## Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Range of Operating Temperatures

August 2, 2001
Rockville, Maryland

Introduction and Objectives

This Technical Exchange and Management Meeting on Range of Operating Temperatures is one in a series of meetings related to the U.S. Nuclear Regulatory Commission (NRC) key technical issue (KTI) and sufficiency review, and the potential U.S. Department of Energy (DOE) site recommendation. The objectives for this meeting were for DOE to (1) summarize the Supplemental Science and Performance Analyses (SSPA) model supplements since the Science and Engineering Report and (2) discuss differences between higher-temperature and lower-temperature operating modes based on process models. This was the first of two separate meetings on this topic. The second meeting, currently scheduled for September 2001, will focus on the NRC staff's questions pertaining to DOE's SSPA.

Consistent with NRC regulations on prelicensing consultations and a 1992 agreement with the DOE, staff-level resolution can be achieved during prelicensing consultation. The purpose of issue resolution is to assure that sufficient information is available on an issue to enable the NRC to docket a proposed license application. Resolution at the staff level does not preclude an issue being raised and considered during the licensing proceedings, nor does it prejudge what the NRC staff evaluation of that issue will be after its licensing review. Issue resolution at the staff level, during prelicensing, is achieved when the staff has no further questions or comments at a point in time regarding how the DOE is addressing an issue.

Summary of Meeting

DOE provided a general briefing on the Yucca Mountain thermal design history, the current thermal management methodology, and the scope of the SSPA and comparison of the thermal operating modes. No NRC/DOE agreements were reached at this Technical Exchange and Management Meeting. The agenda and the attendance list are provided in Attachments 1 and 2, respectively. Copies of the presenters' slides are provided in Attachment 3. Highlights from the Technical Exchange and Management Meeting are listed below.

Highlights

### 1) DOE's Yucca Mountain Project - Thermal Design History

DOE discussed the changes in DOE's thermal goals since the Viability Assessment (see "YMP Thermal Design History" presentation given by Paul Harrington). DOE then discussed its next steps in moving toward a possible license application and stated its license application design would include a fixed design with flexible operational modes. DOE further stated that it would be formulating the decision process for selecting the licensing operating mode. This process would establish the thermal operating mode, determine appropriate thermal limits, and select operational ranges or parameters for licensing. The NRC staff had several questions related to the design. These questions will be more fully discussed during the next meeting on this subject.

**2) DOE's Current Thermal Management Methodology**

DOE discussed its Yucca Mountain methodology for thermal management and the effects of this methodology on the design process (see "Current Thermal Management Methodology" presentation given by Gene Rowe). DOE discussed the design presented in the Science and Engineering Report and the SSPA and stated that it represents a single design which will work over the full range of thermal modes. DOE then discussed these different thermal modes and the potential range of operational variables. DOE stated that some of the attributes of flexible operations are: (1) ability to operate under various thermal modes, (2) ability to accommodate variations in waste stream characteristics, (3) ability to accommodate changes in receipt and emplacement rates, and (4) ability to provide for checks and balances for problem detection and corrective action. The NRC staff had several questions related to the methodology. These questions will be more fully discussed during the next meeting on this subject.

**3) Scope of the SSPA and Comparison of Thermal Operating Modes**

DOE discussed the scope of the SSPA and the comparisons between the thermal operating modes (see "Scope of the SSPA and Comparison of Thermal Operating Modes" presentation given by James Blink and Robert Howard). DOE discussed the organization and scope of the SSPA and provided a summary of the supplemental modes and analyses made since the Science and Engineering Report. DOE then went into a little more detail on these changes. The NRC staff had a number of questions regarding the updated scientific information, uncertainty analysis changes, and how certain changes impacted the cooler thermal operating mode. These questions will be more fully discussed during the next meeting on this subject.

**4) Public Comments**

Ms. Judy Treichel (Nevada Nuclear Waste Task Force) commented that the second meeting of this subject should not occur during the Nuclear Waste Technical Review Board meeting scheduled for September 10-12, 2001. The NRC stated that it was aware of this meeting and would try to avoid scheduling it on the same days.

James W. Andersen, Project Manager
High Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission

Timothy C. Gunter
Regulatory Interactions
Office of Licensing & Regulatory Compliance
U.S. Department of Energy

**DRAFT AGENDA**
**DOE/NRC MEETING ON REPOSITORY THERMAL MANAGEMENT**
**10:00 A.M. - 4:45 P.M. (EDT)**
**August 2, 2001**
**Room O3B-4**
**11555 Rockville Pike**
**Rockville, MD**

Via videocon to: Region IV, DOE, Las Vegas, and CNWRA, San Antonio, Texas

| | | |
|---|---|---|
| 10:00 - 10:15 a.m. | Introduction and Opening Remarks | DOE - Gunter<br>NRC - Andersen |
| 10:15 - 10:45 a.m. | Thermal Management History of the Proposed Repository | DOE - Harrington |
| 10:45 - Noon | Current Thermal Management Methodology | DOE - Trautner/Rowe |
| Noon - 1:00 p.m. | Lunch | |
| 1:00 - 2:45 p.m. | Supplemental Science and Performance Analyses Overview - Evaluation of the Range of Thermal Operating Modes | DOE - Blink |
| 2:45 - 3:15 p.m. | Caucus | |
| 3:15 - 4:15 p.m. | Discussion | DOE/NRC |
| 4:15 - 4:45 p.m. | Conclusion, Closing Remarks and Adjourn | |

Attachment 1

8/2/2001

NRC/DOE Tech Exchange - Thermal Management & Op. Temp

| Name | Org | Phone |
|---|---|---|
| Timothy C. Gunter | DOE | 702-794-1343 |
| James Andersen | NRC | 301-415-5717 |
| Dave Esh | NRC | 301-415-6705 |
| David Brooks | NRC | 301-415-7284 |
| Jeffrey Pohle | NRC | 301-415-6703 |
| Mysore Nataraja | NRC | 301-415-6695 |
| Charles Greene | NRC | 301-415-6177 |
| Robert K. Johnson | NRC | 301.415.6900 |
| Tae M. Ahn | NRC | 301 415-5812 |
| David Siefken | BSC | (202) 479-2104 |
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| John H. Pye | NWTRB | (703)-235-4473 |
| James Firth | NRC | 301-415-6628 |
| Rob MacDougall | BSC | 202.479.2122 |
| Baki Ibrahim | NRC | 301-415-6651 |
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| Mark Senderling | DOE | 202 586-2279 |
| Martha Pendleton | BSC | (702) 295-2117 |
| Don Beckman | BSC | 702-295-4392 |
| James Blink | BSC (LLNL) | 702-295-4371 |
| Amarjit Singh | NRC/ACNW | 301 415-6899 |
| Kirk Lachman | DOE | 702-794-5096 |
| Robert Howard | BSC | 702-295-3097 |
| Paul Harrington | DOE | 702-794-5415 |
| Gene Rowe | BSC | 702-295-4246 |

Attachment 2

8/2/01 NRC ... THERMAL MANAGEMENT

| NAME | ORGANIZATION | PHONE |
|---|---|---|
| April Gil | DOE/YMP/OLRC | 702 794-5578 |
| DAVE LANIER | BSC/LAP/RCC | 702 295-5331 |
| David Rhodes | BSC/Proj/S.P. | 702-295-4358 |
| Ralph Rogers | MTS/BAH | 702-794-1415 |
| Bob Bradbum | MTS/S&W | 702-794-5424 |
| George Hellstrom | DOE | 702-794-1419 |
| ROBERT SAUNDERS | BSC SSFD | 702 295 4380 |
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| BIMAL MUKHOPADHYAY | BAH/MTS | 702-794-5420 |
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| Jennivieve Novero | BSC/BA | (702) 295-5312 |
| Richard Craun | DOE | 702-794-1488 |
| Judy Treichel | NV NWTF | 702-248-1127 |
| Steve Frishman | NV NWPO | 775-687-3744 |
| Harris Greenberg | MTS/BAH | 702-794-1385 |
| John B. Cue | BSC/EBS | 702-295-7472 |
| DAVID SASSANI | MTS/Golder | 702-794-5501 |
| Raina Downing | Nye Co | 775-727-~~7727~~ |
| Ahmed M Monib | BSC | 702-295-7631 |
| JAIME GONZALEZ | DOE | 702 794 5584 |
| CARL DiBELLA | NWTRB (BY PHONE) | (703) 235-9130 |

# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
# MEETING ATTENDANCE

SUBJECT OF MEETING DOE/NRC Meeting on Repository Thermal Management

DATE: 8/2/2001 LOCATION: SwRI Videoconference Room, San Antonio

| PERSON | ORGANIZATION | TITLE/FUNCTION | TELEPHONE NUMBER |
|---|---|---|---|
| Asad Chowdhury | CNWRA | Manager - MGFE | (210) 522-5151 |
| Wes Patrick | CNWRA | President - CNWRA | (210) 522-5158 |
| Debra Hughson | CNWRA | PI TEF KTI | 210 522 3805 |
| Lane Howard | CNWRA | S.E.C. / PA KTI | (210) 522-4881 |
| Pat Mackin | CNWRA | Assistant Technical Director | (210) 522-5054 |
| Doug Gute | CNWRA | Sr. Research Engineer | (210) 522-2307 |
| David Turner | CNWRA | Principal Scientist | (210) 522-2139 |
| Blaine Russell | CNWRA | Analyst | 210-522-6249 |
| Sean Brossia | CNWRA | Sr. Research Eng. | 210 522 5797 |
| James Weldy | CNWRA | Sr. Res. Engr. | (210) 522-6800 |
| Ron Janetzke | CNWRA | Analyst | 210-522-3318 |
| Darrel Sims | CNWRA | Res. Sci. | 210-522-6827 |
| Sitakanta Mohanty | CNWRA | Principal Scientist | 210-522-5185 |
| Osvaldo Pensado | " | Res. Eng. | 522-6084 |
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# Attachment 3

# Presenters' Slides

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

YUCCA MOUNTAIN PROJECT

# YMP Thermal Design History

Presented to:
**U. S. Nuclear Regulatory Commission**

Presented by:
**Paul Harrington**
Systems Engineering
Office of Project Execution
Yucca Mountain Site Characterization Office

August [illegible]
[illegible]

# YMP Historical Time Phases Reflecting Changes in Thermal Goals

- Viability Assessment (VA)
- License Application Design Selection (LADS)
- Nuclear Waste Technical Review Board (NWTRB) and Other Party Inputs
- Thermal Operational Scenarios Considered
- Science and Engineering Report (S&ER)
- Next Step

# Evolution of Design Features

| Parameter | Viability Assessment | Enhanced Design Alternative II | Current Reference Design and Operating Mode | |
|---|---|---|---|---|
| | | | High End | Low End |
| Average waste package maximum surface temperature (°C) | 230 | 230 | ~175 | <85 |
| Maximum drift-wall temperature (°C) | 200 | 200 | <175 | <85 |
| Pillar temperature (°C) | >96 | Center below 96 | 50% below 96 | < 85 |
| Areal mass loading(MTHM/acre) | 85 | 60 | ~60 | ~40 |
| Area for 70,000 MTHM (acres) | 741 | 1,050 | 1,050 | 1,600 |
| Total excavated emplacement drift length (Km) | 107 | 54 | ~60 | ~80 |
| Waste-package spacing (meters) | Variable | 0.1 | 0.1 | 2 |
| Line/point load | Point | Line | Line | Point |
| Drift spacing (meters) | 28 | 81 | 81 | 81 |
| Preclosure ventilation period (yrs) | 50 | 50 | 50 | 300 |
| Preclosure ventilation flow rate ($M^3$/s) | 0.1 | 2 to 10 | 15 | 15 for 50 years NVP *driven for 250 years |
| Waste package max heat output (KW) | 18 | 11.8 | 11.8 | 11.8 |
| PWR waste package avg heat output (KW) | 9.3 | 9.8 | 11.3 | 11.3 |
| Total waste package avg heat output (KW) | 7.3 | 7.4 | 7.6 | 7.6 |
| Avg linear loading (KW /meter) | 0.7 | 1.37 | 1.45 | 1.0 |
| Backfill in emplacement drift | Not precluded | Yes | Not precluded | Not precluded |
| Drip shields | Not precluded | Yes | Yes | Yes |

*NVP = Natural Ventilation Pressure

# Viability Assessment 1998

- Thermal loading — High — 85 metric tons of heavy metal (MTHM)/acre
  - Specific loading slightly higher than ACD loading
- Point loaded drifts (varies, but ~5-m avg. separation)
- 5.5 m diameter drifts spaced 28 m apart
- Boiling fronts extended 100 m above/below horizon
- Entire footprint temperature above boiling for extended period
- Matrix saturation temporarily increases above the high-temperature region

# Considering Alternatives

- **License Application Design Selection 1998/1999**
  - To reduce uncertainty in performance assessment
  - 5 enhanced design alternatives (EDAs) evaluated considering low and high thermal loadings
  - EDA-II recommended — 60 MTHM/acre — lower than VA
    - Linear loading (0.1 m spacing) and 81 m drift spacing
    - 50 years forced ventilation
    - Boiling fronts in host rock but 50% of pillars below boiling
    - Draining of heat-mobilized and percolating groundwater

# LADS Alternatives

| Parameters | EDA-I | EDA-II | EDA-III | EDA-IV | EDA-V |
|---|---|---|---|---|---|
| MTHM/Acre | 45 | 60 | 85 | 85 | 150 |
| Acres for 70,000 MTHM | 1400 | 1050 | 740 | 740 | 420 |
| Line or point load | Point | Line | Line | Line | Line |
| PWR WP Size | 12 | 21 | 21 | 21 | 21 |
| Drift Spacing | 43 m | 81 m | 56 m | 56 m | 32 m |
| Preclosure ventilation | 50 years @ 2 to 10 $m^3/s$ | 50 years @ 2 to 10 $m^3/s$ | 50 years @ 2 to 10 $m^3/s$ | 50 years @ 2 to 10 $m^3/s$ | 50 years @ 2 to 10 $m^3/s$ |
| Total WPs | 15,903 | 10,039 | 10,213 | 10,213 | 10,039 |

# Lower Thermal Operational Modes

- Nuclear Waste Technical Review Board — 1999/2000
  - Uncertainty with basis for high temperature design prompted evaluation of lower temperature alternatives
- Lower thermal operational scenarios — 12/2000
  - One: lower WP temperature through extended ventilation (50/250 years forced/natural); minimal increase in area; increased spacing between WPs (2 m)
  - Two: lower WP temperature through extended ventilation (50/250 years forced/natural); minimal increase in area; lower heat output, tightly-spaced (0.1 meter) WPs;
  - Three: lower WP temperature through extended ventilation (300 years forced); minimal increase in area; reference WP size and spacing; but increased drift spacing (120 m);

# Lower Thermal Operational Modes
(Continued)

- Four: lower WP temperature through increased area; a limited ventilation period (~125 years); no aging; increased spacing between reference WPs (6 m);
- Five: lower rock temperature and in-drift relative humidity through indefinite natural (passive) ventilation of the reference design

# Range of Thermal Operating Modes 2000/2001

- **Higher mode**
  - ~60 MTHM/acre; linear load of 1.45 kW/m (0.1 m spacing); 50 years forced ventilation
- **Lower mode**
  - ~40 MTHM/acre; linear load of 1.0 kW/m (~2 m spacing); forced and natural ventilation for 300 years
- **Fixed design with flexible operational modes**
  - 5.5 m diameter drifts spaced 81 m apart
  - Repository elevation and layout specified
  - Two barrier waste package design
- **Described in Science and Engineering Report — 2001**

# Next Step
# 2001/2002

- **License application design**
  - **Fixed design with flexible operational modes**
  - **Decision process for selecting licensing operating mode**
    - **Establish the thermal operating mode**
    - **Determined appropriate thermal limits**
  - **Selected operational ranges or parameters for licensing**

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

YUCCA MOUNTAIN PROJECT

# Current Thermal Management Methodology

Presented to:
**U. S. Nuclear Regulatory Commission**

Presented by:
**Gene Rowe**
**Repository Design**
**Bechtel SAIC Company, LLC**

**August 2, 2001**
**Rockville, Maryland**

L-1

# Agenda

- **Introduction**
- **Present Repository Design**
  - Single SR Design
  - SR Typical Waste Package Design
  - SR Drift Design
  - SR Layout
- **Operational Modes**
  - Potential Range of Operational Variables
  - Options Considered for SR
  - Thermal Response
- **Attributes of Flexible Operations**
- **Licensing Approach with Respect to Flexible Operating Modes**
- **Summary**

# Introduction

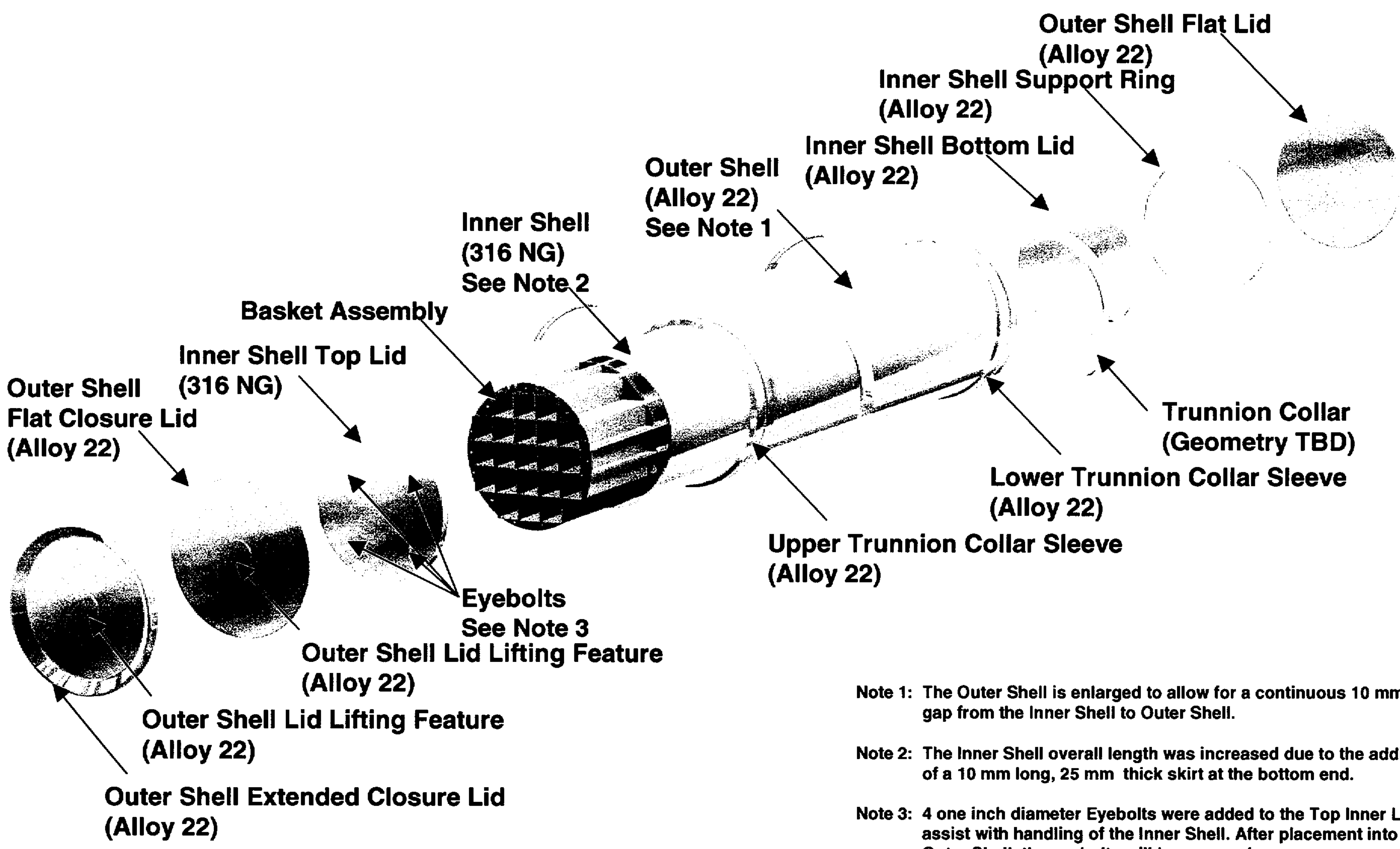
- **Purpose**
  - The purpose of this presentation is to present Yucca Mountain's methodology for thermal management and discuss the effects of this methodology on the design process
- **Background**
  - The majority of the work to date has been to support the Site Recommendation effort. Design parameters have been selected to allow analyzing the performance of the repository for various operating modes. These parameters will be optimized during the final design process
- **Need for Flexibility**
  - Because the repository thermal goals are still evolving, operational flexibility is needed

