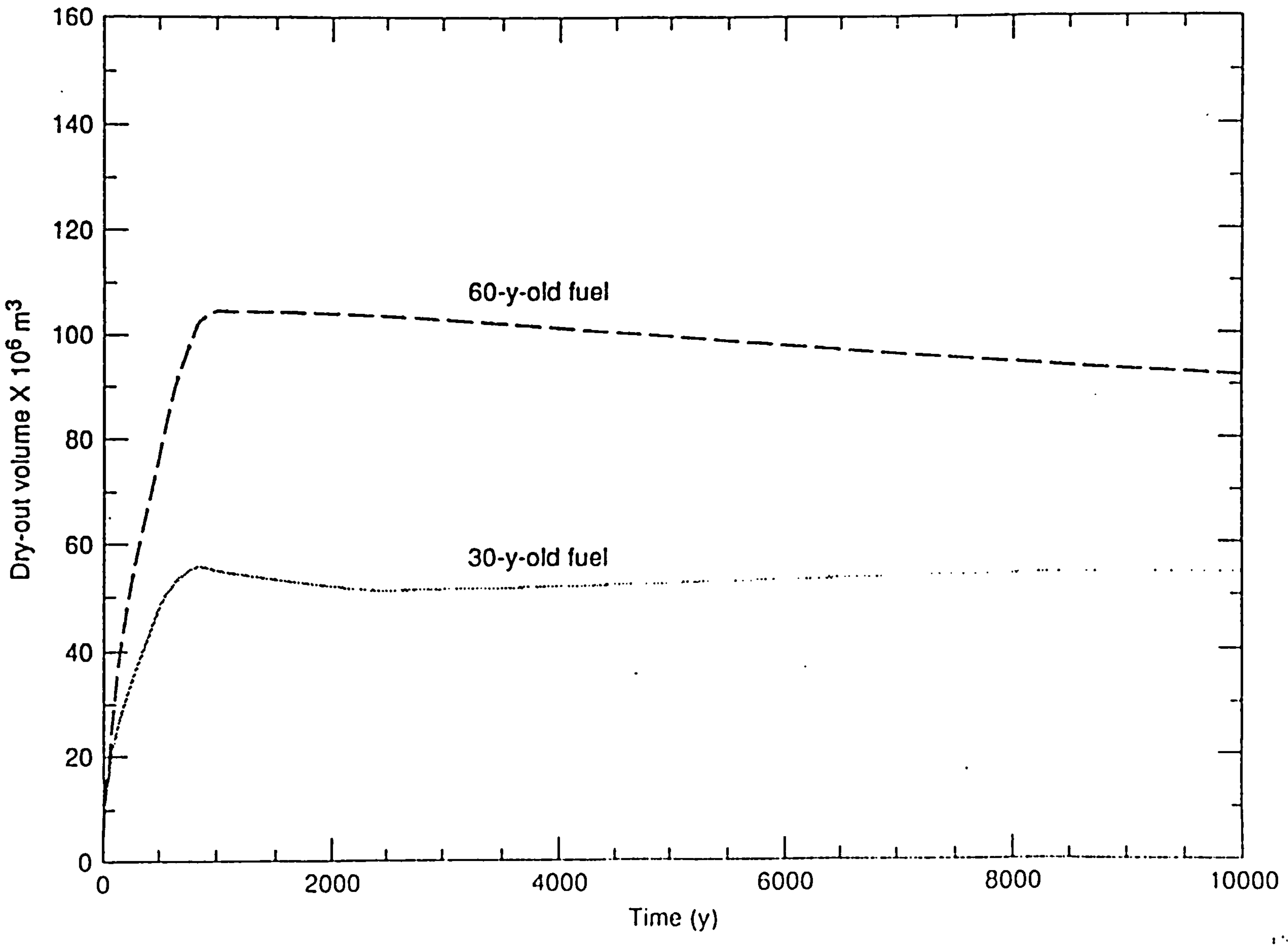
For 30-yr-old fuel, the threshold APD for significant dry-out by boiling lies between 36 and 57 kW/acre

Dry-out volume of liquid water vs. time for 30-yr-old fuel, and a recharge flux of 0.0 mm/yr



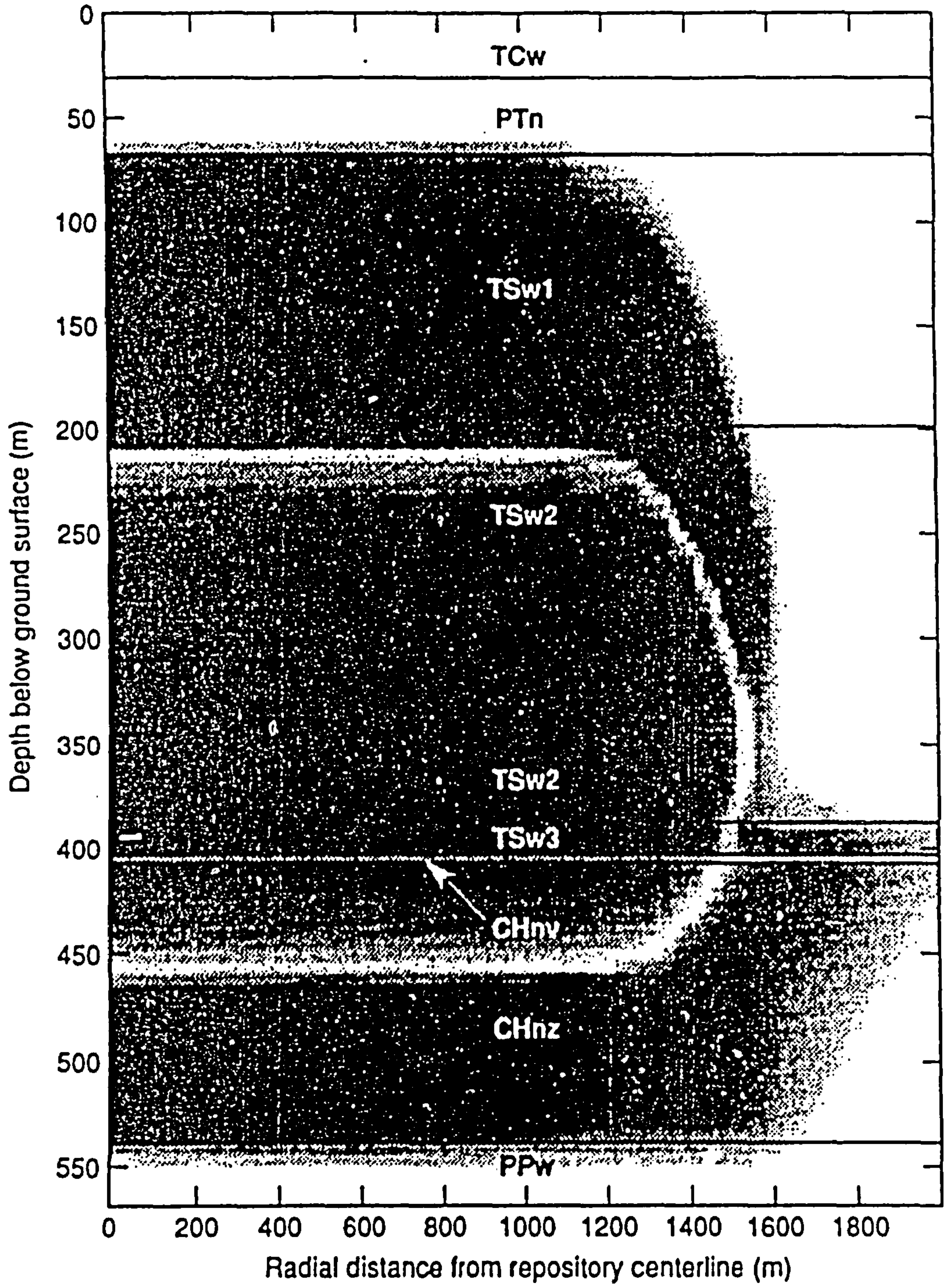
For a given APD, dry-out benefits can be substantially increased using older age fuel

Dry-out volume of liquid water vs. time for an APD of 57 kW/acre, and a recharge flux of 0.0 mm/yr



After 1000 years, boiling has resulted in a 250-m-thick dry-out zone, surrounded by a condensation zone, with condensation drainage extending to the water table

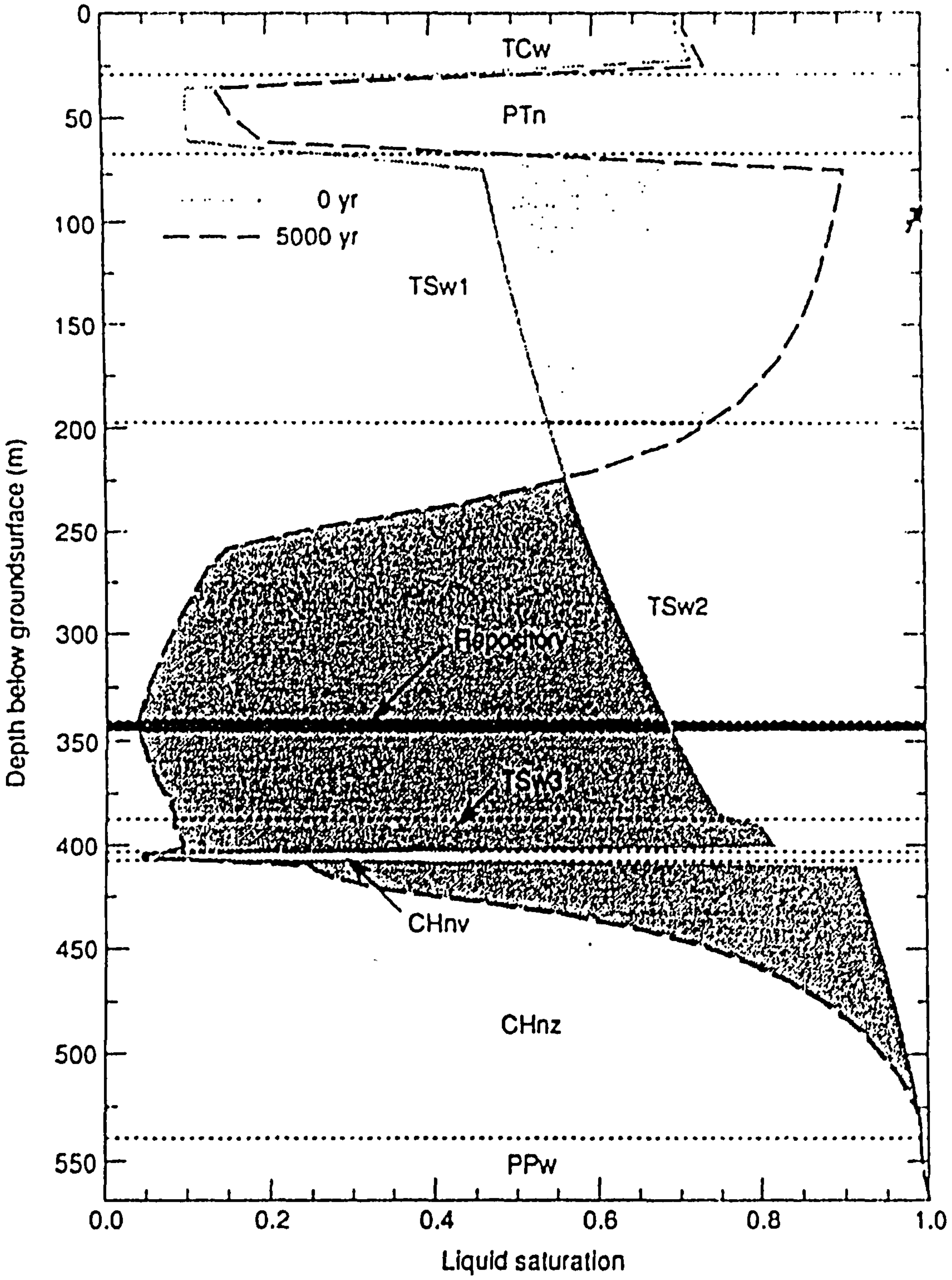
Dimensionless liquid saturation for 30-year-old fuel, an APD of 100 kW/acre, and a recharge flux of 0.0 mm/y



ES TB 1019 28-91) 4

Although boiling ceased after 4200 years, a 150-m-thick dry-out zone remains, and much of the Calico Hills (CHnv and CHnz) is drier than initial saturation at t = 5000 yr

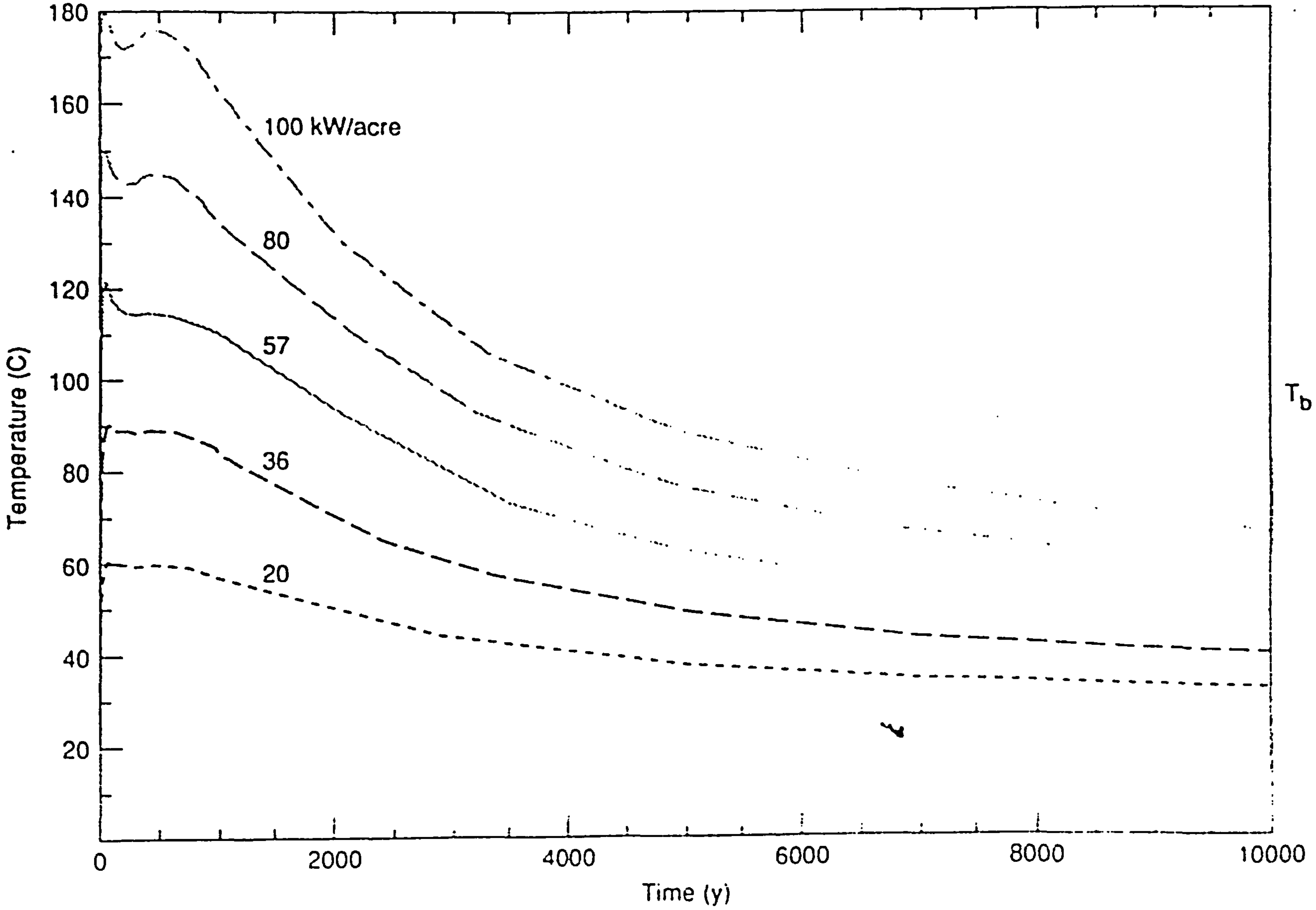
Liquid saturation profile along repository centerline for 30-yr-old fuel, an APD of 100 kW/acre, and a recharge flux of 0.0 mm/yr



[illegible]

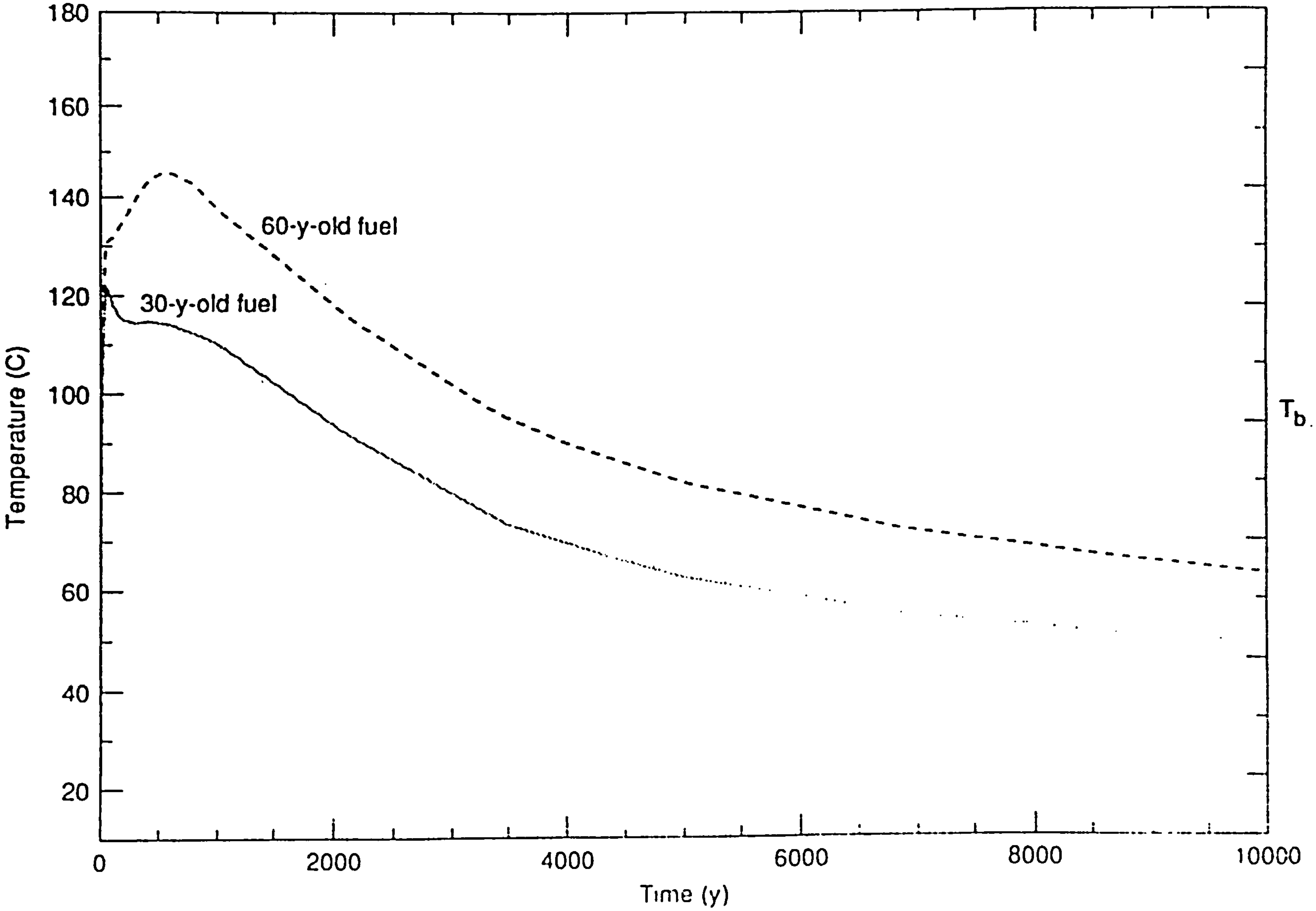
Dry steam boiling conditions persist at waste package environment for thousands of years for high APD's

Drift wall temperature for drift emplacement of 30-yr-old fuel



For a given APD, the duration of dry steam boiling conditions is substantially increased using older age fuel with minimal impact on waste package temperatures

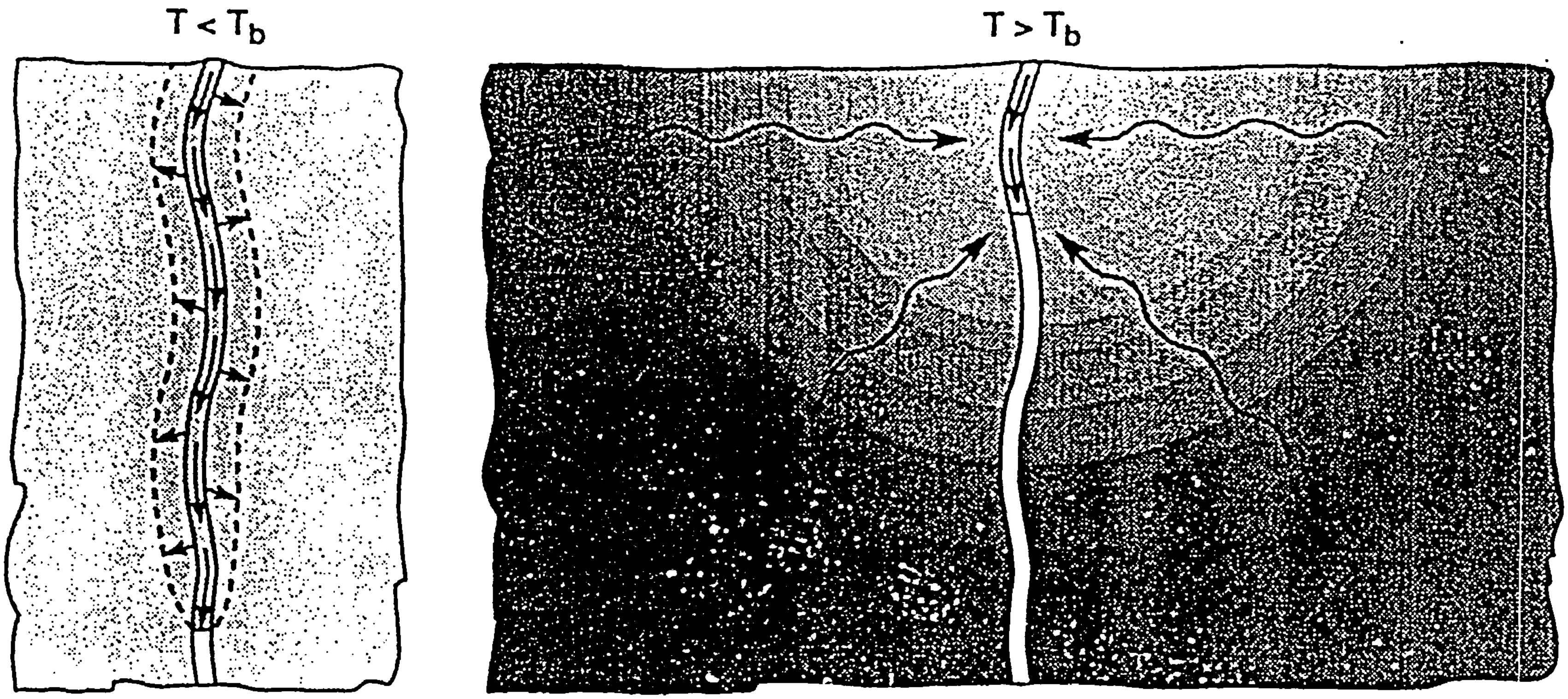
Drift wall temperature history for drift emplacement for an APD of 57 kW/acre



Ground surface temperature effects

- For 30-year-old fuel and APDs up to 100 kW/acre, heat flux at the ground surface never exceeds 1.5 W/m^2
    - Therefore, the temperature rise at the ground surface should never exceed 1°C

Above the repository horizon, the attenuation of fracture flow will be much greater for boiling conditions than for sub-boiling conditions



$T < T_b$

$T > T_b$

$V_m \equiv$ Matrix volume affecting fracture flow

$V_m\,(T < T_b) \sim \sqrt{D_{cap}}$

where $D_{cap} \equiv$ capillary diffusivity

for TSw2, $D_{cap} \approx 2 \times 10^{-9}\ \frac{m^2}{s}$

$V_m\,(T > T_b) \sim \sqrt{D_{th}}$

where $D_{th} \equiv$ thermal diffusivity

for TSw2, $D_{th} \approx 1 \times 10^{-6}\ \frac{m^2}{s}$

$$\therefore\ \frac{V_m\,(T > T_b)}{V_m\,(T < T_b)} \approx 22$$

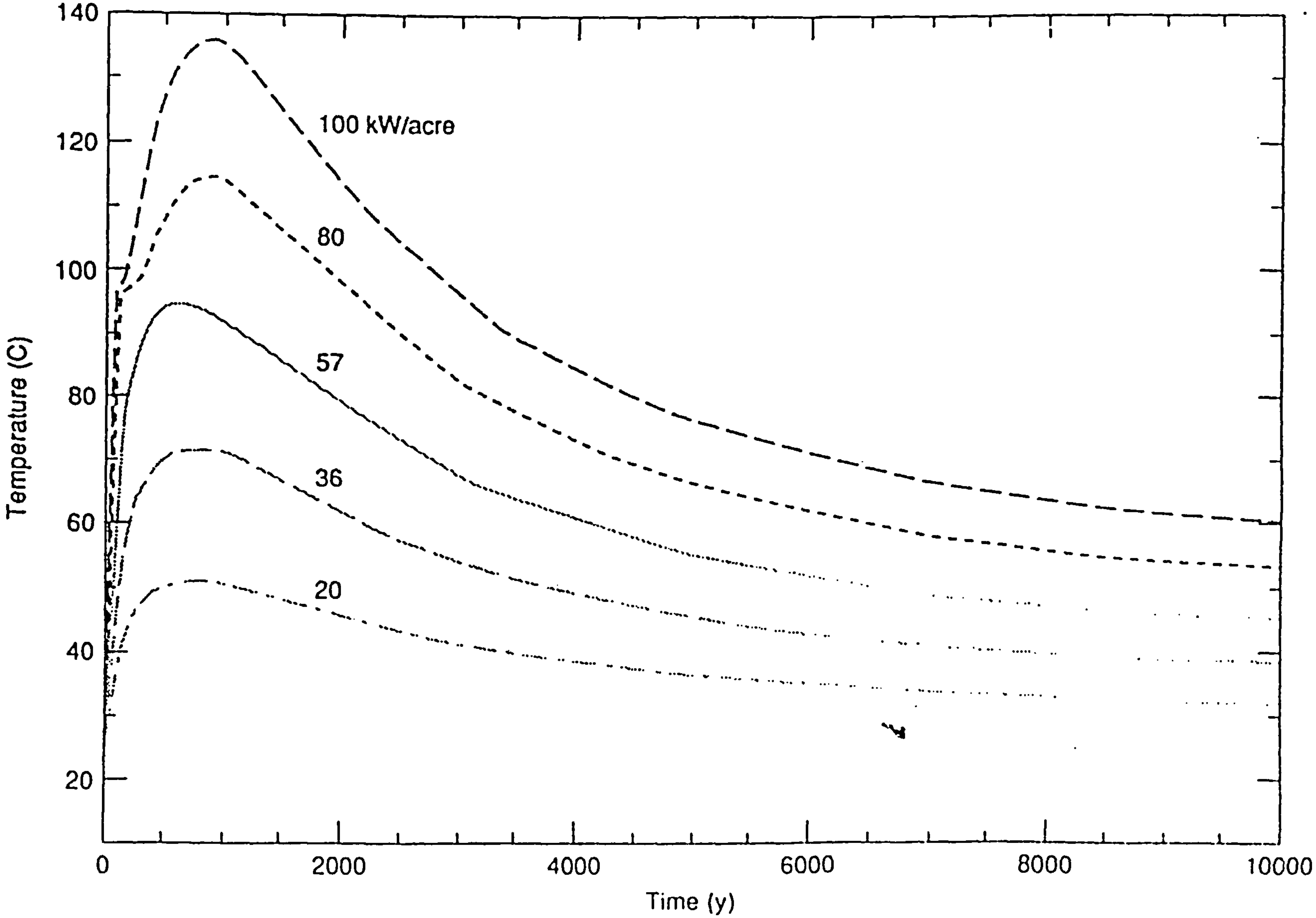
Impact of thermal load on hydrogeologic uncertainties

- For APD's as low as 20 kW/acre, the flow and transport properties of potential radionuclide pathways may be significantly altered

- The hydrologic performance of the repository is much less sensitive to hydrogeologic uncertainty at high APD's than at low APD's

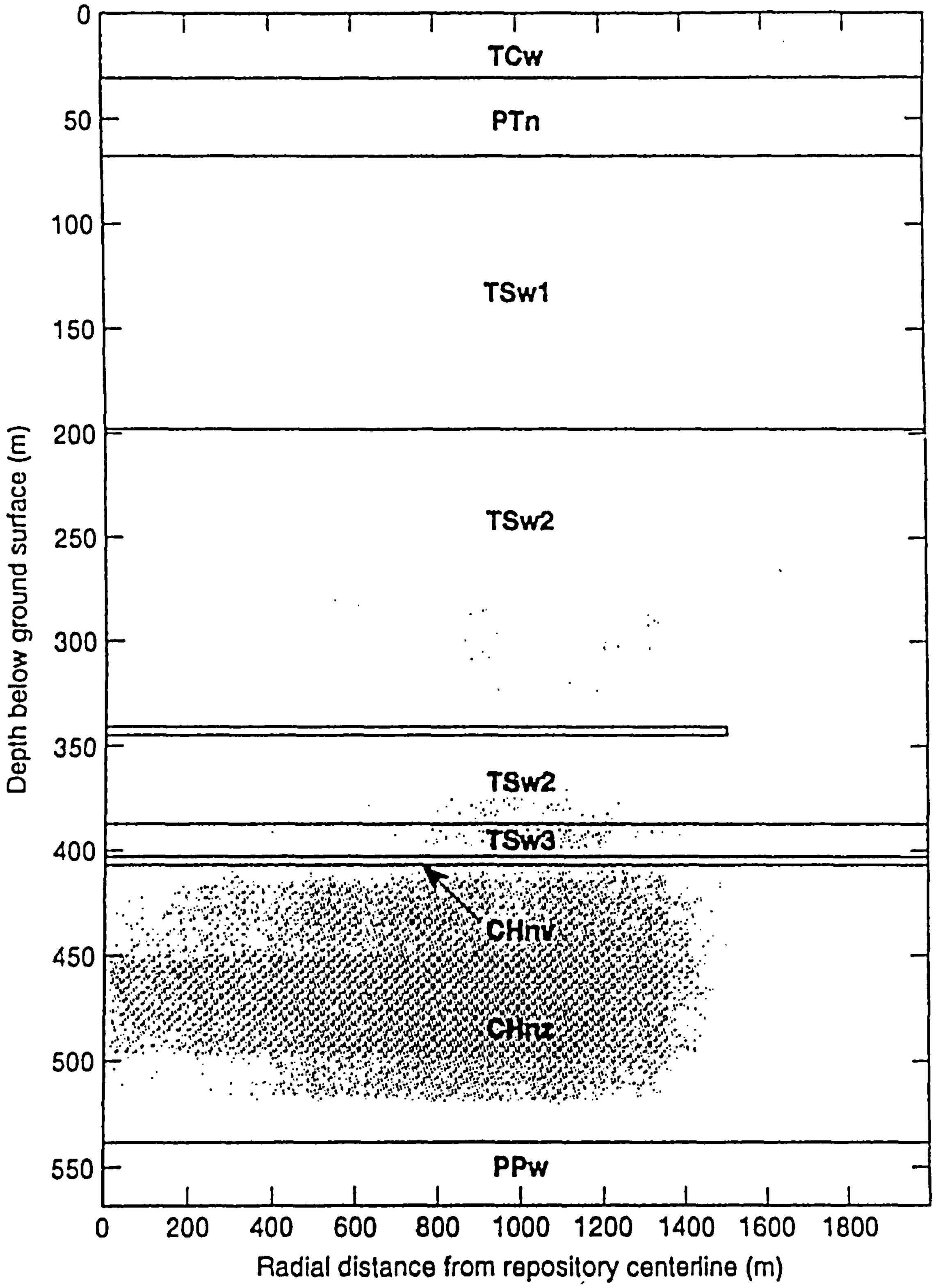
For a given fuel age, temperature rise at the top of the Calico Hills (CHnv) is proportional to APD

Temperature history at top of the CHnv, 60 m below the repository horizon
for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



Although boiling and dry-out benefits are negligible, condensation drainage extends all the way to the water table

Dimensionless liquid saturation for 30-year-old fuel, an APD of 20 kW/acre, and a recharge flux of 0.0 mm/yr



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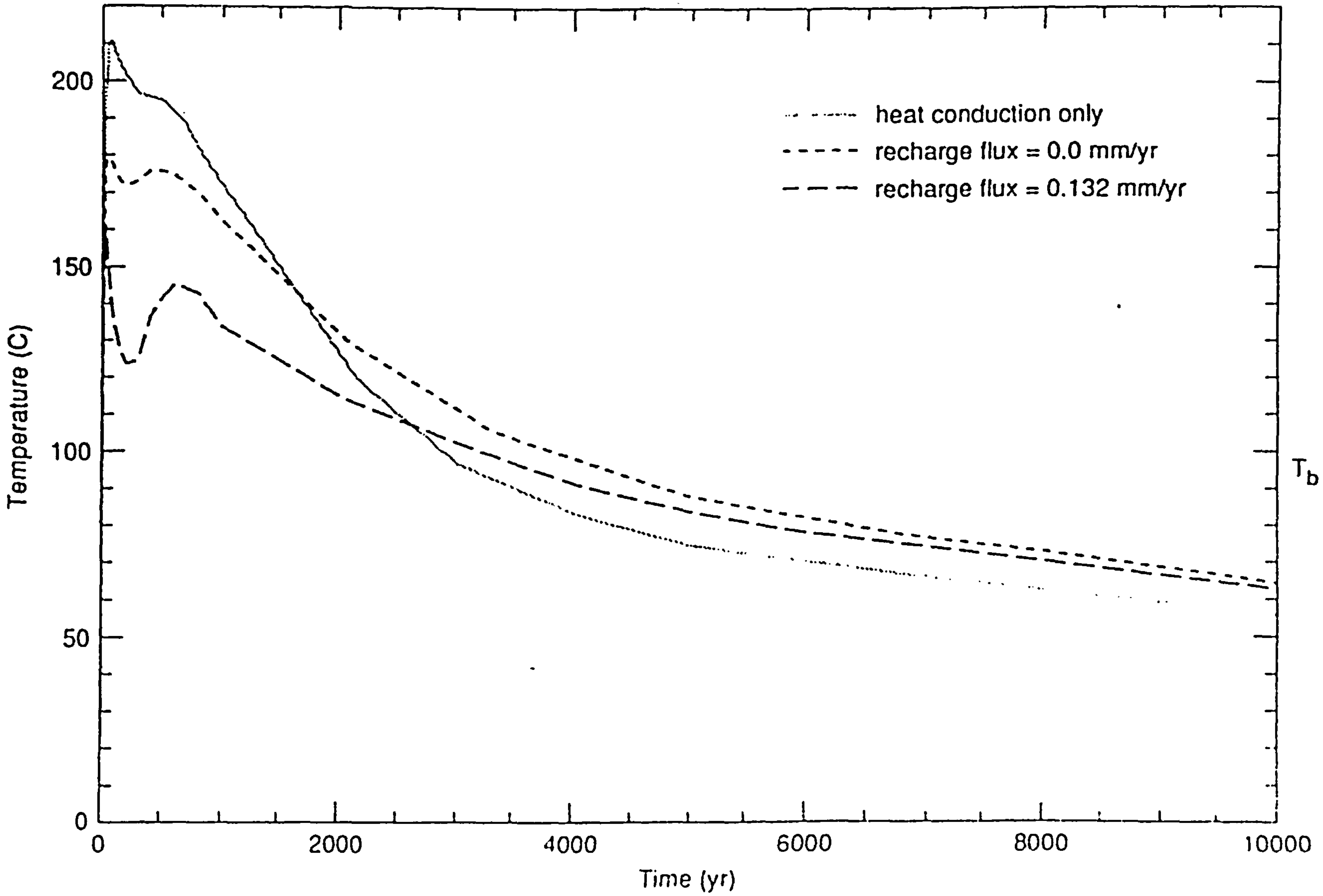
The duration of dry steam boiling conditions is relatively insensitive to a large range in initial saturation; the heat conduction model conservatively predicts duration of boiling conditions

Drift wall temperature for drift emplacement, 30-yr-old fuel, and an APD of 100 kW/acre



Key hydrogeologic/geochemistry uncertainty considerations

- Zeolitization of the vitric nonwelded CHnv even at low APD's
- Alteration of flow and transport properties of fracture pathways in the zeolitized nonwelded CHnz even at low APD's
  - Impact on performance may be significant for low-to-medium APD's
  - Impact on performance is much less significant for high APD's

Key hydrogeologic/geomechanical uncertainty considerations

- Thermally-induced macro-fracturing near openings
    - may result in additional preferential pathways
    - may also result in increased liquid-phase dispersion in fracture networks
- Thermally-induced micro-fracturing out to the boiling front
    - may increase matrix capillary diffusivity, enhancing the impact of matrix imbibition on fracture flow attenuation
- Both macro- and micro-fracturing may enhance rock dry-out rate due to boiling

Conclusions

Questions 1-3: Significance of benefits/problems; associated uncertainties

- Vapor and liquid flow in fractures is the key hydrogeologic consideration
- Repository performance at higher APD's is much less sensitive to hydrogeologic variability/uncertainty
- Unsaturated, fractured tuff promotes rock dry-out by boiling and rapid condensate drainage
    - Rock dry-out volume dominated by thermal load and thermal properties
- For higher APD's and older age fuel, boiling and rock dry-out benefits persist for thousands of years
    - Promoting more favorable waste package conditions
    - Greatly enhancing fracture flow attenuation
- Performance problems remain at lower APD's with no dry-out benefits

Conclusions (continued)

Question 3: Uncertainties

- Performance modeling of high APD's is much less sensitive to hydrogeologic variability/uncertainty
- Data on fracture network properties is currently limited
- In situ test data for hydrothermal model validation is currently limited to G-Tunnel experiments

Question 4: Uncertainty resolution

- Site characterization/ESF testing/prototype testing
    - Testing under boiling conditions provides better experimental basis for model validation
    - More likely to adequately resolve uncertainties associated with high APD's than with low APD's

Appendix

With respect to fracture-matrix flow, the hydrostratigraphic units at Yucca Mountain fall into two distinct categories

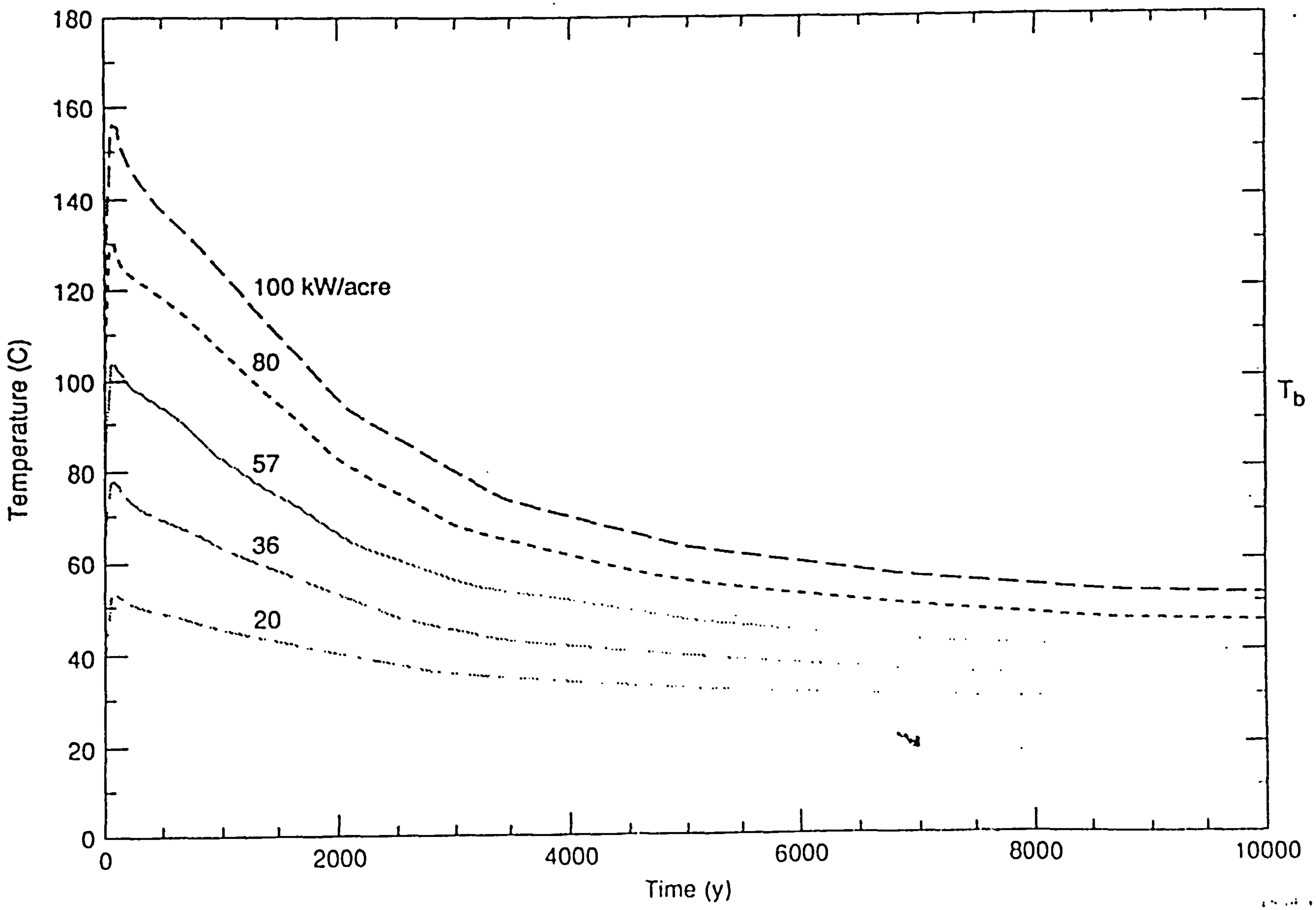
- The low matrix permeability of the welded units (TCw, TSw1, TSw2, and TSw3) and the zeolitized nonwelded unit (CHnz) promotes fracture-dominated flow (given a sufficient infiltration source)

- The high matrix permeability of the vitric nonwelded units (PTn and CHnv) generally promotes matrix-dominated flow

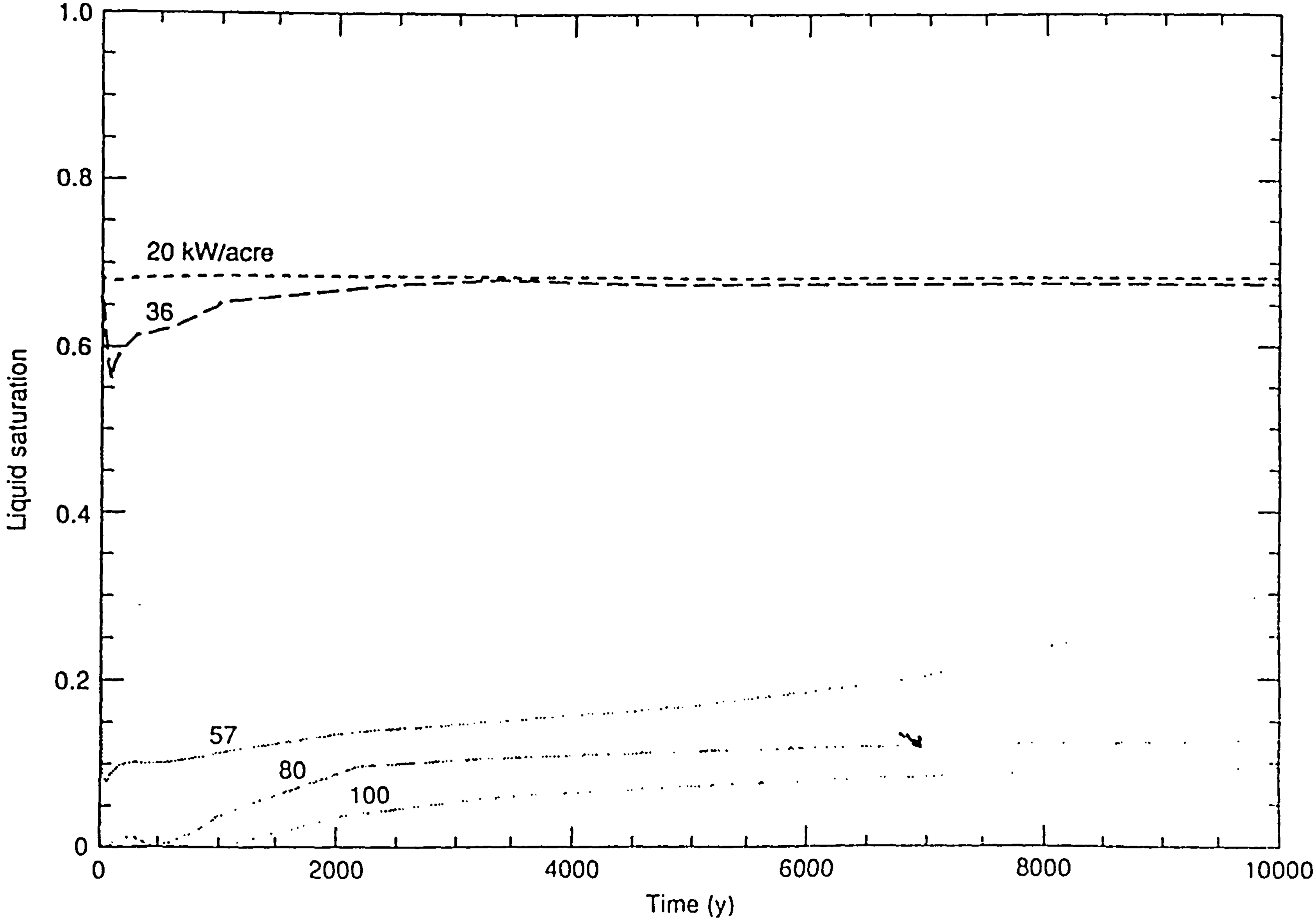
- The hydrostratigraphy and hydrologic property values used in this study are obtained from Klavetter and Peters (1986)

Temperatures decline more quickly at edge of repository; however, dry steam boiling conditions persist for 2000 years for an APD of 100 kW/acre

Temperature history at edge of repository for 30-yr-old fuel and a recharge flux of 0.0 mm/yr

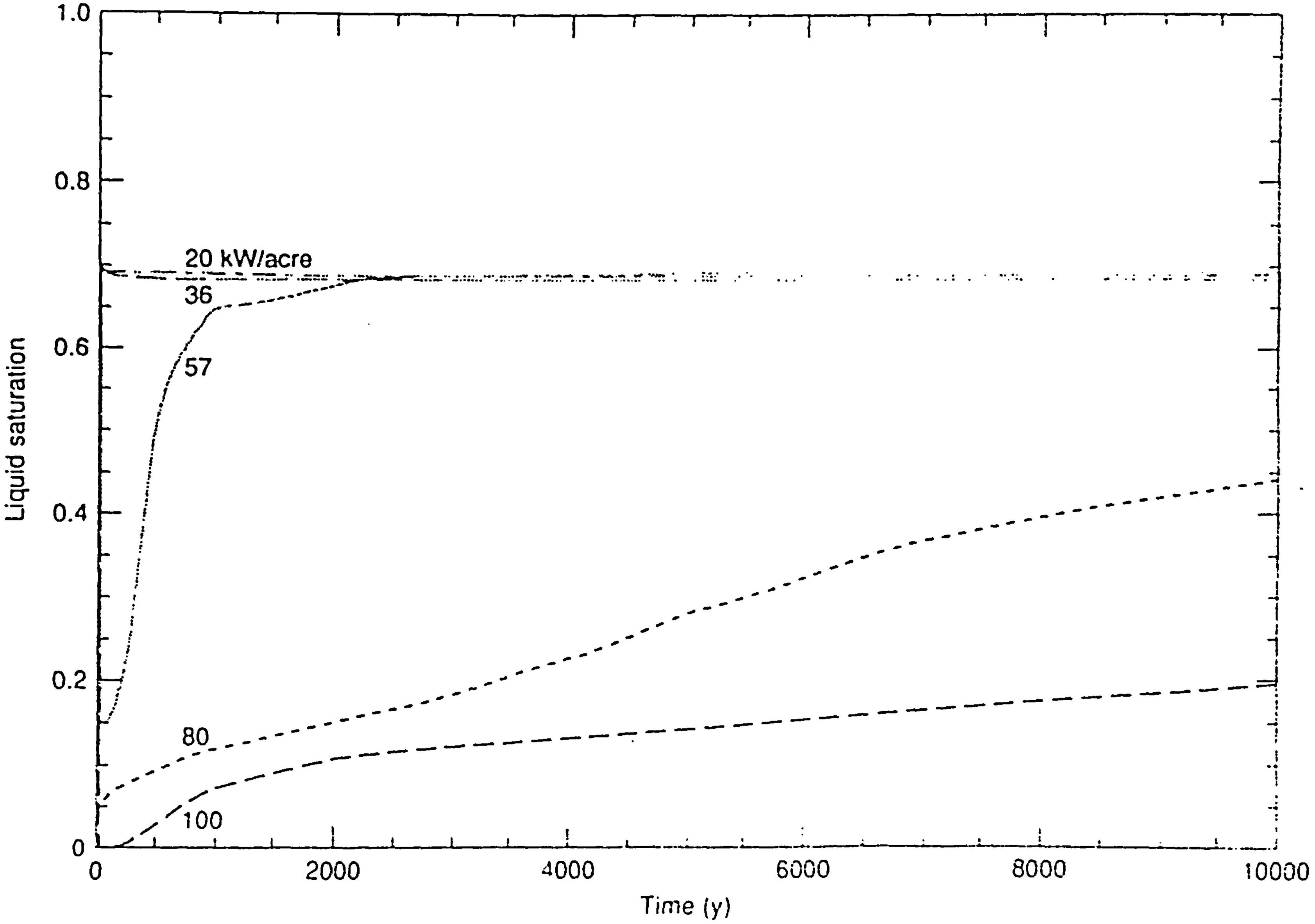


For 30-yr-old fuel, the threshold APD for significant dry-out by boiling lies between 36 and 57 kW/acre


Liquid saturation history at drift wall for drift emplacement for 30-year-old fuel and a recharge flux of 0.0 mm/yr

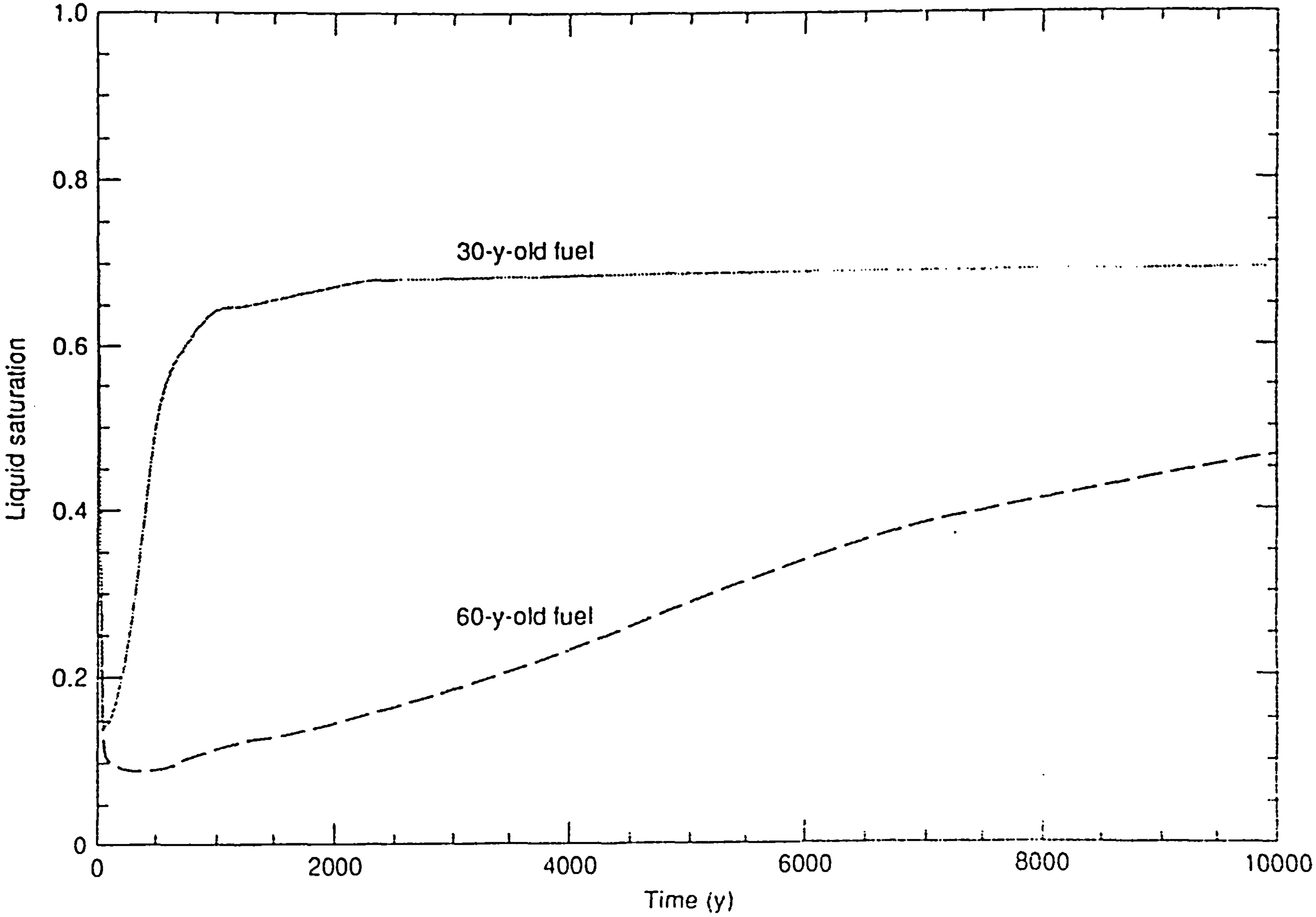
Rock dry-out benefits persist at edge of repository for high APD's

Liquid saturation at edge of repository for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



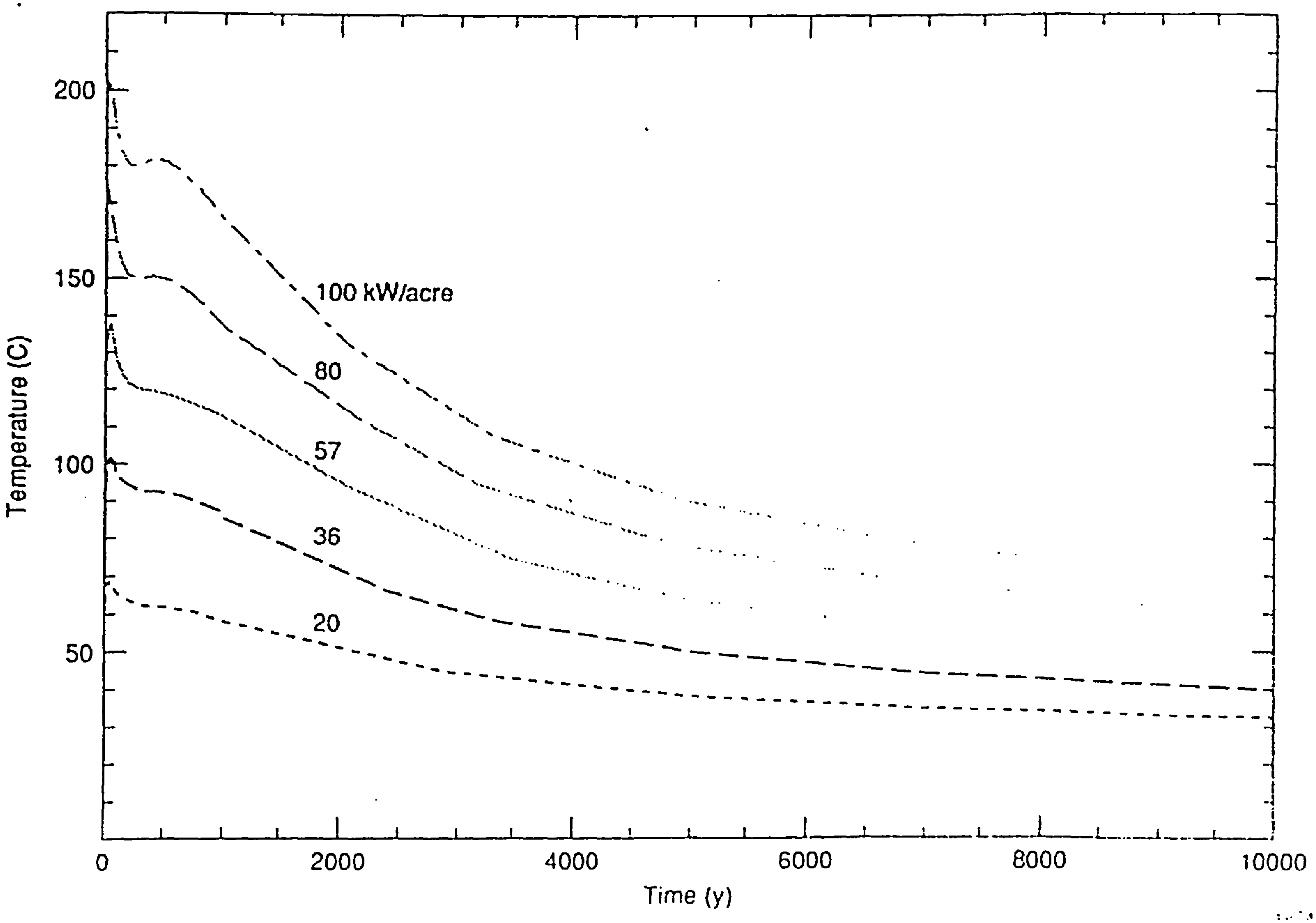
For an APD of 57 kW/acre, rock dry-out benefits persist at edge of repository for 60-yr-old fuel

Liquid saturation at edge of repository for an APD of 57 kW/acre and a recharge flux of 0.0 mm/yr



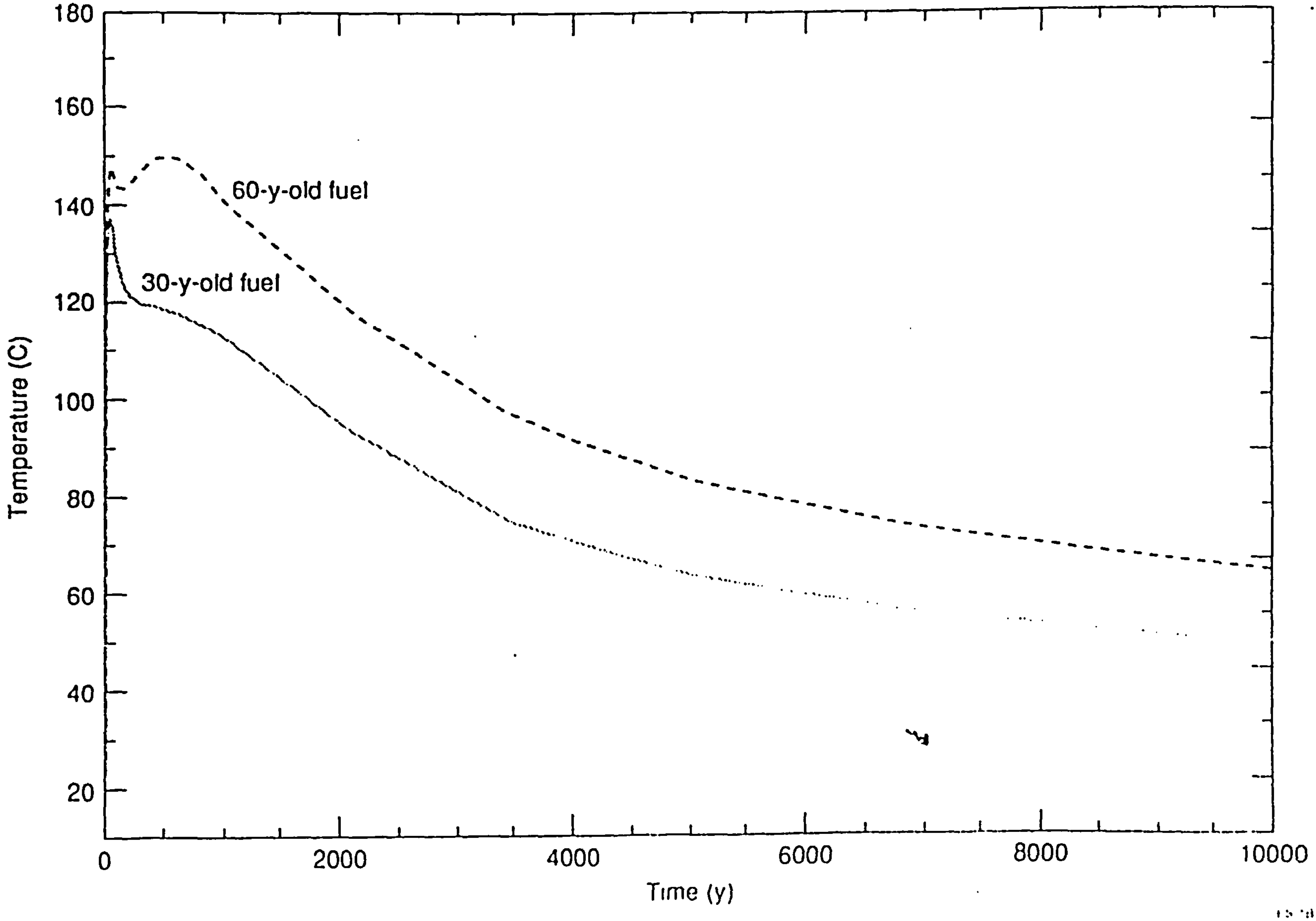
Waste package temperatures for drift emplacement are much lower than for borehole emplacement

Waste package temperature for drift emplacement of 30-yr-old fuel and a recharge flux of 0.0 mm/yr



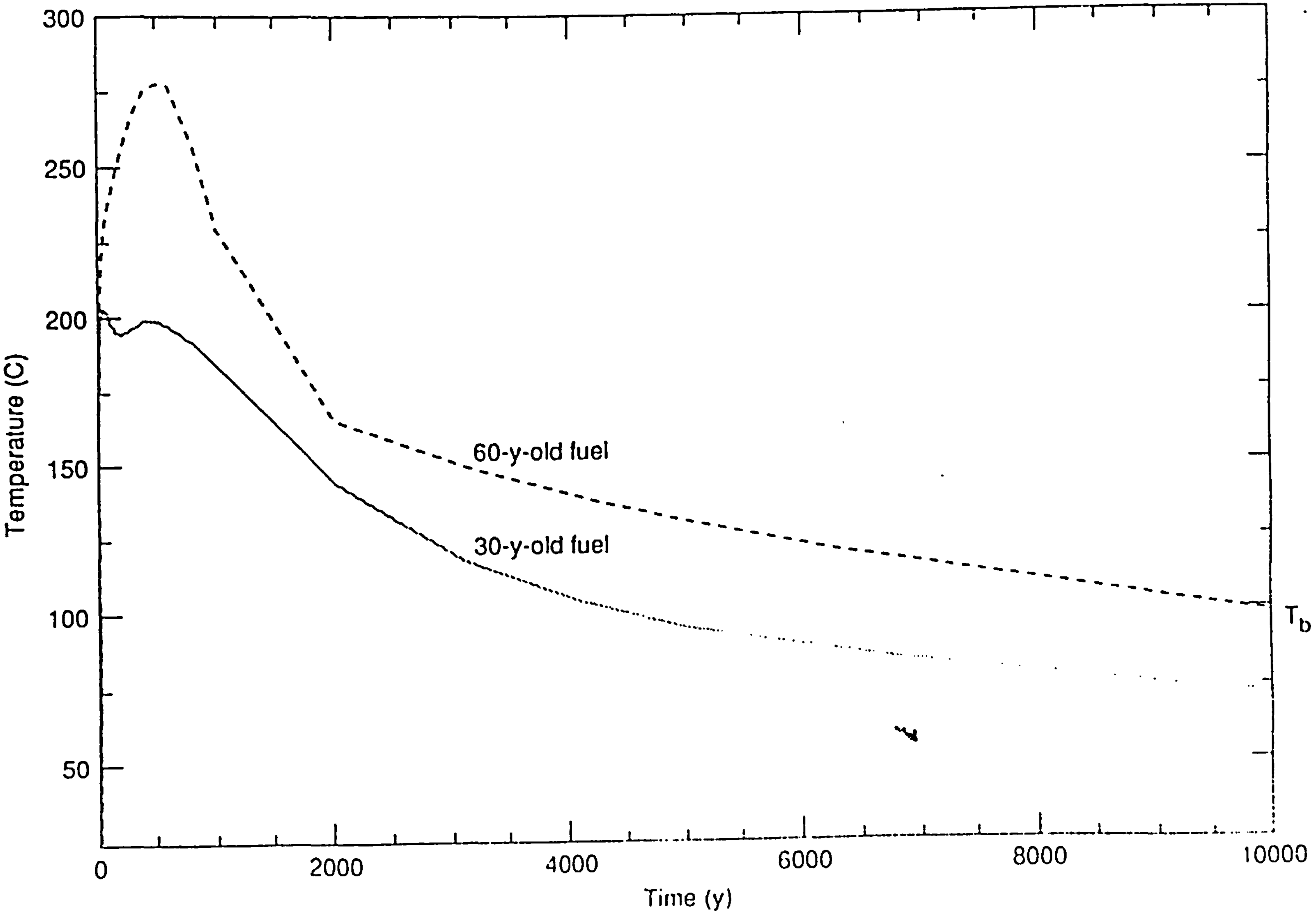
Boiling and rock dry-out benefits are obtained for 60-yr-old fuel with minimal impact on waste package temperature

Waste package temperature for drift emplacement for an APD of 57 kW/acre and a recharge flux of 0.0 mm/yr



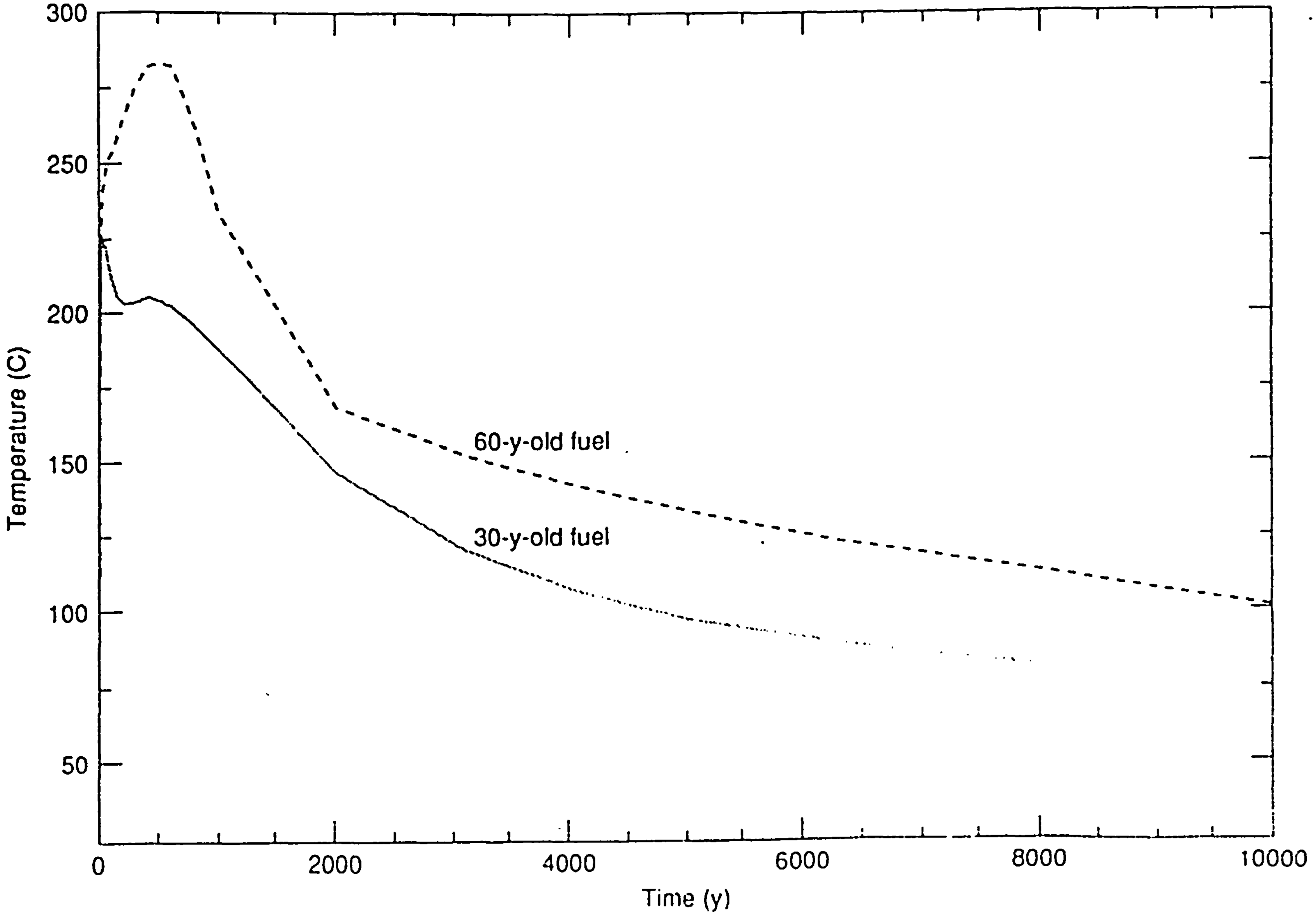
A substantial increase in boiling and dry-out benefits is obtained for 60-yr-old fuel, with dry steam boiling conditions persisting for 10000 years

Drift wall temperature for drift emplacement for an APD of 114 kW/acre



Dry steam boiling conditions persist for more than 10000 years, with waste package temperatures peaking at 275°C

Waste package temperature for drift emplacement for an APD of 114 kW/acre



U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: MINERALOGICAL UNCERTAINTIES

PRESENTER: DR. DAVID L. BISH

PRESENTER'S TITLE AND ORGANIZATION:
TECHNICAL STAFF MEMBER
EARTH AND ENVIRONMENTAL SCIENCES DIVISION
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 667-1165

OCTOBER 8 - 10, 1991

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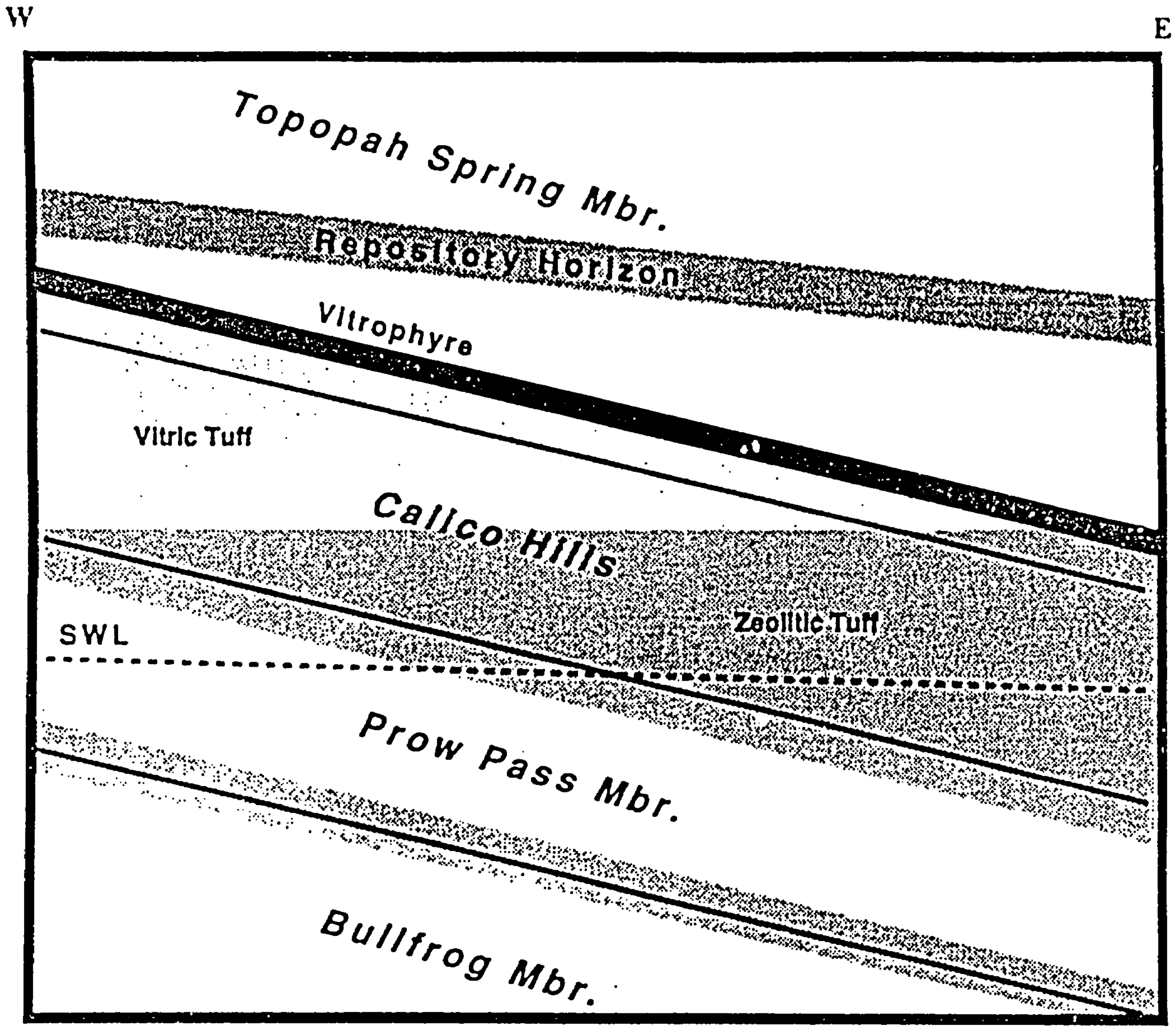
Scope

- Yucca Mountain and host rock mineralogy
- Effects of dehydration/rehydration and associated contraction/expansion of hydrous minerals
- Effects of heating on sorption properties
- Long-term stability of minerals near host rock

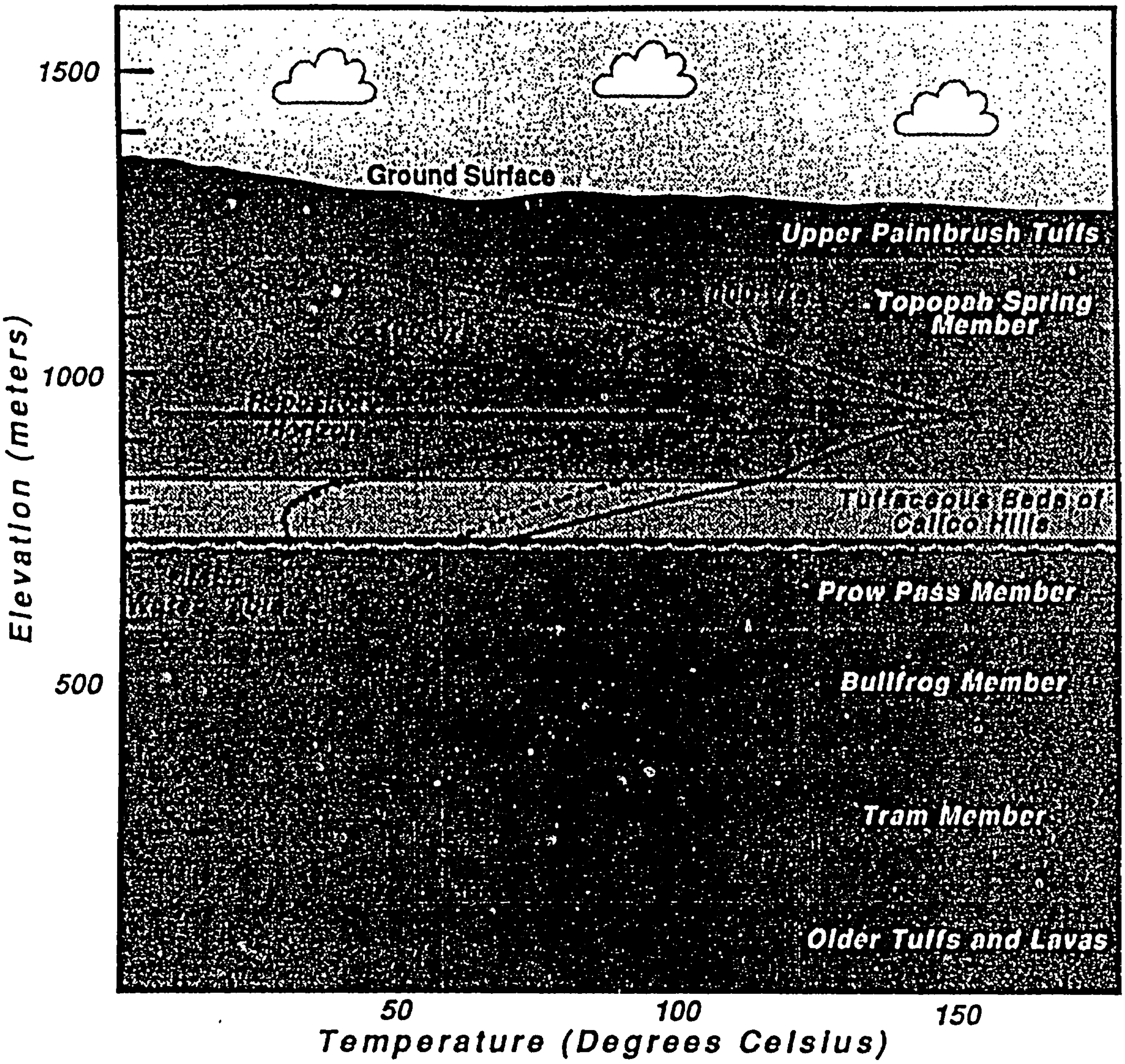
Mineralogy of Candidate Host Rock and Rocks Between Repository and Water Table

- Relatively stable minerals
  - Quartz, Feldspar
- Minerals that dehydrate
  - Smectite, Clinoptilolite, Mordenite, Volcanic Glass
- Minerals that may transform or dissolve
  - Cristobalite, Tridymite, Opal-CT, Volcanic Glass
  - Smectite → Illite through Illite/Smectite
  - Clinoptilolite → Analcime
  - Mordenite → Analcime

Schematic Cross Section in Central Portion of Repository Block



Heating of Tuffs in the Vicinity of Repository Due to Radioactive Decay of Waste



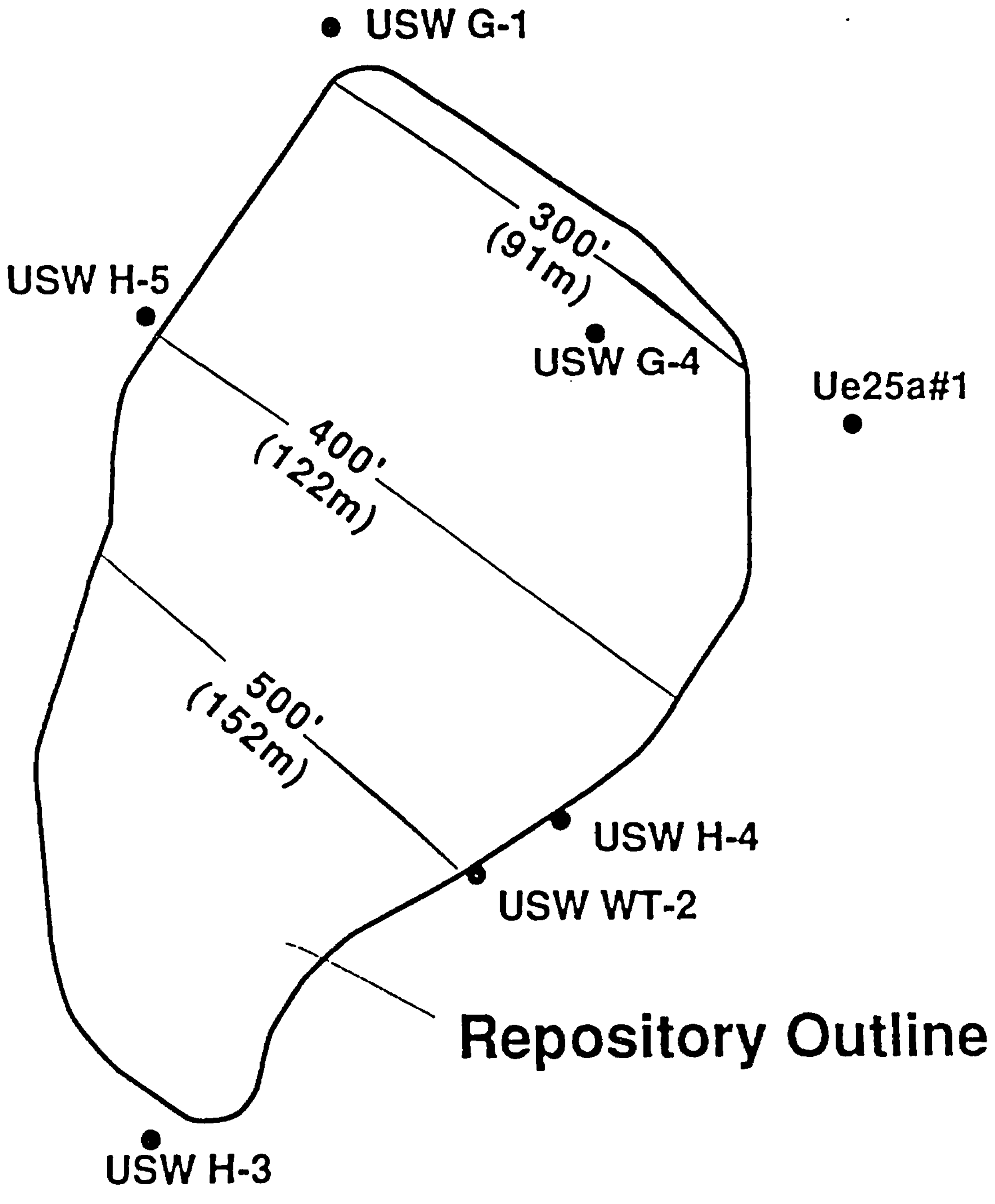
·············· APD = 57 kW/a

———— APD = 80 kW/a

APD = Areal Power Density

Modified from Brandshaug (Figs. 6-1 and 6-2, SAND87-7079). Geologic contacts for USW G-4; position of repository and geotherms adjusted to stratigraphy in USW G-4.

