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

NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

April 25-26, 2000

YUCCA MOUNTAIN PROJECT

ATTACHMENT-1

AGENDA

AGENDA

TECHNICAL EXCHANGE ON YUCCA MOUNTAIN PRE-LICENSING ISSUES
April 25 – 26, 2000 at Las Vegas, NV

PURPOSE AND OBJECTIVE: To review the status, discuss and document the path forward for resolution of NRC Key Technical Issues; discuss role of Key Technical Issues in Sufficiency.

April 25, 2000

08:00 - 08:15 Introduction NRC/DOE/Other Parties

08:15 – 10:15 NRC/DOE Management Considerations
NRC Strategy for Resolving Key Technical Issues (1 hour)
Overall Approach to Addressing Key Technical Issues
- Status and Role of Yucca Mountain Review Plan
- Role of KTI for Sufficiency

DOE Process for Completing Site Recommendation Report (1 hour)
- Site Recommendation Consideration Report Status
- DOE's Actions to Support NRC Sufficiency
- Prioritization and Safety Case

10:15 – 10:30 Break

10:30 – 12:00 Total System Performance Assessment and Integration
- NRC Key Technical Issues Lead (45 minutes)
- DOE Counterpart (45 minutes)

12:00 – 1:00 Lunch

01:00 –02:30 Unsaturated and Saturated Flow Under isothermal Conditions
- NRC Key Technical Issues lead
- DOE Counterpart

02:30 – 04:00 Container Life and Source Term
- NRC Key Technical Issues Lead
-DOE Counterpart

04:00 – 04:15 Break

04:15 – 05:45 Evolution of Near-Field Environment
- NRC Key Technical Issues Lead
- DOE Counterpart

05:45 – 06:15 Closing Remarks NRC/DOE/Other Parties

TECHNICAL EXCHANGE ON YUCCA MOUNTAIN PRE-LICENSING ISSUES

APRIL 26, 2000

08:00 – 08:15 Introduction NRC/DOE/Other Parties

08:15 – 09:45 Repository Design and Thermal-Mechanical Effects
- NRC Key Technical Issues Lead
- DOE Counterpart

9:45 AM- 11:15 Breakout Session to discuss Quality Assurance related issues (Open to All)

09:45 – 11:15 Thermal Effects on Flow
- NRC Key Technical Issues Lead
- DOE Counterpart

11:15 – 11:30 Break

11:30 – 12:45 Radionuclide Transport
- NRC Key Technical Issues lead
- DOE Counterpart

12:45 – 01:30 Lunch

01:30 – 03:00 Igneous Activity
- NRC Key Technical Issues Lead
- DOE Counterpart

03:00 – 04:30 Structural Deformation and Seismicity
- NRC Key Technical Issues Lead
- DOE Counterpart

04:30 – 05:30 Break and Caucus

05:30 Closing Statements and Adjourn
NRC/DOE/Other Parties

Agenda

Breakout Session to Discuss Quality Assurance Related Issues
April 26, 2000 at Las Vegas, NV
9:45 AM- 11:45 AM

Office of Quality Assurance (OQA)

Status and Timeliness of Corrective Actions
Results of Process Model Report Audits
and delay of remaining audits
Implementation of Lessons Learned
Status of Data, Model, and Code Qualification/
Validation and Control Plan
QAMA

ATTACHMENT- 2

LIST OF ATTENDEES

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Las Vegas, Nevada
April 25 and 26, 2000

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ATTACHMENT-3

SET OF BRIEFING MATERIALS

NRC Management Considerations

By
Bill Reamer
Branch Chief
High Level Waste & Performance Assessment Branch
April 25, 2000

Presentation Topics

- Key Technical Issues (KTI) Resolution Process
- Yucca Mountain Review Plan (YMRP)
- Sufficiency Review

STRATEGY FOR RESOLVING KEY TECHNICAL ISSUES

Presentation Outline

- Background
- Objectives
- Basis of Issue Resolution
- Categories of Issue Resolution
- Implementation Schedule
- Benefits
- Conclusions

Background

- Refocused High-Level Waste Regulatory Program in FY 1996
- Organized Program Around 9 KTIs Most Important to Post-Closure Performance
- Made Significant Progress to Date Toward Issue Resolution

Objectives

- Complete Resolution of All 9 KTI's (and 38 Subordinate Subissues) Before DOE Submits a License Application (LA)
  - NRC Staff Needs to Identify the Needed Information
  - DOE Needs to Provide the Needed Information

Objectives
(ctd)

- Group Unresolved Items Consistent with NRC Practice for Regulatory Reviews
  - Closed
  - Closed Pending Construction Authorization (CA) Review
  - Open Items

- To Extent Practical Use Streamline Guidance and YMRP

Basis of Issue Resolution

- Definition Established in NRC Regulations on Prelicensing Process and a 1992 Agreement with DOE
- Staff-Level Resolution Can be Achieved During Prelicensing Process
- Pertinent Additional Information Could Lead the Staff to Raise New Questions About a Previously Resolved Issues
- Does Not Preclude Issue Being Raised in and Considered During the Licensing Proceeding
- Goal is That LA is Sufficiently Complete With Respect to KTIs for Docketing, Commencement of the Review and Preparation of the Safety Evaluation Report

Categories of Resolution
Closed

- Staff Has No Further Questions Regarding the Model, Data, or Other Information Pertaining to an Issue and Its Subordinate Subissues
  - DOE Approach and Available Supporting Information Acceptably Address Staff Questions
  - No Information Beyond What is Currently Available Will Likely Be Required for Staff Regulatory Decision Making at the Time of Construction Authorization (CA)

Categories of Resolution
Closed Pending CA Review

- Staff Has No Further Questions Regarding the Model, Existing Data, or Other Information Pertaining to an Issue and Its Subordinate Subissues
- Staff is Awaiting Receipt of Additional Information From DOE
- DOE Approach and Supporting Information, Together With the DOE Specific Commitment to Provide Additional Information, Acceptably Address Staff Questions
  - The Commitment Should be Documented, and Should Identify the Information and DOE Plan and Schedule to Provide the Information

Categories of Resolution
Closed Pending CA Review (ctd)

- NRC Has Identified Additional Information That Must Be Provided for Staff to Have Confidence That DOE Has Acceptably Addressed Staff Questions

- If the Additional Information Has Not Been Provided Before LA, the LA Will Include the Remaining Required Information, Sufficient for Staff to Make Determinations Required by the NRC Regulations at the Time of CA

Categories of Resolution
Open

- DOE Has Not Yet Acceptably Addressed Staff Questions or Committed to Provide Additional Information Regarding the Model, Data, or Other Information Pertaining to an Issue or its Subordinate Subissues
- Additional Information is Required to Produce an Adequate Basis for Regulatory Decision at the Time of CA
- NRC is Identifying Models, Data and Other Information That DOE Must Provide For the Staff to Complete its Prelicensing Review and Determine Whether DOE Has Acceptably Addressed Staff Questions
- Failure to Provide the Required Information Could Result in the LA Not Being Docketed.

Implementation Schedule

- Issue Resolution is an Ongoing Focus of Staff Activity
- Issue Resolution Status Reports Published for Each of the 9 KTIs Include Paths to Resolution- Use YMRP in FY 2000, 2001
- Brief DOE in a Public Meeting in April 2000
  - Summarize the Current Resolution Status of the KTIs and Associated Subissues
  - Discuss DOE Plans and Schedule for Providing the Required Information
- Establish More Detailed Schedules by September 2000 for Implementing the Paths to Resolution
- Staff Goal is to Resolve All Issues at the Staff Level by LA Submittal (2002)

Benefits

- Gives Early Visibility to Staff Position on Topics That are Significant from a Risk or Performance Perspective
- Ensures Opportunity to Resolve Promptly Issues Before LA
- Facilitates Timely Preparation of any Safety Evaluation Report Using the YMRP
- Streamlines the Licensing Process
- Allows the Staff to Report on Issue Resolution in its Comments on the DOE Site Recommendation Consideration Report
- Supports the Congressional Mandate for NRC to Review Any DOE LA in a 3-year Period

Conclusion

- Issue Resolution Strategy Aims to Close All 9 KTI at the Staff Level Prior to DOE Submission of any License Application for CA
- Paths to Resolution for Post-Closure Performance Issues Have Been Identified and Documented
- Detailed Implementation Plans will be Developed During FY 2000

Yucca Mountain Review Plan

Yucca Mountain Review Plan (YMRP)

- Guidance to NRC Staff on Focus and Depth of the Review of any DOE License Application
  - YMRP Not a Requirement to DOE
  - DOE LA May Demonstrate Compliance With Part 63 by Alternative Approaches
- YMRP, Rev.0 on Postclosure Was Provided to the Commission in April, 2000
- YMRP Revision 1 Will Include Preclosure, Administrative and Programmatic Issues (September 2000)
- Will be Used to the Extent Possible in Resolving KTIs to Sharpen the Staff's Focus

YMRP

- Experienced Gained in Using the YMRP Will Provide Insights Regarding Any Changes Needed in The YMRP
- DOE/ NRC Interactions and Issue Resolution Aids Development of YMRP
- YMRP Will Provide Flexibility to Staff in its Review of LA
  - DOE Safety Case and Design (e.g., presence or absence of backfill)
  - Importance to Performance (e.g., colloids)

SUFFICIENCY REVIEW

Presentation Outline

- Purpose
- Objective
- Information Needs at LA
- Schedule

Purpose of NRC Sufficiency Review

- Evaluate and Comment on DOE Progress Related to Sufficiency of Data, Design, and Analyses for LA
  - Consider Both Current Information and DOE Plans
  - Focus on Foundations for DOE's Safety Case and Performance Estimates (i.e., Data and Conceptual Models)
- Continue Prelicensing Process Focused on Issue Resolution Prior to DOE's Submittal of LA
- Is Not a Licensing Review

NRC Objectives for Sufficiency Review

- Provide Preliminary Comments On:
  - Where Data and Analyses Appear Sufficient/Insufficient
  - What Additional DOE Data or Analyses are Needed
  - When Additional DOE Data or Analyses are Needed
  - Whether Conceptual Models are Supported
  - Status of DOE QA Efforts
- Identify Significant Open Items If Any That Could Prevent Docketing of LA

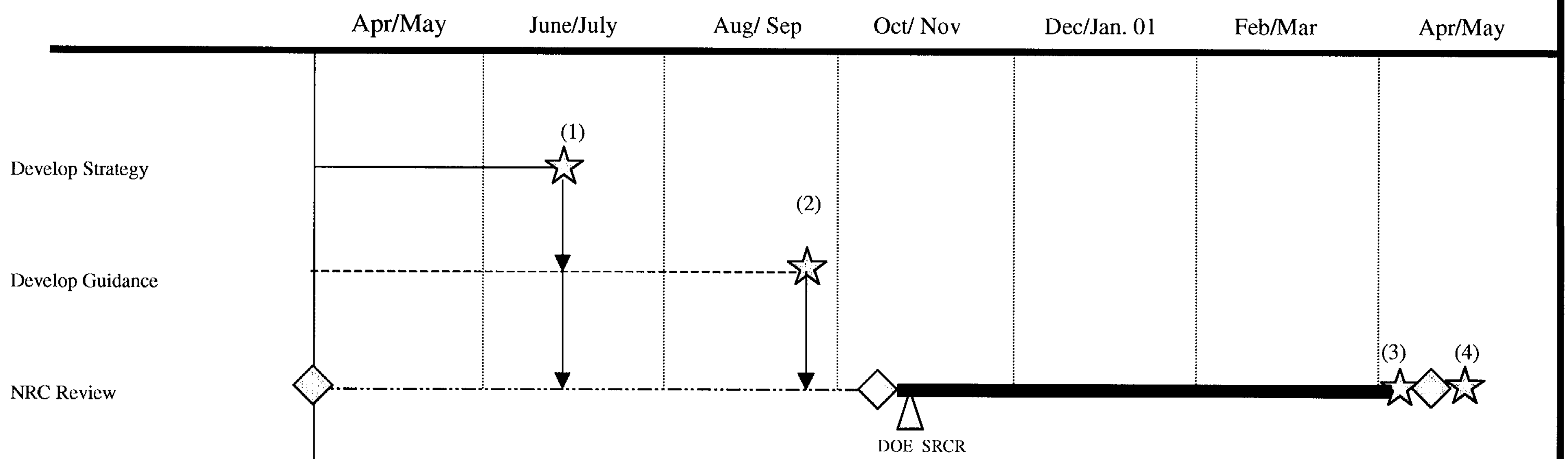
Information Needs at LA

- DOE Licensing Case Must be Adequate to Support a Regulatory Decision on Construction Authorization, Including Adequate:
  - Data
  - Design
  - Analyses
  - QA

NRC Schedule

- Selected NRC Review Milestones
- Complete Review Strategy
  6/30/00
- Complete Review Guidance
  9/29/00
- Provide Sufficiency Comments to DOE
  5/25/01 (Based on DOE Schedule)

NRC SUFFICIENCY REVIEW SCHEDULE



1) Complete Strategy 6-30-00
2) Complete Staff Guidance 9-29-00
3) Complete Staff Review 4-9-01
4) Provide Comments to DOE 5-25-01

(Based on DOE Schedule)

☆ NRC MILESTONE

△ DOE MILESTONE

◇ ACNW BRIEFING

4-18-00

Interactions

- Agree on General Approach Proposed in Brocoum Letter of 11-24-1999 to Support DOE Site Recommendation Decision
- In Particular, Agree to Use Pre Licensing Process for Site Recommendation
- It is Important That DOE Maintains its Schedule, Consistent With Safety
- NRC Staff Will Work with DOE to Coordinate Dates and Sequence of Interactions

What You Will See Today

- A Risk-Informed, Performance-Based Approach
  - Consistent with Proposed 10 CFR Part 63
  - If Risk Significance is Known: Required Information and Analyses are Scaled Accordingly
  - If Risk Significance is Unknown or Uncertain: Required Information and Analyses are Generally Greater
- An Appropriate Level of Detail
  - Responsibility of NRC to Present one Acceptable Method
  - Requirement for NRC staff to Make Reasonable Assurance Findings
  - Commitment by NRC on Our part to Achieve Staff-Level Resolution

What You Will See Today

- The Types of Information Needed from DOE for Issue Resolution
  - Additional Data and/or Analyses
  - Justification of Approach or Parameter Values
  - In a Few Cases, Justification or Revision of Methodology

- An Openness to Dialogue on Alternative Approaches to Issue Resolution

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

Process for Completing the Site Recommendation Report

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Stephan J. Brocoum, Assistant Manager
Office of Licensing and Regulatory Compliance
Yucca Mountain Site Characterization Office

April 25, 2000

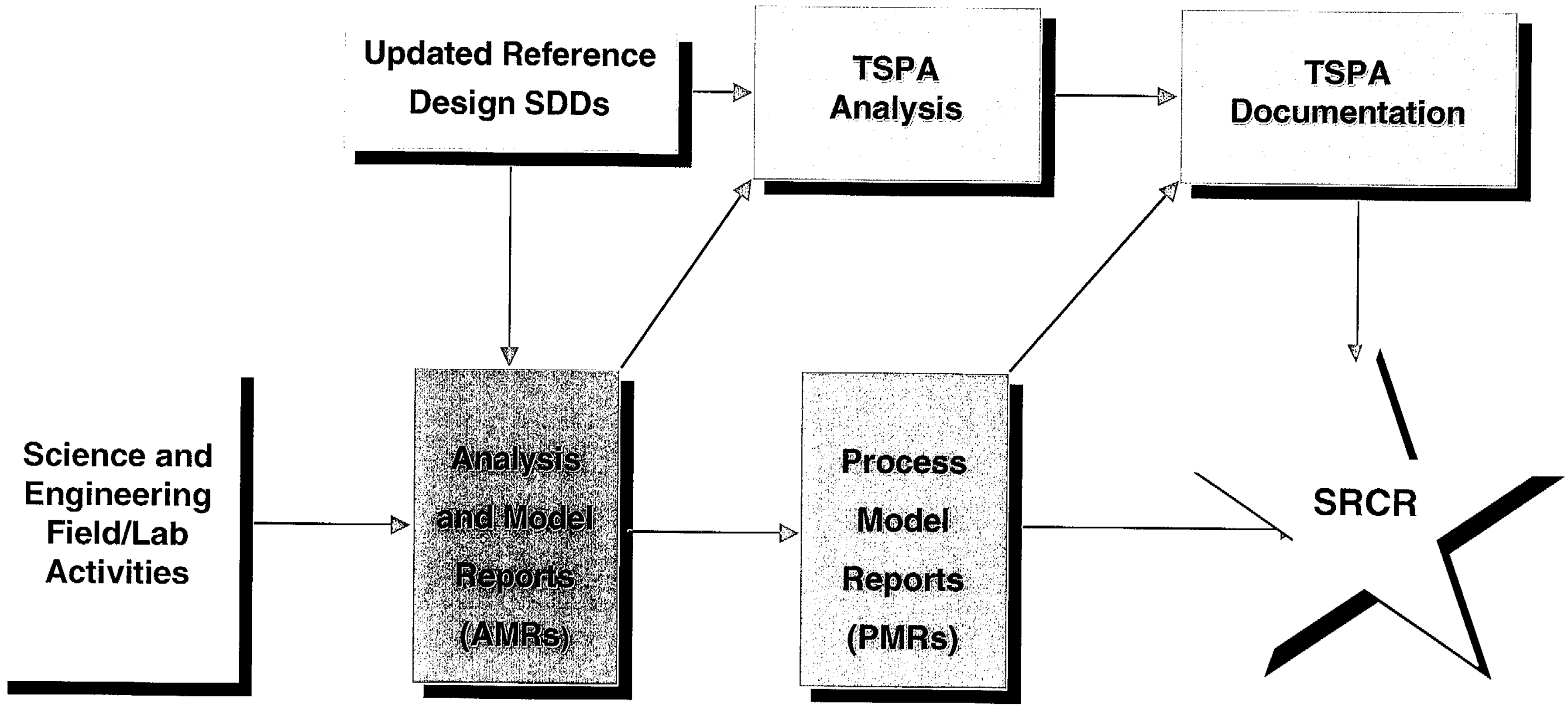
YUCCA MOUNTAIN PROJECT

Overview

- Technical basis for the Site Recommendation Consideration Report (SRCR)
- NRC Sufficiency Review and DOE actions to support review
- DOE's review of NRC's Issue Resolution Status Reports (IRSRs)