# Single SR Design

- **The design presented in the S&ER and the SSPA represent a single design and will work over the full range of thermal modes**

| Design Parameter | Fixed for SR for all Modes Analyzed |
|---|---|
| Repository capacity | 70,000 MTHM |
| Emplacement rate | 3,000 MTHM/year after 5-year ramp-up |
| Emplacement period | ~23 years |
| Sequence of waste package emplacement | Interspersed hotter and cooler packages to achieve average linear power density |
| Waste package design | Large, horizontally emplaced packages with corrosion-resistant outer shell of alloy-22 and structural inner shell of 316NG |
| Number of waste packages | ~11,000 |
| Initial waste package power | 11.8 kW maximum |
| Drift diameter | 5.5 meters |
| Drift spacing | 81 meters |
| Drip shields | Titanium, continuous |

# SR Typical Waste Package Design

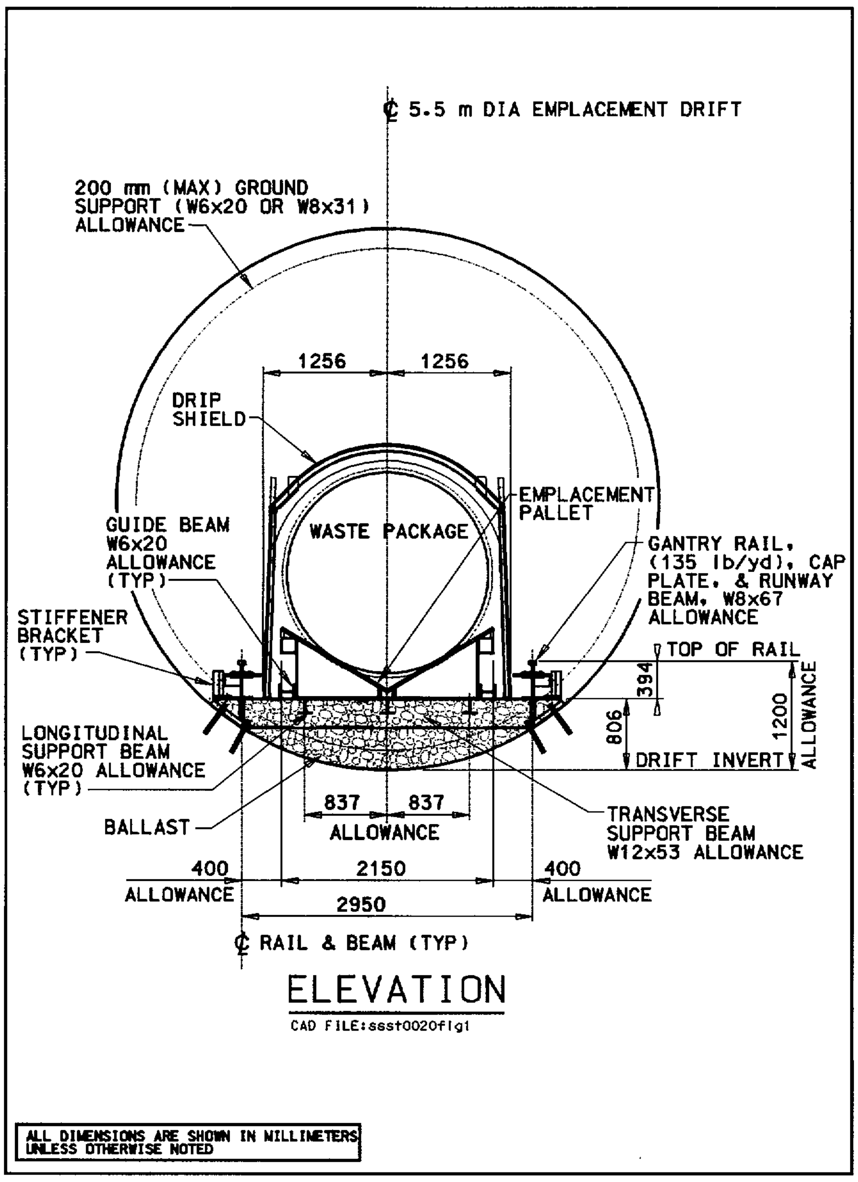



Note 1: The Outer Shell is enlarged to allow for a continuous 10 mm gap from the Inner Shell to Outer Shell.

Note 2: The Inner Shell overall length was increased due to the addition of a 10 mm long, 25 mm thick skirt at the bottom end.

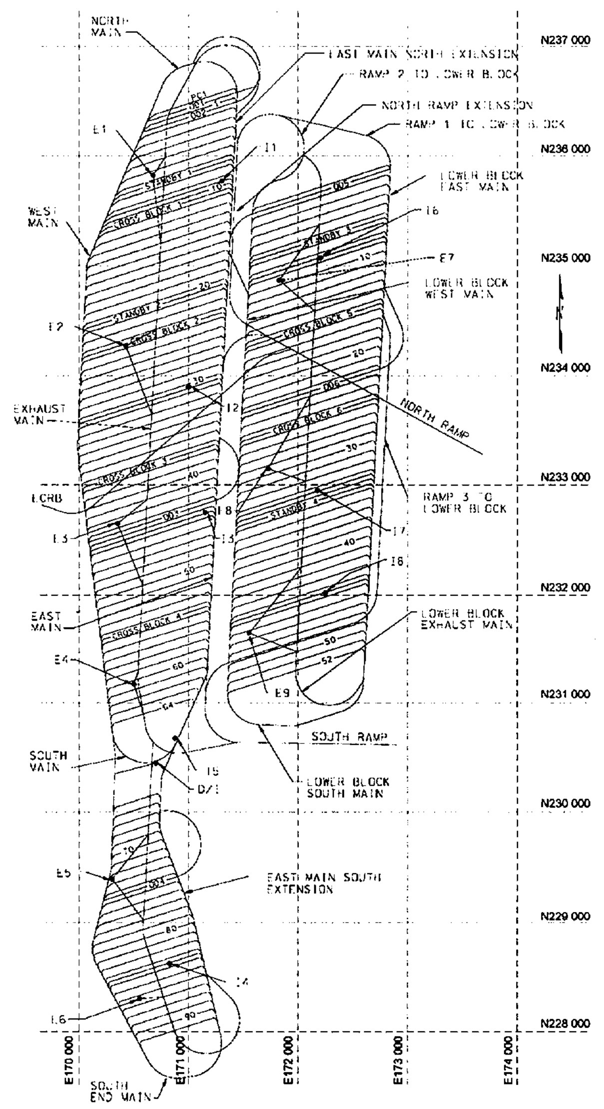
Note 3: 4 one inch diameter Eyebolts were added to the Top Inner Lid to assist with handling of the Inner Shell. After placement into the Outer Shell, the eyebolts will be removed.

# SR Drift Design

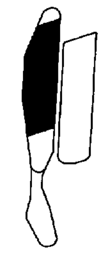


# SR Underground Layout

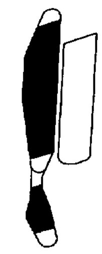
Layout of
Potential Repository
Development Areas



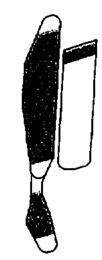

Potential Repository Development Areas_RevC.ai



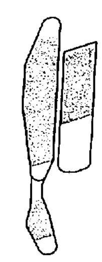
Higher end of thermal operating mode



Lower end of thermal operating mode achieved via 2 meter WP spacing and/or aging



Lower end of thermal operating mode achieved via WP de-rating



Lower end of thermal operating mode achieved via 6 meter WP spacing

# Potential Range of Operational Variables

**These variables and ranges are preliminary and will continue to evolve as the TSPA is refined and the design is optimized.**

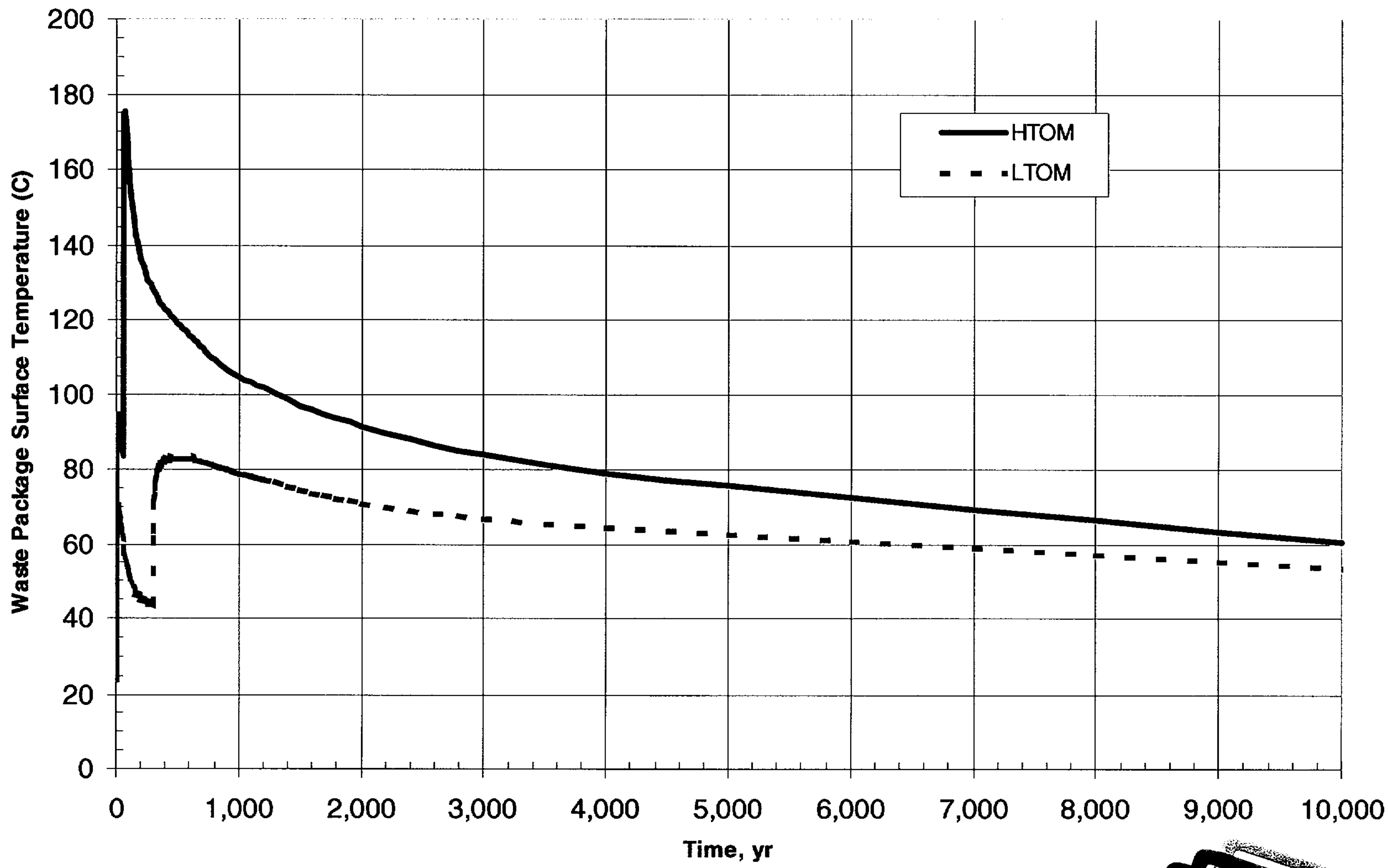
| Variable | Lower Limit | Upper Limit |
|---|---|---|
| **Variables Associated with the Waste Stream** | | |
| Assembly Age at Arrival | 5 years | N/A |
| Assembly Burn-up | N/A | 75 GWd/t |
| Assembly Enrichment | N/A | 5.0% |
| **Variables Associated with Repository Operations** | | |
| Ventilation Duration | 0 years | 300 years |
| Ventilation Rate | 0 CMS | 15 CMS |
| Waste Package Average Spacing | 0.1 meters | 8 meters |
| PWR WP Capacity | 1 assembly | 21 assemblies |
| BWR WP Capacity | 1 assembly | 44 assemblies |
| Duration of Assembly Staging at Site | 0 years | 30 years |
| Amount of Staging at Site | 0 MTHM | 40,000 MTHM |
| Waste Package Power at Emplacement | N/A | 11.8 kW |
| Areal Mass Loading | 25 MTHM/acre | 60 MTHM/acre |
| Linear Line Loading | N/A | 1.45 kW/m |

# Options Considered for SR

| | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | | |
|---|---|---|---|---|---|---|---|---|
| | S&ER Design (TSPA Rev 0) | Increased Waste package Spacing and Extended Ventilation | De-Rated or Smaller Waste Packages | Increased Spacing and Duration of Forced Ventilation | Extended Surface Aging with Forced Ventilation | Extended Natural Ventilation | SSPA HTOM | SSPA LTOM |
| **Design Parameters** | | | | | | | | |
| Drift Center-to-Center Spacing (m) | 81 | 81 | 81 | 120 | 81 | 81 | 81 | 81 |
| Number of Waste Packages | ~11,000 | ~11,000 | ~15,000 | ~11,000 | ~11,000 | ~11,000 | ~11,000 | ~11,000 |
| **Operational Parameters** | | | | | | | | |
| Average Waste Package Spacing | 0.1 | 2 | 0.1 | 6 | 2 | 0.1 | 0.1 | 1.2 |
| Surface Aging (years) | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 |
| Emplacement Period (years) | ~23 | ~23 | ~23 | ~23 | ~243 | ~23 | ~23 | ~23 |
| Forced Emplacement Ventilation After Start of Emplacement(years) | 50 | 75 | 75 | 125 | 125 | 75 | 50 | 300 |
| Natural Ventilation (years) | 0 | 250 | 250 | 0 | 0 | >300 | 0 | 0 |
| **Results** | | | | | | | | |
| Linear Thermal Loading (kW/m) | 1.45 | 1.00 | 1.00 | 0.7 | 0.5 | 1.45 | 1.35 | 1.12 |
| Total Emplacement Drift Excavation Length (km) | ~60 | ~80 | ~90 | ~130 | ~80 | ~60 | ~60 | ~75 |
| Required Emplacement Area (acres) | ~1,150 | ~1,600 | ~1,800 | ~2,500 | ~1,600 | ~1,150 | ~1,150 | ~1,450 |
| Average Waste Package Maximum Temp (°C) | ~160 | <85 | <85 | <85 | <85 | <85 | ~160 | <85 |

# Thermal Response

## HTOM and LTOM Temperature Histories
### SSPA V1, R00 ICN01



# Attributes of Flexible Operations

- Ability to operate under various thermal modes
- Ability to accommodate variations in waste stream characteristics
- Ability to accommodate changes in receipt and emplacement rates
- Ability to provide for checks and balances for problem detection and corrective action

# Licensing Approach With Respect to Flexible Operating Modes

- **License application will be for a single design**
- **Operational parameters will be bounded and included in the License Specifications**
- **Thermal response will be bounded by the design parameters and operating modes analyzed in the TSPA-LA**

# Summary

- **A set of design and operational parameters have been identified for the purpose of SR engineering and performance analyses**
- **The on going design and performance analyses provide us with a foundation that will allow us to continue to converge on a set of optimum design and operational parameters during the licensing phase of the program**
- **License application will be for a single design, with operational parameters specified in the License Specifications, and will be bounded by the TSPA-LA analyses**

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

YUCCA MOUNTAIN PROJECT

# Scope of the SSPA and Comparison of Thermal Operating Modes

Presented to:
**U.S. Nuclear Regulatory Commission**

Presented by:
**James A. Blink**
**Lawrence Livermore National Laboratory**
**Bechtel SAIC Company, LLC**
**and**
**Robert L. Howard**
**Bechtel SAIC Company, LLC**

**August [illegible] 2001**
**Rockville, Maryland**

# Objective

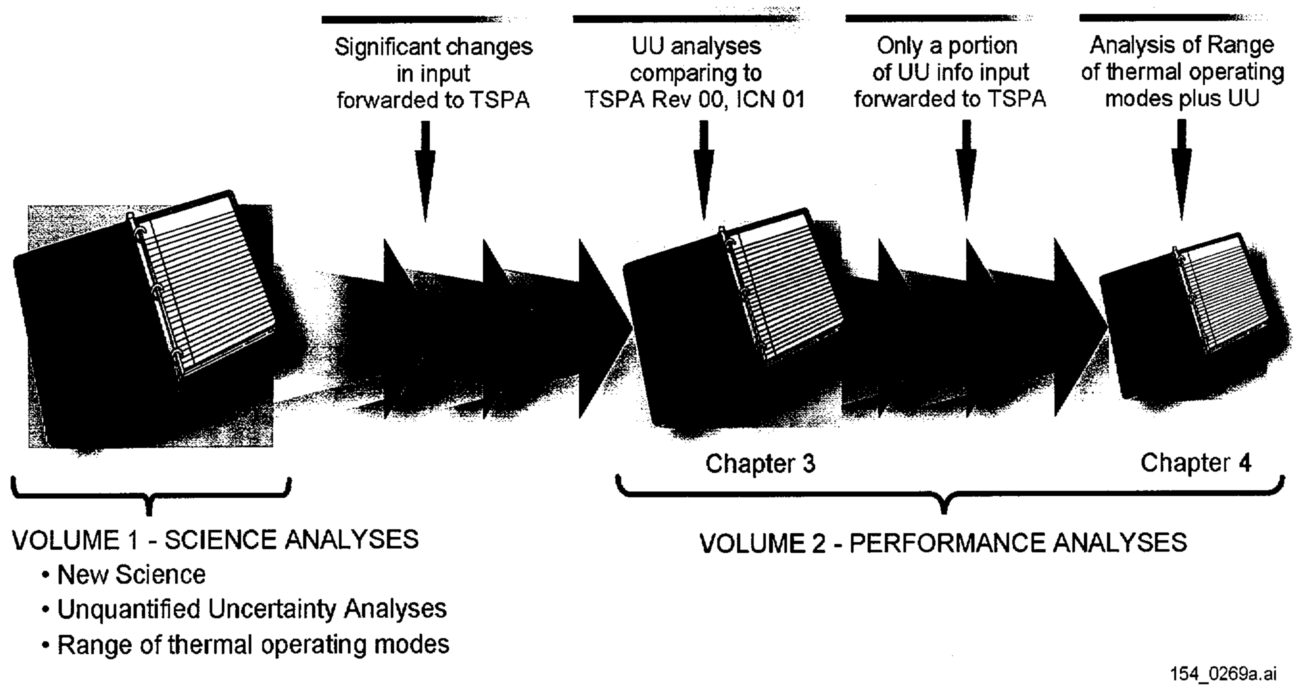
- **Summarize SSPA model supplements since the S&ER**
- **Synthesize higher-temperature and lower-temperature operating modes (HTOM/LTOM) contrast based on process models**