Contour Map of the Thickness Between Base of Repository and Top of Major Zeolite Horizons



Dehydration/Rehydration

- Mineral hydration state will change whenever P_{H_2O} or temperature changes
- Most reactions are reversible, i.e., minerals will rehydrate as temperatures decrease
- Uncertainty is not strongly dependent on temperature
- Critical uncertainty is the vapor pressure of H_2O in the repository environment
- Requires coupled models

Expansion/Contraction of Zeolites and Smectites

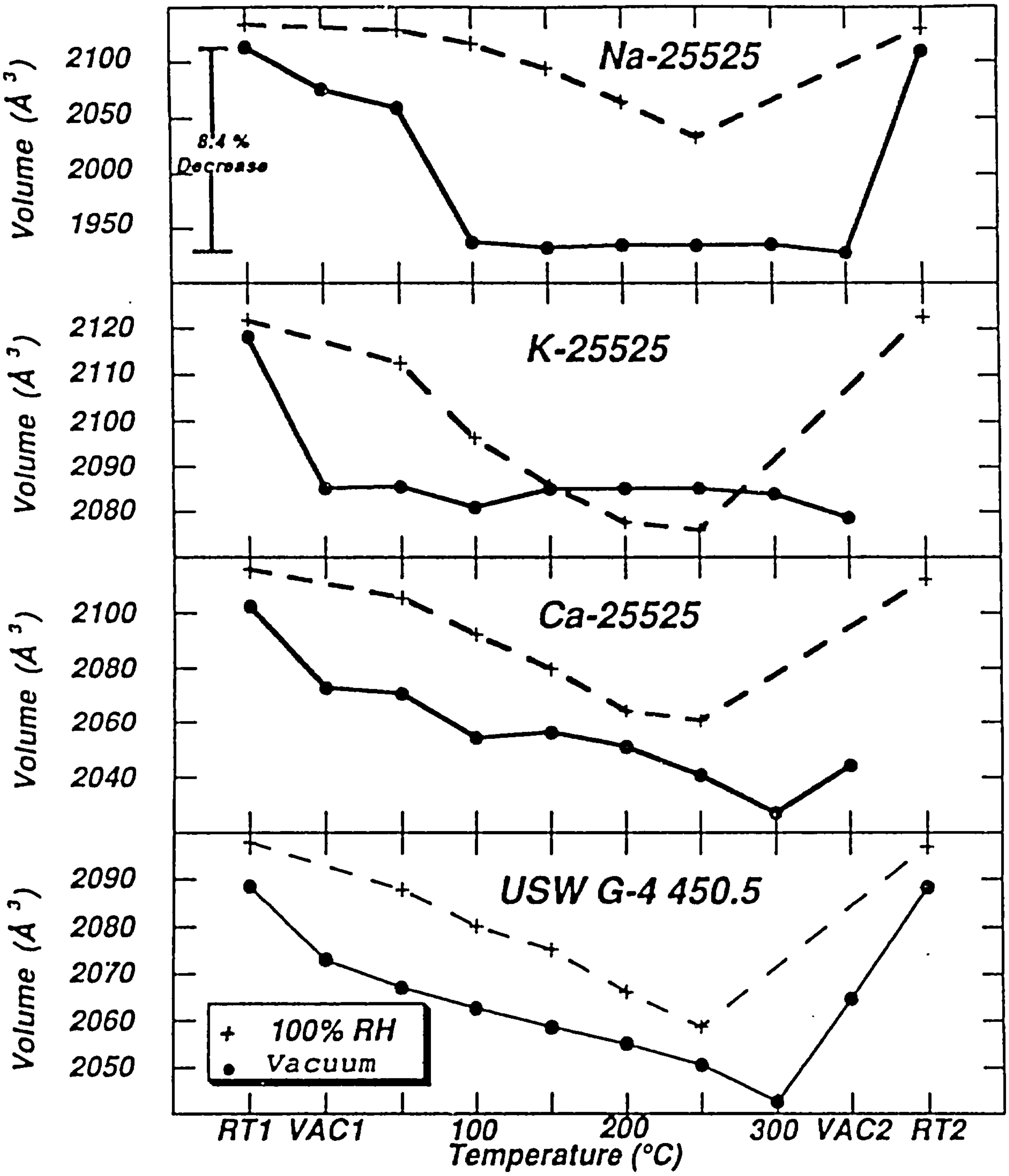
- Function of P_{H_2O} and temperature
- Minerals readily contract on dehydration
  - Zeolites by only several %
  - Smectites by a factor of 2 or more

- Potentially enlarge transport pathways
  - Pathways will probably return to original state when minerals rehydrate (based on volumetric data)
  - Gaseous transport may be more important when dehydrated

- Effects of expansive strains
  - Potential effect on rock strength

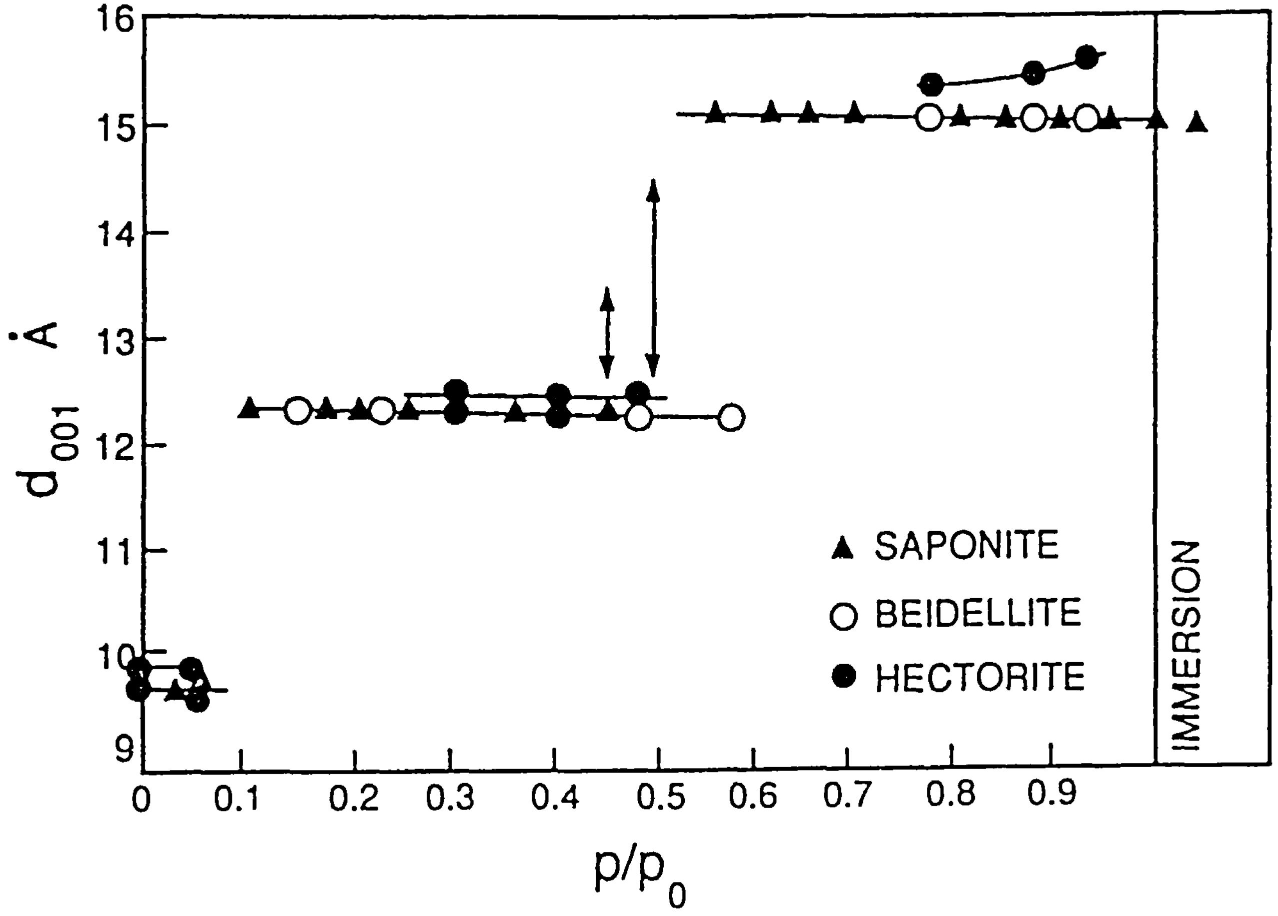
- Short-term contraction is reversible, but long-term contraction may not be easily reversible, particularly for clinoptilolite

Effects of Temperature and P_{H_2O} on Clinoptilolite Unit Cell Volume

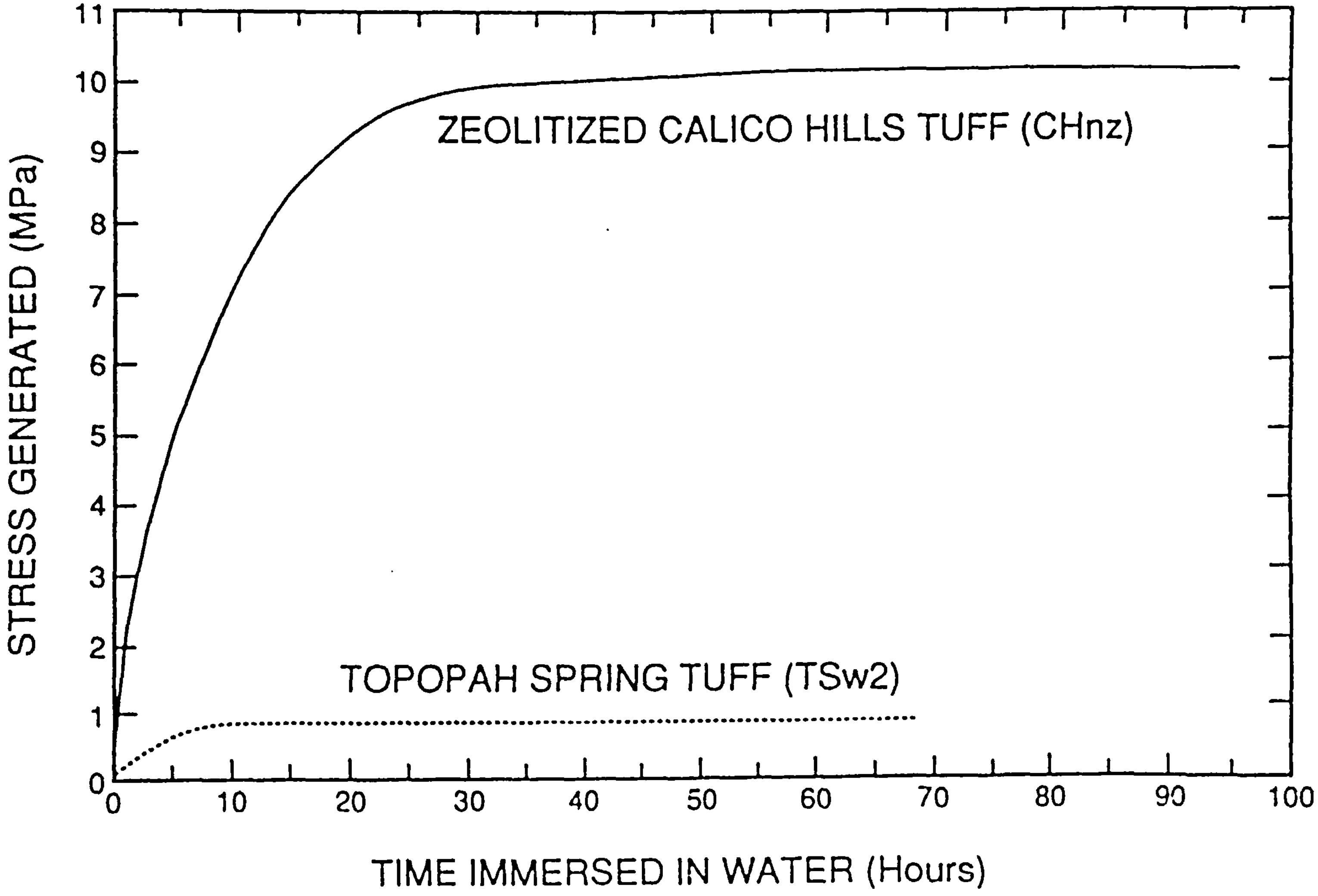


RT1 & RT2 data obtained at 23°C in air.
VAC1 & VAC2 data obtained at 23°C in vacuum.

Basal Spacing/Vapor Pressure Relations for NA-smectites



Yucca Mountain Tuff
Axially Confined Hydration



Effects of Heating on Sorption Properties

- Little or no effects on smectite unless transformed to illite/smectite or illite
- Little or no effects on zeolites, even when irreversibly collapsed

Sorption Ratios (R_D)[1] for Heated and Unheated Clinoptilolite

	Unheated	105° C[2]	200° C[2]
Sr	19100 (9000)[3]	17000 (1800)	29000 (5200)
Cs	13700 (100)	22700 (1700)	37000 (2000)
Ba	433000 (8000)	418000 (65000)	244000 (31000)
Eu	1950 (100)	2800 (300)	2400 (100)

[1] $R_D = \dfrac{\text{activity on solid phase per unit mass of solid}}{\text{activity in solution per unit volume of solution}}$ (measured at 23°C)

[2] All heatings for 385 days, dry

[3] Values in parentheses are estimated standard deviations

Long-Term Stability of Minerals Near Candidate Host Rock

- Clinoptilolite
  - Appears stable in saturated rock to ~100°C, may react to mordenite or analcime [f (a $_{SiO_2}$)?]
- Mordenite
  - Appears stable in saturated rock to at least 130° C
- Glass
  - May alter at low temperatures in saturated rock to silica phases, smectite, or zeolites
  - Non-welded vitric tuffs will probably alter to clinoptilolite and smectite when in contact with hot condensate

Long-Term Stability of Minerals Near Candidate Host Rock

(Continued)

- Cristobalite/Tridymite
  - Can react to quartz at low temperatures (<100° C) through a solution/reprecipitation reaction ($\Delta V_{cr\text{-}q}$ = -3.24 cm^3/mol, -12.5%) (10-20% cristobalite in TSw2)
- $\alpha \succ\!\!- \beta$ cristobalite @ 230 ± 20° C, ΔV = +4.0%
- Smectite
  - Progressively reacts through illite/smectite series with increasing temperature under saturated conditions
  - Requires temperatures above 100° C for times in excess of 10^6 years
- Increasing temperature improves predictability-partially mitigates kinetic problems

Vitrophyre Alteration

- Transition zone between Topopah Spring devitrified tuff (TSw2) and vitrophyre (TSw3) a potential natural analog to repository- induced alteration
  - State of saturation uncertain and spatially variable

- Alteration dynamic, concentrated around fractures

- Natural alteration assemblage suggests vitrophyre alteration to clinoptilolite, smectite, and silica phases between 40 and 100° C (oxygen isotope geothermometry)

ns and Temperatures of ondary Quartz Formation

Sample	$\delta^{18}O$ (‰ , SMOW)	T_A (°C)	T_B (°C)
VH2-3545-q	13.0	65	95
VH2-3565a	11.9	70	100
YF-4-q	17.8	40	70

T_A Calculated from Clayton & others (1972)

T_B Calculated from Bottinga & Javoy(1973)

^{18}O of -13.5‰ assumed for the water

nalyses reproducible to ±0.1‰

Summary

- Significant amounts of volcanic glass, zeolites, and smectites occur in proximity to the repository horizon (beneath)

- Hydration state of zeolites and clays will change whenever temperature or P_{H_2O} changes
  - Volume decreases-reversible
  - Creation of fractures, differential stresses

- Sorptive properties are little affected by dehydration or collapse

- Temperatures of ~100° C and long times (> 10^5 years?) are required to transform the zeolites or smectites to other less sorptive phases

Summary

(Continued)

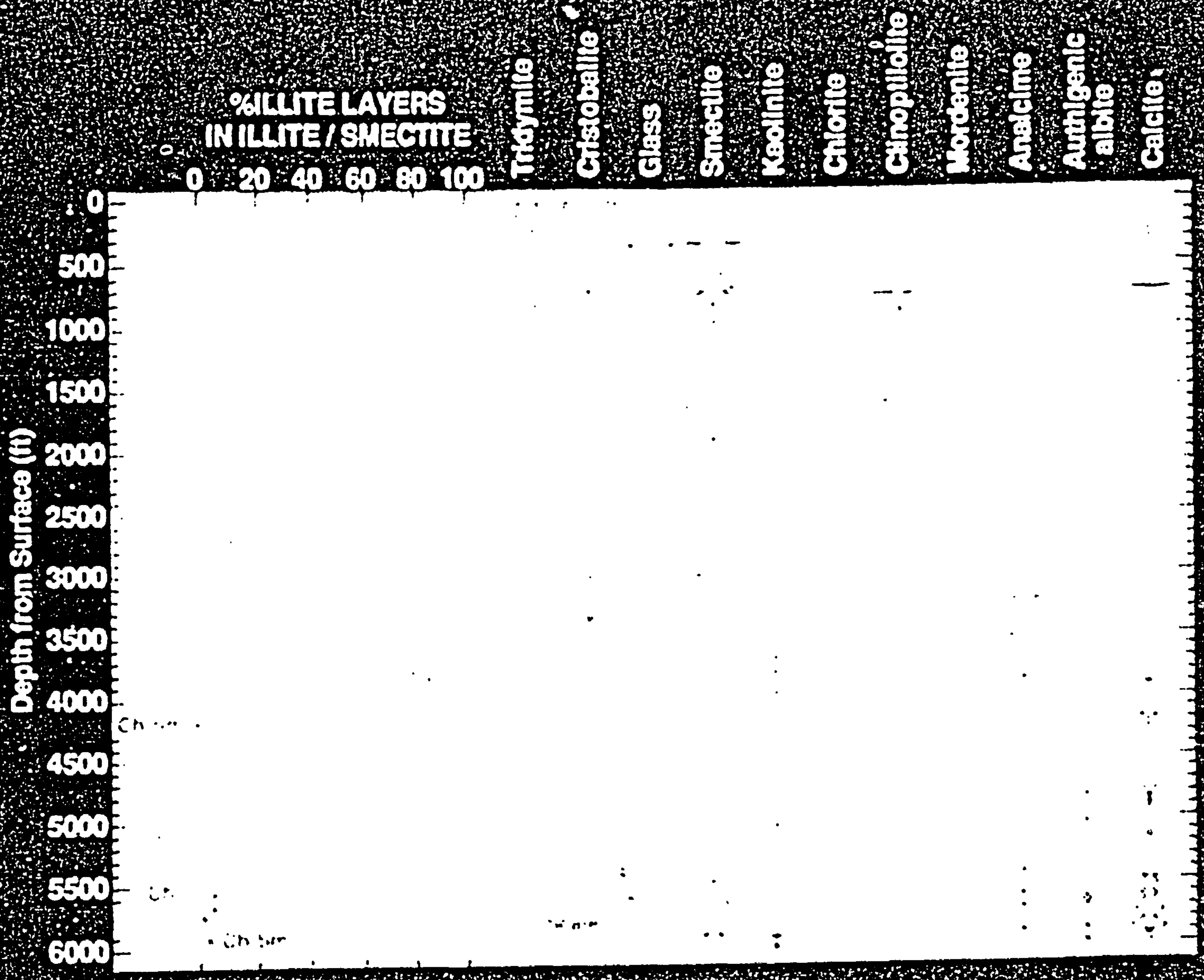
- Volcanic glass may transform to zeolites and/or smectite at temperatures as low as 40° C in the presence of H_2O
- Increasing temperature generally improves predictability because of kinetic problems at lower temperatures
- Some of the thermal reactions, e.g., glass to zeolite and smectite, may be beneficial although they will cause a modification of flow paths

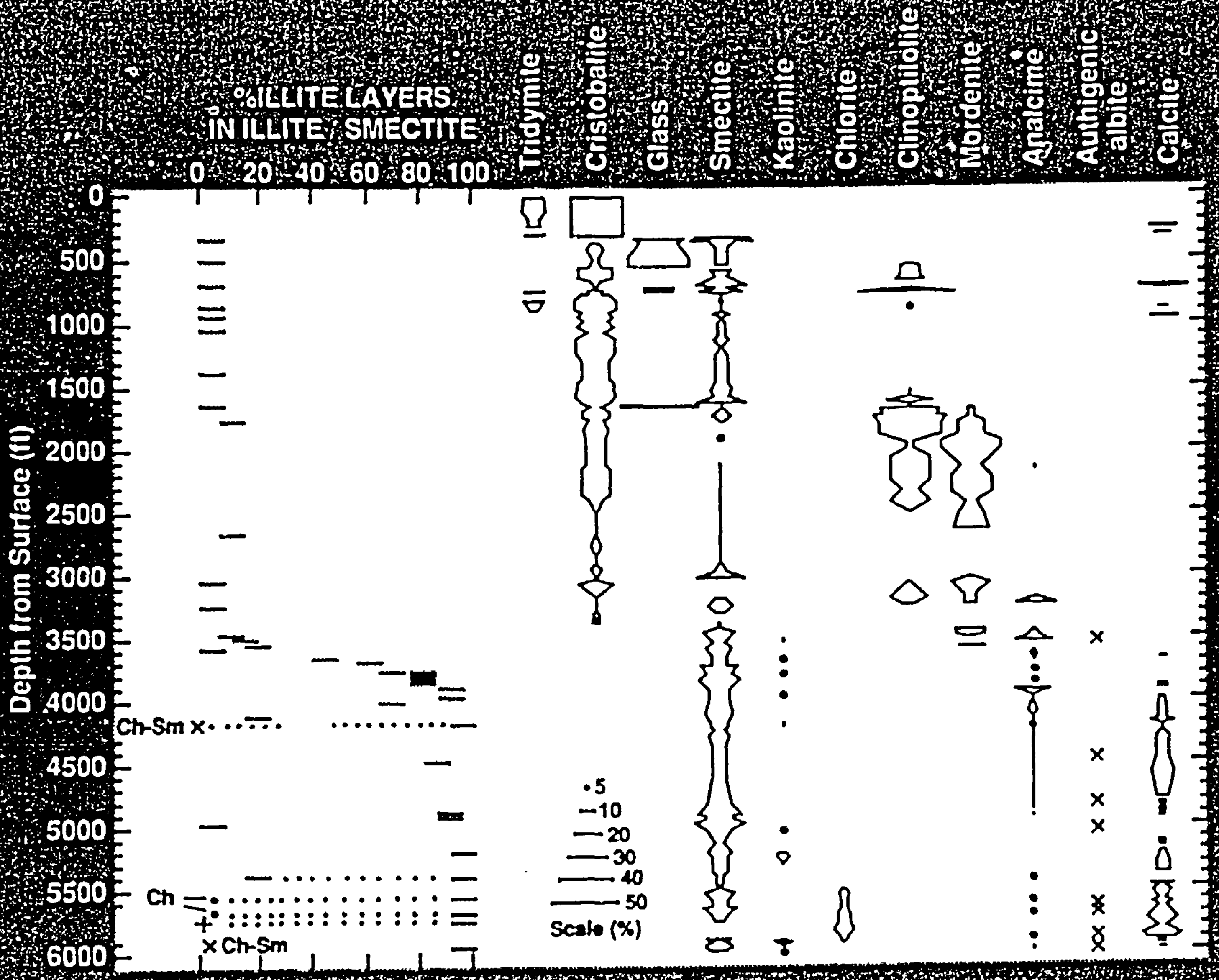
Mineralogical Uncertainties

- Benefits to lower thermal loading (smaller rock volume affected, lower intensity alteration) probably outweigh those of higher thermal loading (larger rock volume dried)
- Potential mineralogical problems associated with higher loading (alteration of zeolitized tuff) are greater than those associated with lower loading
- Uncertainties in mineral alteration
  - time - temperature - saturation information
  - kinetics of low-temperature mineral reactions
- Resolution of uncertainties
  - Experimental data
  - Natural analog - field data
  - Consider mineralogic reactions in modeling

Conclusions

- Changing the thermal load will probably only modify the <u>extent</u> of the above reactions, <u>not</u> <u>eliminate</u> them
- Understanding of thermal effects will require coupled models and some additional experimental data


%ILLITE LAYERS IN ILLITE / SMECTITE
0
20
40
60
80
100
Tridymite
Cristobalite
Glass
Smectite
Kaolinite
Chlorite
Clinoptilolite
Mordenite
Analcime
Authigenic albite
Calcite
Depth from Surface (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000


%ILLITE LAYERS IN ILLITE/SMECTITE
0
20
40
60
80
100
Tridymite
Cristobalite
Glass
Smectite
Kaolinite
Chlorite
Clinoptilolite
Mordenite
Analcime
Authigenic albite
Calcite
Depth from Surface (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Ch-Sm
Ch
Ch-Sm
5
10
20
30
40
50
Scale (%)

U.S. DEPARTMENT OF ENERGY
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SUBJECT: GEOMECHANICAL UNCERTAINTIES

PRESENTER: DR. LAURENCE S. COSTIN

PRESENTER'S TITLE AND ORGANIZATION:
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PERFORMANCE ASSESSMENT APPLICATIONS DIVISION
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 844-0397

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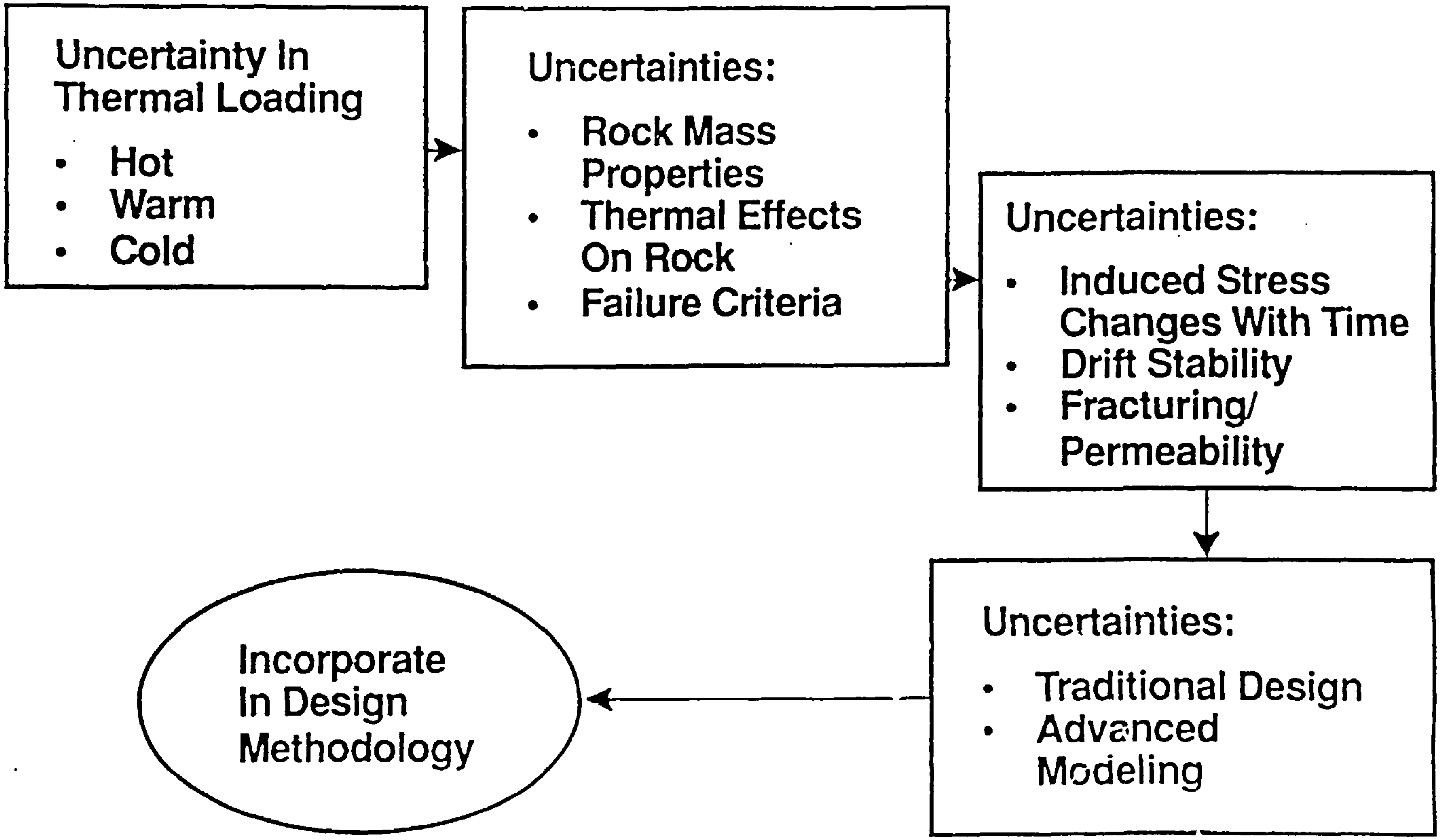
Presentation Topics



Uncertainty In Thermal Loading

- Hot
- Warm
- Cold

Uncertainties:

- Rock Mass Properties
- Thermal Effects On Rock
- Failure Criteria

Uncertainties:

- Induced Stress Changes With Time
- Drift Stability
- Fracturing/ Permeability

Uncertainties:

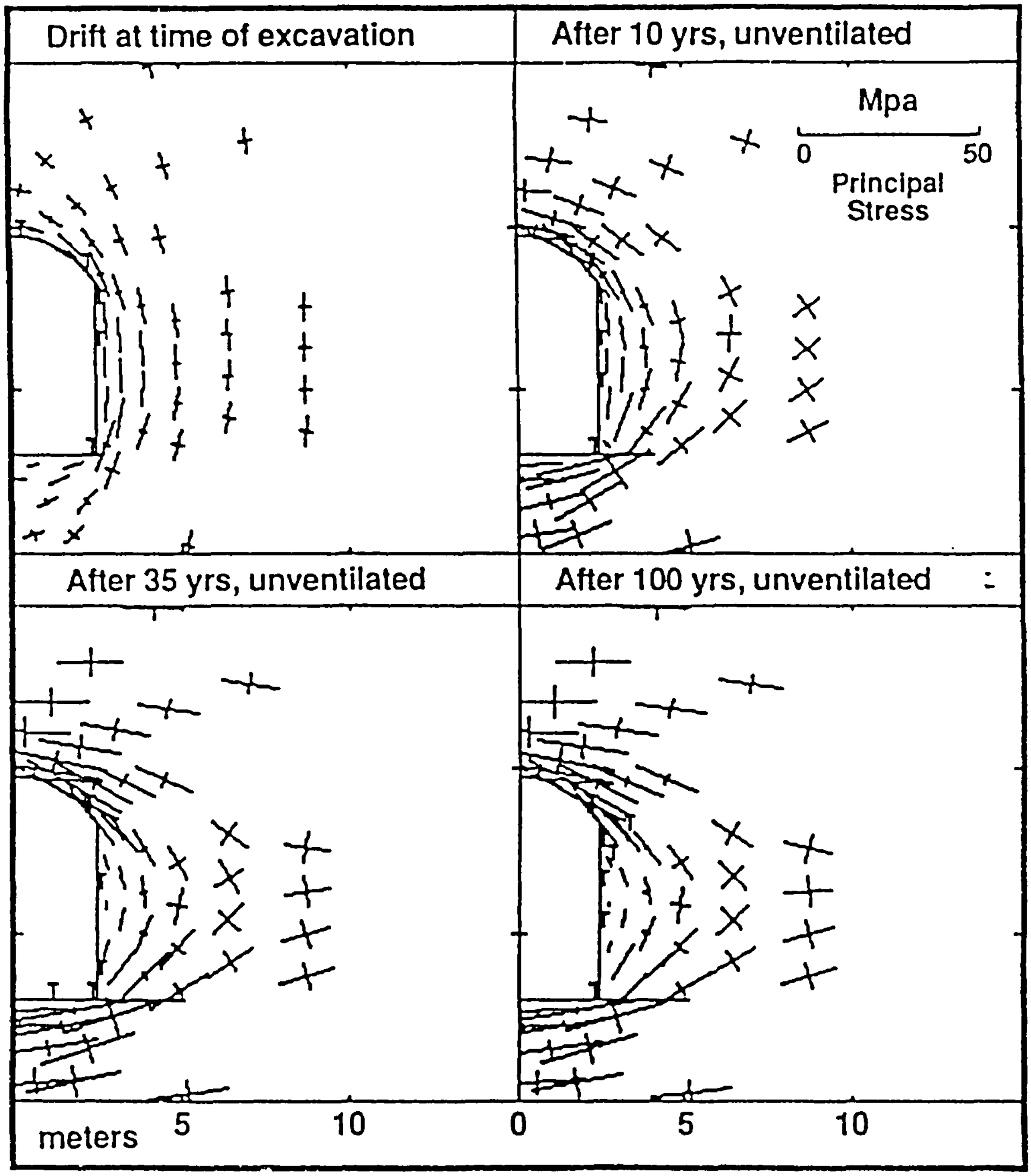
- Traditional Design
- Advanced Modeling

Incorporate In Design Methodology

Effects of Thermal Loading
(Preclosure Period)

- Magnitude of stress field changes with time
- Orientation of stress field changes with time
- Thermal effects on rock properties
- Thermal effects on support structure and materials
- Interaction of support structure with rock mass changes with time

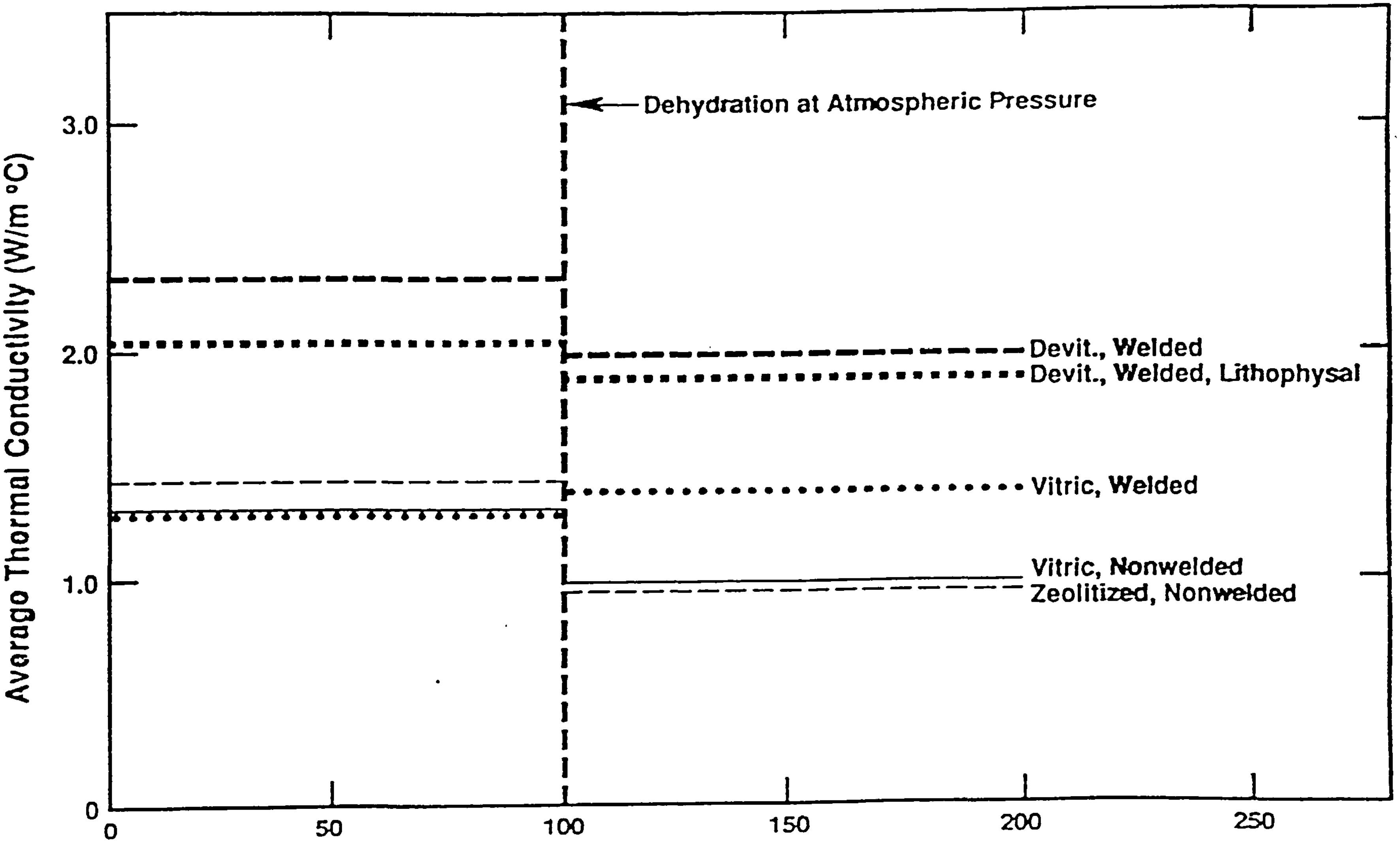
Principal Stresses in the Vicinity of a Vertical Emplacement Drift



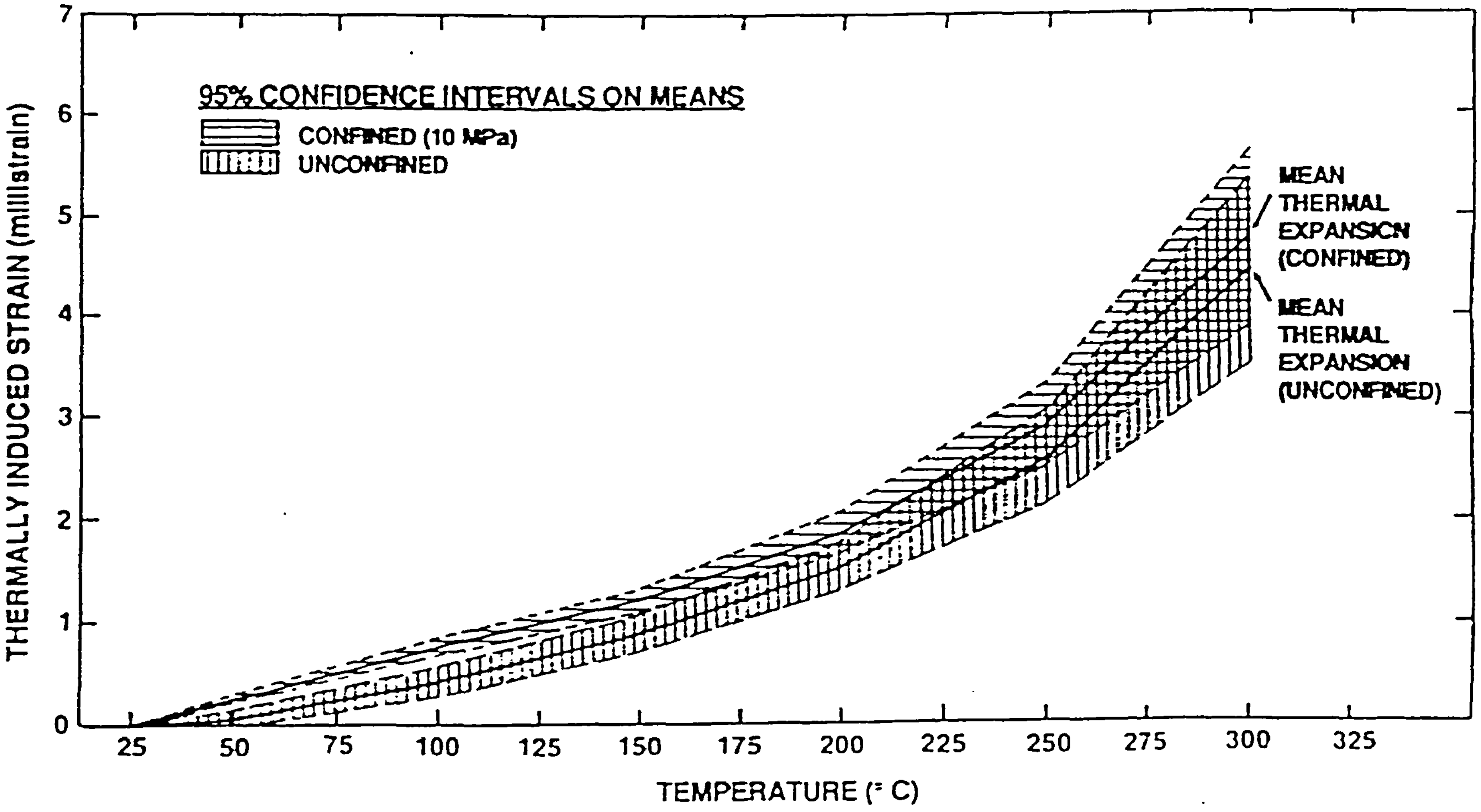
Thermal Effects on Rock Properties

- Thermal Conductivity
- Thermal Expansion
- Modulus
- Failure

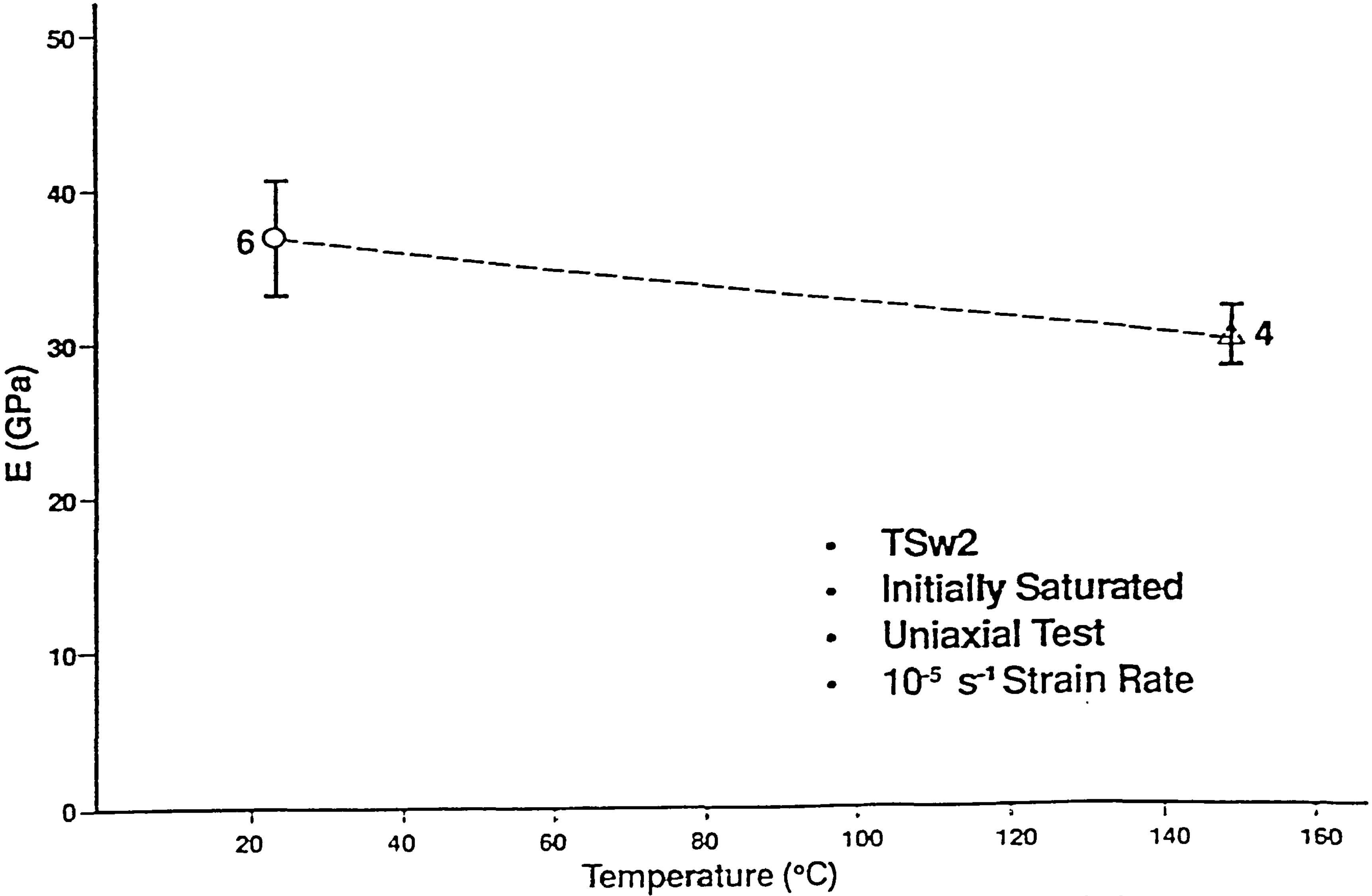
Temperature Dependence of Average Thermal Conductivity



Thermal Expansion Behavior of Confined and Unconfined Samples of Unit TSw2



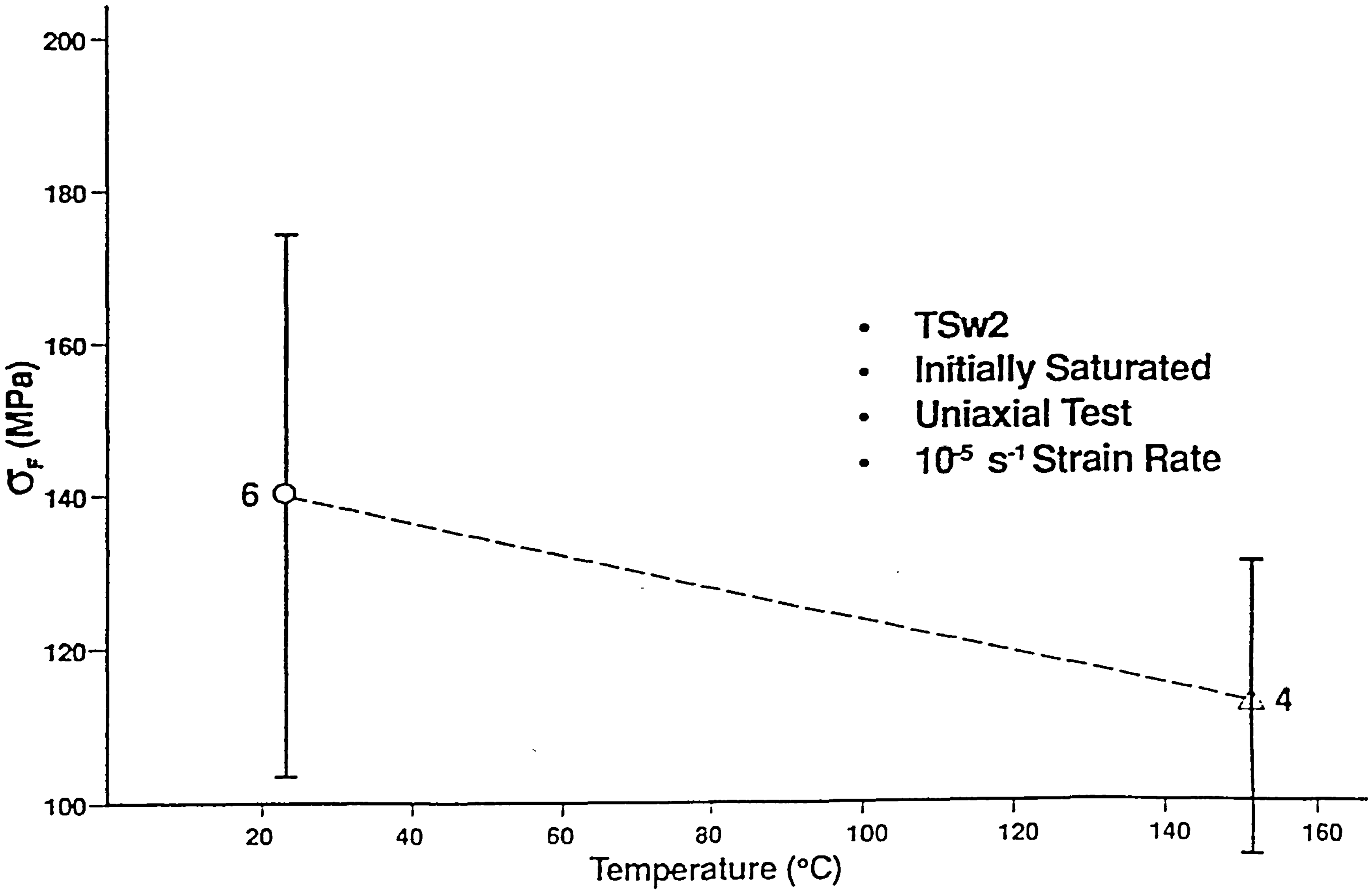
Intact Rock Modulus



- TSw2
- Initially Saturated
- Uniaxial Test
- 10^{-5} s^{-1} Strain Rate

RTGUL CSP 125 NWTRB 10 5 10 91

Intact Rock Failure

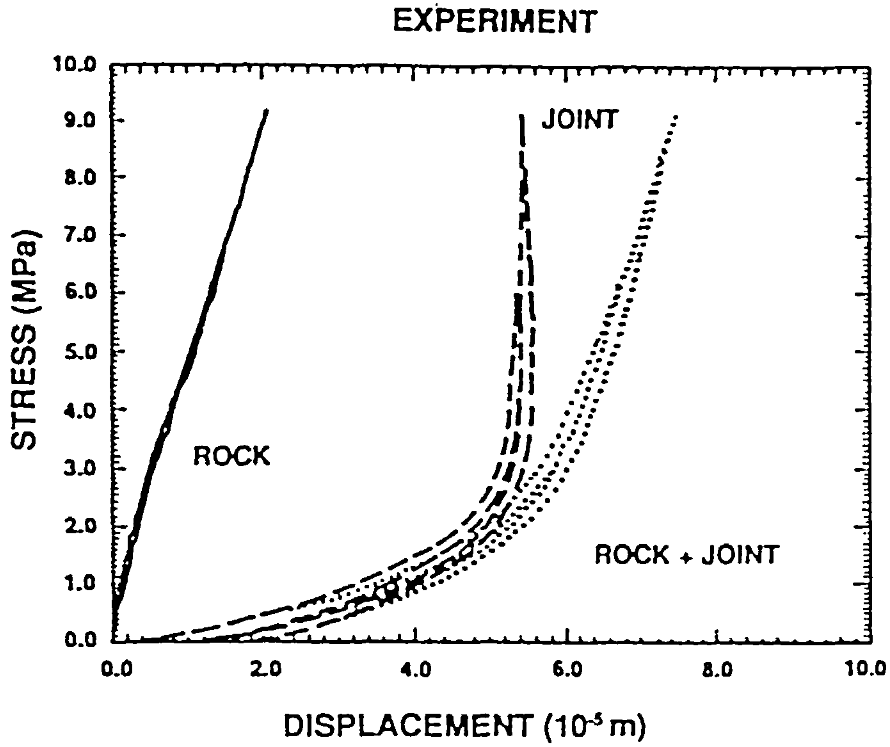


- TSw2
- Initially Saturated
- Uniaxial Test
- 10^{-5} s^{-1} Strain Rate

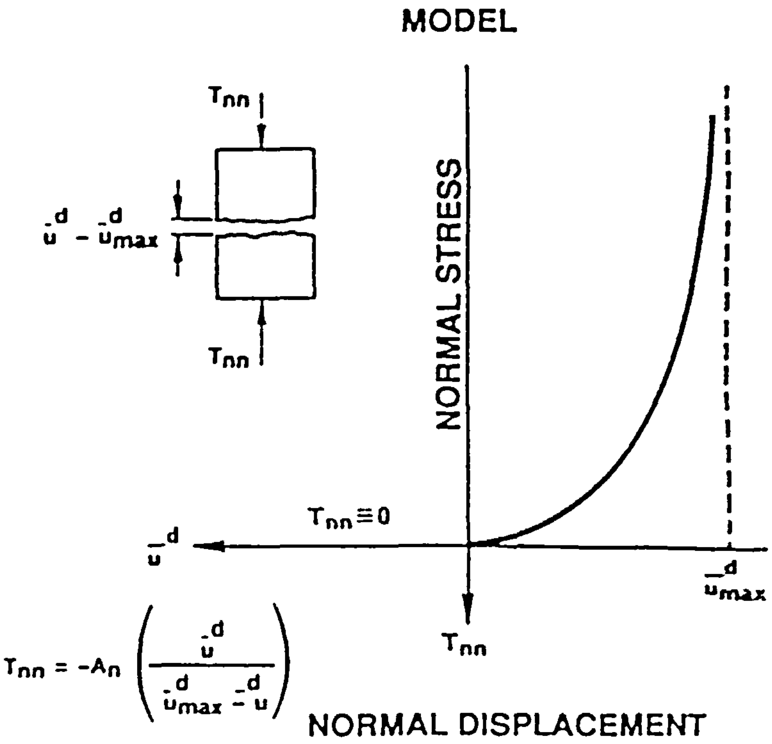
Thermal Effects on Rock Mass

- Jointed rock mass leads to coupling between thermal expansion and rock mass modulus
- Thermal expansion tends to increase modulus (non-linear)
- Rock mass stresses tend to increase (non-linear)
- Fracture permeability tends to decrease (non-linear)

Nonlinear Elastic
Normal Joint Behavior

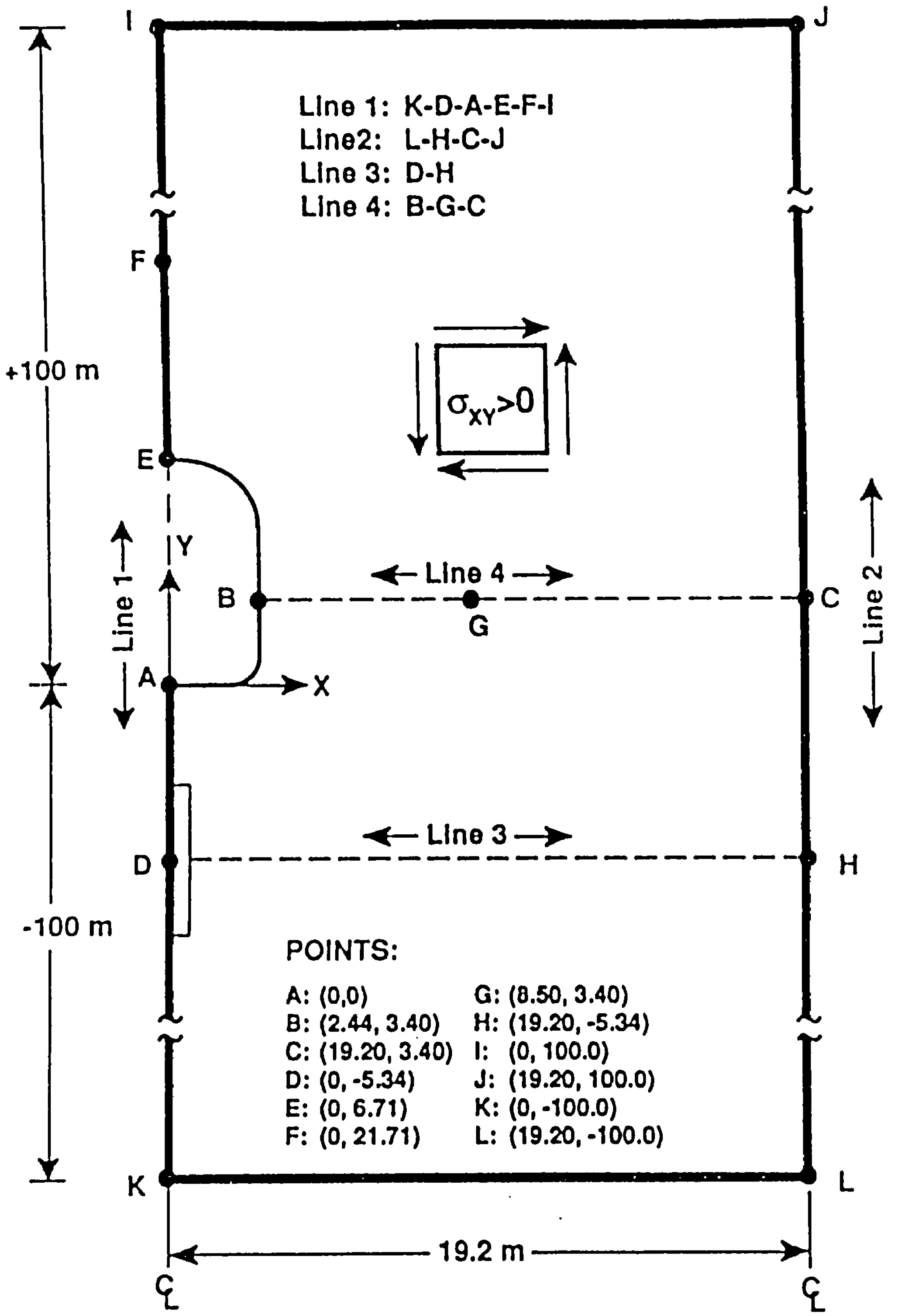


(from W. Olsson)



$$T_{nn} = -A_n \left(\frac{\bar{u}^d}{\bar{u}^d_{max} - \bar{u}^d} \right)$$

Geometry for Benchmark Calculation

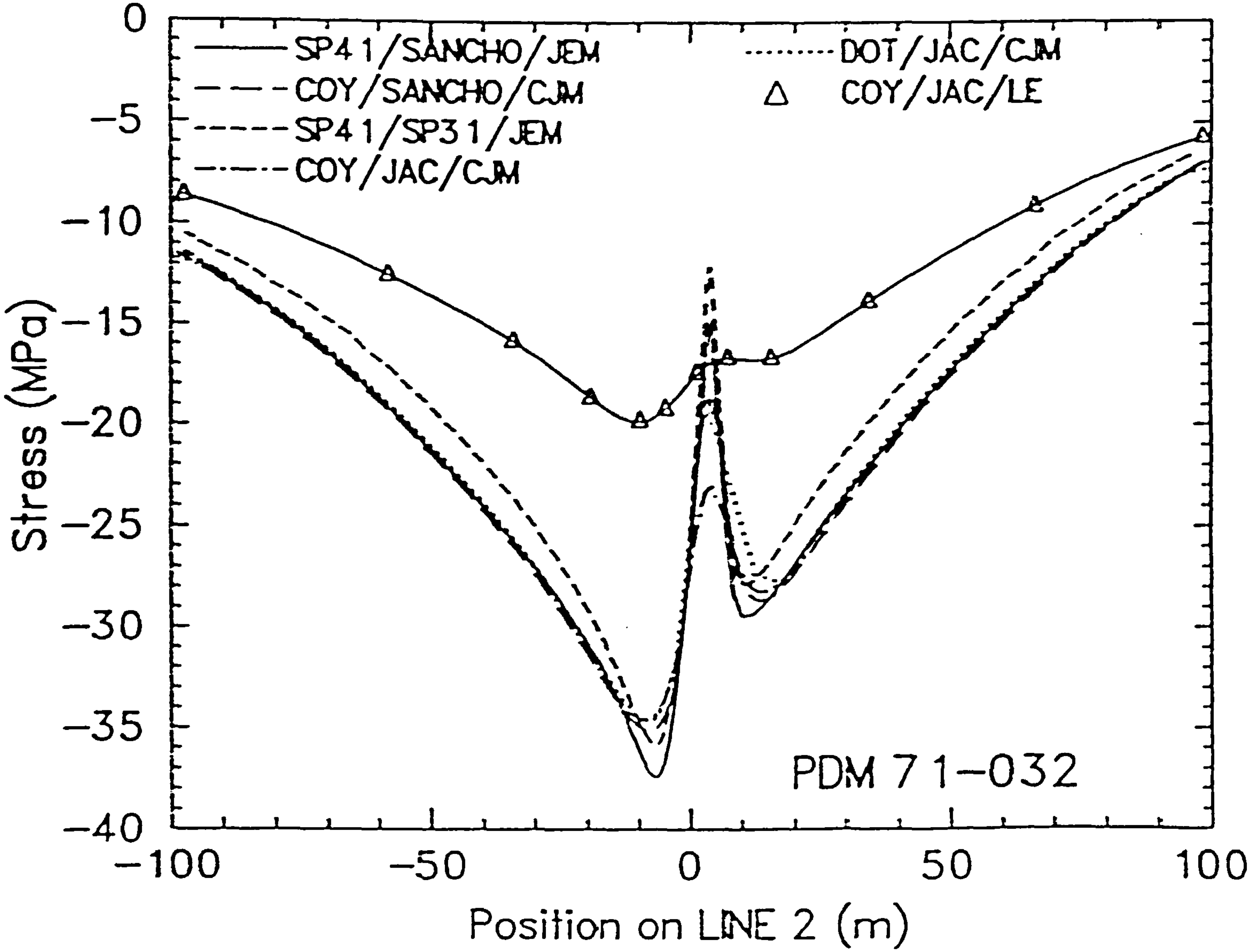


Line 1: K-D-A-E-F-I
Line2: L-H-C-J
Line 3: D-H
Line 4: B-G-C

POINTS:

A: (0,0)
B: (2.44, 3.40)
C: (19.20, 3.40)
D: (0, -5.34)
E: (0, 6.71)
F: (0, 21.71)
G: (8.50, 3.40)
H: (19.20, -5.34)
I: (0, 100.0)
J: (19.20, 100.0)
K: (0, -100.0)
L: (19.20, -100.0)

Horizontal Stress Along Line 2 at 101 Years



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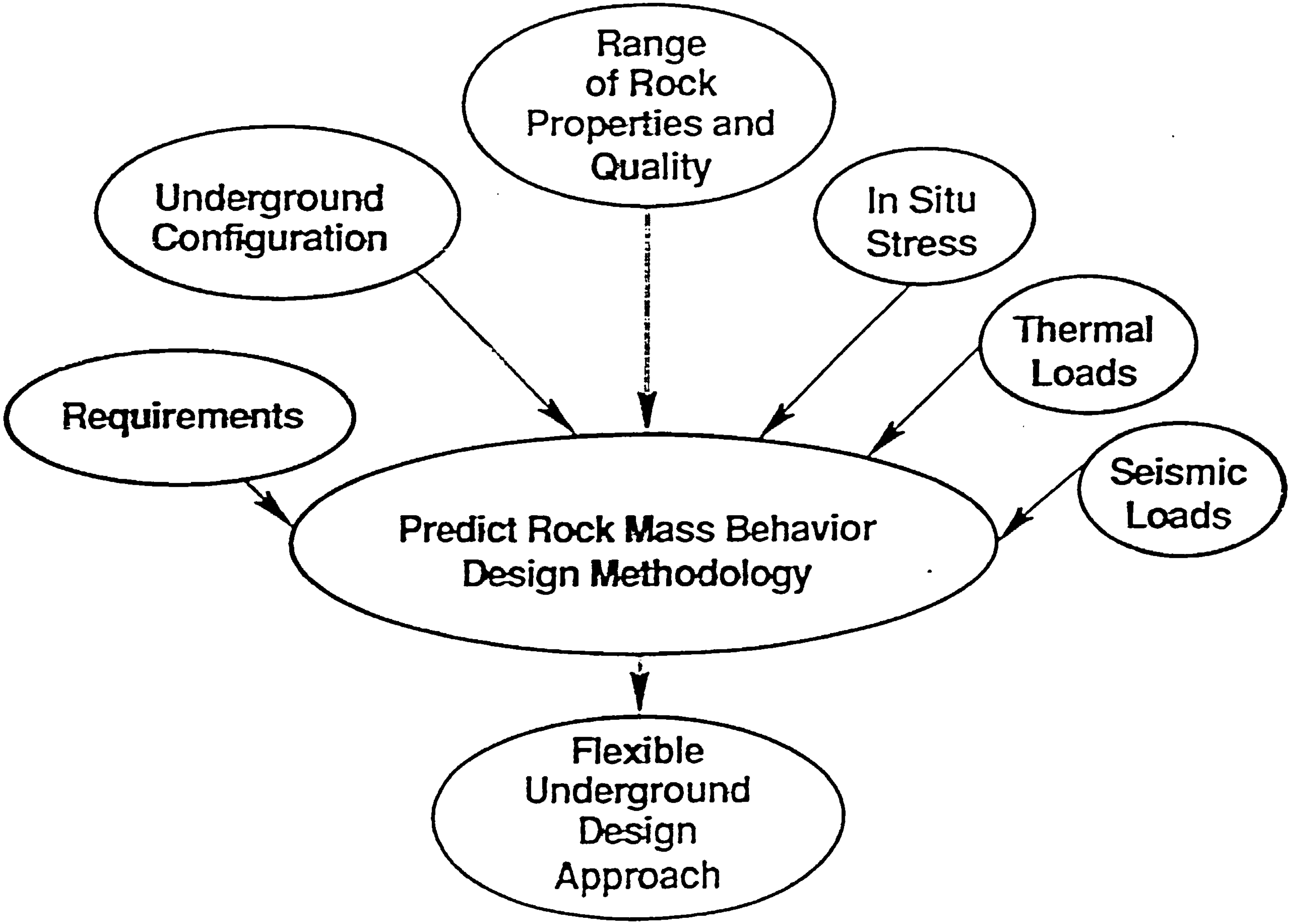
Uncertainty in Design

- Uncertainties associated with in situ conditions and rock quality
- Empirical methods
  - Validated by extensive case history
  - Little experience with thermal stresses
- Numerical methods
  - Can incorporate thermal component easily
  - Validation requires new test results from ESF
  - Are becoming an integral part of mining and civil engineering projects


Range of Rock Properties and Quality
Underground Configuration
In Situ Stress
Thermal Loads
Requirements
Seismic Loads
Predict Rock Mass Behavior Design Methodology
Flexible Underground Design Approach

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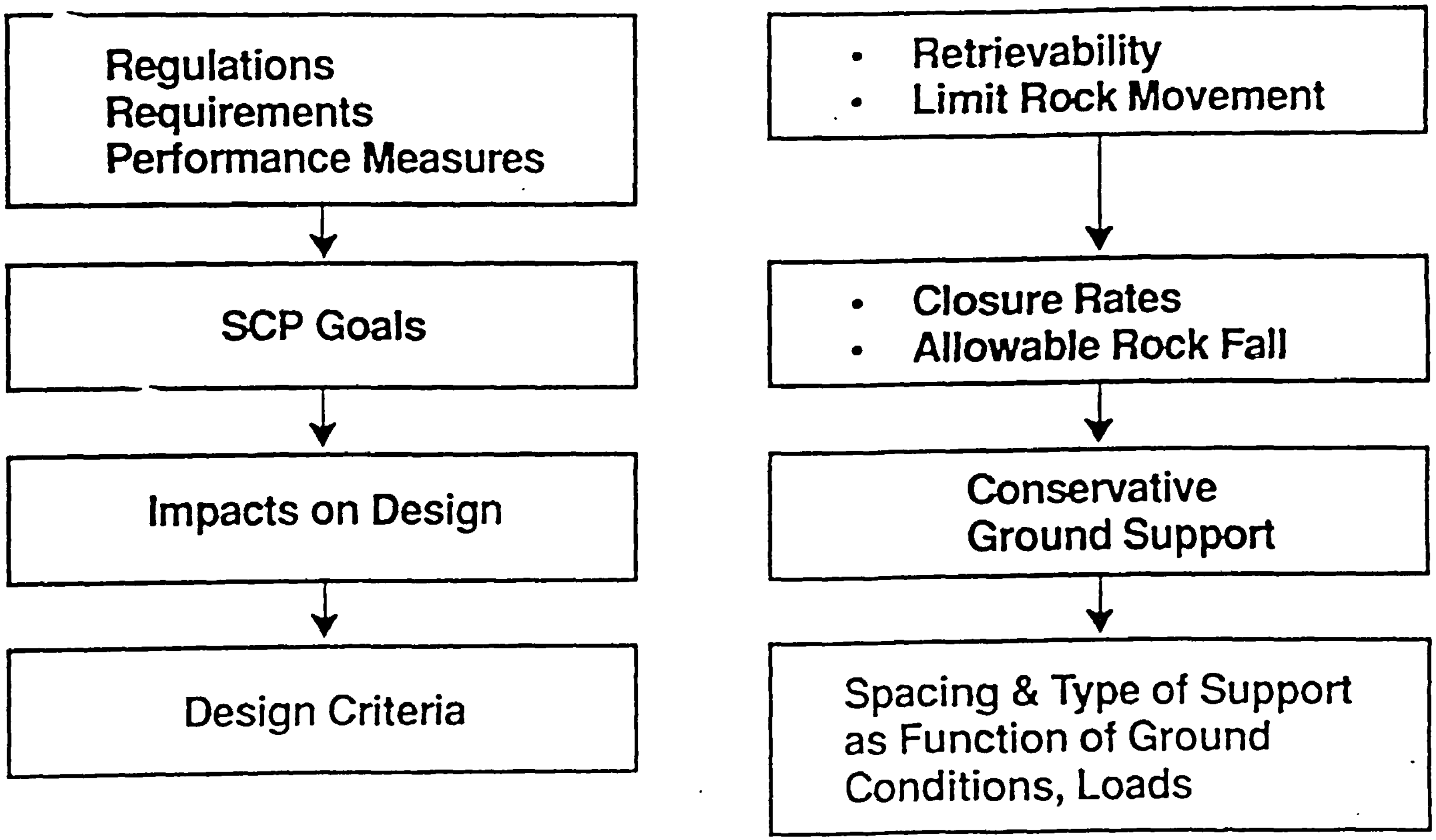
Requirements



Flow-Down

Regulations
Requirements
Performance Measures

SCP Goals

Impacts on Design

Design Criteria

Example

- Retrievability
- Limit Rock Movement

- Closure Rates
- Allowable Rock Fall

Conservative
Ground Support

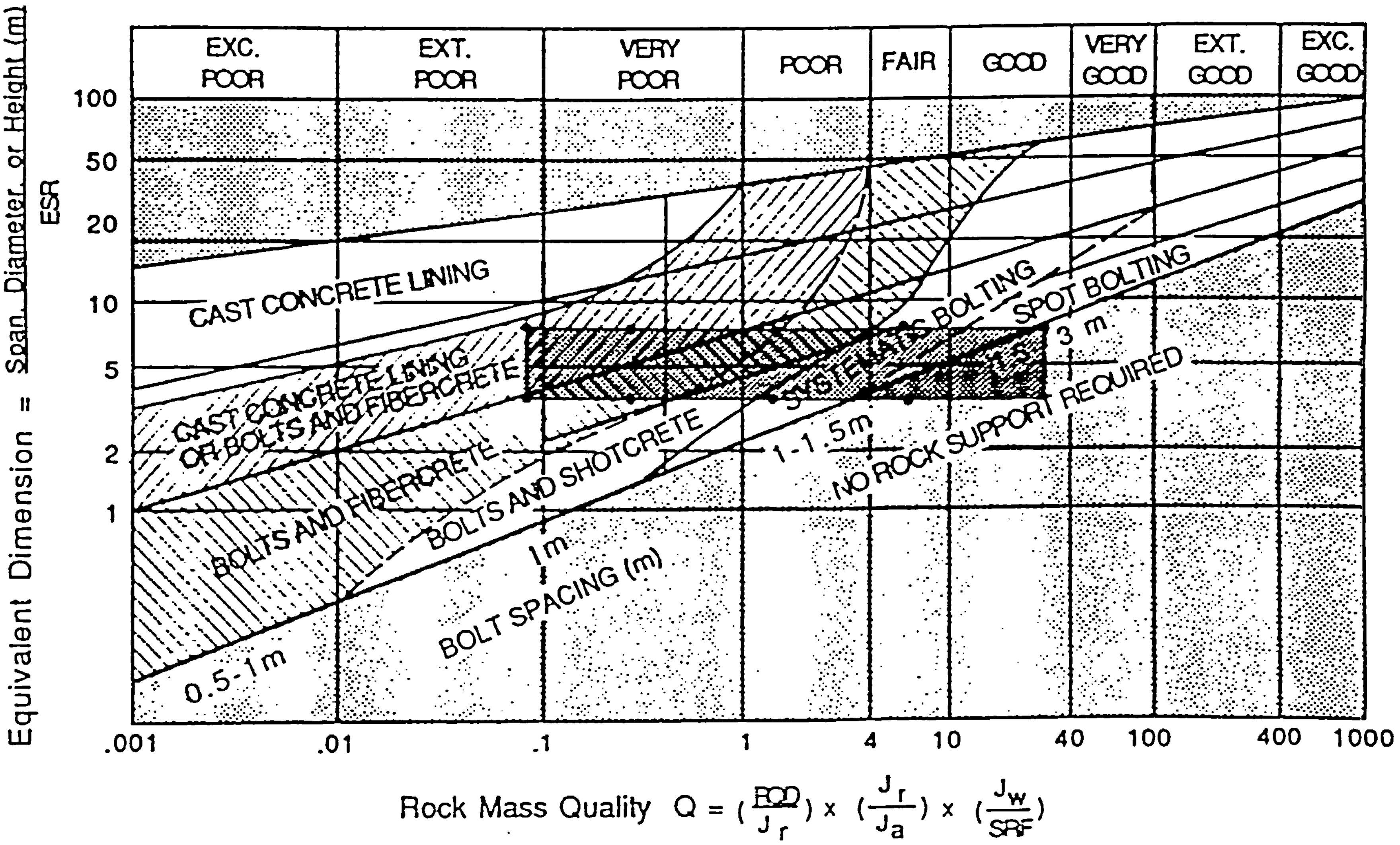
Spacing & Type of Support
as Function of Ground
Conditions, Loads

Uncertain In Situ Conditions: Rock Quality

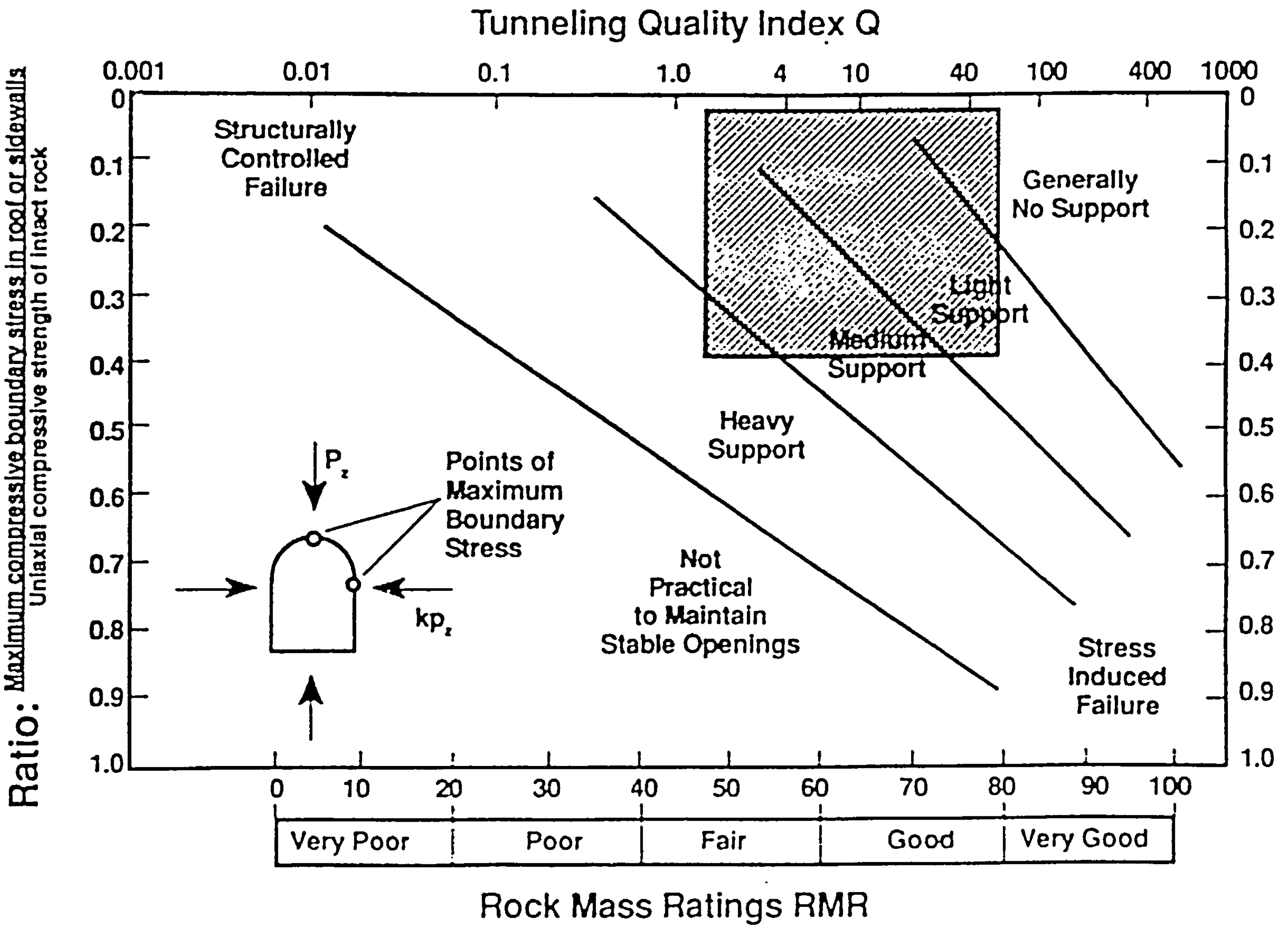
Classification Parameters

CLASSIFICATION SYSTEM	PARAMETER	DESCRIPTION
NGI-Q System	RQD	Rock Quality Designation
	J_N	Joint Set Number
	J_R	Joint Roughness Number
	J_A	Joint Alteration Number
	J_W	Joint Water Reduction Factor
	SRF	Stress Reduction Factor
	Q	Rock Mass Quality
RMR System	C	Intact Core Strength Rating
	F_{RQD}	Rock Quality Designation Rating
	JF	Joint Spacing Rating
	JC	Joint Condition Rating
	JW	Groundwater Rating
	AJO	Adjustment for Joint Orientation
	RMR	Rock Mass Rating

Estimated Support Requirements



Estimated Support Requirement

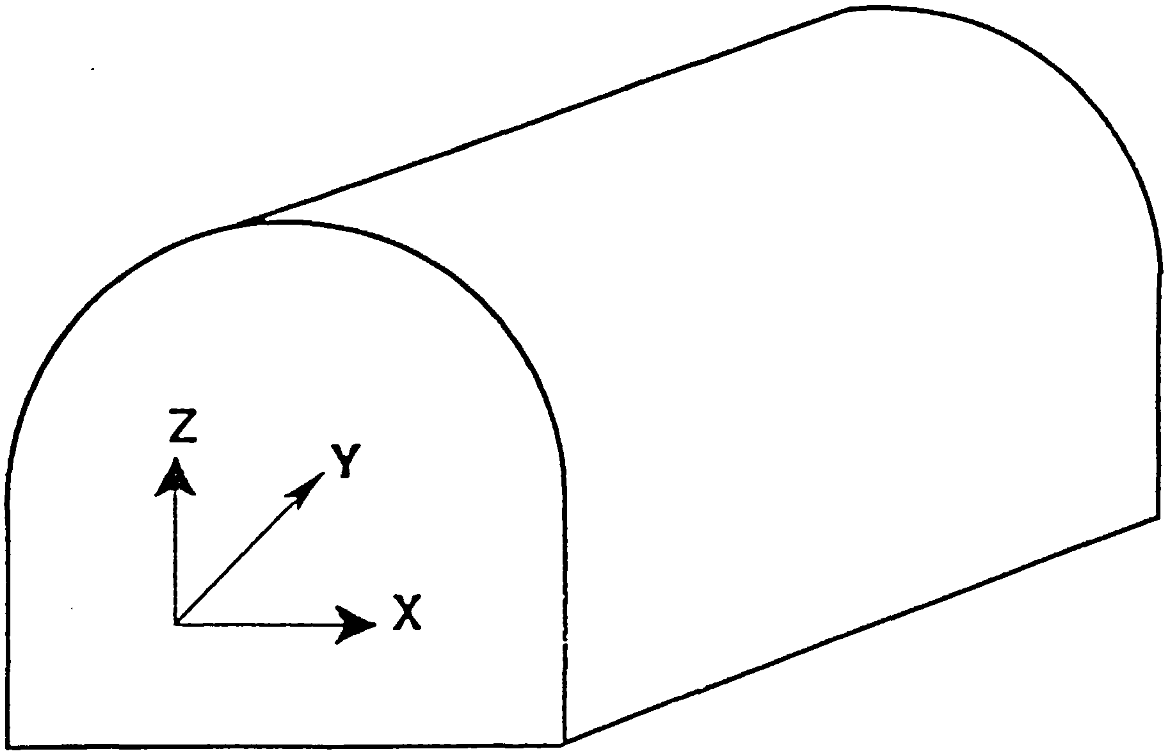


▨ Range of Conditions for Emplacement Drifts

Numerical Design Analysis

- Linear combinations of loads
- Calculate stresses at drift location
  - Stresses depend on time, rock quality (properties), location of drift
- Determine impact on drift excavation and support

3-D Coordinate System



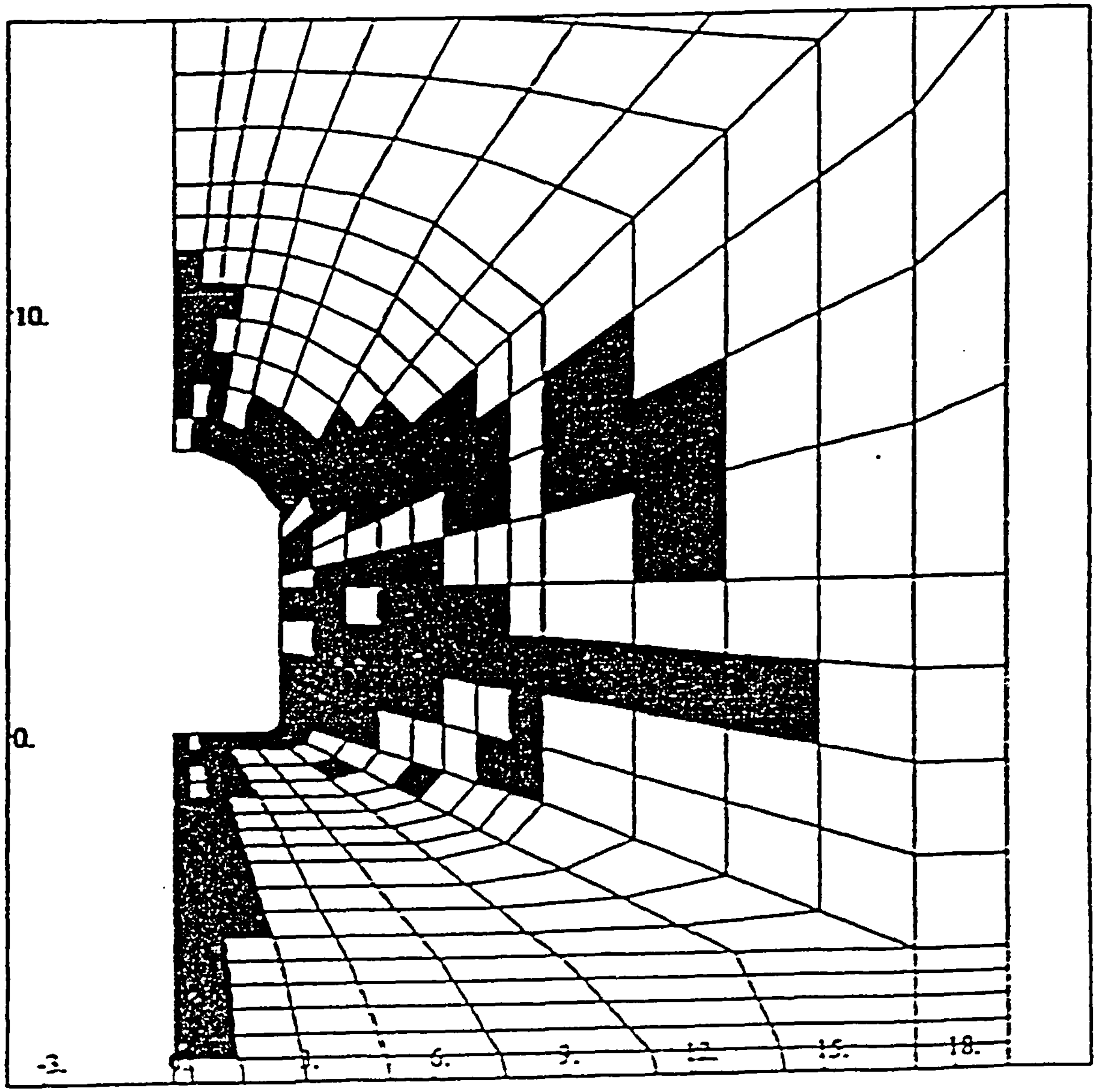
Combined Loads (in MPa) for Midpanel Access Drift at 100 Years

Rock Mass Quality Category	In Situ Stress			Seismic Stress			Thermal Stress			Combined In Situ, Thermal and Seismic		
	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}
1	4.2	3.5	7.0	0.7	0.3	0.8	2.6	1.7	-0.6	7.5	5.5	7.2
2	4.2	3.5	7.0	1.3	0.6	1.4	4.6	3.0	-1.0	10.1	7.1	7.4
3	4.2	3.5	7.0	2.7	1.2	2.9	9.6	6.3	-2.2	16.5	11.0	7.7
4	4.2	3.5	7.0	6.1	2.8	6.7	21.6	14.3	-5.0	31.9	20.6	8.7
5	4.2	3.5	7.0	6.2	2.8	6.7	21.8	14.4	-5.0	32.2	20.7	8.7