Technical Basis for the SRCR

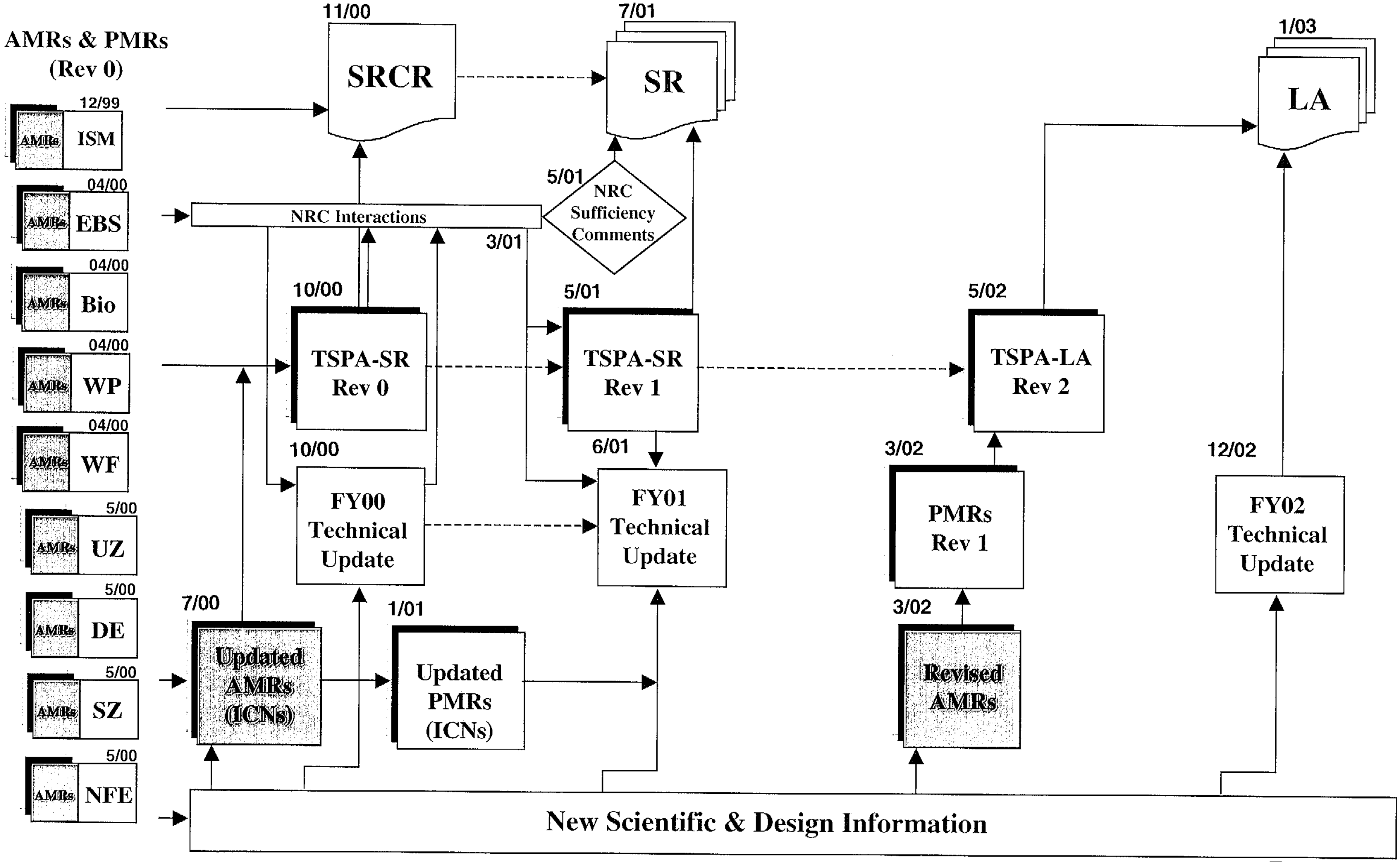
Analyses and Documentation for the Site Recommendation Consideration Report



Technical Basis for SRCR

- DOE letter of November 24, 1999 specified the documentation that will be available for the SRCR technical basis
- Technical basis includes:
  - Process Model Reports (PMRs)
  - Analysis Model Reports (AMRs)
  - System Description Documents (SDDs)
  - Total System Performance Assessment - Site Recommendation (TSPA-SR)
  - Site Description Document
  - Preliminary Preclosure Safety Analysis
  - Technical Update Reports

Technical Basis Documents



Technical Basis for SRCR

(Continued)

- Rev 0 AMRs and PMRs will be updated through Interim Change Notices (ICNs) to reflect new data and analyses, and design evolution
  - If substantial changes are made in supporting AMRs that affect TSPA-SR results, affected Rev 0 PMRs may be revised for SR
- DOE will prepare Technical Update reports to accompany the SRCR and SR
  - Technical Update reports will provide access to the most current information and an assessment of its relevance to the technical basis for SRCR and SR
- PMRs and AMRs will be revised as necessary to support the License Application (LA)

NRC Sufficiency Review and DOE Actions to Support Review

Basis for NRC Sufficiency Review

- **Nuclear Waste Policy Act Section 114(a)(i)(E) requires that the Secretary include with the basis for a SR**
  - "preliminary comments of the Commission concerning the extent to which the at-depth site characterization analysis and the waste form proposal for such site seem to be sufficient for inclusion in any application to be submitted by the secretary"

DOE Understanding of NRC Approach

- NRC's sufficiency review will result in a report on DOE progress toward sufficiency of data, design, and analyses for LA; it is not a licensing review
- In its review, NRC will:
  - Consider both current information and DOE's plans
  - Focus on the foundations for the safety case and performance estimates (i.e., data and models)
  - Consider the status of Key Technical Issue (KTI) resolution
  - Assess DOE progress toward qualifying data and codes, and validating models for use in licensing
- Sufficiency will be evaluated in context of NRC's risk-informed, performance-based approach to licensing

DOE Understanding of NRC Approach

(Continued)

- NRC will provide preliminary comments on:
  - Where data and analyses appear sufficient/insufficient
  - What additional data or analyses are needed and when they are needed
  - Whether conceptual models are supported
  - Status of DOE's quality assurance efforts (data, software, models)
- NRC will not take a position on DOE's dose calculation or evaluate compliance with 10 CFR Part 963
- NRC/DOE prelicensing consultations will continue and focus on issue resolution

DOE Comments on NRC Approach

- The technical documents supporting the SRCR provide the data, design, and analysis information necessary for NRC to complete its sufficiency review and meet the intent of the Nuclear Waste Policy Act
  - Consistent with process proposed in DOE letter of November 24, 1999
- NRC comments on the need for additional data or analyses will be considered by DOE in its planning for LA
- DOE efforts to qualify data and software, and validate models focus on completion for LA

DOE Comments on NRC Approach

(Continued)

- The Yucca Mountain Review Plan establishes the basis for NRC review of the LA; its role, if any, in NRC's sufficiency review is not clear
- DOE will continue to interact with NRC to:
  - Understand the role of KTIs in the sufficiency review
  - Provide an understanding of the relative importance of KTIs in the context of DOE's postclosure safety case
- DOE recognizes that NRC must have adequate confidence to make a "preliminary" assessment that the technical basis for SRCR and the work to be completed prior to LA submittal "seems to be sufficient for inclusion in" a LA

DOE's Review of NRC's Issue Resolution Status Reports (IRSRs)

General Comments on IRSRs

- **DOE has formally responded to NRCs most recent IRSR revisions in 8 letters (March 22, 2000)**
  - Review of IRSR on TSPA and Integration Rev 2 is not complete
- **DOE agrees that some subissues are not fully addressed by information available to NRC**
  - Technical basis documents being developed for SRCR should resolve many of these issues
- **DOE supports the risk-informed performance-based approach reflected in NRC's proposed rule and the flexibility given DOE for demonstrating compliance with the overall performance objectives for the system**

General Comments on IRSRs

(Continued)

- **The IRSRs do not always seem to be consistent with the intent of the proposed approach and may not provide DOE the flexibility as applicant that was intended under the proposed rule**
  - In some cases IRSRs contain implicit or explicit requirements that appear to go beyond the scope of acceptance criteria
  - Some requirements and acceptance criteria appear to be more prescriptive than would be consistent with the proposed approach
  - In some cases there is no clear link between the subissues or acceptance criteria and their importance to performance

General Comments on IRSRs

(Continued)

- PMRs contain tables indicating where discussions related to KTIs and subissues can be found in PMRs and supporting AMRs, and how KTI criteria are being addressed
- DOE is currently in the process of verifying the factors relevant to its postclosure safety case and finalizing the identification of the principal factors for evaluating repository performance
- The documented basis for the postclosure safety case will be presented in Revision 4 of the Repository Safety Strategy (RSS)

General Comments on IRSRs

(Continued)

- The status of the RSS and postclosure safety case are discussed in the next presentation
  - Shows how the information in the technical basis for SRCR relates to the DOE's postclosure safety case
  - Sets the stage for understanding how DOE views the relative importance of the NRC's KTI subissues in the context of the principal factors
- The presentations that follow will provide DOE's current view of each of the KTIs and subissues and will provide more information regarding DOE's approach to resolution of the subissues

Summary

- DOE's primary focus for CY 2000 is on completing the SRCR and its technical basis
- The technical basis documents will be made available to NRC after acceptance by DOE
  - NRC will be advised of any subsequent modifications to the technical basis documents
- DOE agrees with NRC's overall risk-informed, performance-based approach, and the general approach to NRC's sufficiency review
- Future NRC/DOE interactions will focus on the technical basis documents as a means to provide information to NRC for its sufficiency review

Status of the Repository Safety Strategy

Presented to:
NRC/DOE Technical Exchange
on Yucca Mountain Pre-Licensing Issues

Presented by:
Jack Bailey
Director, Regulatory and Licensing
Civilian Radioactive Waste Management System
Management and Operating Contractor

April 25, 2000

Purpose of Presentation

- Show how the information in the technical basis of the Site Recommendation can be related to the DOE's postclosure safety case
- Show how this postclosure safety case relates to NRC's Key Technical Issues (KTIs)

DOE's Consideration of NRC's KTIs

- **DOE continues to summarize data and analyses acquired in its work in terms of the KTIs and the Issue Resolution Status Reports (IRSRs)**
  - **Such a summary was provided in the Viability Assessment**
  - **Section 4 of each Process Model Report (PMR) provides summary discussion and cross-references for each KTI subissue and acceptance criterion**

DOE's Consideration of NRC's KTIs
(Continued)

- All subissues and acceptance criteria are addressed in one or more PMRs, in associated Analysis and Model Reports (AMRs), or in other technical basis documents (e.g. Criticality Topical Report)

- **DOE intends to continue the process to resolve KTIs for the License Application**

Example of PMR IRSR Discussion: Unsaturated and Saturated Flow Under Isothermal Conditions

Table 4.3-1. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: Evolution of the Near-field Environment	
Subissue 1 - Effects of Coupled THC Processes on Seepage and Flow	
Data and model justification acceptance criteria for Subissue 1	
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on seepage and flow were considered.	The TSPA-VA did not explicitly consider the effects of coupled THC processes; the evaluation of coupled THC effects is documented in this PMR. Attachment I summarizes available site data. Section 3.10 documents the abstraction of coupled THC effects for TSPA, based on the process modeling results presented in the same section.
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of coupled processes that may affect seepage and flow.	Attachment I summarizes available data. These data on the site characteristics were used to establish initial and boundary conditions for the evaluation of THC effects on seepage and flow in the near field (Section 3.10).
3 - Sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect seepage and flow.	Attachment I summarizes available site data. The THC model incorporates site data to establish initial and boundary conditions and incorporates specific aspects of the design, including in-drift geometry, drift spacing, and the TH properties of the components of the EBS, such as waste packages and invert (Section 3.10). The current design does not include concrete liners in the emplacement drifts limiting the potential effects of interactions between concrete and tuff on seepage and flow.
4 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional new data are needed to better define ranges of input parameters.	Sensitivity and uncertainty analyses will be included in TSPA-SR.
5 - If the testing program for coupled THC processes on seepage and flow is not complete at the time of license application, or if sensitivity and uncertainty analyses indicate additional data are needed, DOE will identify specific plans to acquire the necessary information as part of the performance confirmation program.	The DOE is developing a plan that will define the performance confirmation program. Performance confirmation testing is not covered in this PMR.

DOE's Consideration of NRC's KTIs
(Continued)

- **At the same time, DOE continues to focus on its safety case**
  - DOE is verifying the factors for the safety case described in Revision 03 of the Repository Safety Strategy to determine the Principal Factors for the postclosure safety case
  - This determination influences the emphasis of the work
  - Although each KTI subissue will be addressed, the information provided will reflect the importance of the subissues to the safety case
- **Path to resolution of the KTIs should include understanding of DOE's safety case and the relationship of the KTIs to it**

DOE's Postclosure Safety Case

- DOE's safety case includes
  - A total system performance assessment (TSPA) to demonstrate the postclosure performance objective of proposed 10 CFR 63.113 is met
  - Additional measures to increase assurance of safety
- The safety case explicitly identifies the Principal Factors, the aspects of the repository system essential to repository performance
- The Principal Factors are being identified in a risk-informed, performance-based approach that is consistent with the requirements of proposed 10 CFR 63.114

Preliminary Principal Factors

(Repository Safety Strategy Revision 3)

- Seepage into emplacement drifts
- Drip shield degradation/performance
- Waste package degradation/performance
- Dissolved radionuclide concentrations
- Retardation in unsaturated zone
- Retardation in saturated zone
- Dilution at the wellhead

Determining the Principal Factors

- The Principal Factors have developed as
  - Site information has increased
  - Repository system design has evolved
  - TSPA models have improved
- Now converging on the Principal Factors for postclosure performance
- The Site Recommendation Consideration Report (SRCR) technical bases will provide information supporting
  - Identification of the Principal Factors
  - Their representation in the postclosure safety case

Determining the Principal Factors
(Continued)

- Understanding of the relative importance of the KTI subissues, in the context of these Principal Factors

- Process to finalize the Principal Factors has involved technical staff from across the Project, oversight by DOE, and outside observers including the Nuclear Waste Technical Review Board and the NRC
- The process involves evaluation of the process models and supporting data described in the PMRs and AMRs
- The features, events, and processes (FEPs) included in the process models were identified and assembled into "process model factors"

Example of Process Model Factors

PMR	Process Model Factor	FEP Number	FEP Title
Waste Package (FEPs analyzed in W0055)	Waste Package Degradation and Performance	2.1.03.01.00	Corrosion of waste containers
		2.1.03.02.00	Stress corrosion cracking of waste containers
		2.1.03.03.00	Pitting of waste containers
		2.1.03.05.00	Microbially mediated corrosion of waste container
		2.1.03.11.00	Container form
		2.1.03.12.00	Container failure (long-term)
		2.1.10.01.00	Biological activity in waste and EBS
		2.1.11.06.00	Thermal sensitization of waste containers increases fragility
	Drip Shield Degradation and Performance	2.1.06.06.00	Effects and degradation of drip shield (general corrosion, localized corrosion, microbial effects)
	Excluded from TSPA models	1.2.02.03.00	Fault movement shears waste container
		1.2.03.02.00	Seismic vibration causes container failure (effects on either waste package or drip shield excluded by design)
		2.1.03.04.00	Hydride cracking of waste containers
		2.1.03.06.00	Internal corrosion of waste container
		2.1.03.07.00	Mechanical impact on waste container (effects of rockfall on drip shield or on waste package—even if drip shield is not present—excluded by design)
		2.1.03.08.00	Juvenile and early failure of waste containers (initial defects of waste packages or drip shields sufficient to result in juvenile failure excluded)
		2.1.03.09.00	Copper corrosion
		2.1.03.10.00	Container healing
		2.1.06.07.00	Effects at material interfaces
		2.1.07.01.00	Rockfall (large block)
		2.1.07.05.00	Creeping of metallic materials in the EBS
		2.1.09.03.00	Volume increase of corrosion products
		2.1.09.09.00	Electrochemical effects (electrophoresis, galvanic coupling) in waste and EBS
		2.1.11.05.00	Differing thermal expansion of repository components
		2.1.12.03.00	Gas generation (H2) from metal corrosion
		2.1.13.01.00	Radiolysis

Determining the Principal Factors

(Continued)

- The process model factors are being evaluated through the risk-informed, performance-based approach
- This approach began with qualitative analyses supported by preliminary TSPA and barriers importance analyses
- These analyses are now being verified through TSPA analyses using updated component models
- All credible engineered and natural processes and events are incorporated in these analyses
- These TSPA analyses will be fully documented in the TSPA-Site Recommendation

Preliminary Results

- Understanding based on data and analyses for waste package degradation suggests waste package performance would be a principal contributor to system performance
- Importance of uncertainties in waste package degradation are being evaluated
  - Preliminary considerations suggest that, even accounting for uncertainties in conditions and measured corrosion rates, waste packages would remain intact for at least tens of thousand of years
  - Analyses of potential initial defects suggest the probability of those leading to failures in less than 10,000 years is less than 0.0001

Preliminary Results
(Continued)

- These analyses suggest waste package degradation and performance is likely to be a Principal Factor
- The risk-informed, performance-based approach includes evaluation of factors contributing margin and defense-in-depth
- The evaluation is considering a hypothetical, nonmechanistic waste package failure scenario to examine the contribution of factors other than the waste package
- These analyses indicate that other potential Principal Factors include:
  - Drip shield degradation/performance

Preliminary Results
(Continued)

- Retardation in the unsaturated zone
- Retardation in saturated zone

- In addition, to evaluate robustness of 10,000-year performance, analyses are conducted for periods beyond 10,000 years
- Additional factors that come into play in the longer period and that are potential Principal Factors include:
  - Seepage into emplacement drifts
  - Radionuclide concentrations at the source (dissolved radionuclide concentrations, colloid-associated radionuclide concentrations)
  - Dilution at the wellhead

Current Status of Safety Case

- **Preliminary Principal Factors for the Nominal Scenario**
  - Seepage into emplacement drifts
  - Drip shield degradation/performance
  - Waste package degradation/performance
  - Radionuclide concentrations at the source
  - Retardation in unsaturated zone
  - Retardation in saturated zone
  - Dilution at the wellhead

Current Status of Safety Case
(Continued)

- In addition, factors for disruptive events are being evaluated to determine Principal Factors for these scenarios
- Determination of all Principal Factors will be complete before SRCR and documented in Repository Safety Strategy Revision 4

DOE Actions to Support NRC Sufficiency

- DOE intends to support NRC's sufficiency review by providing data and analyses regarding KTI subissues, including analyses showing the importance of these subissues to postclosure performance
- A top-level view of the relationship between DOE's understanding of the Principal Factors and the KTI subissues will be provided in this meeting
- More details will be provided in future meetings on each PMR

Example of Relation Between KTI and Principal Factors: Unsaturated and Saturated Zone Flow--Isothermal Conditions

	KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1	Climate Change	Climate	Preliminary analyses suggest these factors do not contribute strongly to postclosure performance. Completed analyses will be documented for SRCR.
2	Hydrologic Effects of Climate Change	Infiltration, Unsaturated Zone Flow	
3	Present-Day Shallow Infiltration	Infiltration	
4	Deep Percolation	Unsaturated Zone Flow, Seepage into Drifts	Seepage is a Principal Factor.
5	Saturated Zone Ambient Flow and Dilution	SZ Flow and Transport (Advective Pathways, Retardation, Dispersion, Dilution)	Retardation of radionuclide transport in the UZ and SZ are Principal Factors.
6	Matrix Diffusion	UZ and SZ Flow and Transport (Advective Pathways, Retardation, Dispersion, Dilution)	

Summary

- DOE plans to provide information in the context of a risk-informed, performance-based approach to safety
- Although each KTI subissue will be addressed, the information provided will reflect the importance of the subissues to DOE's safety case
- The documented basis for this safety case should
  - Facilitate resolution of KTI subissues related to non-Principal Factors
  - Provide a basis to focus DOE-NRC interactions on factors most important to postclosure performance

KEY TECHNICAL ISSUE (KTI) TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION (TSPAI)

TSPAI TEAM:

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[2] Center for Nuclear Waste Regulatory Analyses (CNWRA)
[3] Presenter, NRC Lead

NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION STATUS
APRIL 25-26, 2000, LAS VEGAS, NV