# Organization

- **SSPA Organization, volumes 1 and 2**
- **Subsystem**
  - **Process model developments for SSPA studies**
  - **Comparison of HTOM and LTOM process-level results**
- **Total System dose results from the TSPA-SR and SSPA**
  - **Key model developments affecting dose**
  - **Nominal and disruptive event scenarios**

# Relationship of SSPA Vol. 1 and Vol. 2

- **Vol. 1 provides technical bases for analyses documented in Vol. 2**
- **"One-off" sensitivity analyses in Vol. 2 and guidance from Vol. 1 determine the content of the supplemental TSPA model**



# Scope of SSPA Volume 1

- **Volume 1 Covers the major process expected to occur at Yucca Mountain and supplements the information described in Analyses and Model Reports and Process Model Reports**
- **Subjects are organized in a manner similar to the organization found in the Yucca Mountain Science and Engineering Report**
- **Volume 1 focuses on the technical work within each process model area, encompassing uncertainty quantification, updated scientific bases, and analyses of a range of operating modes**

# Scope of SSPA Volume 1

(Continued)

## Three General Types of Information

- **Unquantified Uncertainties Analysis**
  - Specific uncertainties that were not treated explicity in the AMRs and PMRs supporting the S&ER have been quantified including parameter bounds, conceptual models, assumptions, and in some cases input parameters consisting of statistically biased or skewed distributions
- **Updates in Scientific Information**
  - This includes new experimental results, new conceptual models, new analytical approaches, and the identification and discussion of multiple lines of evidence
- **Thermal Operating Mode Analyses**
  - Includes process level information regarding thermal dependencies; how the process responds to a range of thermal inputs and the impacts on uncertainty in process level results

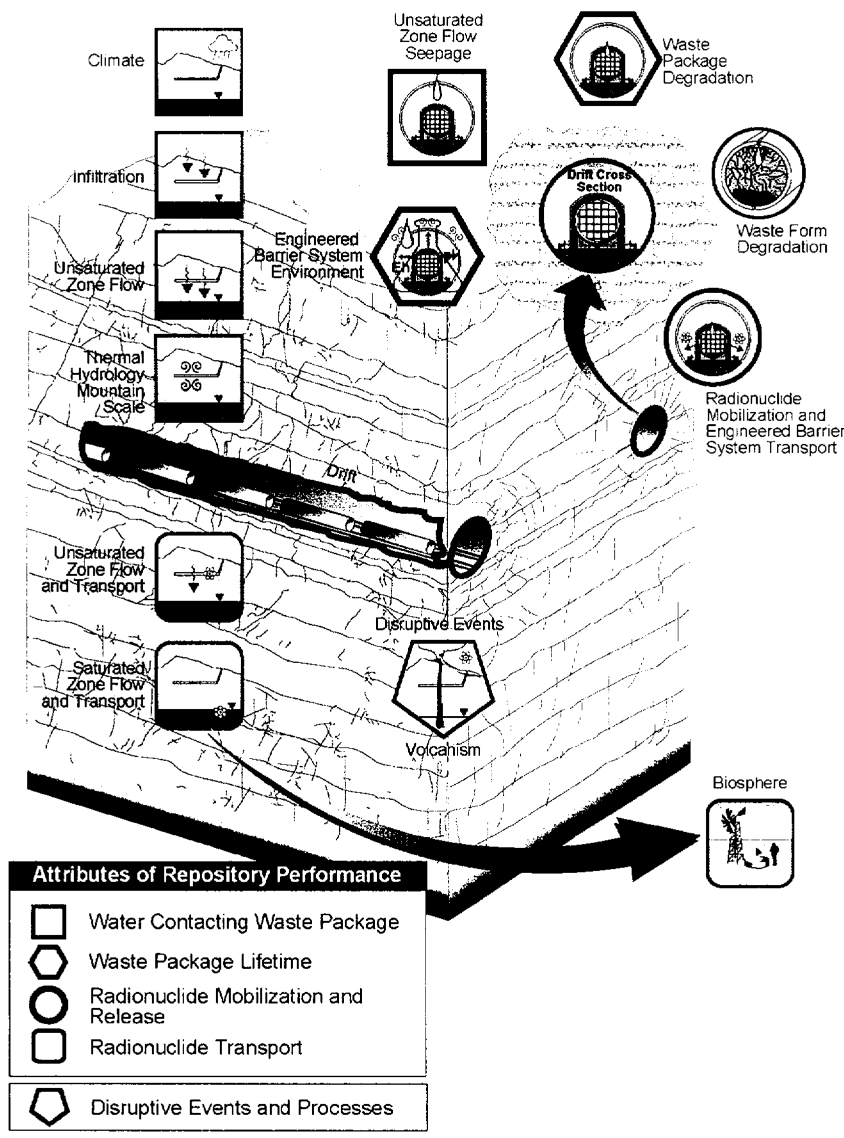
# Scope of SSPA Volume 1
(Continued)

- **Sections 3-14 include a summary of the conceptual basis for models used in the S&ER**
- **Specific content and level of detail of each section varies depending on:**
  - **Extent of the analyses performed**
  - **Amount of new information and data that has been generated since the publication of the S&ER and supporting documents**
  - **Amount of information necessary required to evaluate the range of thermal operating modes**
- **Each section contains a summary of information and recommendations for use in Volume 2 if appropriate**

# Outline of SSPA Volume 2

- Introduction
- Methods and Approach
- Sensitivity Analyses
  - 3.1 System-Level Evaluation--Nominal Scenario
  - 3.2 Subsystem-Level Evaluations--Nominal Scenario
  - 3.3 Evaluations of Disruptive Performance
- Supplemental Total System Performance Assessment Model
  - 4.1 System-Level Evaluations--Nominal Scenario
  - 4.2 Subsystem-Level Evaluations--Nominal Scenario
  - 4.3 System-Level Evaluation of Igneous Disruption
- Summary and Conclusions

# Attributes of Repository Performance



# Summary of Supplemental Modes and Analyses

| Key Attributes Of System | Process Model (Section of S&ER) | Topic Of Supplemental Scientific Model Or Analysis | Reason For Supplemental Scientific Model Or Analysis | | | Section of Volume 1 | Performance Assessment Treatment Of Supplemental Scientific Model Or Analysis[a] | |
|---|---|---|---|---|---|---|---|---|
| | | | Unquantified Uncertainty Analysis | Update in Scientific Information | Cooler Thermal Operating Mode Analysis | | TSPA Sensitivity Analysis | Included in Supplemental TSPA Model |
| Limited Water Entering Emplacement Drifts | Climate (4.2.1) | Post-10,000-year Climate Model | | X | | 3.3.1 | X | X |
| | Net Infiltration (4.2.1) | Infiltration for post-10,000-year Climate Model | | X | | 3.3.2 | X | X |
| | Unsaturated Zone Flow (4.2.1) | Flow in PTn | | X | | 3.3.3 | | |
| | | 3-D flow fields for cooler design; flow fields for post-10,000 yr climate, lateral flow; variable thickness of PTn; fault property uncertainty | | X | X | 3.3.4 | | |
| | | Effects of lithophysal properties on thermal properties | | X | | 3.3.5 | | |
| | Coupled Effects on UZ Flow (4.2.2) | Mountain-scale Thermal-Hydrologic effects | | X | X | 3.3.5 | | |
| | | Mountain-scale Thermal-Hydrologic-Chemical effects | | X | X | 3.3.6 | | |
| | | Mountain-scale Thermal-Hydrologic-Mechanical effects | | X | X | 3.3.7 | | |
| | Seepage into Emplacement Drifts (4.2.1) | Flow-focussing within heterogeneous permeability field; episodic seepage | X | | X | 4.3.1, 4.3.2, 4.3.5 | X | X |
| | | Effects rock bolts and drift degradation on seepage | X | | | 4.3.3, 4.3.4 | | |
| | Coupled Effects on Seepage (4.2.2) | Thermal effects on seepage | X | | X | 4.3.5 | X | X |
| | | Thermal-Hydrologic-Chemical effects on seepage | X | | X | 4.3.6 | | |
| | | Thermal-Hydrologic-Mechanical effects on seepage | | X | X | 4.3.7 | | |

# Summary of Supplemental Modes and Analyses

(Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis | | | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2) | |
|---|---|---|---|---|---|---|---|---|
| | | | Unquantified Uncertainty Analysis | Update in Scientific Information | Cooler Thermal Operating Mode Analysis | | TSPA Sensitivity Analysis | Included in Supplemental TSPA Model |
| Long-Lived Waste Package and Drip Shield | Water Diversion Performance of EBS (4.2.3) | Multiscale thermal-hydrolic model, including effects of rock dryout | X | | X | 5.3.1 | | X |
| | | Thermal property sets | X | X | | 5.3.1 | | X |
| | | Effect of in-drift convection on temperatures, humidities, invert saturations, and evaporation rates | X | | X | 5.3.2 | | |
| | | Composition of liquid and gas entering drift | X | | X | 6.3.1 | X | X |
| | | Evolution of in-drift chemical environment | X | | X | 6.3.3 | X | X |
| | | Thermo-Hydro-Chemical model comparison to plug-flow reactor and fracture plugging experiment | | X | | 6.3.1 | | |
| | | Rockfall | | X | | 6.3.4 | | |
| | In-Drift Moisture Distribution (4.2.5) | Environment on surface of drip shields and waste packages | X | | | 5.3.2 | | |
| | | Condensation under drip shields | X | | | 8.3.2 | X | |
| | | Evaporation of seepage | X | | X | 8.3.1<br>5.3.2 | X | X |
| | | Effect of breached drip shields or waste package on seepage | X | | X | 8.3.3 | X | X |
| | | Waste package release flow geometry (flow-through, bathtub) | X | | | 8.3.4 | X | |
| | Drip Shield Degradation and Performance (4.2.4) | Local chemical environment on surface of drip shields (including Mg, Pb) and potential for initiating localized corrosion | X | | | 7.3.1 | | |

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# Summary of Supplemental Modes and Analyses

## (Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis: Unquantified Uncertainty Analysis | Reason for Supplemental Scientific Model or Analysis: Update in Scientific Information | Reason for Supplemental Scientific Model or Analysis: Cooler Thermal Operating Mode Analysis | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2): TSPA Sensitivity Analysis | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2): Included in Supplemental TSPA Model |
|---|---|---|---|---|---|---|---|---|
| Long-Lived Waste Package and Drip Shield | Waste Package Degradation and Performance (4.2.4) | Local chemical environment on surface of waste packages (including Mg, Pb) and potential for initiating localized corrosion | X | | | 7.3.1 | | |
| | | Aging and phase stability effects on A-22 | X | X | | 7.3.2 | X | |
| | | Uncertainty in weld stress state following mitigation | X | | | 7.3.3 | X | X |
| | | Weld defects | X | | | 7.3.3 | X | X |
| | | Early failure due to improper heat treatment | X | | X | 7.3.6 | X | X |
| | | General corrosion rate of A-22: Temperature dependency | X | | X | 7.3.5 | X | X |
| | | General corrosion rate of A-22: Uncertainty/variability partition | X | | | 7.3.5 | X | X |
| | | Long-term stability of passive films on A-22 | X | | | 7.3.4 | | |
| | | Stress threshold for initiation of stress corrosion cracking | X | X | | 7.3.3 | X | X |
| | | Probability of non-detection of manufacturing defects | | X | | 7.4.3 | X | X |
| | | Number of defects | | X | | 7.3.5 | X | X |
| | | Distribution of crack growth exponent (repassivation slope) | X | X | | 7.3.7 | X | X |
| Limited Release of Radionuclides from the Engineered Barriers | In-Package Environments (4.2.6) | Effect of HLW glass degradation rate and steel degradation rate on in-package chemistry | X | | X | 9.3.1 | X | X |
| | Cladding Degradation and Performance (4.2.6) | Effect of initial perforations, creep rupture, stress corrosion cracking, localized corrosion, seismic failure, rock overburden failure, and unzipping velocity on cladding degradation | X | | X | 9.3.3 | X | X |

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# Summary of Supplemental Modes and Analyses

(Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis | | | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2) | |
|---|---|---|---|---|---|---|---|---|
| | | | Unquantified Uncertainty Analysis | Update in Scientific Information | Cooler Thermal Operating Mode Analysis | | TSPA Sensitivity Analysis | Included in Supplemental TSPA Model |
| Limited Release of Radionuclides from the Engineered Barriers | DHLW Degradation and Performance (4.2.6) | HLW glass degradation rates | X | X | X | 9.3.1 | | |
| | Dissolved Radionuclide Concentrations (4.2.6) | Solubility of neptunium, thorium, plutonium, and technetium | X | X | X | 9.3.2 | X | X |
| | Colloid-Associated Radionuclide Concentrations (4.2.6) | Colloid mass concentrations | X | | | 9.3.4 | X | |
| | EBS (Invert) Degradation and Transport (4.2.6, 4.2.7) | Diffusion inside waste package | X | X | | 10.3.1 | X | X |
| | | Transport pathway from inside waste package to invert | X | X | | 10.3.2 | | |
| | | Sorption inside waste package | X | X | | 10.3.4 | X | X |
| | | Sorption in invert | X | X | | 10.3.4 | X | X |
| | | Diffusion through invert | X | | | 10.3.3 | X | X |
| | | Colloid stability in the invert | X | | | 10.3.5 | | |
| | | Microbial transport of colloids | X | X | | 10.3.6 | | |

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# Summary of Supplemental Modes and Analyses

(Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis | | | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2) | |
|---|---|---|---|---|---|---|---|---|
| | | | Unquantified Uncertainty Analysis | Update in Scientific Information | Cooler Thermal Operating Mode Analysis | | TSPA Sensitivity Analysis | Included in Supplemental TSPA Model |
| Delay and Dilution of Radionuclide Concentrations by the Natural Barriers | Unsaturated Zone Radionuclide Transport (Advective Pathways; Retardation; Dispersion; Dilution) (4.2.8) | Effect of drift shadow zone - advection/diffusion splitting | X | | X | 11.3.1 | X | X |
| | | Effect of drift shadow zone - concentration boundary condition on EBS release rates | X | | | 11.3.1 | | |
| | | Effect of matrix diffusion | X | | | 11.3.2, 11.3.3 | | |
| | | 3-D transport | | | X | 11.3.2 | | |
| | | Effect of coupled Thermo-Hydrologic, Thermo-Hydro-Chemical, and Thermo-Hydro-Mechanical processes on transport | | X | X | 11.3.5 | | |
| | Saturated Zone Radionuclide Flow and Transport (4.2.9) | Groundwater specific discharge | X | X | | 12.3.1 | X | |
| | | Effective diffusion coefficient in volcanic tuffs | X | | | 12.3.2 | X | |
| | | Flowing interval spacing | | | | 12.3.2 | X | |
| | | Flowing interval (fracture) porosity | X | | | 12.3.2 | X | |
| | | Effective porosity in the alluvium | X | | | 12.3.2 | X | |
| | | Correlation of the effective diffusion coefficient with matrix porosity | X | | | 12.3.2 | X | |
| | | Bulk density of the alluvium | X | X | | 12.3.2 | X | X |

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# Summary of Supplemental Modes and Analyses

## (Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis: Unquantified Uncertainty Analysis | Reason for Supplemental Scientific Model or Analysis: Update in Scientific Information | Reason for Supplemental Scientific Model or Analysis: Cooler Thermal Operating Mode Analysis | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2): TSPA Sensitivity Analysis | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2): Included in Supplemental TSPA Model |
|---|---|---|---|---|---|---|---|---|
| Delay and Dilution of Radionuclide Concentrations by the Natural Barriers | Saturated Zone Radionuclide Transport (4.2.9) | Retardation for radionuclides irreversibly sorbed on colloids in the alluvium | X | X | | 12.3.2 | X | |
| | | No matrix diffusion in volcanic tuffs case | | | | 12.5.2 | X | |
| | | Presence or absence of alluvium | | | | 12.5.2 | X | |
| | | Sorption coefficient in alluvium for I, Tc | X | X | | 12.3.2 | | X |
| | | Sorption coefficient in alluvium for Np, U | X | X | | 12.3.2 | X | |
| | | Sorption coefficient for Np in volcanic tuffs | X | | | 12.3.2 | X | |
| | | Kc model for groundwater colloid concentrations Pu, Am | | X | | 12.5.2 | X | |
| | | Enhanced matrix diffusion in volcanic tuffs | | | | 12.5.2 | X | |
| | | Effective longitudinal dispersivity | X | X | | 12.3.2 | X | |
| | | New dispersion tensor | | X | | 12.3.2 | | |
| | | Flexible design | | | X | 12.3.2 | | |
| | | Different conceptual models of the large hydraulic gradient and their effects on the flow path and specific discharge | | X | | 12.3.1 | | |
| | | Hydraulic head and map of potentiometric surface | | X | | 12.3.1 | | |
| | Biosphere (4.2.10) | Receptor of interest | X | | | 13.3.1 | | |
| | | Comparison of dose assessment methods | X | | | 13.3.2 | | |
| | | Radionuclide removal from soil by leaching | X | | | 13.3.3 | | |
| | | Uncertainties not captured by GENII-S | X | | | 13.3.4 | | |
| | | Influence of climate change on groundwater usage and BDCFs | X | | | 13.3.5, 13.3.7 | | |
| | | BDCFs for groundwater and igneous releases | | X | | 13.3.6, 13.3.8, 13.4 | X | X |

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# Summary of Supplemental Modes and Analyses

(Continued)

| Key Attributes of System | Process Model (Section of Yucca Mountain Science and Engineering Report) | Topic of Supplemental Scientific Model or Analysis | Reason for Supplemental Scientific Model or Analysis | | | Section of Volume 1 | Performance Assessment Treatment of Supplemental Scientific Model or Analysis (Discussed in Volume 2) | |
|---|---|---|---|---|---|---|---|---|
| | | | Unquantified Uncertainty Analysis | Update in Scientific Information | Cooler Thermal Operating Mode Analysis | | TSPA Sensitivity Analysis | Included in Supplemental TSPA Model |
| Low Mean Annual Dose Considering Potentially Disruptive Events | Volcanism/Igneous Activity (4.3.2) | Probability of dike intersection of repository for the operating mode described in S&ER | | X | | 14.3.3.1 | | X |
| | | Scaling factors to evaluate impacts of repository design changes | | | X | 14.3.3.2 | | |
| | | Contribution to release of Zones 1 and 2 | | X | | 14.3.3.3 | X | |
| | | Sensitivity to waste particle size distribution | | X | | 14.3.3.4 | X | |
| | | New wind speed data | | X | | 14.3.3.5 | X | X |
| | | Explanation of method for handling ash/waste particle size and density | | X | | 14.3.3.6 | | |
| | | Volcanism inputs for Supplemental TSPA Model | | X | | 14.3.3.7 | | |
| | | New aeromagnetic data | | X | | 14.3.3.8 | | X |