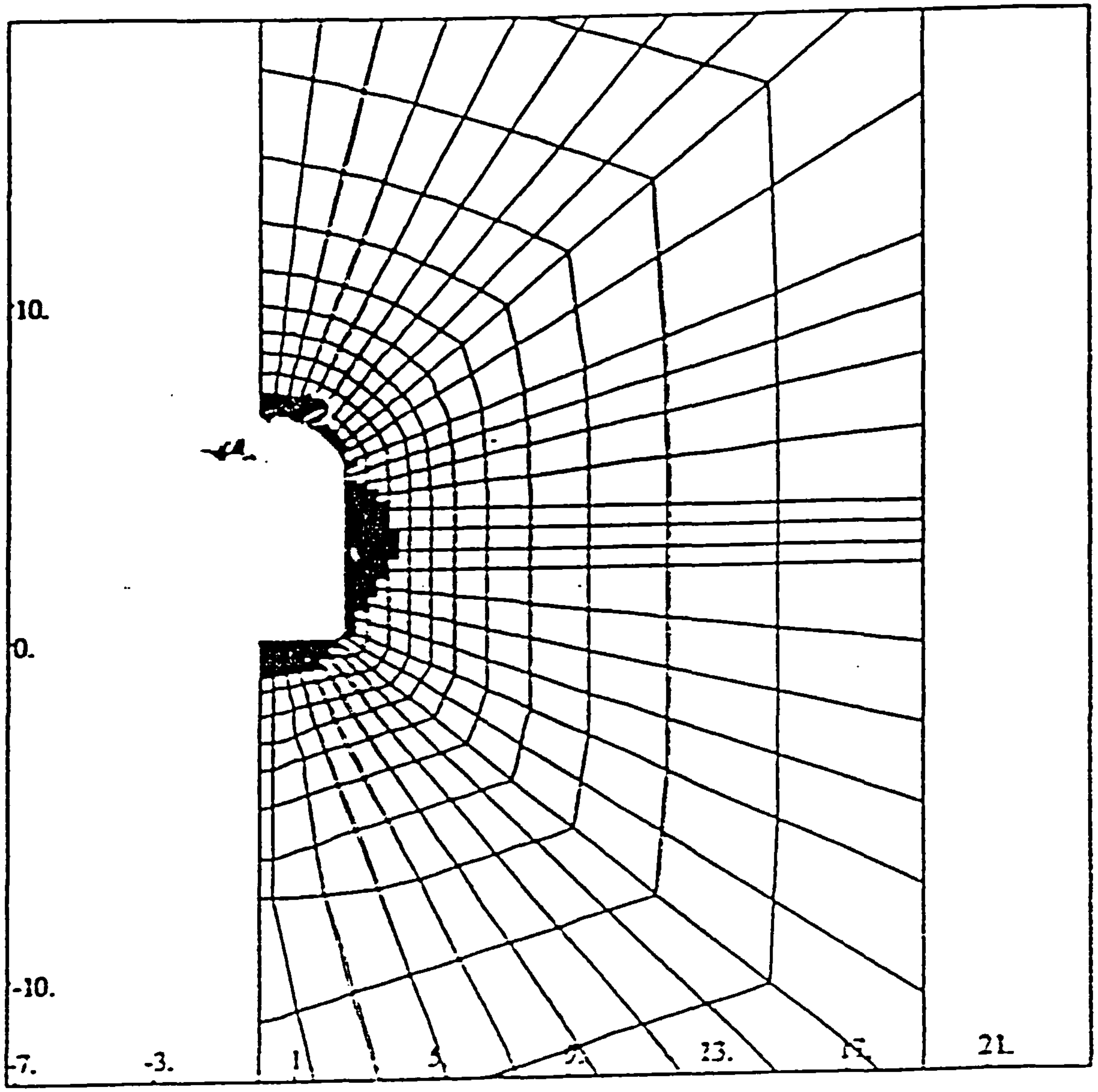
Midway Drift Stress Combinations

Time After Waste Emplacement (Years)	Temp. (° C)	Thermal Stress (MPa)			In Situ+ Thermal (MPa) (MPa)			In Situ + Thermal + Seismic (MPa)			In Situ - Seismic		
		σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}	σ_{xx}	σ_{yy}	σ_{zz}
0	24	0	0	0	4.2	3.5	7.0	6.9	4.7	9.9	1.5	2.3	4.1
10	24	0	0	0	4.2	3.5	7.0	6.9	4.7	9.9			
35	32	4.2	0.8	-3.1	8.4	4.3	3.9	11.1	5.5	6.8			
50	47	6.8	2.7	-3.6	11.0	6.2	3.4	13.7	7.4	6.3			
100	74	9.4	6.2	-2.2	13.6	9.7	4.8	16.3	10.9	7.7			
100	80kW/ ACRE	13.2	8.7	-3.1	17.4	12.2	3.9	20.1	13.4	6.8			

Zones of Joint Slip at 100 Years
(Benchmark Calculation)



Zones of Failure (Drucker - Prager) at 100 Years



Impacts of Thermal Loads on the Underground Design

- Thermal load component can be incorporated into the design through analysis methods; jointed rock models are necessary
- Greater thermal loads (increased stress) may result in additional support or some areas being avoided
  - May enhance stability of some drifts
- Thermal loads may facilitate ground control in some areas when considering possible seismic loads
- Degree of impact depends on local rock conditions

Summary Of Geomechanical Uncertainties

There are some advantages to both higher or lower thermal loading

- Lower thermal loads reduce the complexity of the design analysis and confirmation testing
- In better quality rock, higher thermal loads may facilitate ground control, especially when possible seismic loads are considered
- Higher thermal loads may result in a decrease in fracture permeability due to aperture closure

Summary of Geomechanical Uncertainties

(Continued)

Some problems become more significant as thermal load increases

- In lower quality rock, greater thermal loads may result in additional support or some areas being avoided
- Joint slip and fracture propagation around openings increases
- Higher thermal stresses adds some uncertainty and complexity to the design problem
- Potential effects of changes in stress magnitude and direction are not completely understood. The degree of impact depends on local rock conditions
- High thermal loading would require more extensive modeling, model validation, and confirmation testing

Summary of Geomechanical Uncertainties

(Continued)

Resolution of Problems

- Thermal loads can be incorporated into the design through analysis methods
- Design methodology is independent of degree of thermal load
- Sufficient experience in underground excavations with stress magnitudes comparable to those expected at Yucca Mountain suggest that opening can be supported for the required lifetime, but validation is necessary
- Joint slip or fracture propagation is not expected to extend beyond the drift near-field

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: NEAR-FIELD ENVIRONMENT TESTING CONSIDERATIONS

PRESENTER: DR. WUNAN LIN

PRESENTER'S TITLE AND ORGANIZATION: TASK LEADER
LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 422-7162

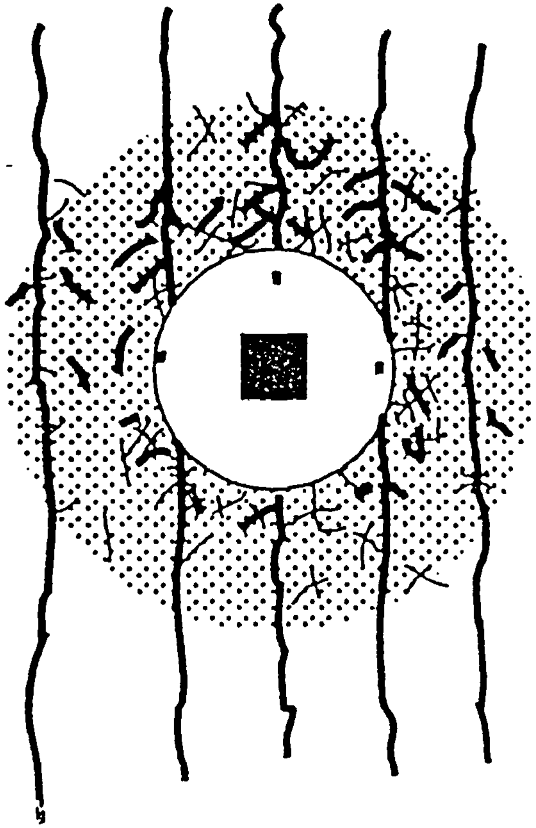
OCTOBER 8 - 10, 1991

Scope

- An Engineered Barrier System includes waste package and the near-field environment
- The near-field environment is an integral part of a repository
- The main concern is the amount and quality of water in the environment
- This talk covers tests required to understand the moisture movement in the near-field environment

EBS Concepts
High and Low Thermal Loadings

High



temperature

cracking

dehydration

rehydration

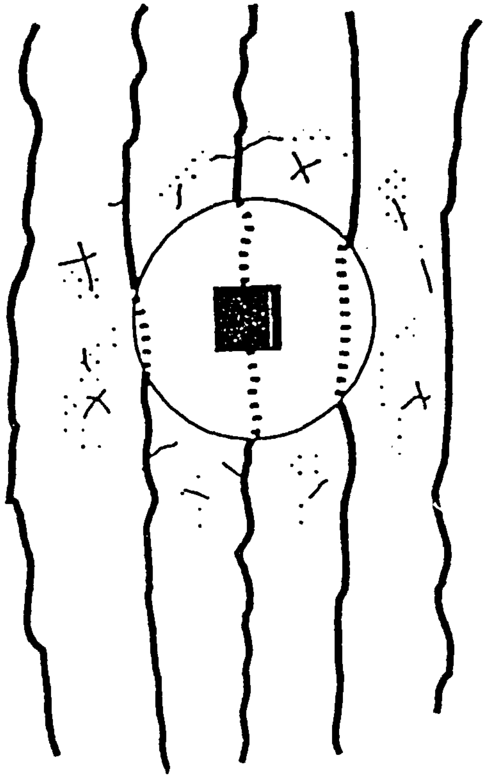
infiltration

geochemistry

flows

stability

Low



Similar tests are required for both cases

Near-Field Environment Tests
Provide Input Data and Validation of Models

- Laboratory tests
- In situ tests

Laboratory Testing
To Study the Hydrologic Properties of Rocks

Will cover:

- Fracture healing
- Model validation experiments
- Matrix properties
- Hydrology and nuclide adsorption experiment

Fracture Healing Experiments

To Study Fracture Healing at Elevated Pressures and Temperatures

Experimental results so far suggest that fracture begins to "heal" when -

- Pressure = 5 MPa
- Temperature above 90° C (high and low)
- Flowing water or steam (high and low)

Model Validation Experiments

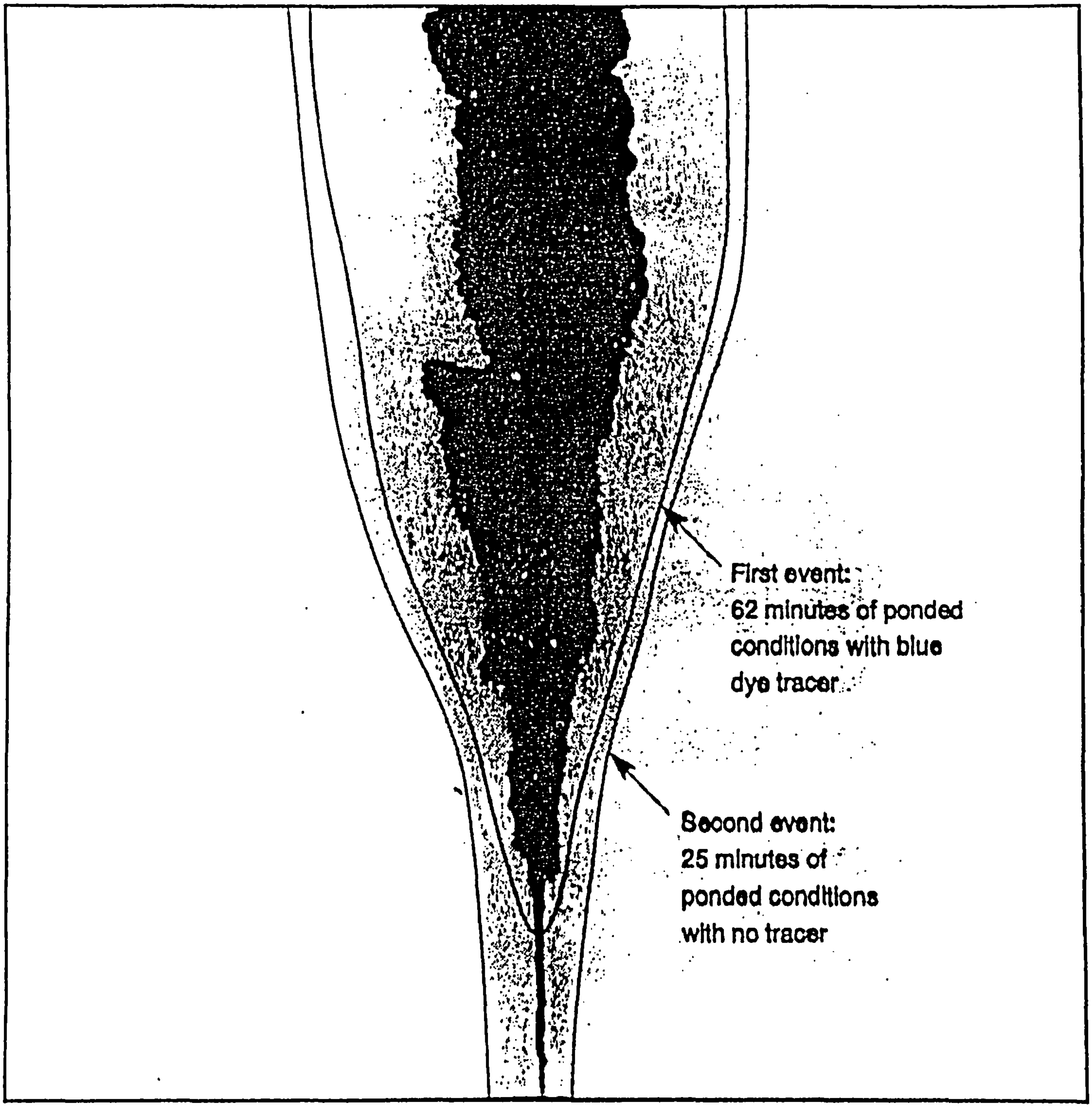
Effect of Temperature on the Flow of Water and Vapor

- Imbibition and drying (high and low)
- Condensation along fractures (high)
- Fracture flow vs. matrix flow (high and low)
- Laboratory heated block experiments (high and low)

Impedance images of a rock sample indicate that rehydration is not a reverse process of dehydration

Prototype Experiment of Fracture-Matrix Flow

First episodic event: wetting front after 62 minutes of ponded conditions using blue dye tracer



First event:
62 minutes of ponded conditions with blue dye tracer

Second event:
25 minutes of ponded conditions with no tracer

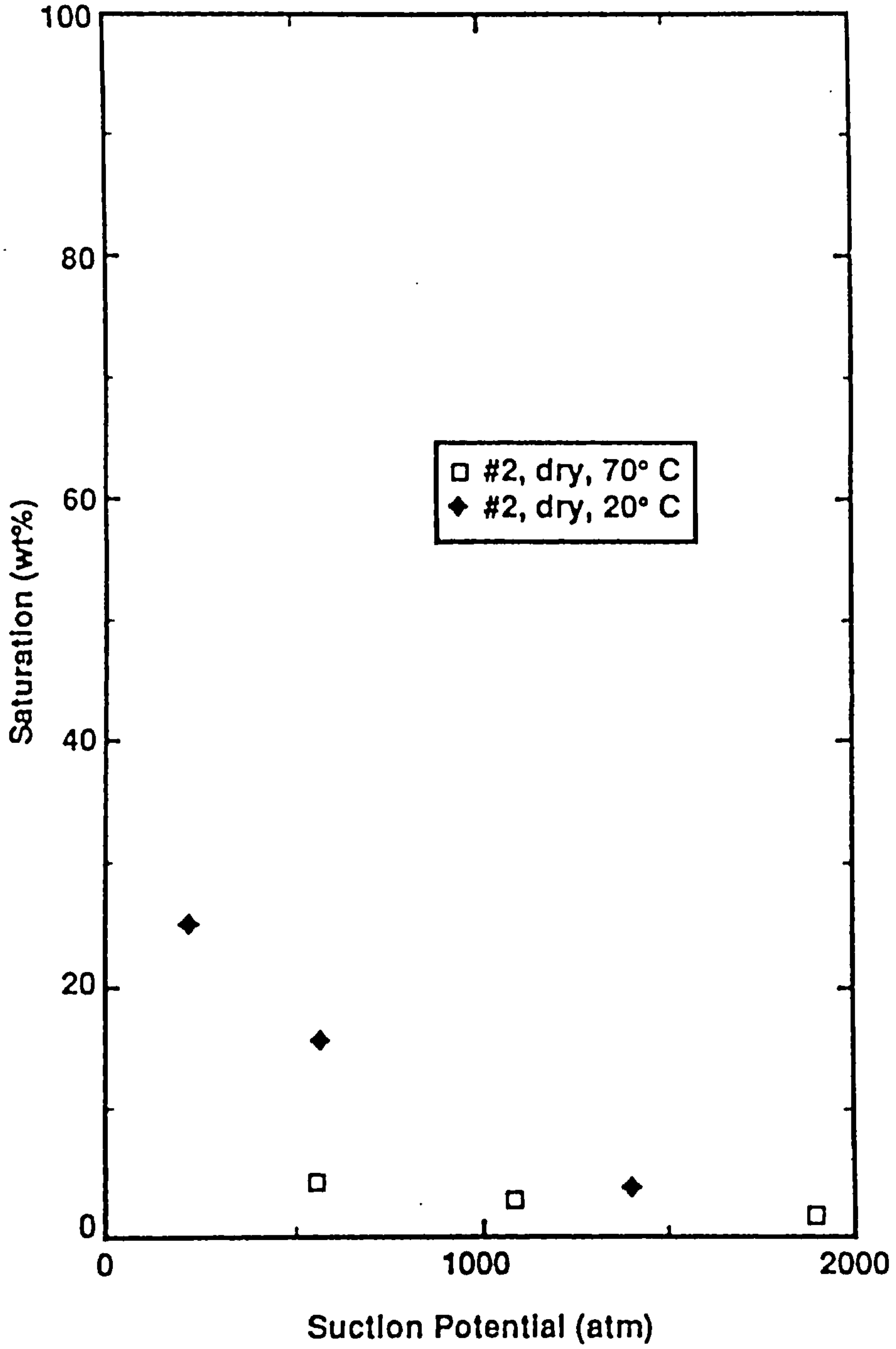
Matrix Properties

Effect of Temperature on Intact Sample

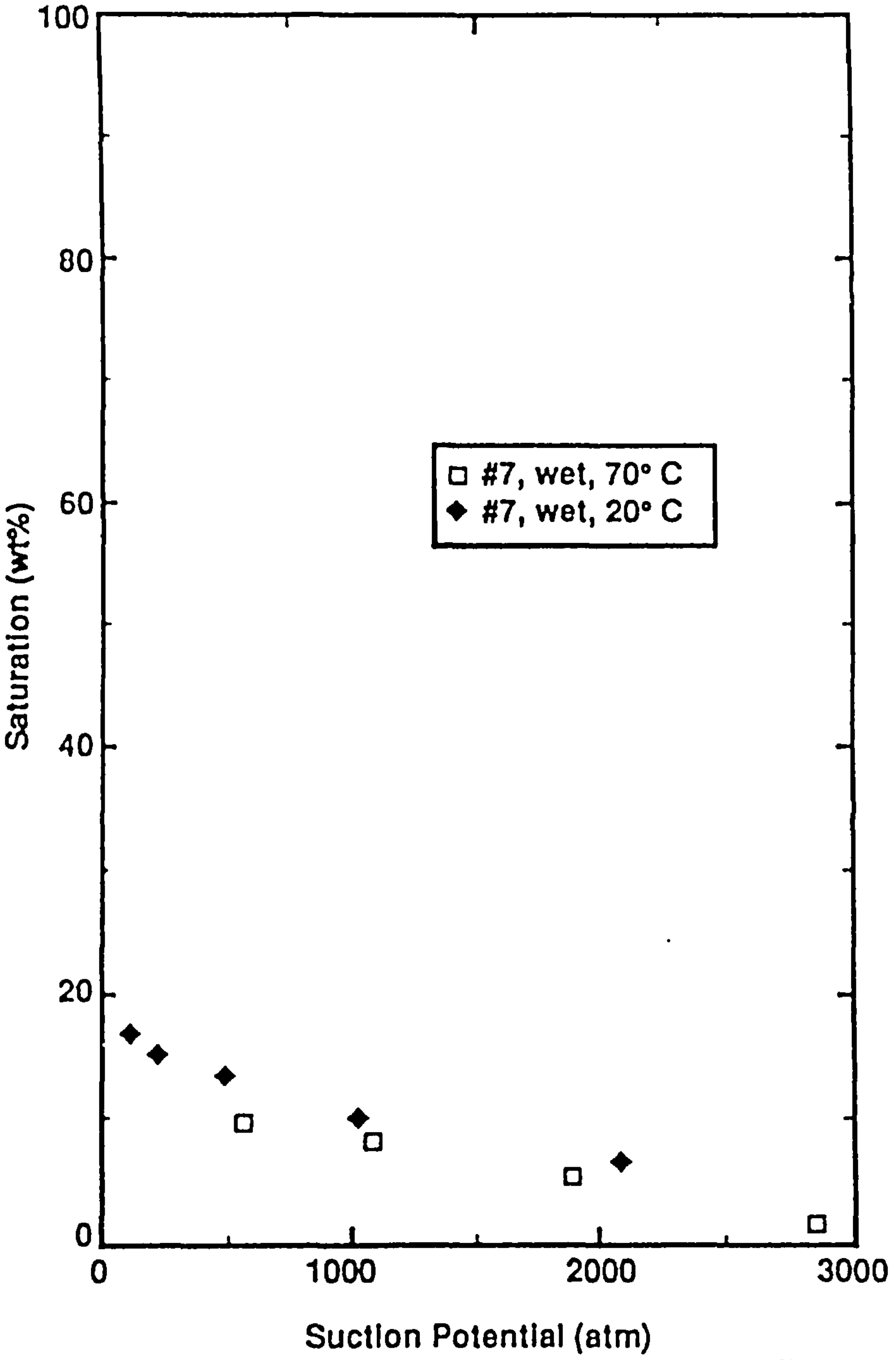
Measure:

- Suction potential (T to 160° C) (high and low)
- Thermal cracking (more at high)
- Permeability (high and low)
- Klinkenberg coefficients (high and low)

Saturation vs Suction Potential of Topopah Spring Tuff, Drying, at 20 and 70° C



Saturation vs Suction Potential of Topopah Spring Tuff, Wetting, at 20 and 70° C



Hydrology and Adsorption

Integrated Study of Flow and Nuclide Adsorption

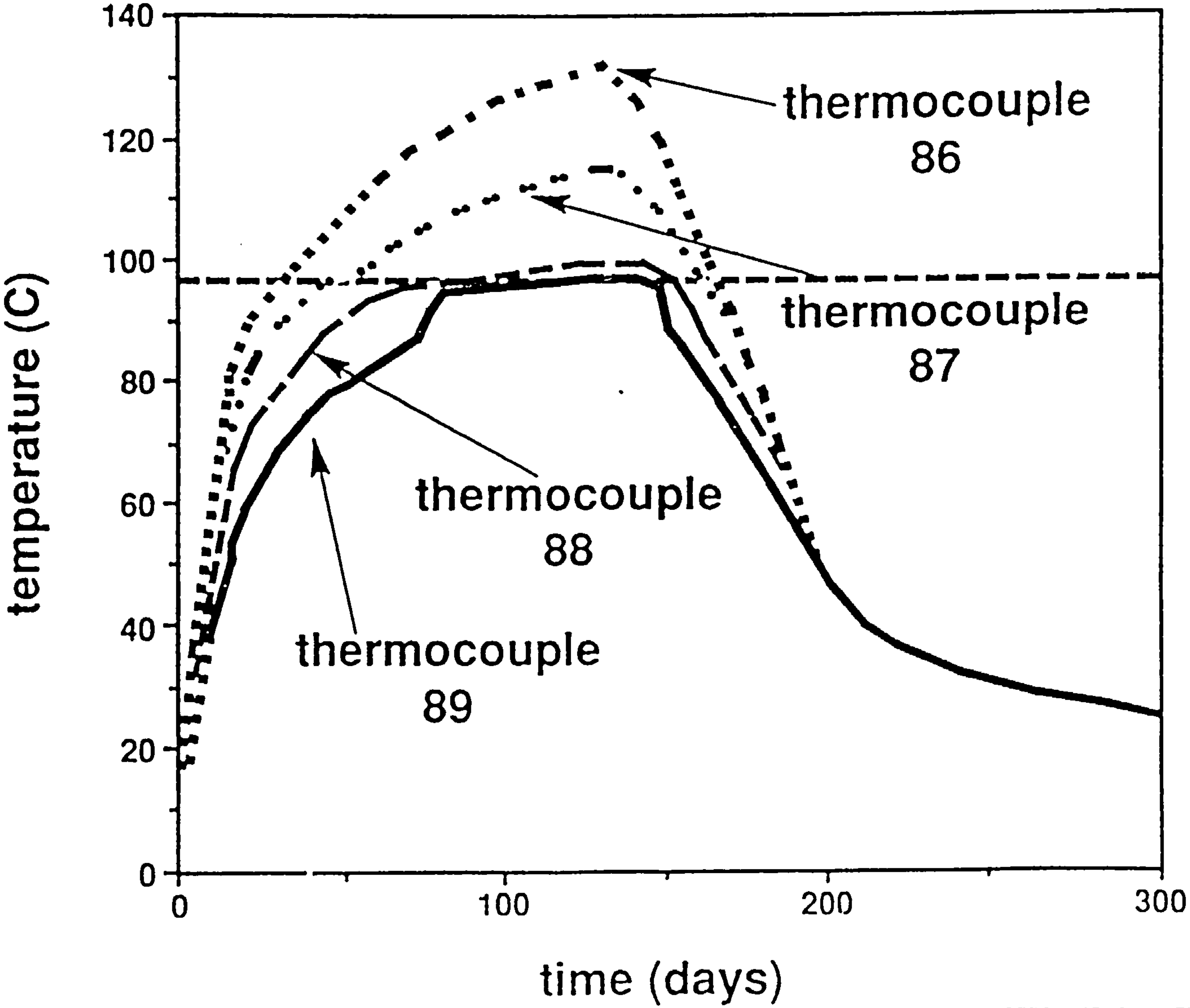
- Temperatures to 150° C
- Various confining pressures and pore pressures
- Both high and low thermal loadings

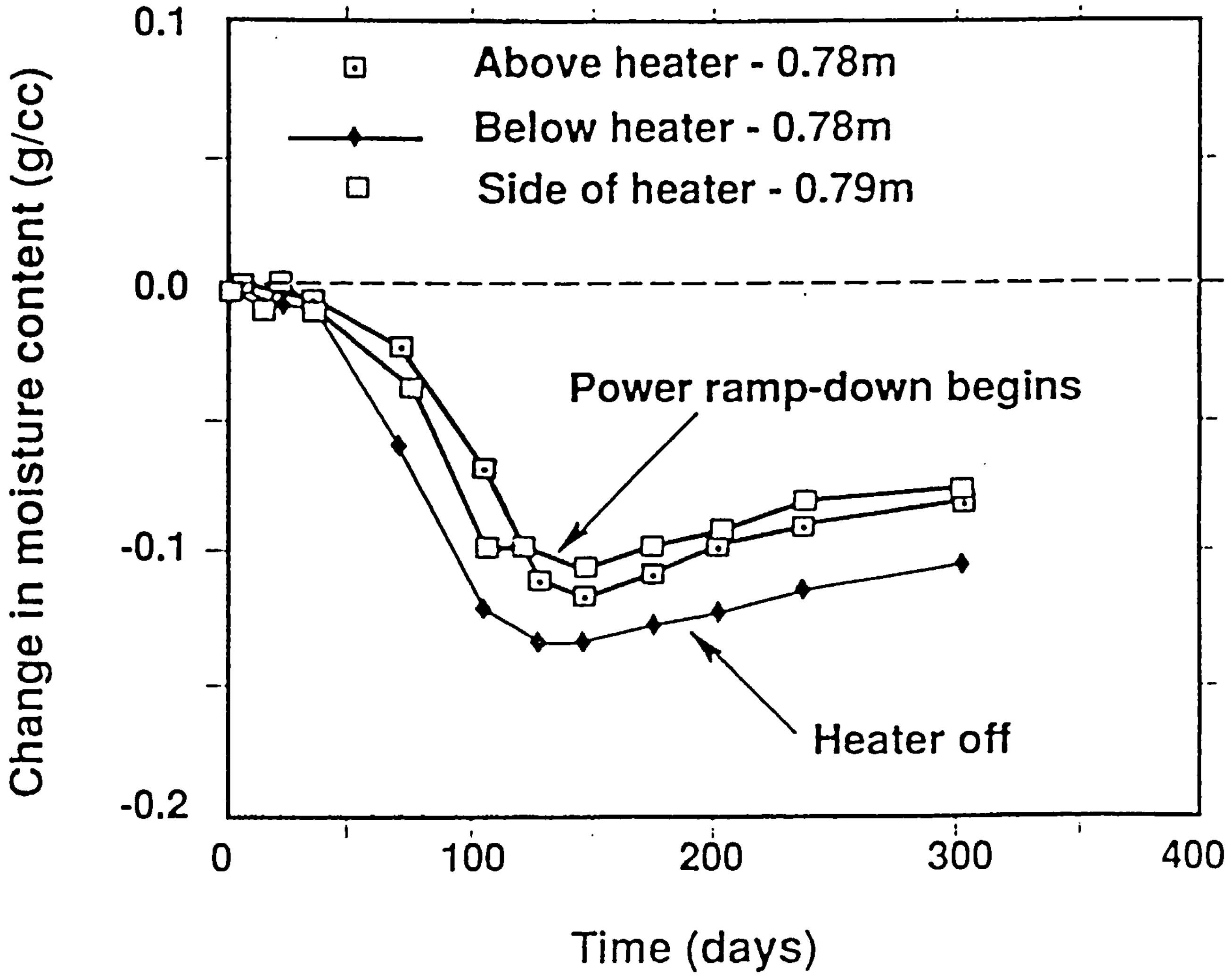
In Situ Tests

Extension of Laboratory and Validation of Model Studies

- Study hydrologic, geochemical, and geomechanical responses of rock mass to thermal loading
- Various power outputs of heater
- Overdrive the rock mass
- Test model at greater range of conditions
- For both high and low thermal loadings

Some Locations Remained At Boiling Temperature




0.1
0.0
-0.1
-0.2
Change in moisture content (g/cc)
0
100
200
300
400
Time (days)
⊡ Above heater - 0.78m
◆ Below heater - 0.78m
☐ Side of heater - 0.79m
Power ramp-down begins
Heater off

In Situ Tests

Measurements and Samplings

- Measurements:
  - Temperature field, f(x,t)
  - Moisture content, f(T,x,t)
  - Gas pressure, f(T,x,t)
  - Borehole stability, f(T,t)
  - Air permeability (effect of heating)
  - Infiltration study
- Samples:
  - Rock samples
  - Water and gas samples

All are needed for high and low thermal loadings

In Situ Tests

Methods and Instruments

- Thermocouple (high and low)
- Neutron and density logs (high and low)
- HFEM (high and low)
- Microwave resonator (high and low)
- Thermocouple psychrometer (low)
- Geotechnical instruments (better at low)

Conclusions

- Both high and low thermal loadings require similar tests
- Technologies exist for both cases
- A few instruments are more reliable for low case
- Some parameters are more detectable in high case

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: CONCEPTUAL CONSIDERATIONS FOR TOTAL SYSTEM PERFORMANCE

PRESENTER: DR. MICHAEL D. VOEGELE

PRESENTER'S TITLE AND ORGANIZATION:
DEPUTY PROJECT MANAGER, TECHNICAL PROGRAMS
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7638

OCTOBER 8 - 10, 1991

Objectives

- Examine implications of higher and lower thermal loading in context of conceptual considerations for total system performance

- Discuss relationships between physical system components, technical uncertainty and 10 CFR Part 60 technical criteria

Approach

- Describe thermal design related aspects of 10 CFR Part 60 technical criteria (post closure emphasis)

- Describe relationships between 10 CFR Part 60 Performance Objectives, 10 CFR Part 60 technical design criteria and MGDS system components

- Summarize geomechanical, hydrogeologic, geochemical, mineralogical, waste form/materials, and biological resource technical uncertainties in evaluating 10 CFR Part 60 Performance Objectives

10 CFR Part 60 Criteria Related to Thermal Loads

1. Content of license application

Section	Concern
60.21c1iF	Anticipated response to maximum thermal loads
60.21c1iiD	Comparative evaluation. . .design features
60.21c11	Features to facilitate closure

10 CFR Part 60 Criteria Related to Thermal Loads

(Continued)

2. Performance Objectives and siting criteria

Section	Concern
60.111b1	Preserve option of waste retrieval
60.112	Overall system performance objective
60.113a1i	Sub. comp. cont. & gradual release rate
60.113a1iiA	300 to 1,000 year waste package
60.113a1iiB	1 part in 100,000 release rate
60.113a2	Pre-waste emplacement groundwater travel time
60.122b4	Thermal impacts on minerals
60.122c20	Conditions requiring complex engineering
60.122c21	Geomechanical props...stable openings

10 CFR Part 60 Criteria Related to Thermal Loads

(Continued)

3. Design criteria for Geologic Repository Operations Area (GROA)

Section	Concern
60.130	Design features to achieve performance objective
60.131b9	Compliance with mining regulations
60.133a1	Geometry and EBS design contribute to isolation. . .
60.133b	Facilities underground flexible conditions
60.133c	Design to permit retrieval
60.133e1	Operations and retrievability option maintained
60.133e2	Reduce deleterious movement or fracturing
60.133f	Limit potential to create pathways
60.133h	EBS assist geological setting
60.133i	Thermal/mechanical response

10 CFR Part 60 Criteria Related to Thermal Loads

(Continued)

4. Design of seals and waste package design criteria

Section	Concern
60.134a	Seal holes...not create pathways
60.134b	Materials/placement effects
60.135a1	Waste package not compromise performance

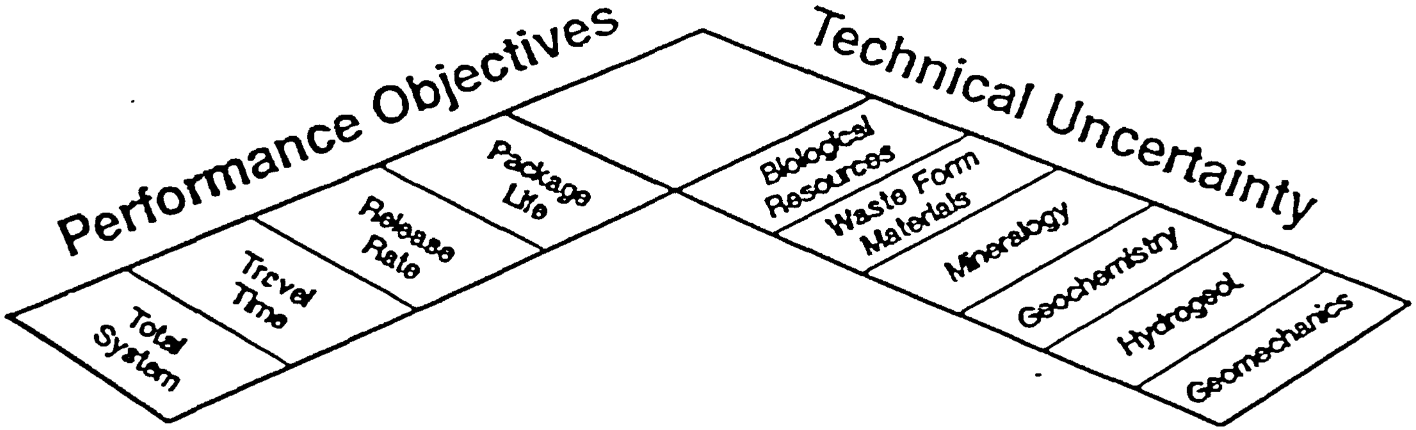
10 CFR Part 60 Thermal DesignTechnical Criteria Performance Objective Relationships

	Performance Objective			
SYSTEM COMPONENT	WASTE PACKAGE LIFE 60.113a1IIA	REL. RATE 60.113a1IIB	PRE-WASTE EMPLACEMT. TRAVEL 60.113a2	TOTAL SYSTEM PERFORM. 60.112
REPOSITORY	.130 .133a1 .133b .133e2 .133f .133h .133i	.130 .133a1 .133b .133e2 .133f .133h .133i	.130 .133a1 .133e2 .133f .133h .133i	.130 .133a1 .133b .133e2 .133f .133h .133i .134a .134b
WASTE PACKAGE	.130 .135a1 .133a	.130 .135a1 .133a	.130 .135a1	.130 .135a1 .133a
TOPOPAH SPRING	.130 .135a1 .133a1 .133b .133c2 .133f .133h .133i	.130 .135a1 .133a .133b .133c2 .133f .133h .133i	.130 .135a1 .133i	.130 .133a .135a1 .133b .133c2 .133f .134a .134b .133h .133i
CALICO HILLS				.130 .133b .133e2 .133f .133h .133i .134a .134b
GROUNDWATER				.130 .133b .133e2 .133f .133h .133i

Repository Design Considerations

- Near-Field Rock Mass Integrity: limit temperatures 1m from borehole wall
- Cladding Integrity: limit temperature of container and borehole wall
- Surface Uplift and Environmental Impacts: limit surface temperature rise and uplift
- Rock Stability: limit intact rock failure or continuous joint slippage
- Extent of Saturated Conditions: limit local saturation; control use of fluids during construction
- Corrosiveness of Container Environment: reduce the potential for liquid water contacting containers
- Potential for Mineral Alteration and Dehydration: limit temperatures in units below the emplacement units

Examine Technical Uncertainty - Performance Objective Relationships



Performance Objectives

Total System

Travel Time

Release Rate

Package Life

Technical Uncertainty

Biological Resources

Waste Form Materials

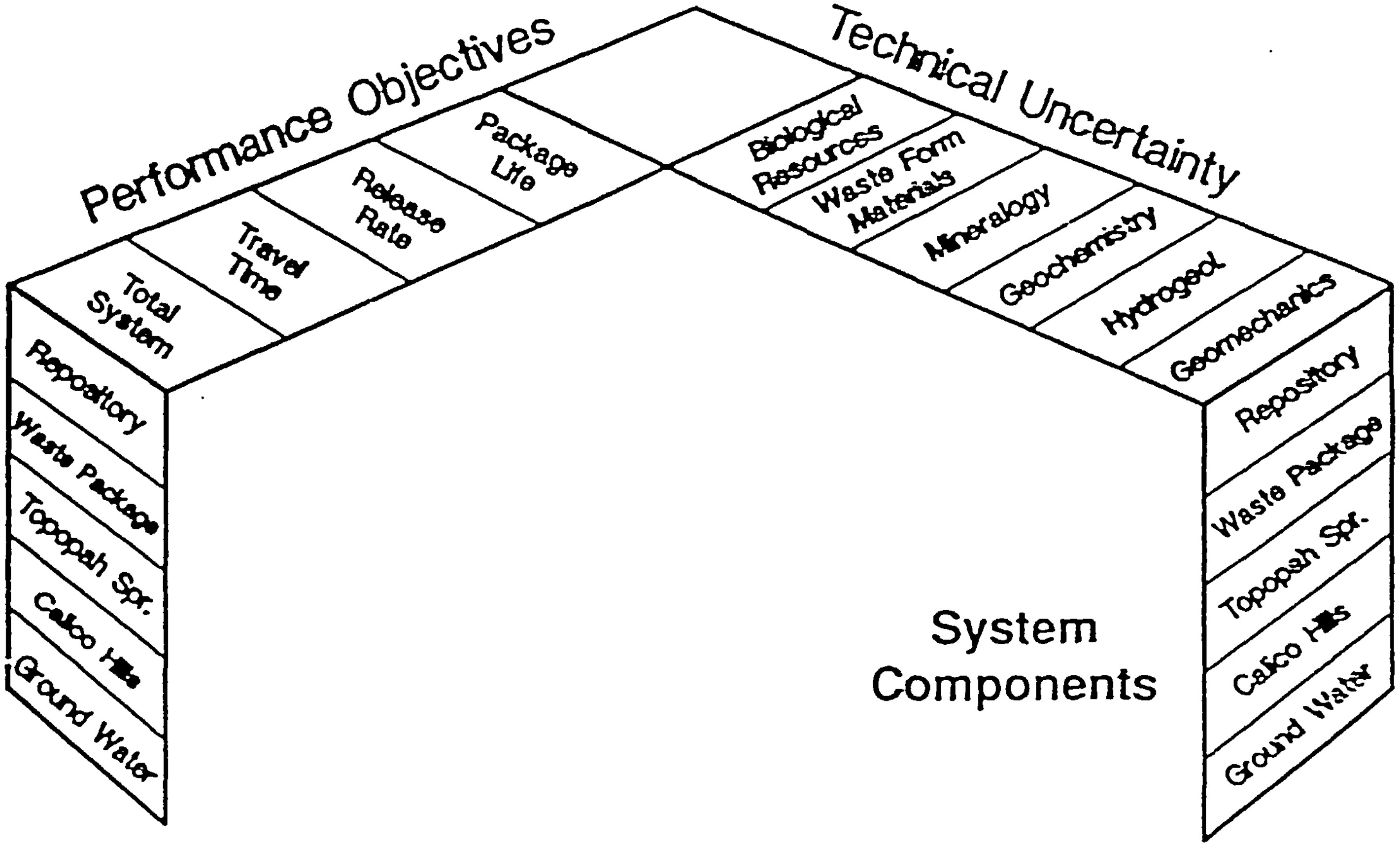
Mineralogy

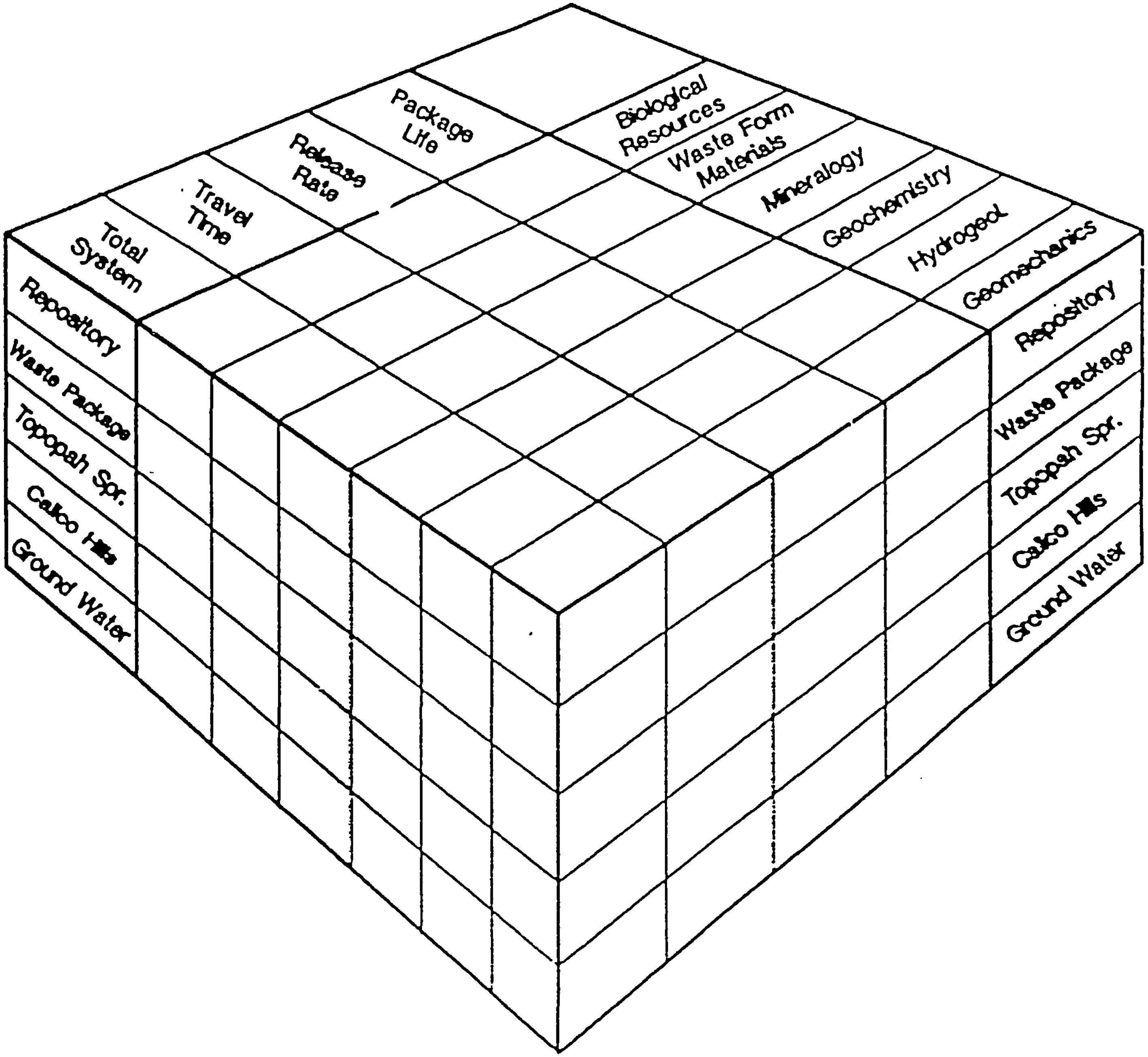
Geochemistry

Hydrogeol.

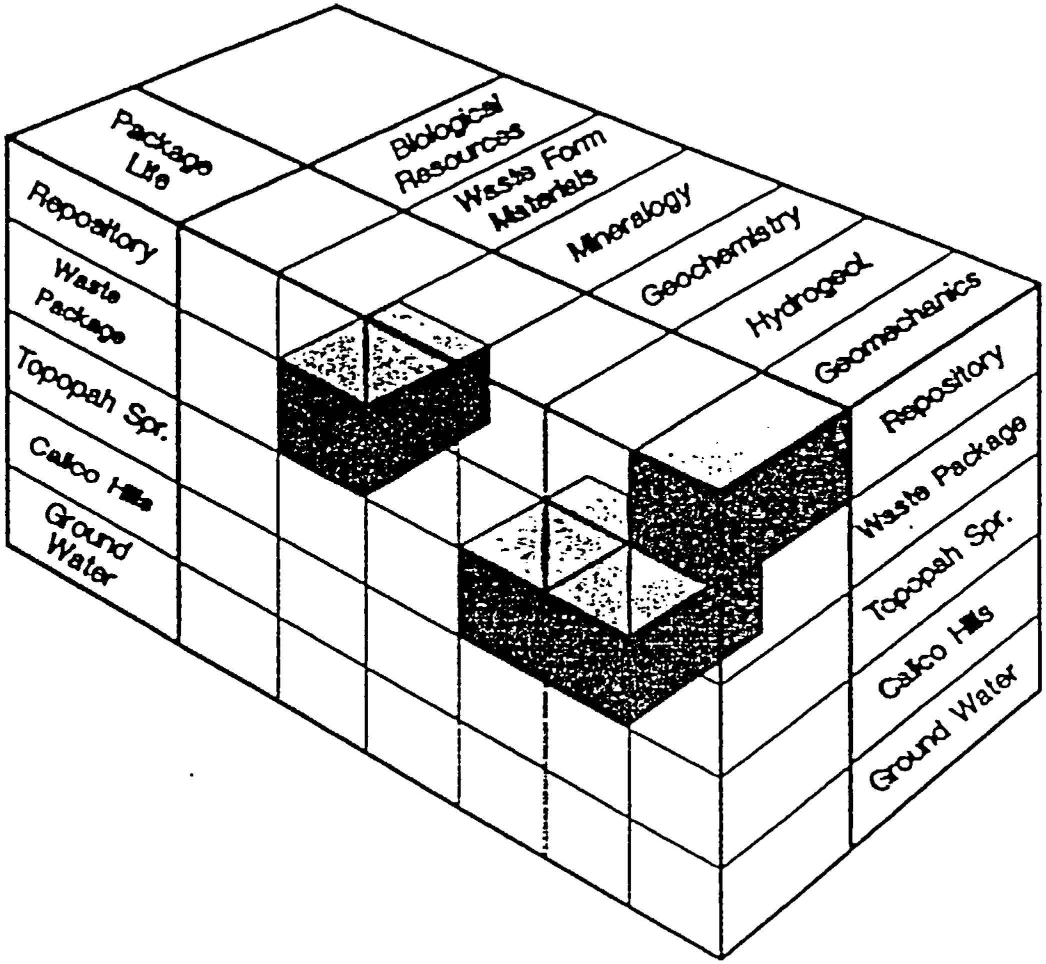
Geomechanics

Also Consider System Component Relationships




Total System
Travel Time
Release Rate
Package Life
Biological Resources
Waste Form Materials
Mineralogy
Geochemistry
Hydrogeol.
Geomechanics
Repository
Waste Package
Topopah Spr.
Calico Hills
Ground Water
Repository
Waste Package
Topopah Spr.
Calico Hills
Ground Water

Waste Package Life - Technical Uncertainty Relationships



Waste Package Life
Technical Uncertainty Relationships

Geomechanical

- Bore hole stability
- Creation of new fractures
- Open or close existing fractures
- Useable area/flexibility
- Lateral diversion

Hydrogeological

- High temperatures promote drying and extend resaturation time, limit contact
- Fractures promote rapid condensate drainage
- Useable area/flexibility

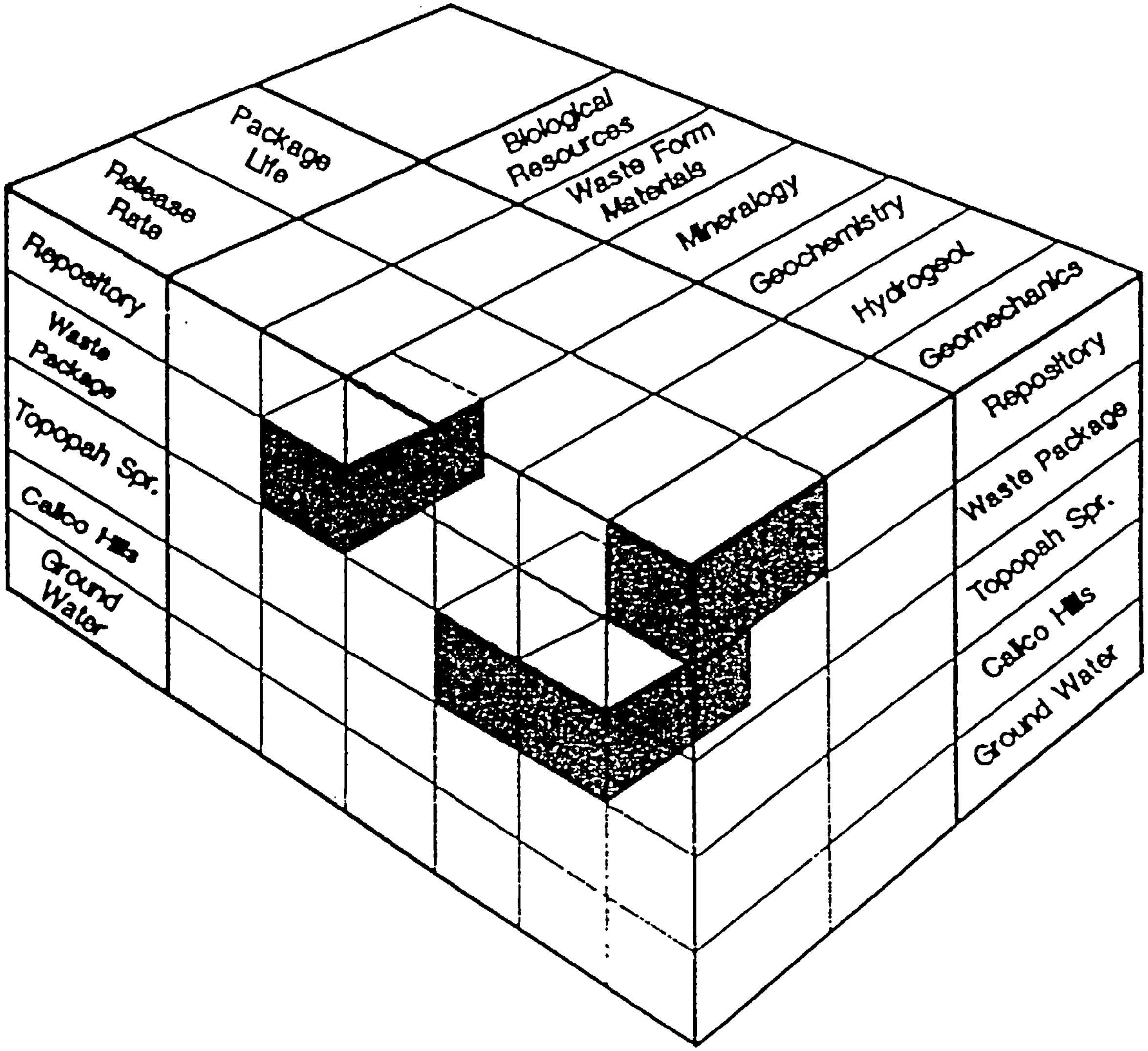
Geochemical

- Changes in environment: chemistry, dissolution, precipitation, sorption
- Mechanistic aspects of corrosion

Waste form/materials

- Container materials above boiling: advantages for corrosion rates and protective oxides

Release Rate - Technical Uncertainty Relationships



Release Rate - Technical Uncertainty Relationships

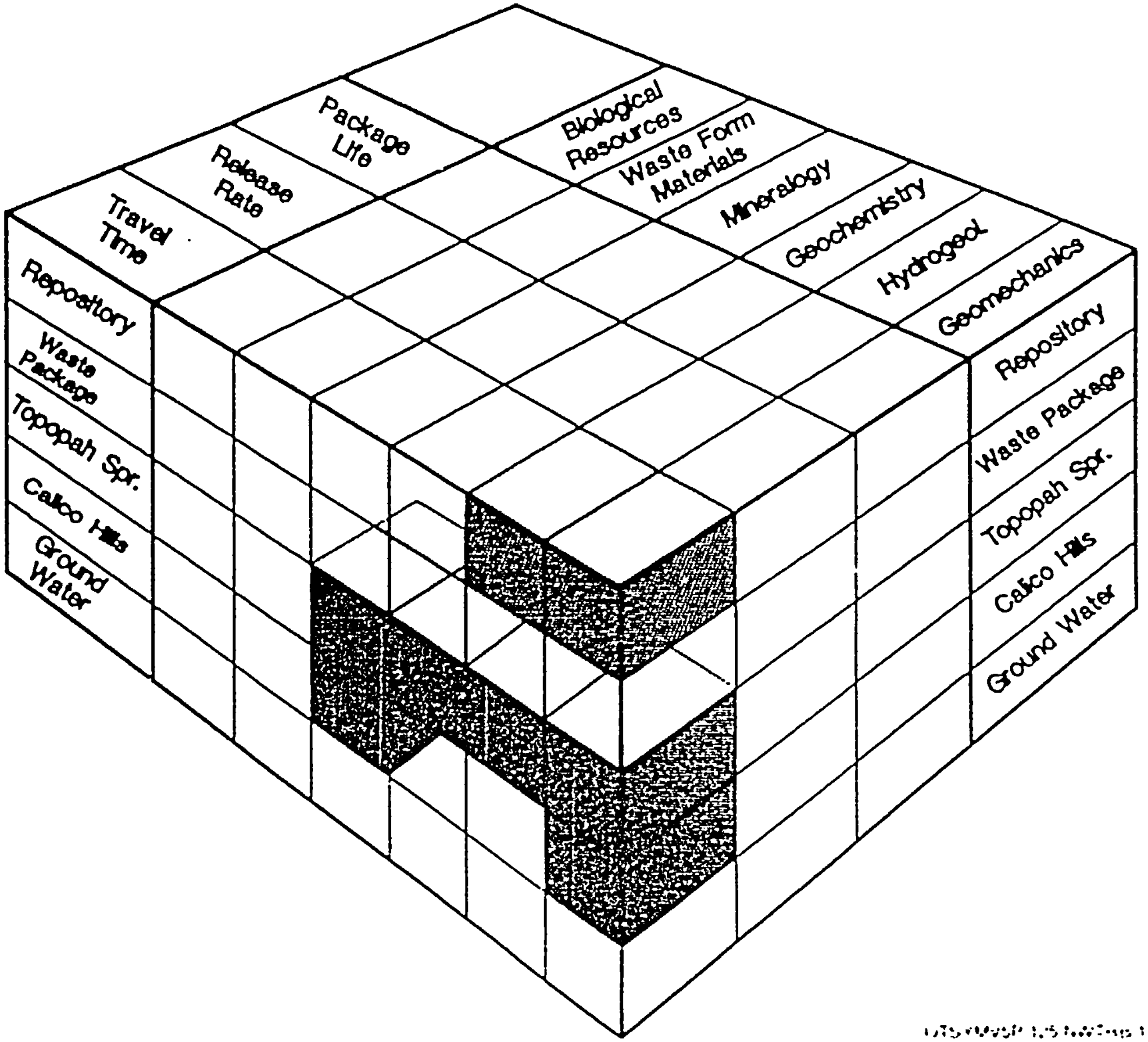
Geomechanical
- Create new fractures
- Open or close existing fractures
- Useable area/flexibility

Hydrogeological
- High temperatures promote drying, extend resaturation time, limit fluids available
- Fractures promote rapid condensate drainage
- Useable area/flexibility
- Lateral diversion

Geochemical
- Changes in environment: chemistry, dissolution, precipitation, sorption
- Mechanistic aspects of corrosion
- Expected phases at elevated temperatures are zeolites and clays
- Region of altered permeability and porosity

Waste form/materials
- Container materials above boiling: advantages for corrosion rates and oxide formation
- Spent fuel, 100 to 250° C: advantages for cladding rupture, oxidation, intact pellets and fuel dissolution
- Borosilicate glass, at or below boiling: advantages for benign water/ glass interactions

Pre-waste Emplacement Travel Time - Technical Uncertainty Relationships



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Pre-waste Emplacement Travel Time - Technical Uncertainty Relationships

Importance is in calculating the extent of the disturbed zone due to

- Stress redistribution
- Construction and excavation
- Thermomechanical effects
- Thermochemical effects

NRC considers 5 opening diameters may be minimum appropriate distance

Pre-waste Emplacement Travel Time - Technical Uncertainty Relationships

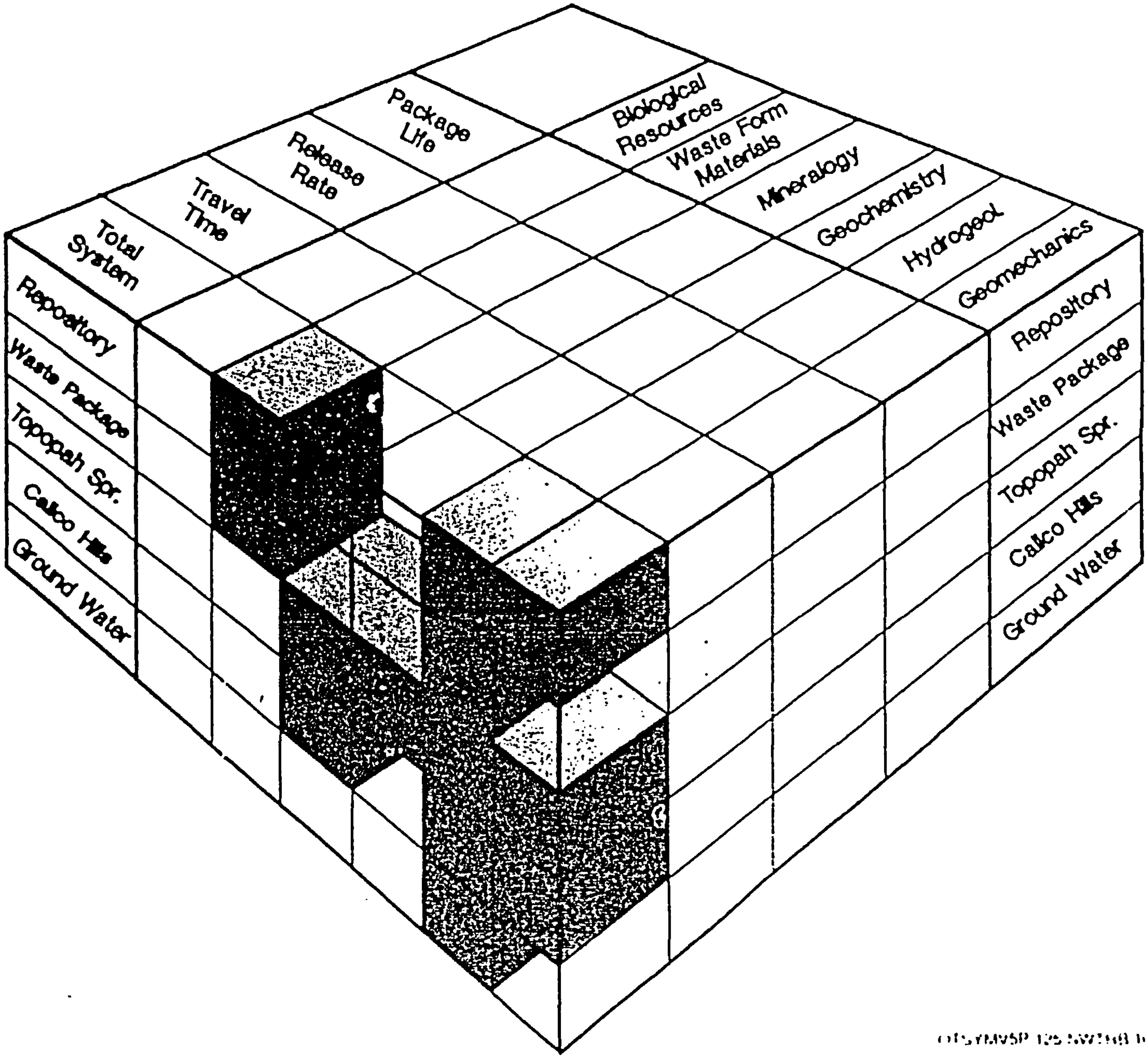
Geomechanical
- Construction and thermally created fractures
- Open or close existing fractures

Hydrogeological
- Construction or operations induced fluid saturation changes
- Lateral diversion

Geochemical
- Development of region of altered permeability and porosity

Mineralogical
- Dehydration and contraction of minerals
- Potential enlargement, contraction, or clogging of transport pathways
- Short term contraction is reversible
- Certain reactions beneficial although they cause flow path modifications

Total System Performance - Technical Uncertainty Relationships



Total System Performance - Technical Uncertainty Relationships

Geomechanical

- Borehole stability
- Create new fractures
- Open or close existing fractures
- Useable area/flexibility

Hydrogeological

- Impact on fracture dominated flow
- Boiling and dryout enhance fracture flow attenuation; consider volume and time
- Promote drying, extend resaturation time and limit fluids available
- Fractures promote rapid condensate drainage
- Reliance on saturated zone flow
- Useable area/flexibility
- Lateral diversion

Geochemical - source term

- Changes in environment
- Potential near-field retardation enhancements
- Region of altered permeability and porosity

Total System Performance - Technical Uncertainty Relationships

Mineralogical

- Dehydration and contraction of minerals
- Potential enlargement of, contraction, or clogging transport pathways
- Reversible short term contraction; long term may be irreversible
- Mineral alteration potential - time

Waste form/materials - source term

- Container materials above boiling: advantages for corrosion rates and oxide formation
- Spent fuel, 100 to 250° C: advantages for cladding rupture, oxidation, fuel dissolution
- Borosilicate glass, at or below boiling: advantages for benign water/glass interactions

Biological Resource Concerns

- Not addressed in technical requirements of 10 CFR Part 60
- Addressed in EIS process
- Addressed in repository design requirements
- Design calculations suggest ~1° C temperature changes at ground surface

Repository Design Considerations

- Near-Field Rock Mass Integrity: limit temperatures 1m from borehole wall
- Cladding Integrity: limit temperature of container and borehole wall
- Surface Uplift and Environmental Impacts: limit surface temperature rise and uplift
- Rock Stability: limit intact rock failure or continuous joint slippage
- Extent of Saturated Conditions: limit local saturation; control use of fluids during construction
- Corrosiveness of Container Environment: reduce the potential for liquid water contacting containers
- Potential for Mineral Alteration and Dehydration: limit temperatures in units below the emplacement units

Concluding Remarks

- Performance objectives provide framework for judging suitability of site
- Design considerations should address attributes to meet performance objectives
- Ranges of APD should be examined during design to develop approaches to meet all design considerations
- System interactions permit trade-offs in component performance requirements

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: REGULATORY/LEGISLATIVE CONSIDERATIONS REGARDING THERMAL LOADING

PRESENTER: MIGUEL A. LUGO

PRESENTER'S TITLE
AND ORGANIZATION: ASSISTANT PROJECT MANAGER,
REGULATORY INTERACTIONS AND TRAINING
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
LAS VEGAS, NEVADA

PRESENTER'S
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OCTOBER 8 - 10, 1991

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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Discussion Topics

- Key regulatory requirements
- Regulatory perspective on licensability
- Compliance approach
- Legislative implications
- Conclusions

Key Regulatory Requirements

10 CFR 60

- "The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, groundwater system" (60.133(i))
- "The safety analysis report shall include. . .the anticipated response of the geomechanical, hydrogeologic, and geochemical systems to the maximum design thermal loading, given the pattern of fractures and other discontinuities and the heat transfer properties of the rock mass and groundwater" (60.21(c)(1)(i)(F))

Key Regulatory Requirements

(Continued)

Preclosure Operations

10 CFR 60.111(a)	Radiation protection for unrestricted areas
10 CFR 60.111(b)	Waste retrievability

Key Regulatory Requirements

(Continued)

Postclosure Performance

10 CFR 60.112	Total system performance
10 CFR 60.113(a)(1)	Waste package containment
10 CFR 60.113(a)(1)	Engineered barrier system releases
10 CFR 60.113(a)(2)	Pre-waste-emplacement ground water travel time

Key Regulatory Requirements

(Continued)

- Nothing in the regulations points to any particular preference regarding thermal loading
- No lesser or greater requirements are imposed based on the choice of thermal loading
- Choice of thermal loading could affect compliance approach

Regulatory Perspective on Licensability

- Licensability:

  Largely a factor of how well technical requirements can be satisfied

- Key considerations during licensing review
  - Data availability
  - QA pedigree
  - Precedence
  - Complexity

- A design with fewest uncertainties and least controversy is more likely to receive a favorable NRC review

Compliance Approach

Preclosure Operations

- **Mostly dependent on design of engineered features and development of operating procedures**
- **Nothing beyond reasonably available technology is expected**

Compliance Approach

(Continued)

Postclosure Performance

- Requires understanding of behavior of engineered barriers and the geologic setting under different thermal loads

- The level of regulatory uncertainty is dependent on the extent to which such understanding can be achieved

- Technical uncertainties are expected to be reduced by site characterization, waste package testing and performance confirmation

Legislative Implications

- NWPA established the federal policy on geologic disposal, including a schedule for key program activities
- Implicit in the NWPA is an emphasis on early disposal, not storage
- If Congress were to emphasize extended storage, rather than disposal (i.e., cooling of waste at an MRS facility), legislative action would be required
    - De-linkage of MRS and repository
    - Revision of MRS capacity limits
    - Authorization for more than one MRS facility

Legislative Implications

(Continued)

- An emphasis on extended storage, rather than disposal, could impact CRWM program
  - Takes focus away from finding a permanent solution to HLW problem
    - * Impact on new reactor licenses
    - * Impact on reactor license extensions
  - Could result in licensing difficulty for the MRS facility (Public view that MRS facility would become de-facto repository)

Conclusions

- Regulatory requirements to be considered do not vary depending on the choice of thermal loading
- Regulatory uncertainty (licensability) is primarily a factor of the defensibility of technical conclusions
- For preclosure operations, a higher thermal loading is not expected to be cause for regulatory concern
- For postclosure performance, the level of regulatory challenge will depend on the extent to which the testing program can reduce technical uncertainties
- An emphasis on cooling of waste at an MRS facility would require legislative initiatives and re-focusing of the CRWM program

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HIGH-LEVEL WASTE (HLW) SYSTEM COMPARATIVE COSTS

PRESENTER: DAVID C. JONES

PRESENTER'S TITLE AND ORGANIZATION: CONSULTANT
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PRESENTER'S TELEPHONE NUMBER: (202) 783-1560

OCTOBER 8 - 10, 1991

Thermal Loading Implications on HLW System Costs

- Current total-system life-cycle cost (TSLCC) estimates
- Cost implications of higher and lower thermal loadings on current system designs
- Potential design/cost implications of different thermal loadings

Current Total-System Life-Cycle Cost (TSLCC) Estimates

Estimates from the December 1990 TSLCC Addendum (billions of 1988 dollars)

Cost Category	Single-Repository System	Two-Repository System
Development & Evaluation	11.5	15.0
Transportation	2.8	2.7
First Repository	8.7	7.0
Second Repository	NA	6.6
MRS Facility	1.9	1.6
Benefit Payments	0.7	0.8
	——	——
Total-System Cost	25.6	33.6

Key TSLCC Assumptions - First Repository (Yucca Mountain)

- Designs based on modified SCP-CDR and RCS designs for both surface and subsurface
- First repository assumed to begin waste acceptance and emplacement in 2010
- All spent fuel assumed to be emplaced as intact assemblies in hybrid disposal containers
- Repository Capacity:

Single-repository system	96,300 MTHM
Two-repository system	70,000 MTHM

- Subsurface layout is based on maintaining 57 kW/acre

Key TSLCC Assumptions - MRS Facility

- MRS facility costs based on a storage-only facility
- MRS facility was assumed to begin limited waste acceptance in 1998 with the full capability MRS facility becoming operational in the year 2000
- Storage concept utilized at the MRS facility was assumed to be dry cask storage

Key TSLCC Assumptions - MRS Facility

(Continued)

- MRS facility assumed to service only the first repository
- All spent fuel shipped from reactors was assumed to go directly to the MRS facility before shipment to the first repository
- The peak MRS facility capacity is 15,000 MTHM of spent fuel. Additionally, the MRS facility will not be allowed to store more than 10,000 MTHM prior to the start of repository operations

Key TSLCC Assumptions - Transportation

- Transportation cask designs based on reference 10 year old spent fuel

- Acceptance and transportation logistics from reactors to the MRS facility were developed based on an "oldest-fuel-first" (OFF) acceptance priority

Key TSLCC Assumptions - Development & Evaluation

- Development and Evaluation (D&E) costs include all siting, preliminary design development, testing, regulatory, and institutional activities associated with the waste management system

- D&E costs also include costs of administration of the high-level waste program by the Federal Government

- D&E costs include all pre-license application design (pre-LAD) costs

Cost Implications of Different Thermal Loadings on Current System Designs

Two Primary Options for Achieving Various Thermal Loadings with Current System Designs

- Customizing the emplacement of waste packages
  - Adjustments to the borehole and/or emplacement drift spacing within the subsurface repository can be made based on the age/burnup/characteristics of the waste to achieve different thermal loadings. In general, a lower thermal loading can be achieved with a larger subsurface area, and a higher thermal loading can be achieved with a more compact subsurface area
- "Levelizing" or "heat tailoring" thermal output of individual waste packages by aging the spent fuel at the MRS facility prior to emplacement
  - For lower thermal loadings, this could be achieved by providing long-term surface storage at the MRS facility to allow for appropriate aging

Customizing the Emplacement of Waste Packages

- Adjusting the spacing between boreholes and/or emplacement drifts would allow for higher thermal loadings with a smaller subsurface and lower thermal loadings with a larger subsurface
- The major cost impacts resulting from this approach would be limited to the subsurface repository costs:

Thermal Load	Mined Volume ($\times 10^6$ ft^3)	Subsurface Costs (billions of $)
30 kW/acre	353	$3.5
57 kW/acre	300	$3.1
80 kW/acre	255	$2.7

- There would be no significant cost impact to the remainder of the system (i.e., transportation, MRS facility, repository surface facilities, etc.)

"Heat Tailoring" of Waste Packages

- Providing long-term surface storage at the MRS facility prior to emplacement at the repository could provide appropriate cooling of the spent fuel in order to achieve a lower thermal loading

- For an MRS facility which provides for a minimum of 50 years of aging of spent fuel prior to emplacement in a repository :

MRS operating costs:	+ $2.0 billion for single-repository + $1.5 billion for two-repository
D & E costs:	+ $2.0 billion

- Assumes an unconstrained MRS facility which accepts the entire inventory of spent fuel prior to its shipment to the repository

Additional Option for Achieving Various Thermal Loadings Which May Warrant Further Consideration:

- "Levelizing" or "heat tailoring" thermal output of individual waste packages by blending the spent fuel at the MRS facility prior to packaging into disposal containers

  - Producing a level pattern of annual average decay heat emplaced could be accomplished with an MRS facility which has a storage capacity between 20,000 and 25,000 MTHM. Thus, an MRS facility would add, by virtue of its storage capacity, greater flexibility to manage the thermal characteristics of spent fuel. A 10,000 MTHM increase in the peak MRS facility storage capacity would result in a $0.5 billion increase in MRS costs

Potential Design/Cost Implications of Different Thermal Loadings

Potential Design Implications of Thermal Loadings

Previous discussions of cost implications were based on existing designs, however targeting a different thermal loading doesn't preclude changing these designs to better achieve this targeted thermal loading. Potential design changes with large cost implications are:

- Repository
  - Waste package - materials, capacity, universal cask...
  - Subsurface layout - total area, number of drifts, excavated tons, emplacement orientation, etc.
  - Surface facilities - waste handling building, hotcells, surface storage capacity, ventilation facilities, etc.

Potential Design Implications of Thermal Loadings

(Continued)

- MRS facility
  - Storage concept/design: modular vault, drywells, etc.
  - Total storage area required
  - Extended operating life implications
- Transportation
  - Transportation cask: materials, capacity, universal cask...

Summary

Summary

Utilizing current system designs

- Repository
  - Achieving higher or lower thermal loading at the repository via adjustments to the subsurface has the least impact on the remainder of the waste management system

30 kW/acre	+ $0.4 billion subsurface cost (1% increase in total system costs)
80 kW/acre	- $0.4 billion subsurface cost (1% reduction in total system costs)

- No significant impact on transportation, MRS facility, D & E, and repository surface facilities costs

Summary

(Continued)

Utilizing current system designs

- MRS facility
  - Utilizing the MRS facility for long-term storage and aging of spent fuel to achieve a lower thermal loading will have significant impacts on MRS costs and D & E costs

    For minimum 50 year old fuel

    MRS costs + $1.5 to $2.0 billion

    D & E costs + $2.0 billion
    (16% increase in total system costs for single repository; 10% increase in total system costs for two-repository)

- No significant impact in repository and transportation costs

Summary

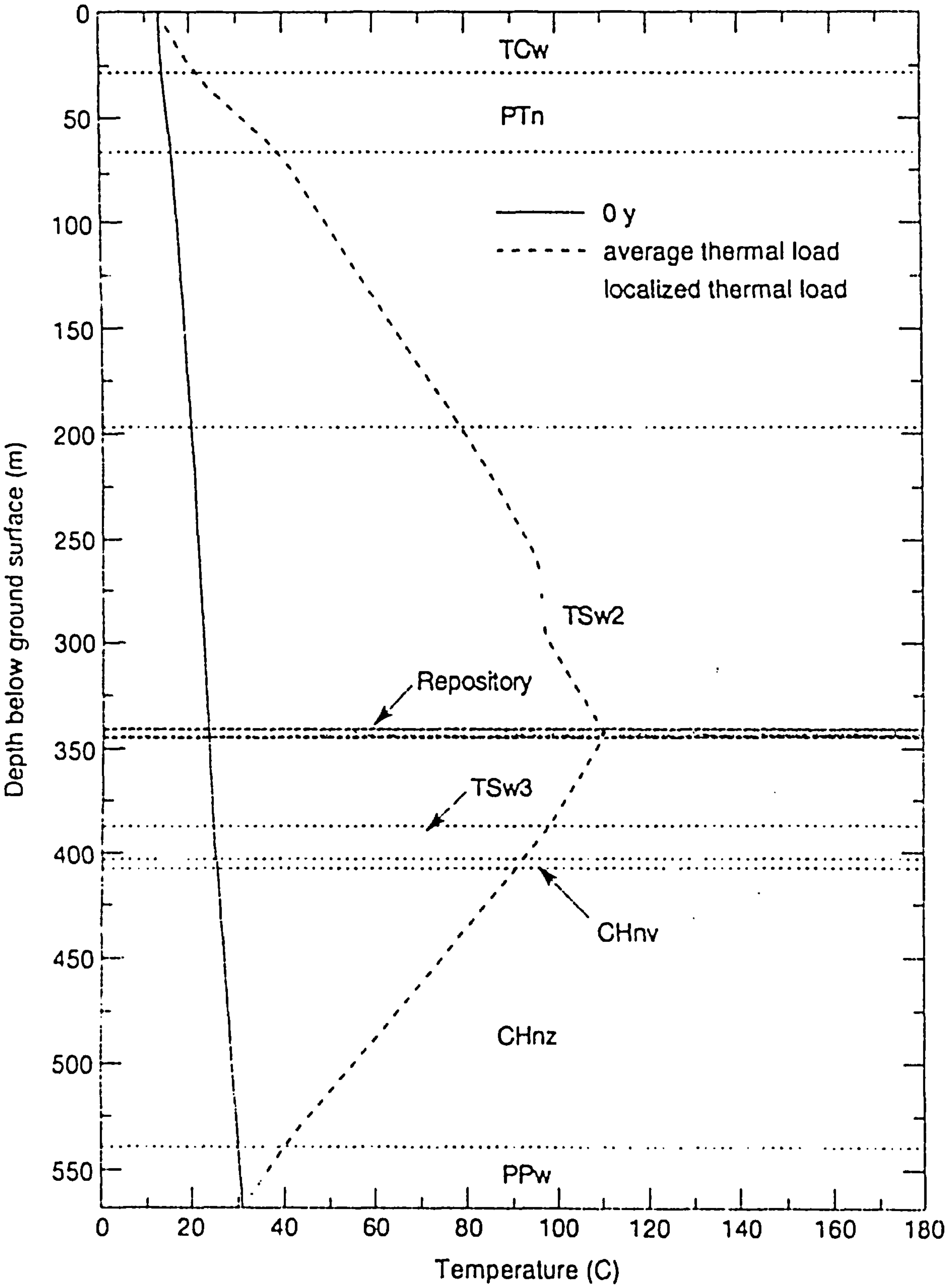
(Continued)

Utilizing current system designs

- **MRS facility**
  - Utilizing the MRS facility to provide a level pattern of annual average decay heat emplaced could be accomplished with a storage inventory of 20,000 to 25,000 MTHM which represents a $0.5 billion increase in MRS operational costs

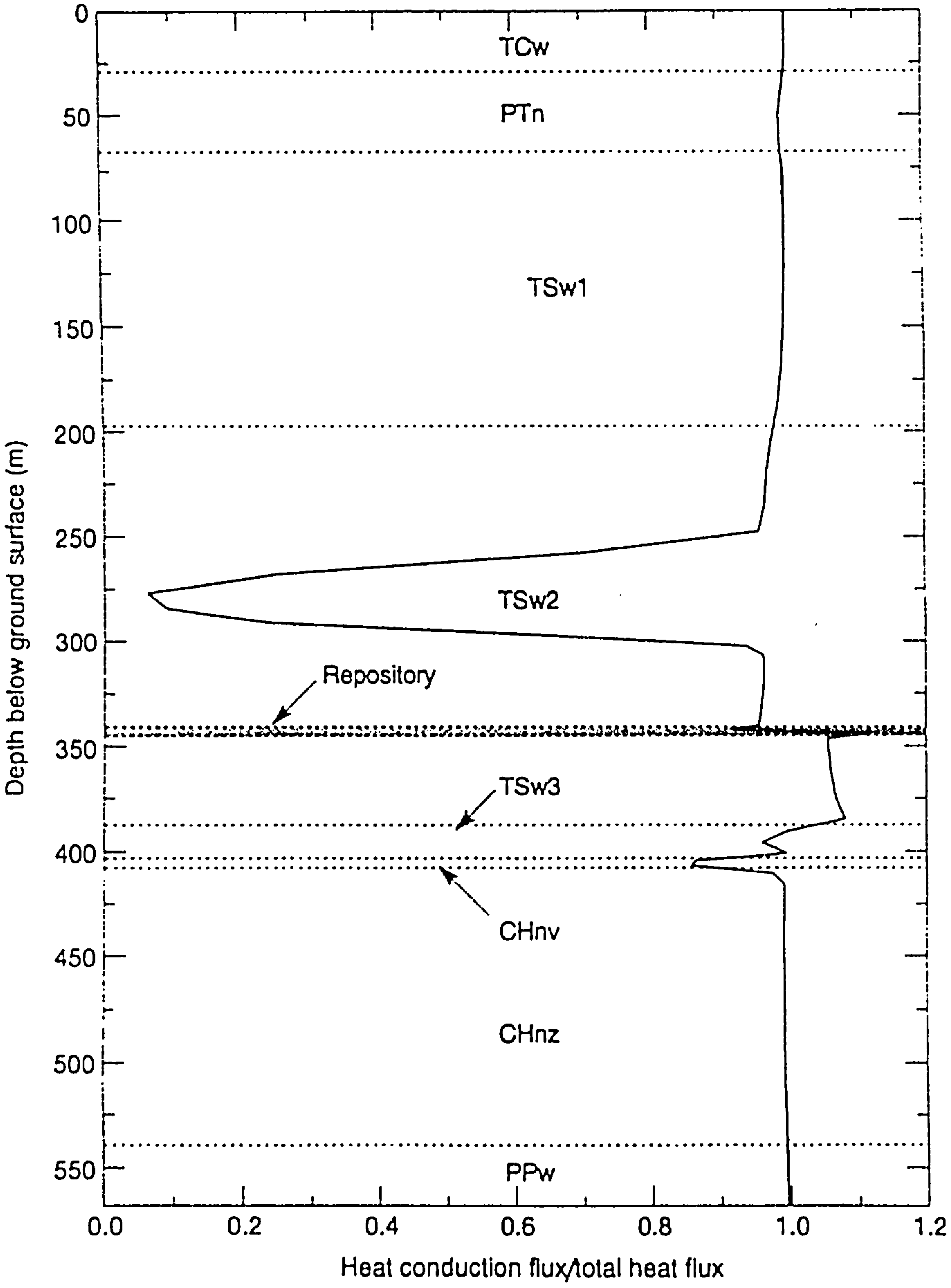
Tom Buscheck

Vertical temperature profile along centerline of repository for 30-year-old fuel, an APD of 57 kW/acre, and a recharge flux of 0.0 mm/y at t = 1000 years for localized and averaged thermal loads



ES-TB-28 (9 23 9[illegible]

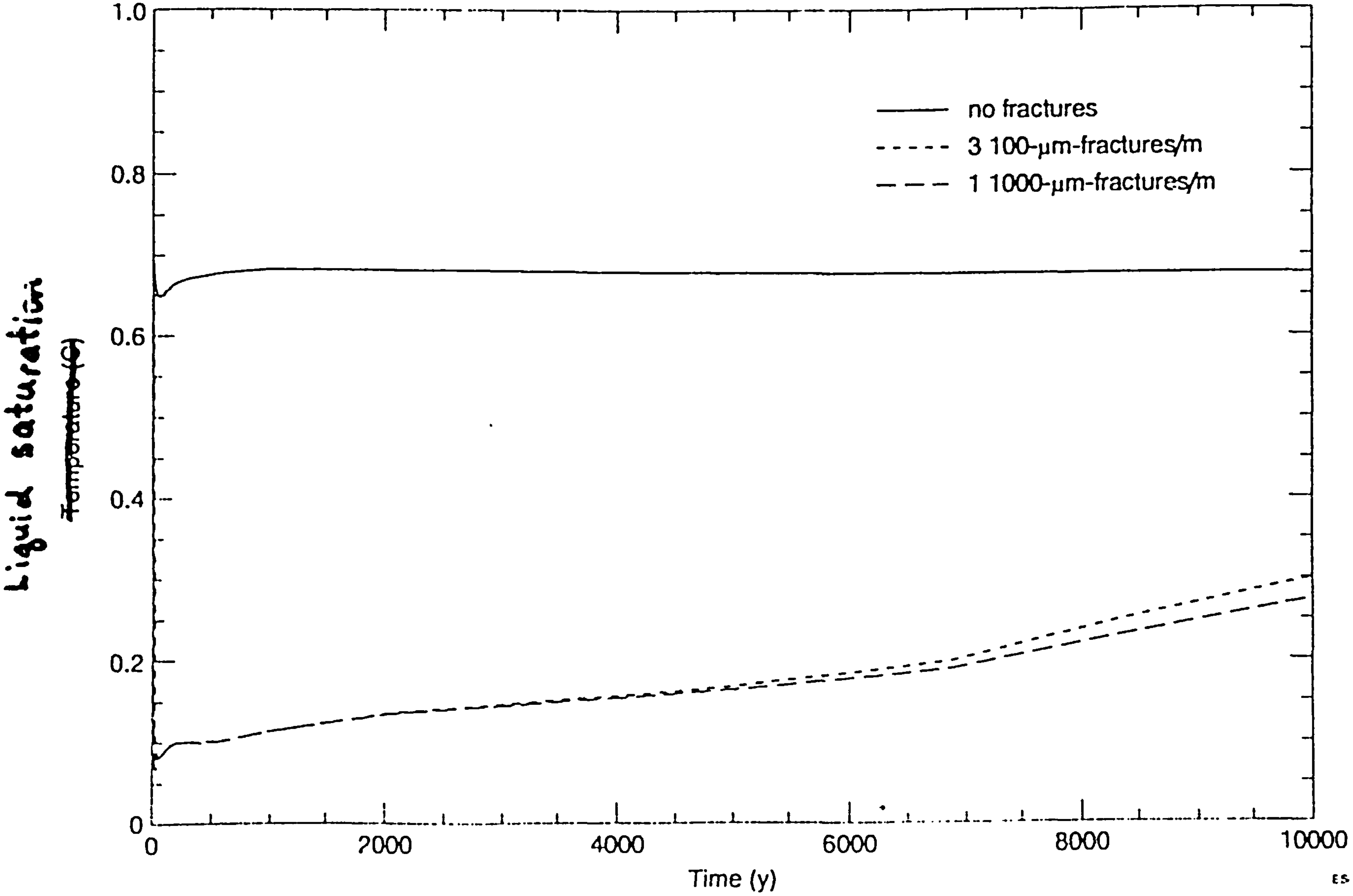
Ratio of heat conduction flux to total heat flux along repository centerline for 30-year-old fuel, an APD of 57 kW/acre, and a recharge flux of 0.0 mm/yr at t = 1000 yr



ES-TB-27 (10-7-91) IL

The existing bulk permeability data for Topopah Spring tuff (TSw2) at the repository horizon is much greater than the threshold bulk permeability for significant rock dry-out

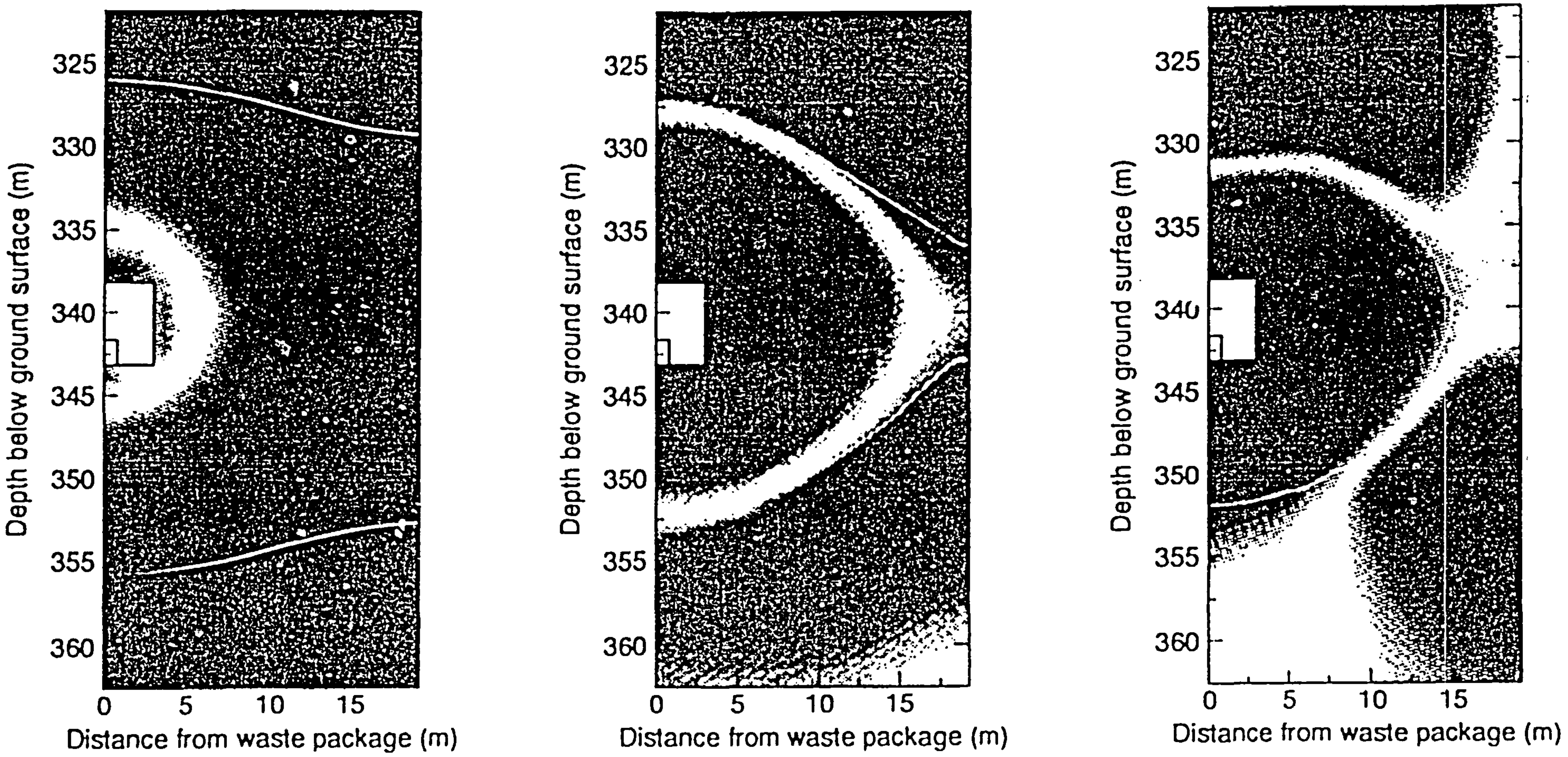
Liquid saturation history at drift wall for drift emplacement for an APD of 57 kW/acre, 30-yr-old fuel, and a recharge flux of 0.0 mm/yr



ES TB-24 (10-7-91) K

The bulk permeability data for Topopah Spring tuff (TSw2) at the repository horizon is much greater than the threshold bulk permeability for significant rock dry-out

Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre,
a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr at t = 60 yr
(the boiling point isotherm, T_b is shown in yellow)



no fractures

3 100-μm-fractures/m

1 1000-μm-fracture/m

ES TB 26 (10 7 91) IL

EPRI

Performance Assessment: Effects of Thermal Loading

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Effects of Thermal Loading on Repository Design
Nuclear Waste Technical Review Board Meeting
October 10, 1991
Las Vegas, Nevada

Performance Assessment: Effects of Thermal Loading

EPRI Methodology Development Team

Introduction	Bob Shaw
Time-Temperature Profiles	Ben Ross
Waste Package Integrity	Dan Bullen
Near-Field Effects	Mick Apted
Overall Performance Assessment	Robin McGuire

TEMPERATURE

Benjamin Ross

Until recently, most calculations of repository temperatures for an unsaturated-zone repository at Yucca Mountain included only conductive heat transfer and ignored gas-phase heat convection. This was due in part to the emphasis in earlier high-level waste disposal research on sites where the gas phase is not present, and in part to the difficulty of calculating convective heat transfer in the subsurface.