STATUS OF TSPAI SUBISSUES

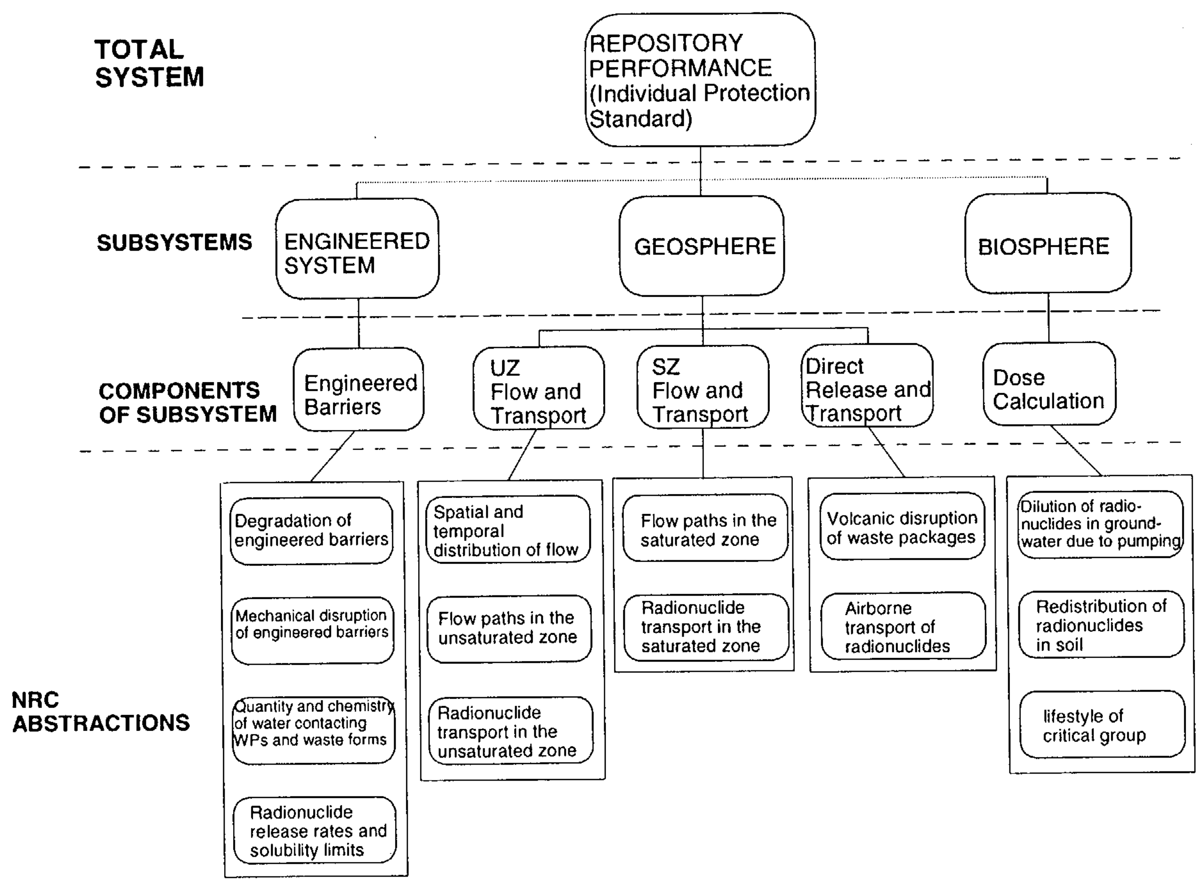
1. System Description and Demonstration of Multiple Barriers [OPEN]

2. Total System Performance Assessment Methodology: Scenario Analysis [OPEN]

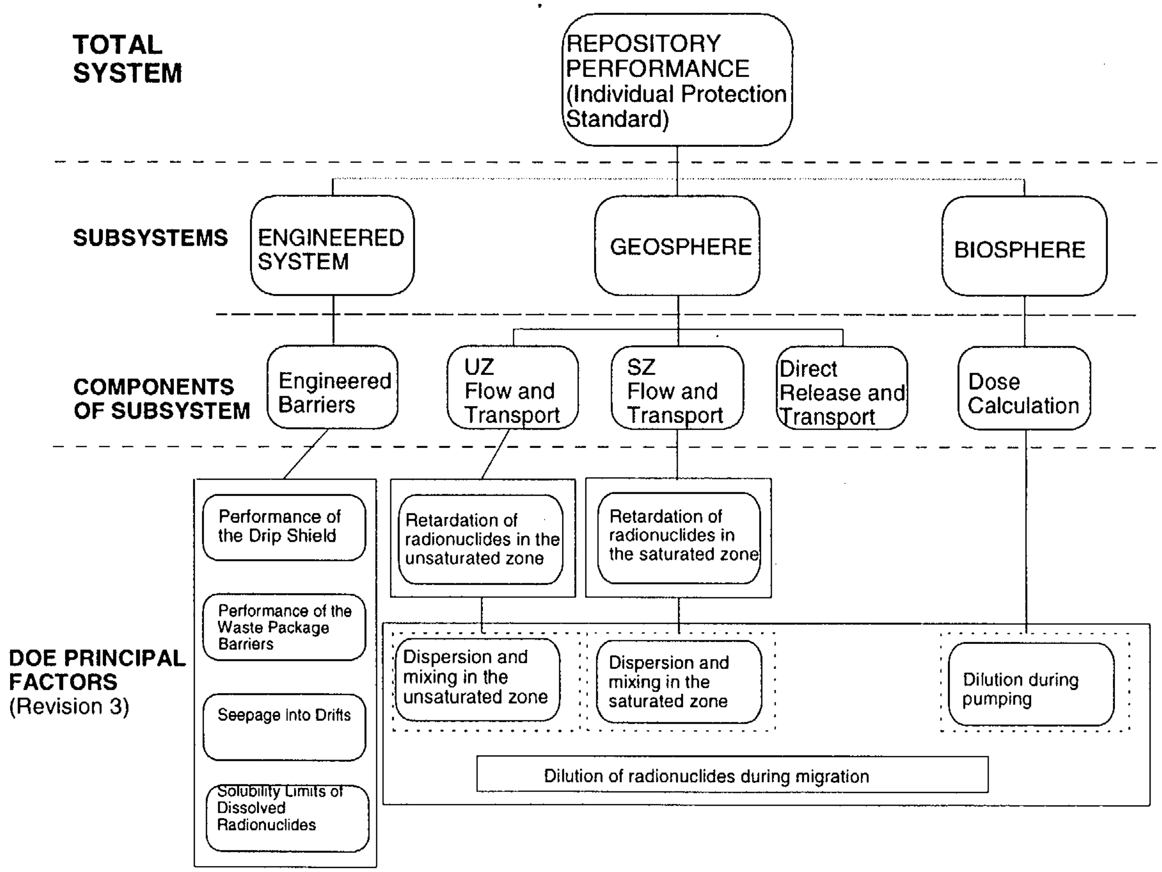
3. Total System Performance Assessment Methodology: Model Abstraction [OPEN]

4. Demonstration of the Overall Performance Objective [OPEN]

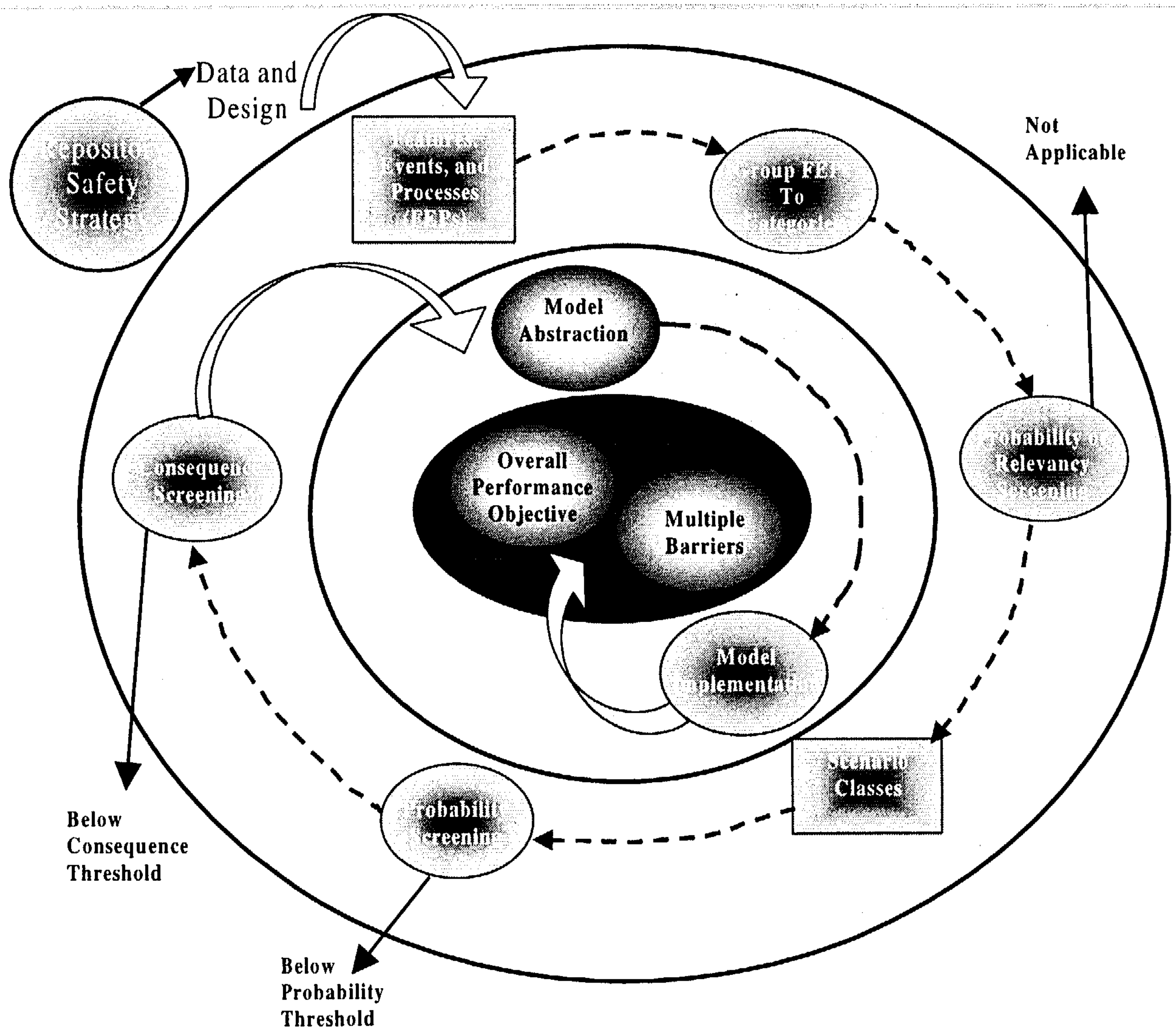
TSPA FLOWDOWN DIAGRAM



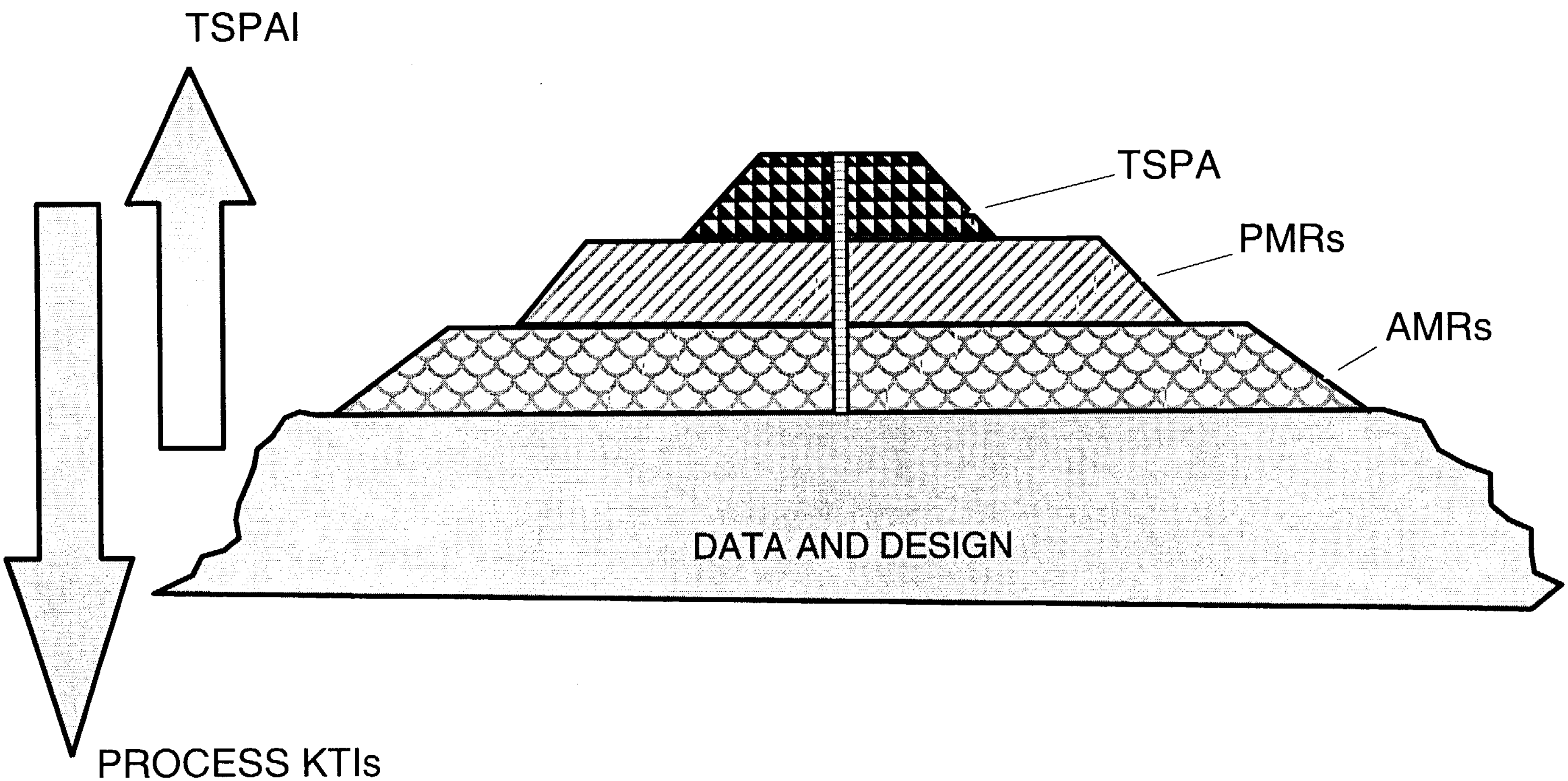
RELATIONSHIP OF DOE'S RSS PRINCIPAL FACTORS TO TOTAL SYSTEM PERFORMANCE



RELATIONSHIP OF DOE'S RSS TO TSPAI SUBISSUES



STYLIZED REPRESENTATION OF PERFORMANCE ASSESSMENT



SYSTEM DESCRIPTION/DEMONSTRATION OF MULTIPLE BARRIERS

- SUBISSUE:
  - The documentation of the PA needs to be sufficiently transparent to allow an independent analysis of the results
    - The capability of multiple barriers is documented and supported by analyses consistent with the PA
- INFORMATION NEEDED BY LA/PATH FORWARD
  - System description (including transparency and traceability)
    - PA process and results need to be traceable through process modeling, supporting analyses, and back to the data
      - PA process needs to be more transparent and traceable than TSPA-VA
        - TSPA-VA traceable back only one step to Technical Basis Document
      - Description of FEPs in AMRs and PMRs do not appear to be congruent

SYSTEM DESCRIPTION/DEMONSTRATION OF MULTIPLE BARRIERS (continued)

- Demonstration of multiple barriers
  - DOE needs to implement analyses for multiple barriers (expected in TSPA-SR)
    - DOE provided outline/general methodology of planned approach for TSPA-SR in TSPA Methods and Assumptions and RSS (January 2000)
    - NRC needs to complete 10 CFR Part 63 rulemaking establishing requirements for multiple barriers
    - NRC will establish acceptance criteria in YMRP
    - NRC will complete review of DOE's proposed approach
    - NRC will use TSPA-SR analysis to evaluate DOE progress and identify steps required to resolve this issue

SCENARIO ANALYSIS

- SUBISSUE:
  - Process of identifying possible processes and events that could affect repository performance and screening processes and events from further analysis
- INFORMATION NEEDED BY LA/PATH FORWARD
  - General agreement on methodology, but additional information is needed:
    - Description of the process used to determine that the assembled FEP list is complete
    - Rationale used to partition FEPs, when different screening arguments are used
    - Justification needs to be provided to support the assertion that an unaffected intermediate performance measure is sufficient to justify screening on consequences

SCENARIO ANALYSIS (continued)

- DOE needs to provide FEP Analysis AMRs to document DOE's implementation of scenario analysis methodology
  - Evaluated for individual NRC abstractions
  - Every KTI will be involved in evaluating DOE's implementation of the scenario analysis methodology
  - ENFE KTI has provided feedback on DOE's implementation of FEPs related to the near-field environment

MODEL ABSTRACTION

- SUBISSUE:
  - Need to integrate the relevant FEPs into the PA to ensure a comprehensive analysis of the total system
- INFORMATION NEEDED BY LA/PATH FORWARD
  - DOE needs to improve integration and coupling within the PA (compared to TSPA-VA)
    - For example, infomation transfer between UZ and SZ flow modeling resulted in smaller calculated doses
  - TSPA-SR and PMRs and FEP analysis AMRs need to be available for review
    - FEP AMRs are among last technical documents available

MODEL ABSTRACTION (cont.)