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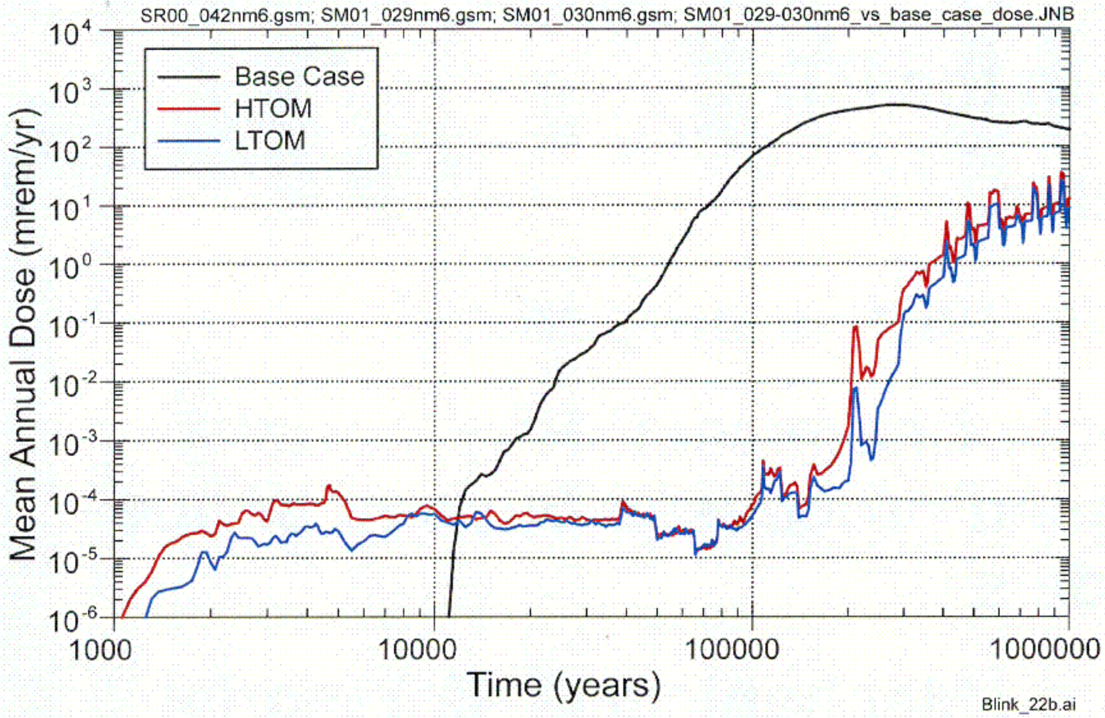
NOTE: S&ER = Yucca Mountain Science and Engineering Report

[a] Performance assessment treatment of supplemental scientific model or analysis discussed in SSPA Volume 2

# Subsystems

- UZ flow
- Thermal seepage
- In-drift thermal hydrology
- Thermal-hydrologic-mechanical (THM) effects
- Thermal-hydrologic-chemical (THC) effects, in-drift water and gas chemistry
- Waste package (WP) corrosion
- Water diversion in the engineered barrier system (EBS)
- Waste form mobilization
- EBS transport
- Unsaturated zone (UZ) transport
- Saturated Zone (SZ) transport
- Biosphere
- Disruptive events

# Total Dose - Nominal Scenario




***Because most WP failures are well beyond the thermal pulse, HTOM and LTOM mean dose rates are similar***

- **Early WP failure—small doses prior to 100,000 years**
- **T-dependent general corrosion delay in larger doses**
- **Post 10,000 year climate changes—about 10x dose variation**
- **Solubility updates—about 10x decrease in peak dose**

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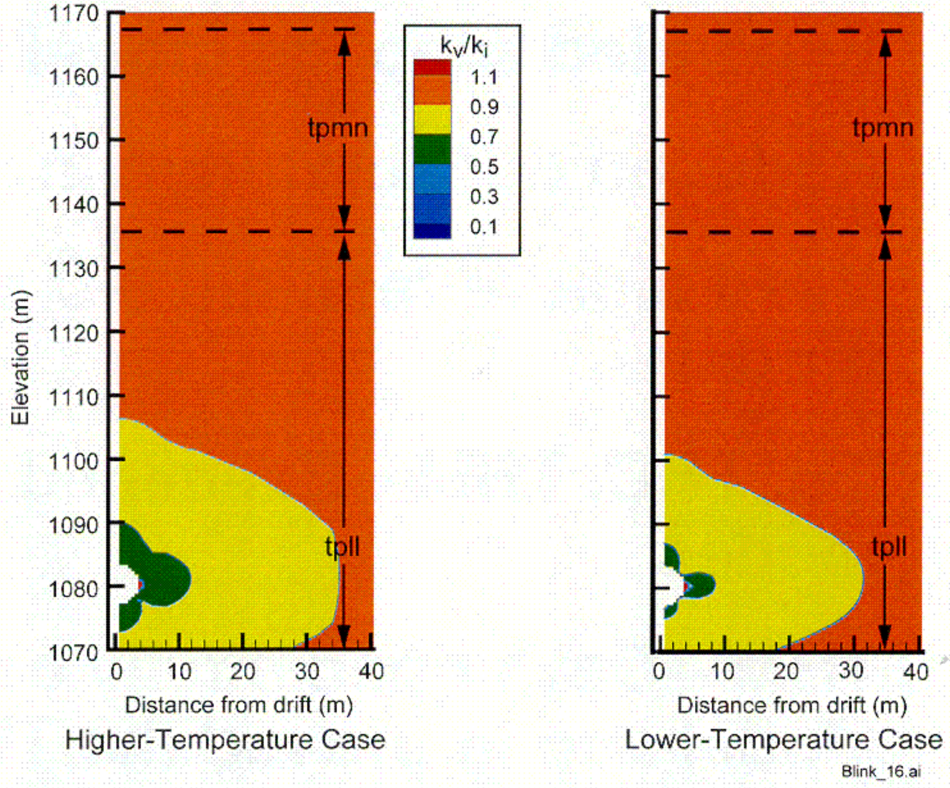
C-3

# UZ Flow Developments since TSPA-SR

- Examined lateral flow in the PTn
- Expanded 3-D flow fields
- Included lithophysae in thermal properties
- New Thermal Hydrologic Chemical (THC) model development—addressed processes beyond scope of drift-scale THC models
- New Thermal Hydrologic Mechanical (THM) model development—addressed multi-phase flow and calculated stress-induced permeability changes

# Thermal-Mechanical Caused Permeability Changes

- At 10 years, both thermal cases show an overall decrease in permeability around the drift due to thermal stress induced by decay heat
- This decrease overcomes the initial excavation-induced permeability increases, except possibly in areas very close to the crown of the drift




***LTOM and HTOM are similar***

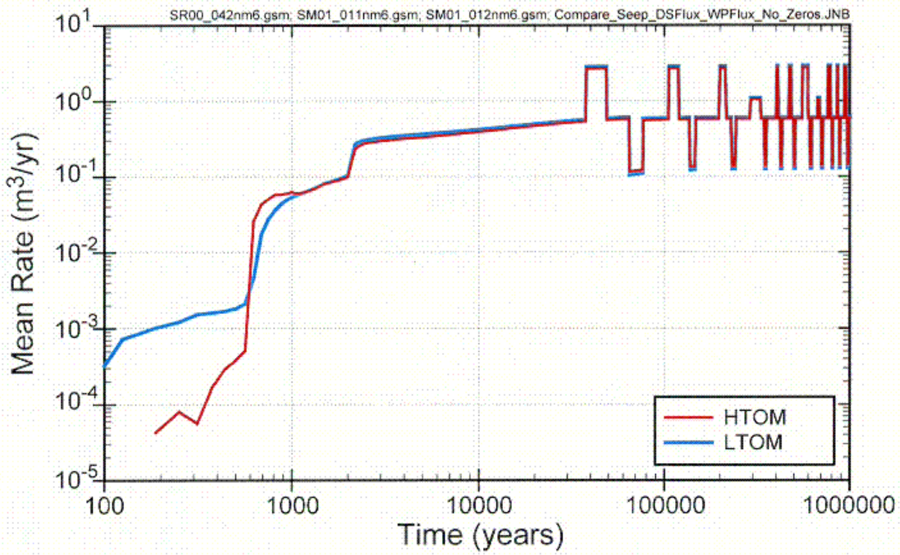


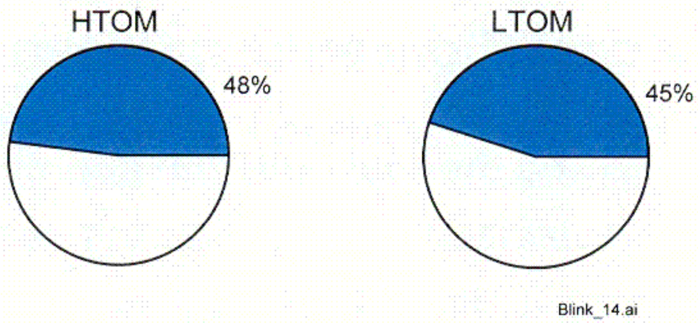
C-4

# Seepage Developments since TSPA-SR

- Expanded seepage model to include Tptpll
- Reduced conservatism in flow focusing factor
- Used a more realistic 3-D drift degradation seepage model
- TH, THC, THM—Examined range of thermal operating modes
- THM—Developed a fully coupled THM Continua Model and improved the THM Distinct Element Model

# Thermal Seepage in TSPA




- **LTOM seepage**
  - **Total System Performance Assessment (TSPA) model ~ Ambient model**
- **HTOM seepage**
  - **Process model < TSPA model < Ambient model**



C-5

# Key Thermal-Hydrologic Environment Uncertainties Evaluated in SSPA Vol. 1

- **Model (Conceptual) Uncertainty**
  - Use of effective thermal conductivity and thermal radiation approaches
  - Neglecting dryout during ventilation
  - Coupling of submodels
  - Localized effects of seepage
  - Neglecting fracture heterogeneity impacts on seepage
  - Neglecting effects of mountain-scale gas-phase convection
  - Effects of lithophysal porosity on vapor storage

**NOTE:**

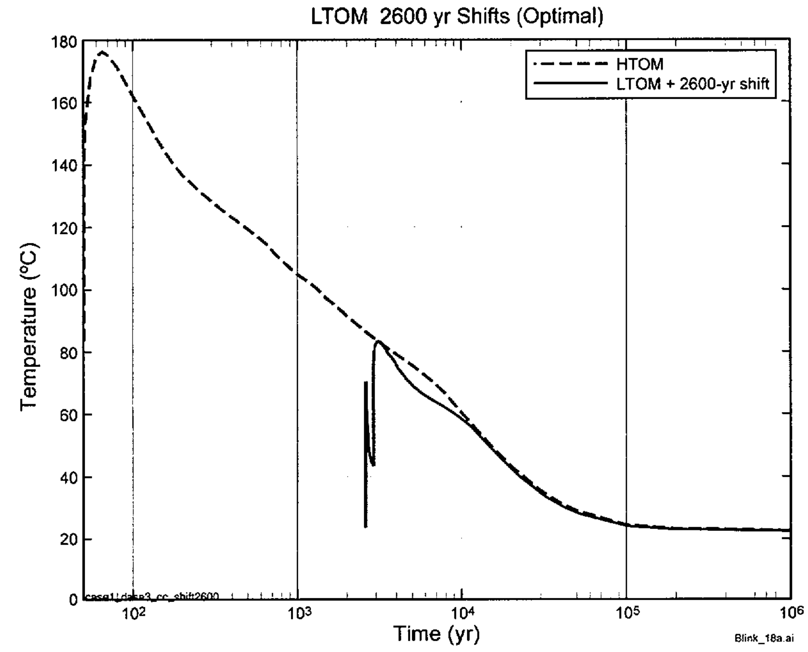
**DKM = dual permeability model**

**THM = thermal-hydrologic-mechanical**

**THC = thermal-hydrologic-chemical**

- **Process Uncertainty**
  - Hysteresis of imbition
  - THM & THC changes to hydrologic properties
- **Input Data Uncertainty**
  - Invert properties
  - Host rock bulk permeability
  - Host rock thermal conductivity (wet & dry)
  - Host rock heat capacity
  - Host rock lithophysal porosity
  - WP thermal output
  - Ventilation duration and efficiency

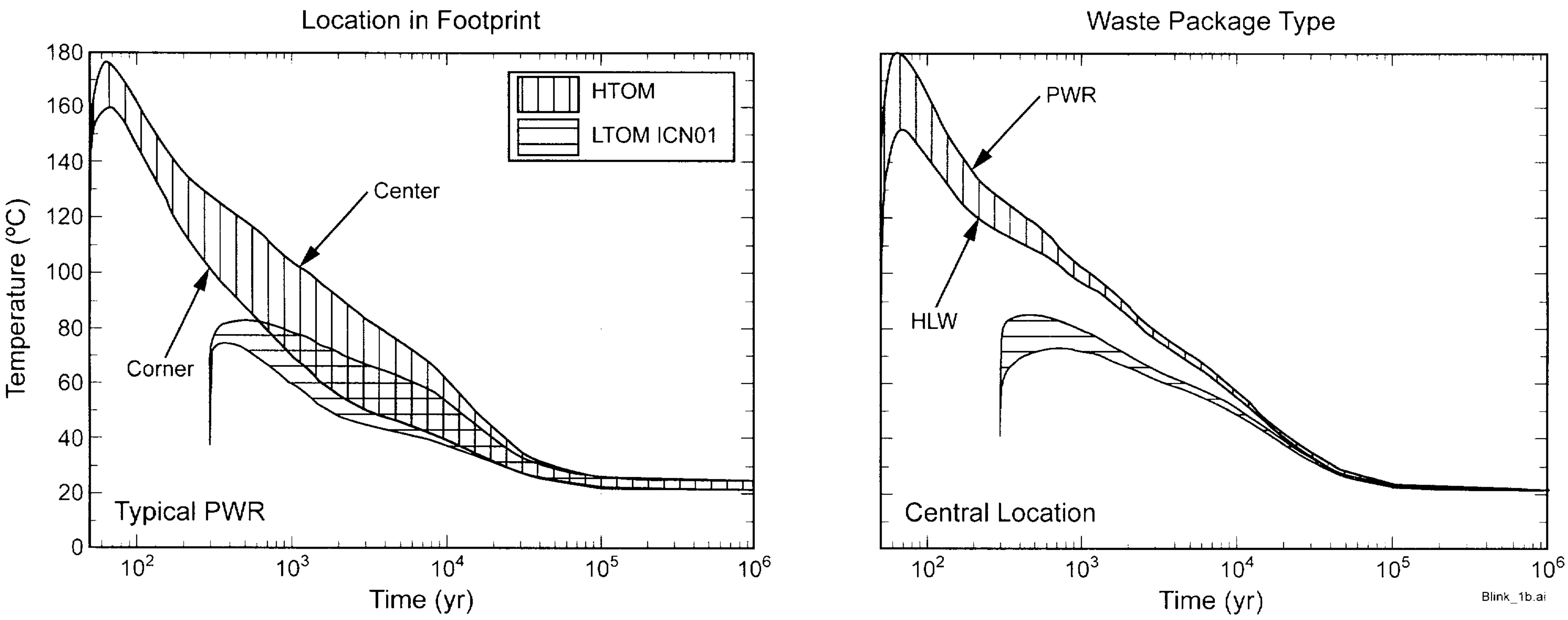
# The LTOM Thermal History is Similar to the HTOM after a Few Thousand Years




- **HTOM models include the LTOM environments**
- **High temperature parts of the models could increase HTOM uncertainty compared to LTOM**

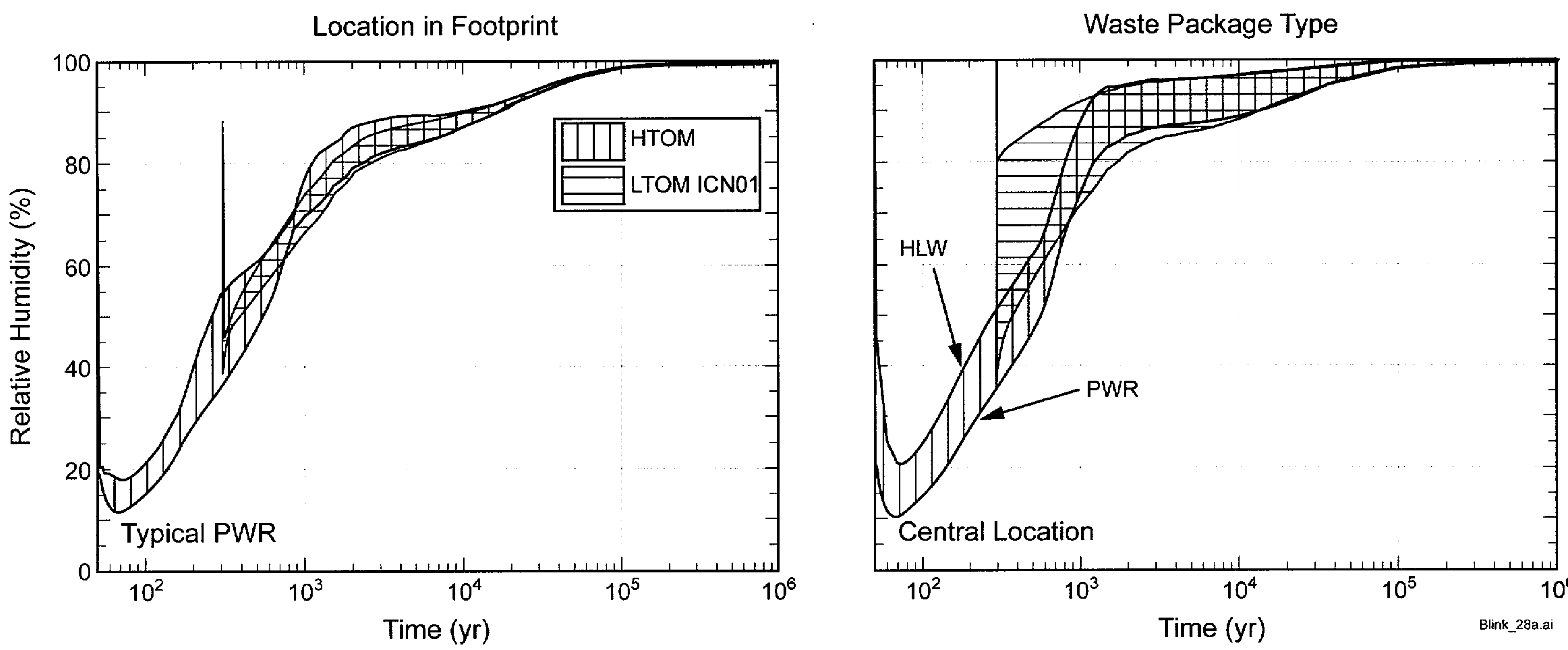
***HTOM and LTOM performance are similar because the HTOM thermal pulse does not significantly affect the EBS or Natural Barrier System***