In the last few years, several studies of heat transfer at Yucca Mountain that include convection have been published. These analyses have greatly clarified the physical mechanisms that may be at work in the repository and provide substantial information about what temperatures may be expected given different assumptions about fluid flow mechanisms and repository operations. But, as will be seen below, none of the published studies is fully adequate to determine the temperature regime in the planned repository.

This chapter will review the mechanisms that may be expected to govern heat transfer in the repository environment, survey published analyses that take convection into account, describe heat transfer regimes that the literature suggests are most likely to occur, present scenarios for repository temperature, and discuss the plausibility of each scenario.

1. Mechanisms of heat transfer

In a porous medium, heat can be transferred by both conduction and convection. (Radiation is not significant because temperatures are relatively low and the rock matrix is opaque.) Heat transfer can be complicated because both liquid and gas phases can move and several driving forces are present. Table 1 lists physical processes that would play a major role in controlling heat transfer under conditions that might plausibly exist around a repository at Yucca Mountain.

Heat conduction is a relatively straightforward process; the complications arise from convection. Convection can carry both sensible and latent heat. Analyses to date indicate that, as long as temperatures are below the boiling point of water (about 96°C at repository elevation), the tuff will be wet enough to keep the relative humidity close to 100% [Tsang and Pruess, 1987;

Table 1

Potentially Significant Physical Processes Affecting Temperature at Yucca Mountain

Heat conduction
Sensible heat convection
Latent heat convection (with evaporation and condensation)
Gas flow away from evaporation zones
Buoyant gas flow
Water removal by gas flow
Suction-driven liquid flow
Gas-phase diffusion
Silica redistribution in liquid phase and precipitation
Removal of water and heat by ventilation
Removal of H_2O by gravity

Nitao, 1988; Pruess et al., 1990a; 1990b; Doughty and Pruess, 1991]. In this situation, the latent heat component of convective heat transfer will be greater than the sensible heat component. At temperatures close to the boiling point but below it, the latent heat component will be much greater.[1] Only above the boiling point, when the partial pressure of water vapor no longer varies with temperature, may sensible heat be a larger component of convective heat transfer than latent heat.

Two mechanisms of highly efficient latent heat transfer at Yucca Mountain have been hypothesized. These are the "heat pipe" effect and repository-scale buoyant gas flow.

The heat pipe effect can occur when the temperature of the porous medium reaches the boiling point of water. Its mechanism is as follows. Where the temperature exceeds the boiling point, the vapor pressure exceeds atmospheric pressure, and therefore the partial pressure of water vapor must be substantially less than the vapor pressure. The liquid phase is in local thermodynamic equilibrium with the gas, so the suction is controlled by the equation for vapor-pressure lowering and must be very large, on the order of a kilobar. (Note that RT at 96°C is

---

[1] This can be seen from the following approximate argument. When a fluid through a temperature gradient, the amount of sensible heat transported is proportional to its specific heat c_p; whereas the latent heat transport is proportional to the heat of vaporization of water multiplied by the change in vapor content of the gas per unit change in temperature. For an ideal gas, the latter quantity is $(H_v/P)\ dP_v/dT$, where P is total pressure and P_v is vapor pressure. At room temperature, H_v is 539 cal/gm-K and $1/P\ dP_v/dT$ is 0.002 K^{-1}. Thus $(H_v/P)\ dP_v/dT$ is about 1 cal/gm while c_p is 0.24 cal/gm. Because dP_v/dT increases rapidly with temperature, the disproportion between latent and sensible heat transfer is even greater at higher temperatures. Use of an exact equation for heat transfer in a wet porous medium [Amter et al., 1991] does not change the qualitative conclusion of this analysis.

equivalent to approximately 1.7 kbar.) This creates an extremely strong gradient of capillary suction in the liquid phase. If liquid water is able to flow through the medium, it is drawn by this suction gradient toward the heat source. As the liquid water flows inward, it warms and evaporates, forming vapor and thus raising the gas pressure. The resulting gas-phase pressure gradient drives an outward flow of gas. When the vapor reaches cooler regions, it condenses and again returns toward the heat source under the influence of suction. By this mechanism, the same water can pass through many cycles, transporting its heat of vaporization each time.

Buoyant heat flow is driven by the temperature difference between the repository and surrounding cooler rock, reinforced by the geometry of Yucca Mountain. Gas near the repository will be warmer than gas at the same elevation elsewhere, so it will rise. Near the repository, temperatures will probably be highest at the repository elevation. The upward-moving gas will therefore warm beneath the repository, evaporating water and absorbing heat. Above the repository it will cool, condensing water and releasing heat. Thus convection will, in general, move heat from below the repository to above it, in contrast to conduction which moves heat away from the repository in both directions.

The driving force for convective gas flow depends on the total difference in weight between gas columns within and outside the repository. Just as a tall chimney draws a better draft than a short one, the gas flux driven by the repository-scale system will be greater than the flux would be in a smaller system.

The region around a nuclear waste repository in a partially saturated porous medium can be divided conceptually into three different zones, in which different heat transfer mechanisms dominate (Figure 1). Far from the heat source, the temperature is less than the boiling point and either conduction or convection may dominate heat transfer. Within this zone is a heat-pipe region where the temperature is very close to the boiling point and heat is transferred very efficiently. Closest to the waste is an inner zone heated above the boiling point, in which liquid water is absent and heat transfer is dominated by conduction. Depending on the temperature attained, not all of these zones may be present.

The picture is further complicated by some other processes that might modify these heat transfer mechanisms. Both heat and water will be removed in ventilation air while the repository operates. Heat removal will tend to lower temperatures, while removing water, a heat transfer medium, will tend to raise temperatures. Water could also be removed from the system by gravity drainage from zones of condensation. Water redistributed by the heat of the repository would be likely to dissolve silica, which when it reprecipitates could reduce fracture permeability [Lin, 1991]. None of these processes has been studied very much, so their significance is difficult to assess.

2. Analyses of repository temperature

All published Yucca Mountain heat transfer calculations that include convection use some version of the TOUGH computer program, which was developed by Karsten Pruess of Lawrence Berkeley Laboratory [Pruess and Wang, 1984; Pruess, 1987; Pruess, 1991].

The first of these analyses was by Tsang and Pruess [1987], who simulated a radial cross-section of a disc-shaped repository in a homogeneous block of welded tuff extending from the ground surface to the water table. The fractured porous tuff was treated as an effective continuum, using a "sequential saturation" relative permeability curve by which fractures do not conduct any appreciable amount of water until the matrix is entirely saturated. The total permeability of the fractured tuff was 1.8×10^{-14} m^2. Tsang and Pruess found that the average temperature at the repository horizon rose no higher than 93°C. (This result did not exclude the possibility of higher temperatures near waste canisters; the grid was too coarse to distinguish variations on the scale of individual waste packages or rooms.) Calculated gas fluxes (Darcy velocities) did not exceed tens of cm/yr near the repository. These fluxes were dominated by water vapor flowing away in both directions from a zone of elevated pressure caused by water evaporation coupled to gas-phase diffusion phenomena; the fluxes due to buoyancy were much smaller.

Nitao [1988], at Lawrence Livermore National Laboratory, used a modified version of TOUGH to simulate a tall, thin two-dimensional column of rock which reached 573 m from the ground surface to the water table but whose width extended only 18.9 m from a waste canister to the middle of the adjoining pillar. The permeability of the fractured medium was 10^{-11} m^2, with a sequential-saturation relative permeability curve. Temperatures at waste canister surfaces rose to a peak value of approximately 200°C at a time 25 yr after waste emplacement. (A peak temperature value only a few degrees higher was obtained in a simulation with no convection, but convection lowered canister temperatures noticeably at times after 600 yr.) However, the area in which temperatures exceeded the boiling point extended only about 10 m from the canisters, and the central portions of pillars were in a heat-pipe region where temperatures never rose above the boiling point. The sizes of the dried-out region and the heat-pipe region reached maximums at approximately 400 yr, and at about 1200 yr the canister surface temperature fell below the boiling point. Gas fluxes were on the order of cm/yr, except in the heat-pipe region where they sometimes exceeded 100 m/yr.

White and Altenhofen [1989] extended Nitao's work by examining the sensitivity of temperatures to different assumptions about the permeability and porosity of the tuff and the amount of water in the system. They found that increased permeability and moisture availability had a relatively small effect on maximum canister temperatures, but could drastically shorten the time period during which liquid water is excluded from the canister surface.

These calculations have some important common features. They all use an effective continuum approximation for the fractured porous tuff, with a sequential-saturation model for the relative permeability. They also do not fully treat buoyant gas flow, either because of a low value of permeability (Tsang and Pruess) or geometrical limitations (Nitao and White and Altenhofen).

The validity of the effective continuum approximation (by which the fractures and matrix pores are approximated by a single porous medium) was analyzed in detail by Pruess et al. [1990a; 1990b], who derived criteria for its validity. Generally, the acceptability of the approximation improves for more permeable rock matrix and larger times. At times of less than one year, the approximation is marginally acceptable for permeabilities like those of welded tuff matrix. At later times, the acceptability of the approximation improves. Considering the many other imperfections in temperature calculations, the calculations of Pruess et al. indicate that the effective continuum approximation is a minor source of uncertainty in long-term repository temperature calculations at Yucca Mountain.

The effect of the sequential-saturation assumption was studied by Doughty and Pruess [1991], using a semianalytical solution for the transient two-phase fluid flow and heat transfer around a linear heat source. This solution incorporates all of the phenomena included in the TOUGH simulations except gravity and temporal decay of the heat source. Space and time dependences are combined into a single variable, making the results easier to visualize. While this solution cannot be applied to realistic repository geometries, it clarifies the nature of controlling physical processes and the roles played by the various parameters of the problem. Calculations with a permeability of 10^{-11} m^2 and sequential saturation yielded results consistent with those of Nitao and White and Altenhofen, with a heat pipe region of moderate size. When parameters were changed to make water more mobile in the fractures, the heat pipe expanded to traverse nearly an order of magnitude of the combined space and time variable. Numerical simulations by Pruess et al. [1990b] with a similar geometry,.a transient heat source, and discrete fractures in the tuff yielded similar results, with canister-surface temperatures never exceeding the boiling point when water was mobile in the fractures.

The potential significance of buoyant gas flow can be assessed by using gas flow simulations by Ross et al. [1991], which assumed a welded-tuff permeability of 10^{-11} m^2. Calculated gas fluxes were tens of cm/yr under pre-construction conditions and rose to m/yr when the repository horizon reached a temperature of 57°C. This is nearly two orders of magnitude larger than the gas fluxes calculated by Nitao under similar circumstances.[2] Yet in Nitao's calculations, convection reduced calculated temperatures by about 5 to 10°C even in regions where temperatures remained below the boiling point (see especially his Figures 10 and 11).[3] It is therefore plausible that the much larger convective fluxes calculated by repository-scale simulations could play a dominant role in heat removal. The same suggestion is made by the observation [Bill Dudley, personal communication -- need to check if there is a printed reference] that under current conditions as much geothermal heat is transferred upward through the Yucca Mountain unsaturated zone by gas convection as by conduction.

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[2] The physical basis for such a large discrepancy is easily explainable. Convection is driven by the density difference between adjoining columns of hot and cold gas. Ross et al. modeled the repository and surroundings; convection in their model was driven by the temperature difference between the hot rock around the repository and rock that had not been heated. Nitao modeled only a narrow column of rock within the repository. Convection was driven by the much smaller temperature difference between rock near waste canisters and rock in the adjoining pillars.

[3] Some of the temperature effect of convection is due to one-time removal of heat of vaporization when water evaporates with rising temperature. This contribution would not be increased with a greater gas flux. However, it is doubtful that all or even most of the temperature lowering by convection shown in Nitao's results is due to this effect. One-time heat removal would cause a symmetrical temperature lowering above and below the repository. In Nitao's results, the temperature is lowered roughly twice as much below the repository as above. This is consistent with an effect of buoyant gas flow, which transfers heat from below the repository to above.

3. Scenarios for heat transfer at Yucca Mountain

The above considerations suggest three different heat transfer regimes that might plausibly occur at Yucca Mountain:

- A regime in which the fractured tuff has a relatively low gas permeability, as simulated by Tsang and Pruess [1987]. Heat transfer is conduction-dominated and there is little buoyant flow. Liquid water is drawn toward the waste by suction and evaporates, raising the gas pressure. Gas moves away by pressure-driven mass flow.

- A regime in which the tuff has a high bulk permeability and a sequential-saturation relative permeability curve, as simulated by Nitao [1988]. A heat-pipe region develops, but its effectiveness depends on the matrix permeability of the tuff. A strong buoyant flow develops, but near the waste there may be a dried-out region in which conduction dominates heat transfer and buoyant flow does not remove heat effectively.

- A regime in which the tuff has a high bulk permeability and liquid water can flow relatively easily in fractures. Buoyant gas flow will remove heat quite effectively by latent-heat convection. If the temperature reaches the boiling point, a strong heat-pipe effect will develop.

Even if the heat transfer regime were known, there would still be uncertainty about repository temperatures. For example, in the high-permeability sequential-saturation regime, it still is uncertain how much water will be removed by ventilation and drainage and how strong the effect of water removal would be. Furthermore, the published heat-transfer calculations are all based on the heat output of 8.5-year-old waste; some or all of the waste will be older when placed in the repository. How much cooler the repository would be if older waste is buried is uncertain, but conduction-only temperature calculations by Altenhofen and Eslinger [1990] suggest that the effect could be substantial.

Maximum canister temperatures above the boiling point, at the boiling point, or below the boiling point thus all are possible.

No matter what the heat-transfer regime, the waste canisters will not all be at the same temperature. Initially, canisters will differ substantially in age and heat output; this alone will cause a substantial temperature variability [Altenhofen and Eslinger, 1990]. Temperatures will also be lower near the edge of the repository. Emplacement holes intersected by highly permeable fractures will experience better convective cooling than holes poorly connected with the fracture network. Holes toward which liquid water drains along fractures will be better cooled than others.

These inhomogeneities may be amplified by hydrodynamic instabilities, which are common in fluid systems heated from below.

4. Temperature scenarios

The uncertainty in repository temperature makes it necessary to define three alternative scenarios. To allow the scenarios to be defined clearly, specific mechanisms that determine temperatures have been identified in each scenario. Other mechanisms might also be important, but they would probably yield scenarios similar to those defined here, because the three scenarios span a wide range of plausible repository temperatures.

The first scenario corresponds to sequential saturation of fractures with the heat-pipe effect and buoyant gas flow playing a limited role. Repository conditions are generally as predicted by Nitao [1988]. However, 10% of the canisters, which have lesser heat output or are located in a wet zone, reach temperatures no higher than the boiling point.

In a second scenario, a stronger heat pipe restrains temperatures. This might occur because water is mobile in fractures or because the repository's heat output is less than assumed in past calculations. Temperatures of most canisters are held at the boiling point by the heat pipe effect. Some 10% of the canisters are in poor contact with the fracture network and have temperatures that rise higher.

In a third scenario, convective heat transfer by buoyant gas flow is very effective, and the repository temperature never even reaches the boiling point.

Curves showing the evolution of canister surface temperature over time are presented in Figure 2. These curves are intended as rough approximations that characterize different heat-transfer regimes. No effort was made to compute predicted temperatures by mechanistically modeling the phenomena discussed above.

Curve *a* describes canisters whose temperature exceeds the boiling point. It is largely taken from Nitao [1988]. Nitao's calculations end at 2567 yr. Temperatures for times between 2567 and 100 000 yr were obtained by scaling the temperature increase (over an assumed final temperature of 27 °C) at 2567 yr in proportion to the heat output of PWR waste (taken from

Mansure [1985]). This extrapolation will be accurate to the extent that heat transfer away from the repository has reached a quasi-steady state by 2567 years. Close correspondence between the scaled heat transfer curve and Nitao's repository temperature curve for times shortly before 2567 years suggests that heat transfer may indeed have become quasi-steady by this time.

Curve β represents a case in which buoyant gas flow efficiently removes heat from the repository. It was obtained by scaling Curve α downward. The scaling factor was written as unity plus a term proportional to the temperature derivative of vapor pressure. The constant in the formula was chosen so that the maximum temperature was 87°C (an arbitrary value chosen to be slightly below the boiling point). The resulting formula was

$$T_\beta = 27 + \frac{T_\alpha - 27}{1 + 1.881\times10^{11}\,\dfrac{\exp\dfrac{-4883}{T_\beta + 273.14}}{(T_\beta + 273.14)^2}}$$

where the second term in the denominator is the temperature derivative of vapor pressure, using the Clausius-Clapeyron equation. The equation was solved by Newton's method.

Curve γ describes canisters whose temperatures are prevented by the heat-pipe effect from exceeding the boiling point. It was obtained from Curve α by reducing all higher temperatures to 96°C.

As discussed above, some scenarios have canisters following more than one temperature curve. The fraction of waste canisters following each of the three curves is given in Table 2.

5. Scenario likelihood

Because the existence of three alternative scenarios reflects uncertainty in our scientific knowledge, the probabilities assigned to each scenarios are determined by the strength of the arguments that it is the correct one. We therefore will briefly present some of these arguments. (DOE might deliberately lower repository temperatures or increase waste densities to maintain planned temperatures; these possibilities are ignored here and we base ourselves on currently planned waste densities.)

The primary argument for Scenario 1 is the high canister temperatures that have been calculated in all attempts to simulate heat flow at Yucca Mountain. As discussed above, each of these simulations omits at least one potentially important heat transfer mechanism, but there are also processes that could keep temperatures as high as calculated or even higher. Any mechanism that removes all the water from a region around the waste canisters will render ineffective such heat transfer mechanisms as the heat pipe and buoyant gas flow. In addition to the effects of high heat input and poor liquid return flow, which are included in published simulations, there are other water removal mechanisms not included in calculations to date. These include ventilation, gravity drainage through pillars and cooler portions of the repository, and possibly rapid drainage along large fractures passing through hotter areas. Field heating tests in tuff, although on different scales in time and space, do show substantial drainage of water out of the system and drying out [Buscheck and Nitao, 1990; Buscheck, 1991]. Plugging of fractures by mineral precipitation might also block convective fluid flow.

Lower temperatures might be caused by several mechanisms. Buoyant gas flow, as discussed above, appears capable of removing large quantities of heat from a repository and has not been fully taken into account. Heat output from the waste also seems to be overestimated in the available calculations. Heat removal by ventilation might be substantial, especially if ventilation continues until the end of the period of waste retrievability.

Water might also be able to move in fractures more easily than assumed in calculations, strengthening the heat-pipe effect. There are several ways this might happen:

- If fracture linings composed of mineral precipitates or weathered tuff have properties intermediate between intact tuff matrix and open fractures, the sequential-saturation model for water transmission could be inapplicable.
- Water would move readily through fractures if the tuff matrix is initially saturated [Doughty and Pruess, 1991]. If unsaturated-zone water flow at Yucca Mountain is controlled by a capillary barrier, a simple model [Ross, 1990] suggests that the tuff matrix in the repository horizon is currently saturated.
- The buoyant gas flow will cause more water to condense above the repository than below. Even if suction forces cannot effectively draw water through fractures, gravity would tend to drain this water down toward the heat source.

Notwithstanding these considerations, the majority of technical opinion currently holds that waste canister temperatures will exceed the boiling point of water. We therefore assign a probability of 0.6 to Scenario 1, in which the rock around most canisters dries out. Scenario 2, in which the heat-pipe effect dominates, is assigned a probability of 0.3, and Scenario 3, the coolest, is given a probability of 0.1.

Table 2 summarizes the three scenarios. For each scenario, it gives the probability of the scenario and the fraction of canisters following each of the three temperature histories shown in Figure 2.

Table 2

Summary of Scenarios

Scenario	Probability	Curve α	Curve β	Curve γ
1	0.6	0.9	0	0.1
2	0.3	0.1	0	0.9
3	0.1	0	1.0	0

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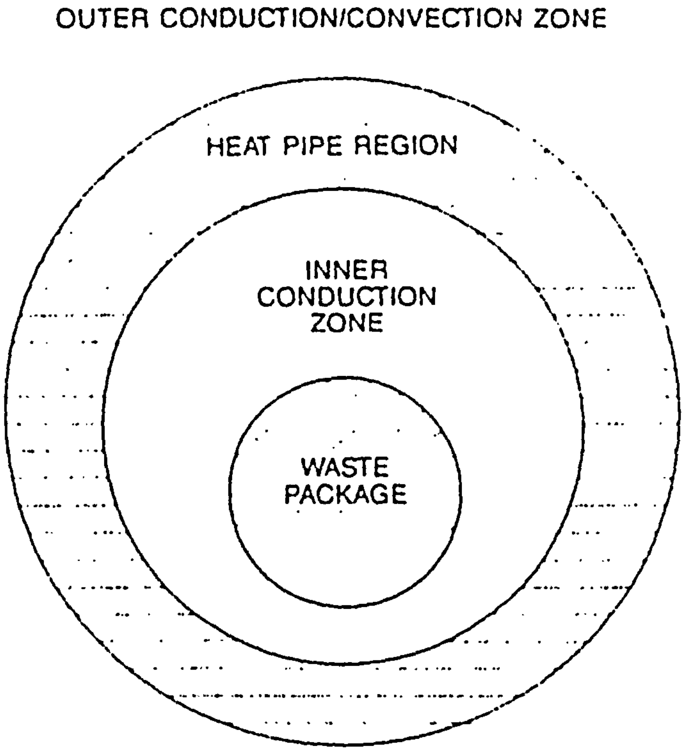
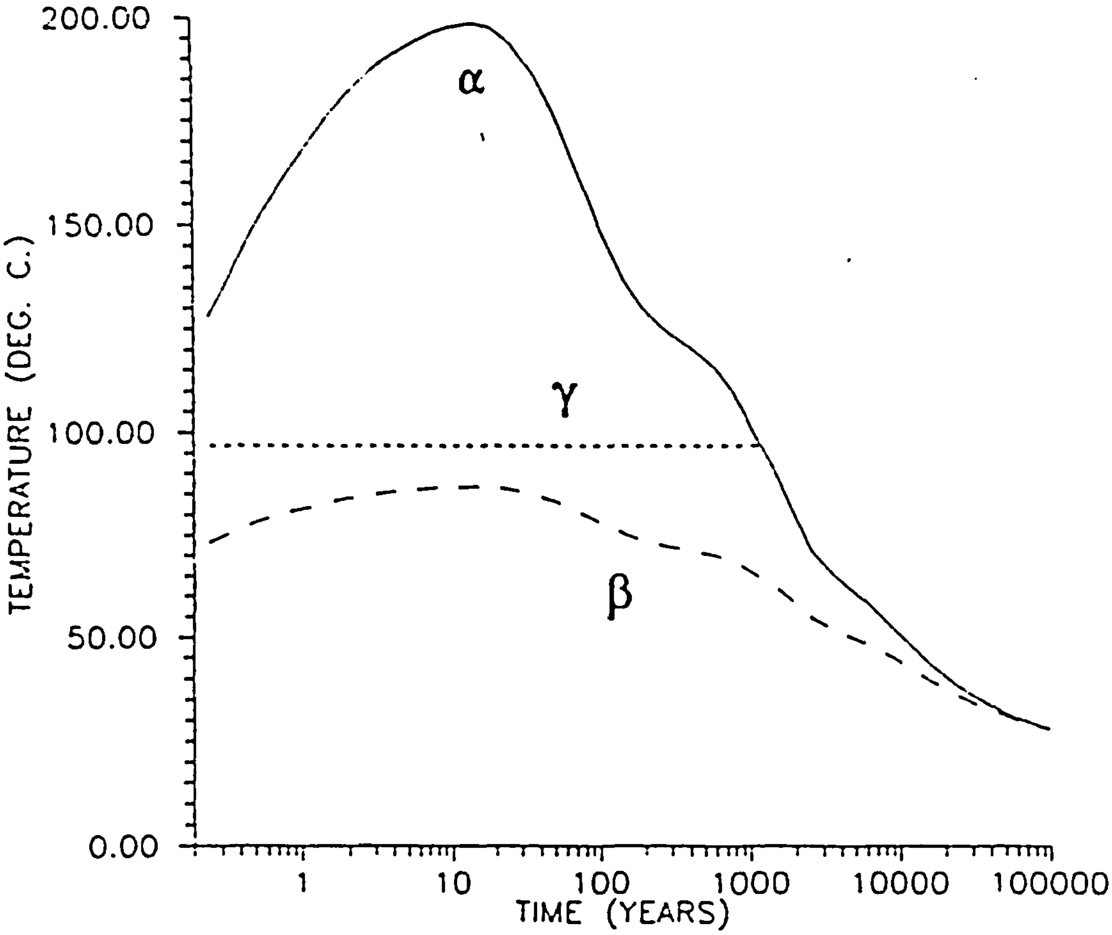
FIGURE CAPTIONS

Figure 1. Zones of different heat-transfer regimes around an unsaturated-zone heat source, shown schematically. [Modified from Pruess et al., 1990a.]

Figure 2. Three alternative curves showing temperatures at the outer surface of a waste emplacement hole as functions of time.


OUTER CONDUCTION/CONVECTION ZONE
HEAT PIPE REGION
INNER CONDUCTION ZONE
WASTE PACKAGE


200.00
150.00
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50.00
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TEMPERATURE (DEG. C.)
α
γ
β
1
10
100
1000
10000
100000
TIME (YEARS)

GAS-PHASE TRANSPORT

Benjamin Ross

Because the proposed nuclear waste repository at Yucca Mountain, Nevada, would be located above the water table, radioactivity could migrate in the gas phase as well as the liquid phase. Carbon-14 is the nuclide most likely to reach the surface in this way.

Field observations [Weeks, 1987; 1991] show that large-scale flows of air through Yucca Mountain are driven by the combination of topographic relief and temperature differences between the surface and subsurface. Because the subsurface is, on average, warmer than the atmosphere, there is a "chimney effect" which causes warm gas inside the mountain to rise. This flow is most rapid in winter and partially reverses itself in summer. Lesser but significant contributions to rock gas flow are made by barometric pressure fluctuations, aerodynamic effects of wind flowing over the mountain, and the effect on density of the humidity difference between rock gas and air.

We have simulated gas flow at Yucca Mountain using TGIF, a model of rock-gas flow driven by temperature and humidity differences. The derivation and numerical development of this model have been described elsewhere [Ross et al., 1991; Amter et al., 1991]. TGIF, which calculates steady-state flows, cannot simulate flows driven by driving forces that change so fast that pressures cannot equilibrate through the system; examples of such driving forces at Yucca Mountain are barometric pressure fluctuations and temperature differences between day and night. These rapidly oscillating flows do not cause net movement of gas at depth. Consequently they should not significantly affect contaminant transport. Another phenomenon not treated by the model, wind, does appear to drive a substantial net gas flux at depth [Weeks, 1991]; further research is needed to devise a way to model this effect.

Using the TGIF model, we calculated the annual-average rock-gas flow through Yucca Mountain. For each simulation, travel paths were determined for particles traveling to the surface from points distributed throughout the proposed repository area. Carbon-14 travel times were calculated along each path line.

The calculations used four equally spaced cross-sections along the east-west lines shown in Figure 1. The sections, depicted in Figure 2, were mostly taken from computer-generated sections presented by Prindle and Hopkins [1990]. The dashed lines in Figure 2 represent parts of the cross-sections that were extrapolated using the geologic map by Scott and Bonk [1984].

The cross-sections contain three hydrostratigraphic subdivisions of the Paintbrush Tuff formation dipping approximately six degrees to the east. The upper and lower layers, the Tiva Canyon and Topopah Spring welded tuff units, were assigned a permeability of 10^{-11} m^2. This value, based on downhole measurements of barometric pressure changes [Montazer et al., 1985], is relatively reliable insofar as it is derived from a large-scale field measurement.

The Paintbrush nonwelded unit, which lies between the two welded units, was assigned a permeability of 10^{-13} m^2 in most places. This value was selected because previous sensitivity studies [Lu et al., 1991] have shown that a permeability contrast between welded and non-welded tuff of 100× or more leads to formation of two separate flow systems above and below the nonwelded layer. Isotopic studies of rock gas at Yucca Mountain indicate that the two welded tuff units differ substantially in age, suggesting that the nonwelded unit provides substantial confinement [Thorstenson, 1991]. To the east of the repository block, there is a zone of intense faulting. In this area, the Paintbrush nonwelded unit was assigned a permeability of 10^{-12} m^2. The nonwelded units beneath the Topopah Spring unit were excluded from the simulation because their relatively small permeability and the presence of a non-flow boundary at the water table imply that little gas will flow through them.

The system was simulated with a natural geothermal temperature gradient of 0.02 K/m and with the repository heated to 42°C, 57°C, and 87°C. Results from the simulations with the natural gradient and the repository at 42°C and 57°C were reported previously [Ross et al. [1991], the case with the repository at 87°C was simulated for this project. Temperature fields were obtained by solving the heat conduction equation; this approximation is necessary because effects of convection cannot currently be simulated with a reasonably modest effort (see chapter on Temperature).

The Darcy fluxes calculated by the gas-flow simulations are converted to seepage velocities by dividing by the drained (gas-filled) porosity. Drained porosity values of 0.04, 0.18, and 0.05 were used for the Tiva Canyon welded, Paintbrush nonwelded, and Topopah Spring welded units.

The results of the gas-flow calculations were used to compute travel times for carbon-14 migration from the repository to the surface. The movement of gas-phase $^{14}CO_2$ is affected by interaction with carbon in the aqueous and solid phases. We conservatively ignored precipitation of ^{14}C into the solid phase and considered only water-gas exchange. Isotopic equilibrium between gaseous and aqueous phases can safely be assumed, but the amount of dissolved bicarbonate depends on the water chemistry [Ross, 1988].

The concentration of dissolved bicarbonate can be specified by assuming thermodynamic equilibrium with solid calcite and the measured composition of the rock gas. These concentrations had previously been calculated with the PHREEQE model, using concentrations of major ions that do not interact with the gas phase measured by Yang et al. [1988]. The ratio of gas velocity to carbon-14 velocity, known as the "retardation factor," also depends on the relative amounts of gas and water in the rock; saturation values of 0.67 in the Tiva Canyon welded unit, 0.61 in the Paintbrush nonwelded unit, and 0.64 in the Topopah Spring welded unit were used [Montazer and Wilson, 1985]. The retardation factors that resulted from these calculations were reported by Doctor et al. [1991] and are shown in Figure 3. For temperatures greater than 60°C, the straight lines shown in the figure were extrapolated.

To follow the trajectories of individual particles from the repository to the surface, a particle-tracking program called PATHLINE was used. This program uses the method of explicit integration of velocity within each grid block originally developed by Pollock [1988]. Pollock's method, which was developed for use with a block-centered finite difference model, was slightly adapted and reprogrammed for use with the lattice-centered finite difference method used in TGIF [Ross et al., 1991].

Travel times were calculated for 323 particles with starting points evenly distributed throughout the repository. One starting point was located randomly on each 25-meter interval within the intersection of each simulated cross section with the repository. The results of these calculations are presented in Figures 4 through 7 as histograms of carbon-14 travel times. Each histogram represents the distribution of travel times throughout the repository (combining all four cross-sections) for a given repository temperature.

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FIGURE CAPTIONS

Figure 1. Location of simulated cross-sections relative to proposed repository.

Figure 2. Cross-sections used in gas-flow simulations. TCw, PTn, and TSw are the Tiva Canyon welded, Paintbrush nonwelded, and Topopah Spring welded hydrostratigraphic units. Solid lines indicate cross section from Prindle and Hopkins [1990]; dashed lines indicate extrapolation.

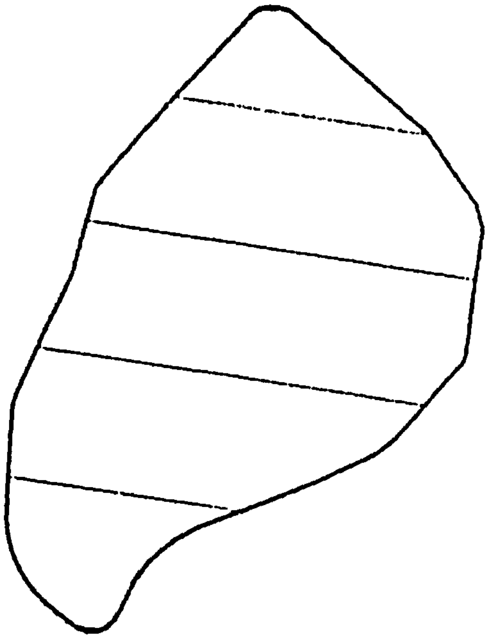
Figure 3. Carbon-14 retardation factor as a function of temperature [from Doctor et al., 1991].

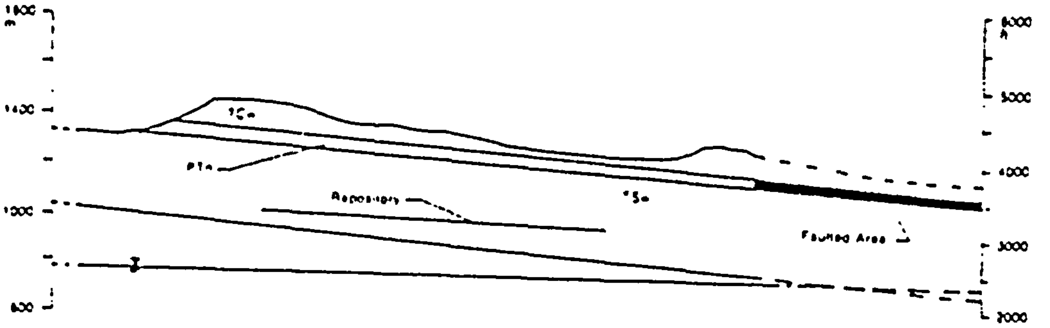
Figure 4. Distribution of carbon-14 travel times from the repository to the atmosphere with geothermal temperature gradient.

Figure 5. Distribution of carbon-14 travel times from the repository to the atmosphere with repository heated to 42°C.

Figure 6. Distribution of carbon-14 travel times from the repository to the atmosphere with repository heated to 57°C.

Figure 7. Distribution of carbon-14 travel times from the repository to the atmosphere with repository heated to 87°C.





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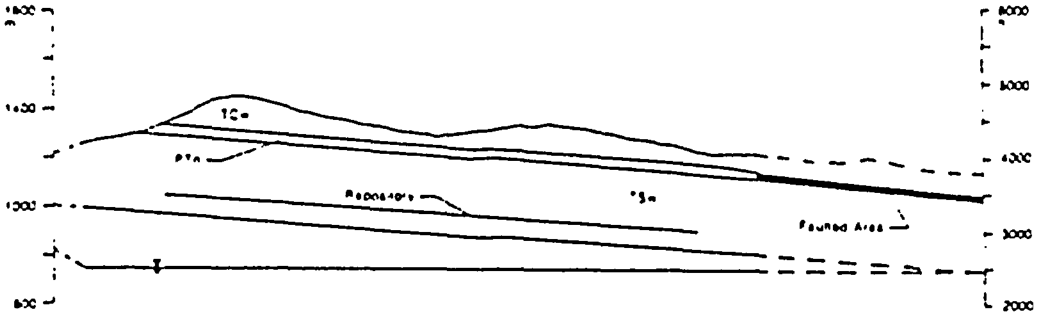

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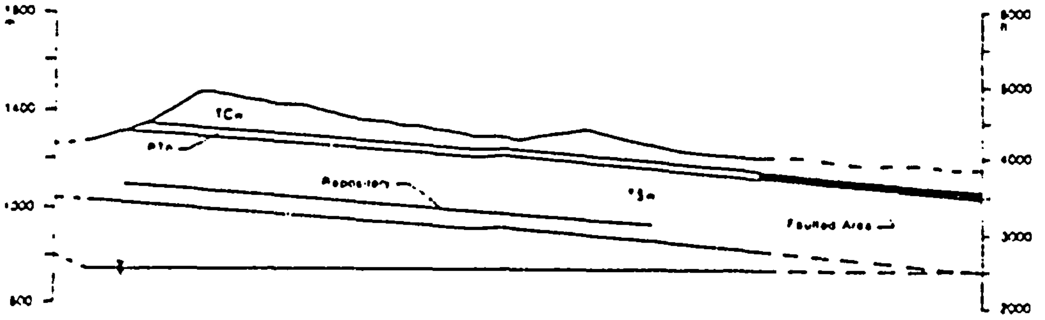

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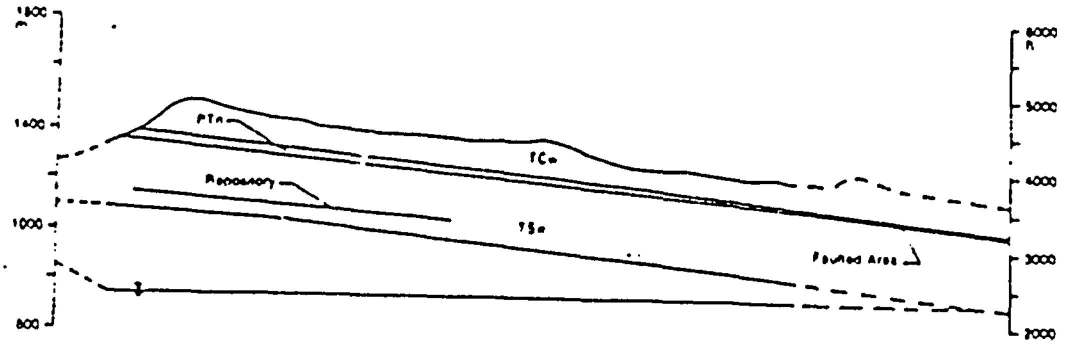

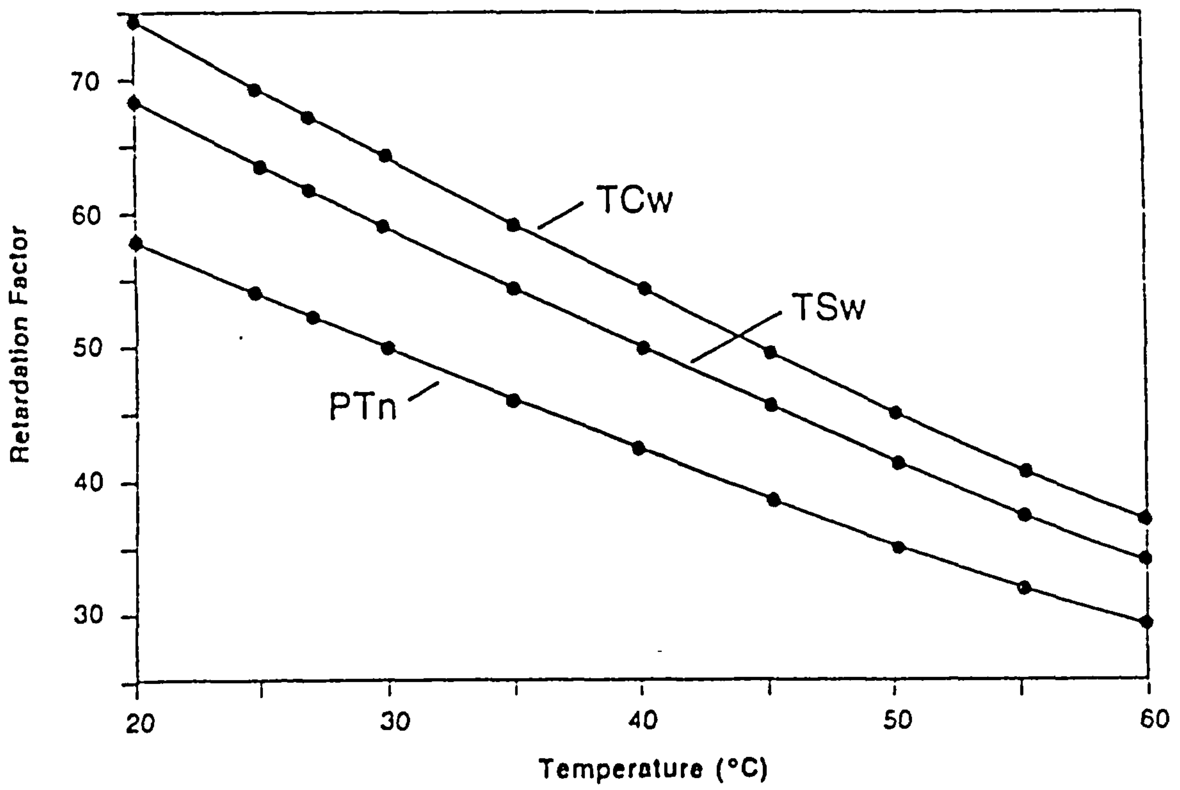

Retardation Factor
70
60
50
40
30
20
30
40
50
60
Temperature (°C)
TCw
TSw
PTn

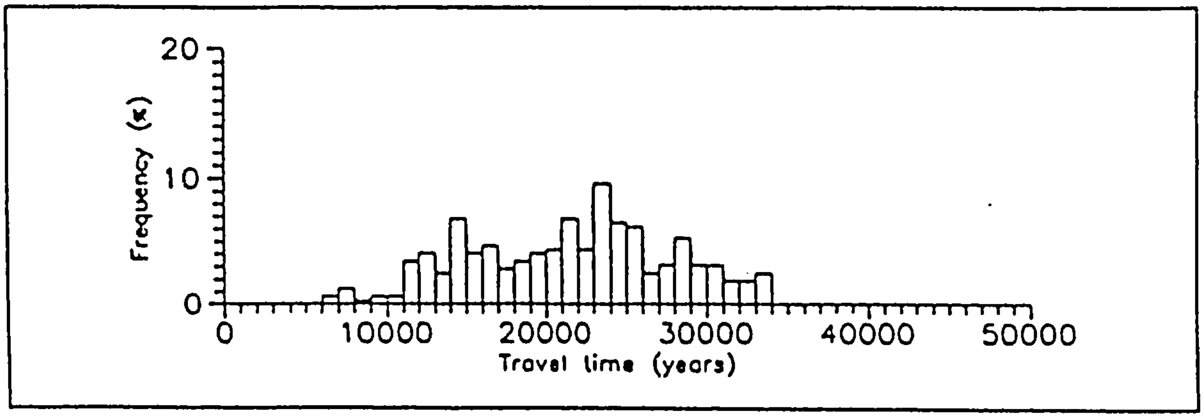

Figure 4.

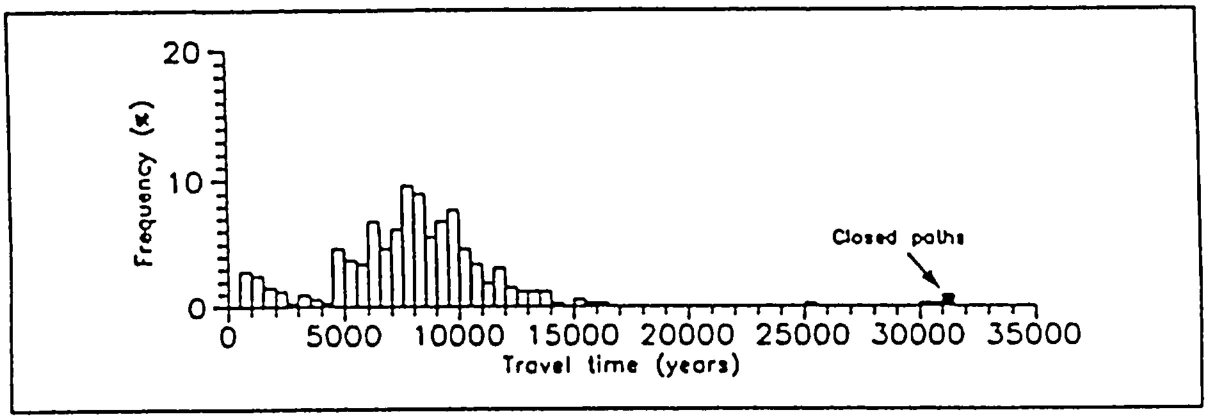

Figure 5.

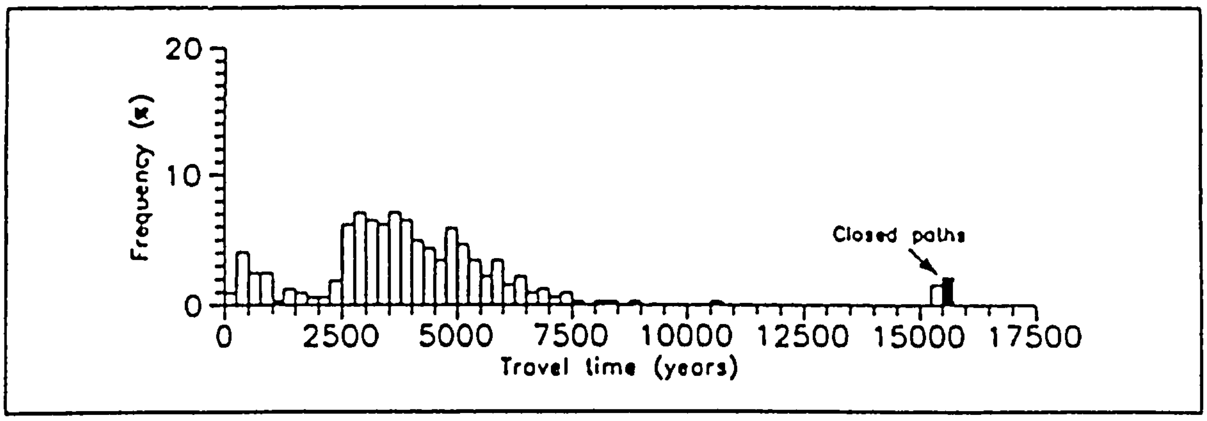

Figure 6.

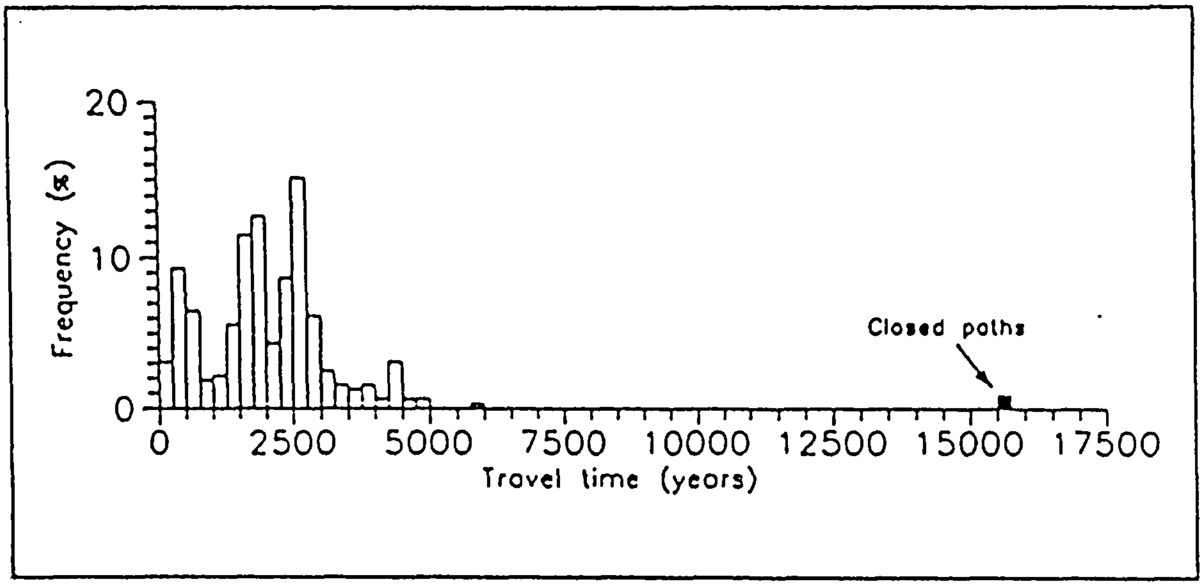
20
10
0
Frequency (%)
0
2500
5000
7500
10000
12500
15000
17500
Travel time (years)
Closed paths

Figure 7.

Engineered Barrier System Failure

Presented to the
Nuclear Waste Technical Review Board

10 October 1991

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Introduction

- Goal of this portion of the project was to develop a model for evaluating the impact of the following.
  - Container failure mechanisms
  - Container failure rates
  - Waste form failure rates

- Review of potential degradation pathways
  - Current EBS design
  - Alternate EBS designs

- Container failure model development
  - Single barrier failure
  - Multiple barrier failure
  - "Premature" failure

- Estimate of initial parameters based on environmental conditions
  - "Hot", "warm", or "cold" conditions
  - Wet vs. dry
  - Oxidizing vs. anoxic

- Results of the initial application of model

EBS Failure Models

- Review of degradation modes indicates numerous failure mechanisms.
  - General oxidation and corrosion
  - Localized corrosion (crevice and pitting corrosion).
  - Stress corrosion cracking
  - Metallurgical phase instability
  - Hydride embrittlement
- Models of uniform oxidation and corrosion, localized corrosion, and stress corrosion cracking were identified.
- Additional information regarding cladding failure was identified.
  - Creep rupture
  - Hydride reorientation

Corrosion Models

Numerous potentially applicable corrosion models were identified.

(1) Initiation of pits on passive austenitic surfaces

(2) Propagation of pits on an active metal surface

(3) Propagation of pits on surfaces covered by salt films

(4) Initiation of cracks at pits

(5) Propagation of cracks on active metal surfaces

(6) Propagation of cracks due to periodic fracture of passive films at crack tips

(7) Propagation of cracks due to film-induced cleavage of the base metal

(8) Crevice corrosion on active metal surfaces

(9) Crevices that behave like active-passive concentration cells

Literature Review Identified Information Needs

1. The need for a model of the local environment that is capable of predicting temperature of the container wall, the levels of chemical species in the ground water that may have been concentrated by refluxing, the concentration of radiolysis products, and the effect of microbial growth on the local environment.

2. Quantification of parameters in the identified corrosion models, where appropriate.

3. A quantitative model applicable to the initiation and propagation of pits in copper-based alloys.

4. Application of statistical techniques into the modeling of the failure of the containers.

Application of Statistical Methods

- Difficult to consider all possible degradation models
- Uncertainty in the repository environment
- Uncertainty in the EBS design
- Employ statistical techniques used in engineering for component lifetime prediction
- Selected 3-parameter Weibull function for late container failure rate determination
- Employed exponential distribution to account for early container failures
- Calculated fraction of failed containers as a function of time

Weibull Distribution

- The cumulative distribution function for the 3-parameter Weibull distribution is given by:

$$F(t)=1-\exp\left[-\frac{t-x_1}{f_1}\right]^{b_1}$$

where:

x_1 = lower limit of container lifetime

f_1 = mean container lifetime

b_1 = Weibull slope (represents the failure rate at the mean lifetime).

- Advantages of Weibull statistics
  - Cumulative failure distribution a function of only 3 variables.
  - Interpretation of these variables can reflect different failure modes or repository conditions.

Early Container Failures

- The exponential distribution was employed to describe the "early" container failures which may occur.

- The exponential distribution is written as

$$C=c_1\left(1-\exp\left[-\frac{t}{t_1}\right]\right)$$

where:

c_1 = Fraction of containers susceptible to early failure

t_1 = Average early failure time

- Early container failures could occur due to:
  - Improper closure of the container
  - Improper emplacement

Possible Temperature Conditions

- Depending upon the age of the spent fuel and the areal power loading density in the repository, the temperature of the waste containers should initially be hot (T > 96°C).
- Power output of each container will diminish as a function of time due to radioactive decay.
- Multi-phase flow characteristics within Yucca Mountain may also affect container thermal history
- Temperature environment could range from $T_{surface} > 250°C$ to $T_{surface} < 96°C$.
- The temperature histories employed in this study include;
  - Hot = $T_{surface} > 250°C$ for extended periods (1500 years)
  - Warm - $T_{surface} = 96°C$ - Heat pipe effect
  - Cold - $T_{surface} < 96°C$ - Multi-phase flow dominates
- Each scenario evaluated for single and multiple barriers.

Container Design Parameters

- Single Barrier Container
  - Single metal barrier
  - Material - Alloy 825
  - Closure seal poses problems
  - Localized corrosion at closure seal may dominate failures
  - Cladding may aid containment at lower temperatures

- Multiple Barrier Container
  - Multiple metal barriers
  - Materials
    - Titanium outer shell
    - Nickel alloy (C-4, C-276) inner container
  - General Oxidation Dominates Container Failure
  - Resistance to localized corrosion
  - Limited sensitization at closure seal in nickel alloy

- Failure scenarios
  - Greater probability of early failure at low temperatures (more water contact)
  - Cladding failure higher at high temperatures

Typical Corrosion Rate Data

- Alloy 825 Single Metal Barrier (LLNL UCID-21362)

Mechanism	Corrosion Rate (µm/yr)	Failure Time (yr)
Oxidation	0.025 - 0.178	56,200 - 400,000
Steam Oxidation	0.51 - 1.86	5,375 - 19,600
Aqueous Corrosion	1.01	9900
Localized Corrosion	2.94 - 10.73	932 - 3,401
Stress Corrosion Cracking	2.5 -25	400 - 4000
Crevice Corrosion (5% $FeCl_3$)	32,000 - 360,000	0.31- 0.03

- C-4 (Ni-Cr-Mo) Multiple Metal Barriers (Ti - Grade 12)

Mechanism	Corrosion Rate (µm/yr)	Failure Time (yr)
Oxidation	0.008	1,250,000
Aqueous Corrosion	0.09 - 0.56	17,857 - 111,111
Brine Concentrate	7	1,429
Localized Corrosion	7.62	1,312
Stress Corrosion Cracking	0 - 2.5	4,000
Crevice Corrosion (5% $FeCl_3$)	2 - 40	250 - 5,000

Single Barrier Container Failure Rate Equation

- The container failure rate as a function of time for the single barrier container can be described by a combination of exponential and Weibull distributions.

$$C = c_1\left(1-\exp\left[-\frac{t}{t_1}\right]\right) + sa\left(1-\exp\left[-\frac{t-x_1}{f_1}\right]^{b_1}\right)\left(1-\exp\left[-\frac{t-x_2}{f_2}\right]^{b2}\right)$$

where: c_1 = Fraction of containers susceptible to early failure

t_1 = Average early failure time

sa = Step function (If $t < x_1$, sa=0)

$x_{1,2}$ = Lower limit of lifetime for barrier 1 and cladding

$f_{1,2}$ = Average barrier 1 and cladding failure time

$b_{1,2}$ = Failure rate @ mean time to failure for barrier 1 and cladding (Weibull slope)

Parameter Values for Single Barrier, T < 96°C

- The following input values were employed for the scenario in which the repository temperature never exceeds 96°C.

$c_1 = 0.05$ (Early failure fraction)

$t_1 = 1000$ years (Mean early failure time)

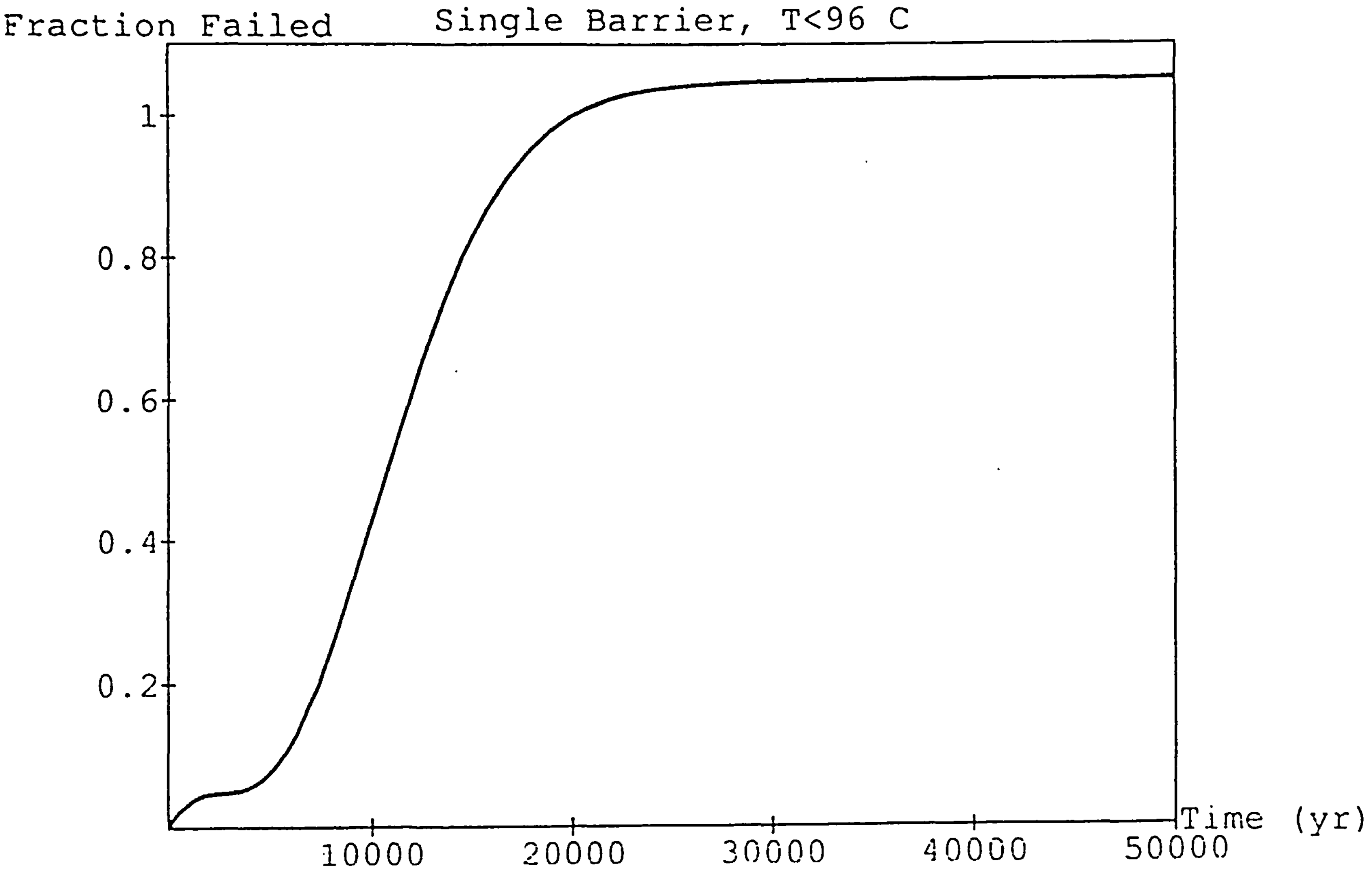
$sa = \text{If } t < 1000, sa=0$ (Step function)

$x_1 = 1000$ years (Failure threshold)
$x_2 = 3000$ years

$f_1 = 5000$ years (Mean barrier failure time)
$f_2 = f_1 + 4000$ years $= 9000$ years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 2.0$

Single Barrier Container Cumulative Failure Distribution for T < 96°C



Parameter Values for Single Barrier, T = 96°C

- The following input values were employed for the scenario in which the repository temperature initially equals 96°C.

$c_1 = 0.025$ (Early failure fraction)

$t_1 = 1500$ years (Mean early failure time)

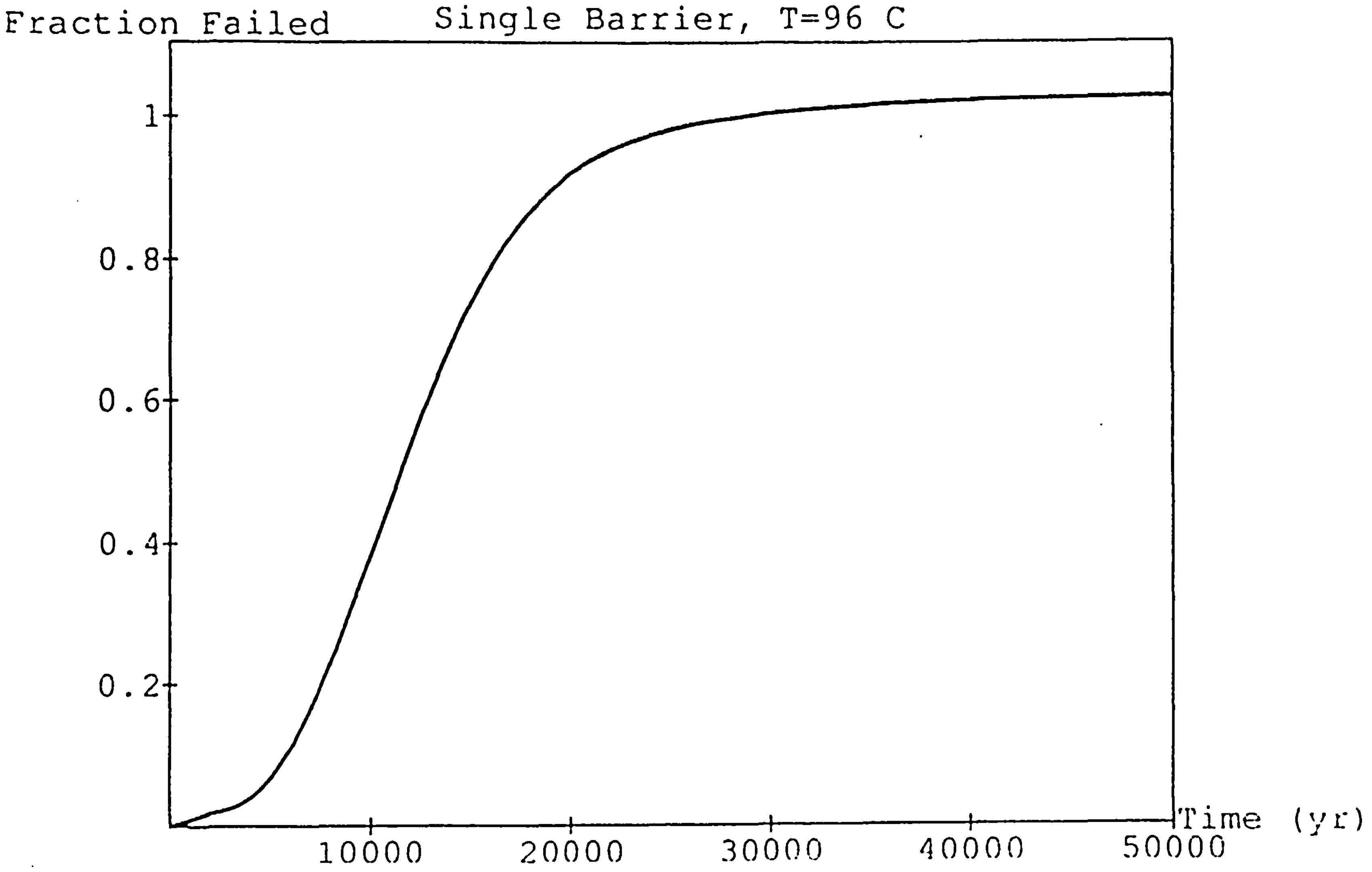
sa = If $t < 1500$, sa=0 (Step function)

$x_1 = 1000$ years (Failure threshold)
$x_2 = 2000$ years

$f_1 = 7500$ years (Mean barrier failure time)
$f_2 = f_1 + 2000$ years = 9500 years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 2.0$

Single Barrier Container Cumulative Failure Distribution for T = 96°C



Parameter Values for Single Barrier, T > 96°C

- The following input values were employed for the scenario in which the repository temperature initially exceeds 96°C.

$c_1 = 0.005$ (Early failure fraction)

$t_1 = 2000$ years (Mean early failure time)

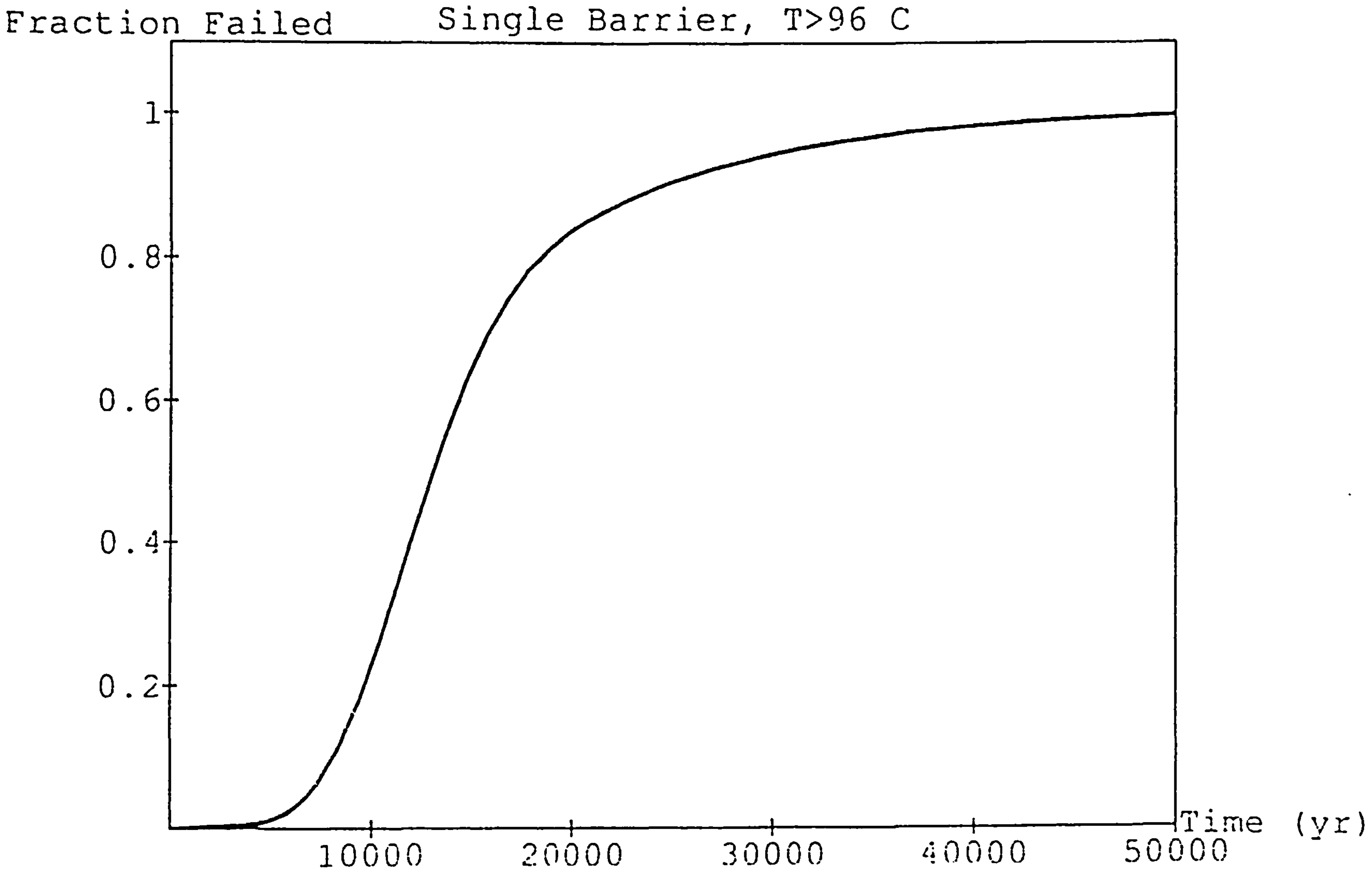
sa = If $t < 2000$, sa=0 (Step function)

$x_1 = 2000$ years (Failure threshold)
$x_2 = 2000$ years

$f_1 = 10000$ years (Mean barrier failure time)
$f_2 = f_1 + 0$ years = 10000 years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 3.0$

Single Barrier Container Cumulative Failure Distribution for T > 96°C



Multiple Barrier Container Failure Rate Equation

- Additional barriers can be accommodated in the model by through the utilization of additional Weibull distributions.

$$C=c_1\left(1-\exp\left[-\frac{t}{t_1}\right]\right)+sa\left(1-\exp\left[-\frac{t-x_1}{f_1}\right]^{b_1}\right)\left(1-\exp\left[-\frac{t-x_2}{f_2}\right]^{b_2}\right)\left(1-\exp\left[-\frac{t-x_3}{f_3}\right]^{b_3}\right)$$

where: c_1 = Fraction of containers susceptible to early failure

t_1 = Average early failure time

sa = Step function (If $t < x_1$, $sa=0$)

$x_{1,2,3}$ = Failure threshold for barrier 1, 2 and cladding

$f_{1,2,3}$ = Average barrier 1, 2 and cladding failure time

$b_{1,2,3}$ = Failure rate @ mean time to failure for barrier 1, 2 and cladding (Weibull slope)

Parameter Values for Multiple Barrier, $T < 96°C$

- The following input values were employed for the scenario in which the repository temperature never exceeds 96°C.

$c_1 = 0.01$ (Early failure fraction)

$t_1 = 1000$ years (Mean early failure time)

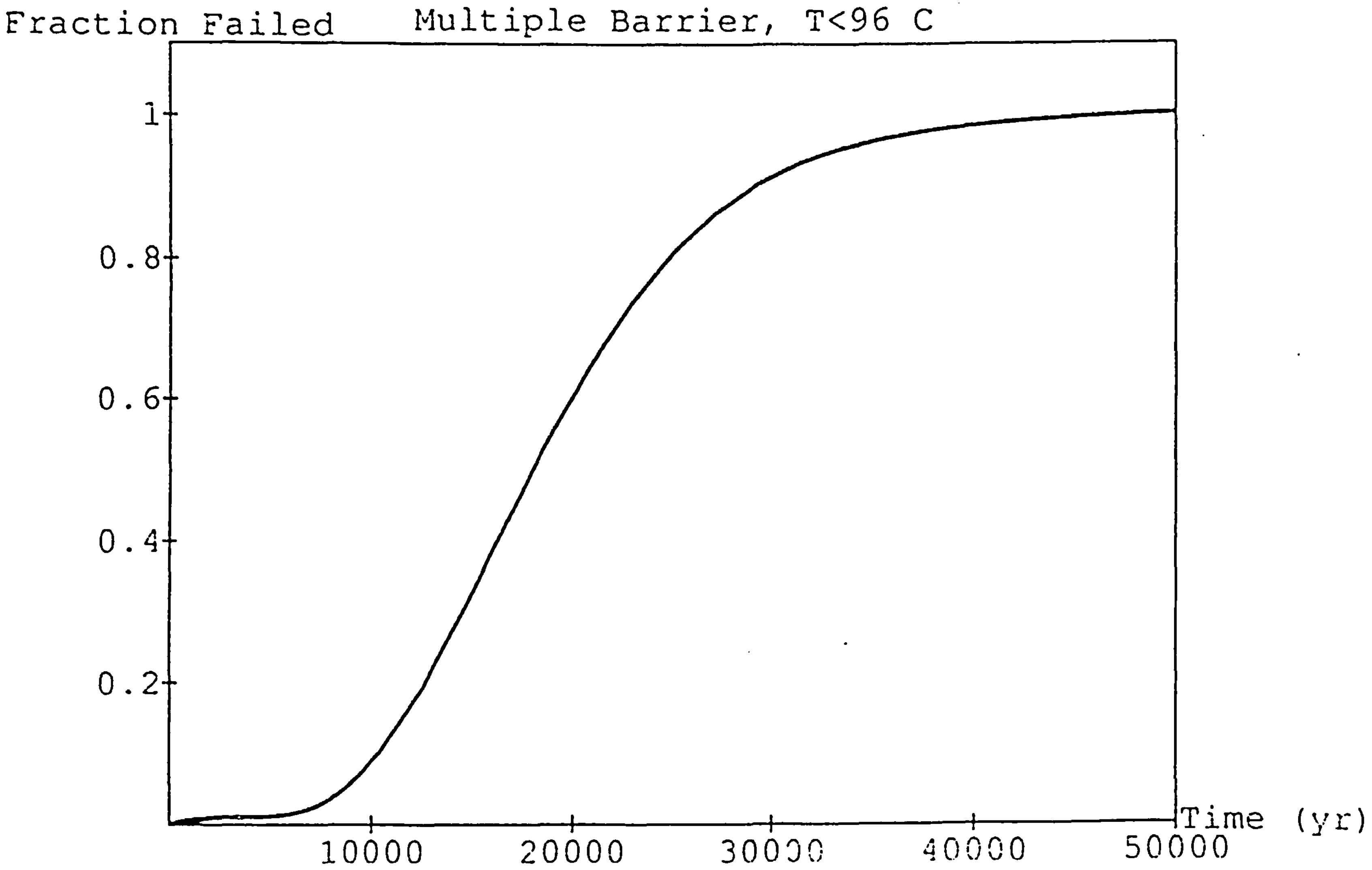
$sa =$ If $t < 1000$, $sa=0$ (Step function)

$x_1 = 1000$ years (Failure threshold)
$x_2 = 2000$ years
$x_2 = 4000$ years

$f_1 = 5000$ years (Mean barrier failure time)
$f_2 = f_1 + 5000$ years $= 10000$ years
$f_2 = f_1 + f_2 + 4000$ years $= 14000$ years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 1.0$
$b_3 = 2.0$

Multiple Barrier Container Cumulative Failure Distribution for T < 96°C



Parameter Values for Multiple Barrier, T = 96°C

- The following input values were employed for the scenario in which the repository temperature initially equals 96°C.

$c_1 = 0.005$ (Early failure fraction)

$t_1 = 1500$ years (Mean early failure time)

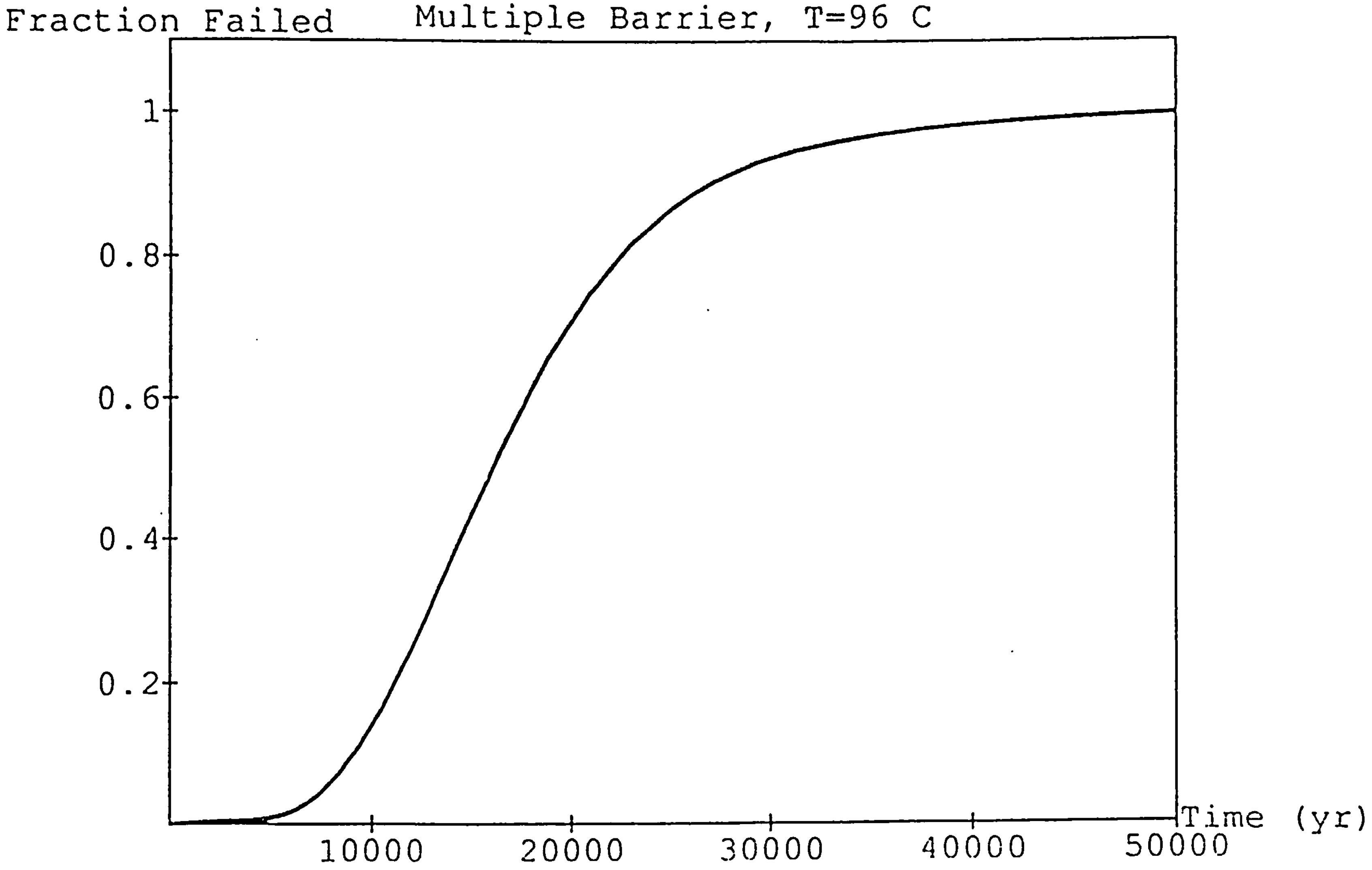
sa = If $t < 1000$, sa=0 (Step function)

$x_1 = 1000$ years (Failure threshold)
$x_2 = 2000$ years
$x_2 = 3000$ years

$f_1 = 5000$ years (Mean barrier failure time)
$f_2 = f_1 + 5000$ years = 10000 years
$f_2 = f_1 + f_2 + 2000$ years = 12000 years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 1.0$
$b_3 = 2.0$

Multiple Barrier Container Cumulative Failure Distribution for T = 96°C



Parameter Values for Multiple Barrier, $T > 96$°C

- The following input values were employed for the scenario in which the repository temperature initially exceeds 96°C.