- KTIs will discuss status of resolution for their subissue (components of NRC abstractions) and information needed by LA

- TSPAI KTI will evaluate the overall PA model and integration issues (compatibility and consistency in models)

  – TSPA-SR, PMRs, and AMRs will be evaluated by TSPAI KTI to determine the current status of resolution for issues not captured by the individual NRC abstractions

OVERALL PERFORMANCE OBJECTIVE

- SUBISSUE:
  - The use of the PA model to demonstrate that the overall performance objectives have been met
- INFORMATION NEEDED BY LA/PATH FORWARD
  - DOE needs to resolve scenario analysis and model abstraction subissues
    - Includes Process KTI subissues
  - DOE needs to implement and document PA for the current design and 10 CFR Part 63 performance objectives
    - DOE provided general methodology of planned approach (RSS) and summarized planned approach for TSPA-SR (TSPA Methods and Assumptions)
    - DOE will document implementation in TSPA-SR, PMRs, and AMRs

OVERALL PERFORMANCE OBJECTIVE (continued)

- DOE needs to implement and document PA for the current design and 10 CFR Part 63 performance objectives
  - DOE provided general methodology of planned approach (RSS) and summarized planned approach for TSPA-SR (TSPA Methods and Assumptions)
  - DOE will document implementation in TSPA-SR, PMRs, and AMRs
  - NRC needs to complete 10 CFR Part 63 rulemaking establishing requirements for demonstration of the overall perfomance objectives
  - NRC will establish acceptance criteria in YMRP
  - TSPAI will use TSPA-SR analysis to evaluate DOE progress and identify steps required to resolve this issue

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

Total System Performance Assessment and Integration

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Abe Van Luik, Senior Policy Advisor
Performance Assessment
U. S. Department of Energy

April 25, 2000

YUCCA MOUNTAIN PROJECT

Key Technical Issue: Total System Performance Assessment and Integration Presentation Overview

- **DOE General Approach to Issue Resolution**
- **Statement of Total System Performance Assessment and Integration (TSPAI) Objective**
- **Discussion of Approach to Addressing TSPAI Subissues**
  - **System Description and Multiple Barriers**
  - **Scenario Analysis**
  - **Model Abstraction**
  - **Overall Performance Objective**
- **Summary**

DOE Approach to Issue Resolution

- DOE is committed to an approach to resolution in the context of NRC's risk-informed, performance-based method
- DOE is reviewing the TSPAI Issue Resolution Status Report, Revision 2
- Issues will continue to be addressed through formal interactions and correspondence - including the upcoming NRC/DOE Technical Exchanges

Objective of TSPAI Key Technical Issue

Outline the elements of an acceptable methodology and approach for conducting assessments of repository performance to demonstrate compliance with total-system performance and multiple barrier requirements

Subissues Supporting the TSPAI KTI Objective

KTI SUBISSUES	IMPORTANCE TO REPOSITORY PERFORMANCE
1 System Description and Demonstration of Multiple Barriers	Demonstrates the effectiveness and diversity of the barriers as a measure of the resiliency of the repository
2 Scenario Analysis	Describes what can reasonably happen to the repository and the processes and events that can affect the system
3 Model Abstraction	Provides for a systematic examination, in the context of the total system performance, whether models, assumptions, and input data have been appropriately identified, incorporated and analyzed in the TSPA
4 Demonstration of the Overall Performance Objective	Provides for a transparent demonstration of compliance with the overall performance objective

Status of Issues Related to the TSPAI KTI

- **32 Site Characterization Analysis (SCA) issues are identified in the TSPAI Issue Resolution Status Report, Revision 2:**
  - **27 are resolved**
  - **5 remain open**
    - **DOE expects that the open issues related to weighting of alternative conceptual models, scenario screening, and clarifying the TSPA method will be resolved by the TPSA-Site Recommendation (SR)**
    - **The data related to expert judgement and to information supporting scenario elimination will be dealt with by other Project activities**

Subissue 1, System Description and Demonstration of Multiple Barriers

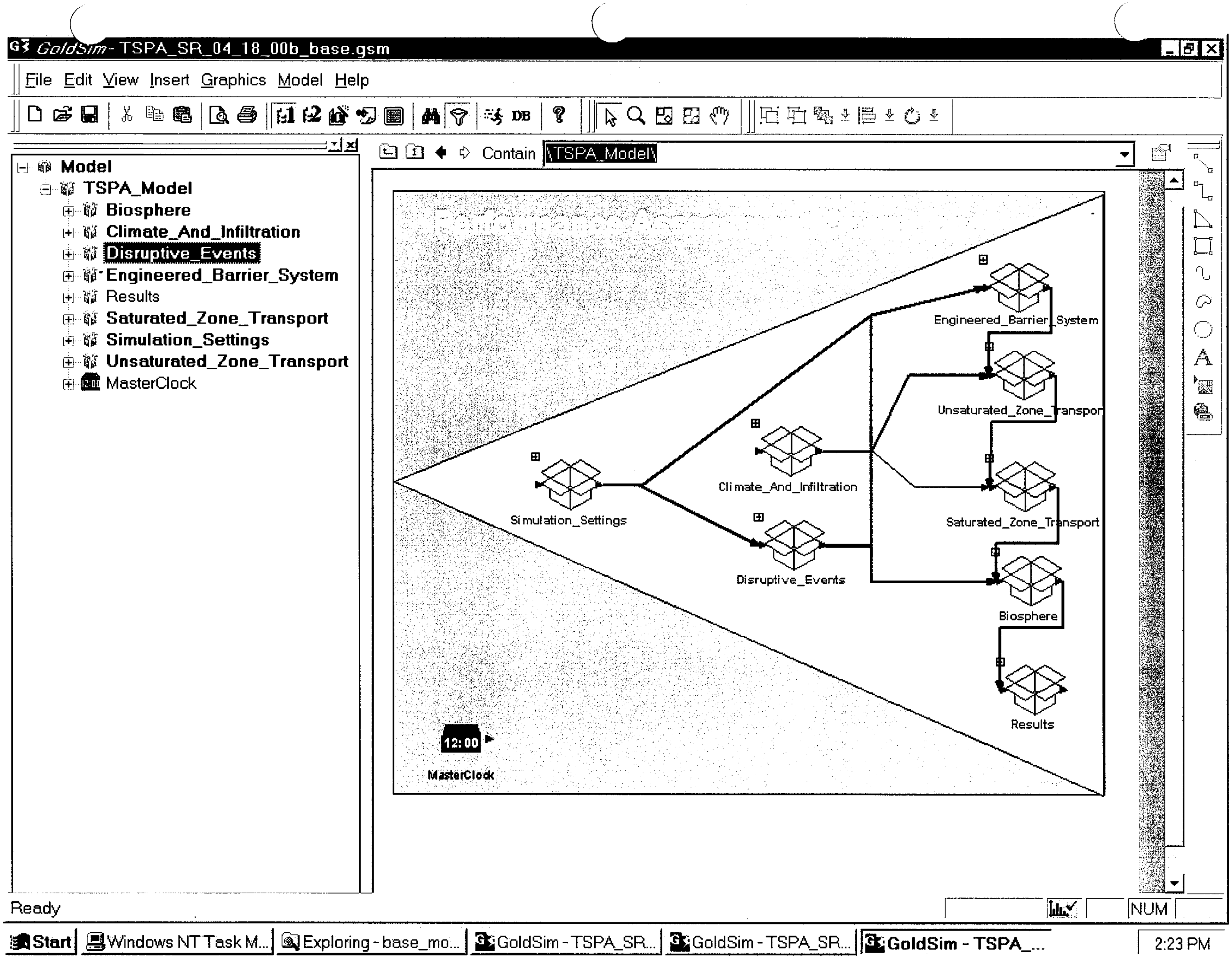
- Three major elements of this subissue are related to:
  - Transparency of documentation
  - Traceability of information used in analyses, including code design and flow
  - Demonstration of the resilience of the system with respect to multiple barriers
- Other elements of the subissue, such as features, events, and processes (FEPs) screening, are addressed under Subissue 2 in this presentation and are also addressed in subsequent presentations

Addressing Transparency

- The TSPA Methods and Assumptions document provided a roadmap for development of the TSPA-SR
- The TSPA-SR document is tied directly through text, table, and graphics to the supporting Analysis and Model Reports (AMRs) and Process Model Reports
- Explicit discussions of the TSPA methodology and treatment of uncertainty are also part of the TSPA-SR

Addressing Traceability

- **Assumptions and details of the analysis will be in the TSPA-SR document and supporting AMRs**
- **The TSPA analysis tool allows direct tracking of information along its entire path through the analysis. This hierarchy allows for tracing information flow, as follows**
  - TSPA model output
  - TSPA subsystem model outputs
  - Component abstraction model inputs
  - Individual parameter distribution inputs
- **All of the above have unique data tracking numbers for traceability and control of Q-status**



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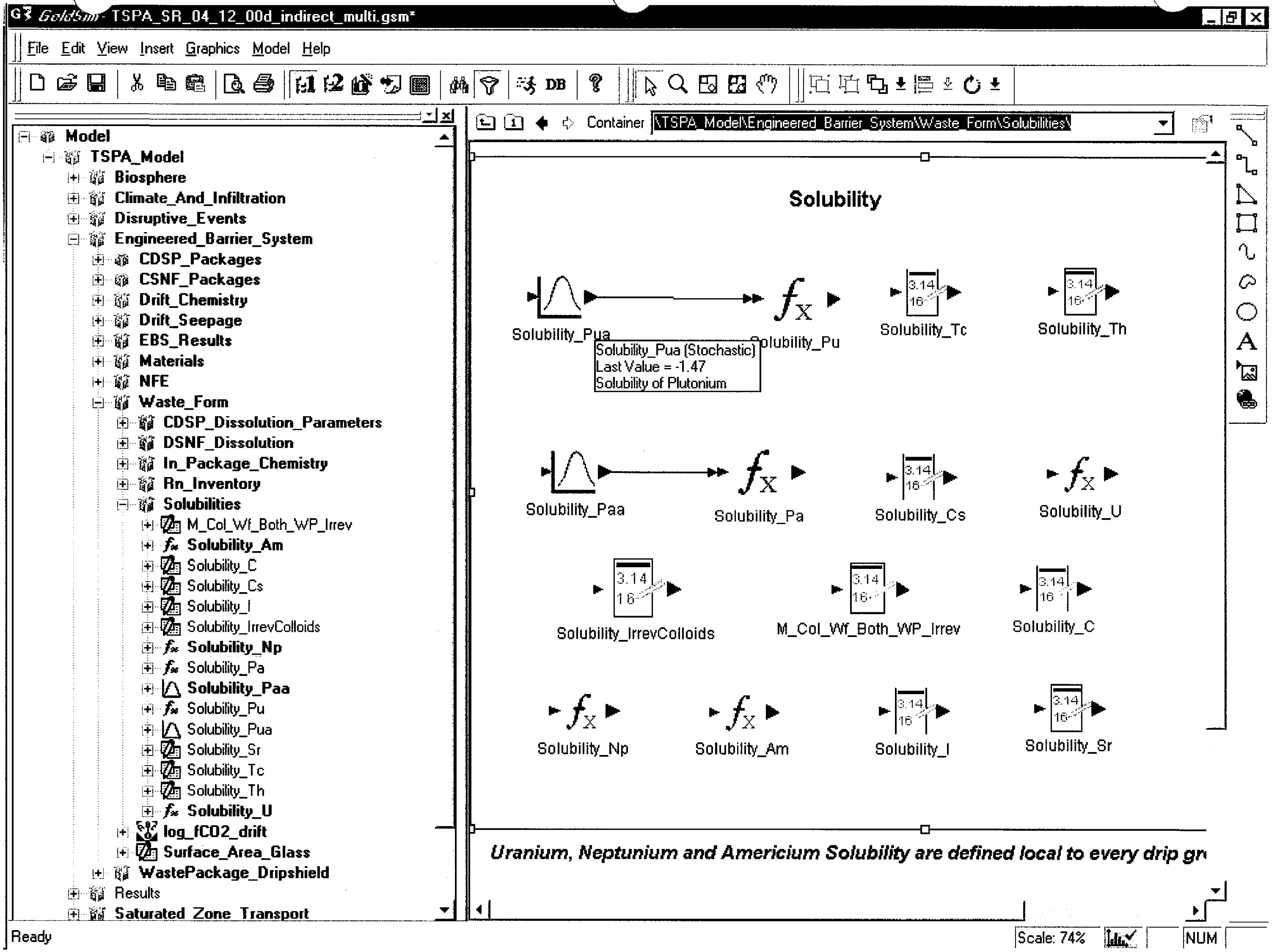
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Solubility_C
Solubility_Cs
Solubility_I
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Solubility_Th
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Solubility_Th
Solubility_Pua (Stochastic)
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Solubility_Paa
Solubility_Pa
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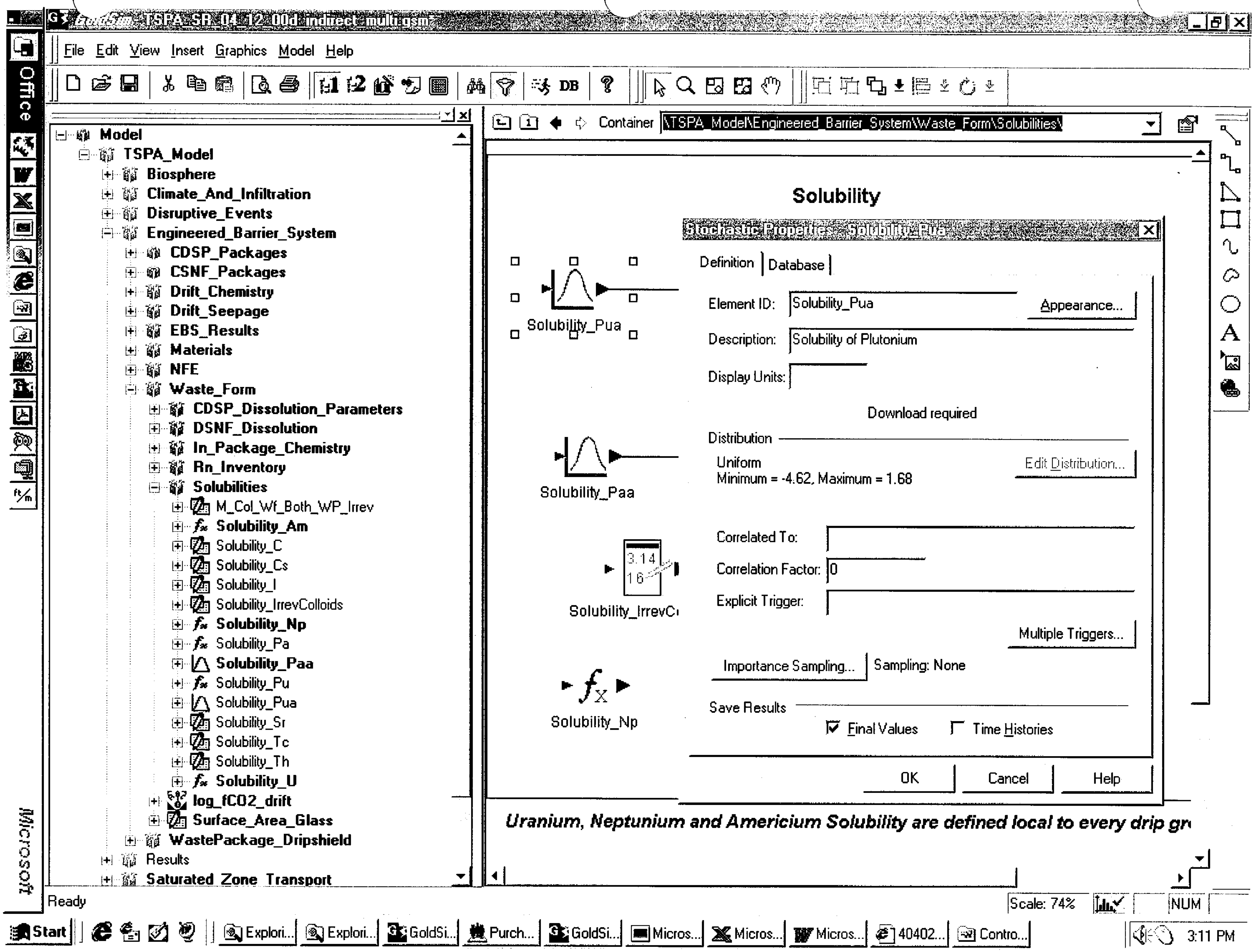
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Element ID: Solubility_Pua
Appearance...
Description: Solubility of Plutonium
Display Units:
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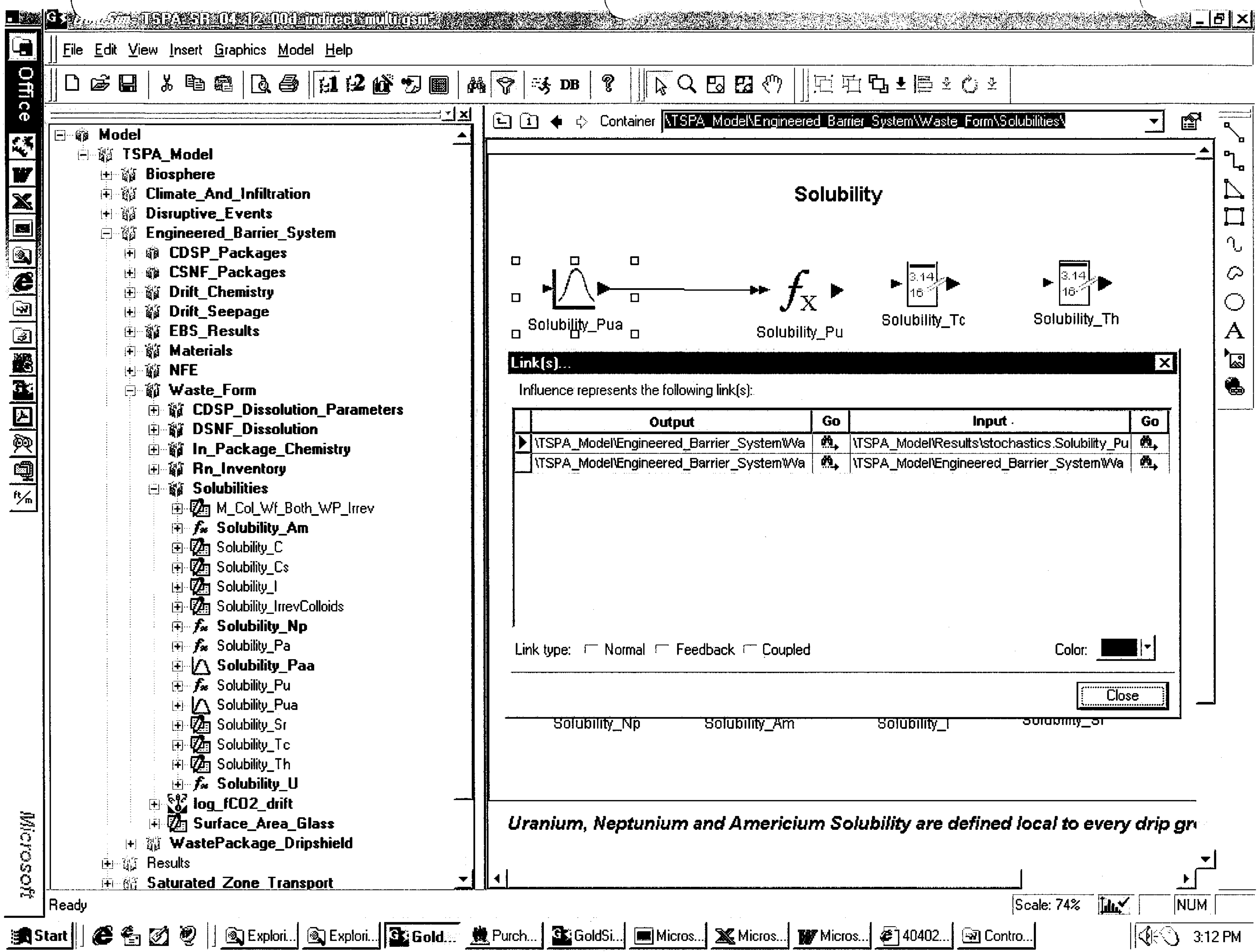
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Solubility_Pu
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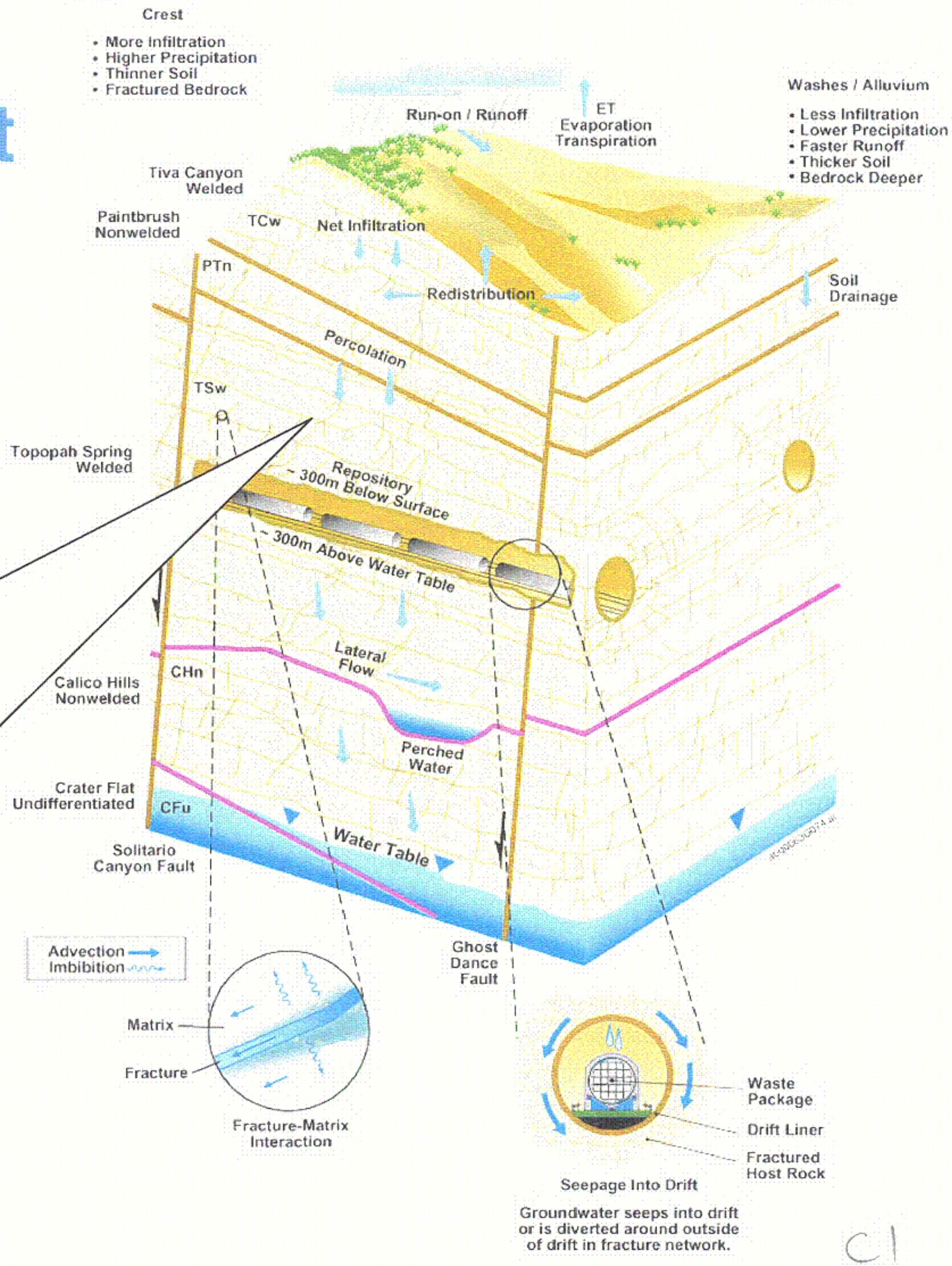
Demonstrating the Effectiveness of Multiple Barriers