# WP Temperature Sensitivity to Location and WP Type



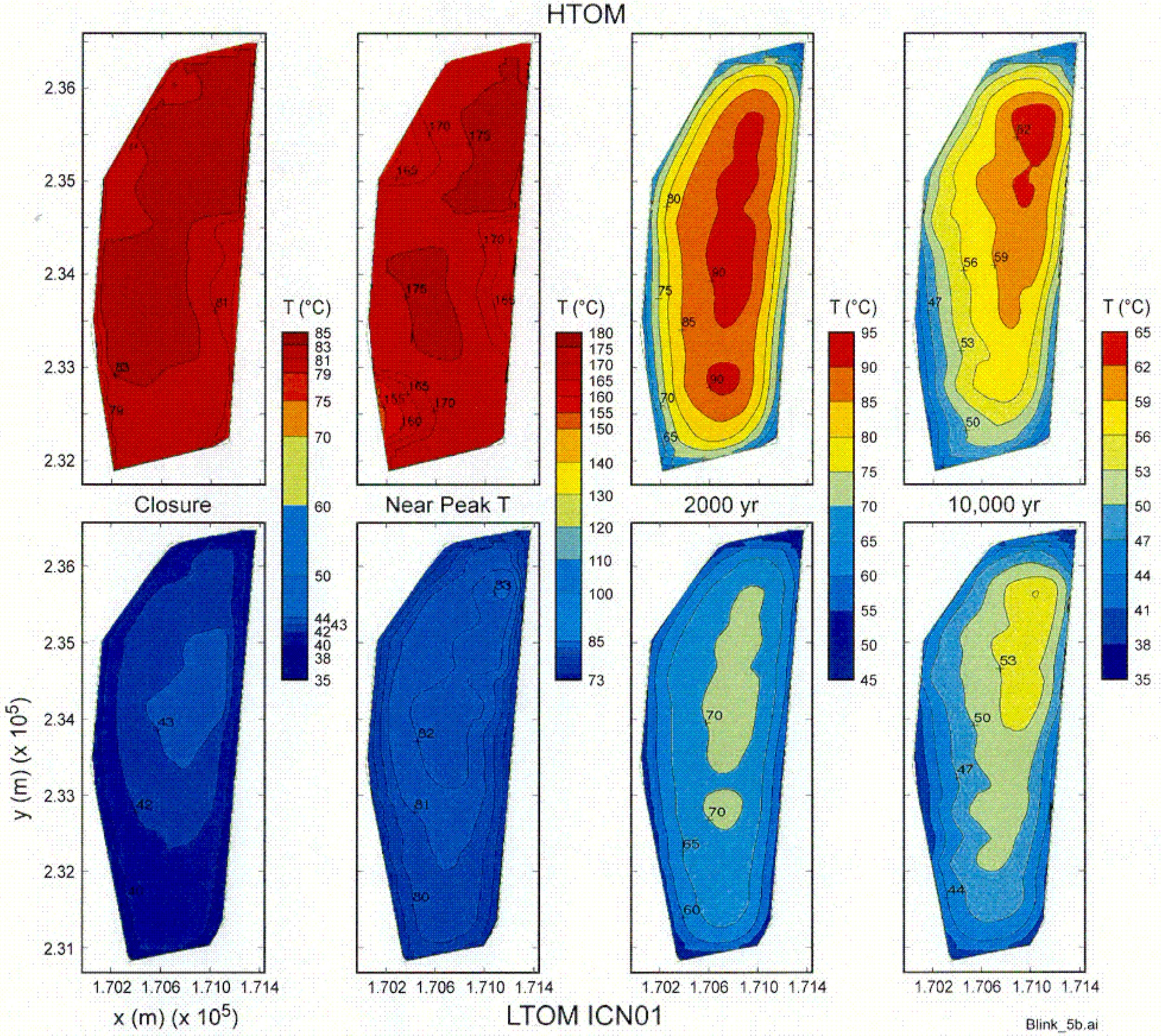

- **The variability range for location and WP type is ~20°C**
- **The variability range for operating mode is ~90°C**

# Sensitivity of WP Relative Humidity (RH) to Infiltration Rate and Operating Mode
## (All WP Types and Locations)




***LTOM low RH duration is similar to HTOM***

# Typical PWR WP Temperature Sensitivity to Location



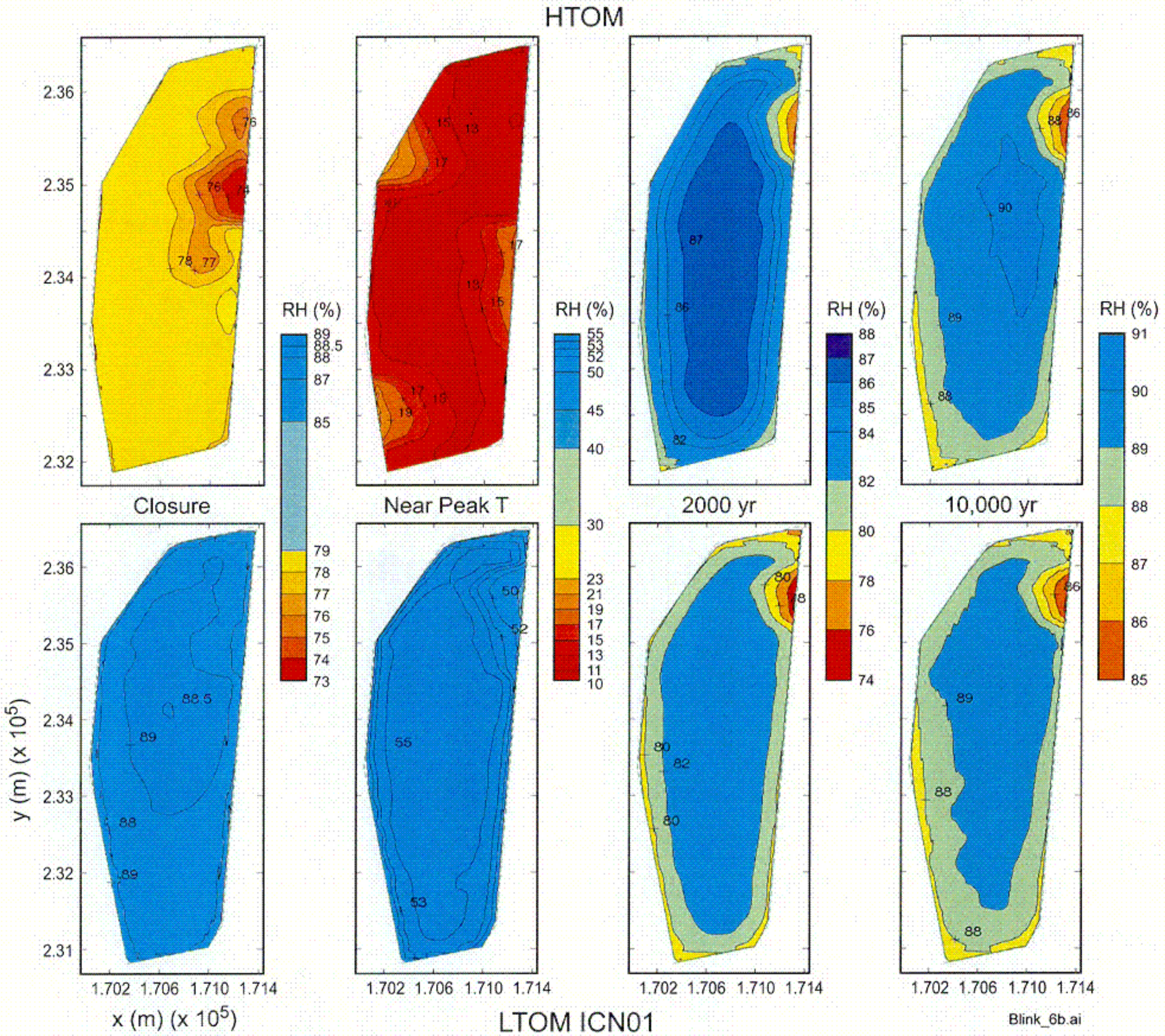

- Common color bar for each time period
- Similar distributions at 10,000 years

***Spatial variability similar for HTOM and LTOM***



C-6

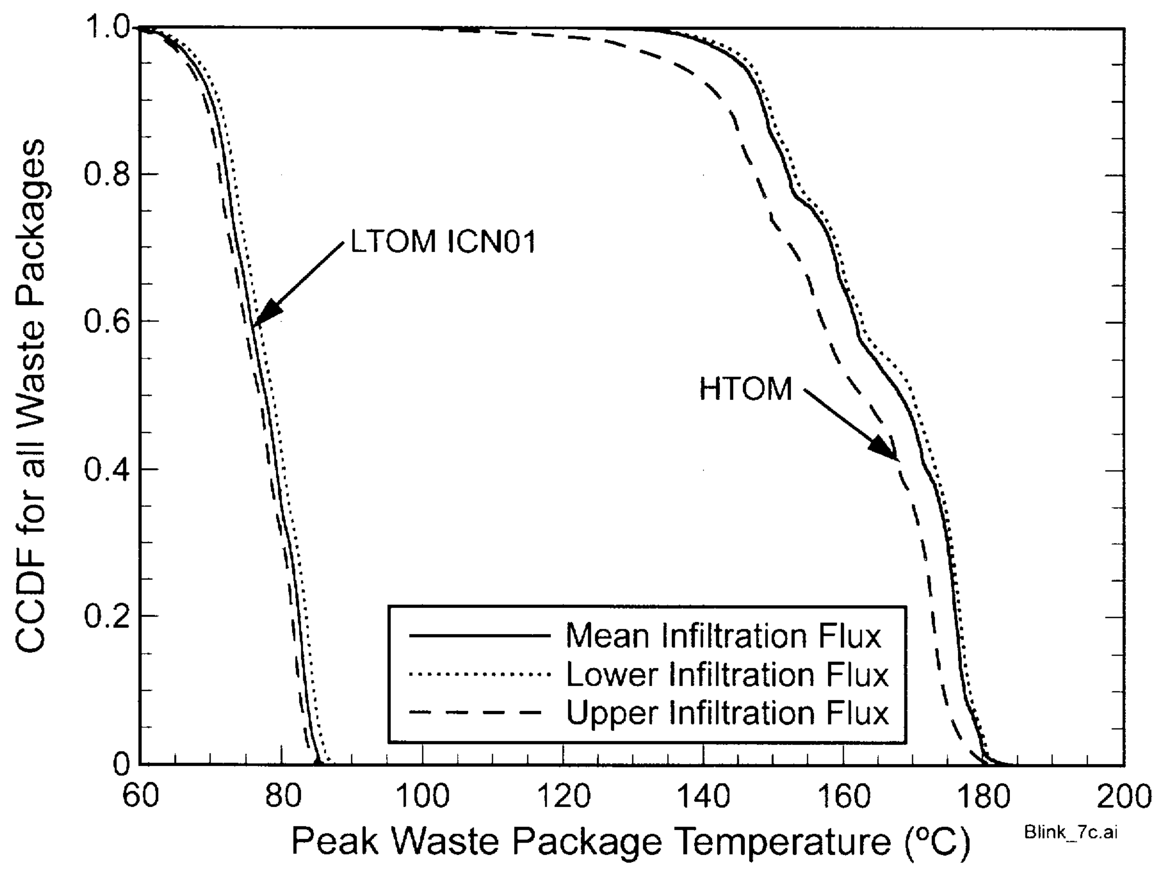
# Typical PWR WP Humidity Sensitivity to Location




- Earlier two snapshots have drier HTOM
  - Earlier "real" time has higher WP heat
  - Near-field dryout
- 10,000 year snapshots have similar RH
  - Similar temperature

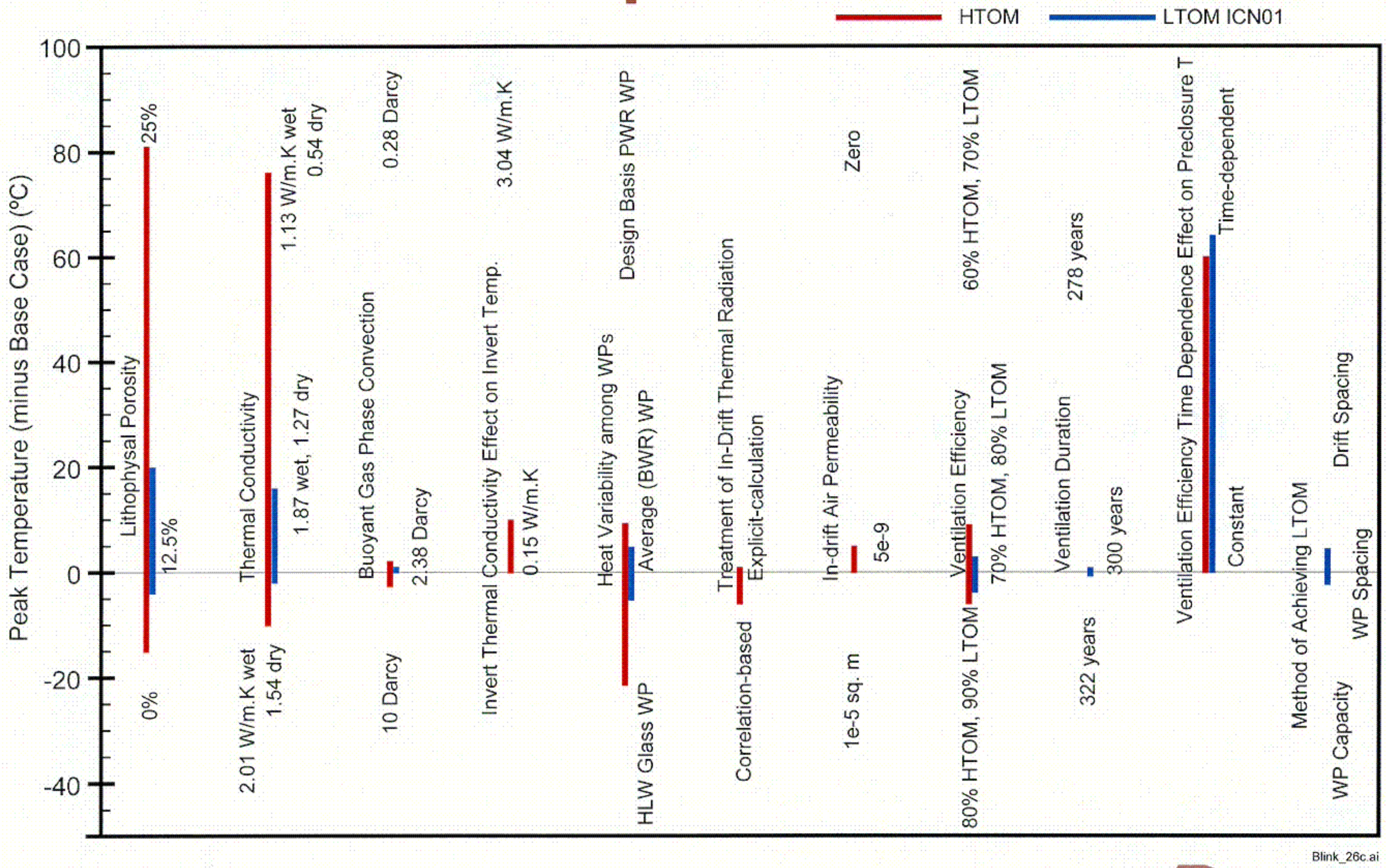
***Spatial variability similar for HTOM and LTOM***

# Sensitivity of Waste Package Temperature to Infiltration Rate and Operating Mode
## (All Waste Package Types and Locations)




- **WPs in the HTOM**
  - **Exhibit larger temperature variability**
  - **Stronger dependence on infiltration flux**

# Sensitivity of Peak Postclosure Temperature






C-8

# Supplemental Engineered Barrier System Chemical Environment Model

- **Main improvement for the TSPA-SR supplemental chemical environment model is the propagation of uncertainty associated with the composition of water and gas entering the emplacement drifts**
  - **Different $PCO_2$ soil horizon starting conditions (high $PCO_2$ and low $PCO_2$ cases)**
  - **HTOM versus LTOM**

# Key Chemical Environment Uncertainties

| Key Uncertainty Not Included in S&ER Models | Model Improvements Discussed in SSPA Volume 1 | Included in Supplemental TSPA Model |
|---|---|---|
| Composition of liquid and gas entering drifts | Yes | Yes |
| Seepage/Invert mixing and interactions | Yes | No |
| Trace elemental compositions and effects on chemistry | Yes | No |
| Radionuclide sorption onto corrosion products | Yes | Yes |
| Cement leachate effects on in-drift chemistry | Yes | No |
| Generation of colloids from corrosion products | Yes | No |

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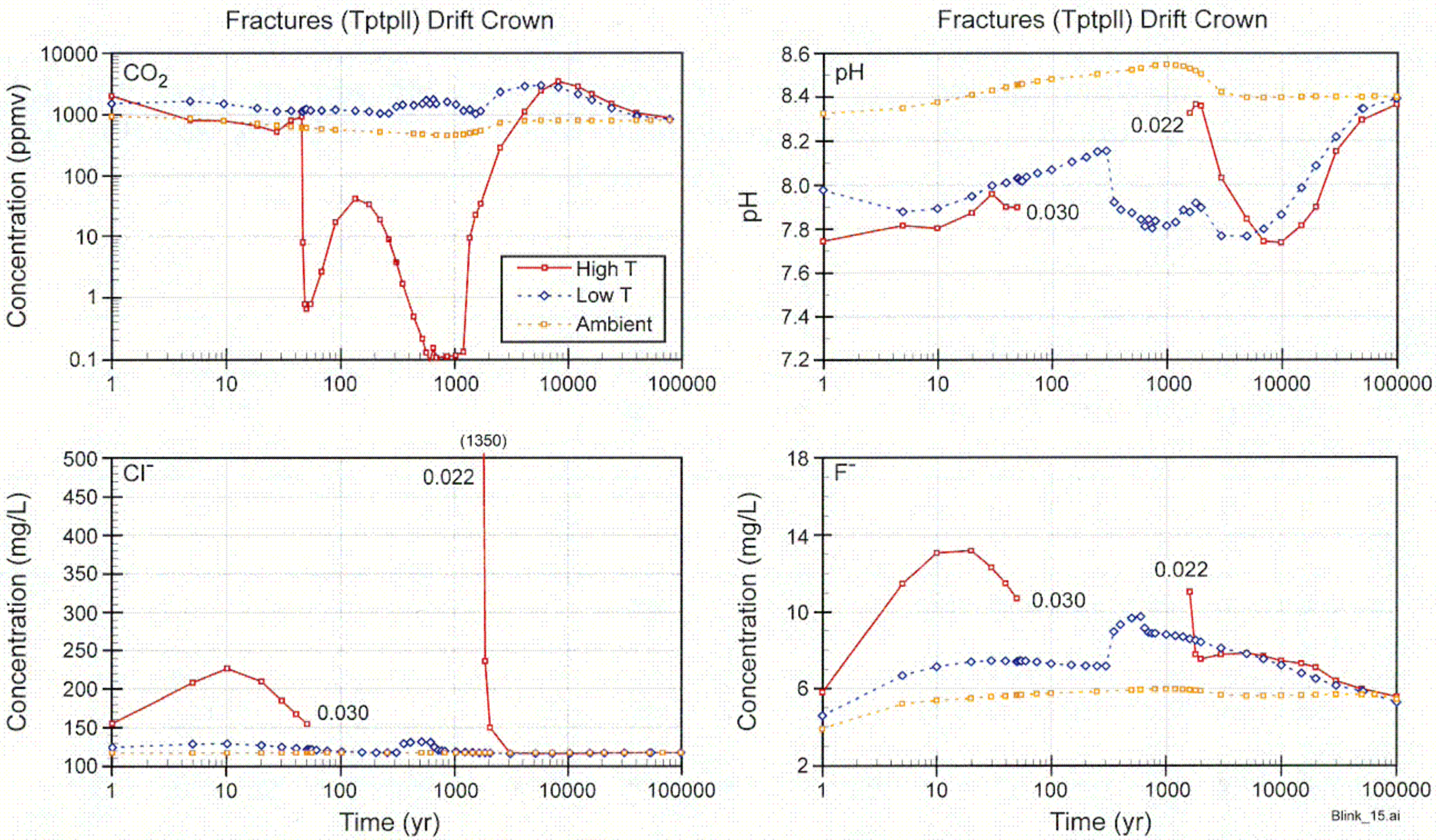
# Seepage Water Chemistry