$c_1 = 0.001$ (Early failure fraction)

$t_1 = 2000$ years (Mean early failure time)

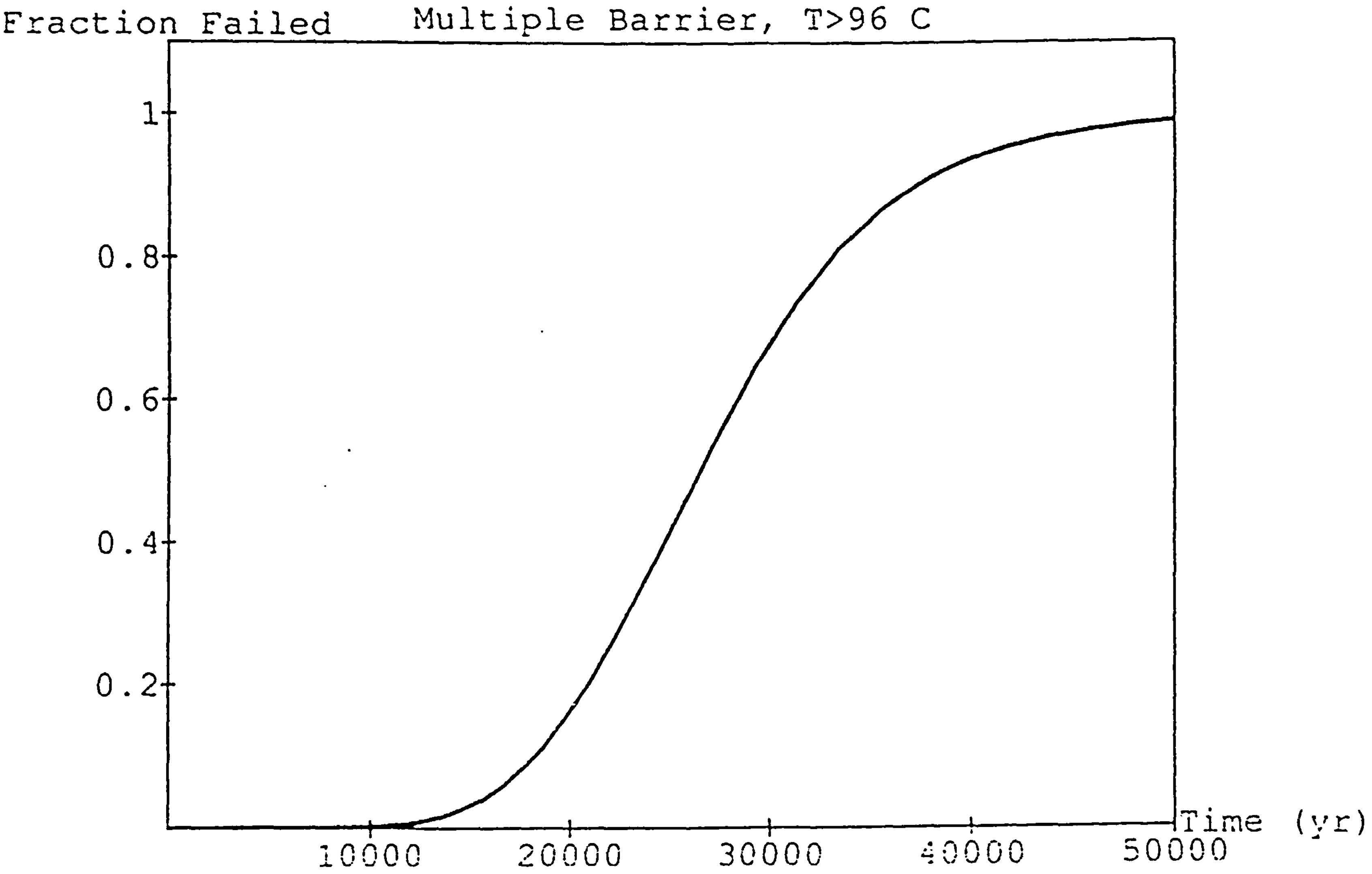
sa = If $t < 1000$, sa=0 (Step function)

$x_1 = 2000$ years (Failure threshold)
$x_2 = 4000$ years
$x_2 = 4000$ years

$f_1 = 10000$ years (Mean barrier failure time)
$f_2 = f_1 + 10000$ years = 20000 years
$f_2 = f_1 + f_2 + 0$ years = 20000 years

$b_1 = 1.0$ (Failure rate parameter)
$b_2 = 2.0$
$b_3 = 3.0$

Multiple Barrier Container Cumulative Failure Distribution for T > 96°C



Summary

- Engineered Barrier System design reviewed
- Degradation modes reviewed.
- Multiple failure mechanisms identified.
- Weibull and exponential distributions selected to model container failure rate
- Failure rates for single and multiple barriers in three (3) temperature regimes were calculated.
  - Weibull parameters identified for each scenario
  - Available technical literature used to estimate Weibull and exponential distribution parameters
- Variation in Weibull parameters allows completion of sensitivity analyses.

Release Rate Models for Source-Term Calculations

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INTERA

Presentation Outline

- Strategy and Assumptions
- Release Modes and Models
- EBS Data

INTERA

Strategy

- All relevant release modes are to be identified, with no *a priori* judgement regarding probability of occurrence,
- Models and parameters are identified for each mode,
- Different scenarios (branches along the fault-tree) define different environmental conditions at the time that release first occurs,
- The proportion of waste packages that are releasing by any given mode are related to the conditions and events that have previously occurred for a given scenario (branch along the fault-tree); these include:
  - Seismic disturbances,
  - Mode and timing of containment failure,
  - Thermally induced failure of the air gap,
  - Elevation of the water table,
  - Number and flow properties of water-bearing fractures intersecting the repository horizon,
  - Time at which temperature for formation of liquid water is attained at the container surface.
- Within the proportion of waste packages that are undergoing release by a certain mode, individual waste packages having different parameters can be independently simulated,
- Release rate, in units of grams per year, into the tuff host rock is calculated, as a source-term to the far field.

Assumptions/ Simplifications

- Two Groups of Radioelements Identified;
  - "Insoluble"/ Solubility-Limited Radioelements (e.g., Cs, Sn, U, Np, Pu, Am),
  - "Soluble"/ Reaction-Rate Limited Radioelements (e.g., Se, Tc, I, C) ,

- Initial "Gap" Portions ~ 2% of Total Inventory,

- "Wet-Drip", "Moist/ Wet-Continuous" and "Dry" Modes

<u>"Wet-Drip" Mode Assumes:</u>

- Entire Water Flux Directed into Waste Packages,
- Filled Bathtub Geometry

<u>"Moist/ Wet-Continuous" Mode Includes:</u>

- Radioactive Decay in Waste Form and During Migration (Decay-Chain Ingrowth Excluded),
- Sorption by Tuff,
- Diffusion or Convection-Diffusion in Porous Tuff,
- Degree of Hydrologic Saturation (Moist or Wet),

- Calculate Steady-State Release Rates (No Transients),
  - Attenuation from Radioactive Decay + Sorption,
  - No Sorption Delay to Reach Final Release Rates,
  - Current Yucca Mountain Waste-Package Design Has No Buffer/Backfill Barrier for Sorption,
  - Relatively Short Pathway (3 cm),
  - Uncertain Aggregate Properties of Crushed Tuff,

- Geometry Simplification (Equivalent Sphere),

- No Credit for Partially Failed Containment.

<u>"Dry" Mode - Only Gaseous C-14 Can Escape.</u>

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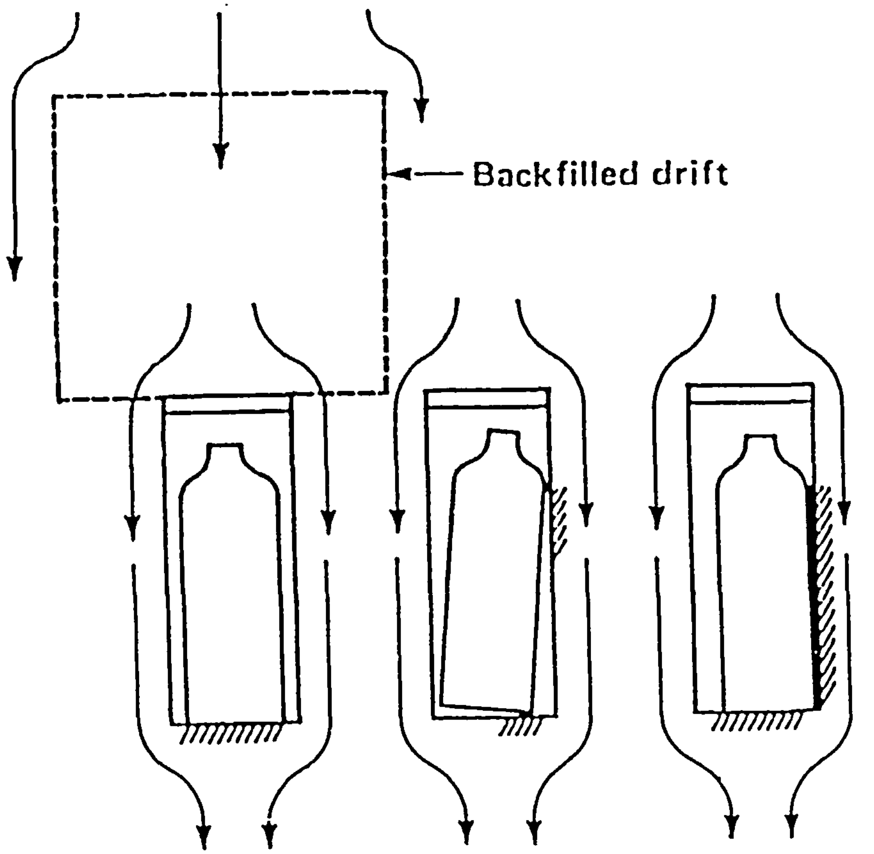
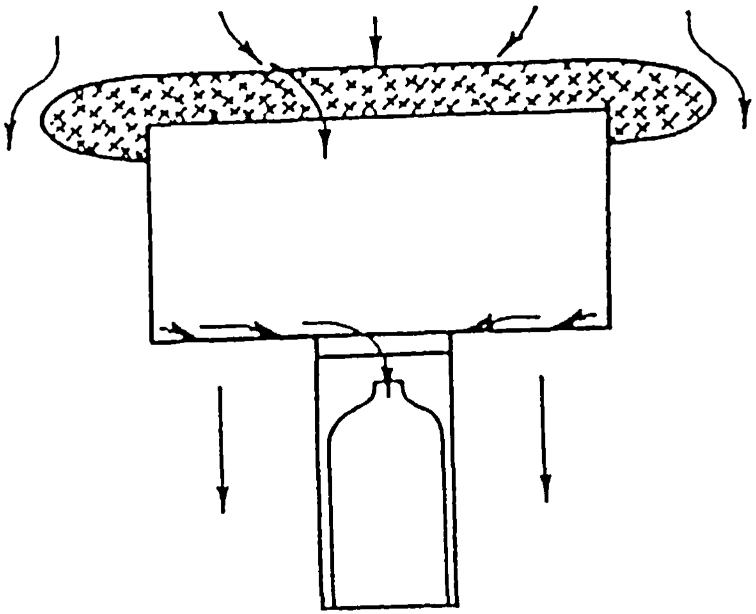
SCHEMATIC OF EBS RELEASE MODES

(O'Connell and Drach, 1986, UCRL-53761)

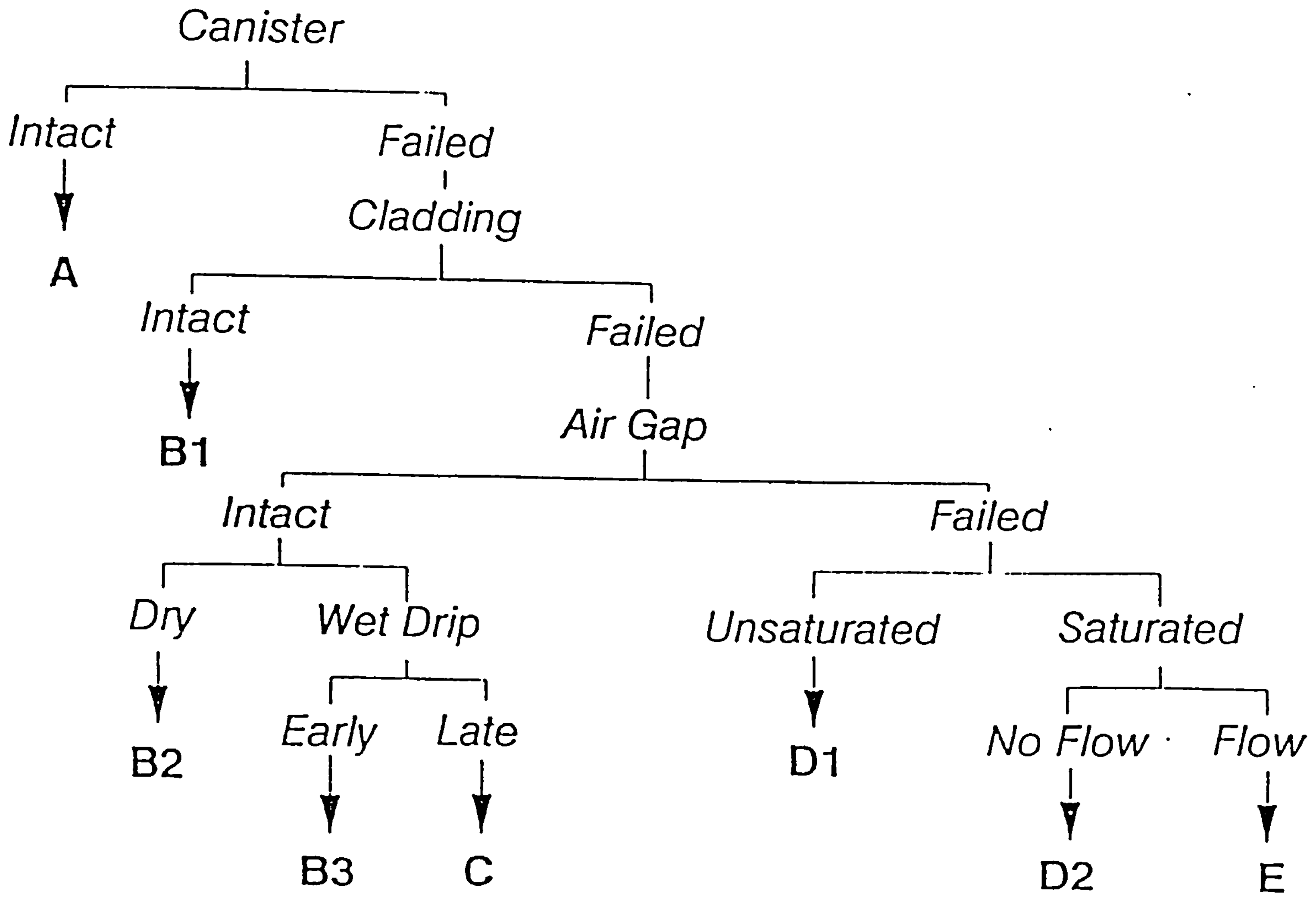


(a) "Dry" and "Wet-Continuous"



(b) "Wet-Drip"

REPOSITORY STATES AND RELEASE ENVIRONMENTS



- *Canister*
  - *Intact* → **A**
  - *Failed*
    - *Cladding*
      - *Intact* → **B1**
      - *Failed*
        - *Air Gap*
          - *Intact*
            - *Dry* → **B2**
            - *Wet Drip*
              - *Early* → **B3**
              - *Late* → **C**
          - *Failed*
            - *Unsaturated* → **D1**
            - *Saturated*
              - *No Flow* → **D2**
              - *Flow* → **E**

Preliminary Release Modes

1. Saturated Conditions with Hydrologic Flow ("Wet-Continuous"),
2. Saturated Conditions with No Hydrologic Flow ("Wet-Continuous"),
3. Unsaturated Conditions with Air Gap Intact and No Dripping Water ("Dry"),
4. Unsaturated Conditions with Air Gap Intact and Dripping Water ("Wet-Drip"),
5. Unsaturated Conditions with Failed Air Gap ("Moist-Continuous").

Summary of Release Models

CASES 1A, 2A, 5A

$$M_i = \frac{4 \pi \varepsilon D_b r_0 c_s [Sh\, r_1 \sqrt{\kappa}]}{[(Sh - 1) \sinh d + r_1 \sqrt{\kappa} \cosh d]}$$

CASES 1B, 2B, 3B*, 5B

$$M_i = \Psi' f_a M^\circ_i \exp(-\lambda_i t)$$

CASES 3A, 3B

$$M_i = 0$$

CASE 4A

$$M_i = Q\,(M_i/M_\Sigma)\, c_s$$

CASE 4B

$$M_i\,(tf > 1/f_a) = \alpha e^{-\lambda t - \alpha t} f_a M^0 \left[\left(\frac{1}{\alpha} \div t_1 \div \frac{1}{f_a} \right) (e^{\alpha t} - e^{\alpha t_1}) - \alpha \left(\frac{e^{\alpha t}}{\alpha^2}(\alpha t - 1) - \frac{e^{\alpha t_2}}{\alpha^2}(\alpha t_2 - 1) \right) \right]$$

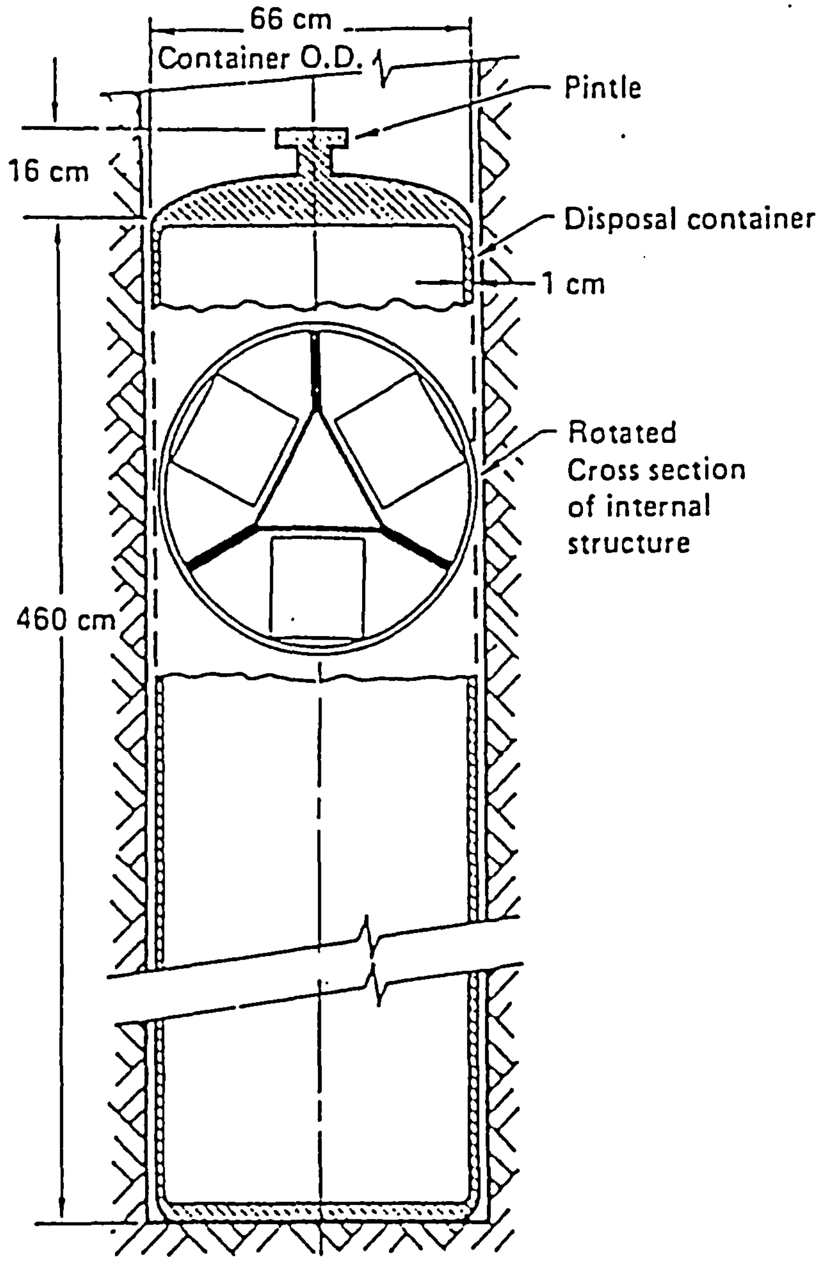
$$\div \alpha \frac{e^{-\lambda t_2} M^0}{(t_2 - t_1)} (t_2 - t_1 - \frac{1}{2 f_a}) e^{(-\lambda - \alpha)(t - t_2)}, \qquad t_2 \le t \le t_2 \div 1/f_a.$$

$$M_i\,(tf < 1/f_a) = f_a M^0 e^{-(\alpha + \lambda) t} \left((e^{\alpha t} - e^{\alpha t_2}) \div \frac{\alpha}{2} (t_2 - t_1) e^{\alpha t_2} \right), \qquad t_2 \le t \le t_2 \div \frac{1}{f_a}.$$

Presentation Outline

- **Strategy and Assumptions**
- **Release Modes and Models**
- **EBS Data**

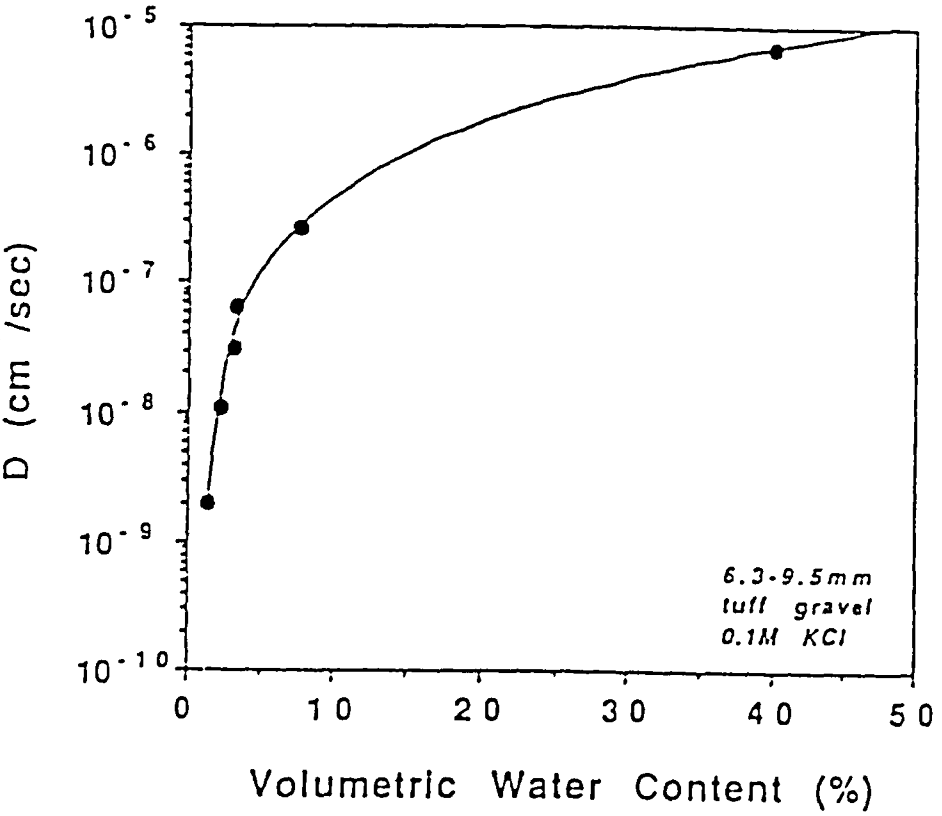
High-Level Waste Packages in Tuff



Spent Fuel

DIFFUSION COEFFICIENT AS A FUNCTION OF WATER CONTENT IN TUFF GRAVEL

(Conca 1990)



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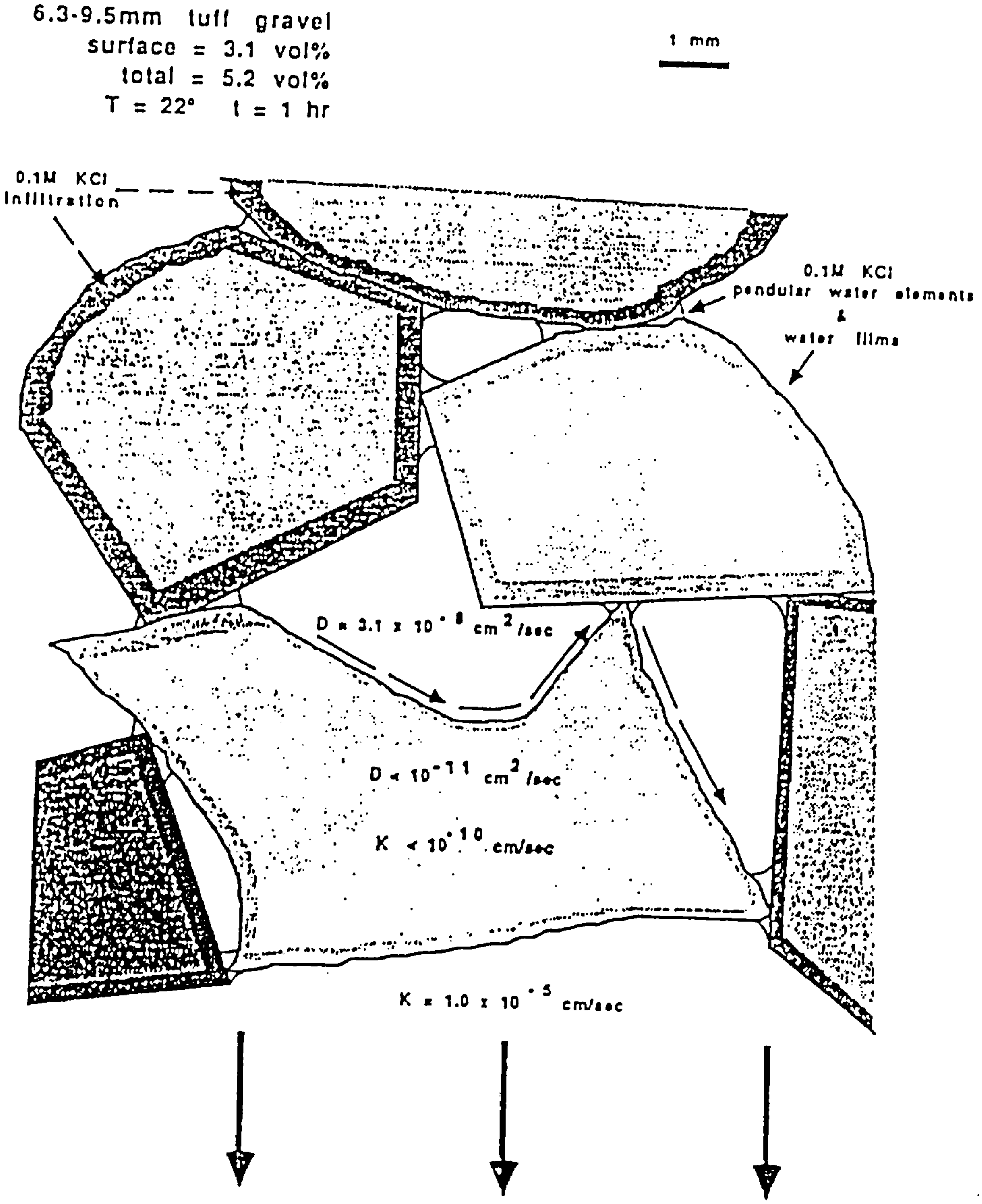
INFERRED WATER DISTRIBUTION IN PARTIALLY SATURATED TUFF GRAVEL

(CONCA 1990)



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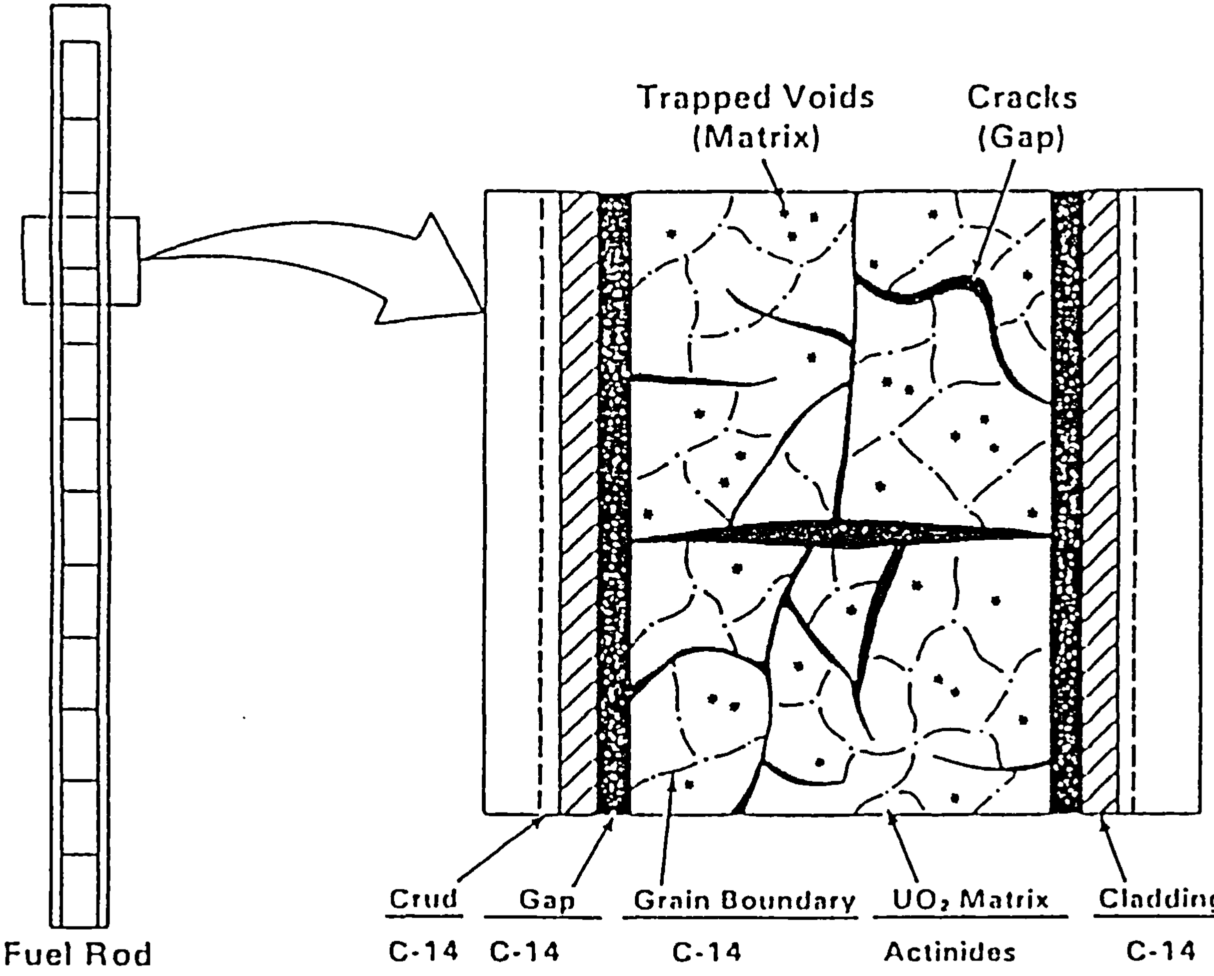
Key Data Affecting Nuclide Transport for Waste-Package Release

- Near-field hydrology
  - Water flow mechanism
  - Water flow rate
  - Effects of waste emplacement
- Diffusion coefficients in partially saturated tuff
  - Intact rock
  - Crushed rock
  - Effects of grain size, water content, geometry
- Stability of emplacement hole/air gap
  - Rock displacements
  - Waste-package displacements
  - Sedimentation
- Containment failures
  - Distribution over time
  - Effect of small apertures

Schematic of Spent Nuclear Fuel



Crud	Gap	Grain Boundary	UO_2 Matrix	Cladding
C-14	C-14	C-14	Actinides	C-14
	I-129	I-129	~98% Fission Products	
	Cs-135	Cs-135		
	Cs-137	Cs-137		
	Se-79	Se-79		
	Tc-99	Tc-99		
	Sr-90	Sr-90		

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Reference Chemical Data

	SOLUBILITY (gm/m^3)			SORPTION	
Element	LLNL*(25°C)	LLNL*(85°C)	PNL #	(ml/gm)	Isotopes
C	----	----	1.4 E0	0	C-14
Se	----	----	5.5 E5	7	Se-79
Tc	3.5 E-2	----	9.9 E5	0.3	Tc-99
Sn	----	----	1.3 E-4	100	Sn-126
I	----	----	7.74 E5	0	I-129
Cs	1.2 E0	2.3 E0	8.1 E5	290	Cs-135
U	5 E0	5 E-1	5 E1	18	U-234, U-238
Np	4 E-4	1.4 E-3	7.11 E2	7	Np-237
Pu	5 E-3	6 E-5	4.3 E-1	64	Pu-239, Pu-240, Pu-242
Am	3 E-4	1.5 E-7	2.4 E-3	1200	Am-241, Am-243
Cm	1.2 E-5	2.4 E-9	2.4 E-3	1200	Cm-245

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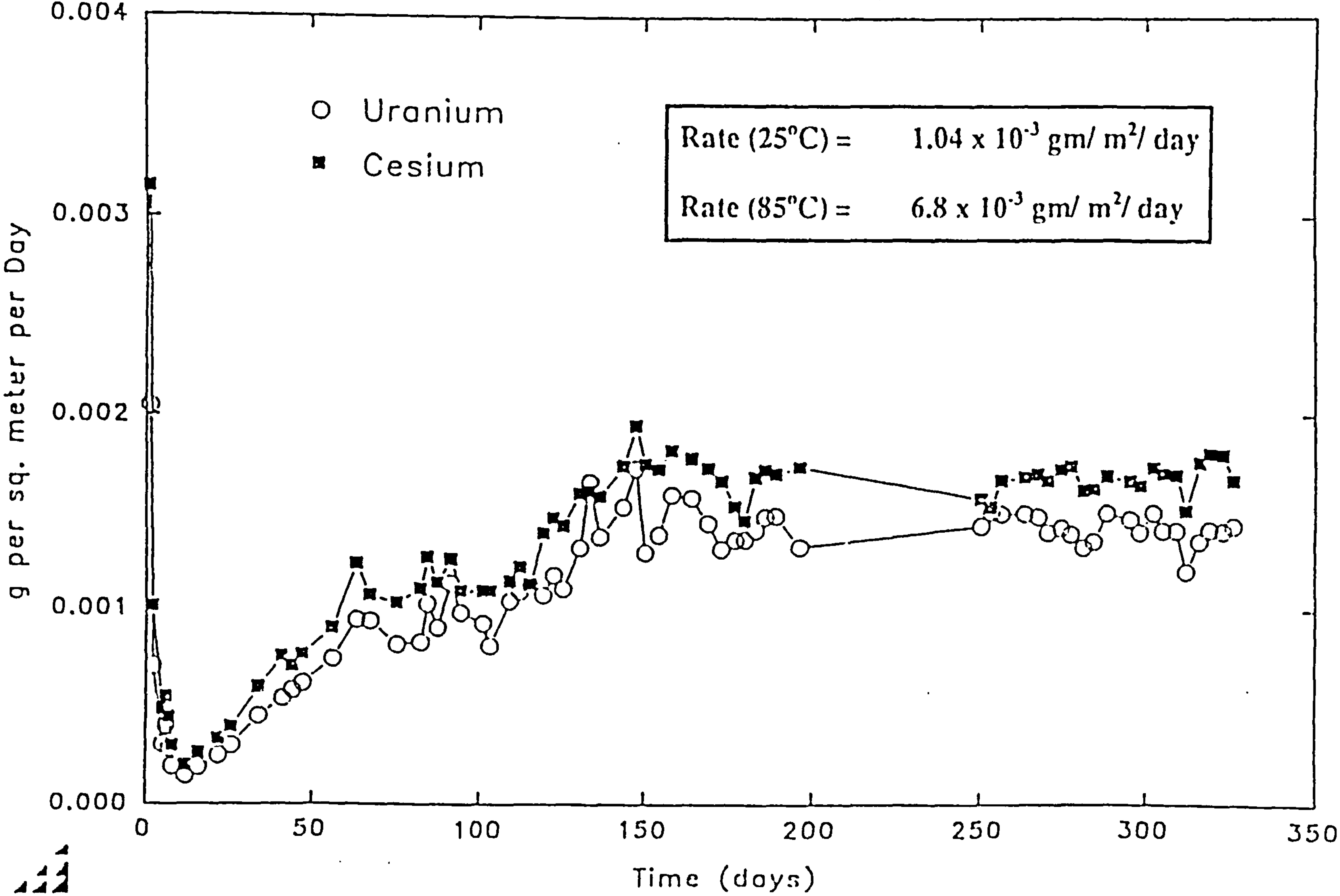
* Data Provided at LLNL Staff Presentation, June 1991.

Data Cited by Apted et al., Analysis of Spent Fuel as a Waste Form, PNL-6347, Pacific Northwest Laboratory, Richland, Washington (1989).

Note: Inventory Data Is Taken from Roddy et al., ORNL/ TM-9591 (1986) for Reference 33,000 MWd/ MTIHM PWR, Tables 3.4, 3.6 and 3.10.

Normalized Dissolution Rate of UO_2 Matrix of Spent Fuel (ATM-105)

(Gray and Wilson 1990)



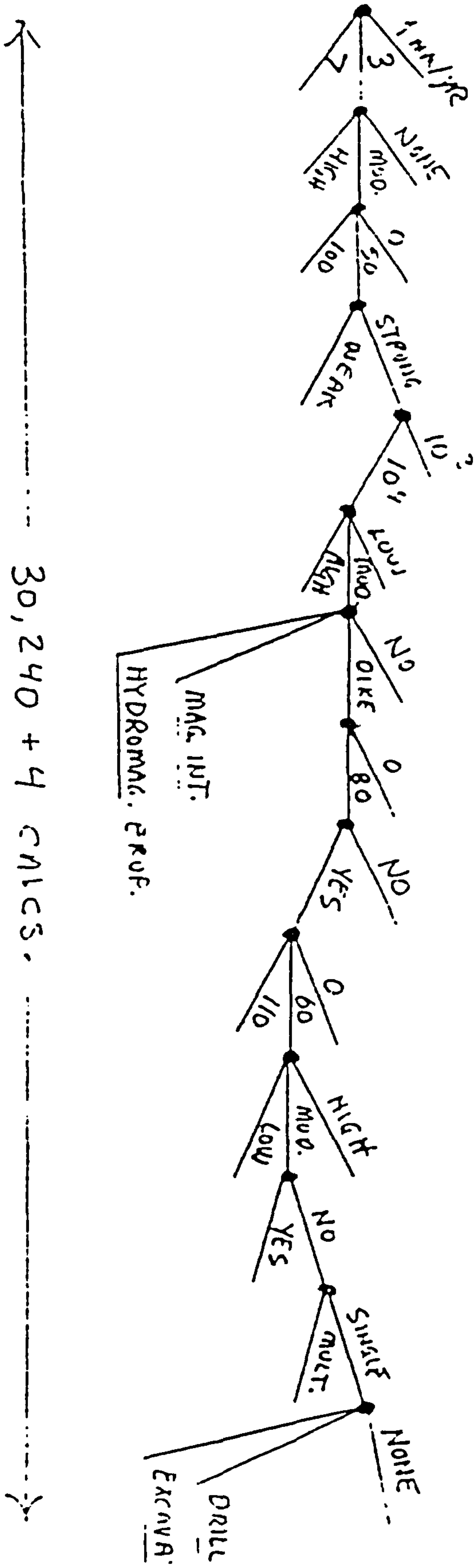
Rate (25°C) = 1.04×10^{-3} gm/ m²/ day

Rate (85°C) = 6.8×10^{-3} gm/ m²/ day

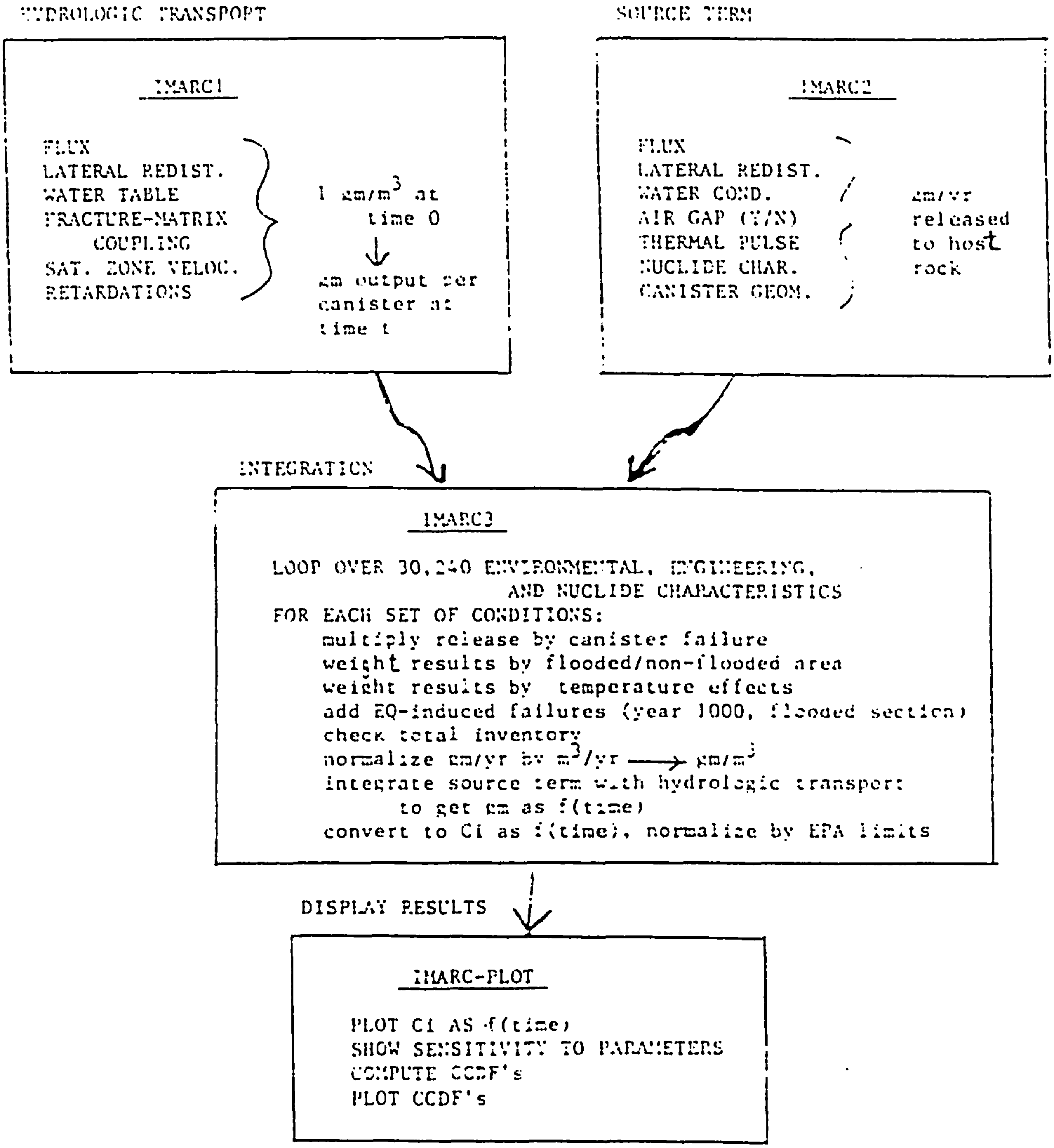
Key Chemical Data for Waste-Package Release

- Composition of water ("Water Quality", SCP)
  - Natural variation at Yucca Mountain Site
  - Effect of boiling
  - Alpha radiolysis
- Release of radionuclides from spent fuel
  - Solubilities of nuclide-bearing solids
  - Alteration rate of UO_2 matrix
  - Stoichiometric dissolution of UO_2 matrix
  - Air-oxidation of UO_2 matrix
- Distribution (sorption) coefficients
  - More important to far-field performance
  - Soluble radionuclides
  - Obtained under partially saturated conditions

R. K. McGuire



1. FLUX
2. LATERAL REDISTRIBUTION
3. ΔWT | FLUX
4. FRACTURE-MATRIX COUPLING
5. SATURATED FLOW VELOCITY
6. MATRIX RETARDATION VALUES
7. VOLCANOES
8. ΔWT | VOLCANOES
9. EARTHQUAKES
10. ΔWT | EQS
11. THERMAL PULSE
12. BOREHOLE FRACTURES | THERMAL PULSE
13. CANISTER PERFORMANCE
14. HUMAN INTRUSION



HYDROLOGIC TRANSPORT

IMARC1

FLUX
LATERAL REDIST.
WATER TABLE
FRACTURE-MATRIX
COUPLING
SAT. ZONE VELOC.
RETARDATIONS

1 gm/m^3 at time 0
↓
gm output per canister at time t

SOURCE TERM

IMARC2

FLUX
LATERAL REDIST.
WATER COND.
AIR GAP (Y/N)
THERMAL PULSE
NUCLIDE CHAR.
CANISTER GEOM.

gm/yr released to host rock

INTEGRATION

IMARC3

```
LOOP OVER 30,240 ENVIRONMENTAL, ENGINEERING,
                AND NUCLIDE CHARACTERISTICS
FOR EACH SET OF CONDITIONS:
    multiply release by canister failure
    weight results by flooded/non-flooded area
    weight results by  temperature effects
    add EQ-induced failures (year 1000, flooded section)
    check total inventory
    normalize gm/yr by m^3/yr ⟶ gm/m^3
    integrate source term with hydrologic transport
         to get gm as f(time)
    convert to Ci as f(time), normalize by EPA limits
```

DISPLAY RESULTS

IMARC-PLOT

PLOT Ci AS f(time)
SHOW SENSITIVITY TO PARAMETERS
COMPUTE CCDF's
PLOT CCDF's

Preliminary Conclusions

- Radioisotope releases not very sensitive to 3 heat transfer scenarios (i.e., hot, warm, cold)
- Waste package behavior very important in model (ie, corrosion)
- Hydrology modeling very complicated, highly uncertain and likely will remain so
- Hydrology + temperature are intimately linked
- Integrated performance assessment is vital

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: TECHNICAL CONSIDERATIONS

PRESENTER: ERIC E. RYDER

PRESENTER'S TITLE AND ORGANIZATION:
TECHNICAL STAFF
PERFORMANCE ASSESSMENT DIVISION
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 844-9644

OCTOBER 8 - 10, 1991

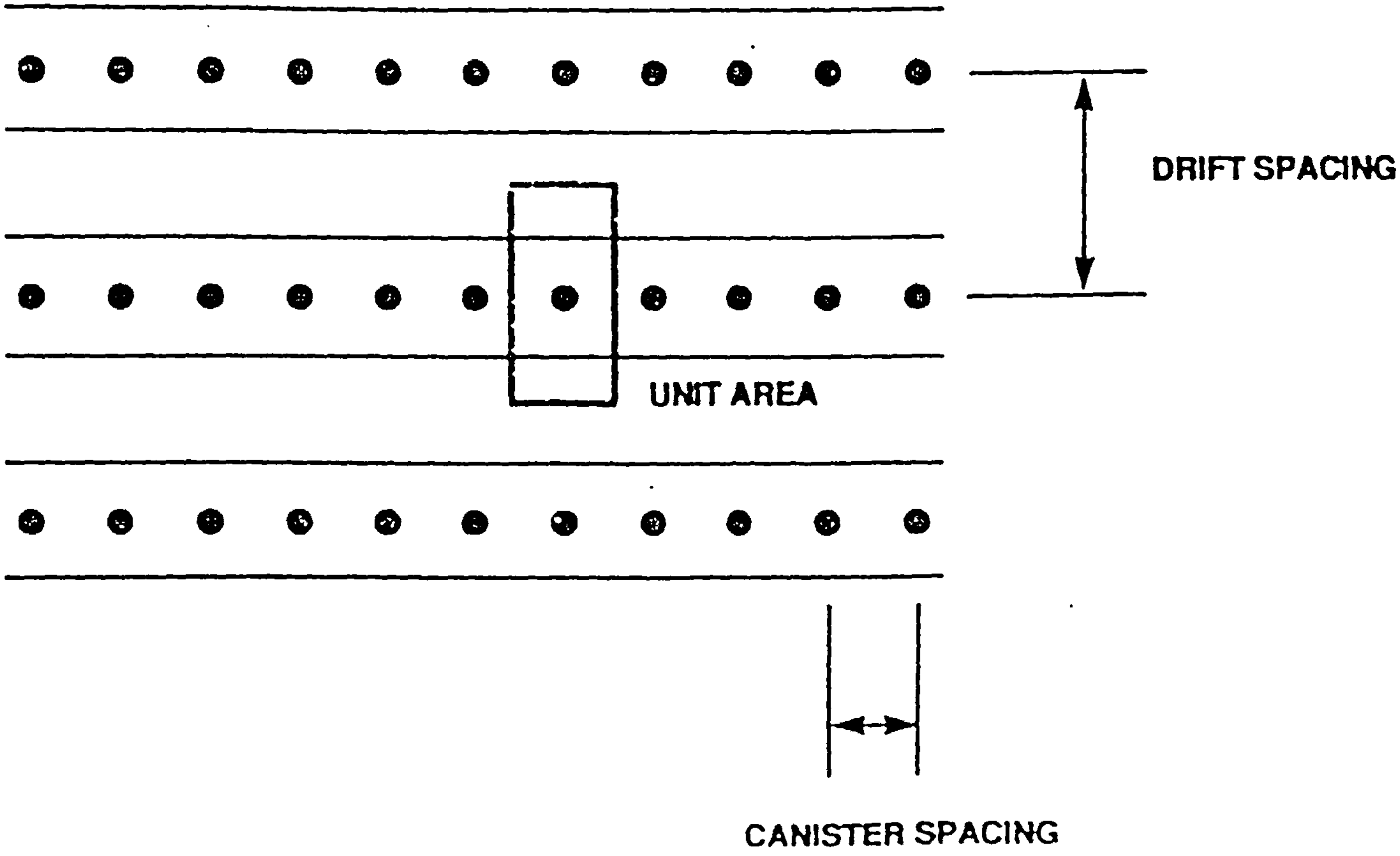
Thermal Design Considerations

Objectives

- Discuss complexities of the repository thermal design process
- Demonstrate why there is no unique set of temperature histories that correspond to a given areal power density
- Emphasize the dependence of calculated thermal responses on model/system assumptions
- Point out some design/system changes that have occurred since the SCP

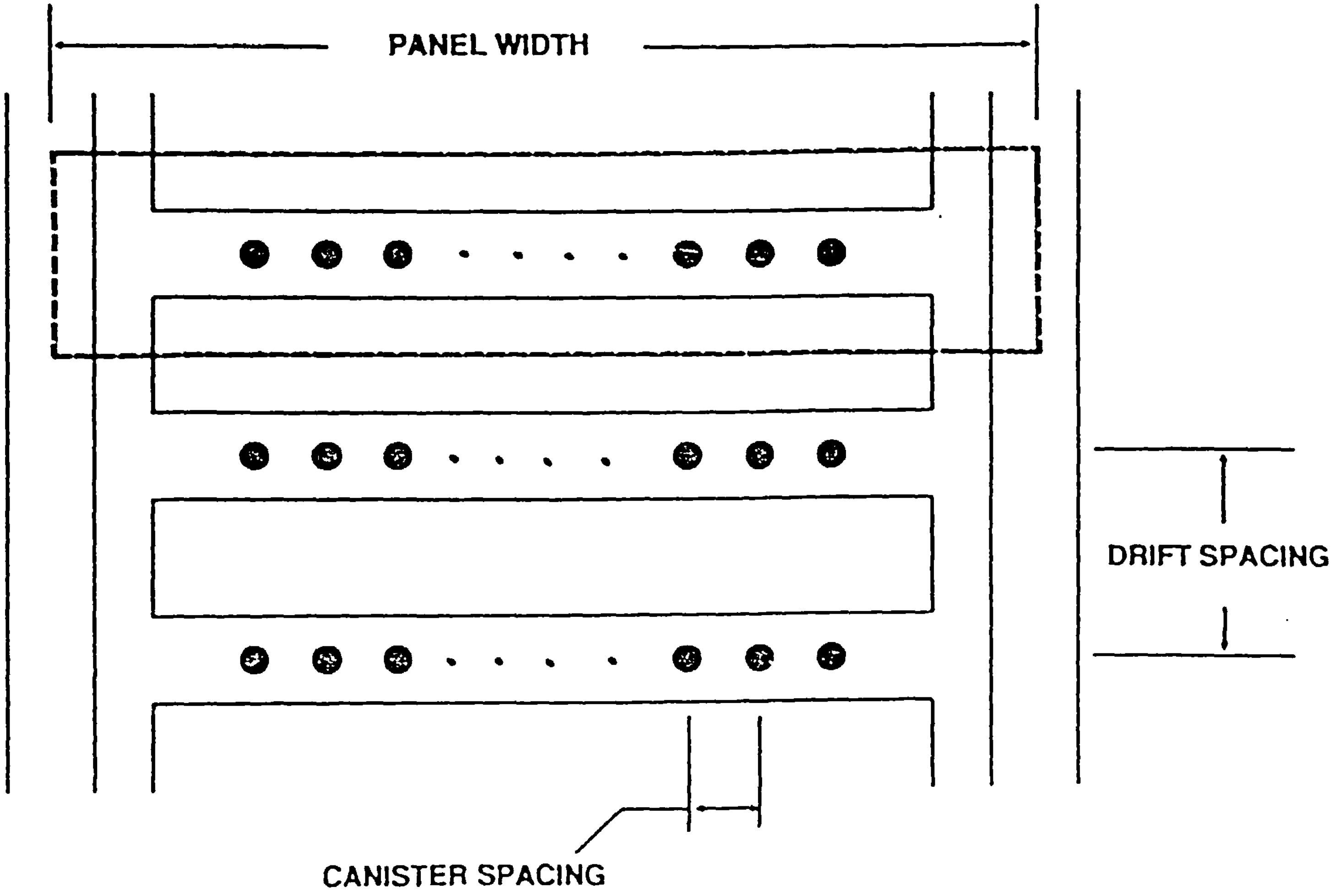
Local Areal Power Density (LAPD) =

$$\frac{\text{Initial Loading}}{\text{Unit Area}}$$



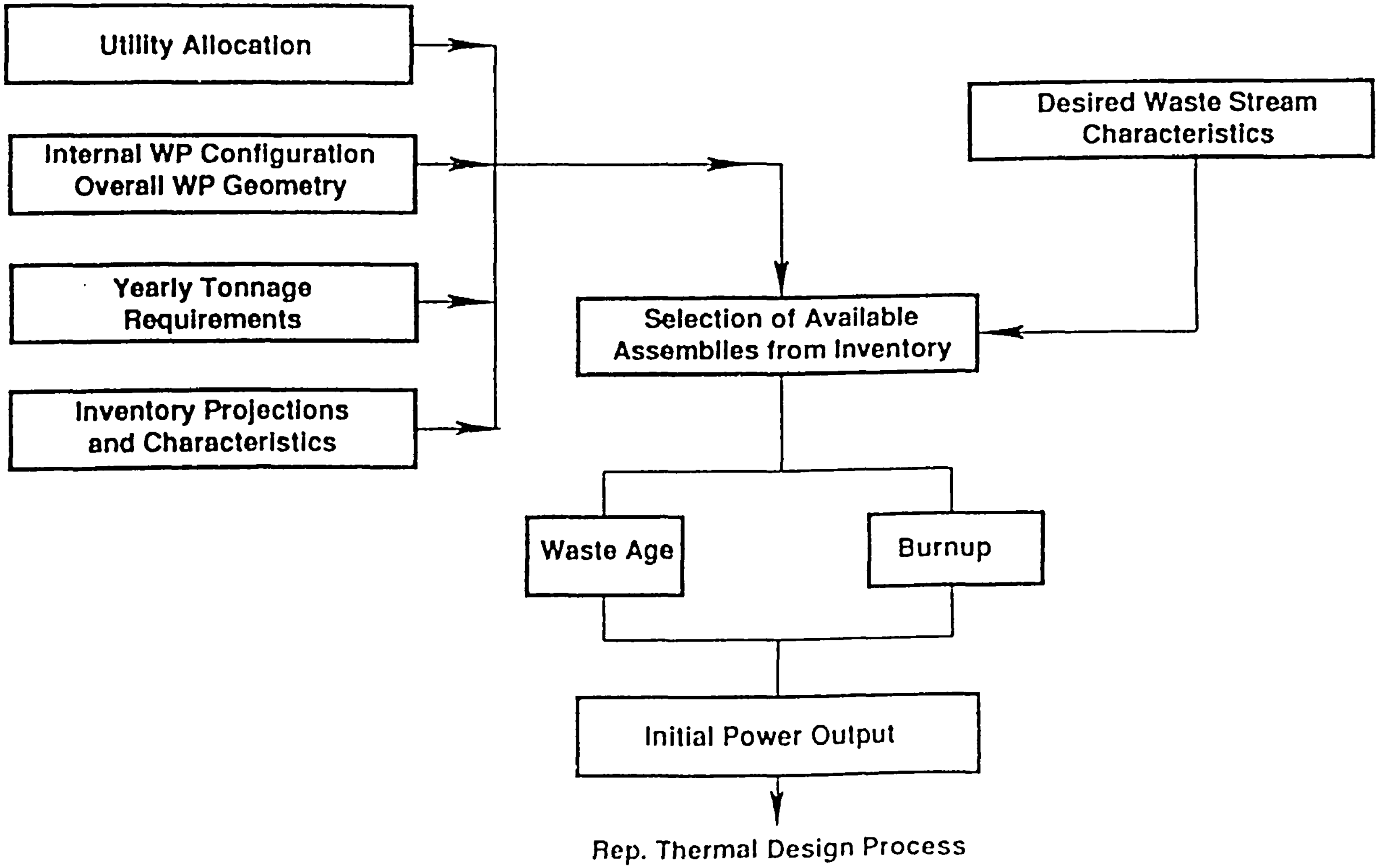
Areal Power Density (APD) =

$$\frac{\text{Initial Loading}}{\text{Unit Area}}$$



ERMYDP 125 NWTRB/10 8 10 91

Waste Stream Characteristics



Utility Allocation

Internal WP Configuration
Overall WP Geometry

Yearly Tonnage
Requirements

Inventory Projections
and Characteristics

Desired Waste Stream
Characteristics

Selection of Available
Assemblies from Inventory

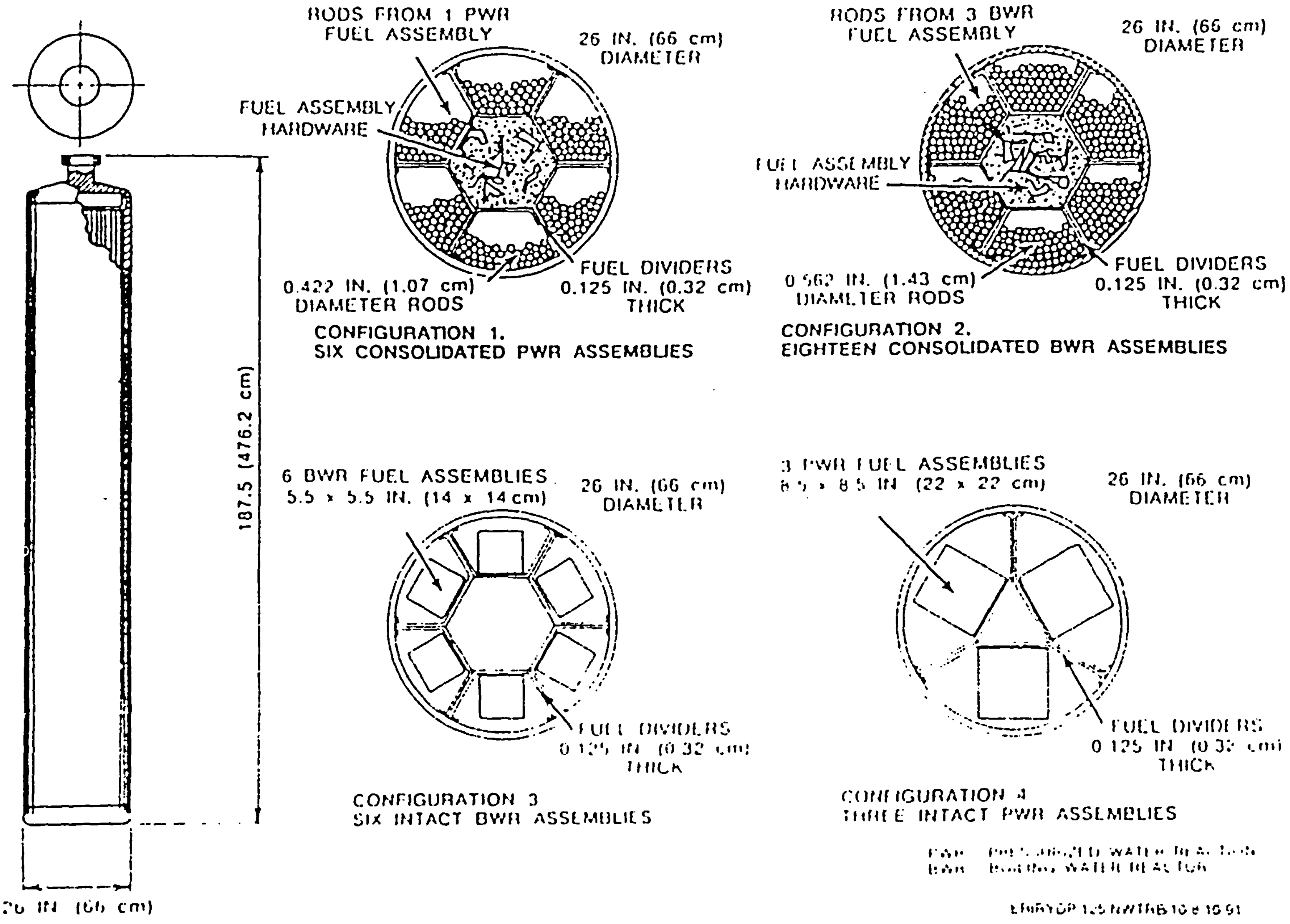
Waste Age

Burnup

Initial Power Output

Rep. Thermal Design Process

SCP Reference Waste Package Configurations



CONFIGURATION 1.
SIX CONSOLIDATED PWR ASSEMBLIES

CONFIGURATION 2.
EIGHTEEN CONSOLIDATED BWR ASSEMBLIES

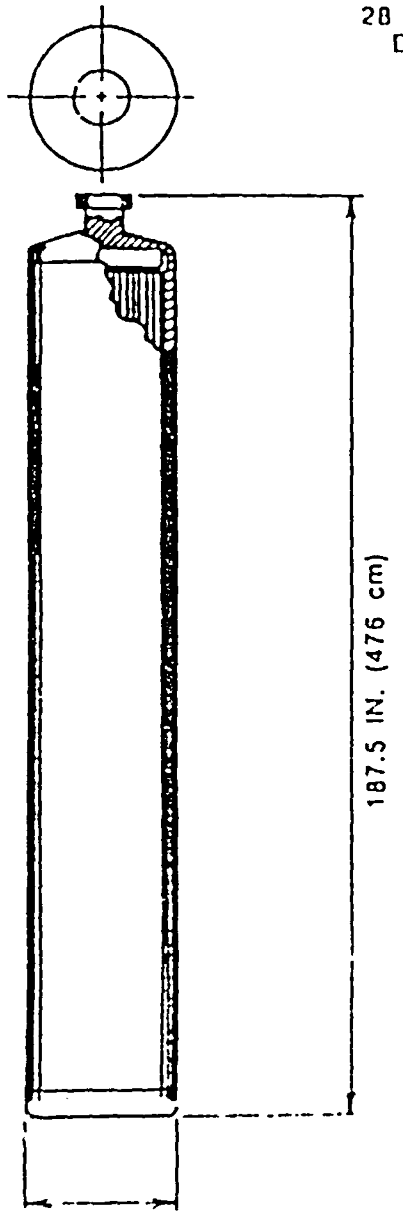
CONFIGURATION 3
SIX INTACT BWR ASSEMBLIES

CONFIGURATION 4
THREE INTACT PWR ASSEMBLIES

PWR PRESSURIZED WATER REACTOR
BWR BOILING WATER REACTOR

EMRYOP 1.25 NWTRB 10 8 10 91

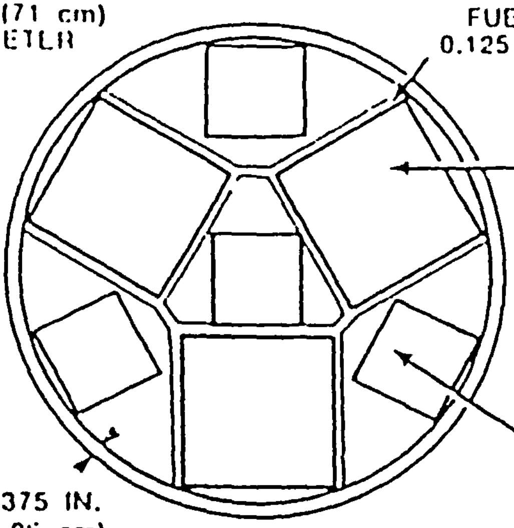
SCP Alternate Waste Pakage Configurations



28 IN. (71 cm)

28 IN. (71 cm)
DIAMETER

FUEL DIVIDERS
0.125 IN. (0.32 cm)
THICK



3 PWR FUEL ASSEMBLIES
8.5 x 8.5 IN. (21.6 x 21.6 cm)

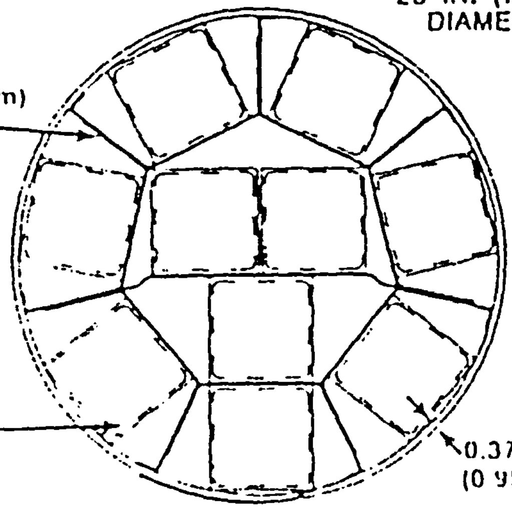
CONFIGURATION 1.
THREE INTACT PWR ASSEMBLIES
FOUR INTACT BWR ASSEMBLIES

4 BWR FUEL ASSEMBLIES
5.5 x 5.5 IN (14 x 14 cm)

0.375 IN.
(0.95 cm)

28 IN. (71 cm)
DIAMETER

FUEL DIVIDERS
0.125 IN. (0.32 cm)
THICK



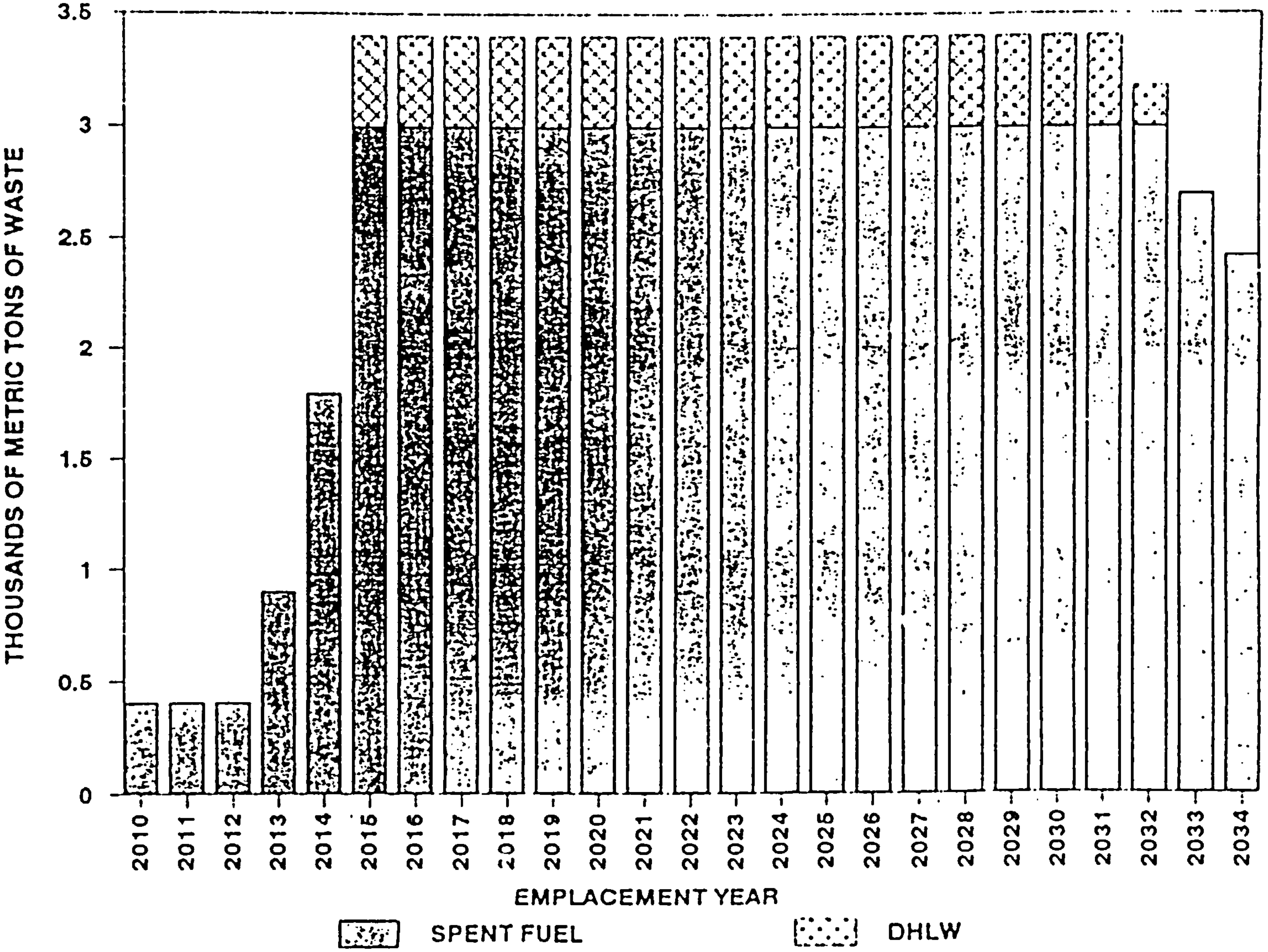
CONFIGURATION 2.
TEN INTACT BWR ASSEMPLIES

10 BWR FUEL ASSEMBLIES
5.5 x 5.5 IN. (14 x 14 cm)

0.375 IN
(0.95 cm)

Acceptance Schedule

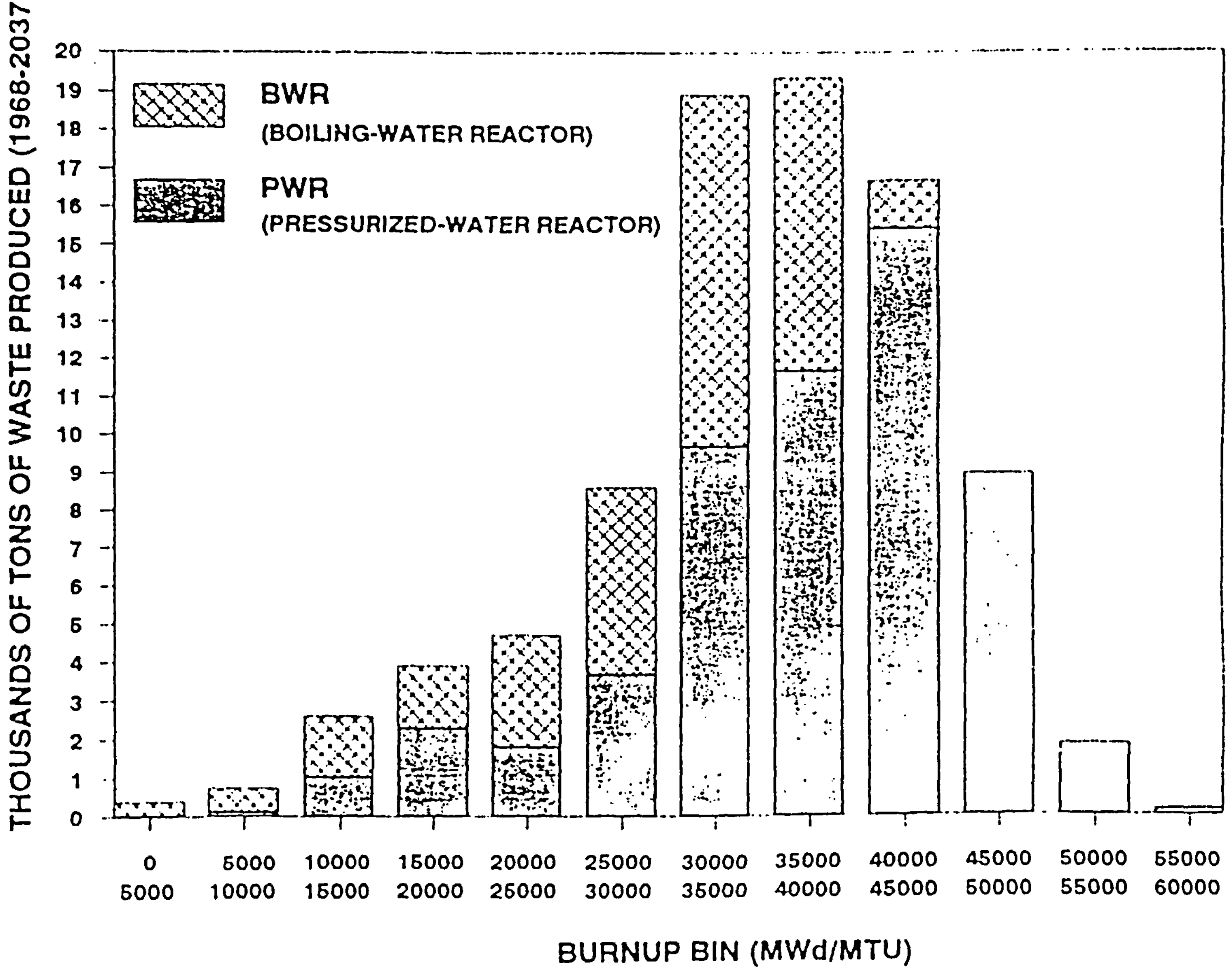
(Mission Plan Amendment, 1988)



ORNL Historical and Projected Spent Fuel Inventory

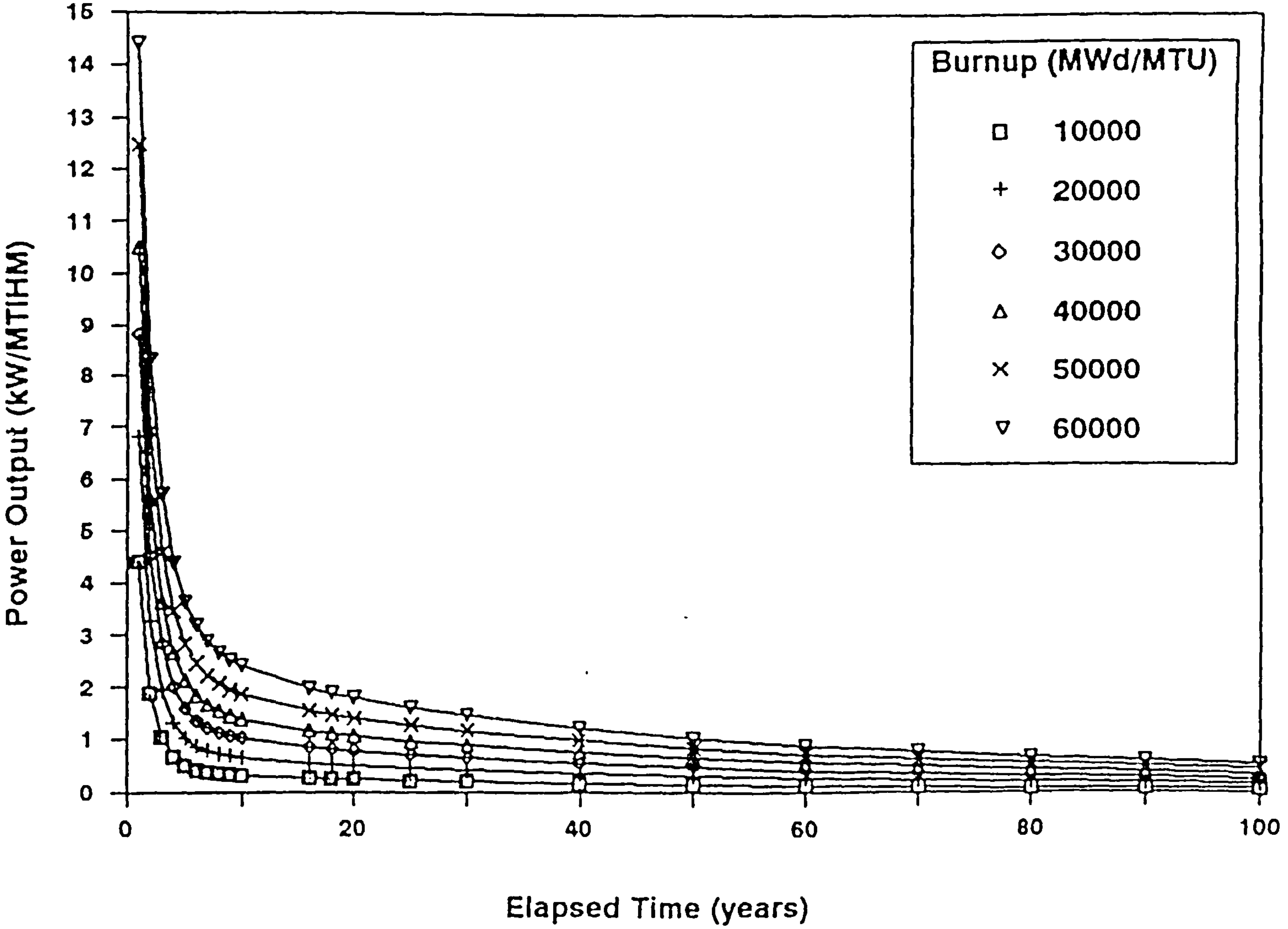
(1968 - 2037)

No New Orders - Extended Burnup Scenario



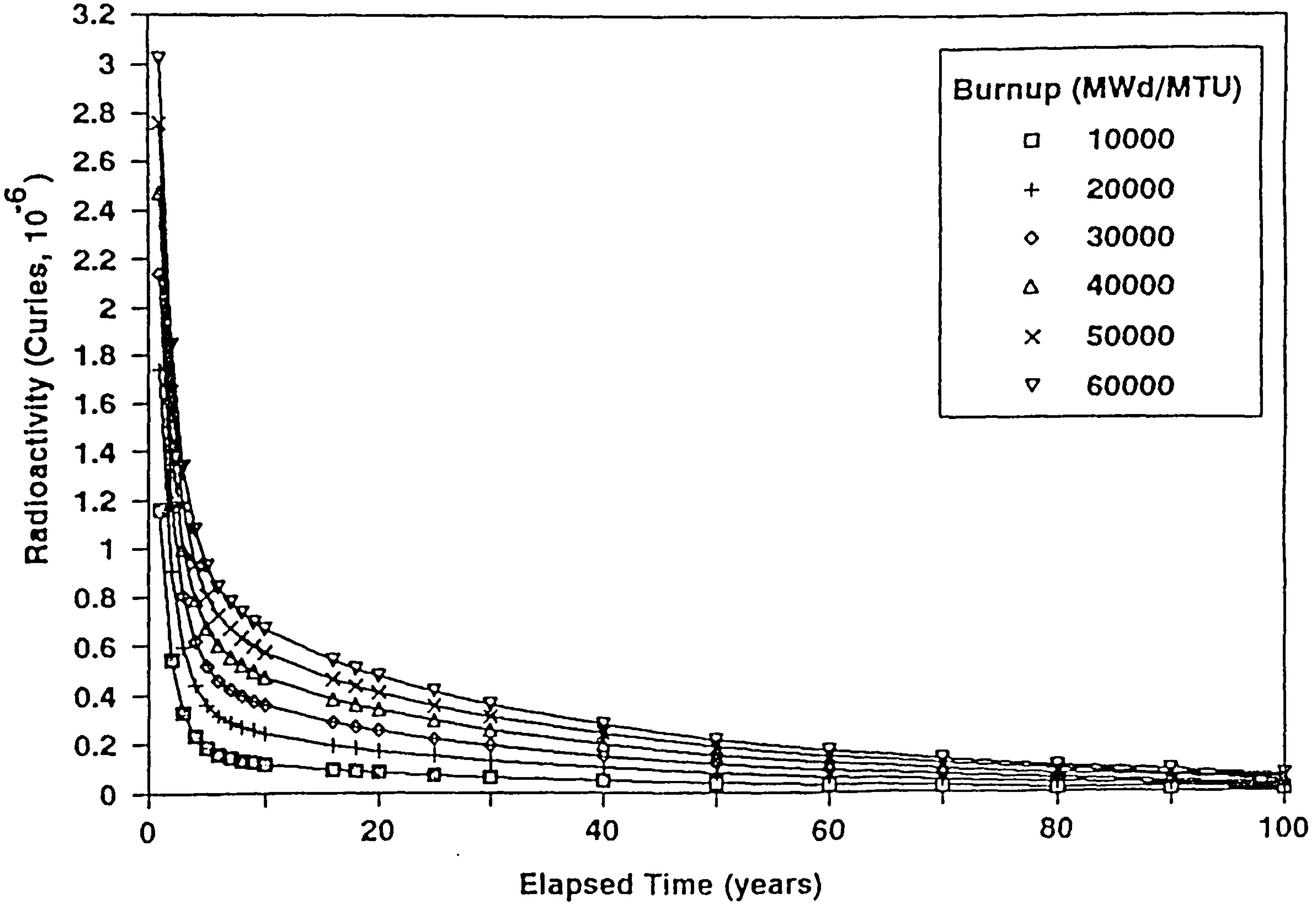
Thermal Decay Characteristics

PWR-type Waste



Radiological Decay Characteristics

PWR-type Waste



Desired Waste Stream Characteristics

FIFO:

Fuel is received and emplaced at the repository on an oldest-fuel-first basis

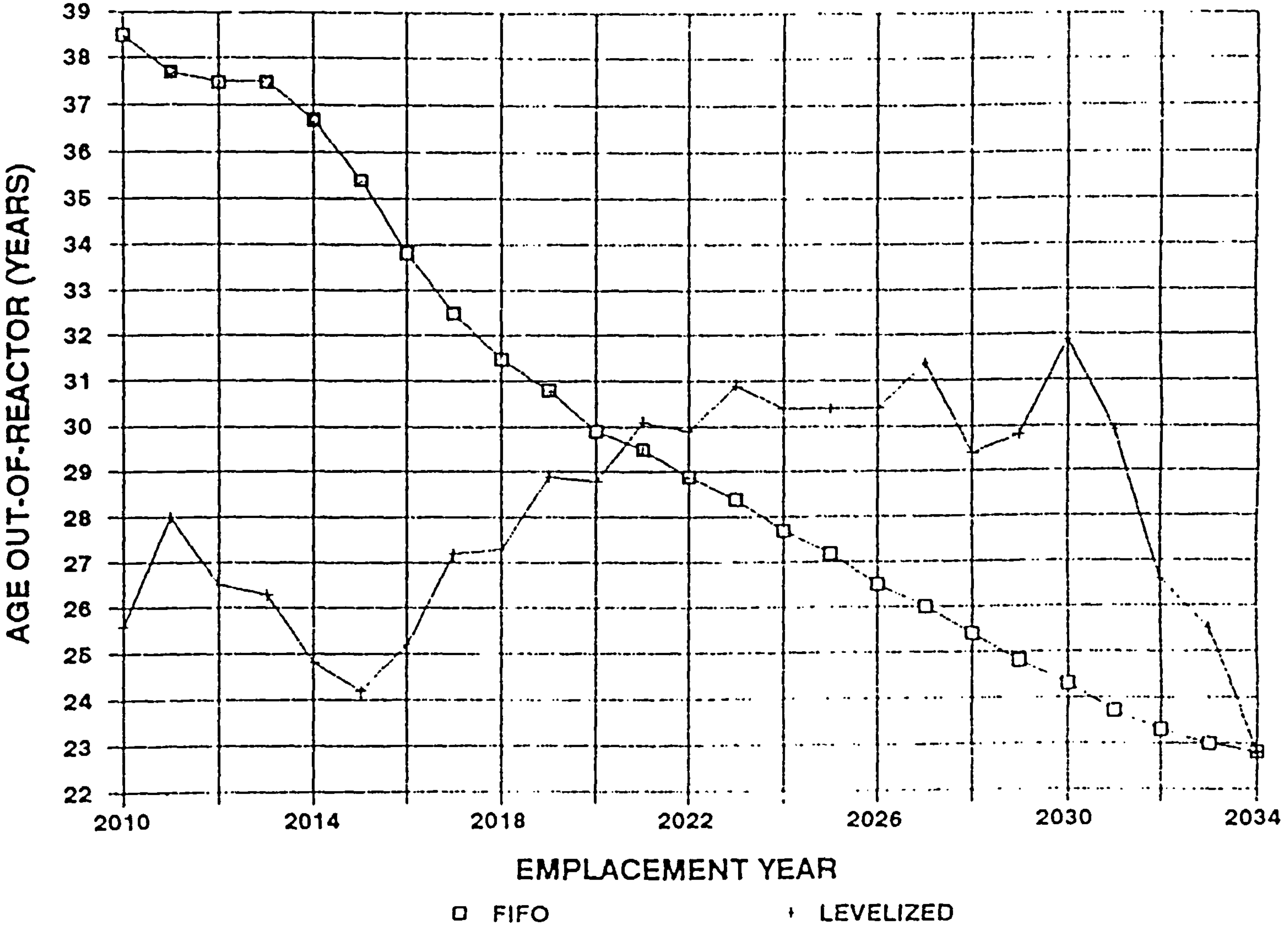
Levelized:

Fuel assemblies are chosen from the available inventory in such a manner that the initial power output and average waste age span a limited range

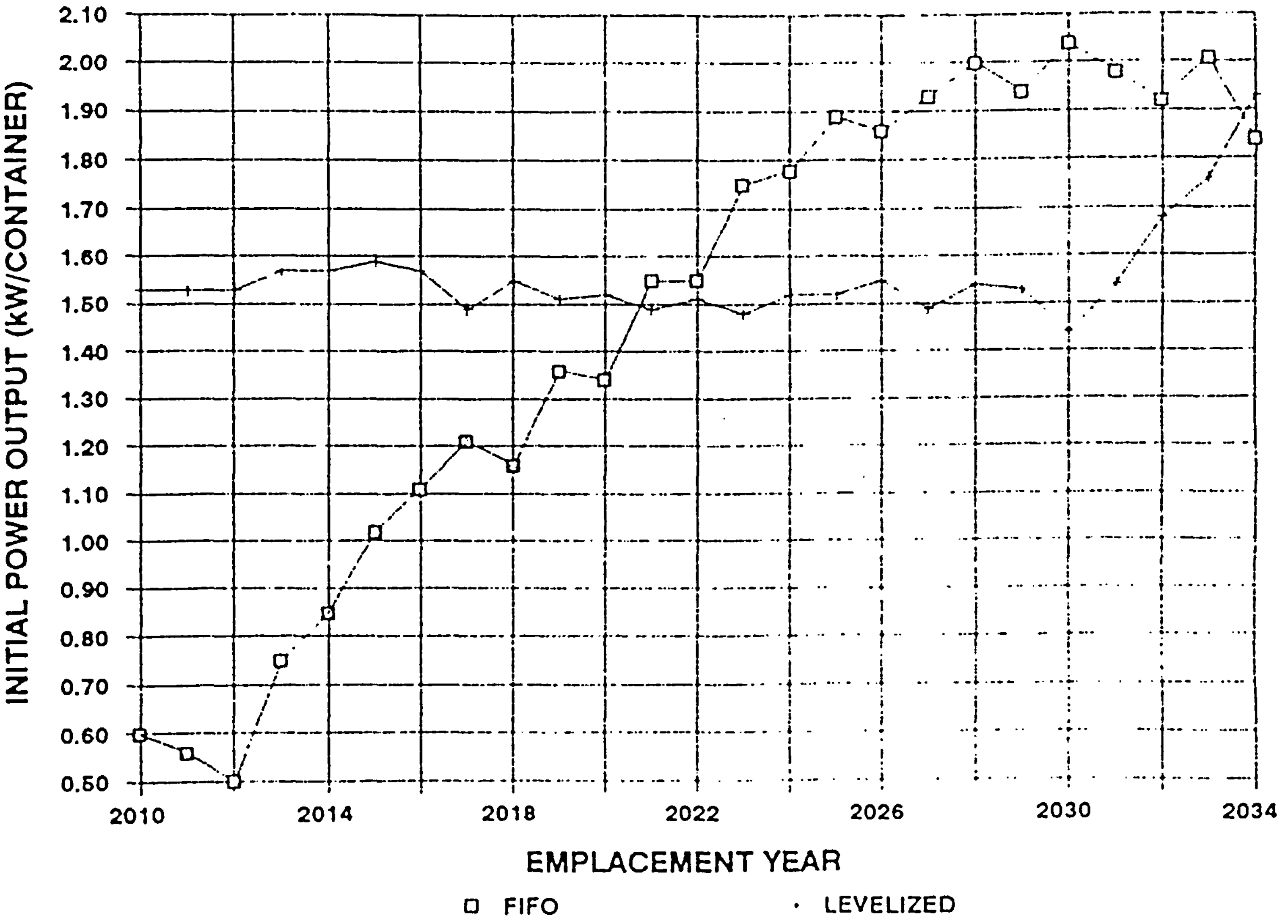
Area Minimization:

Use of the "transportation" algorithm allows assignment of costs on the basis of acres required per ton of material emplaced

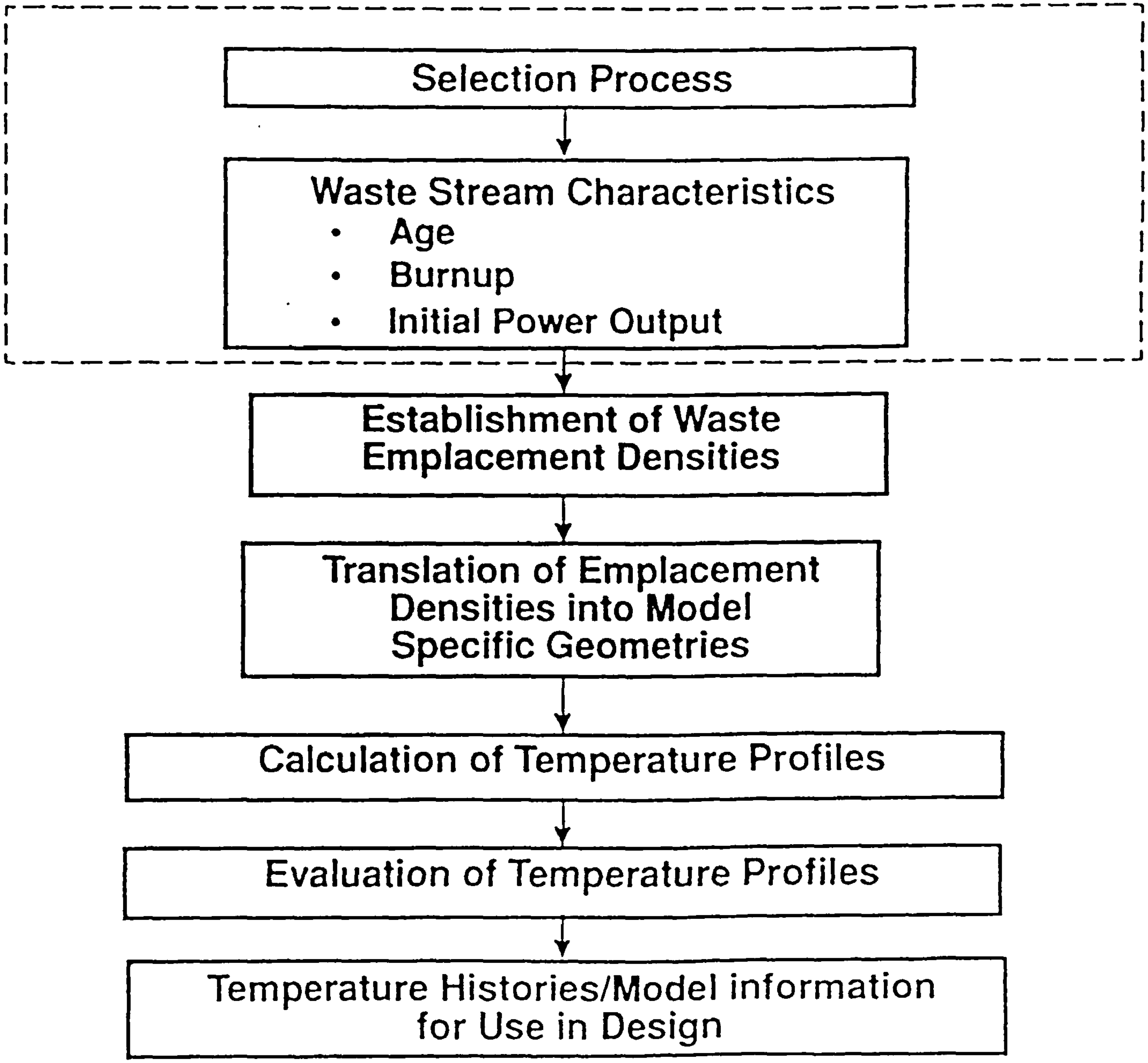
Waste Age Characteristics



Initial Power Characteristics



Repository Thermal Design Process



Selection Process

Waste Stream Characteristics
- Age
- Burnup
- Initial Power Output

Establishment of Waste Emplacement Densities

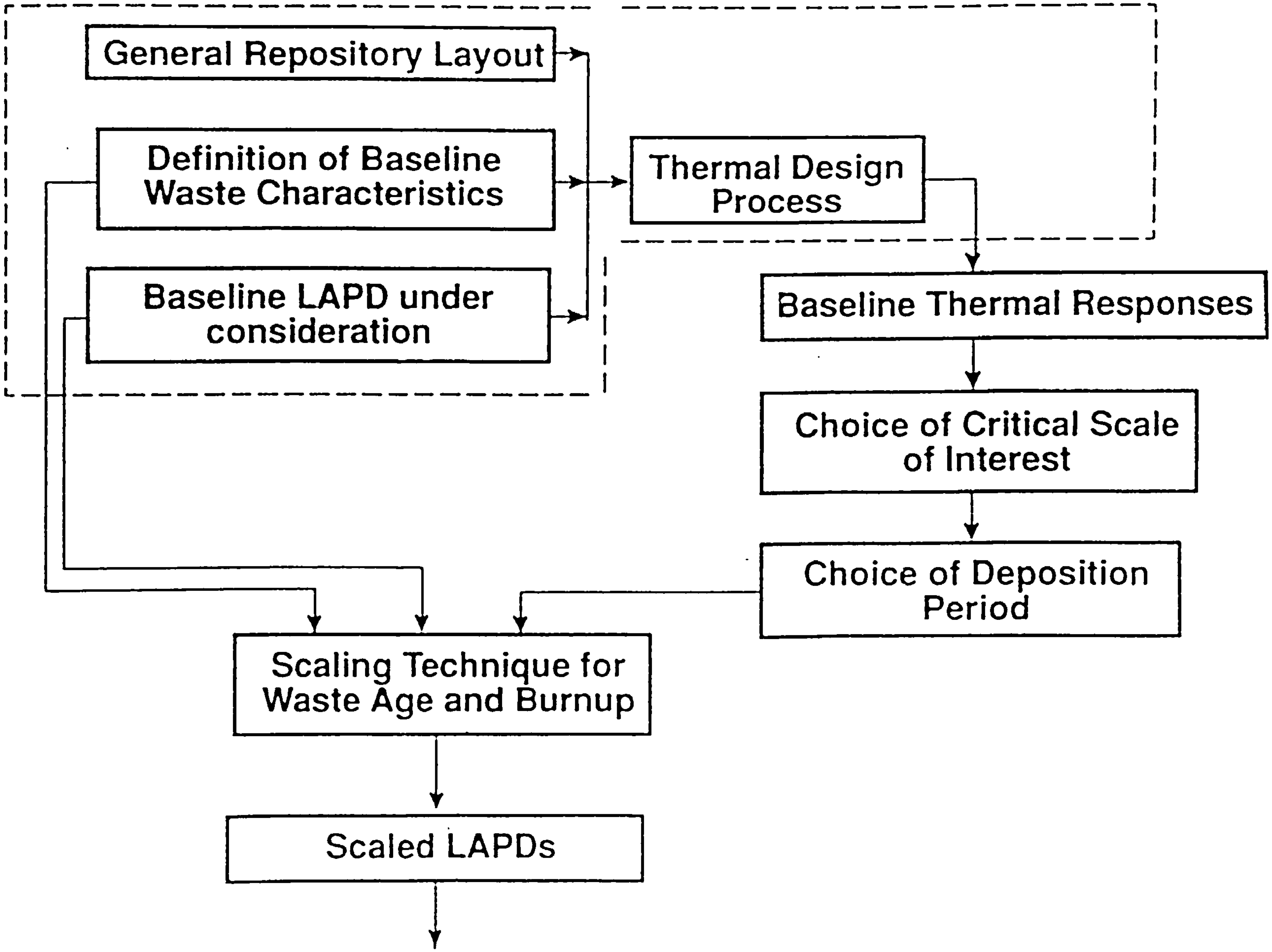
Translation of Emplacement Densities into Model Specific Geometries

Calculation of Temperature Profiles

Evaluation of Temperature Profiles

Temperature Histories/Model information for Use in Design

Establishment Of Waste Emplacement Densities



General Repository Layout

Definition of Baseline Waste Characteristics

Baseline LAPD under consideration

Thermal Design Process

Baseline Thermal Responses

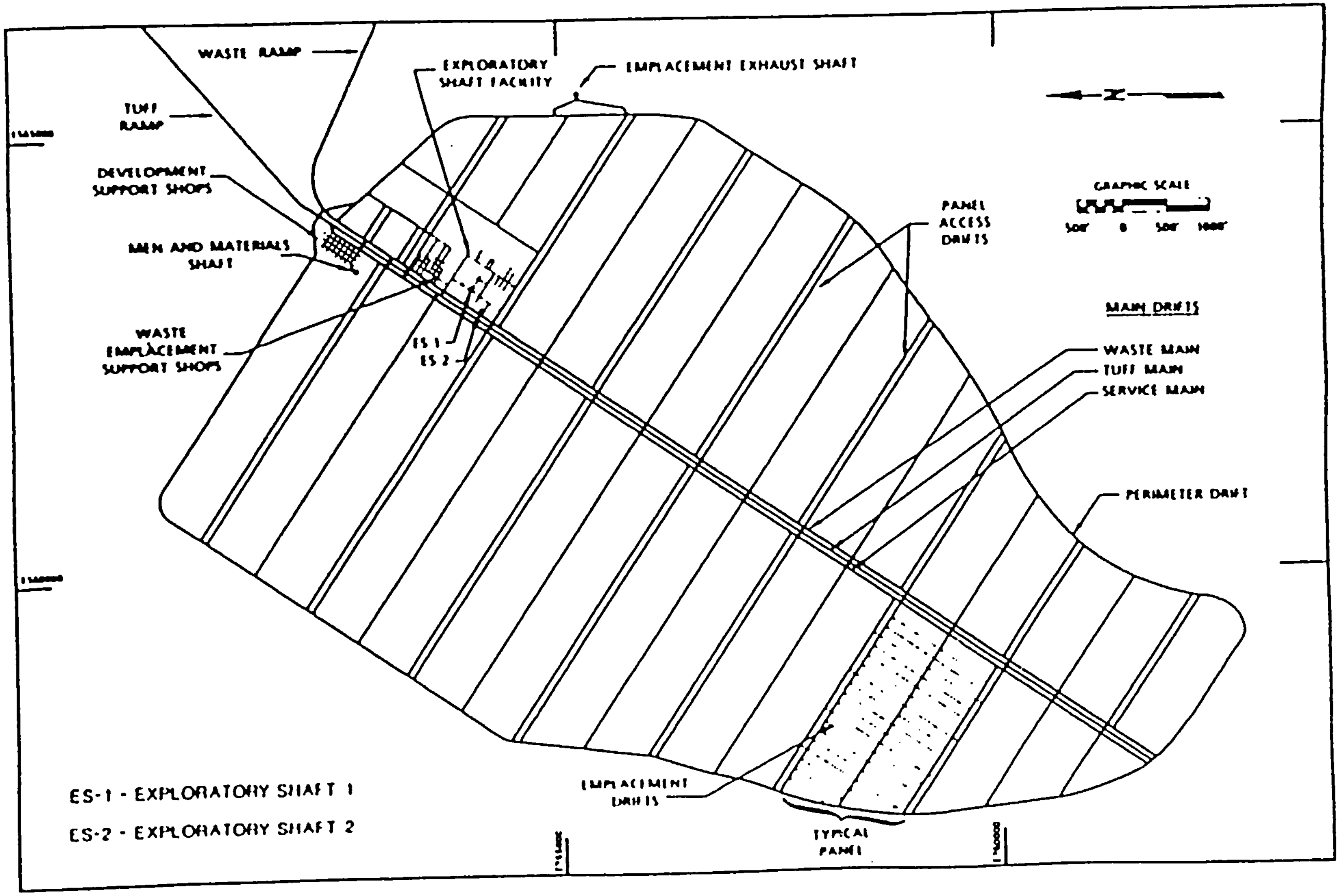
Choice of Critical Scale of Interest

Choice of Deposition Period

Scaling Technique for Waste Age and Burnup

Scaled LAPDs

SCP/CDR Repository Layout



ES-1 - EXPLORATORY SHAFT 1

ES-2 - EXPLORATORY SHAFT 2

Baseline Waste Characteristics

- Considered to be those used by Johnstone et al. in the Unit Evaluation Study (SNL, 1984)
- Baseline waste is considered to have an age of 10 years at time of emplacement
- Closely model the power output of spent fuel with a burnup of 35,000 MWd/MTU for ages out of reactor greater than 10 years

Scaling For Waste Age And Burnup

- Equivalent Energy Density Concept (EED)

Bases its equivalence criterion on the assumption that an arbitrary waste will produce worst-case thermomechanical effects equal to those predicted for a baseline waste description provided that the thermal energy deposited in the host rock over a specified time (deposition period) is the same for both waste descriptions

$$Pa \cdot \int_{a}^{n+a} Na\,(t) \cdot dt = P_{base} \int_{10}^{n+10} N_{base}\,(t) \cdot dt$$

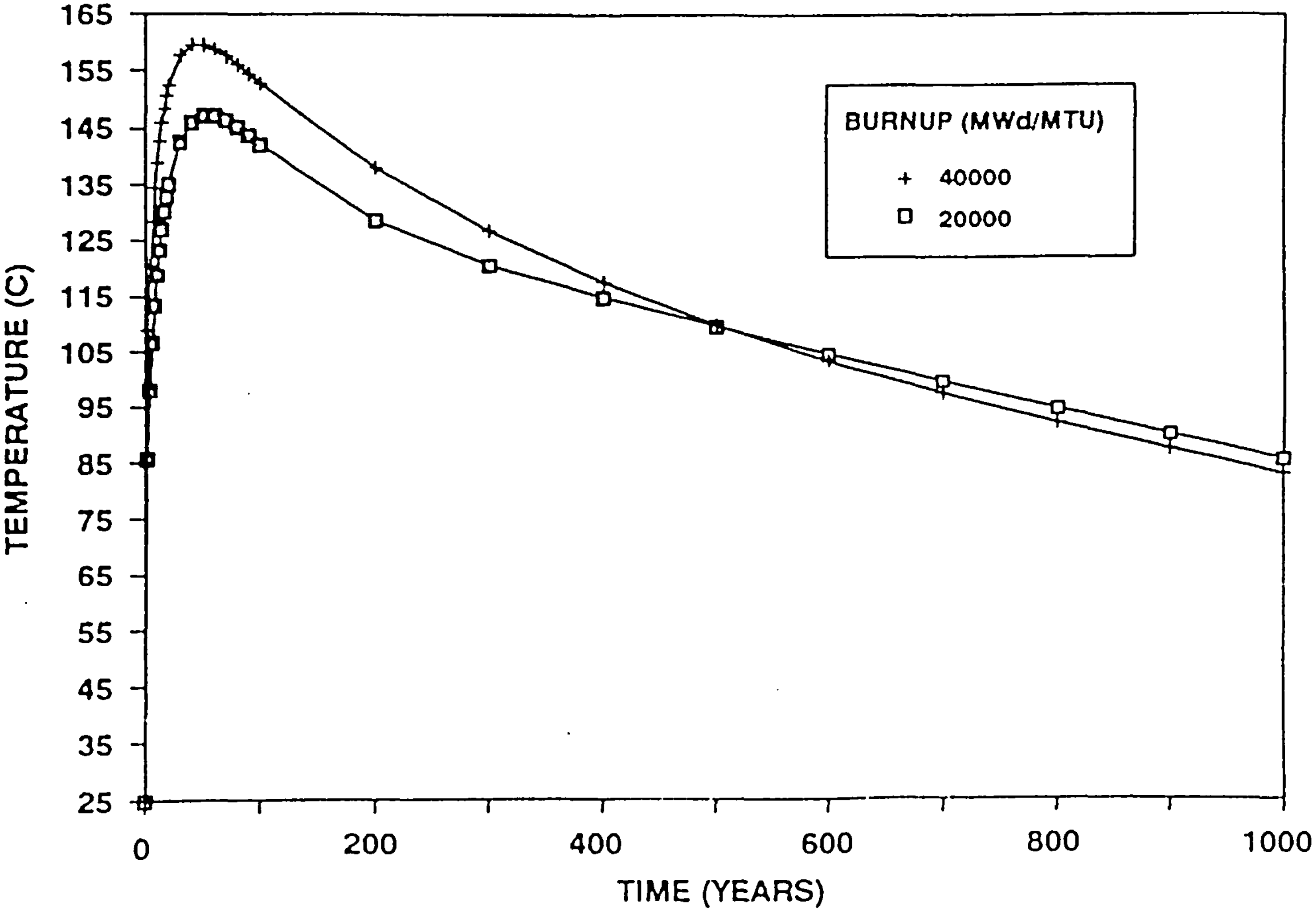
Where:

P_{base} = Initial LAPD of baseline waste
Pa = Scaled LAPD to be calculated
N_{base} = Baseline thermal decay function
Na = Thermal decay function of arbitrary waste
a = Age of spent-fuel at emplacement
n = Deposition period

- Applicable on a LAPD basis

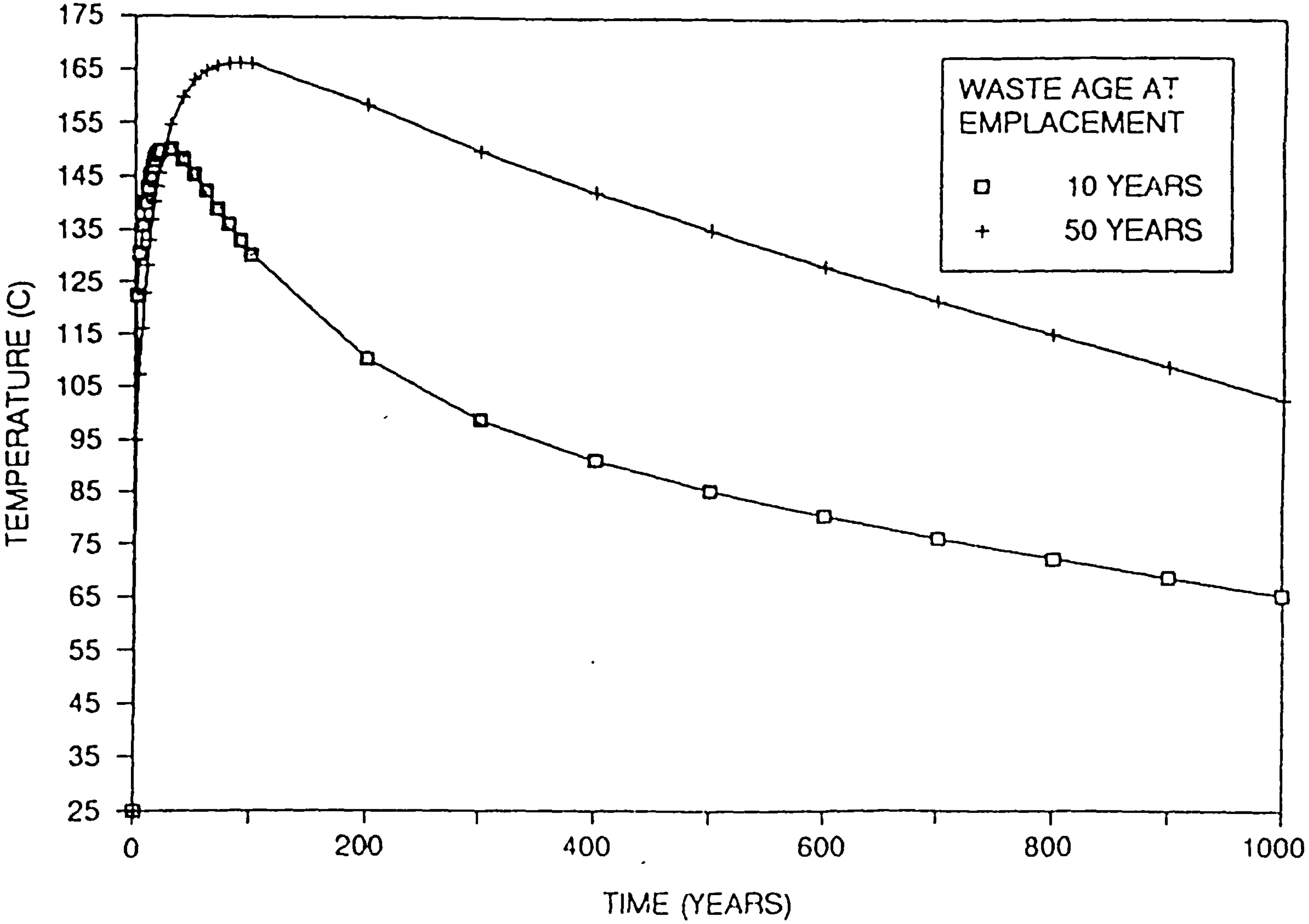
Effect Of Burnup

(Borehole Wall Response For 30-year-old PWR Spent Fuel
Emplaced at an LAPD of 69.1 kW/acre)

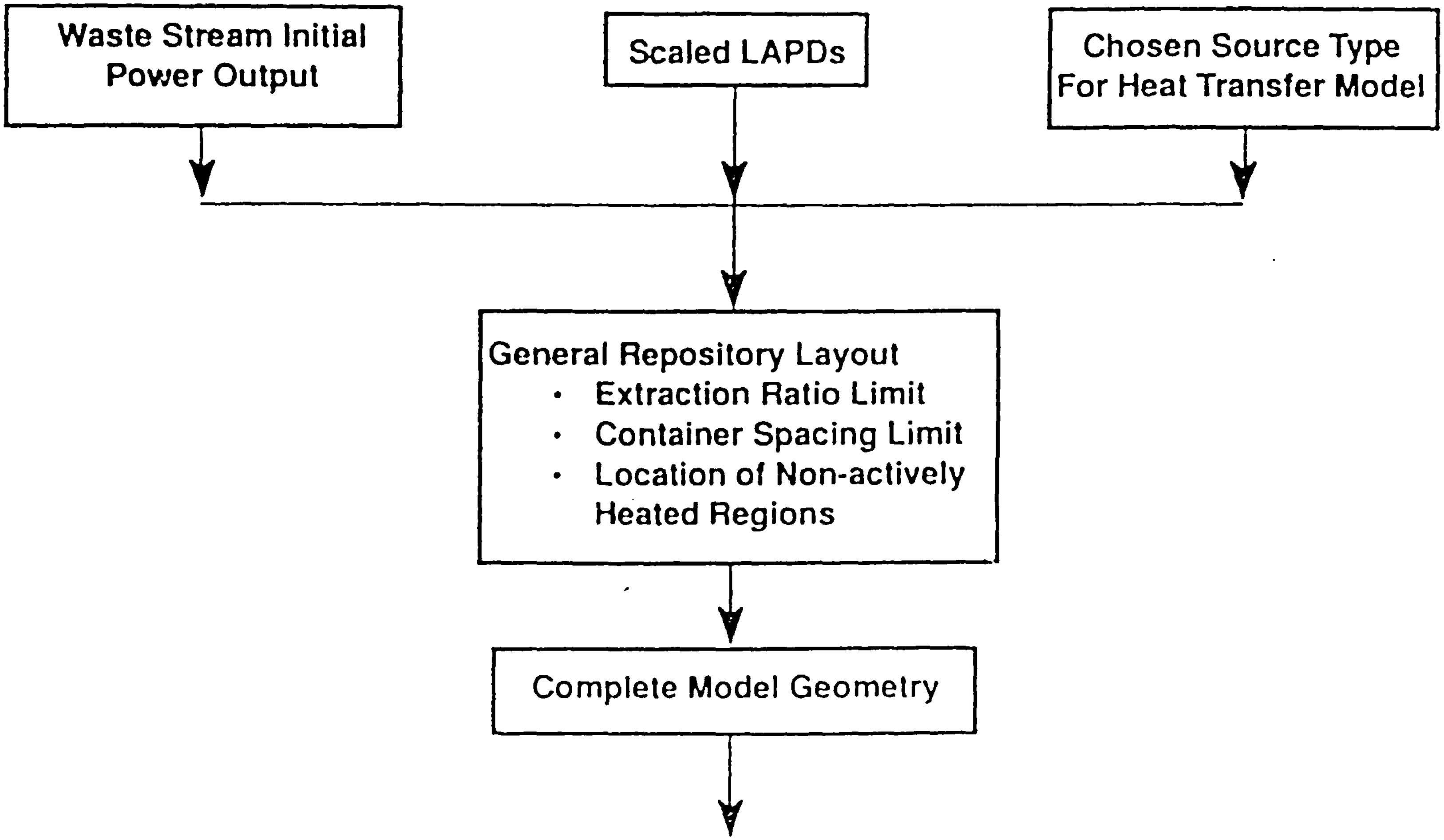


Effect Of Waste Age

(Borehole Wall Response For Baseline Spent Fuel Emplaced at an LAPD of 69.1 kW/acre)



Translation of Emplacement Densities into Model Specific Geometries



Waste Stream Initial Power Output

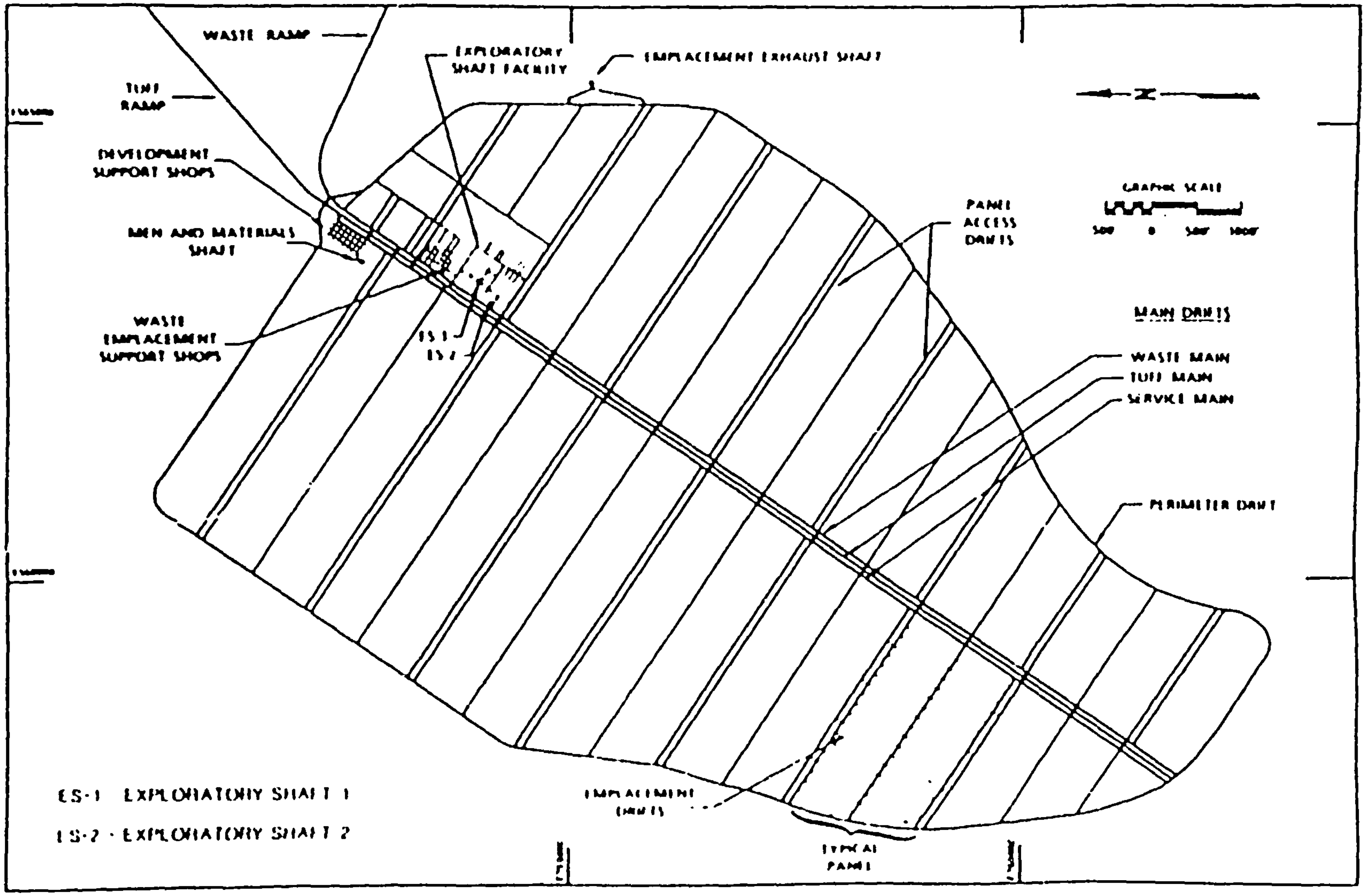
Scaled LAPDs

Chosen Source Type For Heat Transfer Model

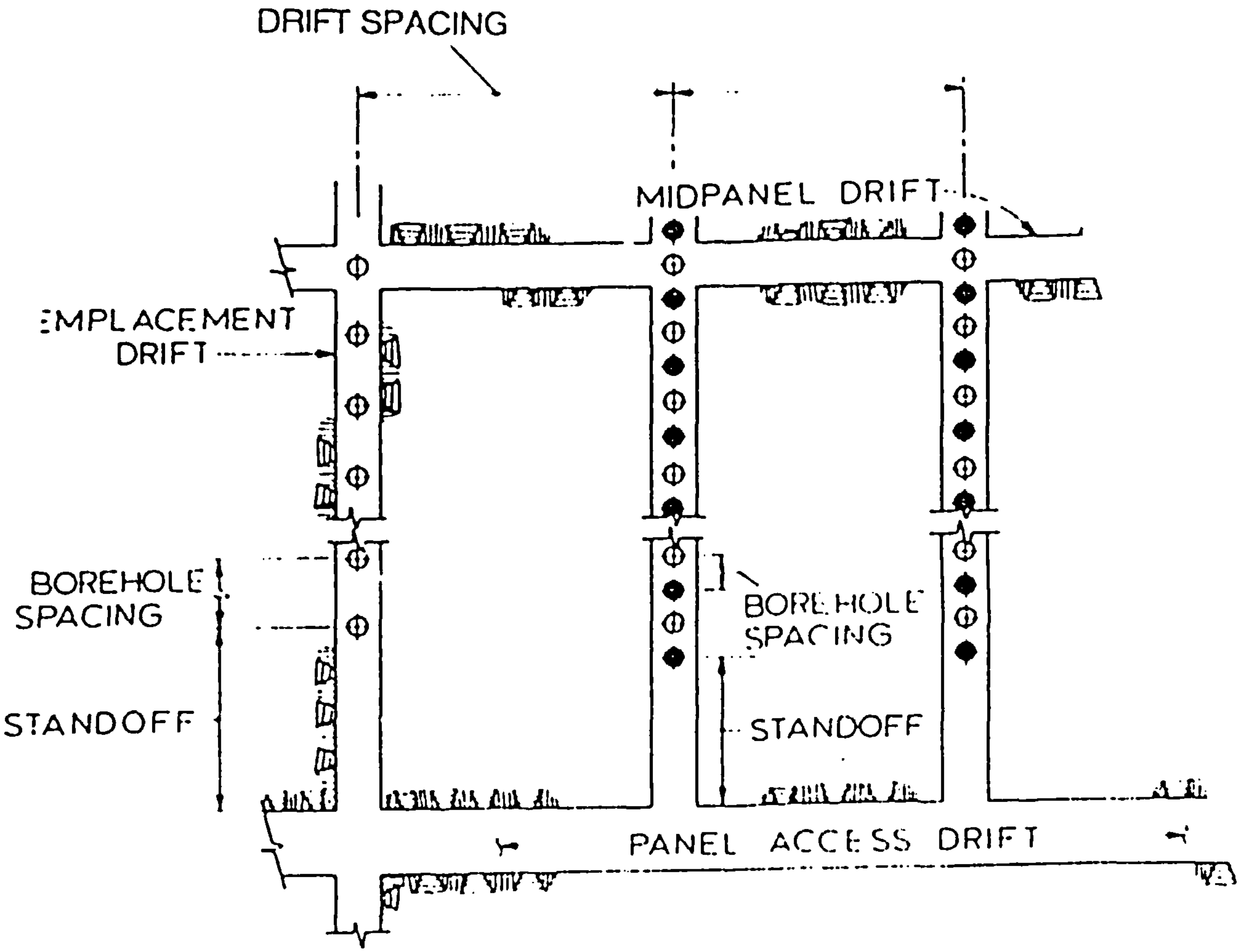
General Repository Layout
- Extraction Ratio Limit
- Container Spacing Limit
- Location of Non-actively Heated Regions

Complete Model Geometry

SCP/CDR Repository Layout

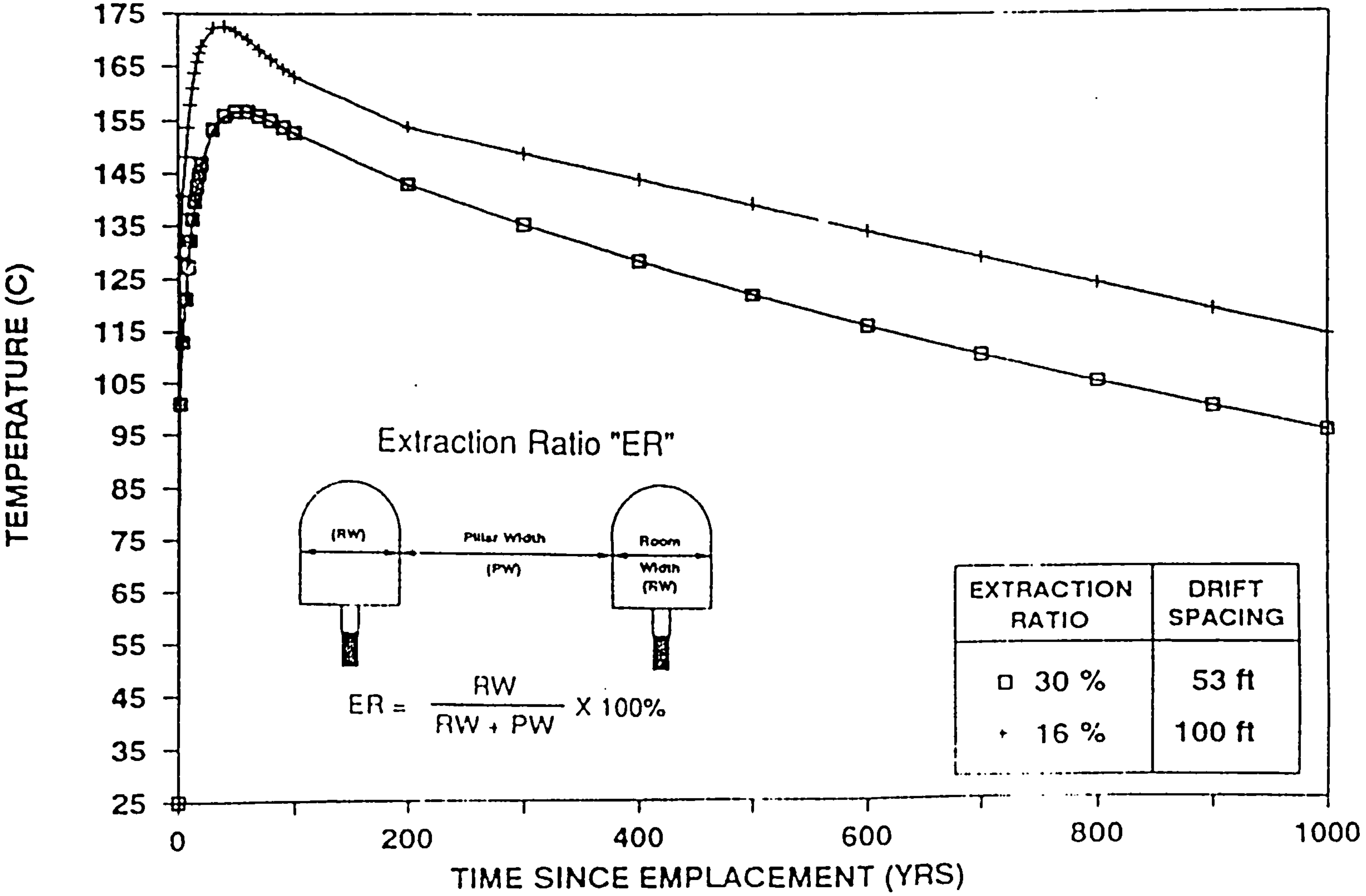


Vertical Emplacement Option



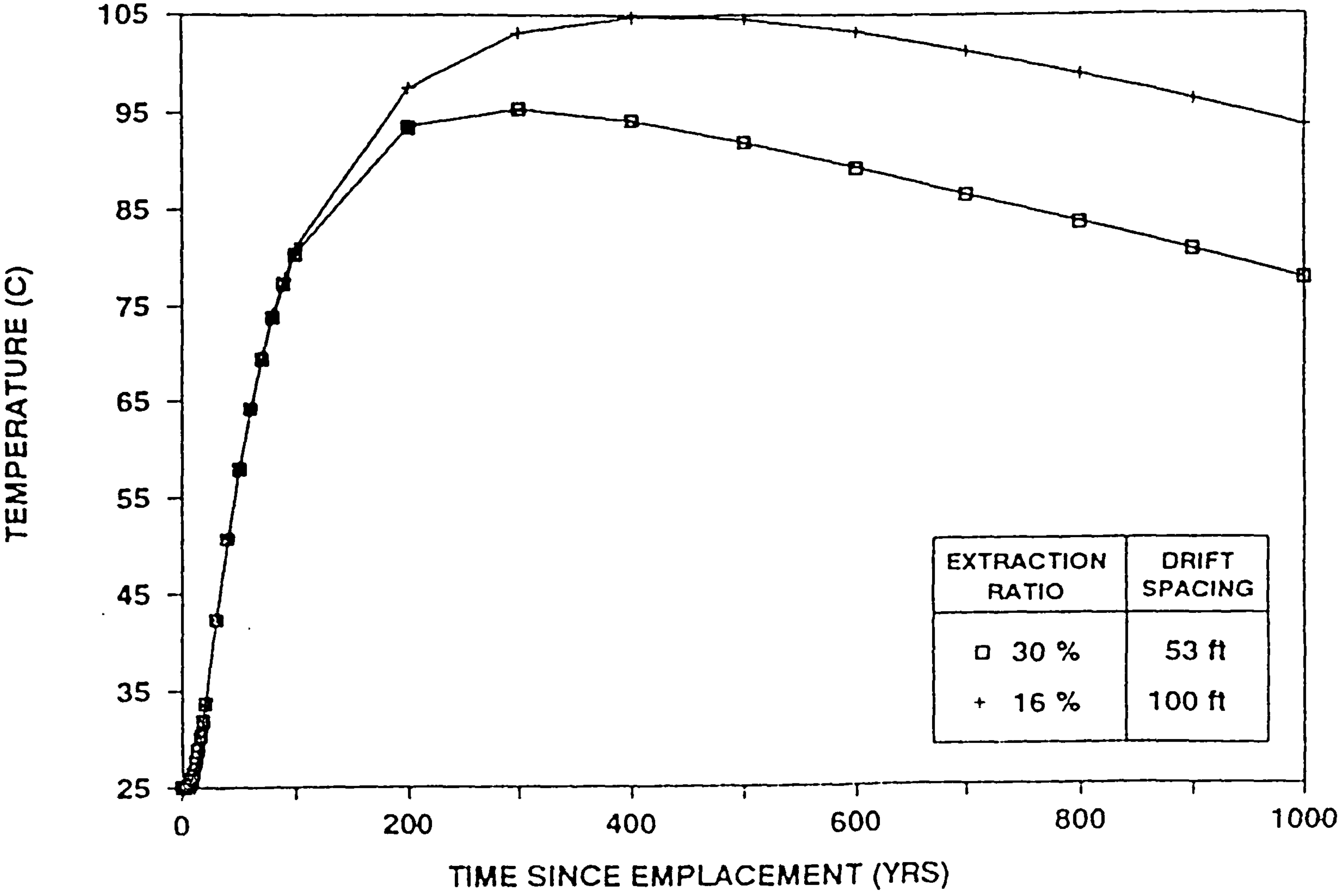
Borehole Wall Response

Baseline Waste-LAPD=69.1 kW/acre

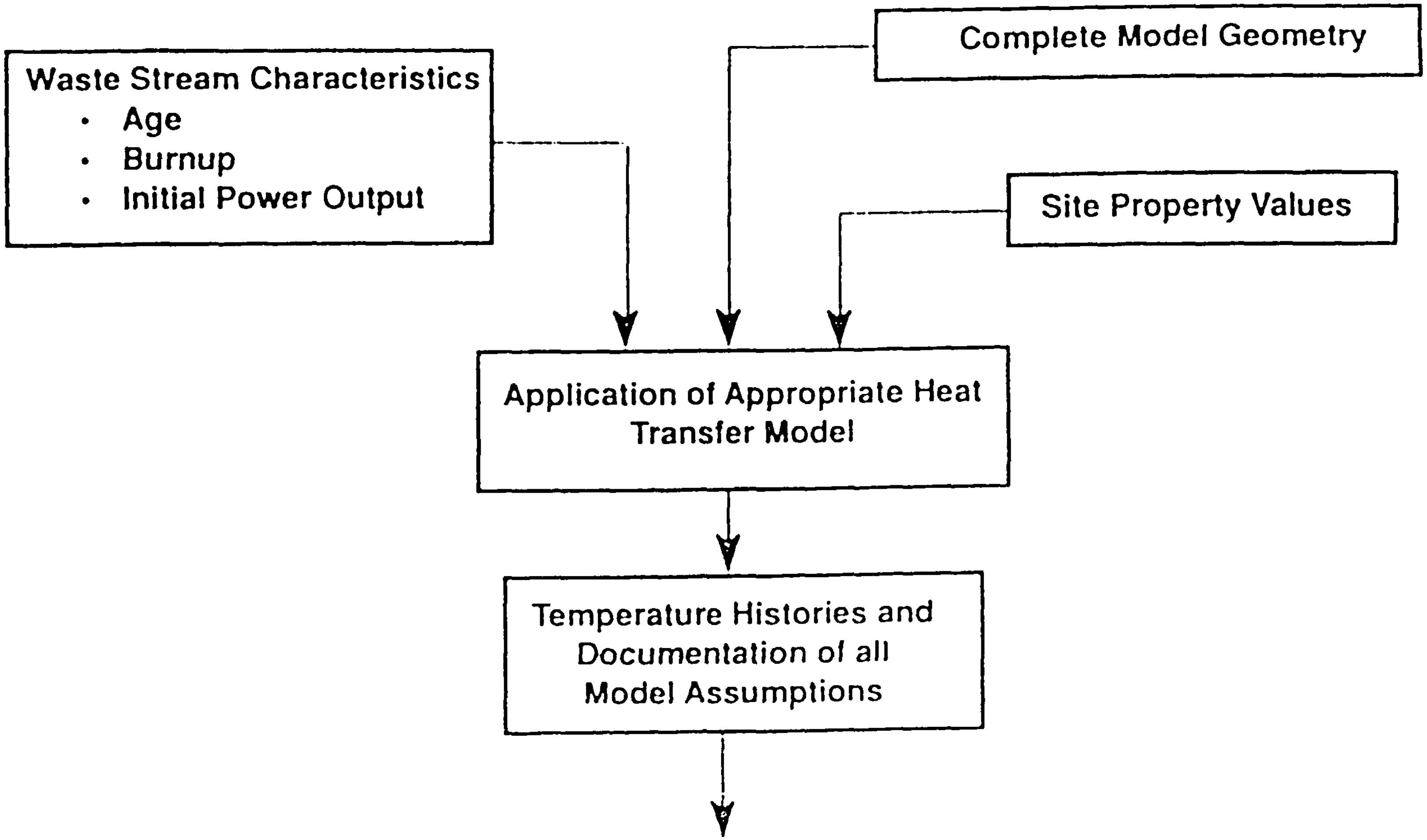


50m Response

Baseline Waste-LAPD=69.1 kW/acre



Calculation Of Temperature Profiles



Waste Stream Characteristics
- Age
- Burnup
- Initial Power Output

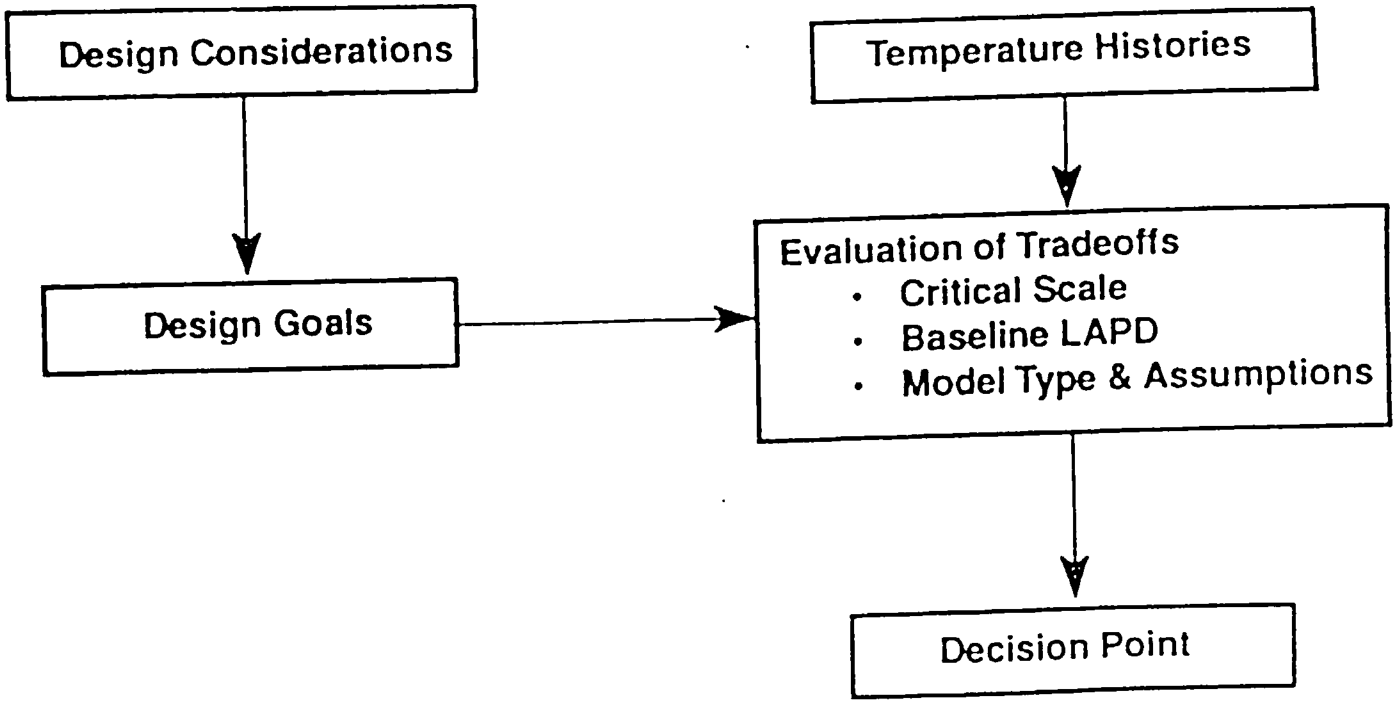
Complete Model Geometry

Site Property Values

Application of Appropriate Heat Transfer Model

Temperature Histories and Documentation of all Model Assumptions

Evaluation Of Temperature Profiles



Design Considerations

Design Goals

Temperature Histories

Evaluation of Tradeoffs
- Critical Scale
- Baseline LAPD
- Model Type & Assumptions

Decision Point

Design Considerations

Near-field rock-mass integrity

Limit temperatures 1m from borehole wall

Cladding integrity

Limit temperature of container and borehole wall

Surface uplift and environmental impacts

Limit surface temperature rise/uplift

Rock stability

No intact rock failure or continuous joint slip

Design Considerations

(continued)

Extent of saturated conditions

Limit local saturation

Control use of fluids during construction

Corrosiveness of the container environment

Reduce the potential for liquid water contacting containers

Potential for mineral alteration and dehydration

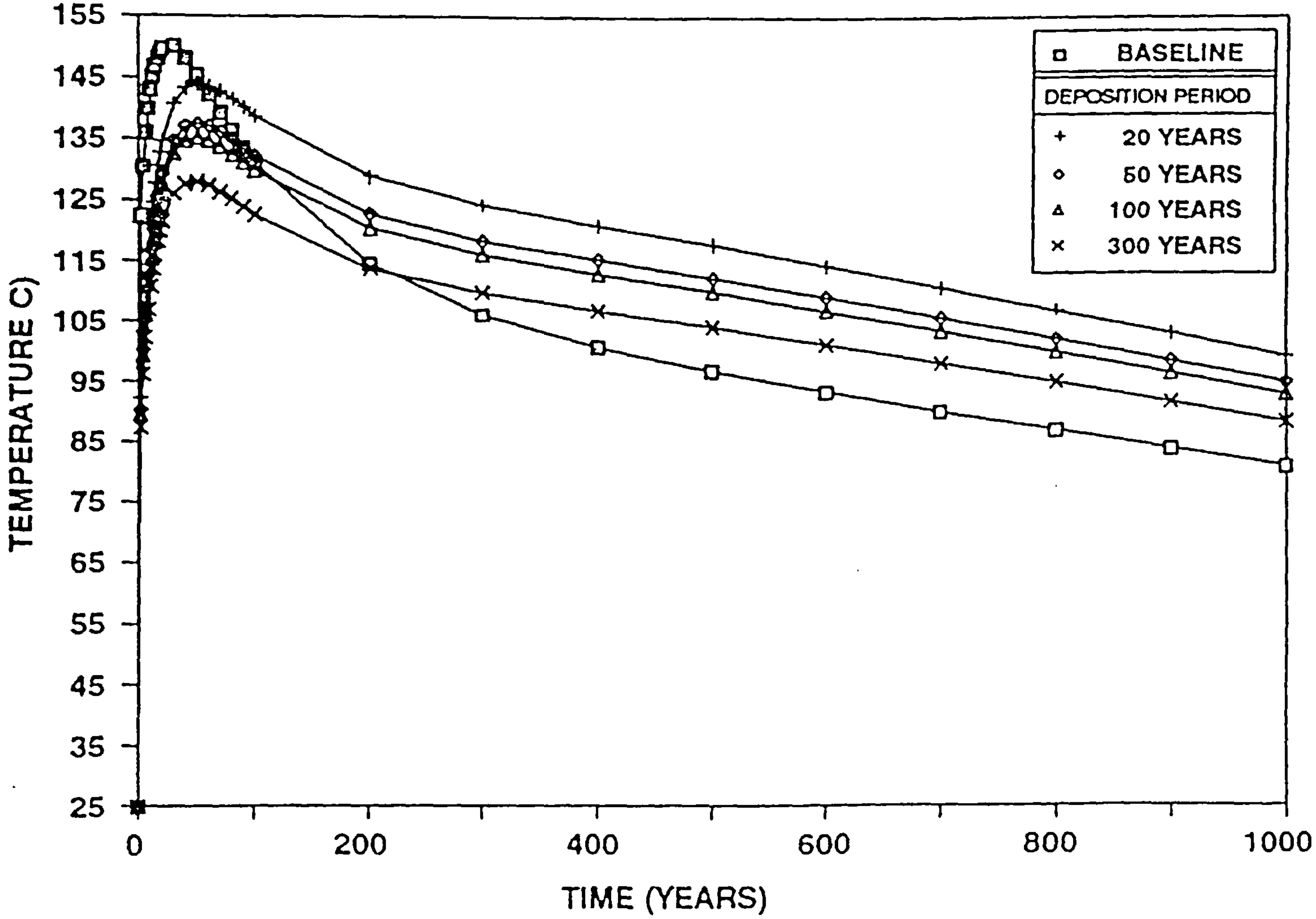
Limit temperatures in units below the emplacement unit (TSw2)

SCP Thermal Goals

Performance Measure	Goal	
Cladding Integrity	Container Centerline Borehole Wall	$T < 350^\circ$ C $T < 275^\circ$ C
Near-Field Rock Mass Integrity	One Meter from Borehole $T < 200^\circ$ C	
Access Drift Wall Temperature	$T_{wall} < 50^\circ$ C for 50 years	
Temperature Change in Adjacent Strata	TSw2 - TSw3 Interface $T < 115^\circ$ C	
Surface Environment	Temperature Change $< 6^\circ$ C	
Limit Corrosiveness of Canister Environment	Maximize Time Spent Above Boiling in Borehole Environment	

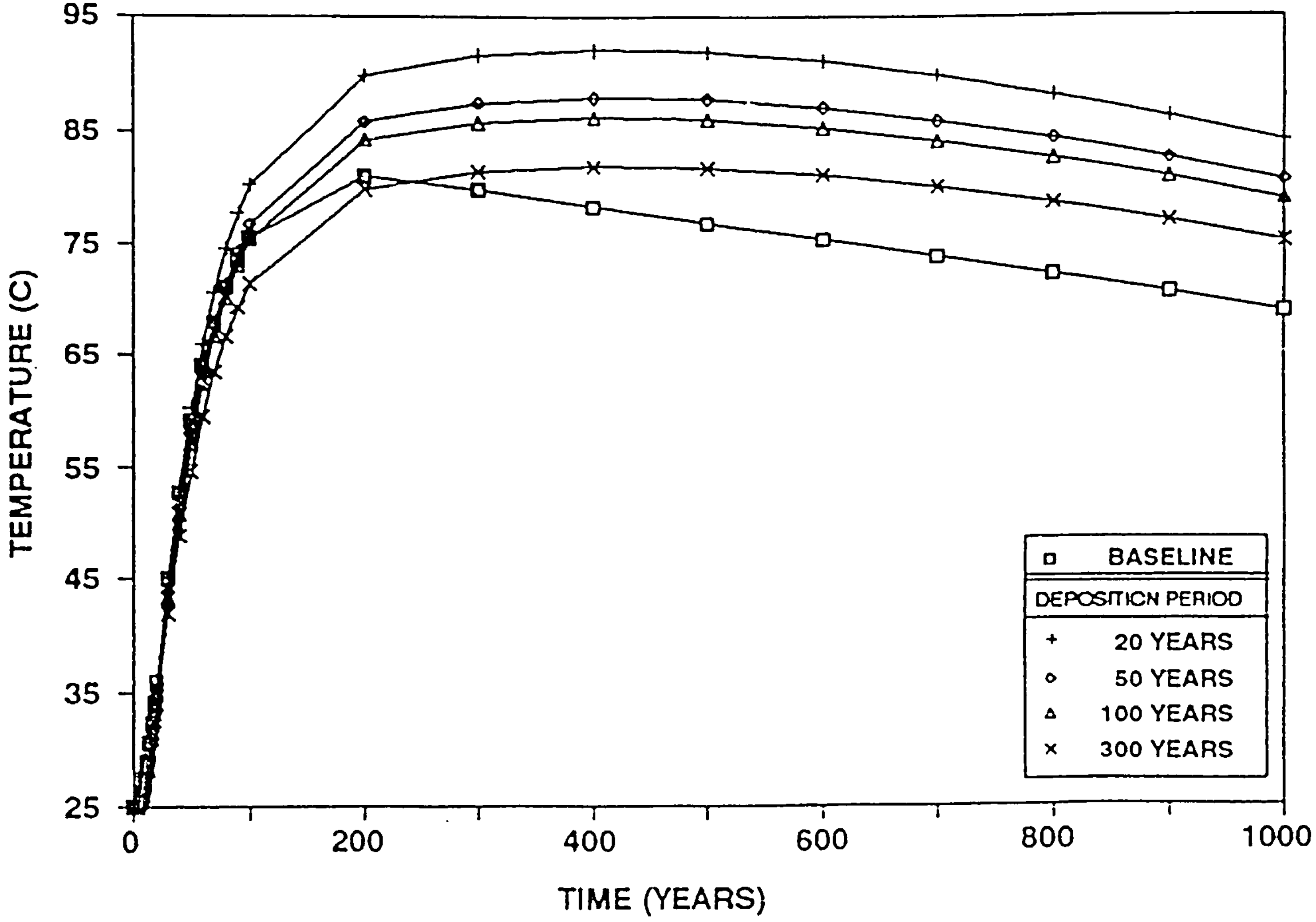
Near-Field Tradeoffs

Borehole Wall Response for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 69.1 kW/acre



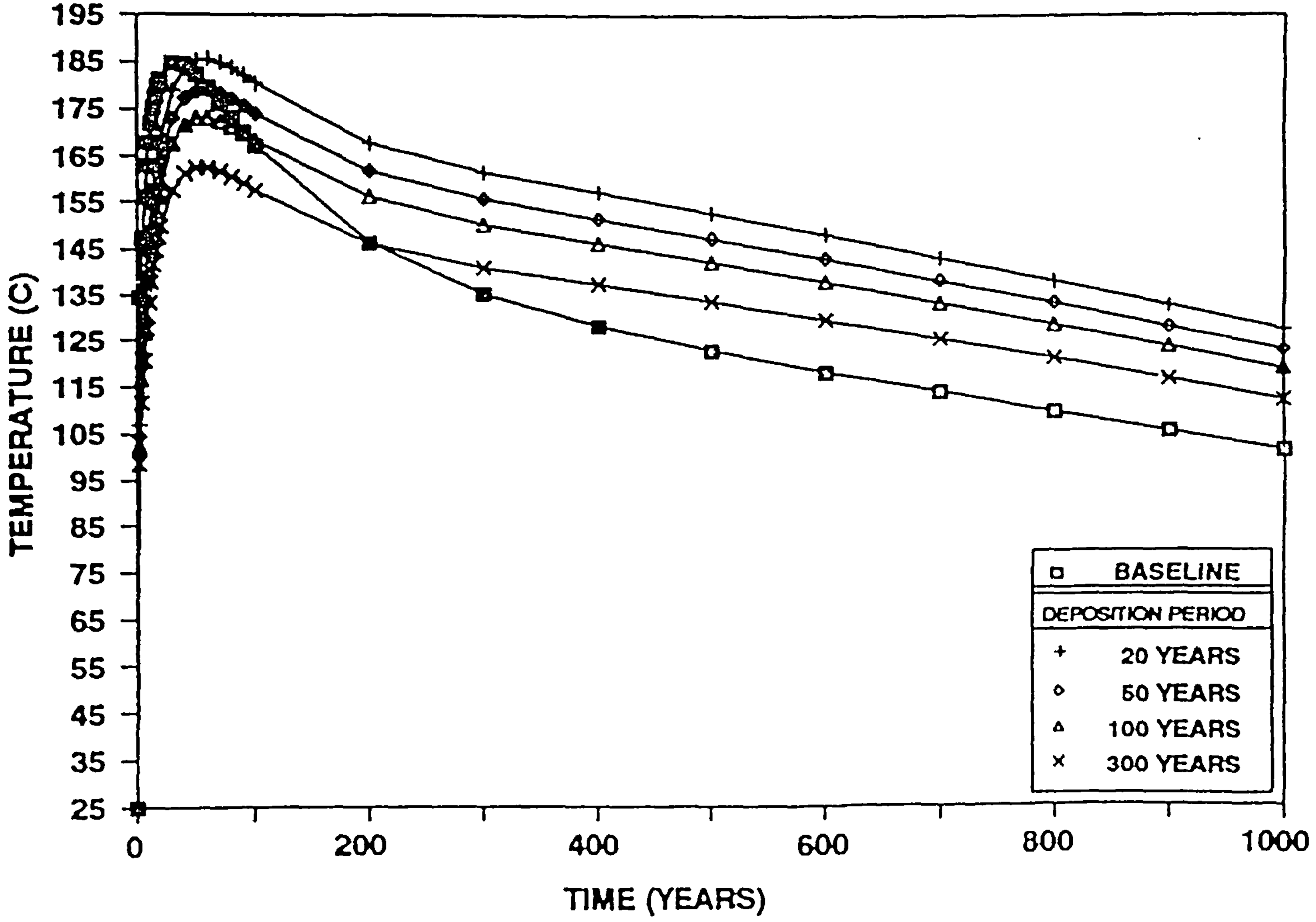
Far-Field Tradeoffs

Response 50m From Repository Floor for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 69.1 kW/acre



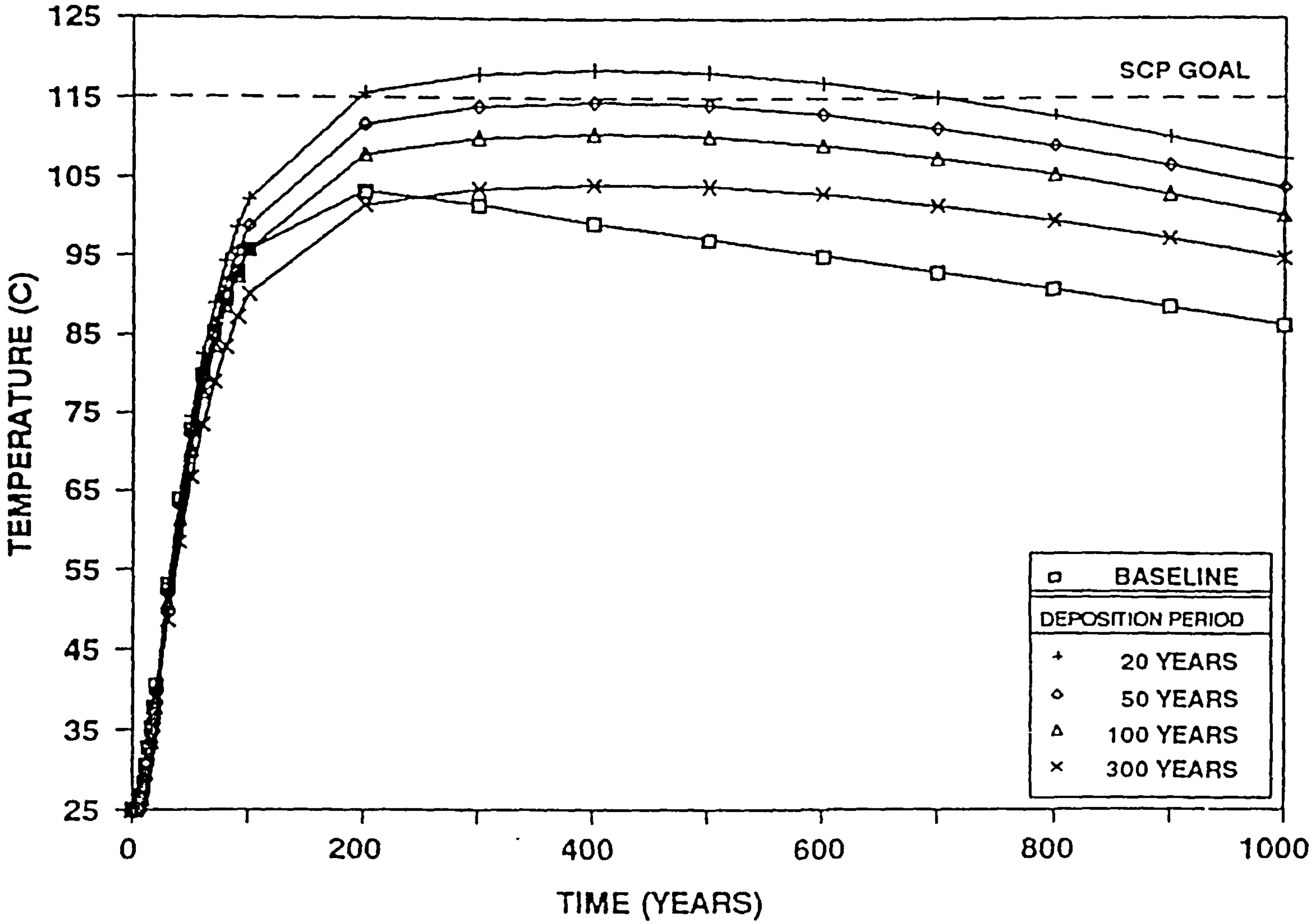
Near-Field Tradeoffs

Borehole Wall Response for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 97 kW/acre



Far-Field Tradeoffs

Response 50m from Repository Floor for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 97 kW/acre



Example Decision Points

- Profiles indicate that temperature goals are violated in a given field. Problem traced back to choice of critical scale (deposition period)
- Waste stream characteristics not compatible with overall analysis, tradeoffs required unacceptable
- Design spacings (canister and drift, as well as standoffs) produce temperature predictions beyond current goals
- Mathematical basis of chosen model does not sufficiently capture the problem under investigation
- All criteria met, tradeoffs acceptable and documented. Recommend temperature histories/model information be examined further for possible input into the final design process

Conclusions

- Changes in the repository design/system can affect the thermal design process and resulting temperature profiles
- When comparing temperature profiles, model assumptions and tradeoffs must be accounted for

Temperature Changes Over Time

Objectives

- Show near- and far-field temperature profiles generated using a consistent set of assumptions
- Discuss trending at critical scales for APDs ranging from 20 to 80 kW/acre
- Discuss/demonstrate some effects of aging, increasing heated repository area, and modifications to the ventilation system

Organization

- DISCUSSION OF MODEL ASSUMPTIONS
- PRESENTATION OF RESULTS

HOT DESIGN-BASIS APDs COLD

80 57 48 | 30 22

☐ WITHIN SCP-CDR PERIMETER DRIFT

☐

OPTIONS AVAILABLE	NEAR-FIELD	FAR-FIELD
AGE FUEL	■	■
INCREASE HEATED AREA	■	
MODIFY VENTILATION SYSTEM	■	

NEAR-FIELD RESULTS

ALL APDs (80, 57, 48, 30, AND 22 kW/ACRE) FOR EMPLACEMENT WITHIN PRIMARY BLOCK (i.e., AGING TO REDUCE APD)

FAR-FIELD RESULTS

ALL APDs (80, 57, 48, 30, AND 22 kW/ACRE) FOR EMPLACEMENT WITHIN PRIMARY BLOCK (i.e., AGING TO REDUCE APD)

ALTERNATIVES

NEAR-FIELD RESPONSE TO INCREASED HEATED AREA (APPROXIMATE DESIGN-BASIS APD OF 19 kW/ACRE)

EFFECTS OF VENTILATION ON NEAR-FIELD FOR 80 kW/ACRE

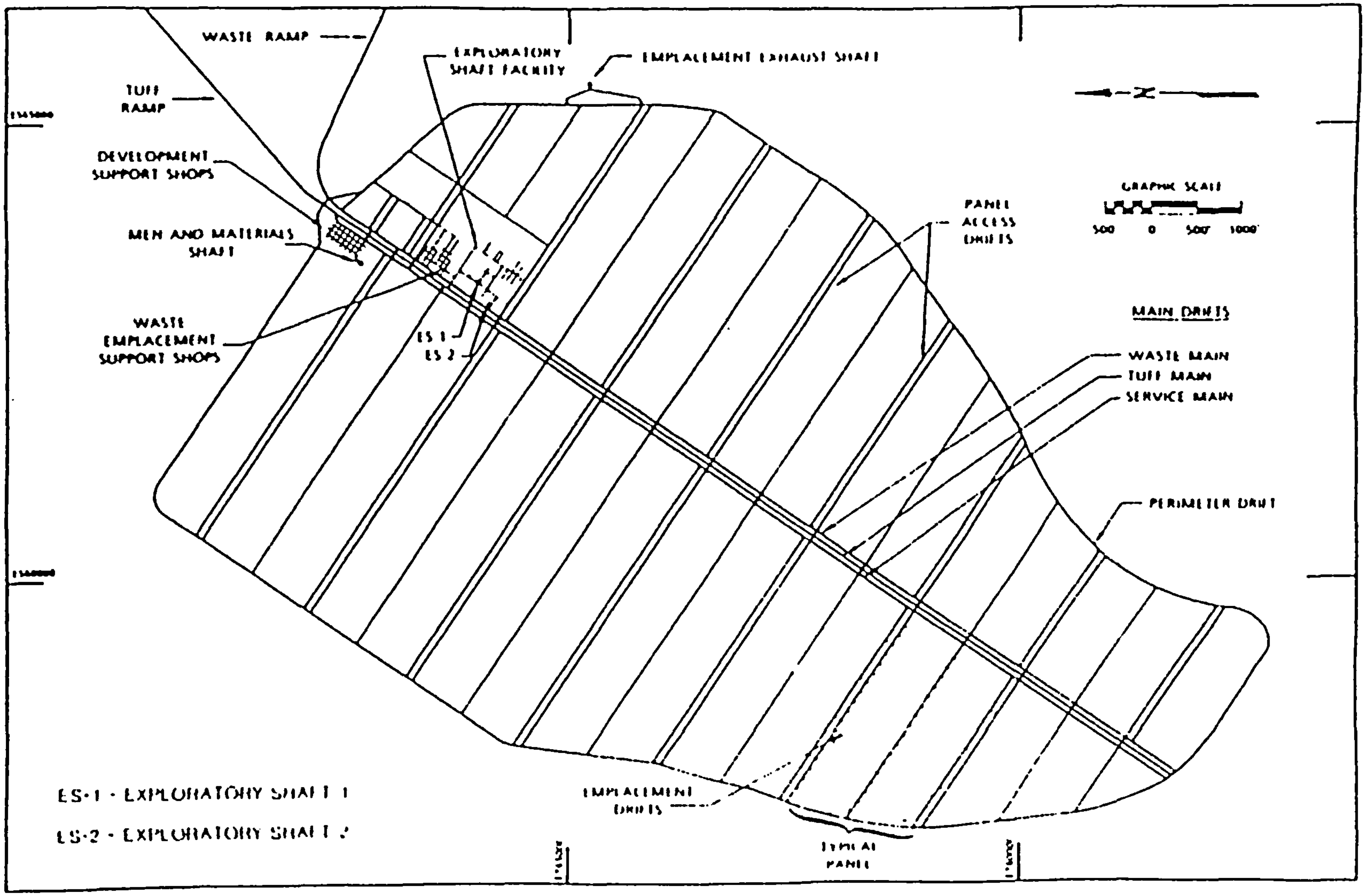
Model Assumptions

- Modified version of the design published in the SCP-CDR used to represent the potential respository
- Fully stepped emplacement of spent fuel considered
- DHLW considered to be segregated in the first few drifts off the mains
- Levelized receipt schedule assumed for a 2010 start date and a hybrid canister configuration
- Surface environment modeled as a constant temperature surface
- Scaling of emplacment densities to account for waste age and burnup carried out using the Equivalent Energy Density Concept and deposition periods of 20 to 300 years
- Analytical solution (3-D linear superposition of heat generating points and cylinders) used
  - Site modeled as an infinite mass of TSw2
  - Constant material properties

$k = 2.1$ W/mK

$\rho c_p = 2.2$ J/cm K

SCP/CDR Repository Layout

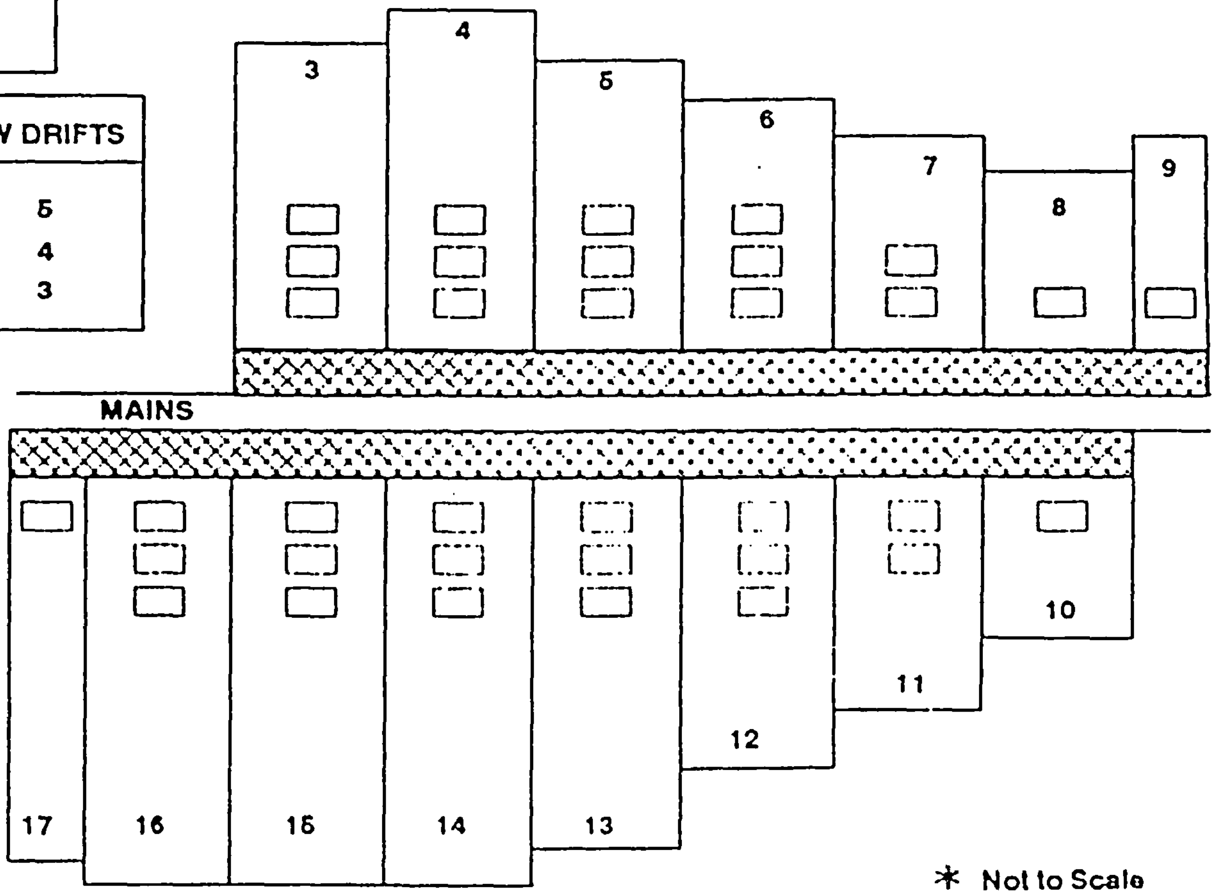


Modeled Repository (Primary Block)