- The entire TSPA analysis is built on a succession of process-level and abstracted models that represent the various parts of the natural and engineered system
- TSPA-SR will show performance analysis results for the total system and also will include intermediate results for the various components of the system
- TSPA-SR sensitivity studies and barrier importance analyses will evaluate the contribution and the relative importance to system safety of major system components and barriers
- The following slides illustrate the major system components

Unsaturated Zone Flow and Transport in TSPA-SR

- 3 climate states - present day, monsoonal, and glacial transition
- Infiltration average over repository ~ 6mm/year
- Flow model includes active fracture-matrix interaction and treatment of perched water
- Model includes matrix diffusion processes
- Transport includes colloids and focuses on mass breakthrough at the water table



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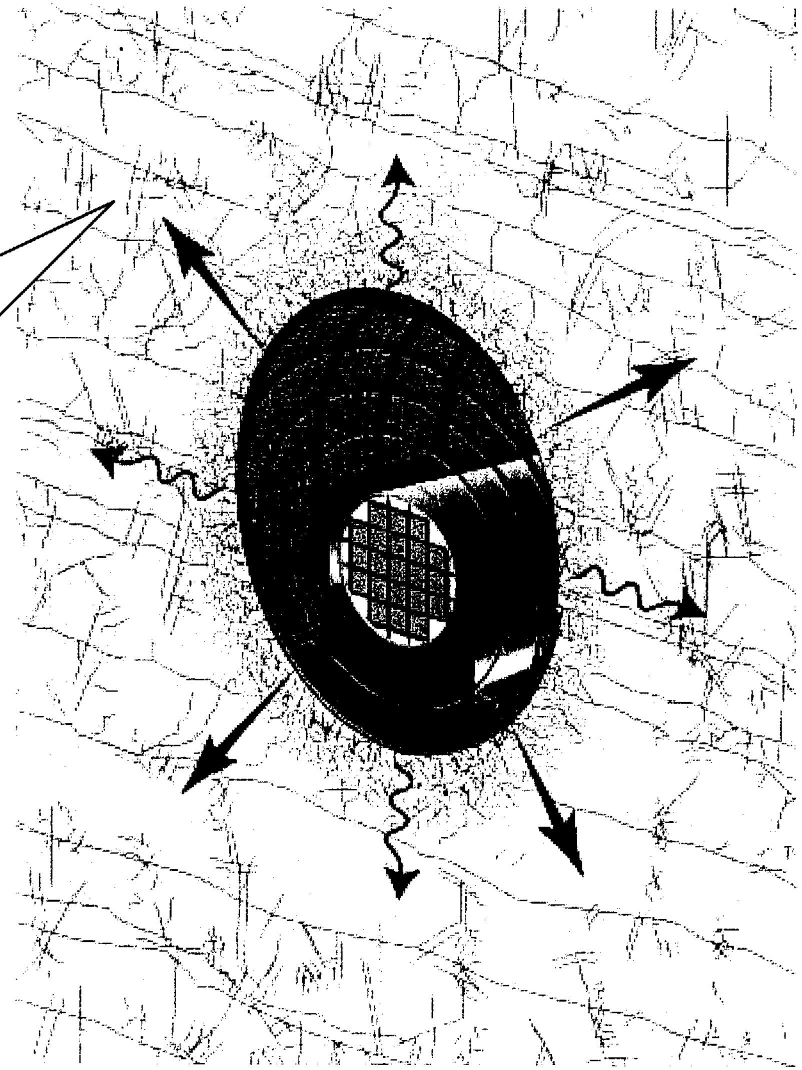
Coupled Processes in TSPA-SR

- Coupled process model includes thermal chemistry effects
- Boiling fronts do not propagate far into the pillars and have a short duration
- Flow focusing and uncertainty in fracture characteristics included in seepage model



Coupled Processes in TSPA-SR

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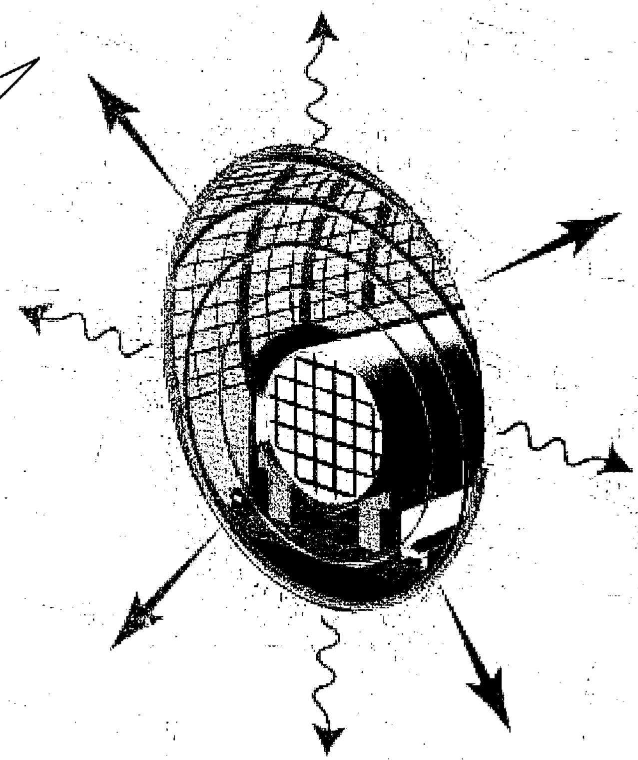
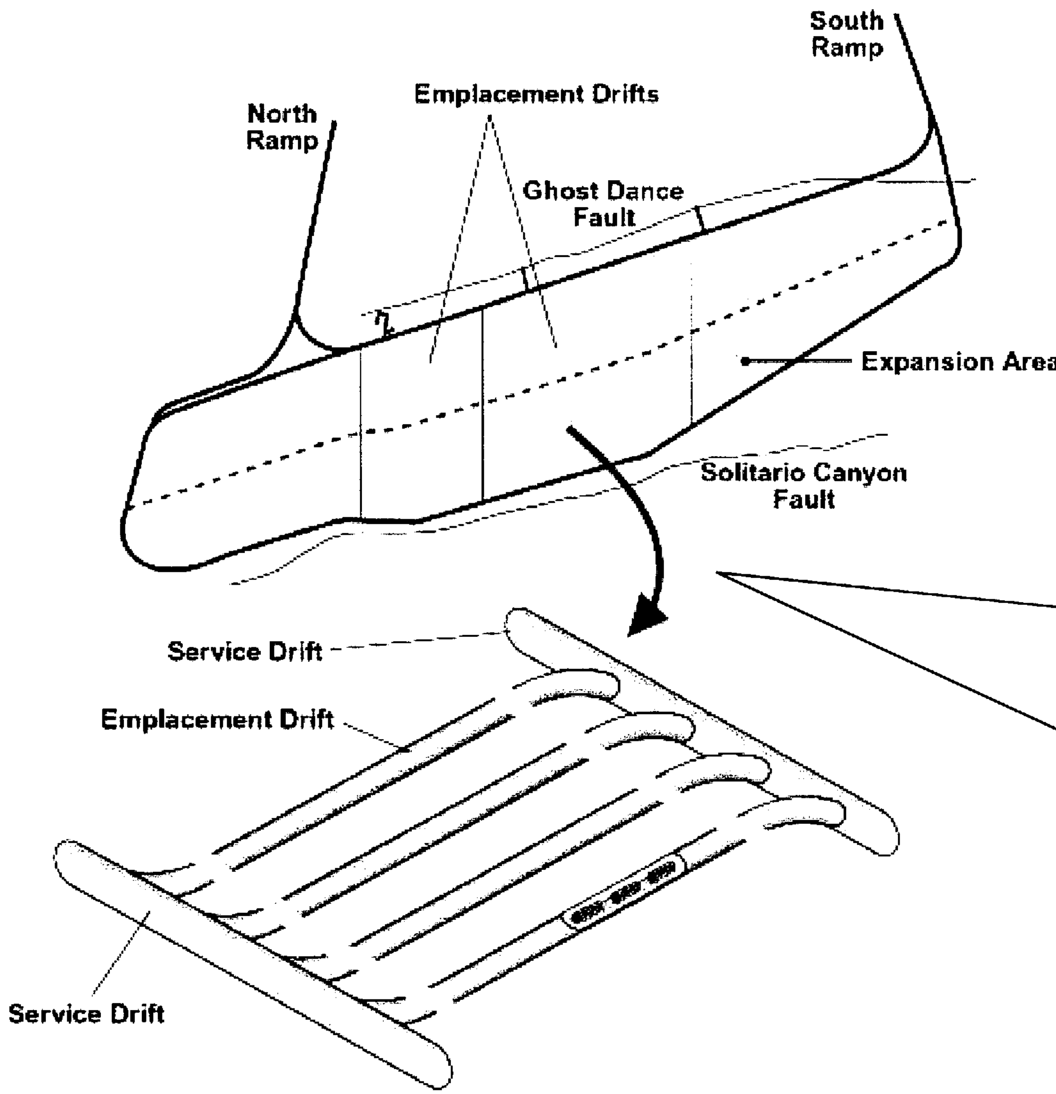
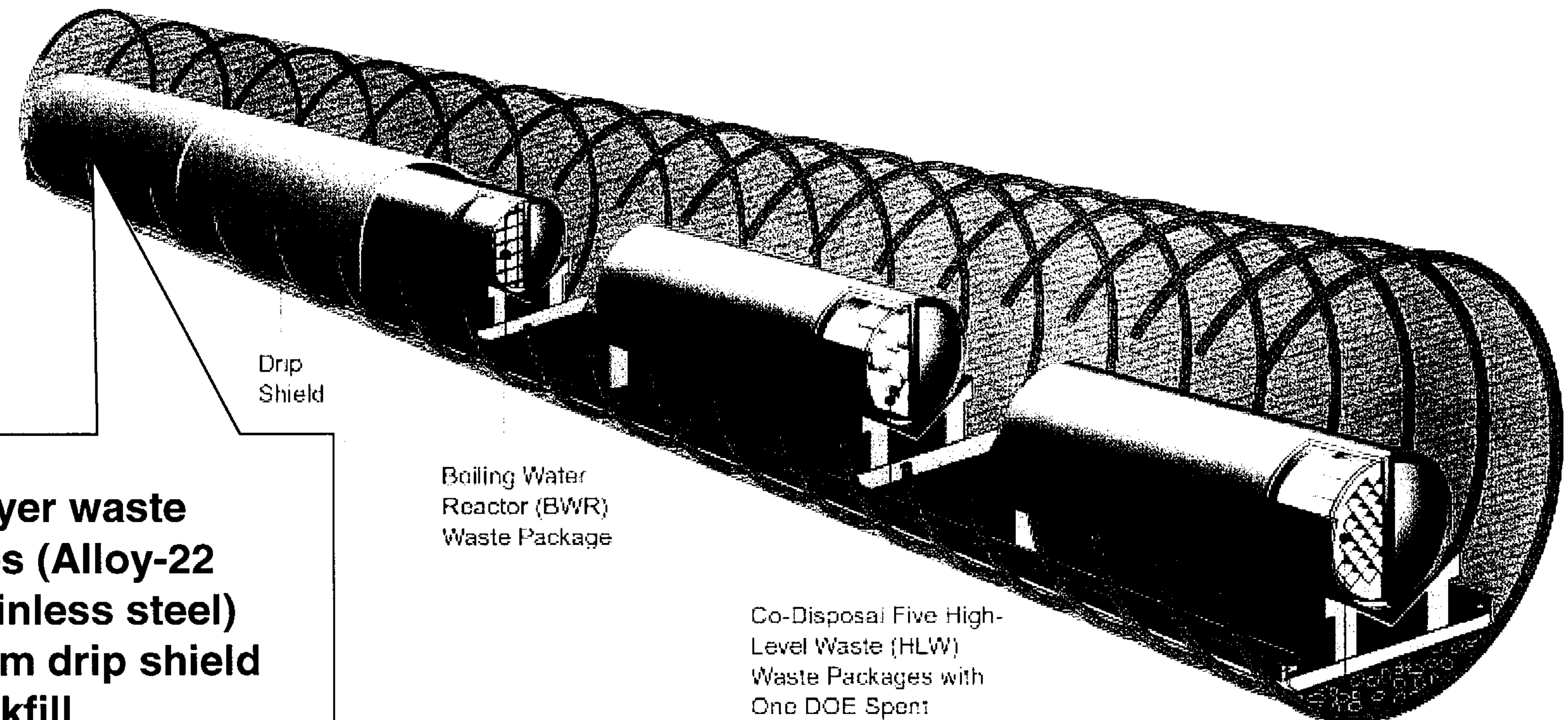


Repository Design in TSPA-SR



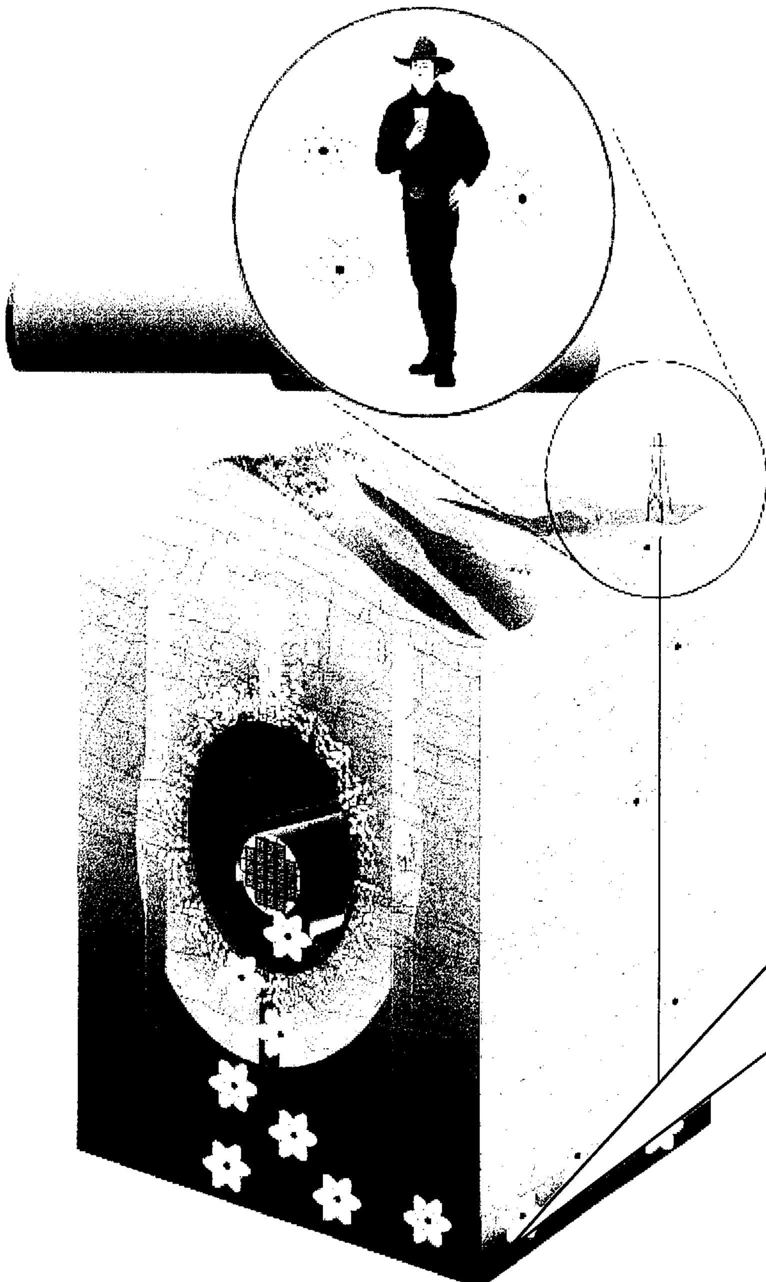
- Current analysis assumes 50 years of ventilation
- Thermal load is ~64 MTHM/acre
- Line load, ~1.4 kW/m
- 70,000 MTHM (includes Commercial and DOE-owned Spent Nuclear Fuel, and Defense High-level Waste)

Engineered Barrier Design in TSPA-SR



- **Two layer waste packages (Alloy-22 over stainless steel)**
- **Titanium drip shield**
- **No backfill**
- **Steel set, wire mesh, and rockbolt wall supports**