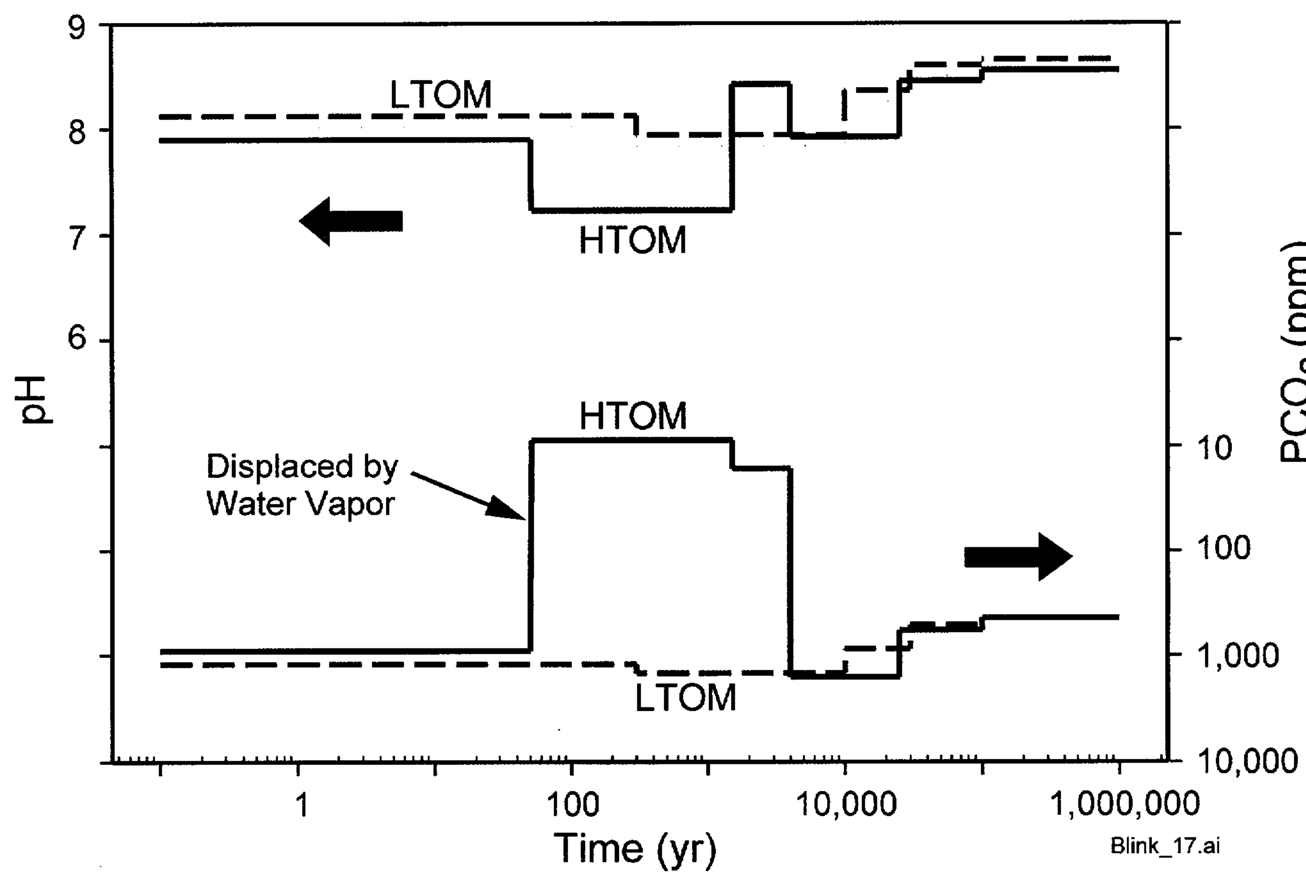



## *LTOM and HTOM are similar after 2000 years*



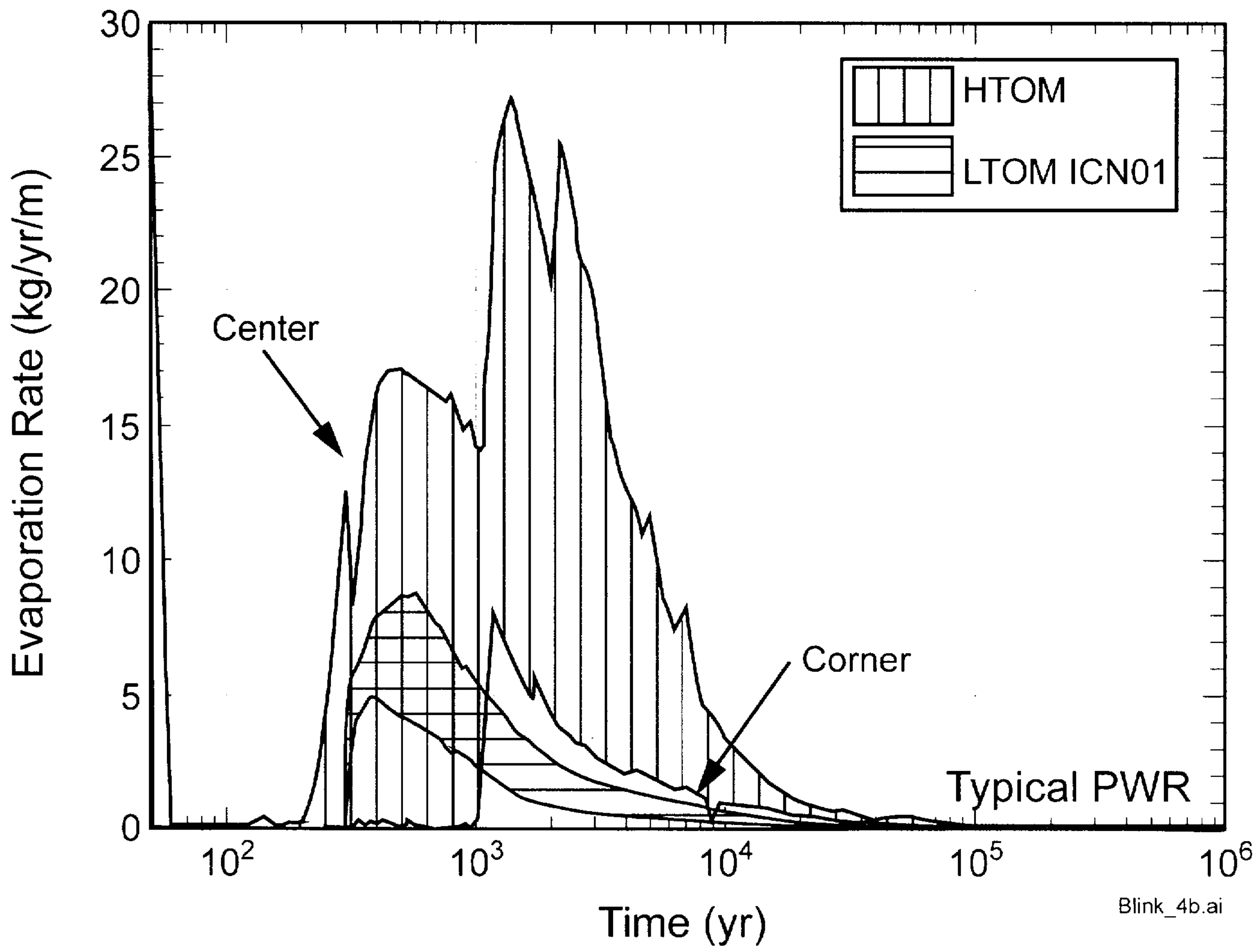
C-9

# In-Drift Water and Gas Chemistry
## (after temporal abstraction, prior to gas-liquid equilibration)



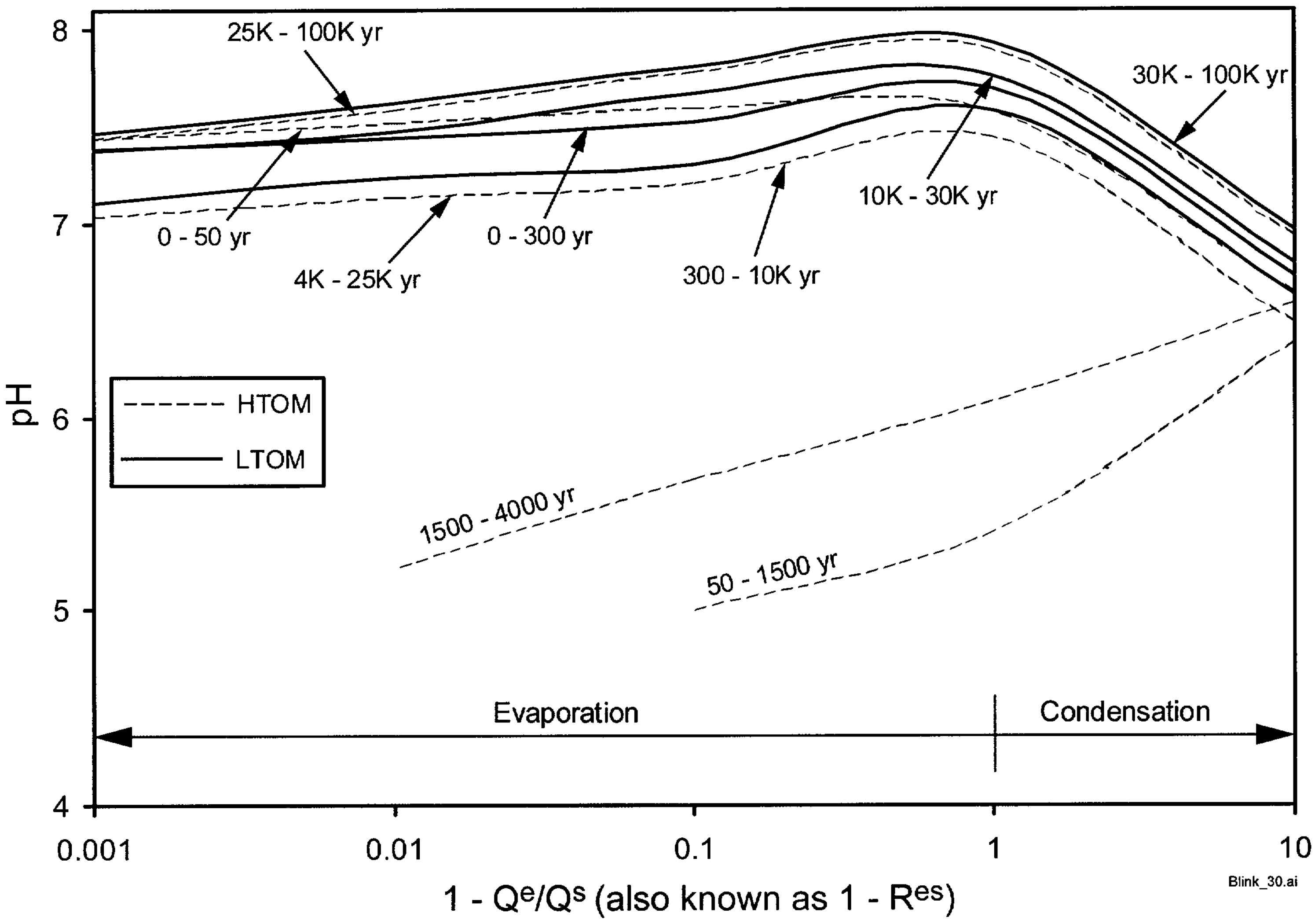

***HTOM and LTOM are similar after a few 1000 years***

# Invert Evaporation Sensitivity to Location



# pH for Higher $CO_2$ Case

## Pore Water - Type Seepage

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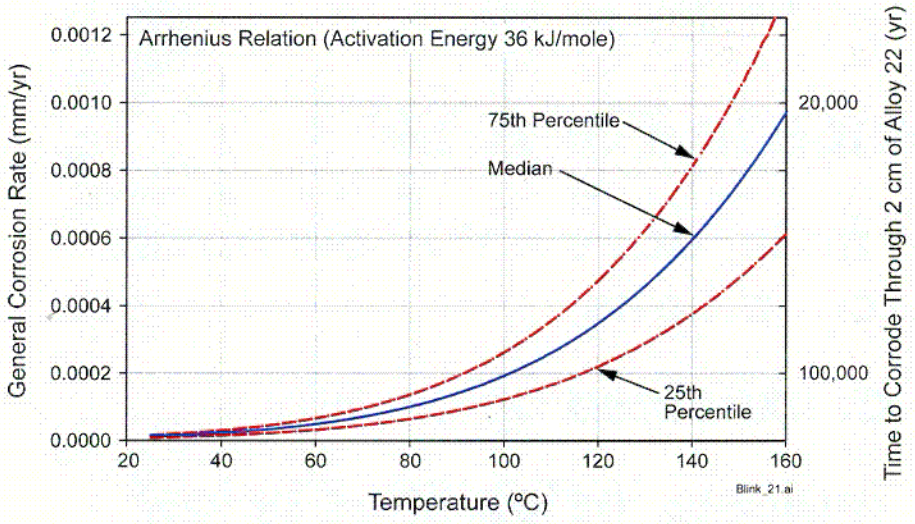
# Waste Package Corrosion Developments Since TSPA-SR

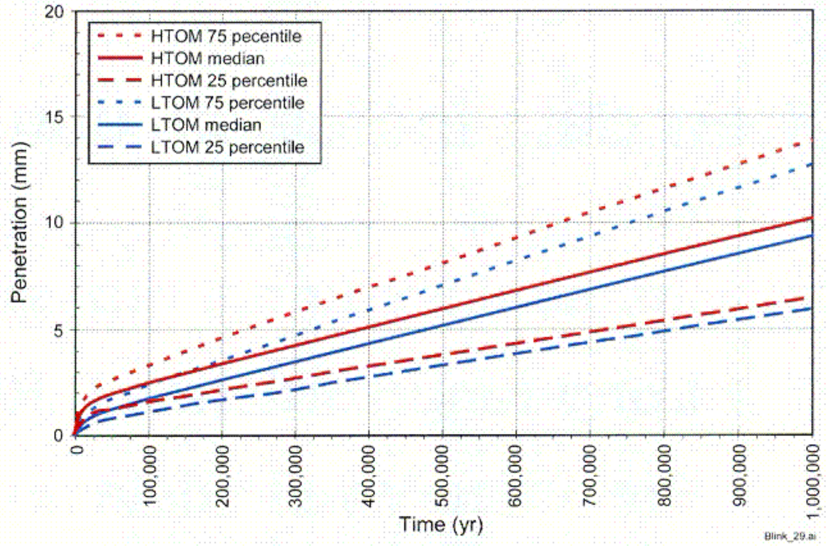
- **Range of water chemistries affect salt development**
  - The WP Critical RH Model in TSPA-SR considered only carbonate base brines
  - The SSPA considered near-neutral pH brines, and the possibility of soluble calcium and magnesium halides
- **Considered potential effect of soluble Pb and other minor constituents in natural systems**
- **Also considered other sources of soluble salts**
  - Entrained matter in ventilation air
  - Rock dust

# Alloy 22 Phase Stability in SSPA

- **New data increases confidence in TSPA-SR**
  - Theoretical modeling of base metal does not show phase instabilities under repository conditions
  - Long-range ordering (LRO) not expected below 300°C
  - Preliminary weld data do not indicate instabilities below approximately 200°C
- **Alternative lines of evidence**
  - Degradation in mechanical and corrosion properties due to aging does not appear likely at temperatures below 300°C
  - Two-phase metastable structures in Josephinite stable for more than 100 million years

# WP General Corrosion




- Potentiostatic polarization measurements determined T-dependence
  - pH 2.75 and 7.75
  - LiCl, $Na_2SO_4$, $NaNO_3$ aqueous environment
  - Chloride to (Sulfate + Nitrate) ratios 10:1 and 100:1

- SSPA V1, R00 ICN01
- Average PWR, Central Location
- Assumes aggressive dust chemistry → corrosion initiation at closure
- No MIC enhancement

***HTOM has ~1 mm more general corrosion that LTOM due to the thermal pulse***

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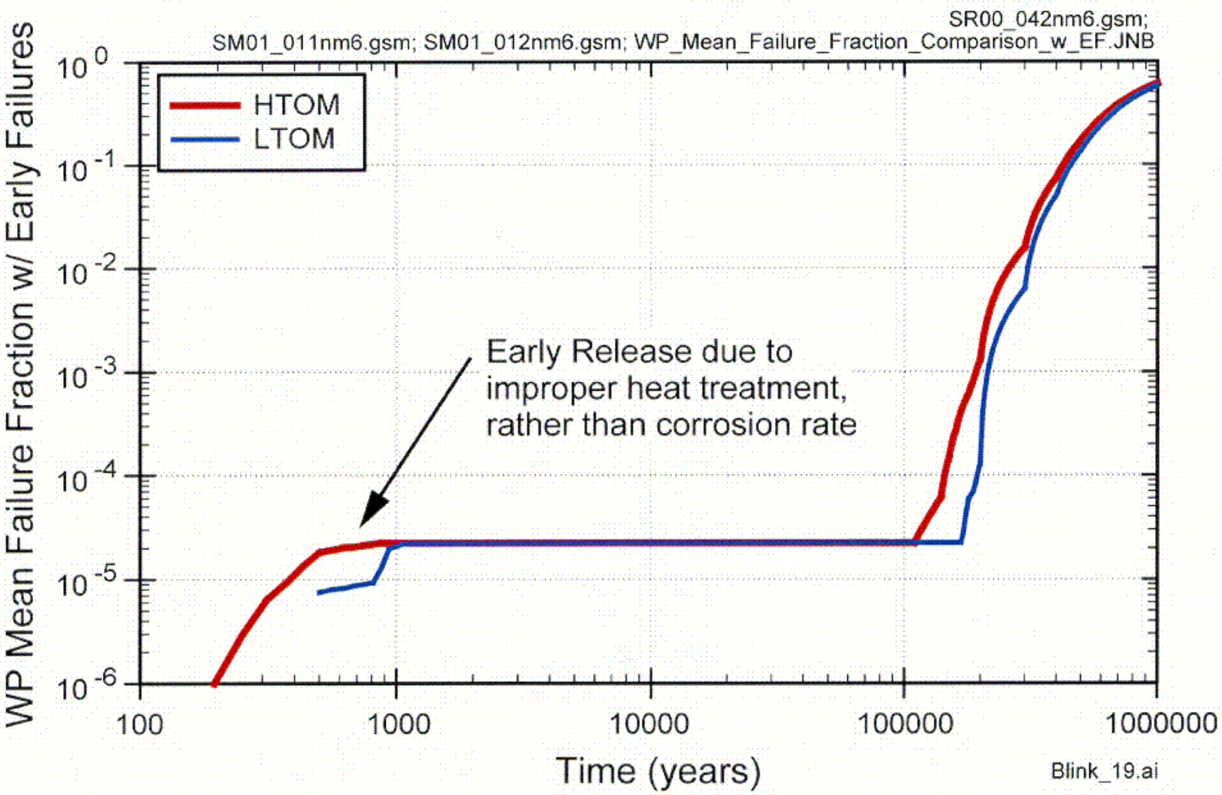
# WP Failure, Including Early Failures