☐ Spent Fuel

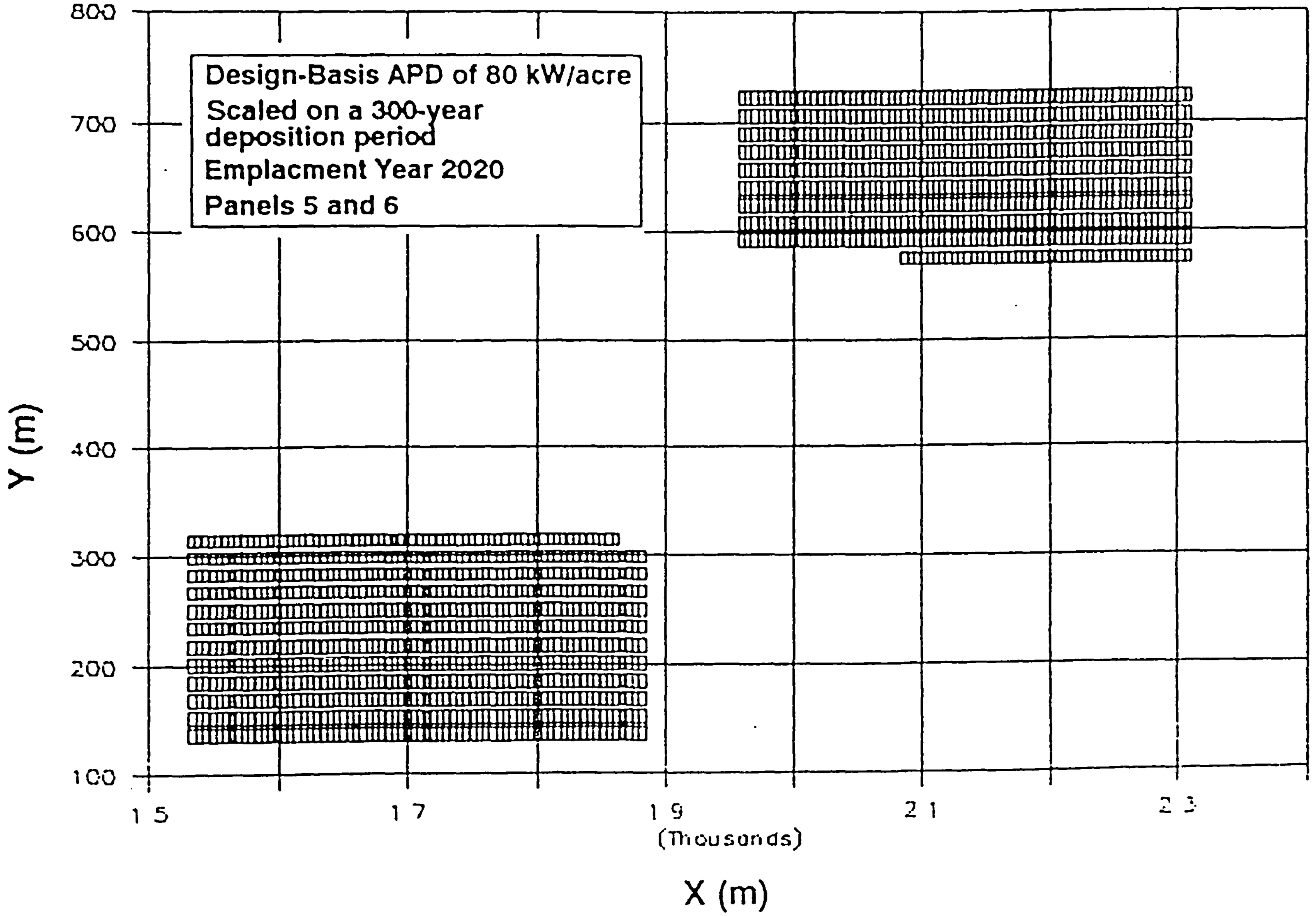
▨ DHLW and Main Drift Standoff

PANELS USED	# DHLW DRIFTS
☐ 80 kW/acre	5
☐ 57 kW/acre	4
☐ 48, 30, 22 kW/acre	3

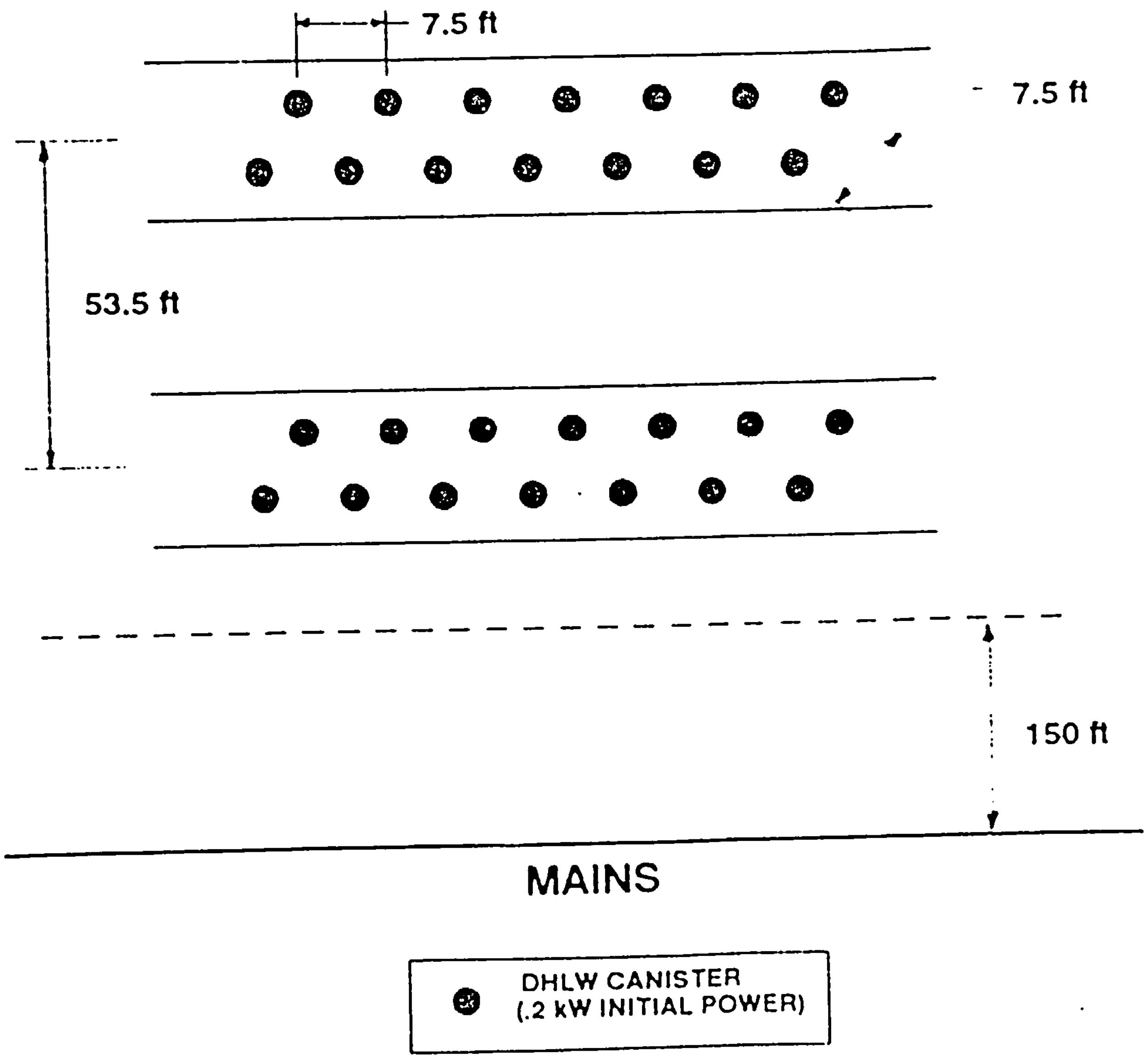


✳ Not to Scale

Stepped Emplacement Example



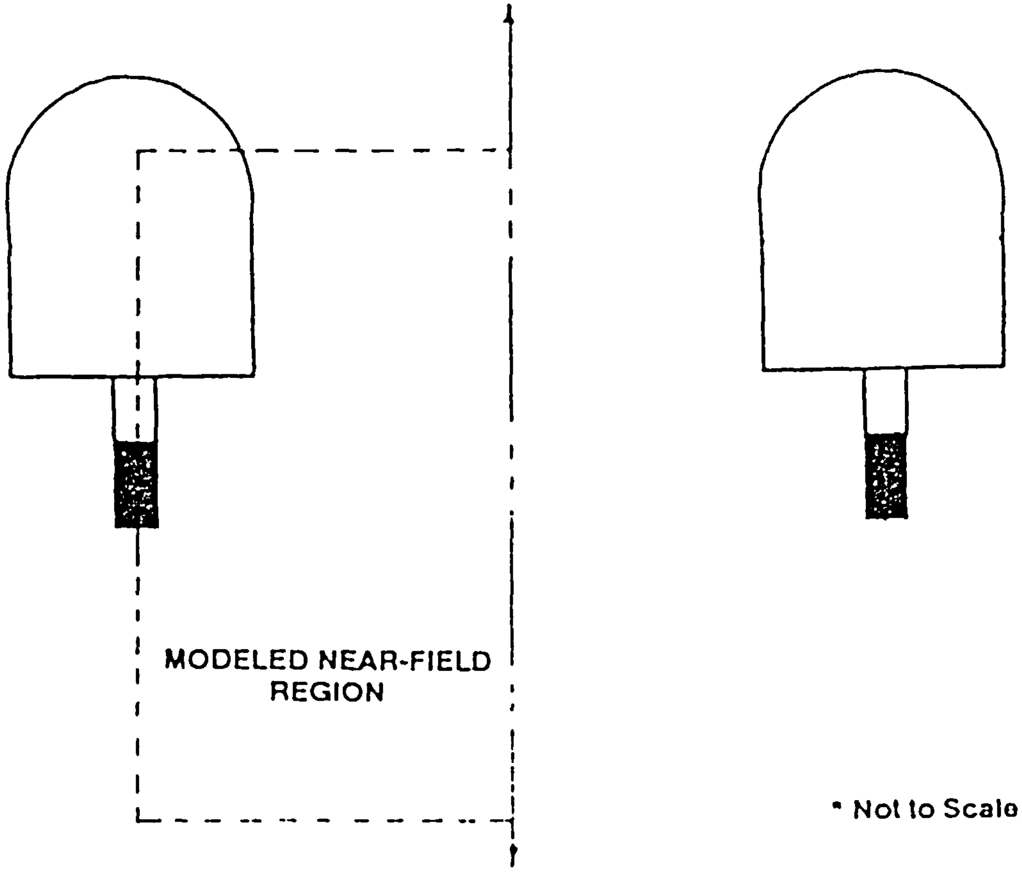
Segregration of DHLW



Modification Summary

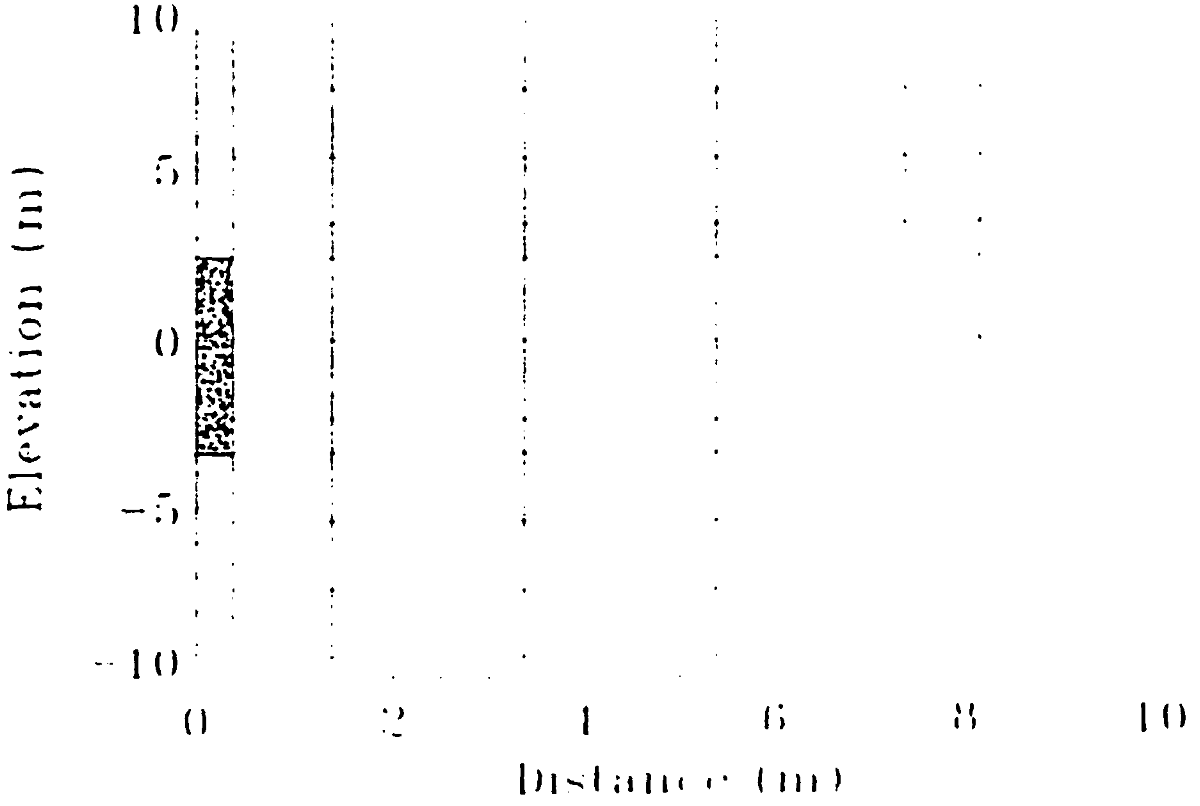
Feature	SCP-CDR Design	Modified Design
Orientation	Vertical/Horizontal	Vertical
Available Panels	17	15
Start Date	1998	2010
Receipt Schedule	FIFO	Levelized
Treatment of DHLW	Commingled	Segregated
DHLW Intial Power Output	.2 to .4 kW/container	.2 kW/container
SF Container Configuration	Consolidated	Intact Hybrid (4 BWR, 3 PWR)
Number of SF Containers	~12,000	~31,000
Average SF Age	10 years	30 to 90 years
Average SF Initial Power Output	3 kW/container	1.5 to 0.66 kW container
Design-Basis APD	57 kW/acre	80 to 22 kW/acre
Drift Spacing	126 ft	53 ft
Container Spacing	15 ft	Variable
Standoffs from Mains	200 ft	150 ft

Near-Field Environment



* Not to Scale

Near-Field Grid



Near-Field Peak Temperature Summary

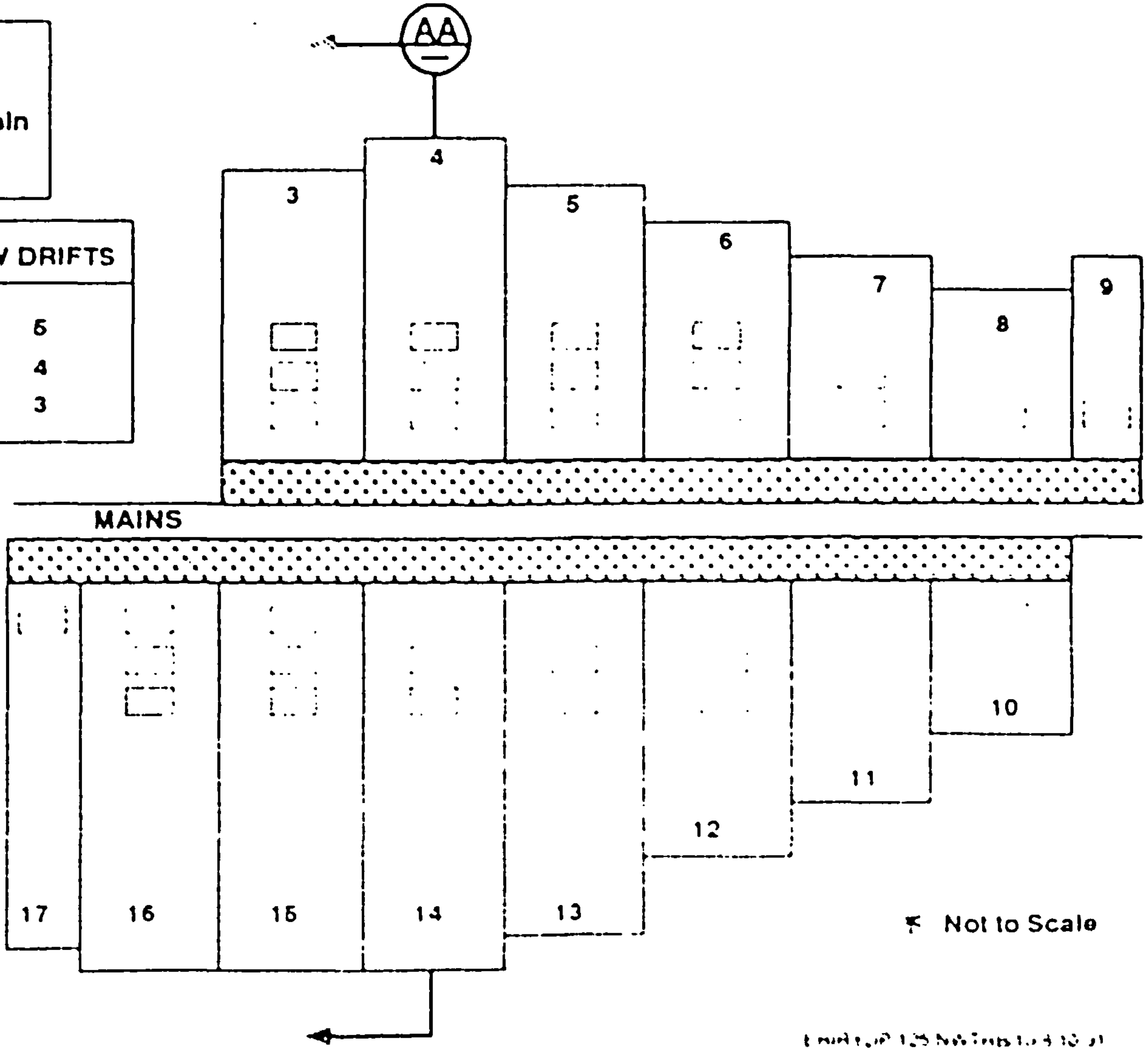
	Design-Basis APD (kW/acre)				
	80	57	48	30	22
Location	Temperature (°C)				
Borehole Wall	170	147	132	103	95
1-meter Radially	158	135	118	97	91
Time to Boiling Front Coalescence (years)	12	19	31	N/A	N/A
Average Waste Age (years)	30	30	30	60	90
Average Initial Power Output (kW/container)	1.52	1.52	1.52	0.95	0.66
Deposition Period Used (years)	300	20	20	20	20

Modeled Repository with Vertical Cross-Section AA indicated

☐ Spent Fuel

▨ DHLW and Main Drift Standoff

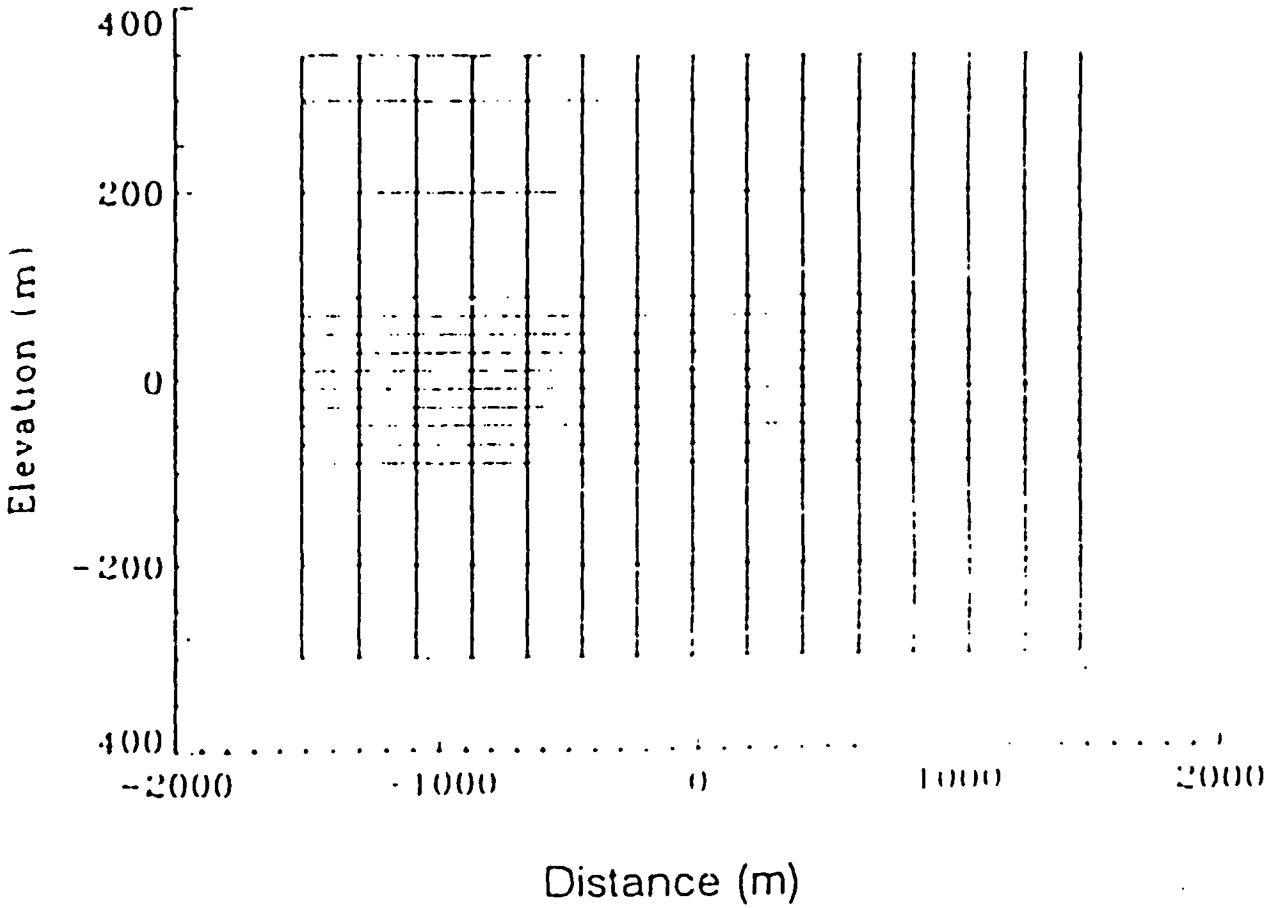
PANELS USED	# DHLW DRIFTS
☐ 80 kW/acre	5
☐ 57 kW/acre	4
☐ 48, 30, 22 kW/acre	3



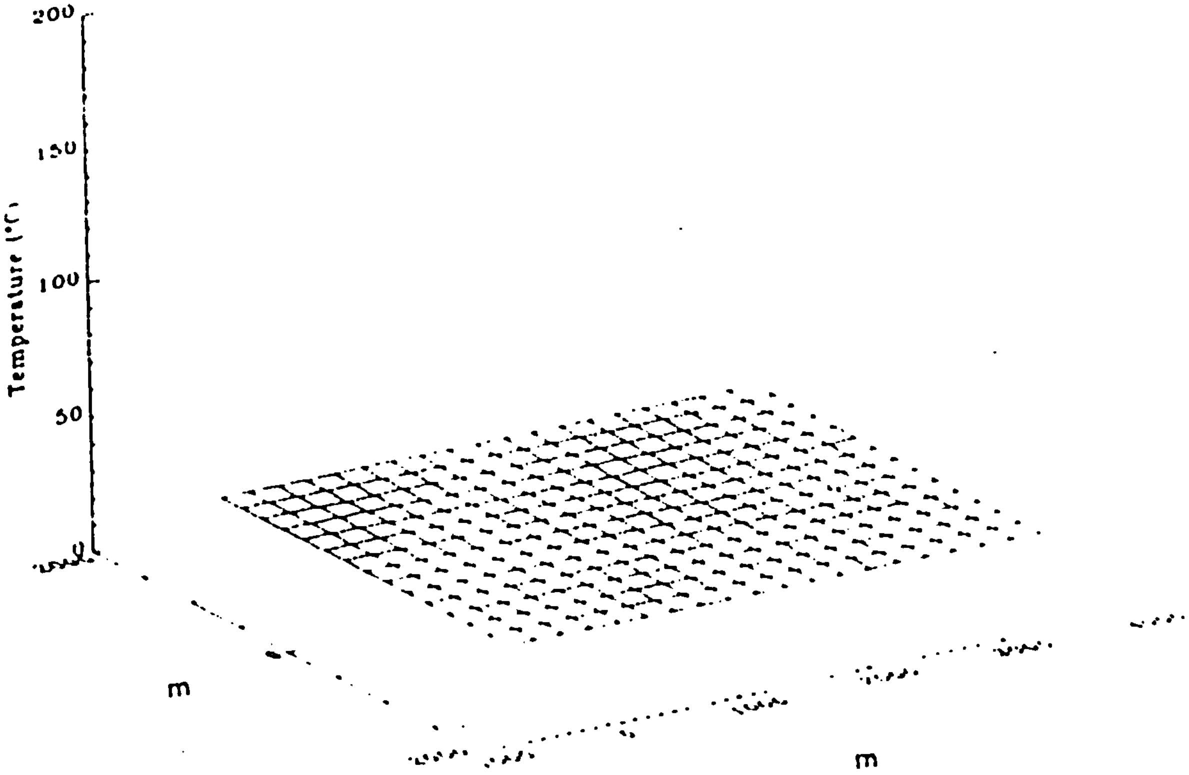
Not to Scale

[illegible]

Grid for Vertical Cross-Section AA



Grid for Horizontal Cross-Section 50m Below Waste Package Centerpoints



Far-Field Peak Temperature Summary

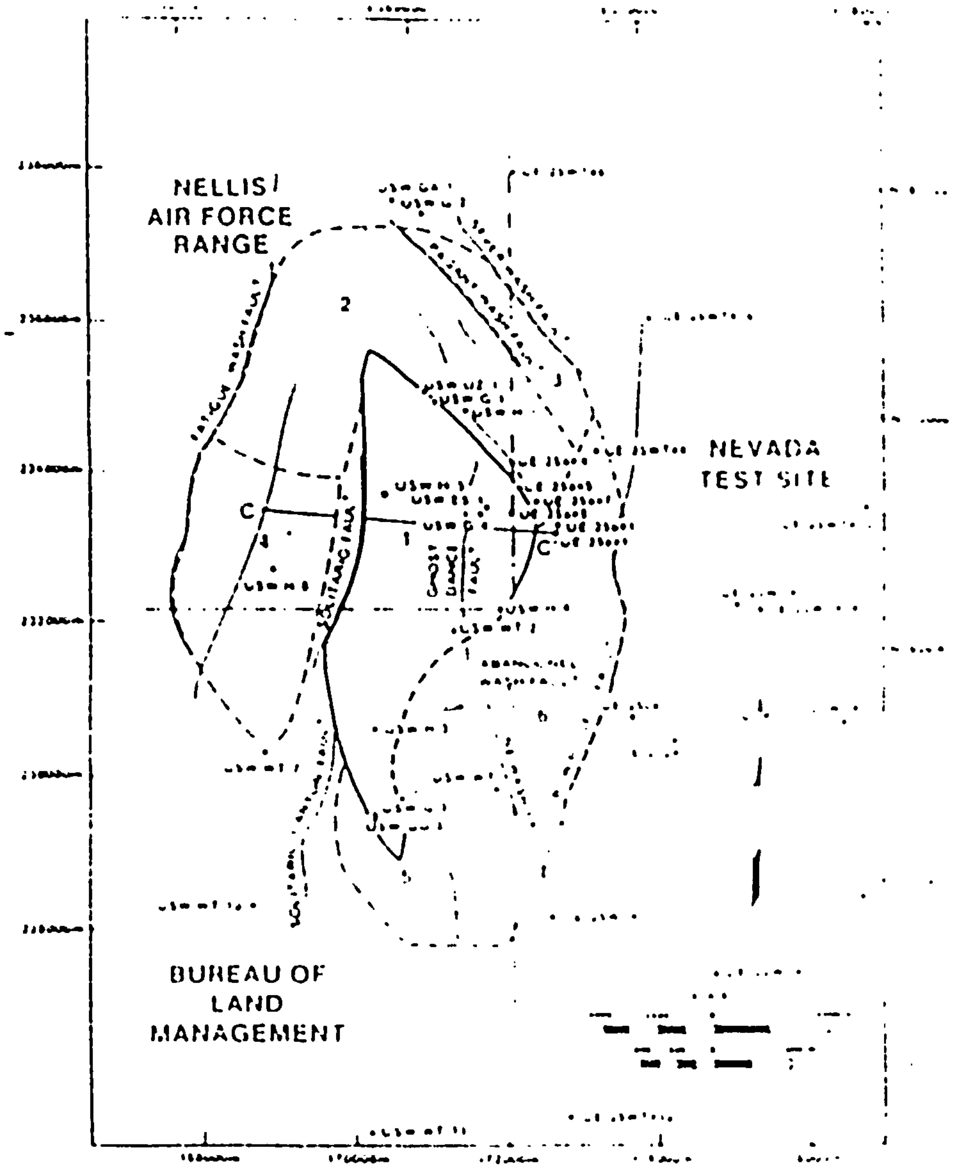
Depth Below Canister Centerpoints	Design-Basis APD (kW/acre)				
	80	57	48	30	22
	Temperature (°C)				
50 m	107	94	86	77	74
70 m	100	89	81	74	71
90 m	94	84	77	60	59
Average Waste Age (years)	30	30	30	60	90
Average Initial Power Output (kW/container)	1.52	1.52	1.52	0.95	0.66
Deposition Period Used (years)	300	20	20	20	20

Additional Options

- Increase heated area within perimeter drift

- Modify ventilation system

Available Area



Zone	Area (acres)
1	1850
2	2250
3	400
4	1500
5	500
6	2650

Ventilation Effects

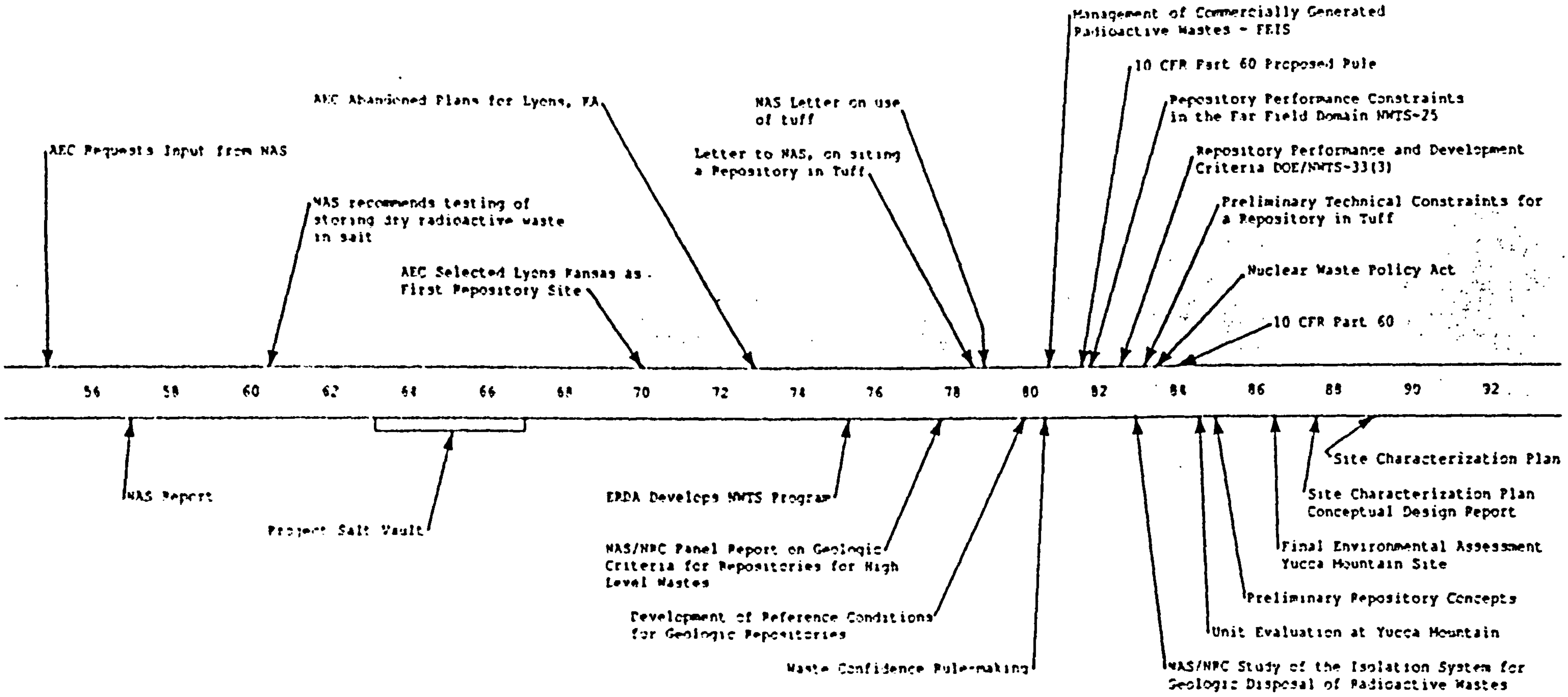
- Vented emplacement drifts modeled as cylindrical heat sinks with constant strengths of 30 kW
- Centerpoint of sink placed 8.4 m above canister centerpoints
- Two near-field cases examined for a design-basis APD of 80 kW/acre
    1. Drifts vented for 5 years
    2. Drifts vented for 10 years

Summary of Results for Additional Options

- The occurrence of a boiling front can be virtually eliminated by expanding the heated area and using receipt schedule selection to limit initial canister power output

- Ventilation can be used to mitigate the near-field thermal response, but the magnitude of the effects appear to be relatively small and short-term for other than significantly extended periods of active ventilation

CHRONOLOGY OF HIGH LEVEL WASTE PROGRAM EVENTS RELEVANT TO THERMAL LOADING QUESTIONS



U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: REPOSITORY DESIGN CONSIDERATIONS

PRESENTER: DR. THOMAS E. BLEJWAS

PRESENTER'S TITLE AND ORGANIZATION: TECHNICAL PROJECT OFFICER,
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

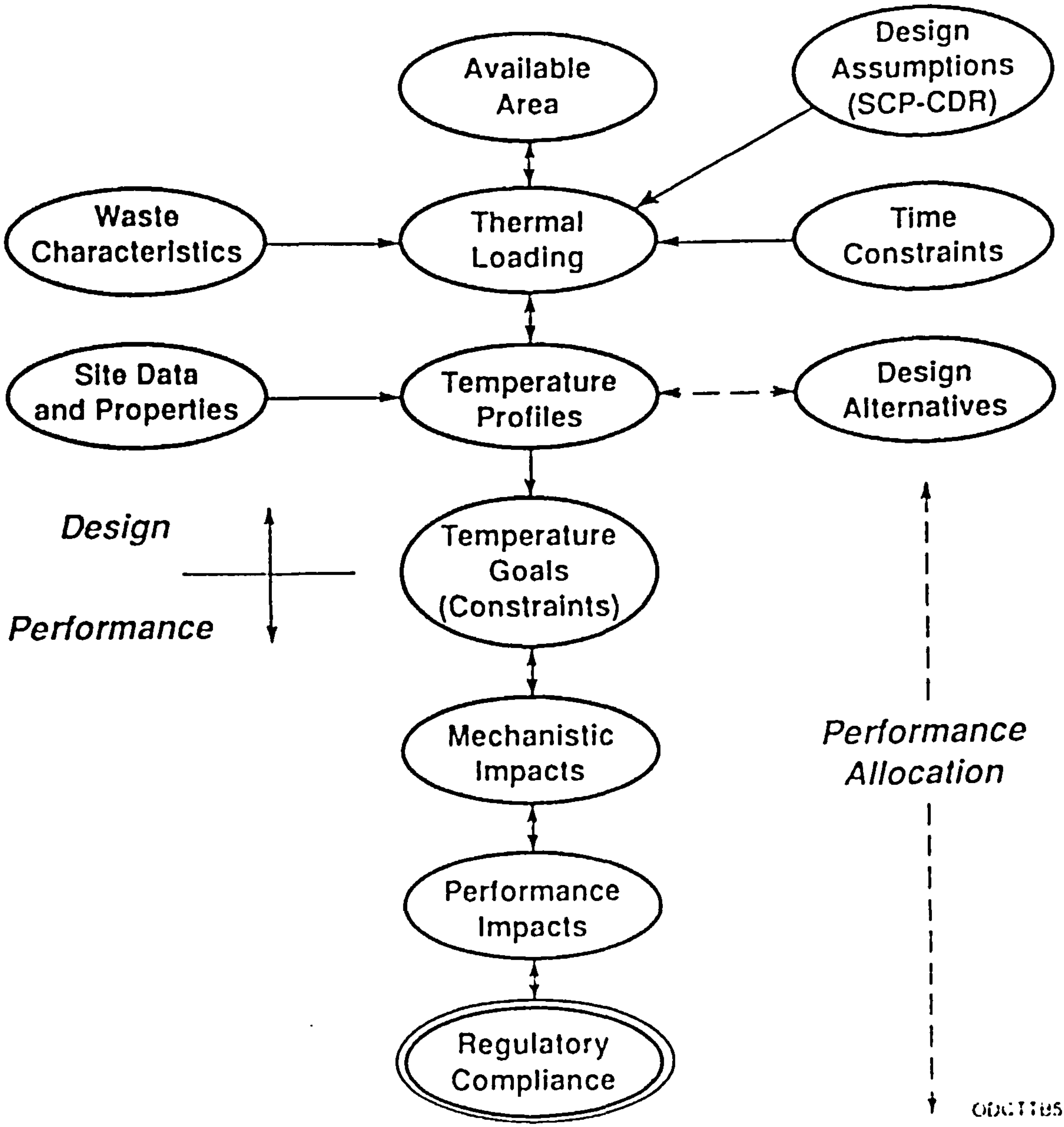
PRESENTER'S TELEPHONE NUMBER: (505) 844-9160

OCTOBER 8 - 10, 1991

Outline

- SCP approach
- Possible changes
- Plans

SCP Approach



Available Area

Design Assumptions (SCP-CDR)

Waste Characteristics

Thermal Loading

Time Constraints

Site Data and Properties

Temperature Profiles

Design Alternatives

Design

Performance

Temperature Goals (Constraints)

Mechanistic Impacts

Performance Impacts

Regulatory Compliance

Performance Allocation

ODCTTBSP 1.25 NWTRB 10 8 10 91

SCP Temperature Goals

Goal	Possible Effect on Design
t < 200° C one meter from borehole wall	Vary package loading, borehole and drift spacing; limit APD
t < 275° C at borehole wall and t < 350° C at container centerline	Vary package loading, borehole and drift spacing; limit APD
Δ t < 6° C on surface and surface uplift < 0.5 cm/yr	Limit APD
No intact rock failure or continuous joint slip	Limit APD
Local saturation < 90%	Limit usable area
Borehole walls above boiling > 300 yrs	Raise package loading and APD
t < 115° C in TSw3, CHnz, and CHnv	Limit APD

SCP Temperature Goals

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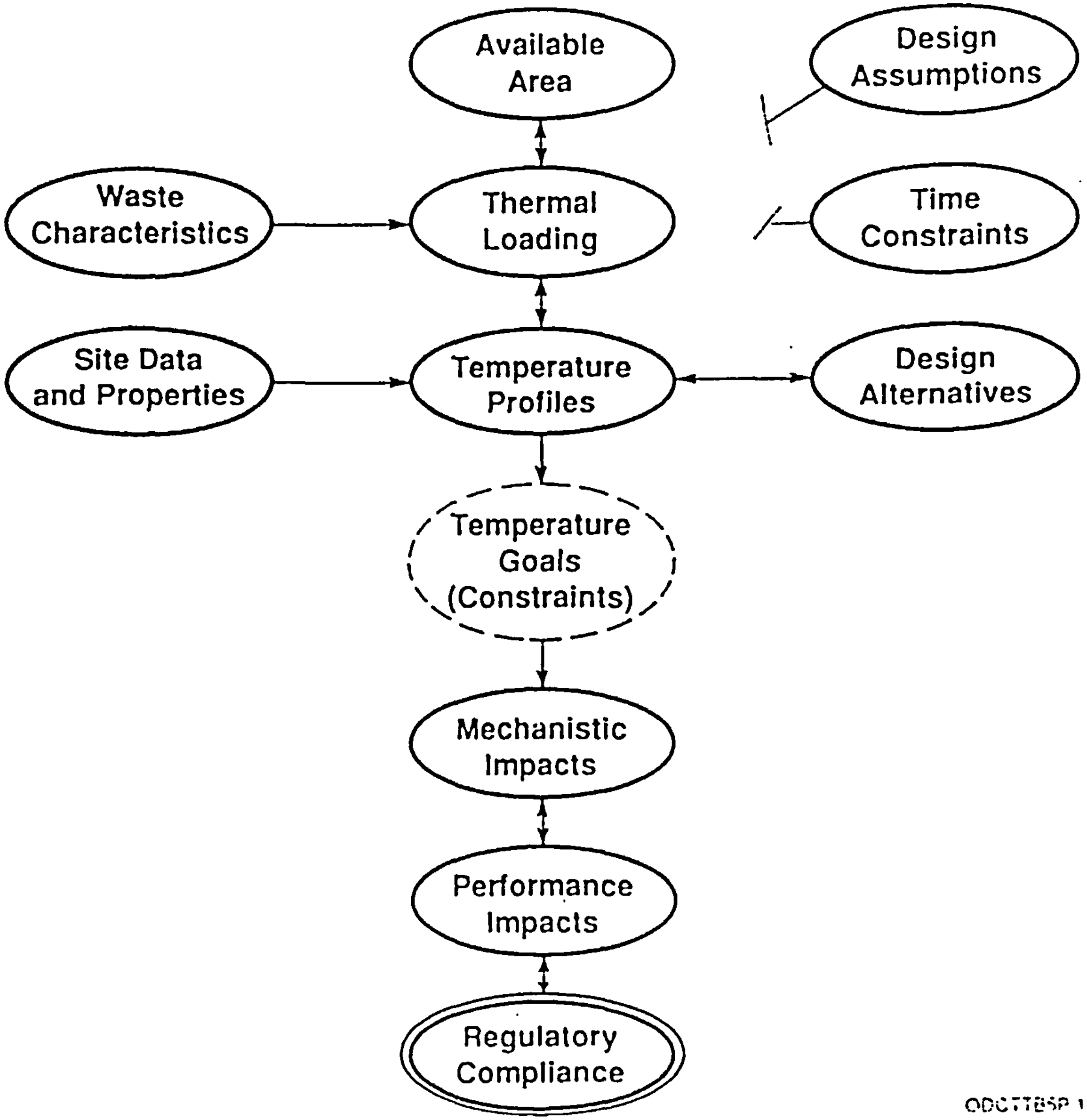
Local saturation $< 90\%$	Limit usable area
Borehole walls above boiling > 300 yrs	Raise package loading and APD
$t < 115^\circ$ C in TSw3, CHnz, and CHnv	Limit AP

Alternative Approach



Available Area

Design Assumptions

Waste Characteristics

Thermal Loading

Time Constraints

Site Data and Properties

Temperature Profiles

Design Alternatives

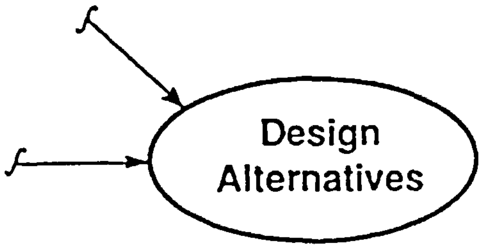
Temperature Goals (Constraints)

Mechanistic Impacts

Performance Impacts

Regulatory Compliance

Design Alternatives



Alternative:

Ventilation Concepts

Layouts

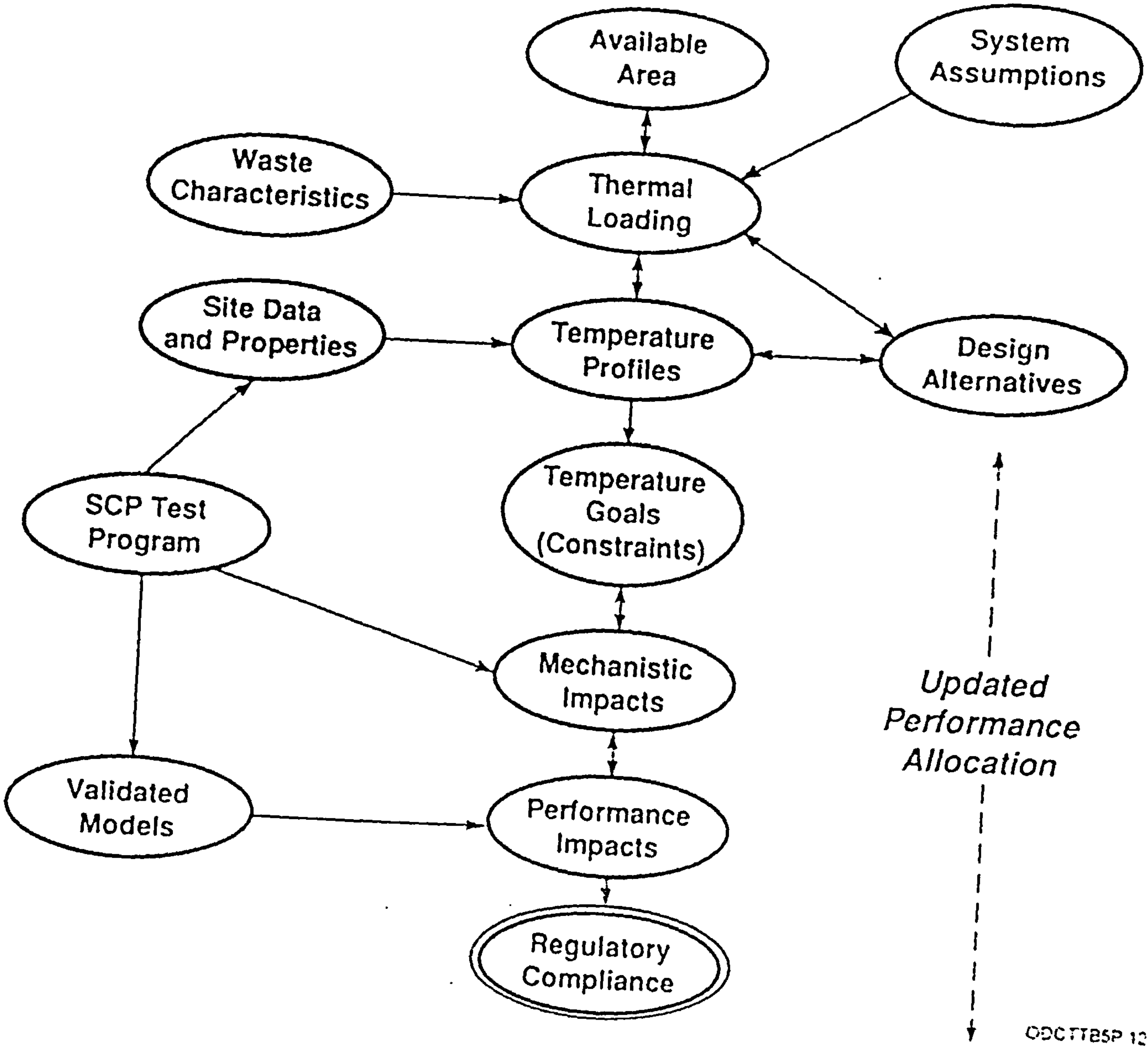
Emplacement Modes

Waste-Package Concepts

Backfill Concepts

Operational Approaches
    Emplacement Schedules
    Waste Treatment
    Comingling Strategies
    Consolidation Strategies

Planned Approach



Available Area

System Assumptions

Waste Characteristics

Thermal Loading

Site Data and Properties

Temperature Profiles

Design Alternatives

SCP Test Program

Temperature Goals (Constraints)

Mechanistic Impacts

Updated Performance Allocation

Validated Models

Performance Impacts

Regulatory Compliance

Proposed Plans Through ACD

Conduct mechanistic studies where appropriate

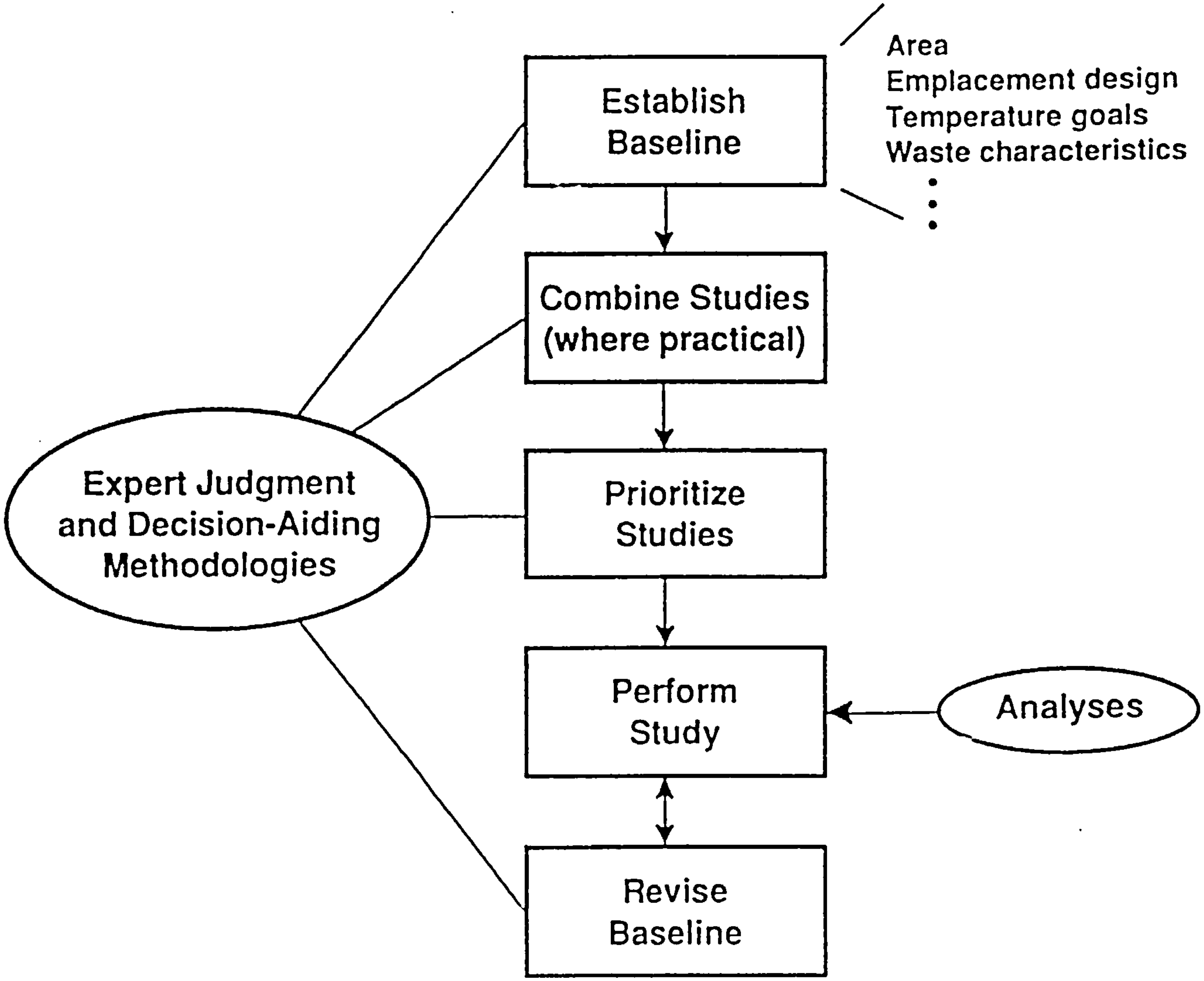
Update temperature goals recognizing:

- Uncertainties in impacts & benefits
- Prudence of early conservatism
- Improved understanding of mechanisms
- Improved performance models

Develop boundaries of design alternatives

Perform design studies

Design Studies



Establish Baseline

Area
Emplacement design
Temperature goals
Waste characteristics
⋮

Combine Studies (where practical)

Prioritize Studies

Perform Study

Analyses

Revise Baseline

Expert Judgment and Decision-Aiding Methodologies

Design Studies

- Update temperature constraints/goals (input to ACD)
- Perform studies during advanced conceptual design that lead to detailed design during LAD

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: WASTE FORM AND MATERIALS TESTING CONSIDERATIONS

PRESENTER: DR. GREGORY E. GDOWSKI

PRESENTER'S TITLE AND ORGANIZATION: CHEMICAL ENGINEER
KMI/LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 423-3486

OCTOBER 8 - 10, 1991

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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OCTOBER 8 - 10, 1991

Outline of Presentation

- Introduction
- Low thermal loading testing considerations
- High thermal loading testing considerations
- Other testing considerations
- Summary

Thermal Loading Temperature Scenarios

- Low thermal loading
  - Temperature always remains below boiling
- High thermal loading
  - Temperature initially above boiling but eventually will be below boiling

Low Thermal Loading Testing Considerations

Low temperature testing

- Degradation of container materials and Zircaloy cladding
- Hydride precipitation and reorientation in Zircaloy cladding
- Oxidation and dissolution of UO_2 fuel pellets
- Hydration and dissolution of borosilicate glass

High temperature testing

- Accelerated testing
  - Must ensure that mechanisms of degradation do not change with temperature

High Thermal Loading Testing Considerations

High temperature testing

- Aging and oxidation of container materials
- Other degradation modes of container materials
- Creep/stress rupture of Zircaloy cladding
- Hydrogen effects in Zircaloy cladding
- Oxidation of UO_2 fuel pellets
- Hydration of borosilicate glass
- Accelerated testing

High Thermal Loading Testing Considerations

Low temperature testing

- Low thermal loading testing

- Tests on materials modified by high temperature processes
    - Dissolution of U_3O_8 / UO_3
    - Dissolution of hydrated borosilicate glass
    - Degradation resistance of oxidized and aged container materials

Other Testing Considerations

- Backfill/container material interaction
- Waste package component interaction
- Final closure

Summary

- Degradation phenomena and concerns have been identified for both high and low thermal loading scenarios
- Testing is required to characterize and model the degradation modes of materials and waste forms
- Testing should proceed simultaneously with engineered barrier system design

Strategic Implications of Heat in a High-Level Radioactive Waste Repository

Lawrence D. Ramspott
Lawrence Livermore National Laboratory
University of California

U.S. Nuclear Waste Technical Review Board Meeting
"Effects of Thermal Loading on Repository Design"

Las Vegas, Nevada
October 8, 1991

Main Points of Talk

- Strategic implications of
  - — temperatures greater than the boiling point of water
  - — temperatures between ambient and the boiling point of water
  - — ambient temperatures
- Strategic implications of heat on the
  - — selection of Yucca Mountain as a repository site
  - — need for long-term surface storage

Definitions for this Talk

- "Hot" means distribution in space and time of rock temperatures greater than the boiling point of water sufficient to produce significant dryout benefits to repository performance
  - hot enough long enough over a large enough volume to do some good
- "Warm" means a repository is designed to remain below some maximum temperature, such as 90° C
- "Ambient" means within a few degrees of the ambient rock temperature prior to waste emplacement

Only three concepts address 10,000 year isolation from a simple viewpoint

- Partitioning and transmutation
- Super container concept
- Hot repository for 10,000 years

Perspective of this Talk

- Mainly directed at effect of heat on a potential repository at Yucca Mountain
- Drying will limit container corrosion and prevent dissolution and aqueous transport of radionuclides
- The repository can be designed to optimize effects of heat
- The Engineered Barrier System and the natural environment work together - they cannot be assessed independently
- Yucca Mountain is a fractured open system - additional fractures resulting from heat or EBS designs are not likely significant to isolation
- Emphasis on 1,000 and 10,000 year time frames is based on need for compliance with EPA standard and the NRC sub-system performance objectives

Strategic Implications of a Hot Repository

- If above boiling point of water for 10,000 years
  - only have to show that repository will not flood for 10,000 years to meet EPA standards and NRC subsystem requirements for EBS

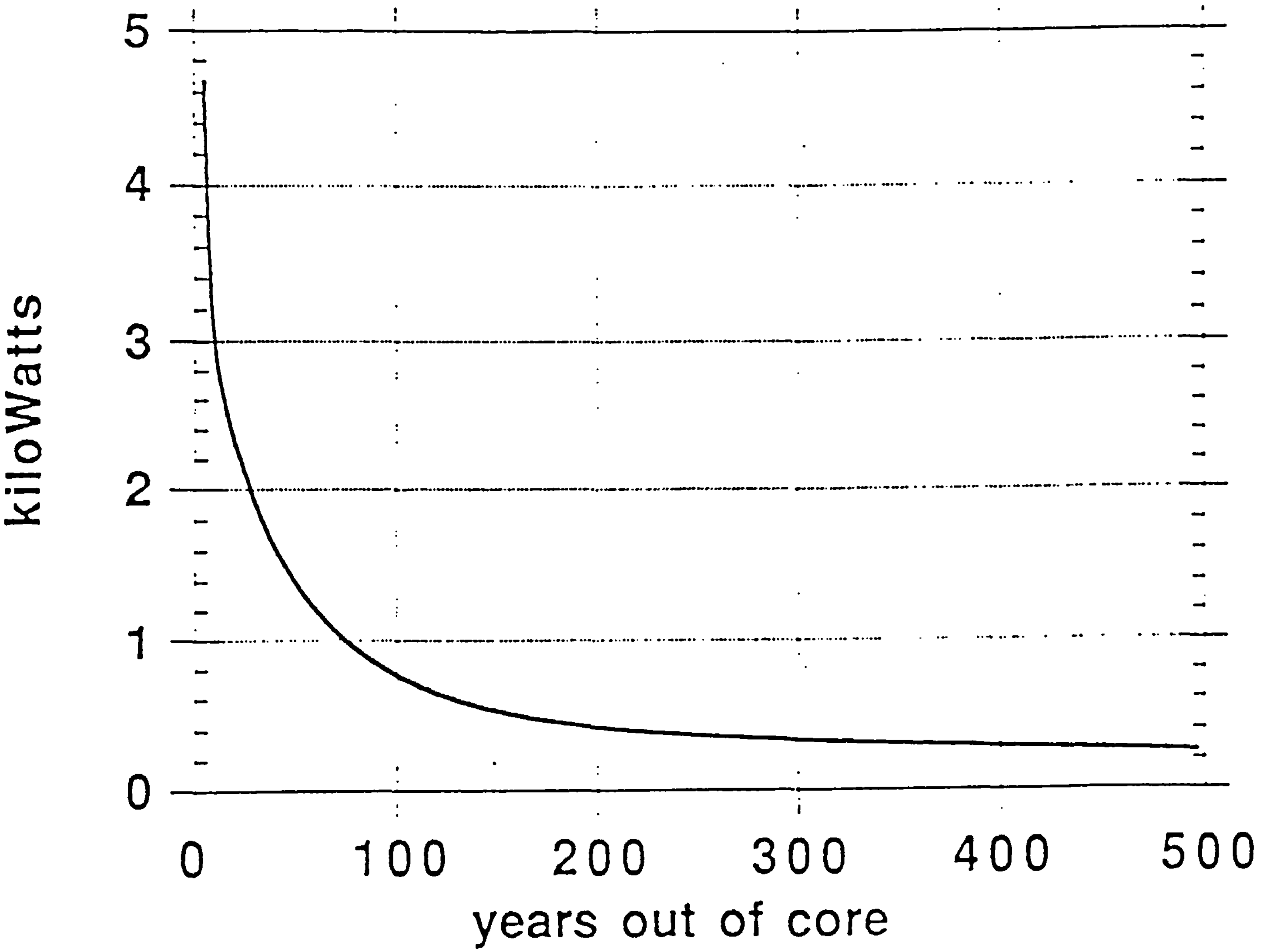
- If above boiling point of water for 1,000 years
  - demonstrate substantially complete containment by showing that repository does not flood for 1,000 years
  - must also show compliance with EPA standard and other NRC subsystem requirements
  - must also model sub-boiling processes beyond 1,000 years

Implications of Methods of Keeping the Repository Hot

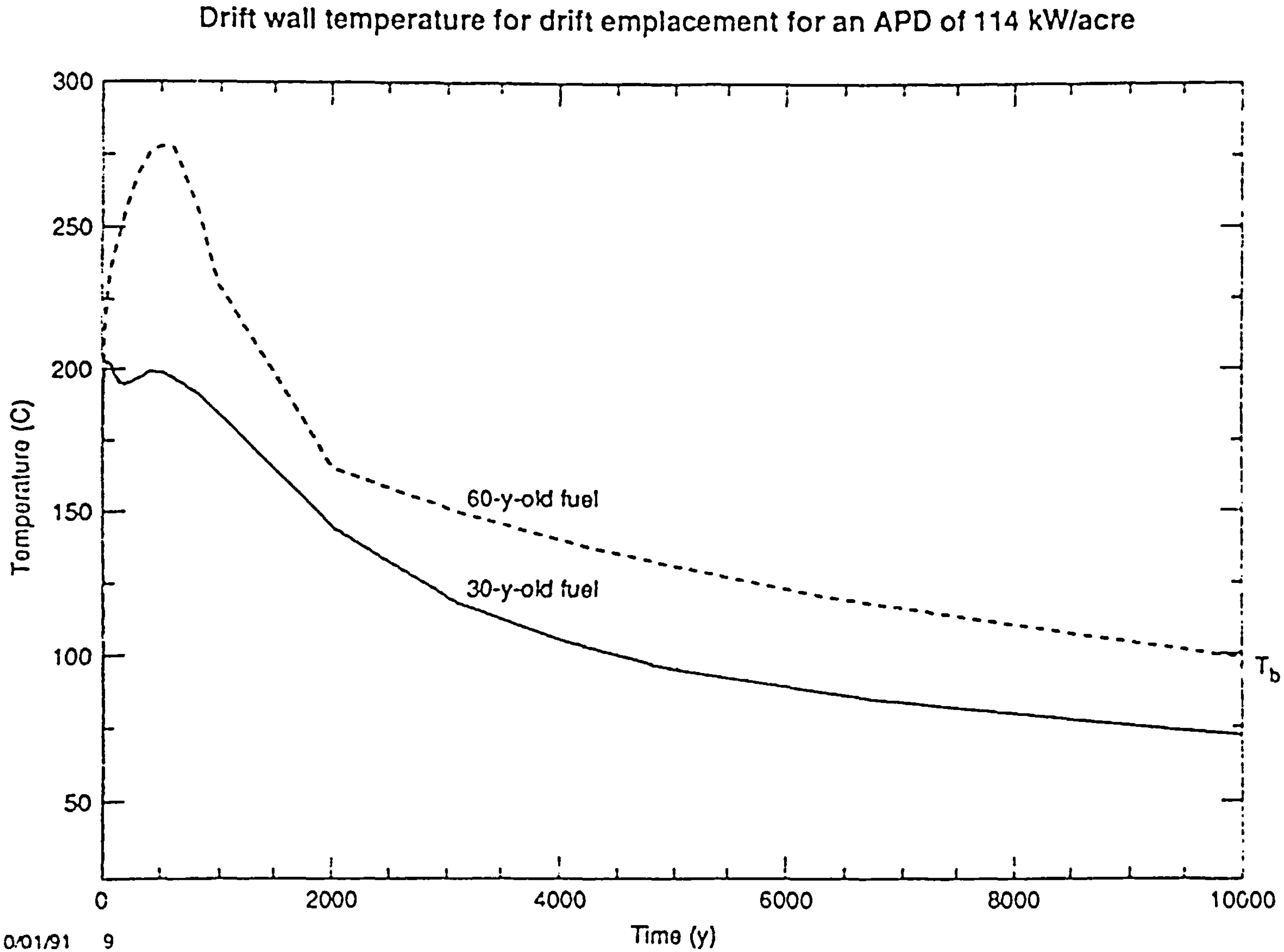
METHOD	IMPLICATION
Closer borehole/drift spacing	Cost savings
— young fuel	Limited by facility constraints and temperature limits on components
— old fuel	Long-term central storage facility
Put very young fuel in repository	Limited by system constraints
Age fuel and pack more in containers	Possibly limited by criticality
Rock with low thermal conductivity	Thermal conductivity of most rock media may be too high - this may be tuff - specific
Drift emplacement	Possible technical and cost advantages

WP Heat Load for PWR Spent Fuel

(SCP-CDR, 3kW @ 10y out of core)



A Substantial Increase in Boiling and Dry-Out Benefits is Obtained for 60-yr-old Fuel, with Dry Steam Boiling Conditions Persisting for 10,000 yrs



Drift wall temperature for drift emplacement for an APD of 114 kW/acre

Advantages and Disadvantages of Hot Temperatures

Advantages

- presumption that aqueous corrosion and dissolution do not operate
  - easy to explain
- Ability to validate models of fluid flow
  - matrix dominated flow
  - more homogeneous response
  - more amenable to verification by field testing

Disadvantages

- concept unique to United States
- within the United States, unique to Yucca Mountain or other unsaturated sites
- possible change in hydraulic properties of rock
- possible effect on retrievability

Strategic Implications of a "Warm" Repository

- Will have to show that repository will not flood in 1,000 or 10,000 years, just as in the "hot" scenario
- If temperature remains below boiling
  - — cannot assume absence of liquid water on containers or waste
- At temperatures between ambient and boiling
  - — still have to model and understand nearly all processes involved at temperatures above boiling as well as additional processes in the sub-boiling region
  - — how will these sub-boiling hydrothermal process models be validated?
- Must decide two issues
  - — what upper temperature limit is technically justified?
  - — how will this limit be achieved?

Implications of Methods of Keeping Repository "Warm"

METHOD	IMPLICATION
Store on surface for 50-100 yrs.	Long-term central storage facility Safeguards and security issues Less safe than in repository
Decrease areal loading	
— by spacing	Increase in cost
— less waste per container	Increase in cost, solubility-limited release increases with number of sources
Redesign using drift emplacement and an engineered cooling system	Cost (?) Rethink isolation strategy

Advantages and Disadvantages of Warm Temperatures

Advantages

- this is the international "standard" conceptual design

Disadvantages

- at Yucca Mountain, possible change in hydraulic properties of rock

- most potentially deleterious processes that operate above boiling also operate in this thermal range

- appears to also have disadvantages of the ambient concept
  - difficulty of model validation
  - fracture-dominated flow

- possible effect on retrievability

Strategic Implications of Ambient Temperatures

- Will have to show that the repository will not flood in 1,000 or 10,000 years, just as in the hot scenario

- Relieved of having to address processes at greater than ambient temperatures in the repository
  - however, thermal gradient in the site cannot be neglected in modeling
  - vapor-phase transport is still very important, must model two-phase transport

- Have to be able to describe and model scenarios for water to contact and corrode containers and dissolve waste

Implications of Methods of Keeping Repository Ambient

METHOD	IMPLICATION
Partitioning and transmutation	Increase in cost
	Need 200-year surface-storage facility for Cs-Sr
	Need to locate, construct, license and operate P-T facilities
	Legislative and licensing changes

Advantages and Disadvantages of Temperatures near Ambient

Advantages

— Yucca Mountain ambient (23° C, atmospheric pressure) is close to STP, where there are thousands of measurements of all types of physical and chemical phenomena

Disadvantages

— validation of near-field flow models is harder

— at Yucca Mountain under current conditions, flow appears fracture dominated; under possible future pluvial conditions there is even more chance of fracture dominated flow

— fracture-dominated flow leads to faster transport should waste ever be dissolved

Strategic Implications of Heat on Selection of Yucca Mountain as a Repository Site

- Although the SCP-CD design would lead to a 1,000 year hot repository, performance assessments are conducted for warm conditions
- Assuming expected Yucca Mountain conditions, most containers would remain dry even if temperatures were ambient
- Aging of fuel increases the length of time that a repository at Yucca Mountain can remain hot
- Aging helps the "warm" repository concept at any site or media.
- Therefore, remaining at Yucca Mountain or switching to another site is not impacted by technical issues regarding fuel age
- Hot repository concept may be unique to Yucca Mountain; warm and ambient repositories could be anywhere

Strategic Implications of Heat on the Need for Long-Term Surface Storage

- Surface storage can be replaced by enhanced ventilation and other engineered cooling in the underground facility during the 50 year retrievability period

- At Yucca Mountain, a wide range of thermal environments can be achieved by repository design without long-term surface storage
  - can have a hot repository without surface storage (but must redesign repository to achieve 10,000 years hot)
  - can have a warm repository without surface storage (but may not handle 70,000 MT)

- An ambient temperature repository requires long-term surface storage (for Cs-137 and Sr-90)

General Strategic Conclusions

- The ambient repository concept requires partitioning and transmutation, which has strategic implications well beyond high-level waste management

- With the warm repository concept, the issue can be stated
  - is there a simple licensing strategy that can keep the site characterization effort bounded?

- With the hot repository concept, site characterization at Yucca Mountain becomes focussed on one issue: will the repository flood in 1,000 or 10,000 years?

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: OPENING REMARKS
PROJECT STATUS

PRESENTER: CARL P. GERTZ

PRESENTER'S TITLE AND ORGANIZATION: PROJECT MANAGER
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7900

OCTOBER 8 - 10, 1991

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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OCTOBER 8 - 10, 1991

Project Status

- 1991 Accomplishments
- 1992 Plans and priorities
- Status of lawsuits
- Status of permits

1991 Major Accomplishments

- Started limited new work at Yucca Mountain July 8, 1991, at 3:20 p.m.
- Developed site suitability methodology, criteria and data requirements
- Continued non-surface disturbing activities
- Completed four on-going major studies:
  - Test prioritization task
  - Exploratory studies facility (ESF) alternatives study
  - Calico Hills risk/benefit analysis
  - Alternative license application strategy
- Completed revised ESF Title I Design Summary Report

Yucca Mountain Project has started major new site characterization activities

Major 1992 Priorities Reflect Limited Funding

- Complete initial early site suitability evaluation draft report. Continue ongoing suitability evaluation

- Initiate new surface disturbing (drilling) site characterization activities including:
  - Prototype drilling at Yucca Mountain
  - Park Service monitoring borehole
  - Unsaturated zone boreholes
  - Geologic investigation boreholes
  - Field trenching
  - Test pits

- Continue ongoing surface-based site characterization activities

- Begin limited ESF Title II design in October 1991 (update repository design as appropriate)

Major 1992 Priorities

(Continued)

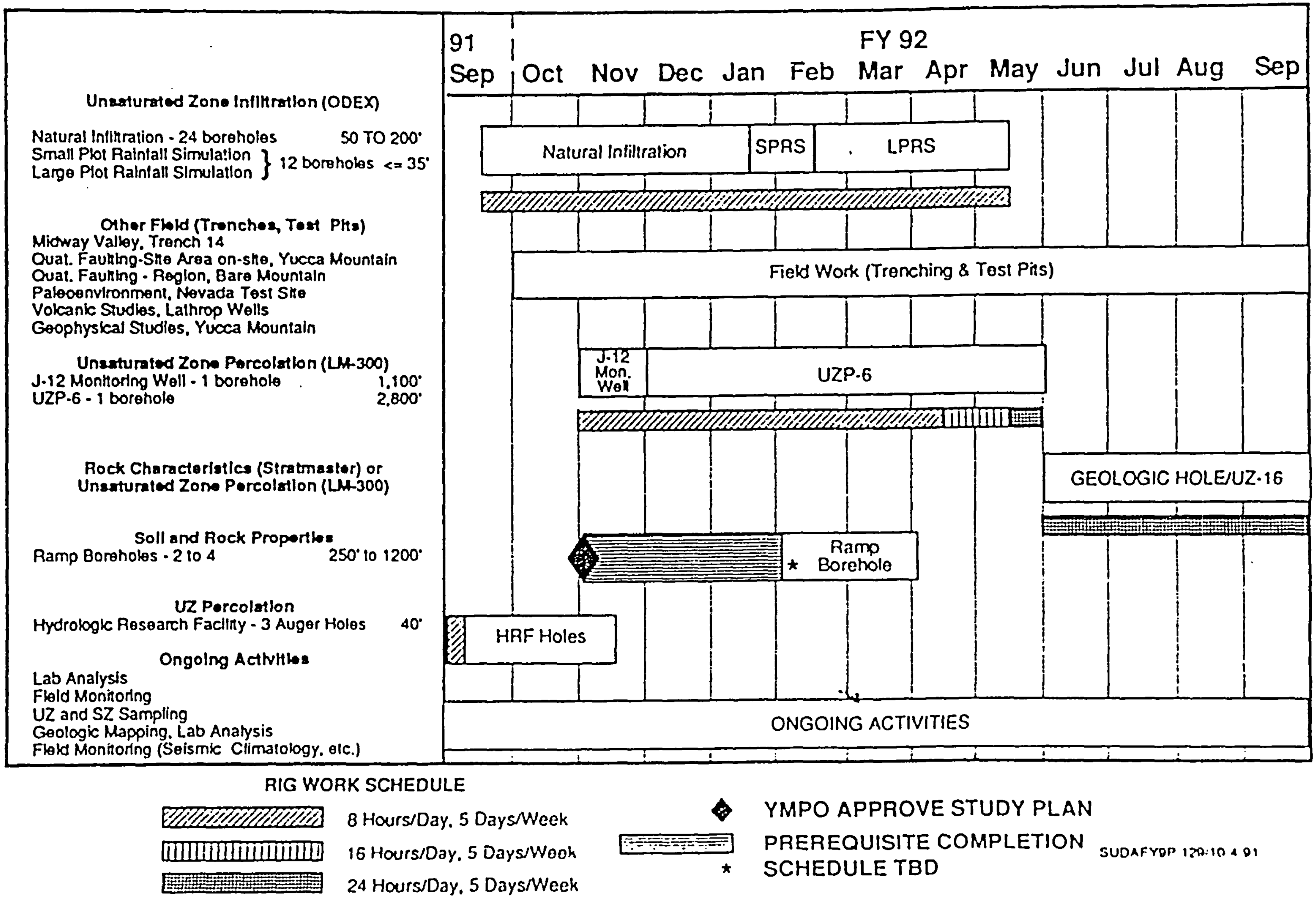
- Maintain a sound environmental program and provide support to field activities as necessary
- Conduct performance assessment to support project priorities/activities
- Continue to fully implement a YMP-wide Quality Assurance program and planning and control system (PACS)
- Conduct a minimal waste package/EBS/near-field environment/waste form characterization program

Major 1992 Priorities

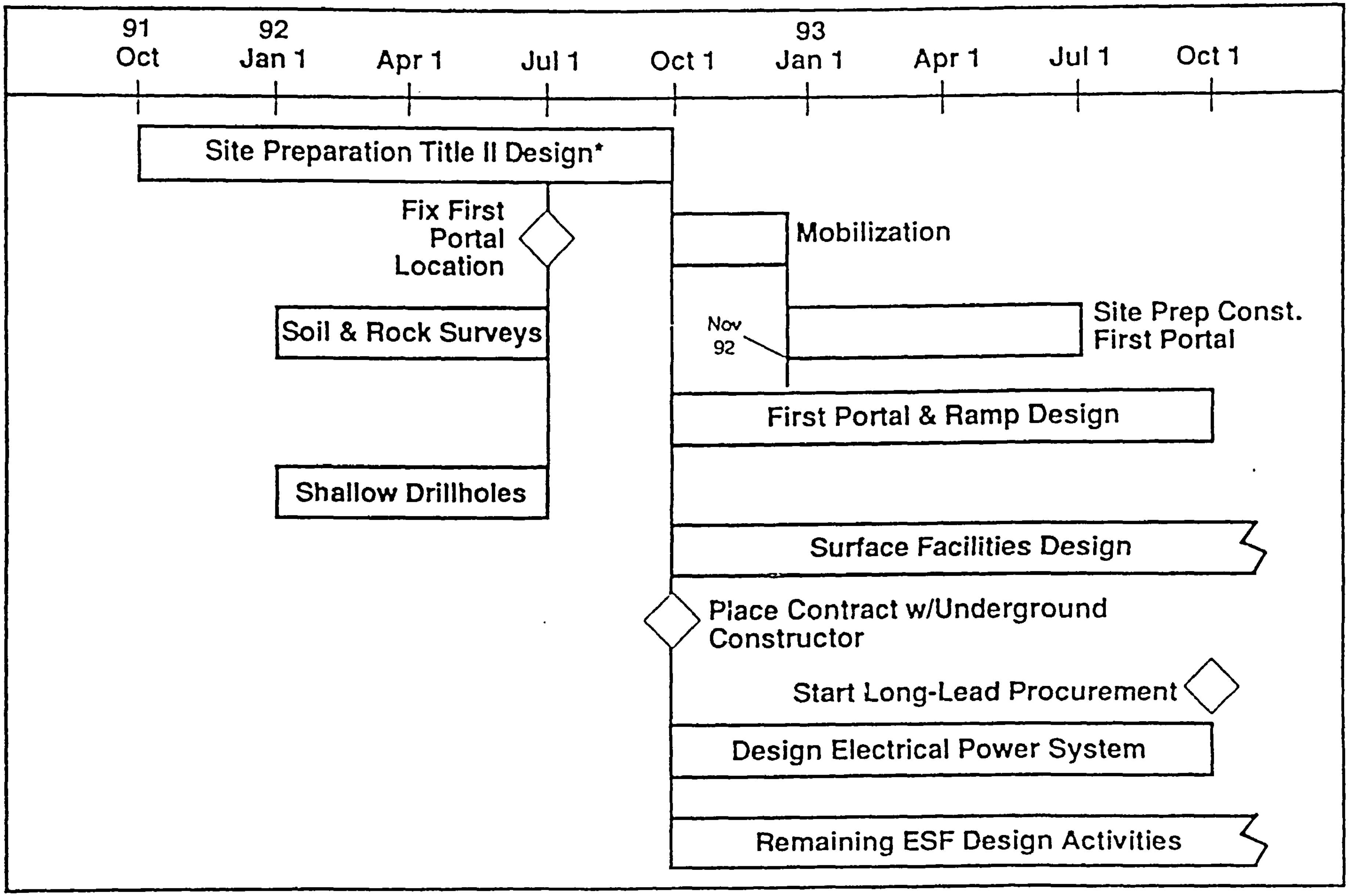
(Continued)

- Maintain fixed cost items (i.e., roads, buildings, records centers, etc.)
- Conduct institutional/outreach programs
- Transition M&O (TRW) into project activities

Proposed FY 1992 Surface Disturbing Activities



PROPOSED ESF DESIGN/CONSTRUCTION ACTIVITIES FY 1992 & 1993



91 Oct
92 Jan 1
Apr 1
Jul 1
Oct 1
93 Jan 1
Apr 1
Jul 1
Oct 1

Site Preparation Title II Design*

Fix First Portal Location

Soil & Rock Surveys

Shallow Drillholes

Mobilization

Site Prep Const. First Portal

Nov 92

First Portal & Ramp Design

Surface Facilities Design

Place Contract w/Underground Constructor

Start Long-Lead Procurement

Design Electrical Power System

Remaining ESF Design Activities

* INCLUDES

- PORTAL DESIGN SUFFICIENT FOR BLASTING
- AREA DESIGN SUFFICIENT FOR BLASTING AND SITE GRADING
- TOPSOIL AND SUBSOIL STORAGE
- WASTE WATER DISPOSAL
- POTABLE AND INDUSTRIAL WATER DISTRIBUTION
- ELECTRICAL SUBSTATION ENVELOPE
- FACILITY LAYOUTS
- BUILDING ENVELOPES

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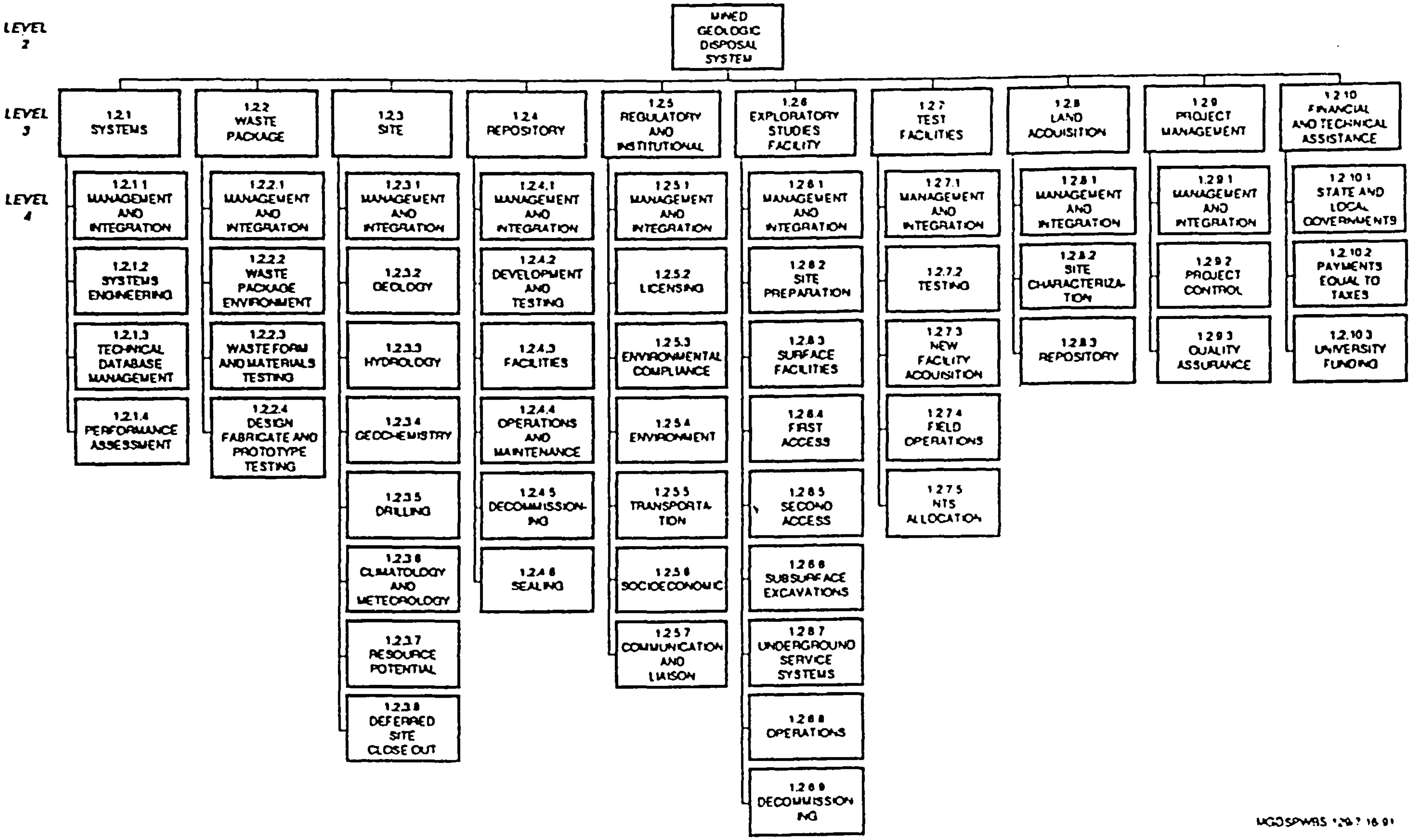
YMP Work Breakdown Structure



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WBS Numbers

1.2.1 Systems, Performance assessment, Technical data

1.2.3 Waste Package/near-field environment

1.2.3 Site investigation

1.2.4 Repository/ESF interfaces

1.2.5 Regulatory, Institutional, Environment

1.2.6 Exploratory Studies Facility

1.2.7 Facilities

1.2.9 Project Management

- Management
- Administration
- Project control
- Quality assurance

WBS Numbers

WBS		FY 1991 Actuals	FY 1992 Planning
1.2.1	(Systems)	24.7	18.6
1.2.2	(Waste pkg.)	10.8	5.2
1.2.3	(Site)	40.8	47.6
1.2.4	(Repository)	4.8	4.3
1.2.5	(Regulatory/Institutional)	20.3	18.4
1.2.6	(ESF)	13.9	7.0
1.2.7	(Facilities)	6.7	6.0
1.2.8	(Land)	.2	.2
1.2.9			
	Management	8.4	7.1
	Administration	23.7	19.2
	Project Control	7.3	9.2
	Quality Assurance	13.5	11.6
	Project Subtotal	175.1	154.2
1.2.10	(Assistance)	30.5	15.5
Total		*205.6*	*169.7*

State And DOE In Legal Battle

- State filed lawsuit against DOE in January 1990
  - U.S. 9th Circuit Court of Appeals unanimously ruled in DOE's favor September 1990
- Supreme Court denied the state's request to review 9th Circuit Court decision March 1991
- State filed a request for reconsideration to the Supreme Court that was also denied on June 14, 1991
- Suit considered closed

Lawsuits

(Continued)

- DOE filed lawsuit in U.S. District Court against state in January 1990 to obtain permits
  - State issued air quality permit on June 12, 1991
  - State issued underground injection control (UIC) permit July 17, 1991
  - State engineer began hearing on water appropriations request September 24, 1991;
    Court continues jurisdiction over this activity

Ninth Circuit Court Of Appeals Recently Ruled In DOE's Favor On The "Guidelines" And "Environmental Assessment" Cases

"In 1987, Congress ordered the Secretary to conduct site characterization at Yucca Mountain. Nothing in the NWPA suggests that this clear legislative command is contingent upon the promulgation of a valid, adequate, and sufficient EA. We hold that Congress's 1987 amendments to the NWPA have rendered moot all aspects of Nevada's challenge to the Yucca Mountain EA. Accordingly, the petition is DISMISSED"

State Issued Permit Allowing DOE To Use Water From Well VH1 To Conduct Site Characterization Activities

- Well is approximately 45 road miles from current storage tanks

- Permit expires May 1992

TO DEMONSTRATE FEDERAL RESOLVE DOE NEEDS ASSISTANCE

YES

- ☑ LITIGATION AND/OR LEGISLATION TO OBTAIN PERMITS TO BEGIN NEEDED SURFACE-DISTURBING WORK
- ☑ ADMINISTRATION (OMB) AND DEPARTMENTAL (DOE) SUPPORT TO OBTAIN ADEQUATE RESOURCES
- ☑ CONGRESSIONAL SUPPORT OF FULL FUNDING

WITHOUT ALL THREE OF THE ABOVE, THE REPOSITORY PROGRAM WILL BECOME STALLED AND THE NUCLEAR POWER OPTION WILL BECOME LESS VIABLE AS PART OF THE NATIONAL ENERGY STRATEGY

Nuclear Waste Technical Review Board
Full Board Meeting

Evaluation of Ranges of Thermal Loading for High-Level Waste Disposal

October 8-10, 1991
Las Vegas, NV

Tuesday, October 8, 1991

8:30	Welcome Opening Remarks	D. Deere, NWTRB C. Gertz, DOE
8:45	Strategic implications of heat in a high-level radioactive waste repository	L. Ramspott, LLNL

NWTRB Full Board Meeting
Agenda

Overview Session

Thermal Loading Rationale for the Design of a HLW Repository

9:15	The Swedish geologic repository	N. Rydell, SKN
10:00	Break (15 min.)	
10:15	The German geologic repository	K. Kuhn, GFS/IFT
11:00	The Canadian geologic repository	G. Simmons, AEC
11:45	Lunch (1 hr. 15 min.)	

NWTRB Full Board Meeting
Agenda

Overview Session

The Repository and Thermal Loading Concept for Yucca Mountain

1:00	Historical Perspective of U.S. Program	C. Gertz, DOE
1:30	History of Evolution of Repository Concept for a Potential Repository at Yucca Mountain	M. Voegele, SAIC
3:00	Break (15 min.)	
3:15	Repository Design Considerations	T. Blejwas, SNL

Repository Thermal Design

3:45	Technical considerations • Thermal Design Considerations • Temperature Changes Over Time	E. Ryder, SNL
5:15	Adjourn	

NWTRB Full Board Meeting
Agenda

Wednesday, October 9, 1991

Uncertainties Associated with High and Low Thermal Loading

- During this session, the following questions will be asked for both high and low thermal loading concepts, in the areas listed below. An attempt will be made to quantify the answers.