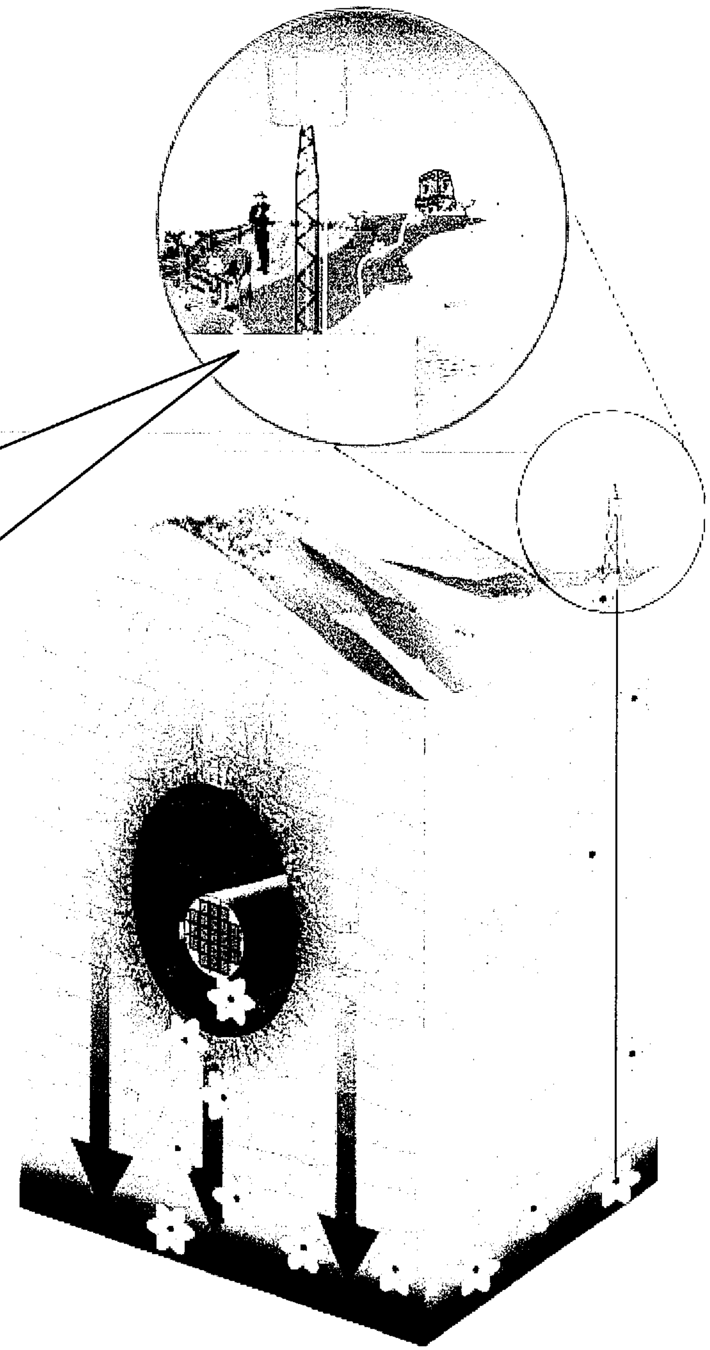
Saturated Zone Flow and Transport in TSPA-SR



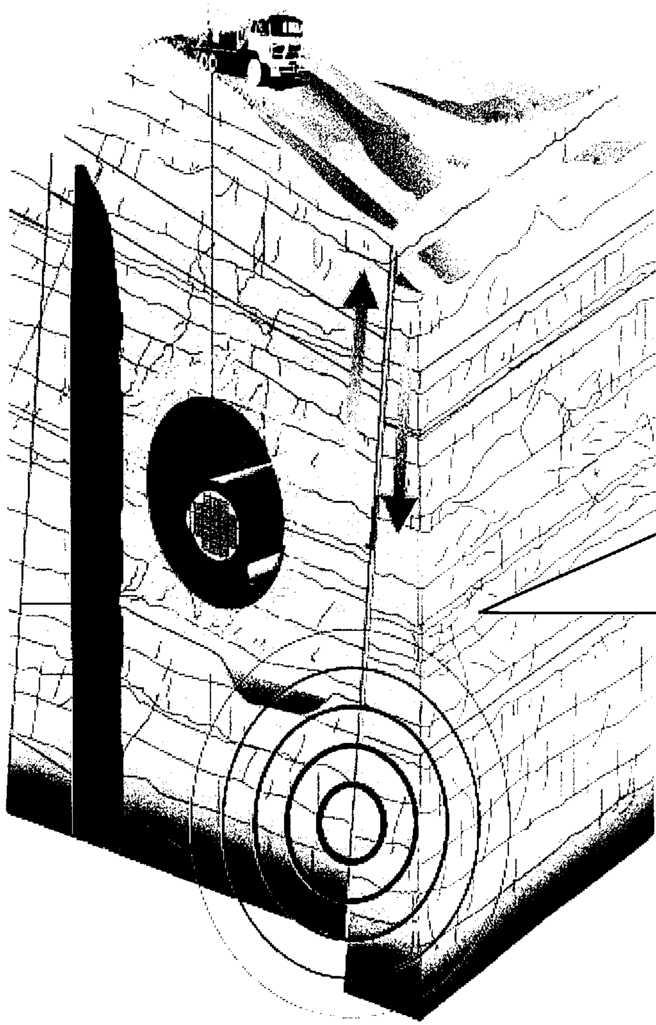
- 3-D model uses geologic framework model
- Includes variable location of tuff-alluvium contact
- Anisotropy yields more southerly flow paths
- TSPA calculates mass flux across boundaries

Biosphere in TSPA-SR

- Critical group water usage consistent with 10 CFR Part 63 approach
- Includes uncertainty in plant uptake factors
- Using Reasonably Maximally Exposed Individual for Biosphere Dose Conversion Factors (BDCF) development consistent with 10 CFR Part 197
- BDCFs developed for nominal release and direct release scenarios



Disruptive Events in TSPA-SR



- Model for characteristics of volcanic eruptions has been modified from Viability Assessment
- Seismic effects are generally screened out, except for effects on cladding
- Nuclear criticality is screened out
- Human intrusion is a stylized analysis

Subissue 2, Scenario Analysis

- **This subissue addresses the method used to develop the suite of plausible scenarios used in the TSPA to represent the evolution of the repository system**
  - Discussion of scenario methodology is included in the TSPA-SR document (Chapter 1.6)
  - Description of the individual FEPs for each process, including the screening analysis results, is included in the associated PMR and supporting AMR
  - The FEPs database has been revised to enhance the understanding of the database structure

Subissue 3, Model Abstraction

- This subissue addresses the adequacy with which the various components of the engineered system, geosphere, and biosphere are treated in the TSPA-SR (Chapter 3) and supporting analyses (AMRs)
  - PMRs summarize the technical basis supporting each process model and abstraction feeding the TSPA
  - Data and model justification, data uncertainty, model uncertainty, model support, and integration of relevant features, phenomena, and couplings at the process model level are also included in the PMRs and the underlying AMRs
  - Subsequent discussions at this Technical Exchange will cover the details of the various component models

Subissue 4, Demonstration of the Overall Performance Objective

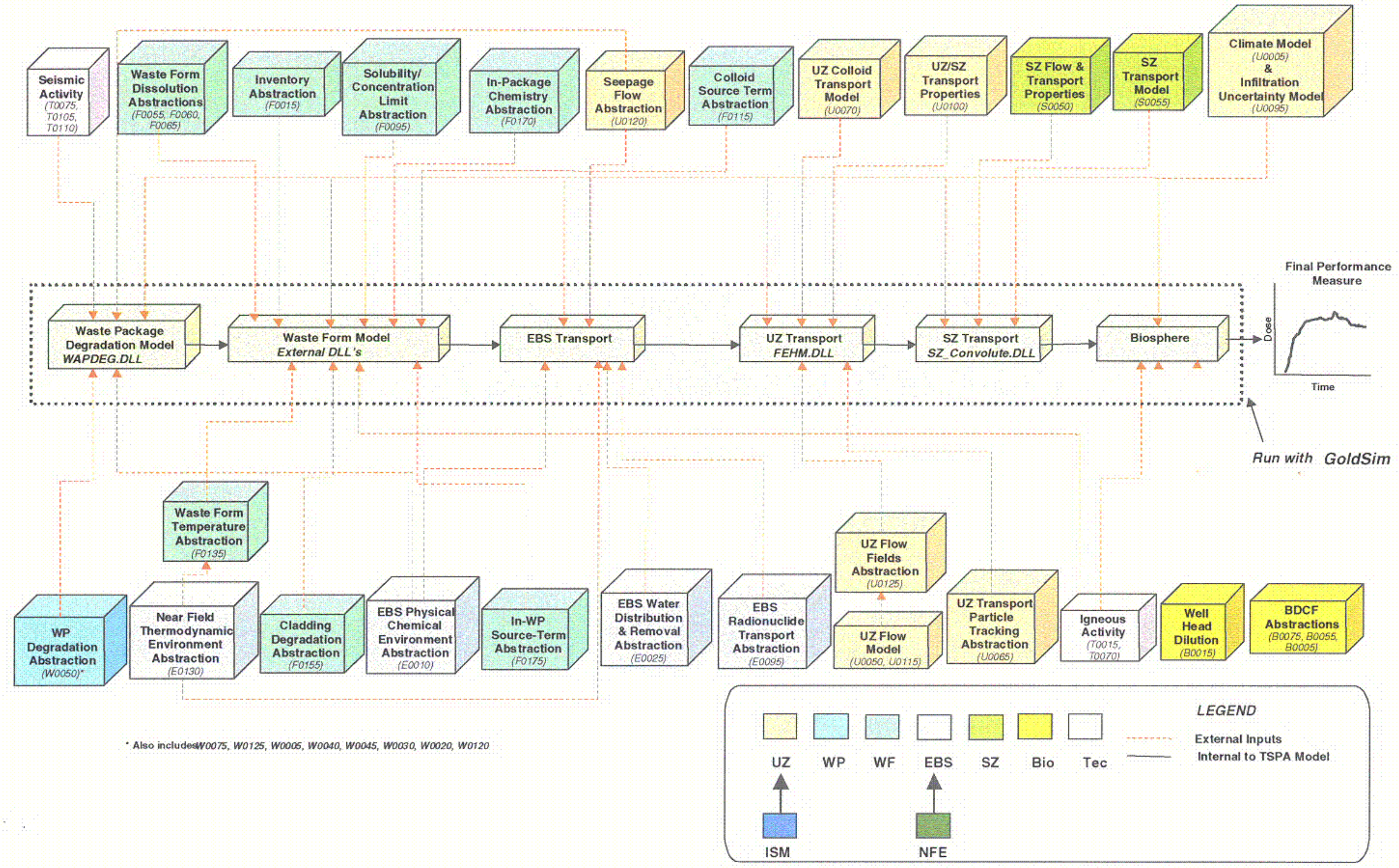
- **Integration of the components, identification of the most important information, and illustrating the assessment of the system performance measure is the objective of this subissue**
  - The TSPA is constructed to ensure that information is appropriately represented and sampled at every step in the analysis
  - TSPA-SR will be conducted to comply with proposed 10 CFR Part 963, 10 CFR Part 63, and 40 CFR Part 197 in terms of addressing the prescribed requirements for the total system
  - Chapter 4 of the TPSA-SR will consist of the nominal, disturbed, and combined performance results

Subissue 4, Demonstration of the Overall Performance Objective
(Continued)

  - Chapter 5 shows the results of uncertainty analyses, sensitivity analyses, and barrier importance analyses

- TSPA results are used to define the more important factors determining system performance. These analyses contribute to the determination of the Principal Factors for the safety case

Integration of Component Models in TSPA-SR



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Integration of Component Models in TSPA-SR

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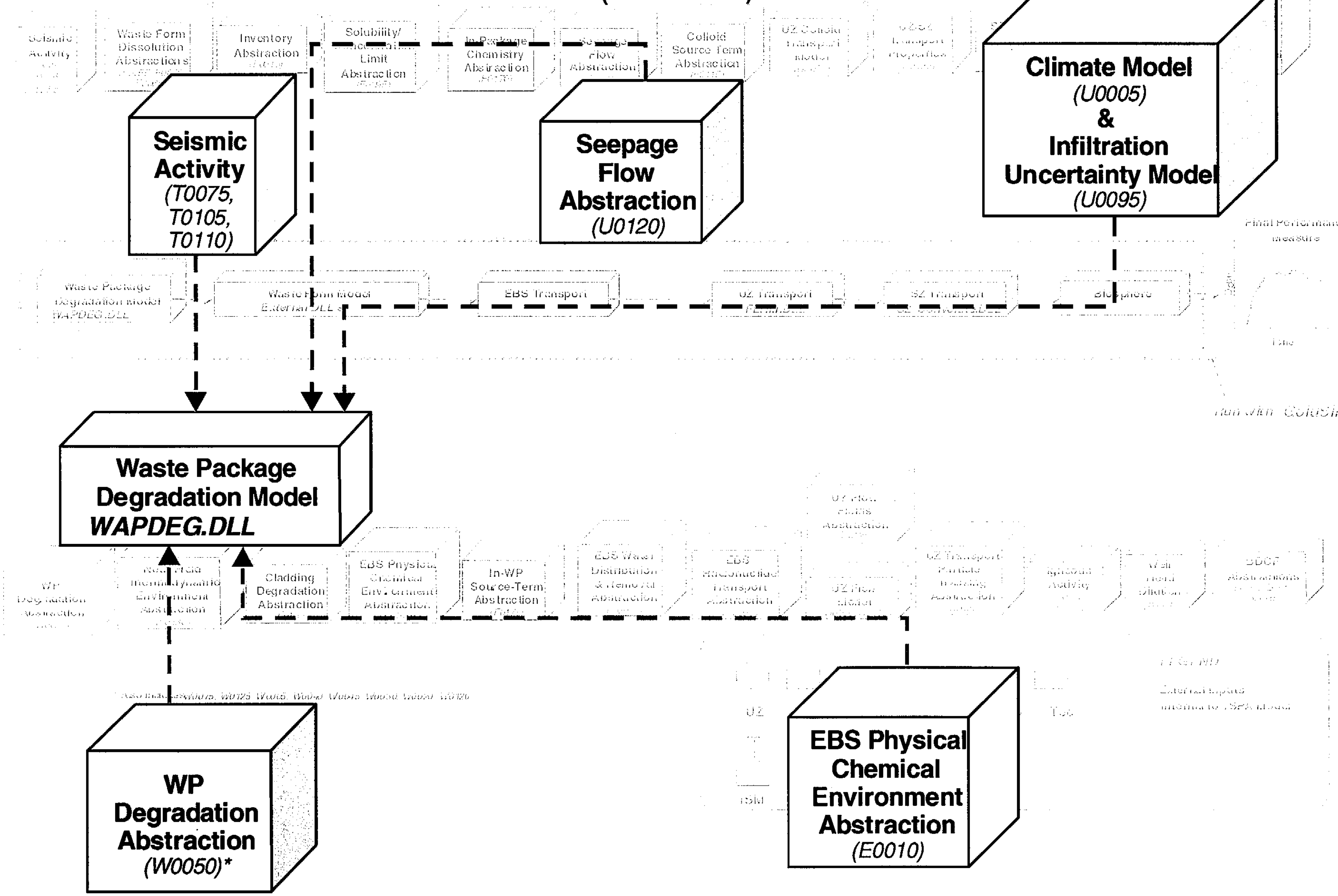

Integration of Component Models in TSPA-SR

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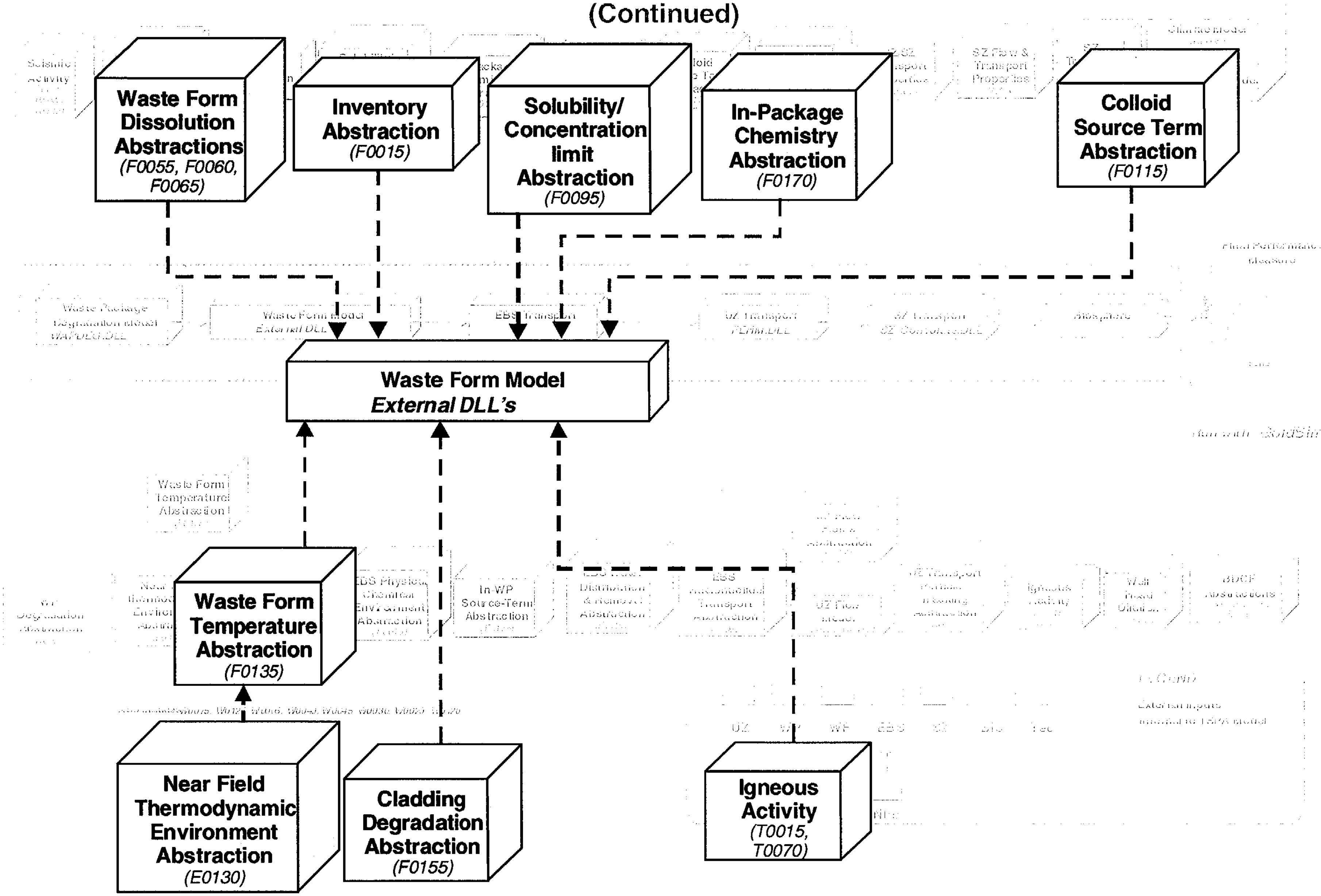