- Includes general corrosion, local corrosion, and stress corrosion cracking
- General corrosion mode increased
  - by 1.0 to 2.0 for MIC
  - by 1.0 to 2.5 for aging (at closure weld)

***LTOM and HTOM are similar***



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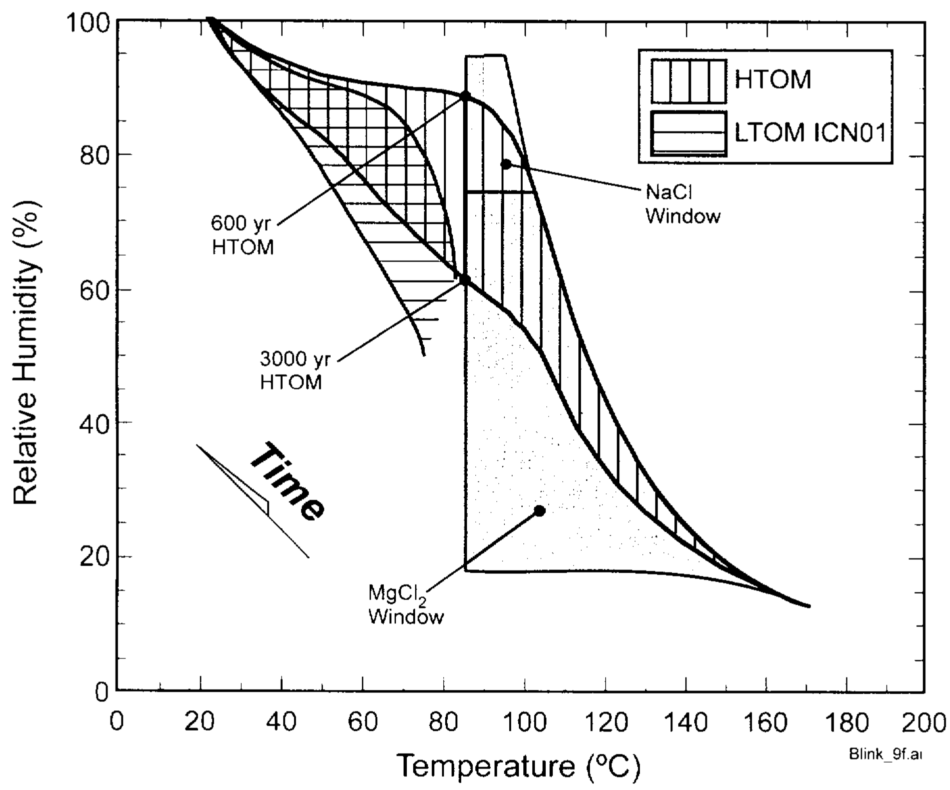
# WP Temperature-Humidity Trajectories and the Crevice Corrosion Initiation Window of Susceptibility

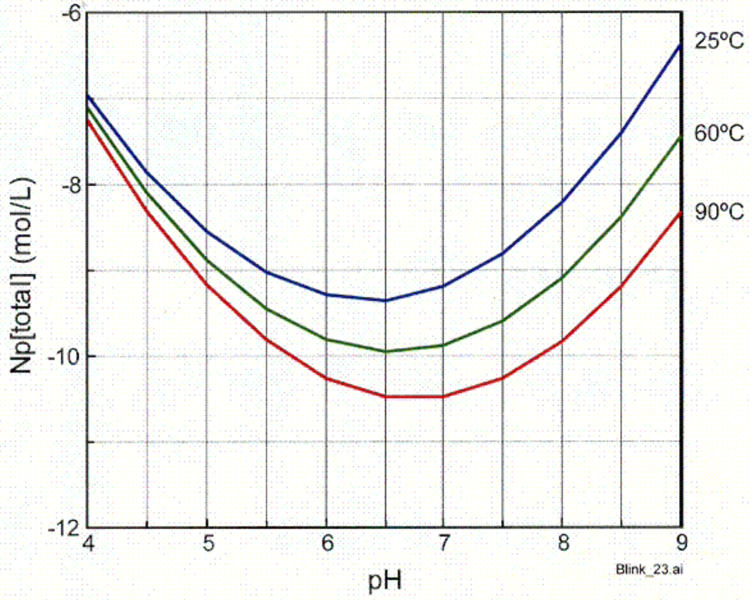


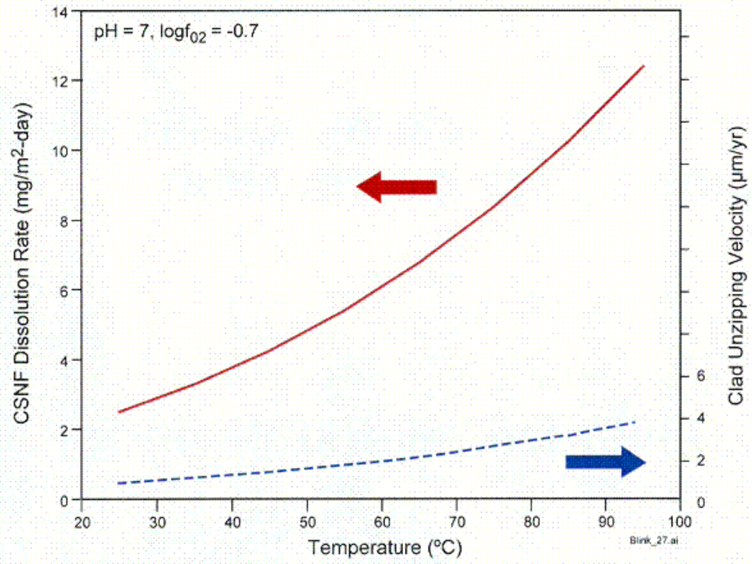

- **Crevice corrosion initiates by breaching the passive film**
- **The process model crevice corrosion initiation window includes T, [$Cl^-$] and pH**
  - **The pH dependence dominates T and [$Cl^-$]**
- **The TSPA crevice corrosion initiation is based on pH**
- ***Both LTOM and HTOM avoid crevice corrosion***
  - **LTOM: Temperature criterion**
  - **HTOM: Chemistry (pH) criterion**

# WF Mobilization Developments Since TSPA-SR

- **In-Package Chemistry**
  - Effects of HLW glass and steel degradation rates (on pH-time trajectories and actinide dissolution)
- **Dissolved Concentrations of Th, Np, Pu and Tc**
  - Effects of thermodynamic data uncertainties, oxygen fugacity, concentration-limiting solid
  - Updated solubilities have lower means and wider ranges
- **Cladding**
  - Effects of creep rupture and stress corrosion cracking, localized corrosion rate uncertainty, seismic failures, rock overburden failure, unzipping velocity uncertainty
- **Colloids**
  - Simplified model with expanded range, includes reversible and irreversible Pu attachment

# Waste Form Mobilization




- Other factors had little or no T-dependence
  - In-WP pH: used 25°C-dominated database
  - Lower Pu solubility at high-T still too uncertain for SSPA model
  - In-WP diffusion coefficient not strongly T-dependent
  - In-WP sorption T-dependence uncertain, higher sorption at higher-T is likely
  - Clad Creep is T-dependent, but negligible total creep
  - Little T-dependence for colloids

# Supplemental Engineered Barrier System Flow and Transport Model

- **Main improvements for the TSPA-SR supplemental EBS flow and transport model are**
  - Seepage evaporation at the DS
  - DS and WP flux models
  - In-package diffusion
  - Radionuclide sorption

# Key Flow and Transport Uncertainties

| Key Uncertainty Not Included in S&ER Models | Model Improvements Discussed in SSPA Volume 1 | Included in Supplemental TSPA Model |
|---|---|---|
| Seepage evaporation | Yes | Yes |
| Drip shield and waste package fluxes | Yes | Yes |
| Drip shield condensation | Yes | No |
| Bath-tub flow | Yes | No |
| Diffusion in waste package | Yes | Yes |
| Diffusion from waste package to invert | Yes | No |
| Diffusion through invert | Yes | Yes |
| Microbial sorption and transport | Yes | No |

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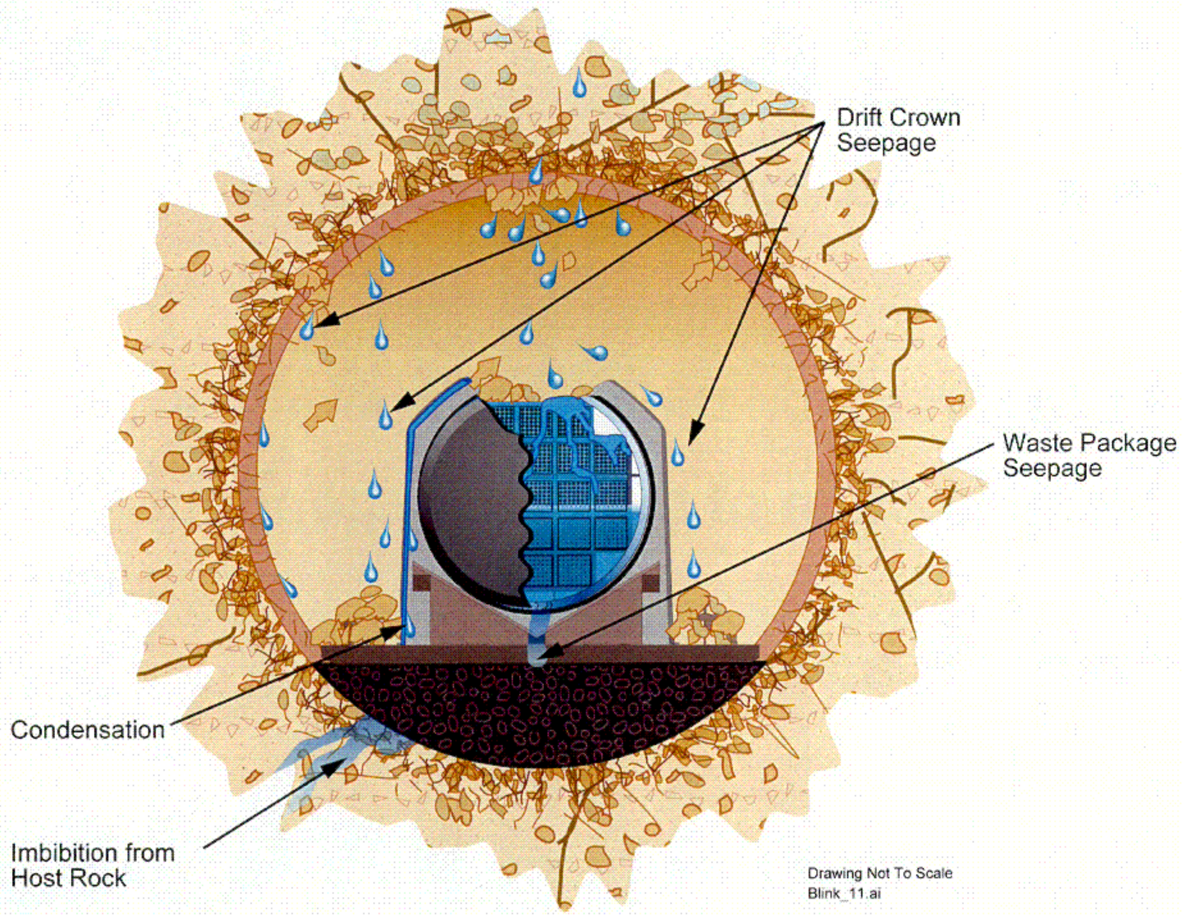
# Impact of Thermal Operating Mode on Engineered Barrier System Transport

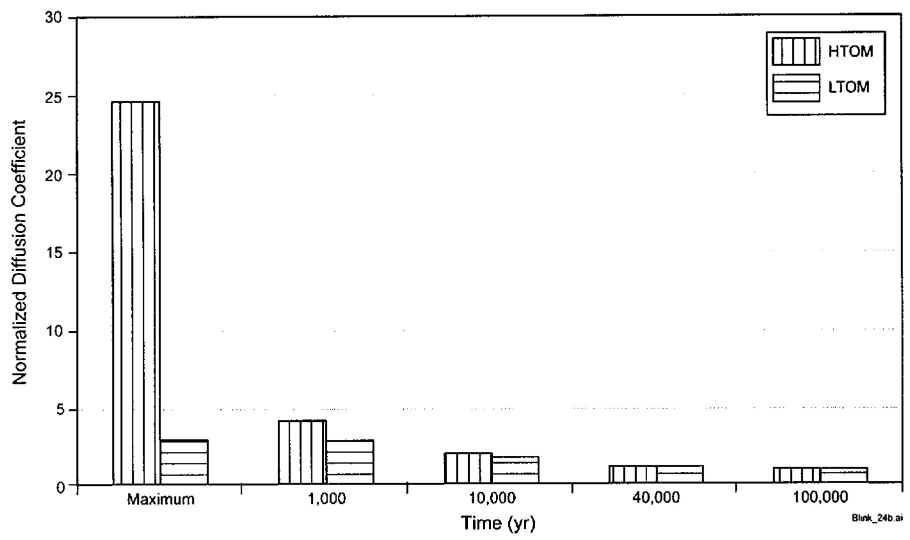
- **EBS Flow**
  - Evaporation rates are a function of thermal response
- **EBS transport**
  - Diffusion coefficient is a direct function of temperature
  - Diffusion coefficient is a function of the time-dependent saturation
  - Adsorption of water vapor is a function of RH

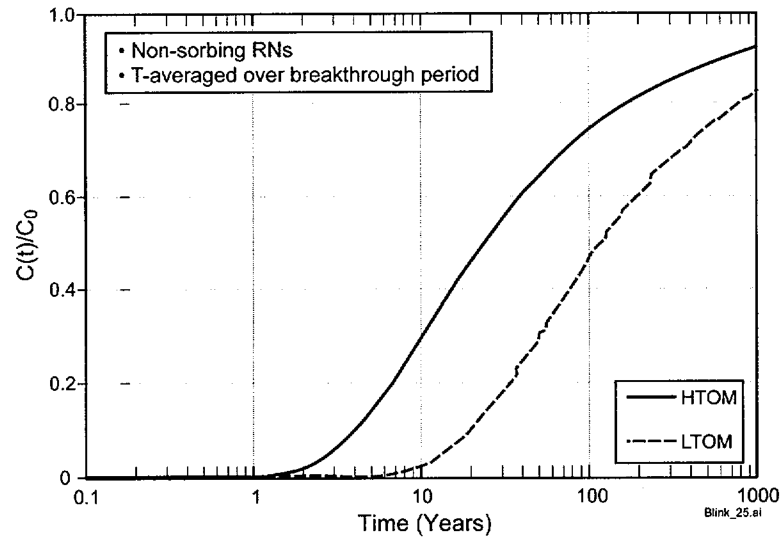
# Water Diversion in EBS




- Model geometry realism was improved
- Not sensitive to operating mode

# Engineered Barrier System Transport




- **Parameters depend on T**
  - **Diffusion coefficient is f(T, $S_{invert}$)**
  - **Absorption of water vapor (condensate thickness)**
  - **Evaporation/condensation fluxes**

***Negligible difference between HTOM and LTOM because very few WPs fail when temperatures are different***

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# UZ Transport Developments Since TSPA-SR

- Transport times in the drift shadow are orders of magnitude longer than predicted by the existing PA model. The transport times in the drift shadow model are significant relative to the 10,000 year regulatory time frame
- Process model representation of matrix diffusion is conservative due to matrix discretization effects, resulting in shorter predicted breakthrough times. The PA model is conservative relative to the process models over most of the breakthrough curve
- Including the southern extension to the potential repository block results in slightly longer transport times to the water table
- Local dryout from TH processes will delay or reduce radionuclide transport immediately beneath potential waste emplacement drifts for 2000 to 3000 years. Other thermally-driven coupled process effects are expected to have minimal effects on transport

# Unsaturated Zone Transport

- **Calico Hills peak temperature (~75°C HTOM)**
  - **Is not high enough**
  - **For long enough**
  - **For significant zeolite alteration which could change flow patterns or sorption**

# SZ Developments Since TSPA-SR

- **New Data**
  - Lithology of Nye County wells
  - Hydraulic head and water level elevations
- **New Field Test Results**
  - Alluvial Testing Complex (ATC) hydraulic measurements
  - Preliminary ATC single-well tracer test results
- **New Model Analyses (Process model level)**
  - Alternate conceptual model for Large Hydraulic Gradient
  - Alternate representation of Solitario Canyon Fault

# SZ Developments Since TSPA-SR
(Continued)

- **New Model Analyses (total system level)**
  - Dispersion and matrix diffusion analyses
  - Sensitivity to flow path length in alluvium
  - Sensitivity to reversible colloid model uncertainty
  - Location of accessible environment (EPA final rule)
- **New Values Used in SSPA**
  - Bulk density of alluvium
  - Sorption coefficients (Tc and I)