Questions

1. What are the potential problems?
2. What is the significance of each of the potential problems?
3. What are the uncertainties associated with the potential problems?
4. Can these uncertainties be resolved?
5. What are the time and cost risks associated with the resolution?
6. Will there be residual uncertainties?

NWTRB Full Board Meeting Agenda

Uncertainties Associated with High and Low Thermal Loading

8:30	Opening Remarks	W. North, NWTRB
8:40	Introduction	M. Cloninger, DOE
8:45	Geomechanical Uncertainties	L. Costin, SNL
9:15	Hydrogeologic Uncertainties	T. Buscheck, LLNL
10:00	Geochemical Uncertainties	B. Viani, LLNL
10:15	Break (15 min.)	
10:30	Mineralogical Uncertainties	D. Bish, LANL
11:00	Waste Form Degradation and Materials Uncertainties	G. Gdowski, LLNL
11:30	Biological Resource Concerns	K. Ostler, EG&G
12:00	Lunch (1 hr. 15 min.)	

NWTRB Full Board Meeting
Agenda

Implications of Higher and Lower Thermal Loading

1:15	Introduction	M. Cloninger, DOE
1:20	Repository Design Enhancements	T. Blejwas, SNL
1:35	Repository Testing Considerations	T. Blejwas, SNL
2:05	Near-Field Environment Testing Considerations	W. Lin, LLNL
2:25	Waste Form and Materials Testing Considerations	G. Gdowski, LLNL
2:35	Candidate Engineered Barrier Concept	P. Stevens-Guille, Ontario Hydro
3:05	Break (15 min.)	

NWTRB Full Board Meeting
Agenda

Implications of Higher and Lower Thermal Loading

3:20	Preclosure Thermal Enhancements	G. Danko, UNR
3:50	Geologic Heat Pipes • State-of the-art review geologic heat pipes	H. Rosenburg, TRW
4:20	Overview of Preclosure Ventilation Options	A. Ivans-Smith, Tunneling Tech. Corp./ G. Sandquist, U. of Utah
4:50	Adjourn	

NWTRB Full Board Meeting
Agenda

Thursday, October 10, 1991

Implications of Higher and Lower Thermal Loading

8:30	Opening Remarks	NWTRB
8:45	Performance Assessment Considerations • Time-temperature profiles • Waste package integrity • Near-field effect • Overall performance	McGuire/Ross Apted/Bullin/ Shaw, EPRI
10:15	Break (15 min.)	
10:30	Introduction to Continued DOE Implications Discussions	M. Cloninger, DOE
10:35	HLW System Comparative Costs • Repository Costs • Transportation Costs • Storage Costs	D. Jones, Weston

NWTRB Full Board Meeting
Agenda

Implications of Higher and Lower Thermal Loading

11:05	Regulatory and Legislative Considerations Regarding Thermal Loading • Human health and safety (i.e. preclosure) • Licensing considerations • Legislative implications	M. Lugo, SAIC
11:35	Conceptual Considerations for Total System Performance	M. Voegele, SAIC
12:05	Summary	M. Cloninger, DOE
12:10	Lunch (1 hour 15 min.)	

The Thermal Loading Issue, Roundtable Discussion, Conclusions and Comments

1:25	Opening Remarks	NWTRB
1:35	Discussion	All
5:00	Adjourn	

Supplemental Information on FY 1992 Planning Priorities

FY 1992 Planning Priorities

1.2.1 Systems, Performance assessment, Technical data

- Provide configuration management support
- Provide plans and procedures support
- Provide performance assessment support to surface-based testing and ESF
- Enhance technical data bases
- Support systems engineering/requirements development

FY 1992 Planning Priorities

1.2.2 Waste package/near-field environment

- Continue ongoing waste form testing
- Complete systems approach to EBS design concepts for ACD
- Provide near-field environment, waste form and materials properties reports

FY 1992 Planning Priorities

1.2.3 Site investigation

- Continue Midway Valley, Trench-14, and volcanic investigations
- Continue ongoing surface-based site characterization activities
- Initiate new surface disturbing (drilling) site characterization activities including:
    - Prototype drilling on the NTS
    - Park Service monitoring borehole
    - Unsaturated zone boreholes
    - Geologic investigation boreholes

FY 1992 Planning Priorities

1.2.4 Repository/ESF interfaces

- Provide repository/ESF design interface support
- Provide limited geomechanical testing and thermomechanical development

FY 1992 Planning Priorities

1.2.5 Regulatory, Institutional, Environment

- Submit the Early Site Suitability Evaluation report to OCRWM
- Provide environmental support to surface-based testing
- Conduct institutional program
- Support NRC, ACNW, and NWTRB interactions

FY 1992 Planning Priorities

1.2.6 Exploratory studies facility

- Complete ESF site preparation Title II design for first portal location
- Implement construction management in preparation for start of first area site prep construction

FY 1992 Planning Priorities

1.2.7 Facilities

- Provide field operations center support to surface-based testing site characterization activities
- Implement field change control procedures
- Assure safety of existing facilities

FY 1992 Planning Priorities

1.2.9 Project management (management, administration, project control, quality assurance)

- Continue QA program implementation to support surface-based testing and ESF design
- Continue full implementation of the planning and control system (PACS)
- Maintain core cost infrastructure

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HISTORY AND EVOLUTION OF REPOSITORY CONCEPT FOR A POTENTIAL REPOSITORY AT YUCCA MOUNTAIN

PRESENTER: DR. MICHAEL D. VOEGELE

PRESENTER'S TITLE AND ORGANIZATION: DEPUTY PROJECT MANAGER, TECHNICAL PROGRAMS
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7638

OCTOBER 8 - 10, 1991

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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Thermal Technical Constraints and Criteria Were Used to Develop a Conceptual Design to Support the SCP

Discuss

- Logical evolution of design constraints related to repository induced impacts
- Performance measures established to ensure repository performance
- Site specific technical considerations and evaluations supporting repository design
- Repository conceptual design developed to meet performance measures and constraints

Thermal Technical Constraints and Criteria Were Used to Develop a Conceptual Design to Support the SCP

Discuss

- Logical evolution of design constraints related to repository induced impacts
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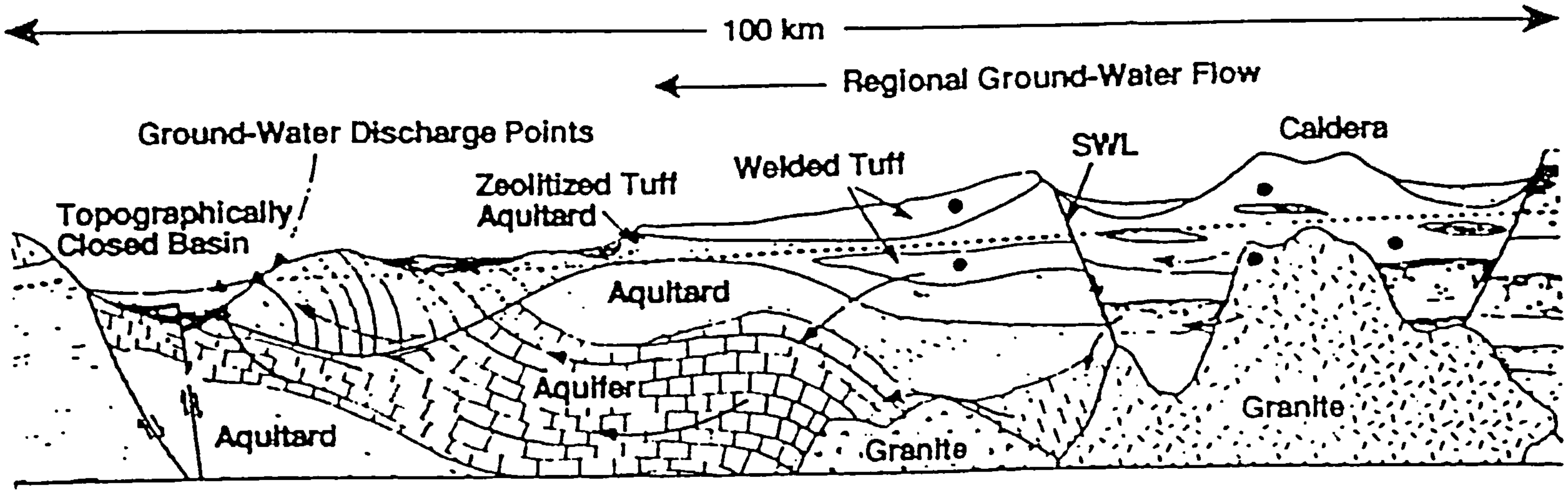
- Site specific technical considerations and evaluations supporting repository design
- Repository conceptual design developed to meet performance measures and constraints

Identification of Tuff as a Candidate Material

1978 Recommendation to NAS on siting a repository in tuff

- Addressed favorable and unfavorable aspects of disposal in tuff
- Preliminary evidence suggested dominant zeolites stable for short periods to 500° C and metastable above 250° C
- Comparable to other igneous rocks in strength, thermal conductivity, heat capacity and mineability
- Repository would be relatively shallow
- Issue related to water content-zeolite stability

Multiple Natural Barrier Model of Tuff in Great Basin



SWL - Static Water Level

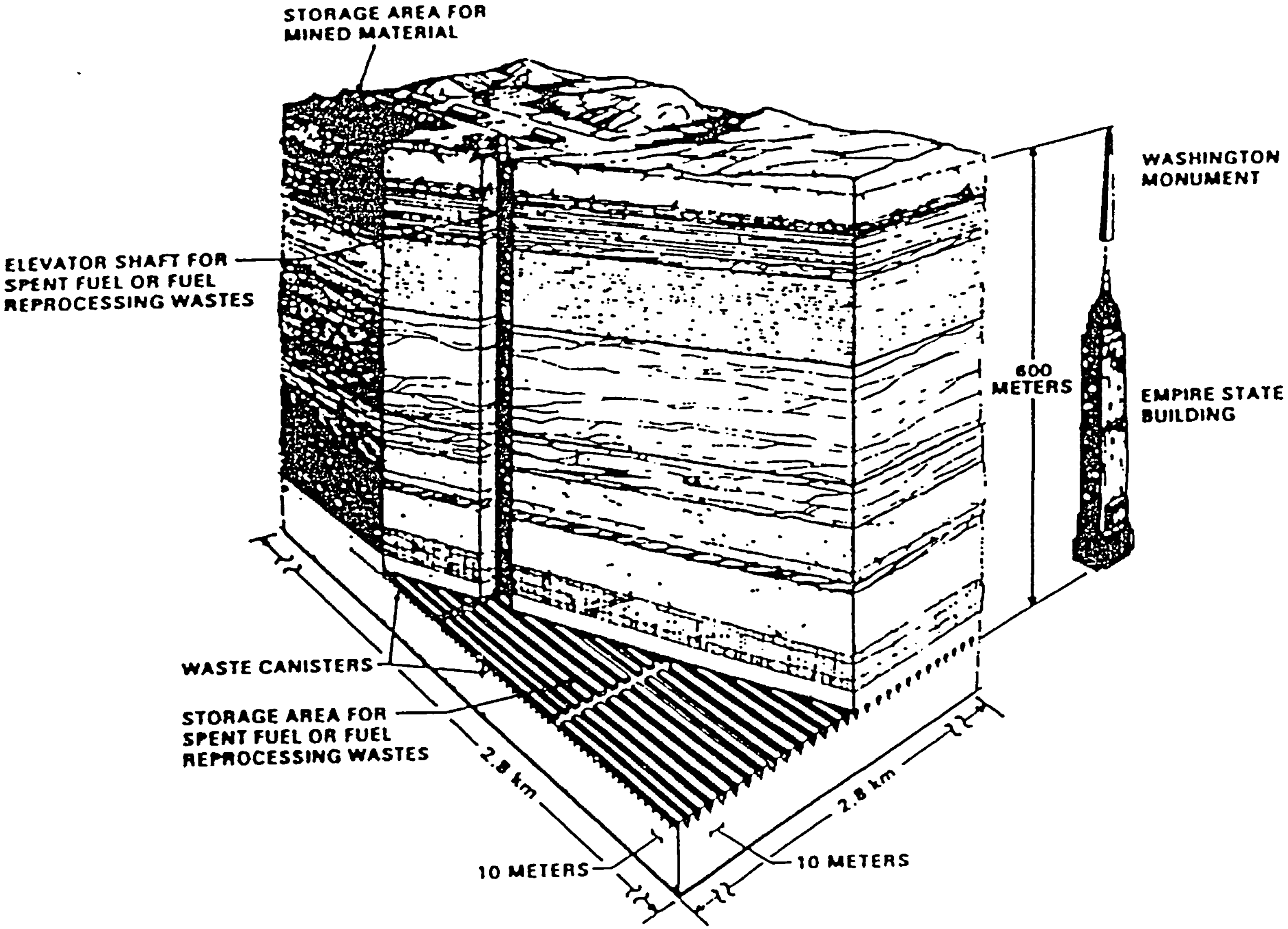
● Possible Repository Site

1980 FEIS Management of Commercially Generated Radioactive Wastes

Recommendation for subsurface geologic disposal accounted for thermal loading and its effects

- Repository concept - 3 sq. mi. disposal area (Approximately 65 kW/acre)
- Six generic factors relevant to geologic disposal addressed: depth, rock properties, tectonic stability, hydrologic regime, resource potential, multibarrier safety features
- Waste emplacement concepts controlled by thermal criteria
  - Addressed, with margins: uplift; surface and aquifer temperature rise; retrievability; HLW, fuel pin, canister and rock temperatures
  - Design APD {50 kW/acre (salt), 80 kW/acre (shale), 130 kW/acre (granite and basalt)}

FEIS - Repository Concept



National Waste Terminal Storage (NWTS) Program Siting Documents

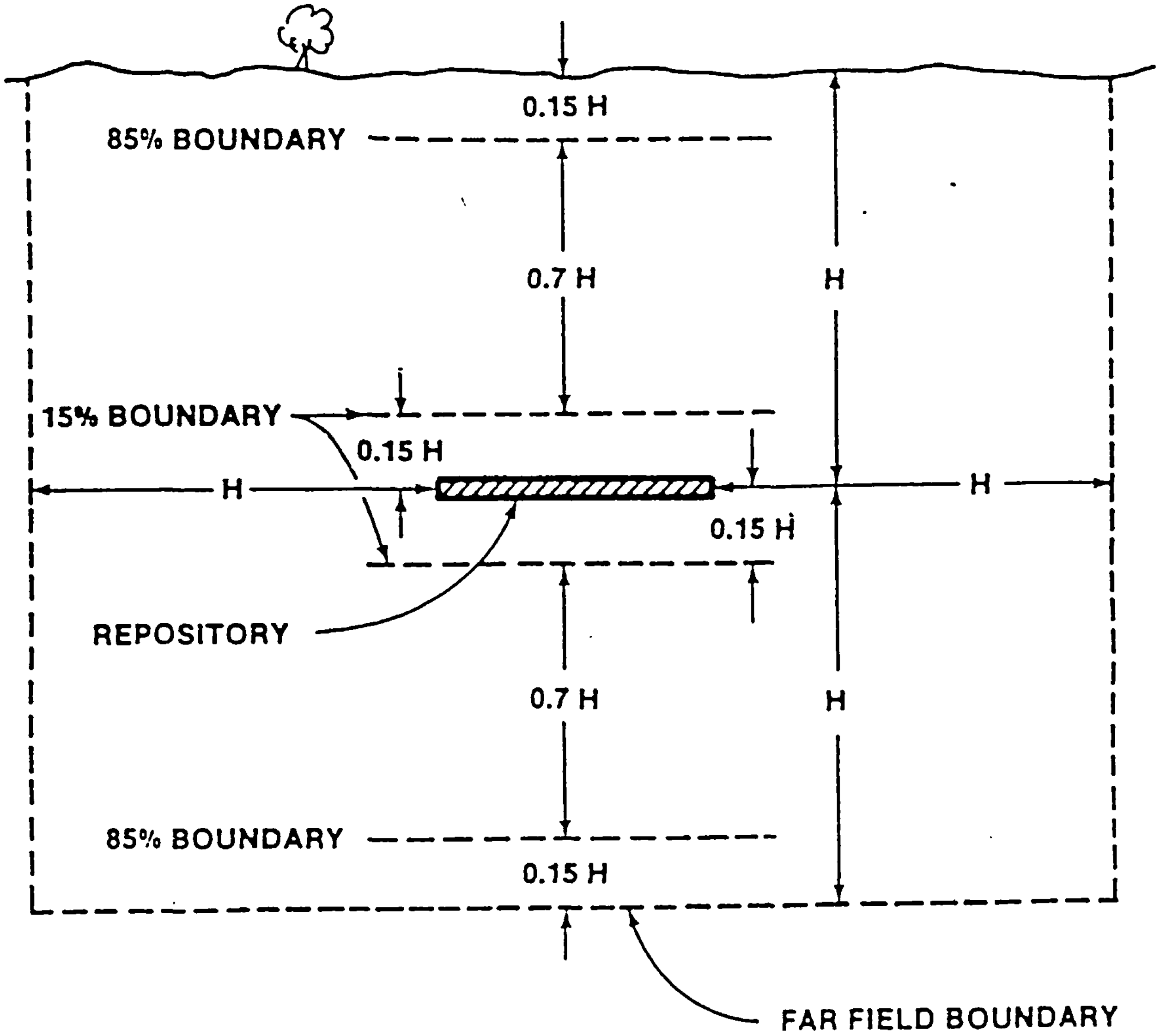
- 1981 (NWTS-25) Repository Performance Constraints in the Far-Field Domain:
  - Developed performance constraints for design and performance evaluation
- 1982 (NWTS-33(3)) Repository Performance and Development Criteria:
  - Functional requirement that repository contribute to the containment and isolation capability of the system

Generic Thermal Criteria Developed in NWTS Program

Repository performance constraints in the far-field domain (1981, NWTS-25)

- Developed performance constraints for design and performance evaluation
- Included irreversible thermochemical perturbations in the far-field
- Recommended that temperatures not exceed 100° C out to .15 H and not exceed 75° C outside that region

NWTS-25: Performance Constraints



NWTS-25: Performance Constraints

(Continued)

Fracturing

- Granite & tuff - thermomechanical stresses not cause shear failure in the middle 70% of the rock between repository horizon and surface
- All rock types - vertical extent of the perturbed fissure zone not extend downward from the surface more than 15% of the repository depth

Thermally perturbed groundwater

- Basalt, granite & tuff - the time for groundwater to travel from the repository facility to the ground surface as a consequence of thermal convective forces be greater than 1,000 years

NWTS-25: Performance Constraints

(Continued)

Shaft and borehole integrity

- All rock types - during the preclosure phase, the shaft and its components undergo no fracturing due to the thermomechanical stresses and have no significant water leakage
- All rock types - deformations of the shafts and shaft liners during the preclosure phase be sufficiently small to not impede routine operations and major remedial work is not required
- Tuff - shafts be located so that they do not intersect major faults
- Granite and tuff - during the post closure phase, permeability of sealed boreholes and shafts be approximately the same as the host rock permeability for the middle 70% of their vertical length

NWTS-25: Performance Constraints

(Continued)

- Thermomechanical perturbations

  (1) Temperatures not exceed 125° C for granite and 100° C for other types in region extending from near-field outward to 15% of the repository depth, and

  (2) Temperatures not exceed 100° C for granite and 75° C for the other rock types anywhere outside of the region defined above

- Heating of the ground surface and near surface

  - All rock types - maximum temperature increase within 3m of the ground surface be less than 4° C

  - Vertical surface displacements be less than variations of natural processes such as glacial rebound and erosion, say, less than approximately 3m, and smooth fashion over time

Generic Criteria Developed in NWTS Program

Repository performance and development criteria (1982, NWTS-33(3))

- Functional requirement to contribute to containment and isolation capability of the system
- Limit adverse impacts of repository development and operation on site performance
- Restrict temperatures to limits within which thermal impacts can be shown to have no significant degradation on system's containment and isolation capability
- Thermal limits to be prescribed, including thermochemical interactions that accelerate the rate of transport of radionuclides

Site Specific Criteria

1980 RRC-IWG* developed reference conditions

- Developed for salt, basalt, tuff, granite, and shale
- Addressed temperature, pressure, fluid, chemical and radiation effects
- Intended to guide tests, designs, be technically conservative basis for LA, waste form development
- Developed reference repository description
  - Characteristics include: depth, room dimensions, canister thermal loads, local areal thermal loads, and average areal thermal loading
- Evaluated peak near-field temperature

* Reference Repository Conditions - Interface Working Group

Reference Repository Description

Repository Characteristics	Salt		Basalt		Tuff		Granite		Shale	
	CHLW	SF	CHLW	SF	CHLW	SF	CHLW	SF	CHLW	SF
Repos. depth (m)	600	600		1000	800	800	1000	1000	600	600
Room width (m)	5.5	5.5		4.3	7.5	5.0	7.5	7.5	5.5	5.5
Room height (m)	6.4	5.5		6.1	7.0	5.0	7.0	7.0	6.4	5.5
Pillar width (m)	21.3	18.3		32.3	30	20	22.5	22.5	18	18
Hole spacing (m)	1.67	3.66		3.66 (1.22)	1.19	3.50	1.83	2.67	2.34	2.85
Canister loading (kW)	0.55	2.16		1.65 (0.55)	0.55	2.16	0.55	1.0	0.55	1.0
Local areal thermal loading (W/m²)	25	25		12.3	25	25	20	25	10	10
Average areal thermal loading (W/m²)	15	<25		8.2	<25	<25	<20	<25	8	8

1980 NWTS Information Meeting: ONWI-212

Reference Repository Description
Peak Near-Field Temperatures (°C)

Host Rock	Location	CHLW	SF
Salt	Host Rock	140	160
T_o = 34° C	Canister Wall	145	260
	Waste	175	320
Basalt	Host Rock		145 (165)
T_o = 57° C	Canister Wall		255 (170)
	Waste		275 (185)
Tuff	Host Rock	190	215
T_o = 35° C	Canister Wall	195	235
	Waste	230	275
Granite	Host Rock	150	165
T_o = 20° C	Canister Wall	170	205
	Waste	190	225
Shale	Host Rock	125	140
T_o =38° C	Canister Wall	140	210
	Waste	165	235

1980 NWTS Information Meeting: ONWI-212

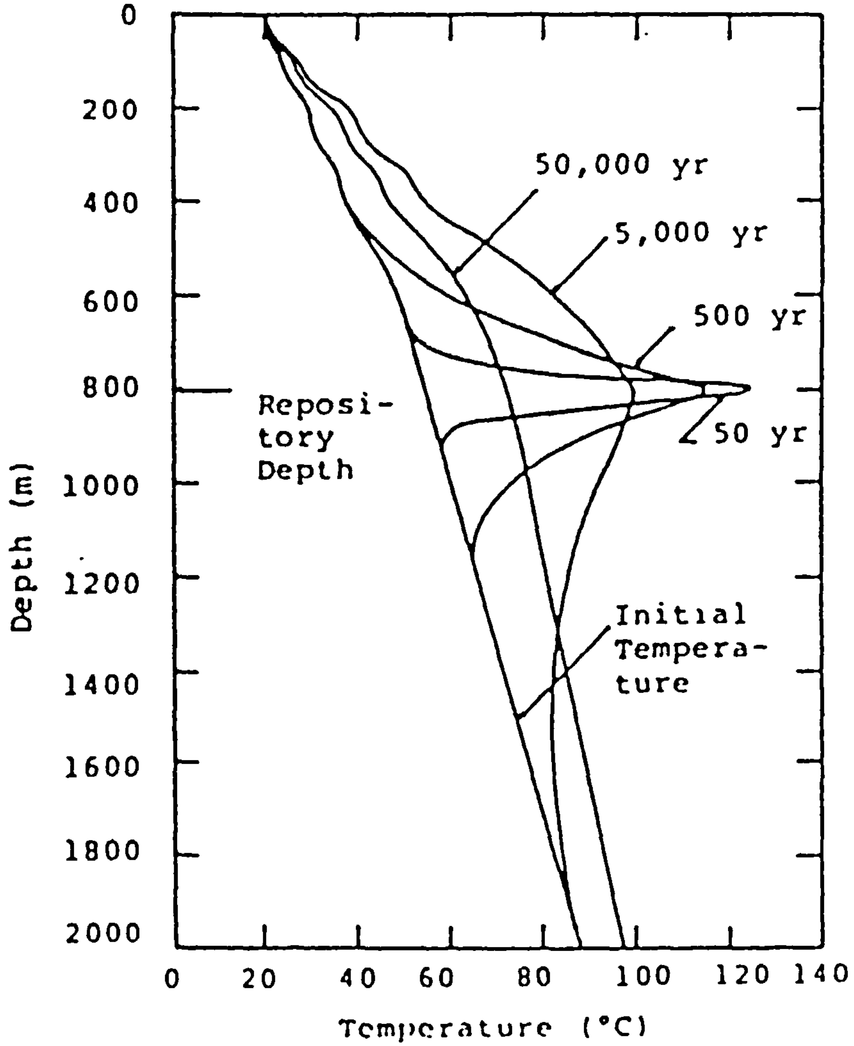
Early Yucca Mountain Site
Design Criteria and Concepts

1980 Thermal/mechanical modeling for a tuff repository

- Repository depth 800m - saturated zone
- Primary focus of study was fracturing of intact rock and changes in rock properties due to boiling of water
- GTL upper limit of 100 kW/ac

Workshop on Thermo-Mech. - Hydrochem. Modeling for
Hard Rock Waste Repository - ONWI-164

Far-Field Temperature Along Repository Vertical Centerline for GTL of 75 kW/acre



Workshop on Thermo-Mech. - Hydrochem. Modeling for
Hard Rock Waste Repository - ONWI-164

Early Yucca Mountain Site Design Criteria and Concepts

1980 Thermal/mechanical analysis of tuff

- Identify critical data needs, test plans, repository environment and integrate into data base for conceptual repository design
- Looked at near, room, and far scale heat effects as function of boiling temperature, gross thermal load, extraction ratio, changes in rock thermal properties
- Upper limit to GTL of 100 kW/acre at 20% extraction ratio as reference case

1980 NWTS *Info Meeting* ONWI-212

Early Yucca Mountain Site
Design Criteria and Concepts

- 1982 Preliminary technical constraints for a repository in tuff
  - Developed quantitative limits for assessing performance
  - Summarized technical constraints, including temperature limits in very near-, near-, and far-field, that impact mineral hydration or dehydration

1982 NWTS Information Meeting: DOE/NWTS-30

NNWSI Program
Preliminary Technical Constraints
Very Near-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Waste Form: Spent Fuel	$t_{(\text{CLAD})} < 425^\circ$ C	No constraint	No constraint
CHLW	$t_{(℄)} < 500^\circ$ C	$t_{\text{Surface}} < 100^\circ$ C if exposed to water	$t_{\text{Surface}} < 100^\circ$ C if exposed to water
Canister	No constraint	No constraint	No constraint
Overpack	To be determined	To be determined	No constraint
Backfill:			
Na-Montmorillonite			Function according to design
(tamped)	$t < \sim 390^\circ$ C	$t < 100^\circ$ C	
(compacted)	$t < 100^\circ$ C	$t < 100^\circ$ C	
Particulate	No constraint	No constraint	No constraint
No backfill	No constraint	No constraint	No constraint
Tuff	No constraint	No constraint	No constraint

1982 NWTS Information Meeting: DOE NWTB- 30

NNWSI Program
Preliminary Technical Constraints
Near-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Disposal room stability	Operational serviceability	No constraint	No constraint
Pillar stability	Factor of safety >1.5	No constraint	No constraint
Floor heave	Operational serviceability	No constraint	No constraint
Mineral dehydration/ alteration	t < 150° C	No constraint	No constraint
Environment temp.	To be determined	No constraint	No constraint
Disposal rm. floor temp.	t < 100° C	No constraint	No constraint
Tunnel backfill temp.	t < 100° C	No constraint	No constraint
Radionuclide release rate	No release	No release	< 1 part in 10^5 per year

1982 NWTS Information Meeting: DOE NWTB- 30

NNWSI Program
Preliminary Technical Constraints
Far-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Shaft pillar stability	Δ Alignment < Constr. misalignment Intersect no major faults	No constraint	
Shaft & borehole seals		Effective perm. = tuff	Apply to 70% regions above & below repository
Rock mass fracturing		No new fracturing	
Mineral dehydration/alteration		$t < 75°$ C	
Surface uplift & subsidence		< Natural analogs	
Max surface temp. increase		$\Delta t < 6°$ C (comparable with natural analog)	
Thermally perturbed groundwater flow		Travel time to accessible environment >1000 yrs	

1982 NWTS Information Meeting: DOE NWTS- 30

Early Yucca Mountain Site Design Criteria and Concepts

(Continued)

1983 NNWSI* Repository Design Approach

- Thermal loadings of 12-15 W/m^2 (48-60 kW/acre)
    - Selected to satisfy performance constraints to ensure isolation not significantly degraded
    - Repository impacts on host rock identified
- Concluded thermally induced mineral alteration not of concern in far-field

* Nevada Nuclear Waste Storage Investigations

1983 CRWM Information Meeting: CONF-831217

Repository Impact on the Host Rock

Item	Near-Field	Far-Field
Mining induced stress redistribution	Yes	No
Rock temperature change	Yes	Yes
Thermal induced stress	Yes	Yes
Thermal induced uplift	N.A.	Yes
Alteration of site hydrology		
- Repository above water table	Slight	Slight
- Repository below water table	Yes	Yes
Radiation induced rock property change	No	No
Thermal induced mineral alteration	Potential	no
Rock-groundwater-waste interaction	Yes	No

1983 CRWM Information Meeting CONF-831217

Study of the Isolation System for Geologic Disposal of Radioactive Wastes

1983 - NAS Board on Radioactive Waste Management assessed status of technology for waste disposal

- Evaluated geologic disposal performance and release control mechanisms
- Delay of water, slow dissolution, slow release, long travel, sorption, dispersion, dilution were favorable conditions
- Tuff repository benefits seen in unsaturated zone and retardation. Uncertainties seen in hydrology and thermal effects on geochemistry

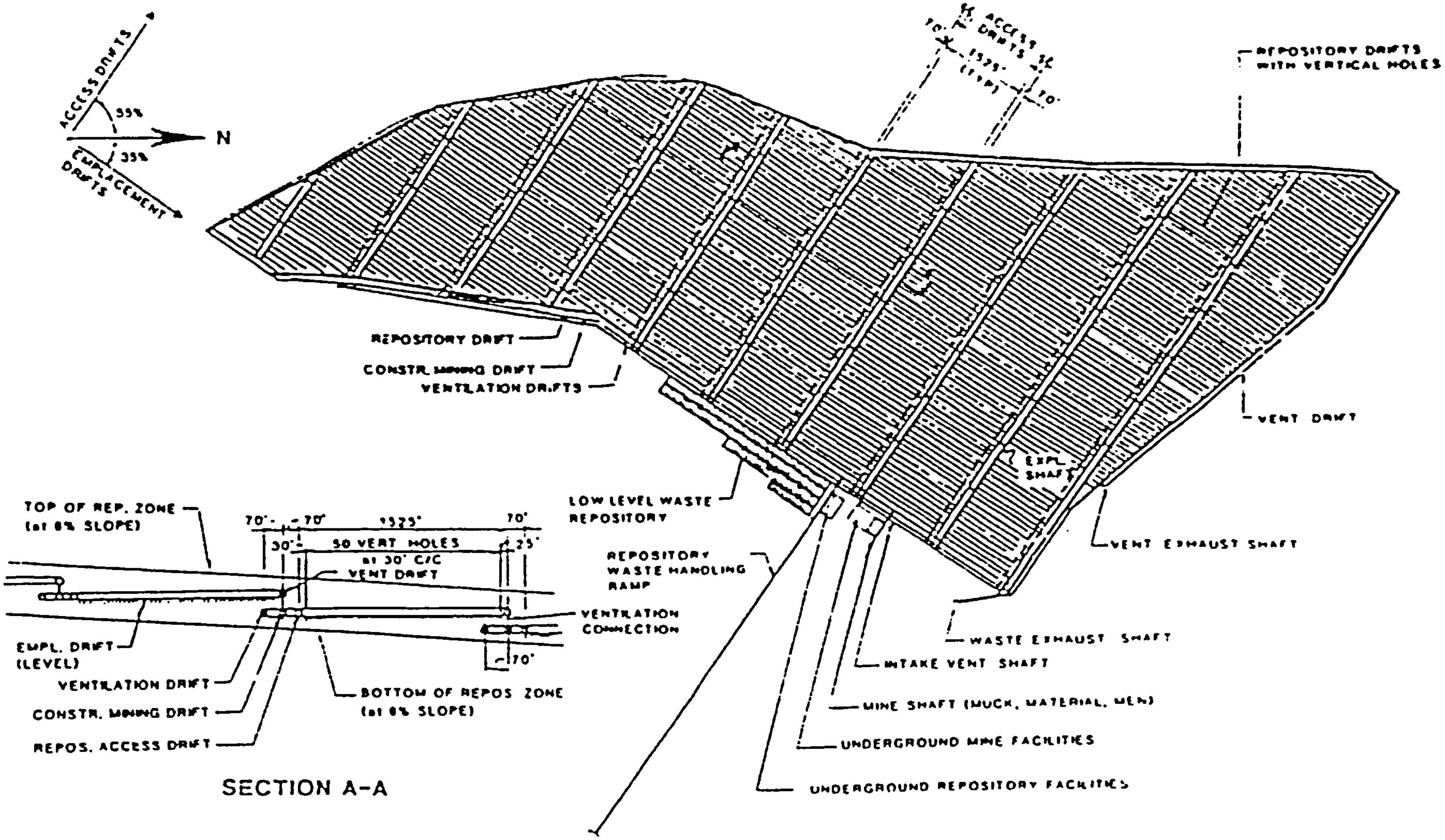
Preliminary Repository Concepts

1984 - Addressed preliminary technical constraints for 10 yrs out-of-reactor spent fuel:

- 14.1 W/m^2 (57 kW/acre) was an acceptable APD for all preliminary constraints
- Preliminary bounding calculations indicated that an APD of 22.2 W/m^2 (90 kW/acre) or more violated far-field constraints
- An APD of 18.8 W/m^2 (76 kW/acre) was acceptable for near-field concerns

SAND 83-1877

NNWSI Preliminary Repository Concepts



SECTION A-A

Preliminary Evaluations of Thermal Aspects of Site Suitability - Environmental Assessment

- Geochemistry guideline addressed thermal impacts on retardation
- Post Closure Rock Characteristics guideline addressed thermal impacts on isolation

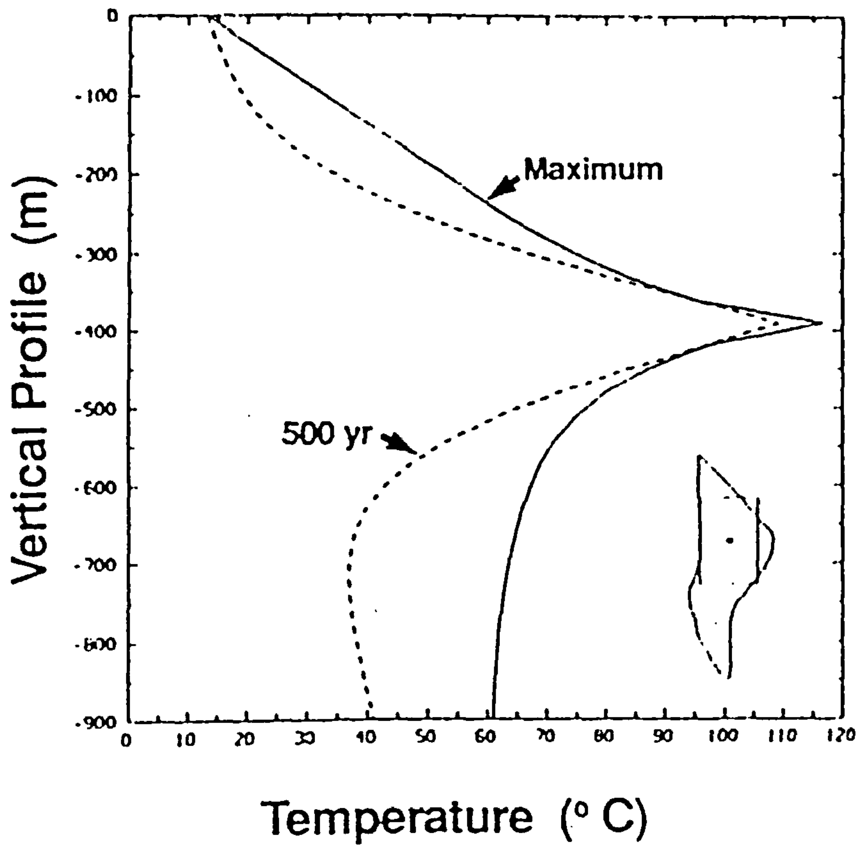
DOE/RW-0073

Temperature Profiles Determined to Support Preliminary Findings of Environmental Assessment

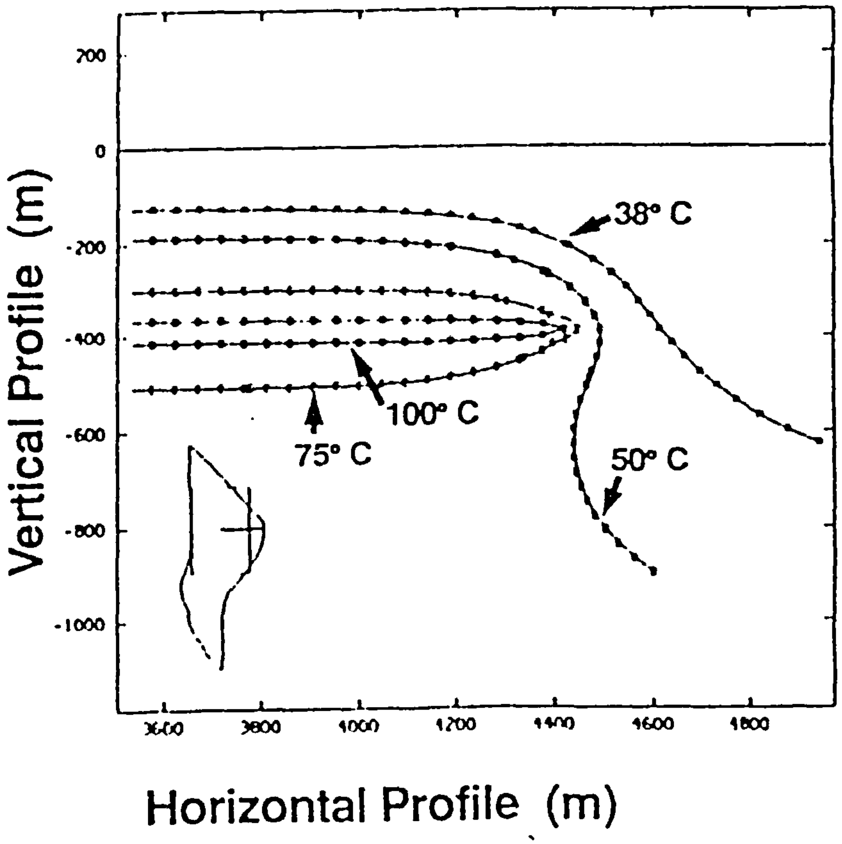
- Evaluate maximum temperature reached as function of distance from repository
- Single rectangular panel, 1260 acres at 57 kW/acre, 390m depth of repository
- Thermal properties chosen to simulate detailed thermal stratigraphy in Unit Evaluation Study

SAND 85-2509

Temperature Profiles to Support EA



Vertical Temperature Profile



Maximum Temperature Contours

Final Environmental Assessment Yucca Mountain Site, 1986

- Post closure geochemistry guideline - favorable condition

  (3) Mineral assemblages subjected to expected repository conditions have equal or increased retardation capability

  - Most sorptive zeolites more than 300m below repository, where maximum induced temperature is 60° C (Δ=23° C). Unlikely that significant zeolite decomposition would take place over 100,000 yrs

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - favorable conditions

  (2) High thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures

  - Present: low thermal expansion coefficient; calculated behavior suggests no adverse response

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - potentially adverse conditions
  - (1) Rock conditions requiring engineering measures beyond reasonably available technology to ensure waste containment or isolation
    - Not present: no conditions identified requiring other than ordinary measures to ensure isolation
  - (2) Thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation
    - Not present: expected to be physically and chemically stable; calculations indicate that thermally induced fracturing would be minor

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - potentially adverse conditions

  (3) Combination of geologic structure, geochemical and thermal properties, and hydrologic conditions so heat could significantly decrease the isolation

  - Not present: properties and conditions not expected to cause a decrease

SCP/CDR Development Process: Post Closure Considerations for Performance

1984 Unit Evaluation Study at Yucca Mountain: horizon selection evaluation

- Thermal/mechanical evaluations to confirm that none of the technical constraints were violated
- Mineral hydration/dehydration limit at t<150° C
- Plots of temperature history at far-field boundary developed
- Maximum GTL = 57 kW/ac needed to meet operational constraint of drift floor temperature <100° C

SAND 83-0372

Near-Field Preliminary Technical Constraints
Unit Evaluation Report

	SYSTEM COMPONENT	OPERATIONAL PERIOD	CONTAINMENT PERIOD	ISOLATION PERIOD
NEAR FIELD	ROOM:			
	ROOF, RIB, FLOOR	OPERATIONAL SERVICEABILITY	NO CONSTRAINT	NO CONSTRAINT
	ENVIRONMENT	TO BE DETERMINED	NO CONSTRAINT	NO CONSTRAINT
	FLOOR	T < 100°C	NO CONSTRAINT	NO CONSTRAINT
	BACKFILL	T · 100°C	NO CONSTRAINT	NO CONSTRAINT
	PILLAR	SAFETY FACTOR · 1.5	NO CONSTRAINT	NO CONSTRAINT
	MINERAL DEHYDRATION/ ALTERATION	T ·. 150°C	NO CONSTRAINT	NO CONSTRAINT
	ENGINEERED SYSTEM	NO RADIONUCLIDE RELEASE AT BOUNDARY	NO RADIONUCLIDE RELEASE AT BOUNDARY	· 10^{5} PER NUCLIDE PER YEAR

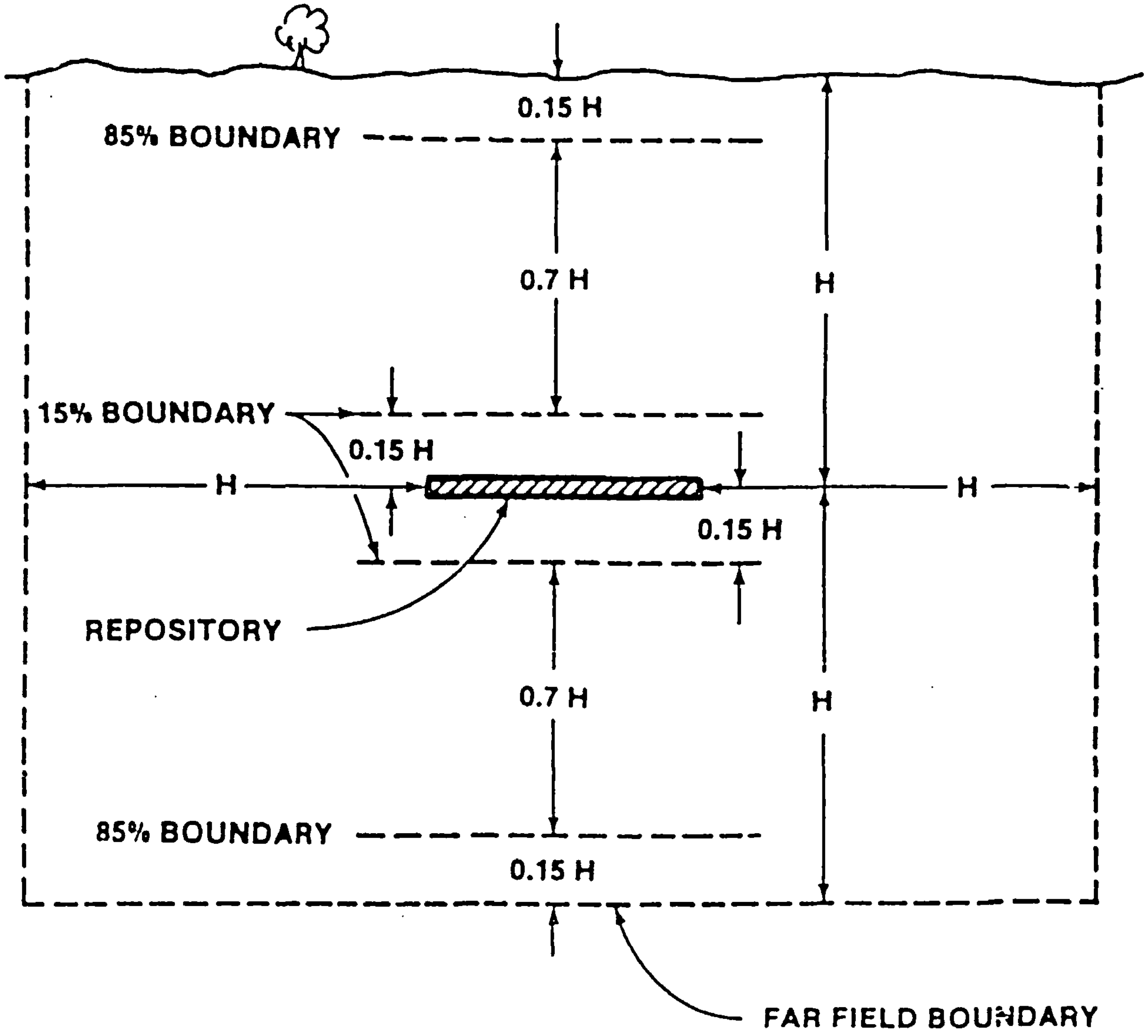
RTLHMV5P 125 NWTRB/10-8/10 91

Far-Field Preliminary Technical Constraints
Unit Evaluation Report

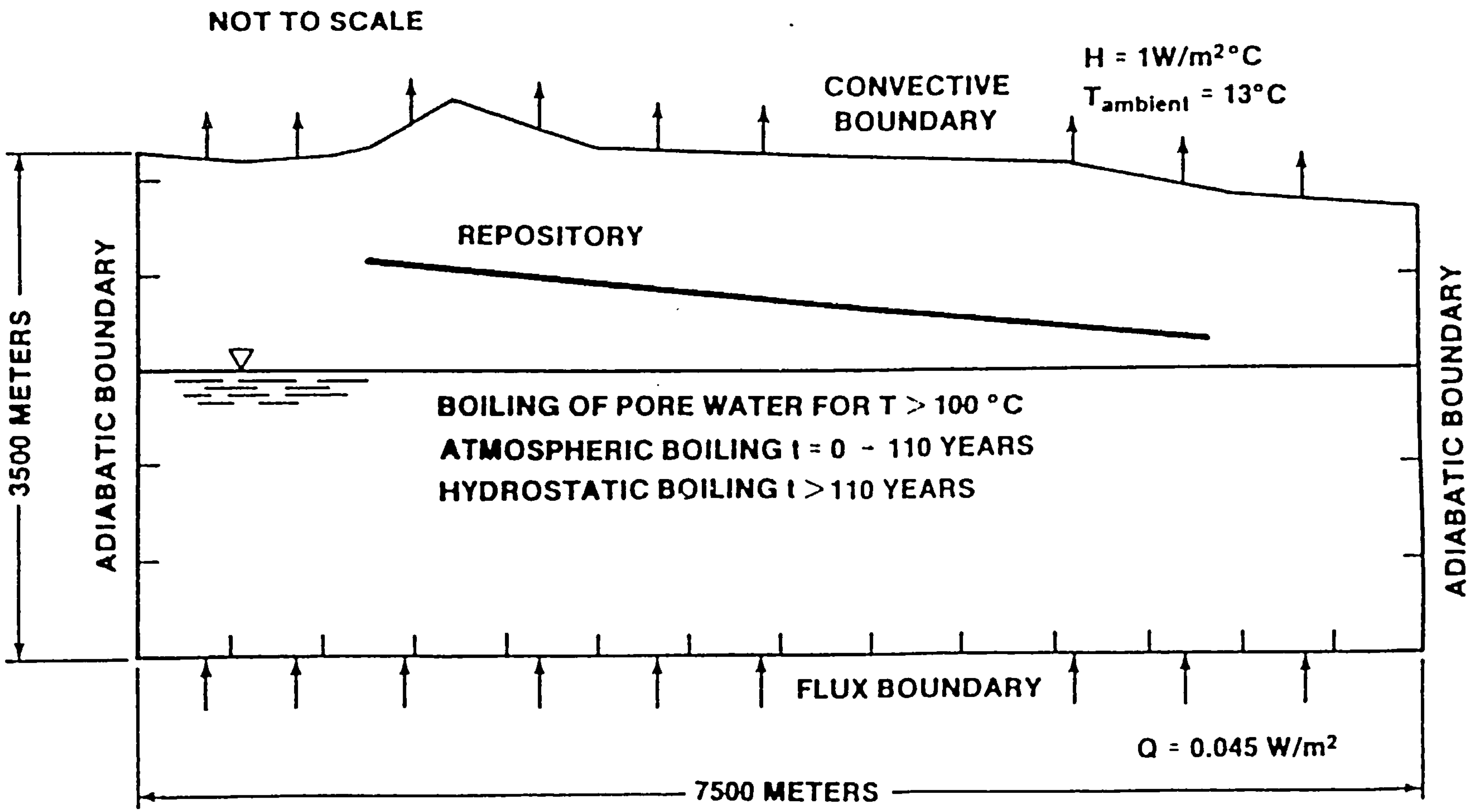
	SYSTEM COMPONENT	OPERATIONAL PERIOD	CONTAINMENT PERIOD	ISOLATION PERIOD
FAR FIELD	SHAFT	OPERATIONAL SERVICEABILITY INTERSECT NO MAJOR FAULTS	NO CONSTRAINT	
	SEALS:			
	SHAFT AND BOREHOLE		EFFECTIVE PERMEABILILTY ≤ TUFF*	
	ROCKMASS:			
	MECHANICAL BEHAVIOR		NO NEW FRACTURES*	
	MINERAL DEHYDRATION/ ALTERATION		T < 150°C*	
	SURFACE UPLIFT AND SUBSIDENCE		< NATURAL ANALOGS	
	SURFACE TEMPERATURE INCREASE		ΔT < 6°C (COMPARABLE TO NATURAL VARIATIONS)	
	THERMALLY PERTURBED GROUNDWATER FLOW		TRAVEL TIME TO ACCESSIBLE ENVIRONMENT > 1000 YEARS	

*THESE CONSTRAINTS APPLY TO THE "INTACT" (70% REGION) ROCKMASS

NWTS-25: Performance Constraints

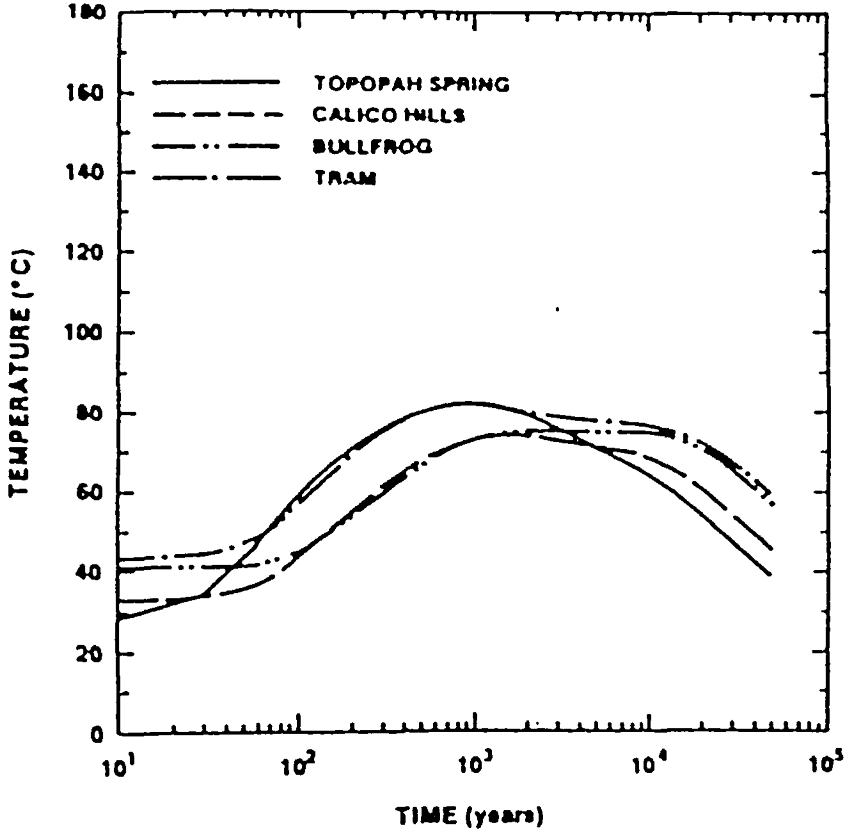


Conceptual Thermal Model

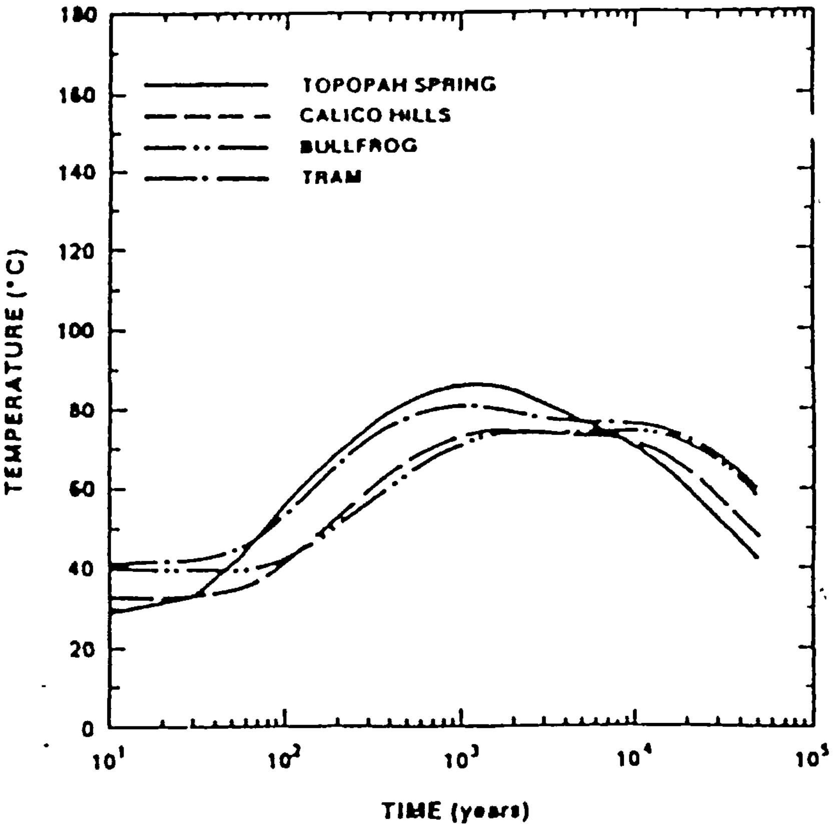


SAND 83-0372

Thermal History of Selected Boundaries: Unit Evaluation Report



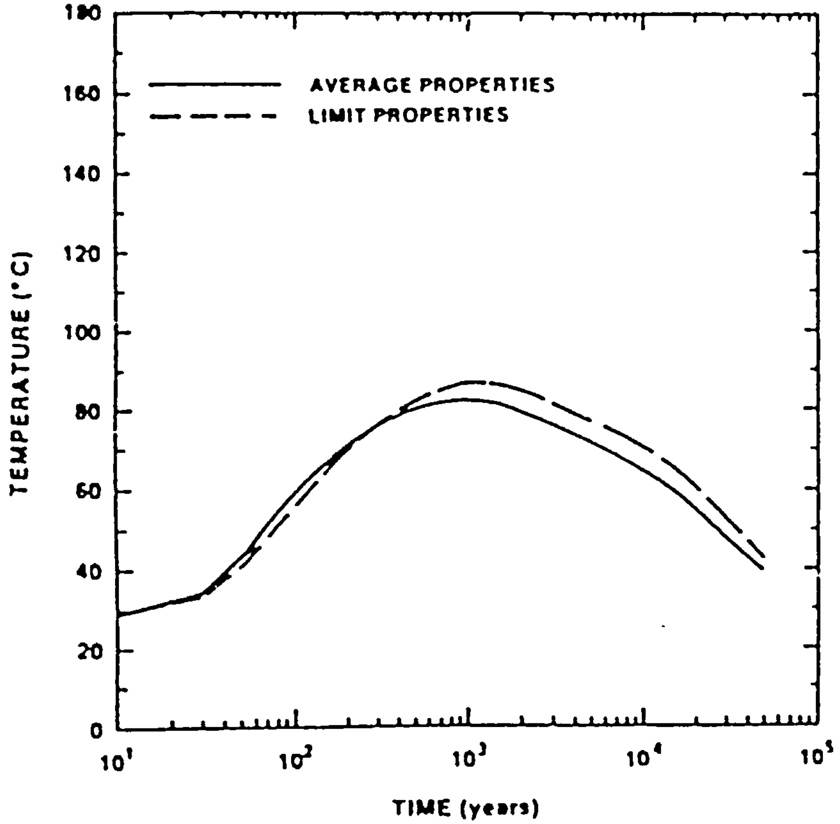
15% Boundary Below the Potential Repository Horizons (Average Properties)



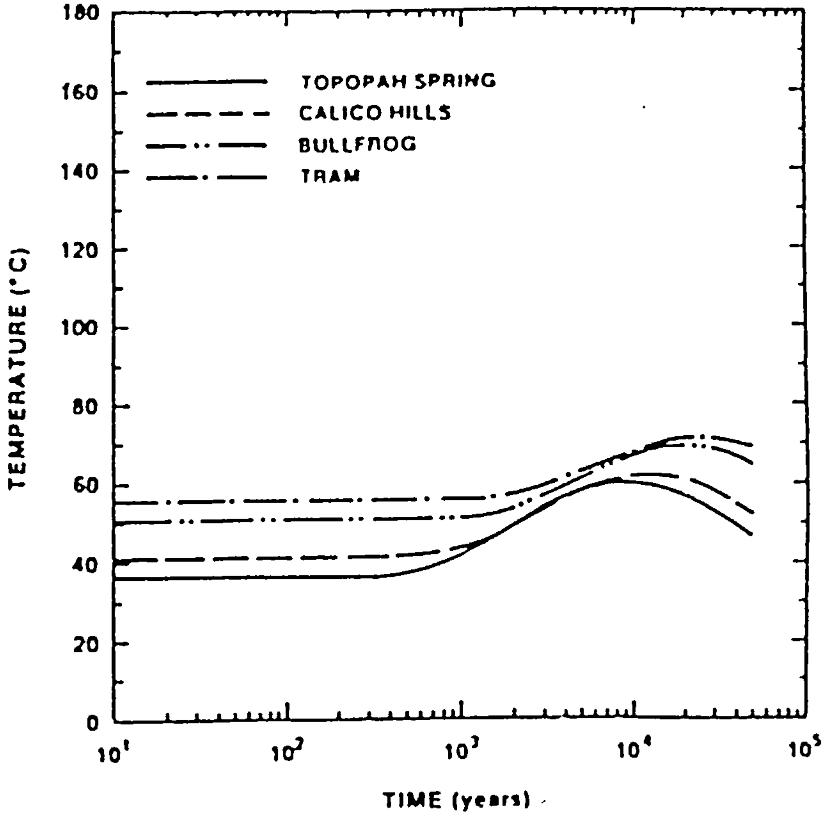
15% Boundary Below the Potential Repository Horizons (Limit Properties)

SAND 83-0372

Thermal History of Selected Boundaries: Unit Evaluation Report



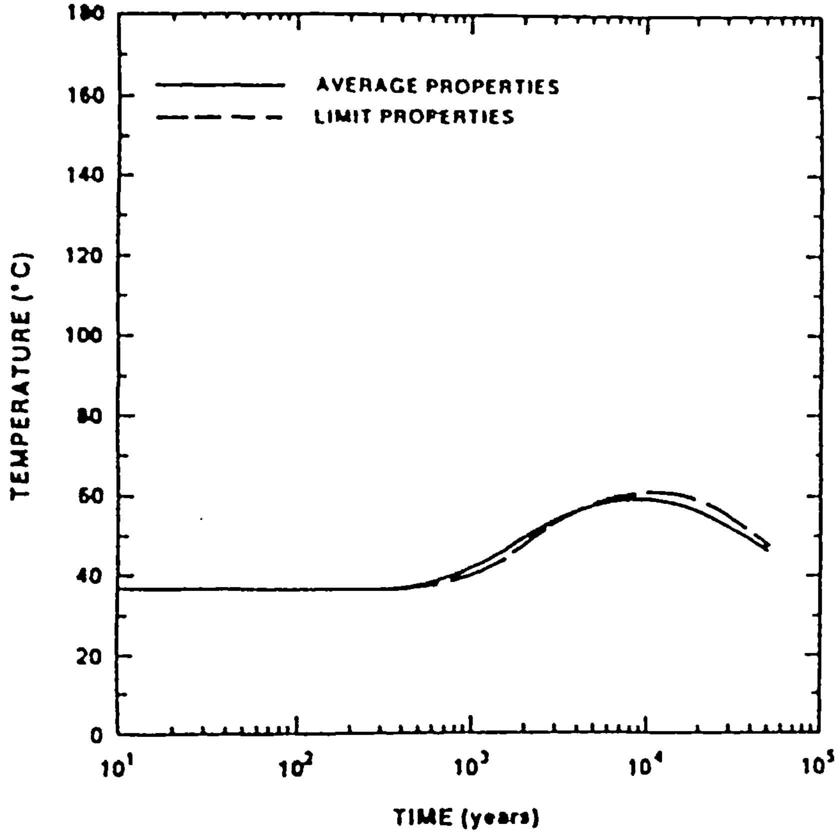
15% Boundary Below the Topopah Spring Horizon



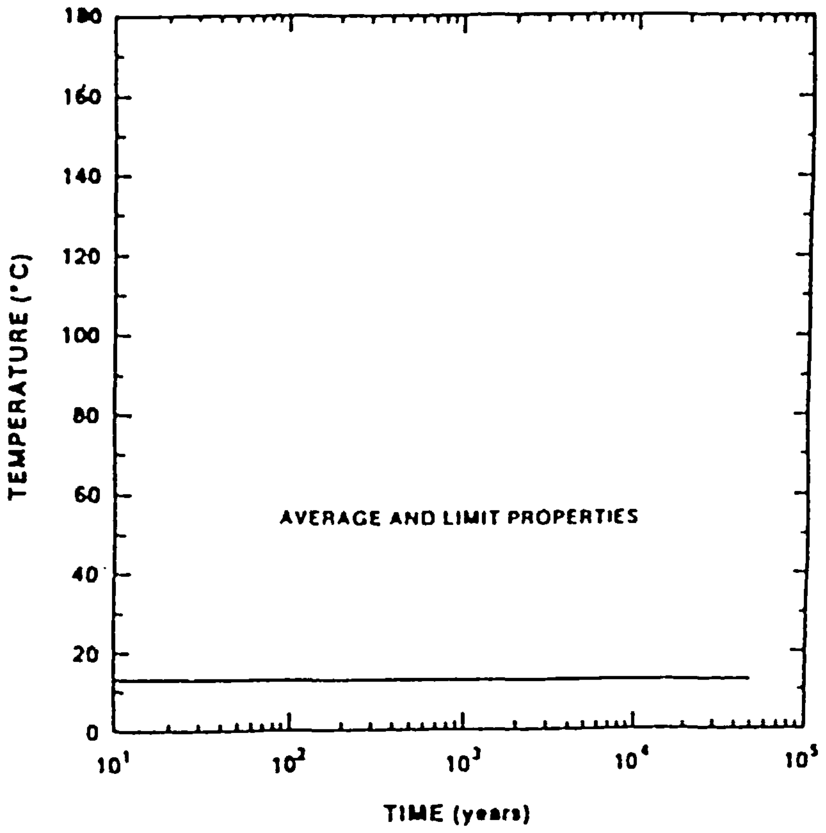
85% Boundary Below the Potential Repository Horizons

SAND 83-0372

Thermal History of Selected Boundaries: Unit Evaluation Report



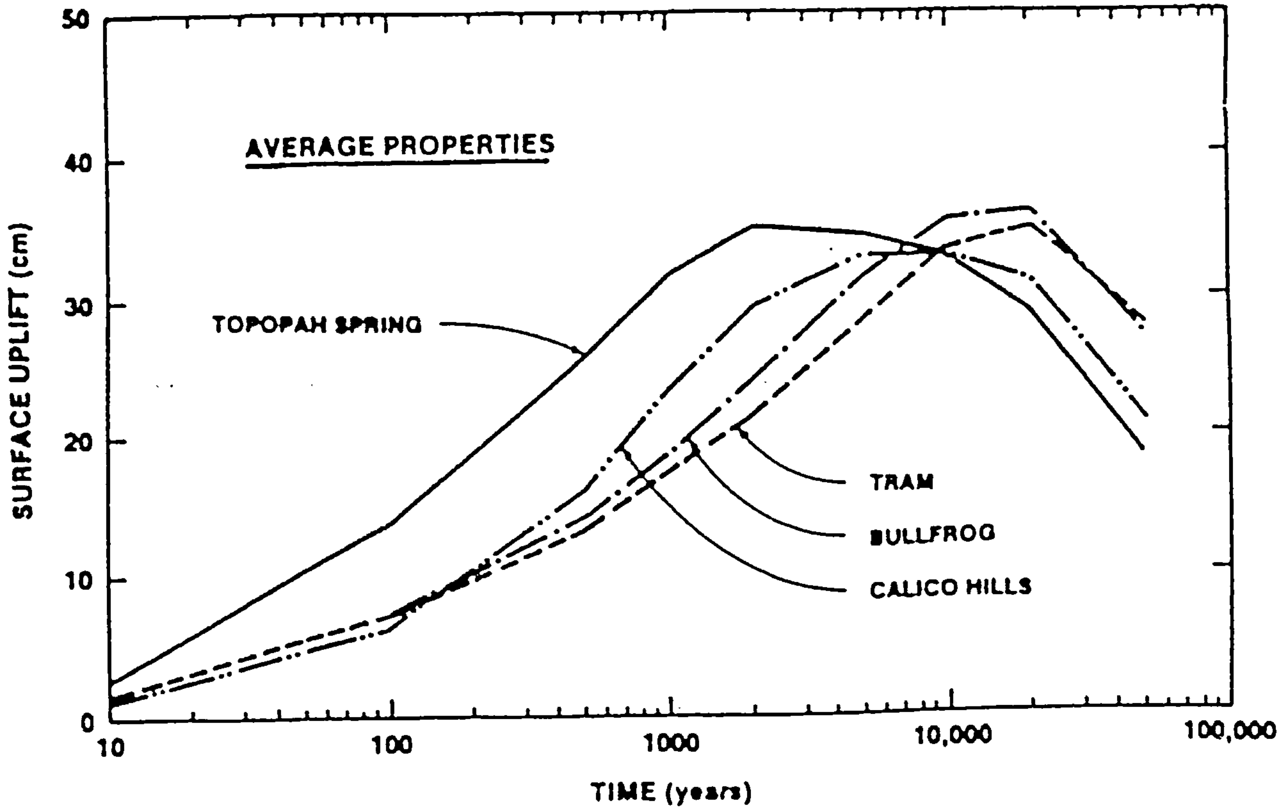
85% Boundary Below the Topopah Spring Horizon



3m Below Ground Surface,
Repository in
Topopah Spring Horizon
(Max Δt = 0.6° C at time = 3,000 yrs)

SAND 83-0372

Surface Uplift Resulting From a Repository Emplaced in the Designated Units (Average Properties Throughout the Section)



SAND 83-0372

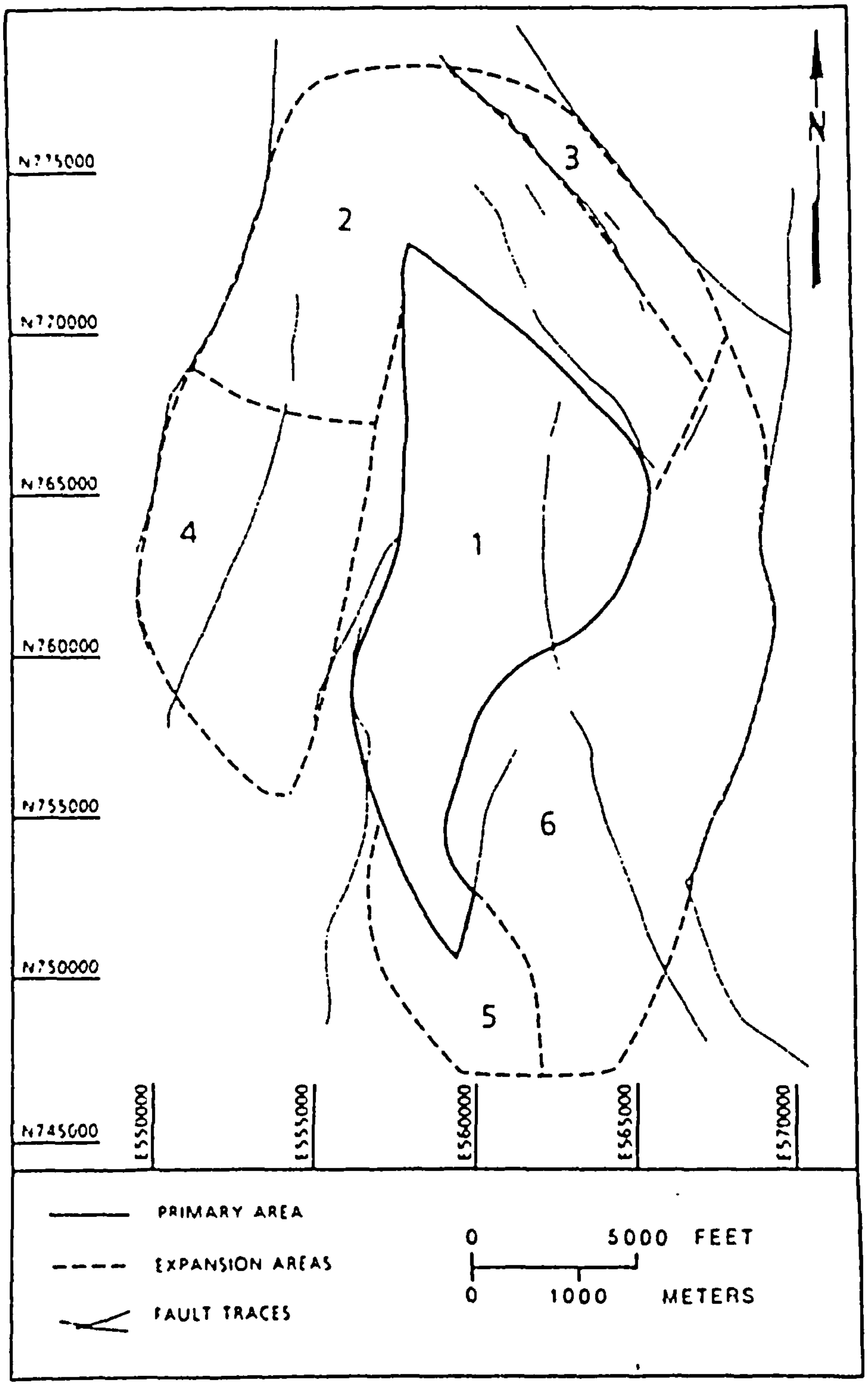
SCP/CDR Development Process: Post Closure Considerations For Performance

1984 Area available for a potential repository at Yucca Mountain

- Area requirement of 1520 acres based on 57 kW/ac APD
- Noted that value could change with other conceptual design changes
- Primary area 2200 acres, primary expansion area similar in size and properties

SAND 84-1153

Primary Area (Area 1) For the Underground Repository and Potential Expansion Area (Areas 2 Through 6)



RDBCNV5P 125 NWTRB9 18/19-91

Assessment of Repository Related Impacts - Disturbed Zone

NRC Generic Technical Position (GTP) on extent of the disturbed zone - 1986

- Four factors of concern:
  - Stress redistribution
  - Construction and excavation
  - Thermomechanical effects
  - Thermochemical effects
- Conclude
  - Five diameters reasonably conservative estimate
  - Need site specific evaluation

Assessment of Repository Related Impacts - Disturbed Zone

(Continued)

Disturbed zone boundary for a repository at Yucca Mountain - 1987

- Volume of rock with significant changes in flow of groundwater
- Site specific evaluation of the extent of the disturbed zone
  - Units with large amounts of clay and zeolites far enough away to ensure temperatures remain below values (115° to 125° C) at which changes in their hydrologic properties might occur;
  - Looked at silica dissolution and deposition
  - Looked at temperature effects on permeability
- Concluded disturbed zone extent less than 10m

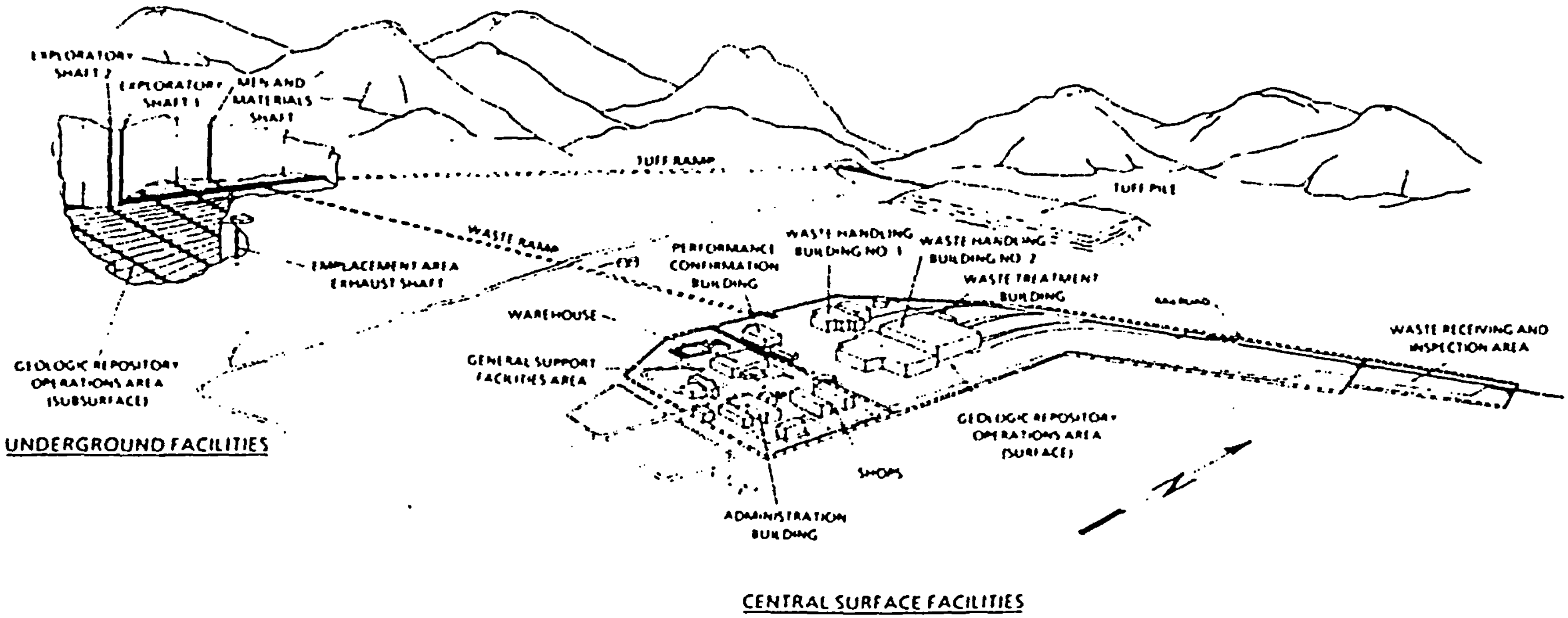
SAND 86-1955

Site CharacterizationPlan
Conceptual Repository Design

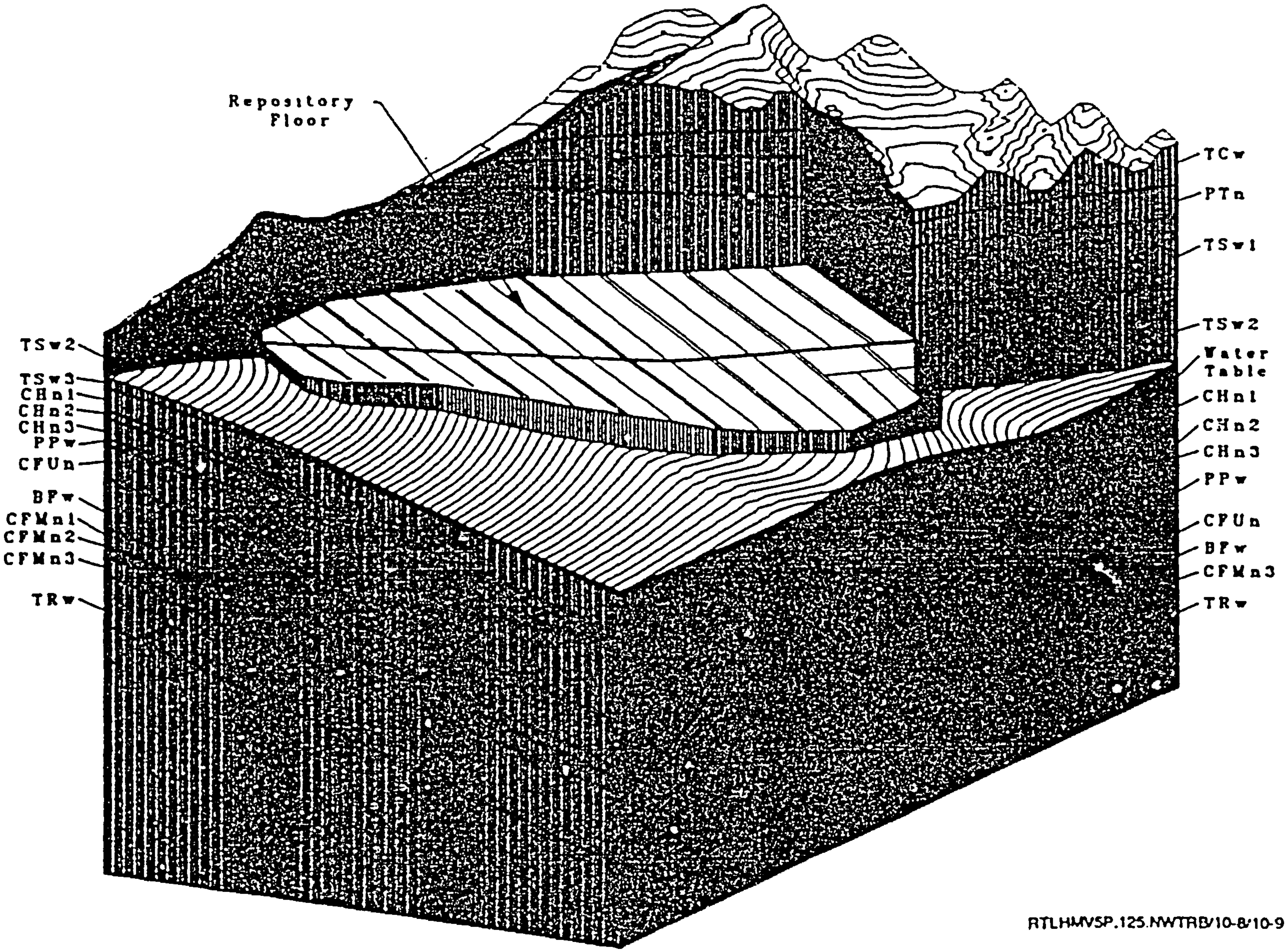
- Basis is equivalent energy density through 2,000 years of 10 year old average burnup spent fuel emplaced at 57 kW/ac
- Borehole wall temperature <275° C (to ensure waste temperature less than 350° C)
- Temperatures limited in selected barriers (<200° C - 1m from borehole wall; <115° C - in Calico Hills; <115° C - in TSw3). (Rationale for the latter two limits derived from zeolite, glass, and clay alteration below the repository horizon and the potential disturbed zone boundary)

SAND 86-1955

PRELIMINARY DRAWING OF PROPOSED REPOSITORY COMPLEX



Repository Conceptual Design



Concluding Remarks

- Thermal impacts and induced changes have been addressed in both requirements and design studies
- Yucca Mountain Conceptual Repository Design is consistent with early program concepts
- Yucca Mountain Conceptual Repository Design appears to meet constraints designed to limit impacts to system performance

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HISTORICAL PERSPECTIVE OF U.S. PROGRAM

PRESENTER: CARL P. GERTZ

PRESENTER'S TITLE AND ORGANIZATION: PROJECT MANAGER
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7900

OCTOBER 8 - 10, 1991

Criteria For Nuclear Waste Disposal Have Been Developed in a Logical Process

- Top level criteria established in 1978 by National Academy of Science
- Thermal limit criteria proposed in the 1980 DOE statement for the Waste Confidence Rulemaking
- Thermal loading margins were proposed in 1980 Final Environmental Impact Statement for Management of Commercially Generated Radioactive Waste
- General and specific thermal constraints have been established

National Academy of Science Was Involved in Development of Early Criteria

- 1955: Asked to help establish a scientific base for the waste management program
- 1957: Stated mined geologic disposal feasible and salt appeared promising (assumption waste would be low concentrate in liquid)
- 1978: Established geologic criteria for repositories for high-level waste
  - Long term stability criteria
  - Heat should not reach levels high enough to compromise geologic containment

National Waste Terminal Storage (NWTS) Program Developed

- 1975 NWTS program studies initiated
  - Multi-site survey of underground disposal in 36 states, designed to lead to the development of 6 pilot scale repositories by 2000
  - Focus on rock types other than salt reflected both medium and environment
- 1978 NAS involved in decision to consider siting a repository in tuff

Thermal Issues Were Addressed in Early Program Rulemakings:

- 1980: Waste Confidence Rulemaking: DOE position provided guidelines for thermal design criteria
- 1983: 10 CFR Part 60 technical criteria concerned with thermal loads
- 1985: 10 CFR Part 960 siting guidelines concerned with thermal effects on site

Final Environmental Impact Statement on Management of Commercially Generated Radioactive Waste Issued in 1980

- Discussed generic factors relevant to geologic disposal
- Repository concept - 3 sq. mi. disposal area (approx. 65 kW/acre)
- Waste emplacement concepts controlled by thermal criteria (salt-50 kW/acre; shale-80 kW/acre; granite and basalt-130 kW/acre)

NWTS Program Siting Documents Provided Specific Guidance

- 1981 (NWTS-25) Repository Performance Constraints in the Far-Field Domain:
  - Developed performance constraints for design and performance evaluation
- 1982 (NWTS-33(3)) Repository Performance and Development Criteria:
  - Functional requirement that repository contribute to the containment and isolation capability of the system

Nuclear Waste Policy Act (NWPA) Defined DOE's Mission

1982 Nuclear Waste Policy Act

- Established the Federal responsibility and a definite Federal policy for the timely disposal of HLW and SF
- Established an ambitious schedule for the development of repositories
- Directed DOE to develop guidelines for the recommendation of sites that would specify detailed geologic considerations that would be the primary criteria for selection of sites

Nuclear Waste Policy Act Amended

1987 Nuclear Waste Policy Amendments Act

- Redirected nuclear waste program to study the suitability of the Yucca Mountain site
- Single site to be studied is in unsaturated zone
- Established the Nuclear Waste Technical Review Board

NWTRB Reports to Congress

First Report: March, 1990

- Concerns about thermal loading of a repository and reduction of uncertainty in geologic disposal by reducing the thermal loading

Second Report: November, 1990

- Concerns about uncertainties in factors influencing the thermal loading of the repository host rock and the Calico Hills nonwelded unit
- Concerns about thermally-induced changes in conditions and effects on engineered barriers

NWTRB Reports to Congress

(Continued)

Third Report: May, 1991

- Concerns about repository conceptual design alternatives addressing thermal loading
- Concerns about thermal loading and waste aging relationships and their impact on design

Concluding Remarks

- DOE has a repository conceptual design that appears to meet criteria developed in the program
- Clearly, scientific data from characterization is needed to reduce uncertainties in design inputs
- DOE understands the concerns of the Board and will address them in this meeting
- We view this meeting as an opportunity to discuss constraints on thermal criteria so a range of thermal loading approaches can be examined in future design activities