Integration of Component Models in TSPA-SR

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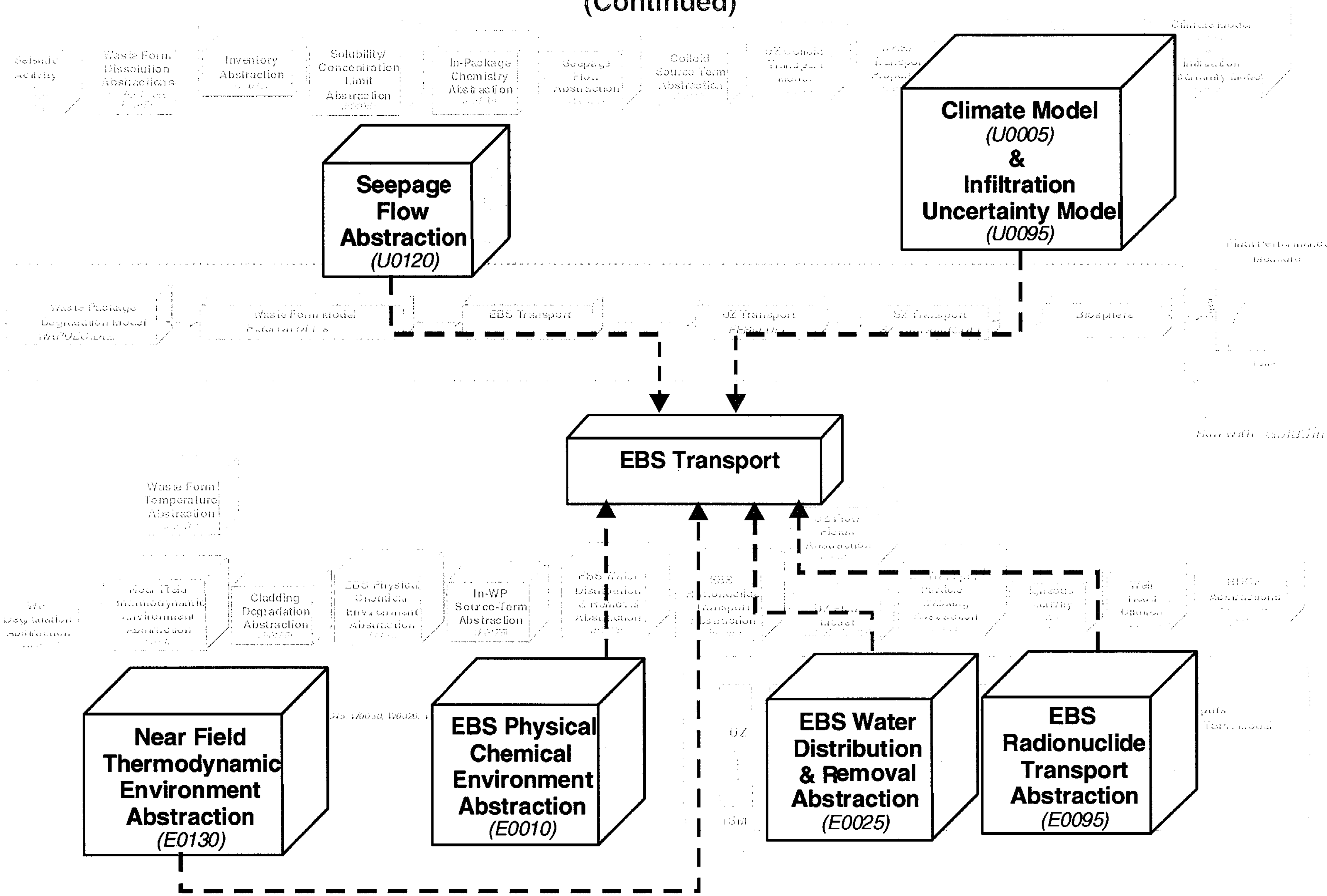

Integration of Component Models in TSPA-SR

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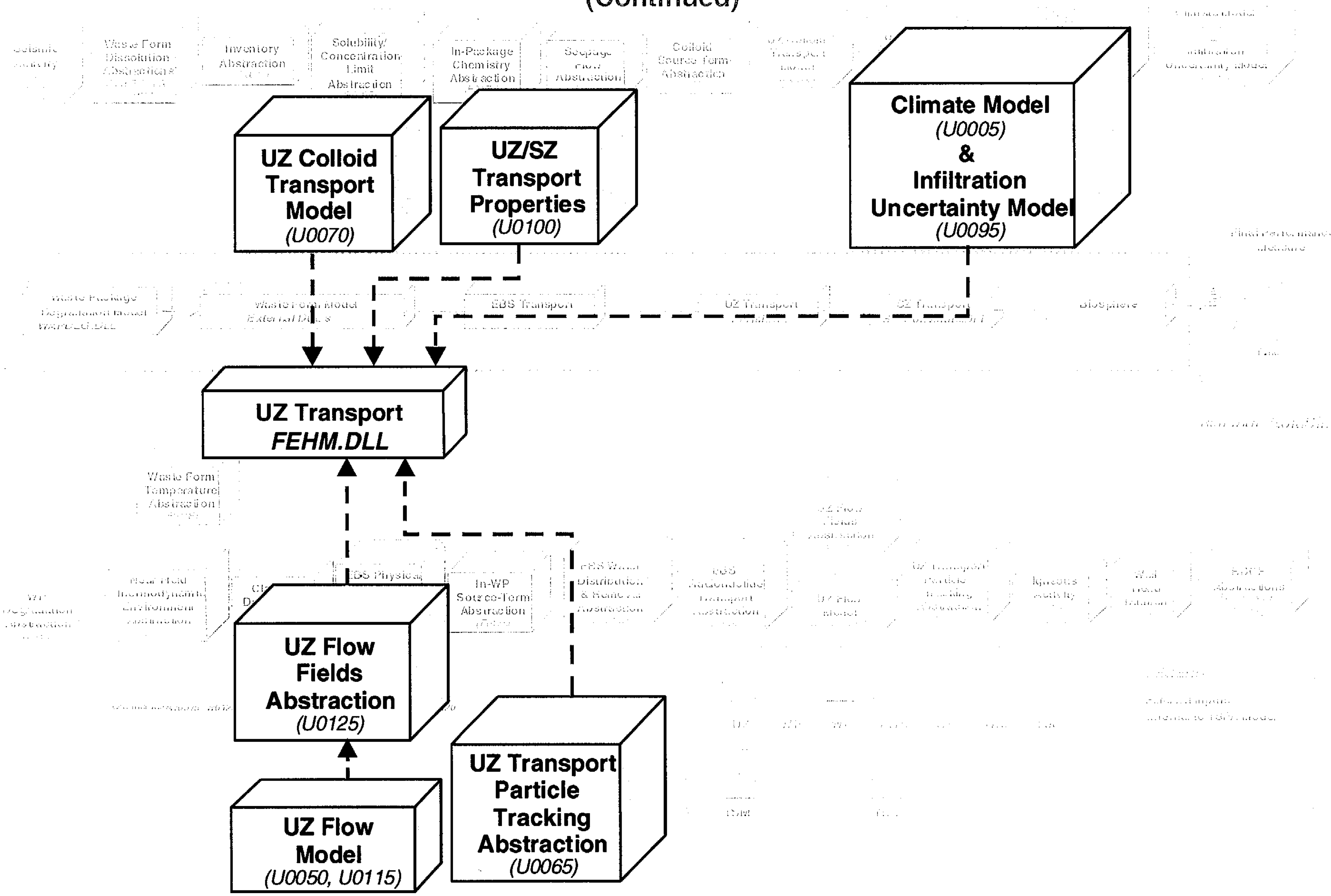

Integration of Component Models in TSPA-SR

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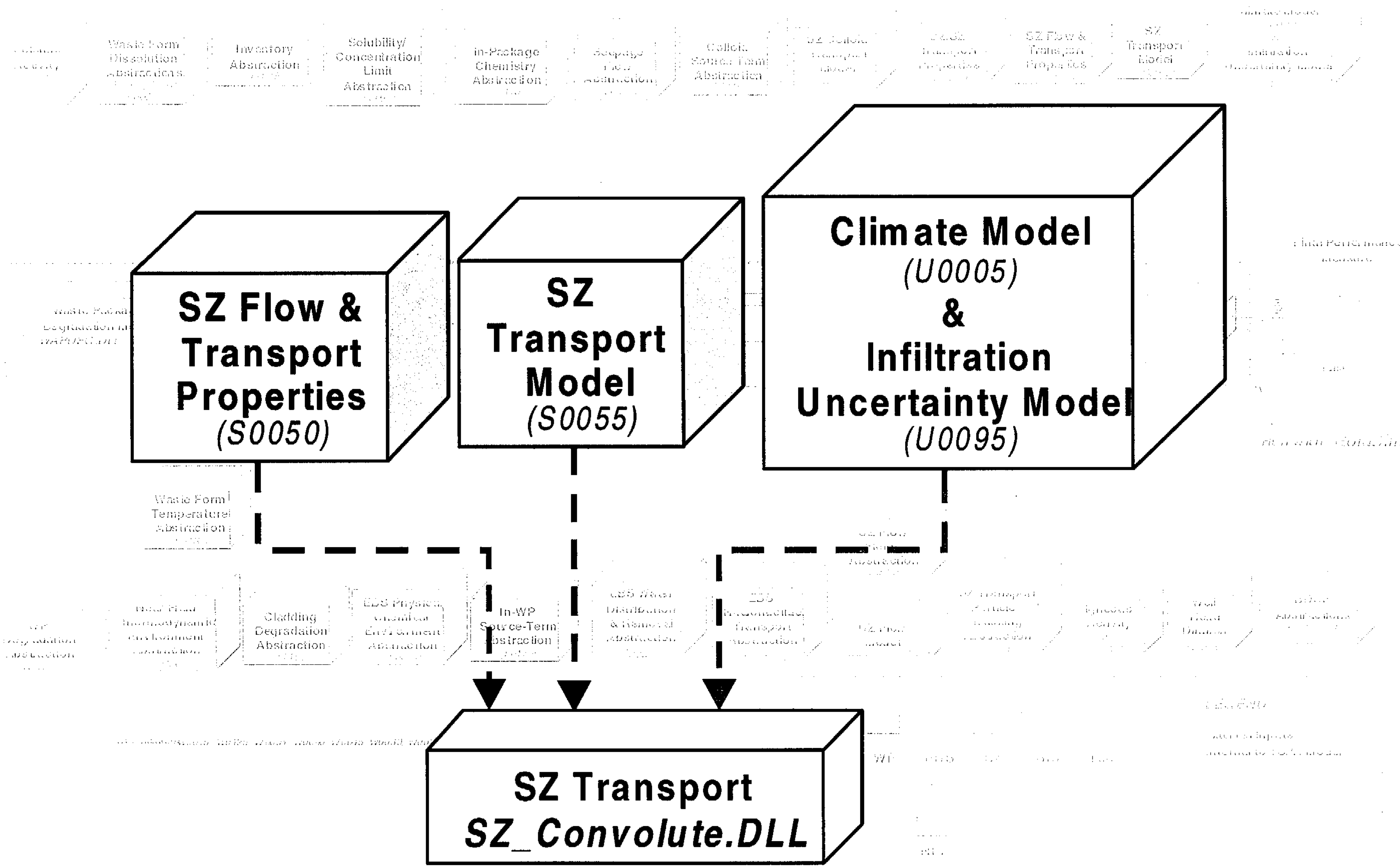

Integration of Component Models in TSPA-SR

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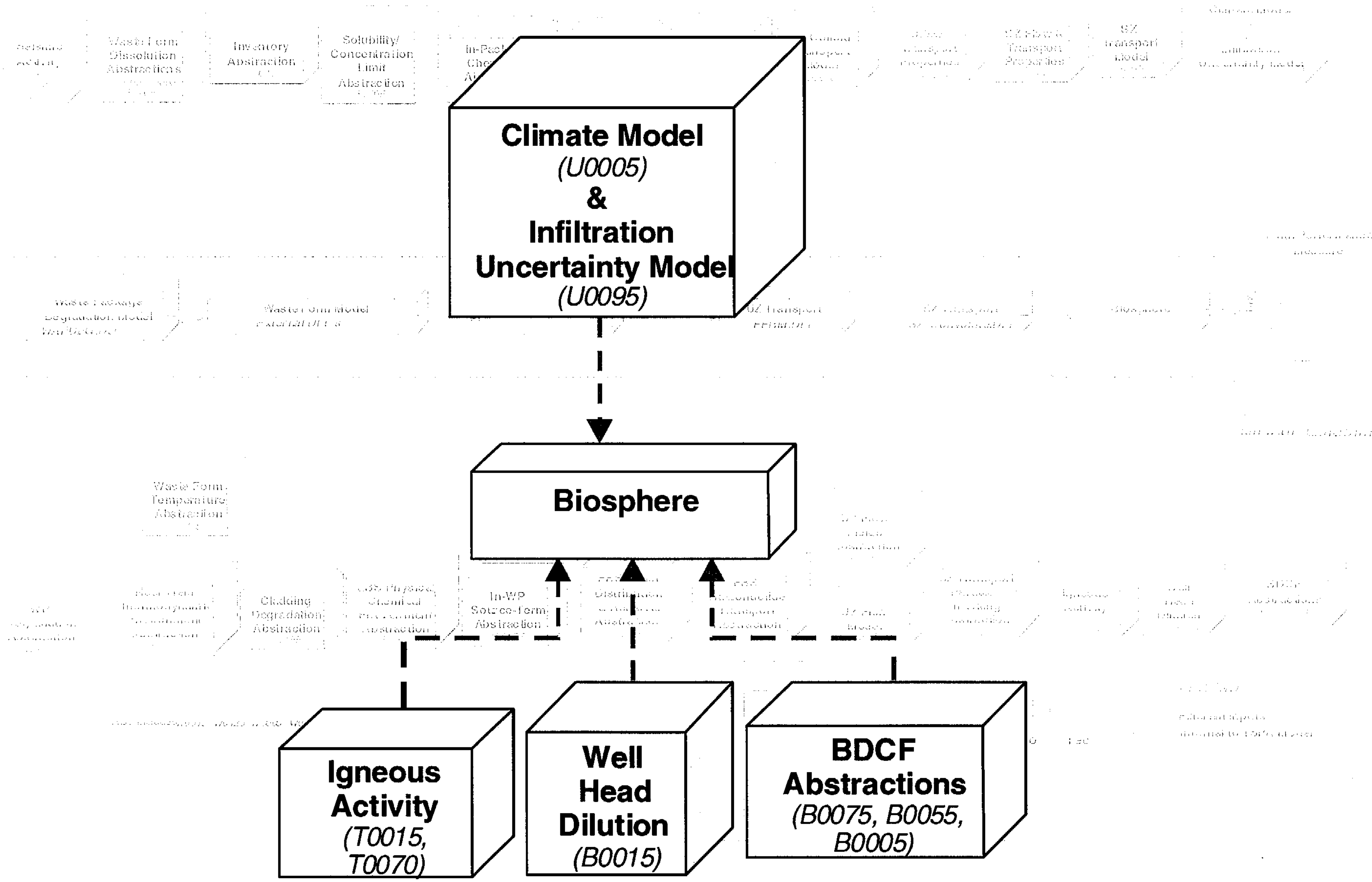


Summary

- DOE continues to make significant progress to address the issues related to the TSPAI KTI
- TSPAI Issue Resolution Status Report Revision 2 is currently being reviewed
- Comments on the current revision will be forwarded to NRC upon completion of review

202-586-

KEY TECHNICAL ISSUE

UNSATURATED & SATURATED FLOW UNDER ISOTHERMAL CONDITIONS

NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION
APRIL 25-26, 2000
LAS VEGAS, NV

TEAM MEMBERS:

Neil Coleman [1]
Latif Hamdan [1]
Jeff Ciocco [1]
Hans Arlt [1]
Jim Winterle [2]
Debra Hughson [2]
Randy Fedors [2]
Dave Farrell [2]
Walter Illman [2]

[1] US Nuclear Regulatory Commission
[2] Center for Nuclear Waste Regulatory Analyses

SUBISSUES AND STATUS OF RESOLUTION

1: Climate Change (CLOSED)

2: Hydrologic Effects of Climate Change (CLOSED)

3: Present-Day Shallow Infiltration (CLOSED)

4: Deep Percolation (Present-Day and Future) (OPEN)

5: Ambient flow in the saturated zone and dilution (OPEN)

6: Matrix Diffusion (OPEN: nearing resolution)

Subissue 1: Climate Change

- RSS Principal Factor: limited seepage into drifts
- NRC abstraction: spatial & temporal distribution of flow

STATUS: CLOSED (based on TSPA-VA review)

Subissue 2: Hydrologic Effects of Climate Change

- RSS Principal Factors: limited seepage into drifts
- NRC abstraction: spatial & temporal distribution of flow; flow paths in the saturated zone

STATUS: CLOSED (based on TSPA-VA review)

Subissue 3: Present-day Shallow Infiltration

- **RSS Principal Factors: limited seepage into drifts**

- **NRC abstraction: spatial & temporal distribution of flow**

STATUS: CLOSED (based on TSPA-VA review)

Subissue 4: Deep Percolation (Present-day and Future)

RSS Principal Factors: limited seepage into drifts; retardation in the unsaturated zone

NRC Abstractions: spatial & temporal distribution of flow; quantity & chemistry of water contacting waste packages; flow paths in the unsaturated zone

Seepage into drifts has a potentially large effect on repository performance because it controls the amounts of water that can contact drip shields and waste packages

STATUS: OPEN

Need for Additional Data and Analysis

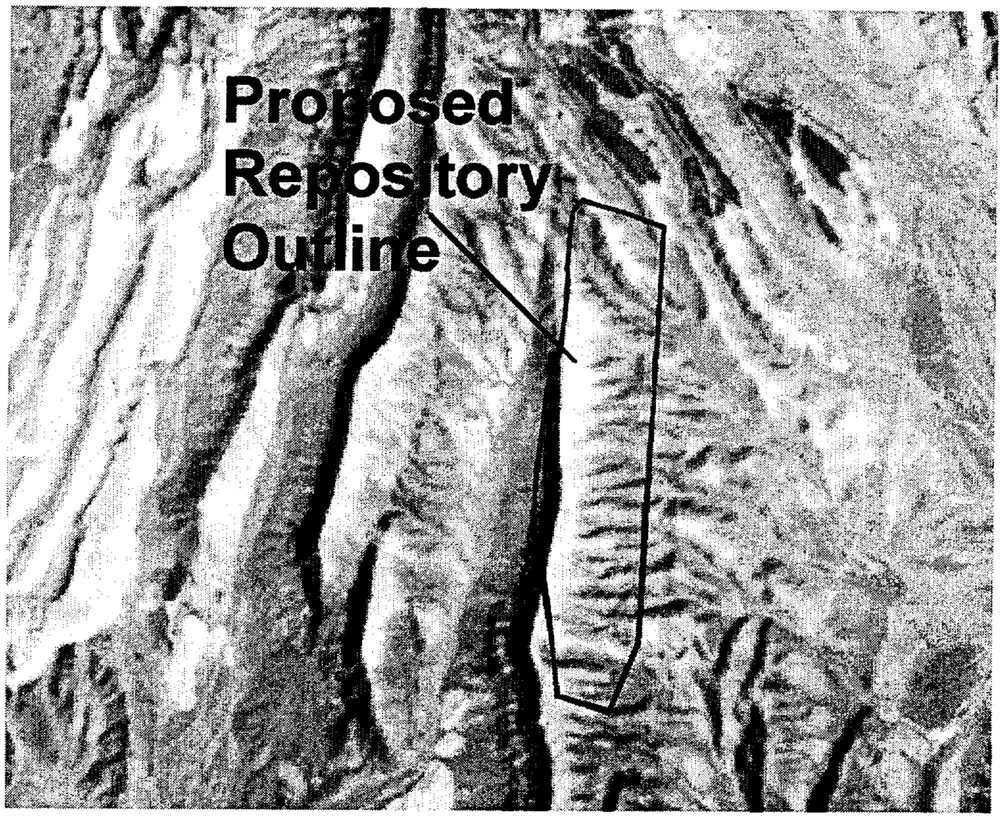
<u>Spatial Distribution of Deep Percolation (Above the Repository)</u>

- Determine UZ matrix moisture potentials under natural conditions (needed to calibrate UZ models)

- Justify key assumptions, or show they have little effect on performance

  Assumption: Steady-state infiltration and percolation - dampening of pulses by PTn layer is basis for steady-state flow assumption, but:

  (1) part of the repository west of Yucca crest has no overlying PTn, and


Proposed
Repository
Outline

(2) perched water chemistry & CL-36 data suggest significant flux bypasses the PTn (models need to be consistent with Cl-36 data)

Assumption: Intra-layer homogeneity (heterogeneity may cause lateral diversion or focusing, e.g., Pruess, 1999)

- Include effects of surface-water routing on infiltration and percolation

Seepage into Underground Openings

- Possible path to resolution: conservatively assume the fraction of percolation that intercepts footprint area of waste packages will contact them (or their drip shields)

  Or, reduce this fraction by making observations of drift seepage under natural conditions - this would estimate how much percolation is diverted away from drifts - needed because we see problems in DOE's approach:

  Concept of seepage threshold - minerals in lithophysal cavities suggest seepage occurs even in openings much smaller than drifts (Hughson and Codell, 2000)

  DOE has not considered drift collapse and other isothermal changes in wall rock

Drift seepage models use a grid with a ~0.5 m spacing. The basis for assumed fracture properties at this scale is unclear.