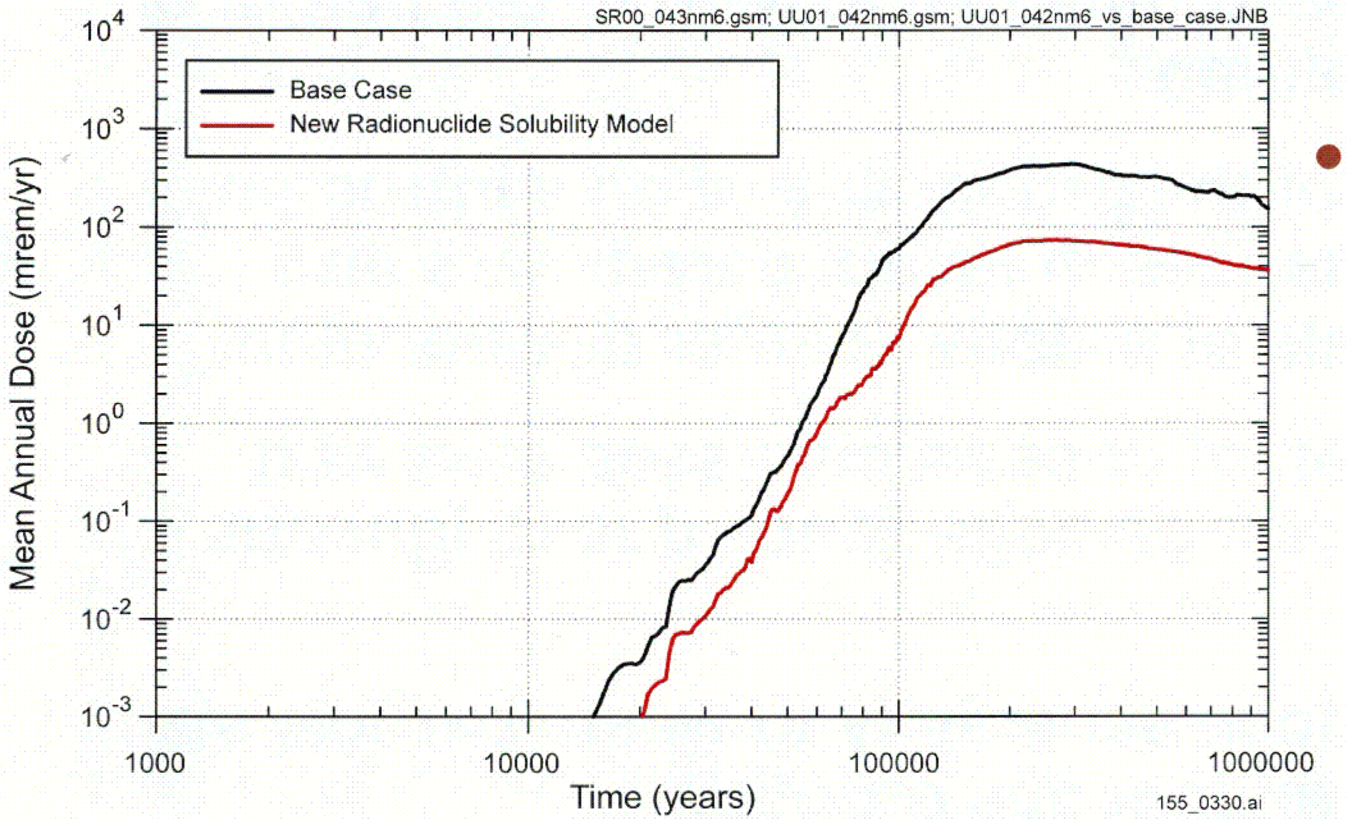
# Biosphere Developments Since TSPA-SR

- Updated FEPs
- Relative exposures to receptor groups
- Improved distributions for input factors in External and Inhalation exposure analyses
- Climate effects on water usage & ingestion exposure
- Improved transfer coefficients (soil to plant, etc.) for Pb, Bi and Po
- Revised BCDFs
- Increased GENII-S sample size
- Revised volcanic eruption BDCF analysis

# Disruptive Events Developments Since TSPA-SR

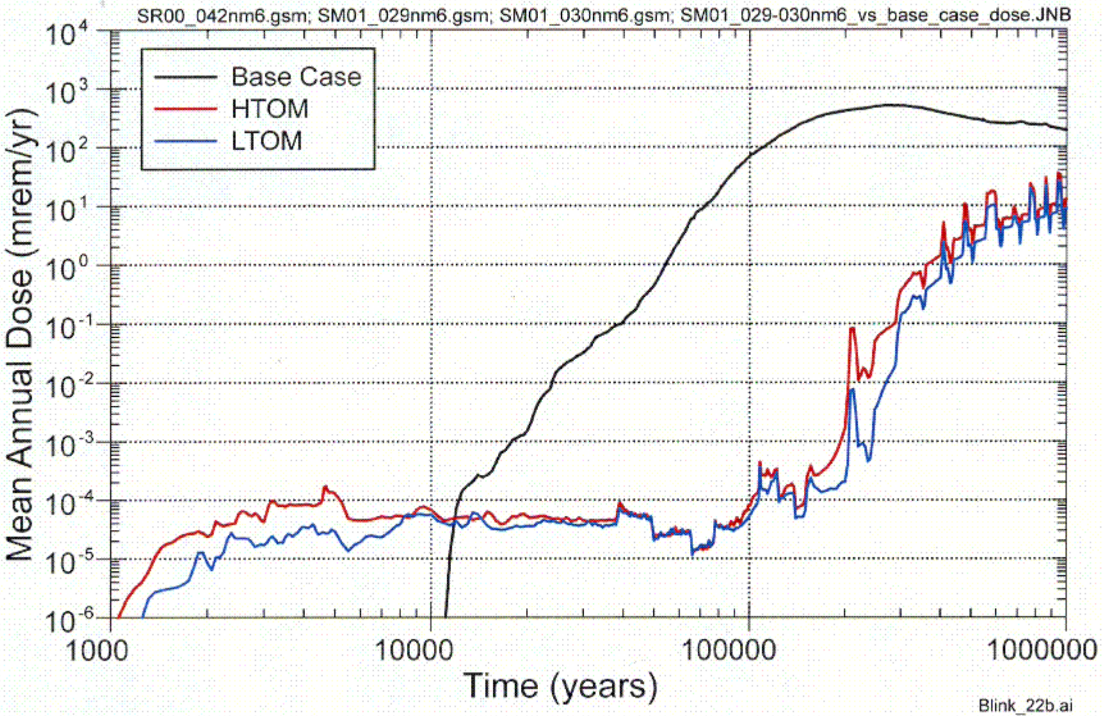
- **Use of wind speed data that extend to the height of the eruptive column**
- **New analyses of the probability of dike intrusion, considering changes in layout parameters and alternate models of eruptive center development**
- **Characterization of uncertainty associated with emplacement drift damage zones due to igneous intrusion**
- **Evaluation of dose sensitivity to waste particle size distribution in an igneous eruption**

# Effect of Updated Solubility Model




- **Improvements in Np solubility reduce doses by about 10x**

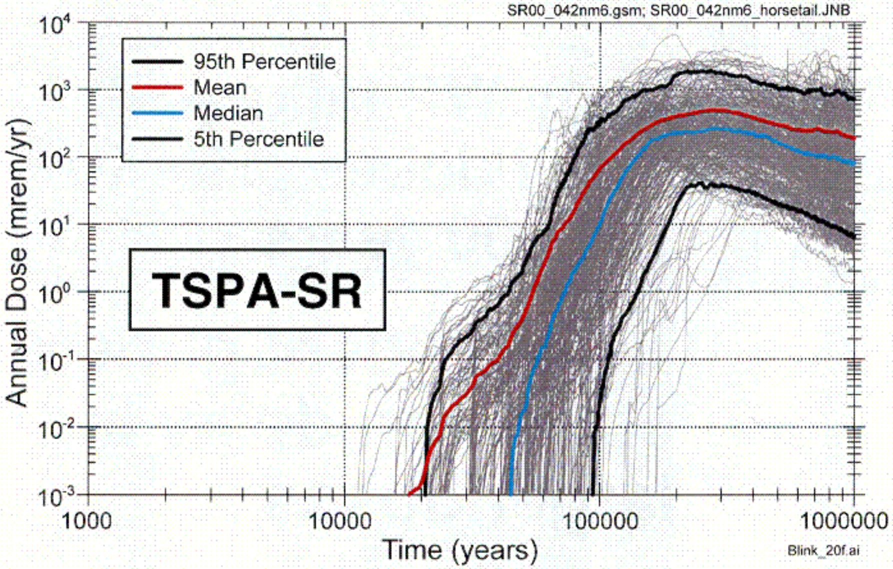
# Total Dose - Nominal Scenario

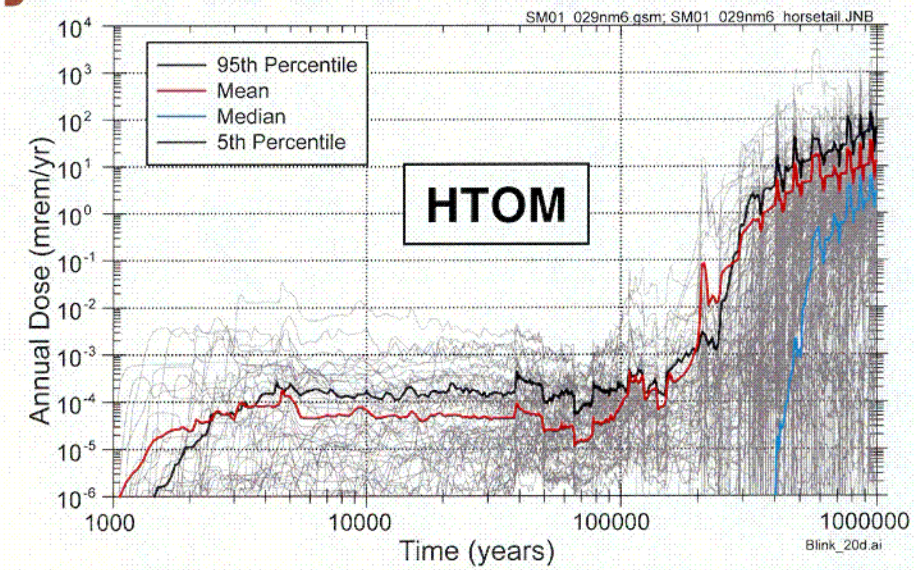


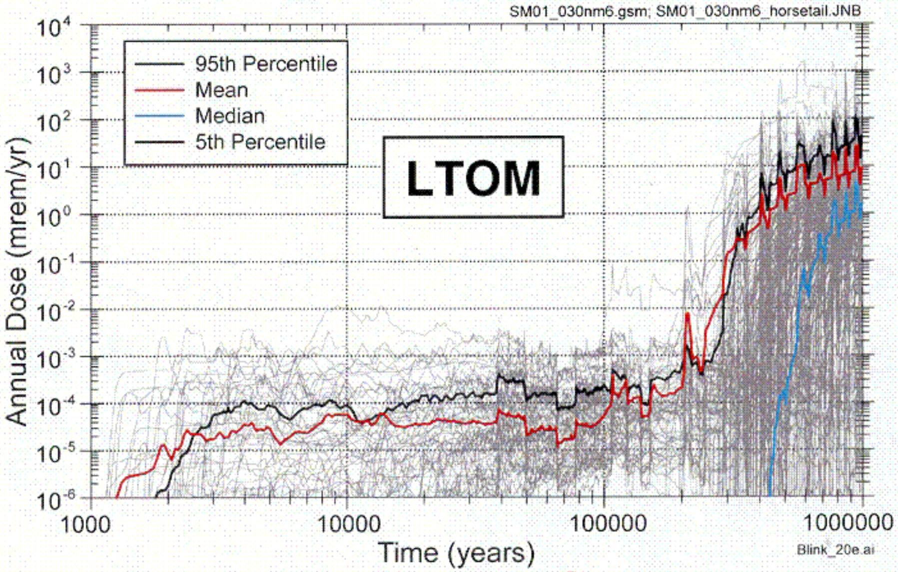

***Because most WP failures are well beyond the thermal pulse, HTOM and LTOM mean dose rates are similar***

- **Early WP failure—small doses prior to 100,000 years**
- **T-dependent general corrosion delay in larger doses**
- **Post 10,000 year climate changes—about 10x dose variation**
- **Solubility updates—about 10x decrease in peak dose**

# Total Dose Uncertainty - Nominal Scenario




- ***TSPA models apply to both LTOM and HTOM***
- **Process level models evaluate subsystem uncertainties, which in some cases, are propagated in TSPA abstractions**

***The TSPA uncertainty ranges for HTOM and LTOM are similar***



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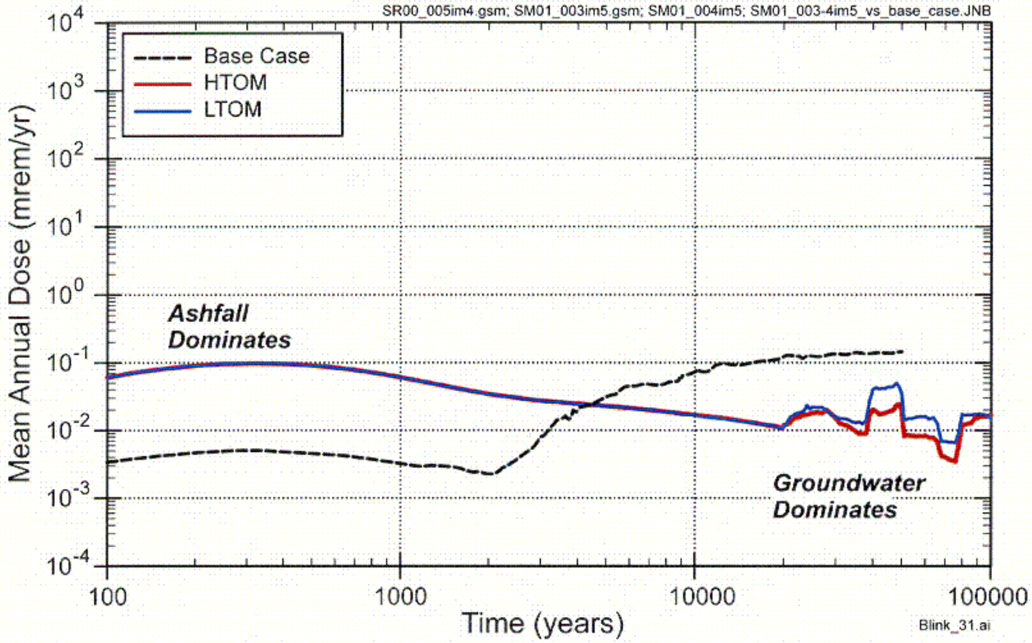
# Supplemental TSPA Model Results
# Igneous Disruption

- Eruptive doses increase by ~20x, dominate for >10 kyr
  - Changes in probability, BDCFs, wind speed, # of packages damaged
- Intrusive groundwater doses peak with 38 kyr climate change
- Overall peak probability-weighted dose is similar to base case, but dominant pathway shifts from groundwater to eruptive ashfall



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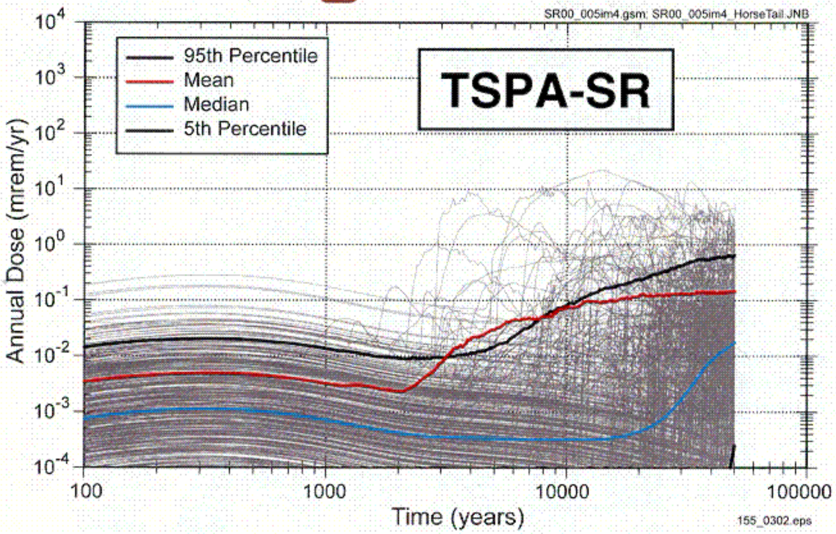
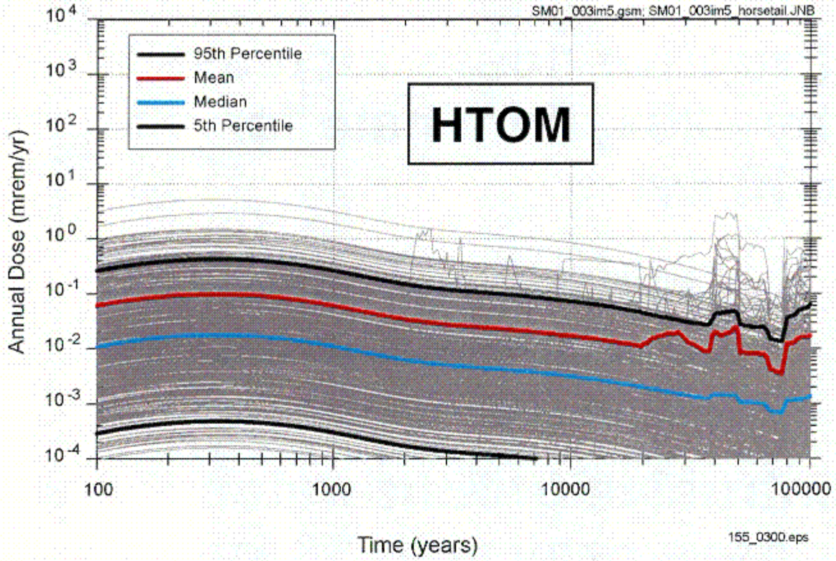
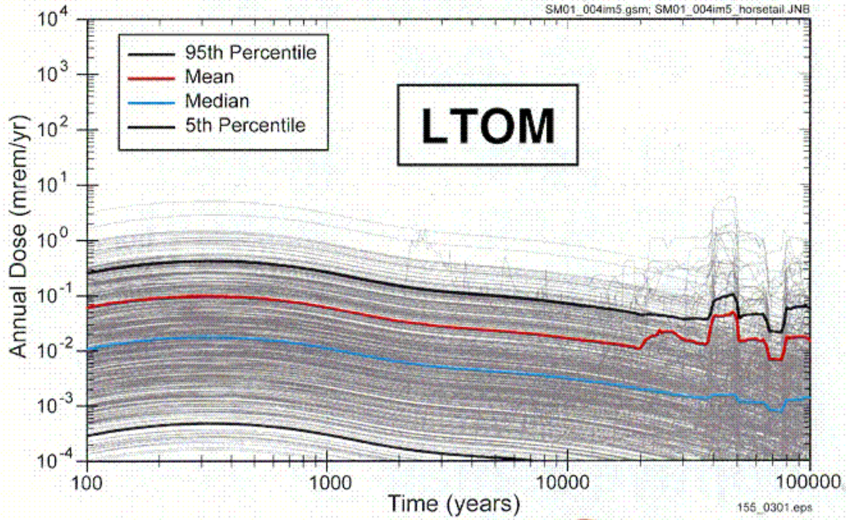
# Total Dose Uncertainty - Igneous Disruption Scenario




***LTOM and HTOM results are similar***



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# Process Model Effects on Dose

- Updated Np solubility - 10x peak dose decrease
- 1,000,000 year climate model - 10x dose variation
- Temperature-dependent general corrosion
  - 700,000 year delay in peak dose
  - ~350,000 year delay in 1 mrem/yr dose rate
- Early failure of a few WPs - dose rate ~$10^{-4}$ mrem/yr