Flow Paths in the Unsaturated Zone Below the Repository

- UZ model calibrations should be consistent with *in situ* data that show rock matrix is wetter & moisture more evenly distributed than expected

- Hydraulic properties and vitric/zeolitic content of Calico Hills must be based on borehole and perched water data; models should predict creation of perched water

- How will DOE address comments from external peer review groups (US Nuclear Waste Technical Review Board, peer review of TSPA-VA, drift seepage peer review, and expert elicitation for the UZ)?

Subissue 5: Saturated Zone and Dilution

RSS Principal Factors: retardation in the SZ; dilution during migration

NRC Abstractions: flow paths in the saturated zone; dilution due to well pumping

Properties of the SZ (especially alluvium) have a large effect on performance, and compliance must be shown at downgradient locations where groundwater is pumped from the SZ

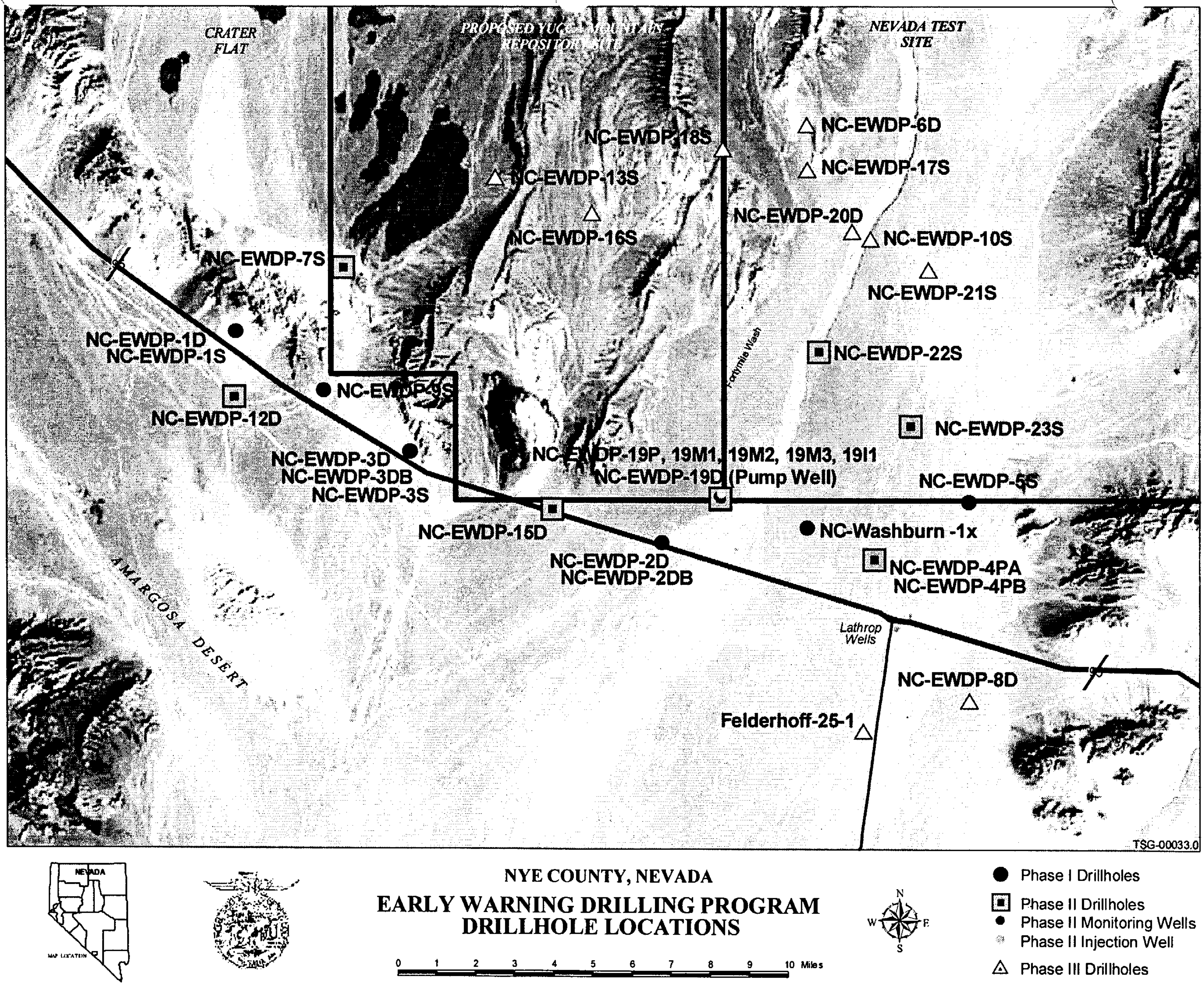
STATUS: OPEN

Need for Additional Data and Analysis

- Show where the water table transitions from the tuffs to valley fill, or conservatively use the shortest lengths of alluvial transport paths that can be justified

- Provide and analyze data from the C-holes, SD-6, and WT-24; obtain hydraulic conductivity & effective porosity for saturated valley fill at 20-km and in data gaps to the south; performance seems more sensitive to properties of alluvial flowpaths than to those of tuffs

- Do C-14 dating of organic carbon in groundwater from the SZ to estimate residence times (independent check on regional flow models)



NYE COUNTY, NEVADA
EARLY WARNING DRILLING PROGRAM
DRILLHOLE LOCATIONS

- **For SZ models, include horizontal anisotropy in hydraulic conductivity for tuffs**

- **Develop revised potentiometric maps that include Nye County data; enough groundwater elevation data should be available to reasonably bound the direction of lateral flow from the repository**

- **Consider future water-table rise in performance assessments; We are closely tracking results of the UNLV fluid inclusion study, which relates to water-table rise.**

- **If DOE takes credit for wellbore dilution, as mentioned in TSPA-SR (methods & assumptions), provide analysis**

- **How will DOE address external peer review comments? For example, the SZ expert elicitation criticized the adequacy of SZ models.**

Subissue 6: Matrix Diffusion

RSS Principal Factors: retardation in the UZ and SZ

NRC Abstractions: unsaturated and saturated zone transport

Matrix diffusion appears of secondary importance to performance.

STATUS: OPEN (nearing resolution)

Need for Additional Analysis

<u>Unsaturated Zone</u>

- If credit is taken for UZ diffusion, explain patterns in pore water chemistry that suggest limited diffusion. Pore water chemistry suggests matrix diffusion in UZ not very effective, except perhaps in perched zones

- In the VA, sensitivity studies suggest the UZ matrix diffusion has a small effect on performance

- Possible path to resolution: take little credit for UZ matrix diffusion; otherwise, explain patterns in pore water chemistry

Saturated Zone

- **Lab analyses, tracer tests, and analysis of flow interval spacing give sound basis for SZ matrix diffusion**

- **Possible path to resolution: NRC will review SZ Process Model Report to evaluate approach to matrix diffusion in SZ transport modeling and other parameter estimates**

SUMMARY TABLE			
SUBISSUE IN ISOTHERMAL HYDROLOGY	RESOLUTION STATUS	RELATED NRC ABSTRACTIONS	RELATED DOE PRINCIPAL FACTORS
Climate change	Closed	spatial & temporal distribution of flow	limited seepage into drifts
Hydrologic effects of climate change	Closed	spatial & temporal distribution of flow; flow paths in the SZ	limited seepage into drifts
Present-day infiltration	Closed	spatial & temporal distribution of flow	limited seepage into drifts
Deep percolation	Open	spatial & temporal distribution of flow; quantity & chem. of water contacting WPs; flow paths in UZ	limited seepage into drifts; retardation in UZ
Flow in the saturated zone and dilution	Open	flow paths in the SZ; dilution due to well pumping	retardation in SZ; dilution during migration
Matrix diffusion	Open (nearing resolution)	UZ transport; SZ transport	retardation in UZ; retardation in SZ

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

Unsaturated and Saturated Flow under Isothermal Conditions

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Russell Patterson
Yucca Mountain Site Characterization Office
U. S. Department of Energy

April 25, 2000

YUCCA MOUNTAIN PROJECT

Current Status

(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Climate Change**
  - All 4 technical acceptance criteria are closed
- **Subissue 2 - Hydrologic Effects of Climate Change**
  - All 3 technical acceptance criteria are closed
- **Subissue 3 - Present-Day Shallow Infiltration**
  - Four acceptance criteria are closed
  - One acceptance criterion is open, based on a potential bias in upper bound values of mean infiltration multipliers; new analyses may resolve this concern

Current Status
(Continued)

- **Subissue 4 - Deep Percolation**
  - All technical acceptance criteria open pending review of ongoing testing in the Exploratory Studies Facility (ESF), the Cross Drift, the Busted Butte Facility, and associated analysis and modeling
    - Current work addresses these criteria
- **Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution**
  - Eight technical acceptance criteria open pending review of ongoing testing and associated analyses and modeling
    - Current work addresses these criteria
  - One technical acceptance criterion closed (wellbore dilution)

Current Status
(Continued)

- **Subissue 6 - Matrix Diffusion**
  - Two technical acceptance criteria open pending review of current testing and associated analysis and modeling

Key Activities

- Fiscal Year (FY) 1998
  - Continued the collection and analysis of data from the ESF and the Busted Butte Facility
  - Updated the unsaturated zone (UZ) and saturated zone (SZ) flow models, taking into account additional site data and analyses
  - Used the results to support the Total System Performance Assessment (TSPA) for the Viability Assessment (VA)

Key Activities
(continued)

- FY 1999
  - Continued data collection and monitoring in the ESF and the Busted Butte Facility
  - Initiated testing and monitoring in the Cross Drift
  - Initiated testing and analyses under the cooperative agreement with the Nye County Drilling Program
  - Initiated enhancements to UZ and SZ flow models for the Site Recommendation Consideration Report (SRCR) to
    - Address comments on the VA models
    - Incorporate new site data
    - Reflect the current understanding of the flow systems

Key Activities
(Continued)

- FY 2000
  - Documented evaluation of current site information, analysis and modeling in Process Model Reports (PMRs) for UZ Flow and Transport and SZ Flow and Transport
  - Continue testing in the ESF, the Cross Drift, and the Busted Butte Facility to reduce uncertainties
  - Continue cooperative work with Nye County
  - Initiate testing at the SZ alluvial testing complex

Key Activities
(Continued)

- FY 2001
  - Plan to conduct Busted Butte transport tests, crossover drift test and monitoring in the ESF, and continue testing at the SZ alluvial testing complex
    - For testing in the ESF
      - » Improved data on seepage and seepage threshold
      - » Improved on hydraulic properties
    - For testing at Busted Butte
      - » Improved understanding of flow behavior in the Calico Hills nonvitric unit
    - For the alluvial testing complex
      - » Additional data on the locations of contacts for alluvium
      - » Improved flow characterization in alluvium

KTI Subissues and Associated Factors of the Safety Case

KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1 Climate Change	Climate	Preliminary analyses suggest these factors do not contribute strongly to postclosure performance. Completed analyses will be documented for the SRCR.
2 Hydrologic Effects of Climate Change	Infiltration, UZ Flow	
3 Present-Day Shallow Infiltration	Infiltration	
4 Deep Percolation	UZ Flow, Seepage into drifts	Seepage is a Principal Factor.
5 SZ Ambient Flow Conditions and Dilution	SZ Flow and Transport (advective pathways, retardation, dispersion, dilution)	Retardation of radionuclide transport in the UZ and in the SZ are Principal Factors.
6 Matrix Diffusion	UZ and SZ flow and transport (advective pathways, retardation, dispersion, dilution)	

Subissue 1 - Climate Change

- **Estimates of future climate are based on a defensible interpretation of available data**
  - Timing and nature of climate change primarily based on the paleoclimate record from Devils Hole, Nevada, and microfossil data from Owens Lake, California
  - Three climate states have been defined using analog climate sites: modern, monsoon, and glacial transition over the next 10,000 years
  - Uncertainty in the future climate states has been addressed by placing an upper and lower bound on precipitation and temperature values
- **Preliminary analyses suggest that climate change does not contribute strongly to postclosure performance**

Subissue 2 - Hydrologic Effects of Climate Change

- **For the UZ**
  - The infiltration model was used to estimate net infiltration for each of the future climate states
  - Detailed Monte Carlo analysis of uncertainty was completed to provide uncertainty distributions for performance assessment
- **For the SZ**
  - For SR, the effect of climate change is modeled, using the modern, monsoon, and glacial transition climate states
- **Preliminary analyses suggest hydrologic effects of climate do not contribute strongly to postclosure performance**

Subissue 3 - Present-Day Shallow Infiltration

- **Net infiltration model has been modified to more accurately simulate net infiltration at the site**
  - Used a wide range of detailed physiographic and hydrologic information
  - Reformulated model boundaries into 10 small water sheds
  - Added a surface-flow, runoff routing module
  - Improved representation of surface evaporation and root-zone transpiration

Subissue 3 - Present-Day Shallow Infiltration

(Continued)

 - Calibrated by comparison of simulated streamflow to discharge measurements at five stream-gauging sites at Yucca Mountain

- Results provide the upper boundary condition for the UZ flow model for modern, monsoon, and glacial transition climate states

Subissues 4 - 6 - Deep Percolation, Saturated Zone Ambient Flow Conditions and Dilution, and Matrix Diffusion

- The following slides focus on 1 acceptance criterion for each of the remaining subissues. These are examples of criteria that map to the postclosure safety case
  - Subissue 4 - Deep Percolation
    - Criterion 3: Drift seepage with thermal/hydrologic/chemical/mechanical coupled effects and drift collapse effects (Principal Factor: seepage)

Subissues 4 - 6 - Deep Percolation, Saturated Zone Ambient Flow Conditions and Dilution, and Matrix Diffusion

(Continued)

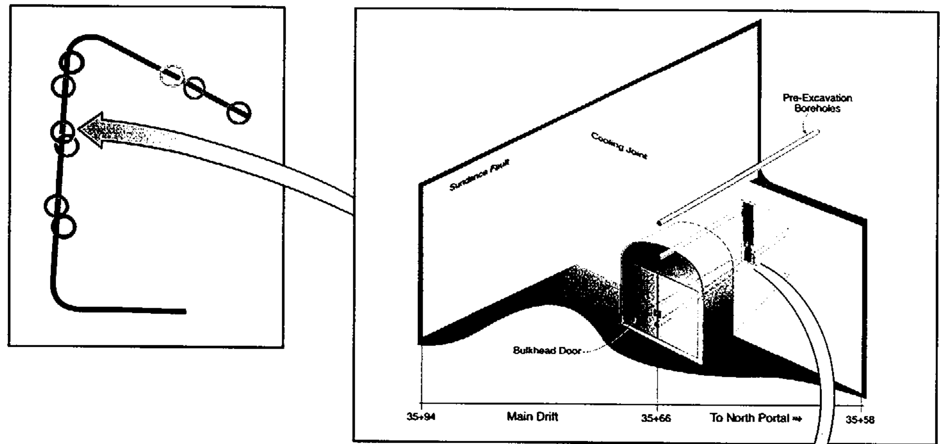
- Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution
  - Criterion 2: Flow paths from repository to potential receptor (Principal factor: retardation of radionuclide transport in the SZ)
- Subissue 6 - Matrix Diffusion
  - Criterion 1: UZ Matrix diffusion and site geochemistry (Principal Factor: retardation of radionuclide transport in the UZ)

Subissue 4 - Deep Percolation, Criterion 3

- **Direct observations of dripping in test drifts or tunnels under ambient conditions in the repository horizon**
  - **No continuous natural seepage has been observed in the ESF or Cross Drift**
  - **No seepage was observed at the cross-over point when the Cross Drift tunnel boring machine passed over the ESF**
  - **A wet feature observed in an ESF Niche dissipated quickly and has not returned after 2 years**

Damp Feature Observed during Dry Excavation of Niche 3566

(Modified from UZ Flow and Transport PMR Figure 2.2-4)



(a) Schematic of Sealed Niche 3566 in the ESF

Objective:

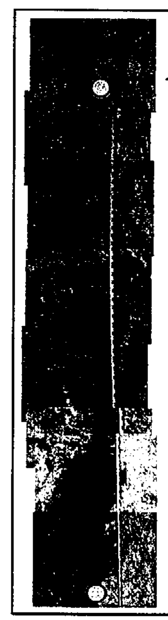
- Quantify seepage processes.

Approaches:

- Mine the niche without spreading water to the ceiling during excavation.
- Close the bulkhead to prevent moisture removal by ventilation.
- Monitor the rock and drift over long time periods.

Results:

- One damp feature observed after dry excavation at end of the niche.
- Feature dried up before bulkhead installation.
- Feature did not rewet after long-term monitoring over two years.



(b) Photograph of a Damp Feature in the Brecciated Zone at the Back of Niche 3566

UZPMR2.2-4REV00

Subissue 4 - Deep Percolation, Criterion 3

- **Model calculations that account for the effects of backfill (if used)**
  - Thermal-Hydrological-Chemical (THC) Seepage Model simulations included backfill, consistent with Enhanced Design Alternative II. Simulations indicate that its inclusion only alters the timing of THC effects
- **Model calculations that account for the effects of drift collapse**
  - Model simulations with the Seepage Model for performance assessment included drift collapse scenarios and indicated that the effect of a single rock fall is not significant for seepage. A deeper rock failure in the drift roof increases seepage

Seepage Percentage (%) for Alternative Drift Degradation Scenarios, for Percolation Flux = 500 mm/year and Parameter Set B.*

(Seepage Models for PA Including Drift Collapse AMR Table 12)

Condition	Seepage Percentage		
	Realization 1	Realization 2	Realization 3
No degration case (Set B)	4.5	4.5	6.9
1-m rockfall from crown of drift	4.5	4.7	7.0
1-m rockfall from springline of drift	4.5	4.5	7.4
3-m rock failure in drift roof	5.8	8.6	10
3-m rock failure case: calc. From Set B nondegraded case	5.8	5.9	9.0

Parameters Set B from the AMR Seepage Calibration Model and Seepage Testing Data

Subissue 4 - Deep Percolation, Criterion 3

- **Calibration of models to niche studies and tracer tests in the ESF**
  - The Seepage Calibration Model was developed and calibrated to seepage testing data from an ESF niche
  - Tracer tests in the ESF were used to directly estimate the fracture porosity of the Topopah Spring middle nonlithophysal

Seepage Issues

(UZ Flow and Transport PMR Figure 3.9-3)

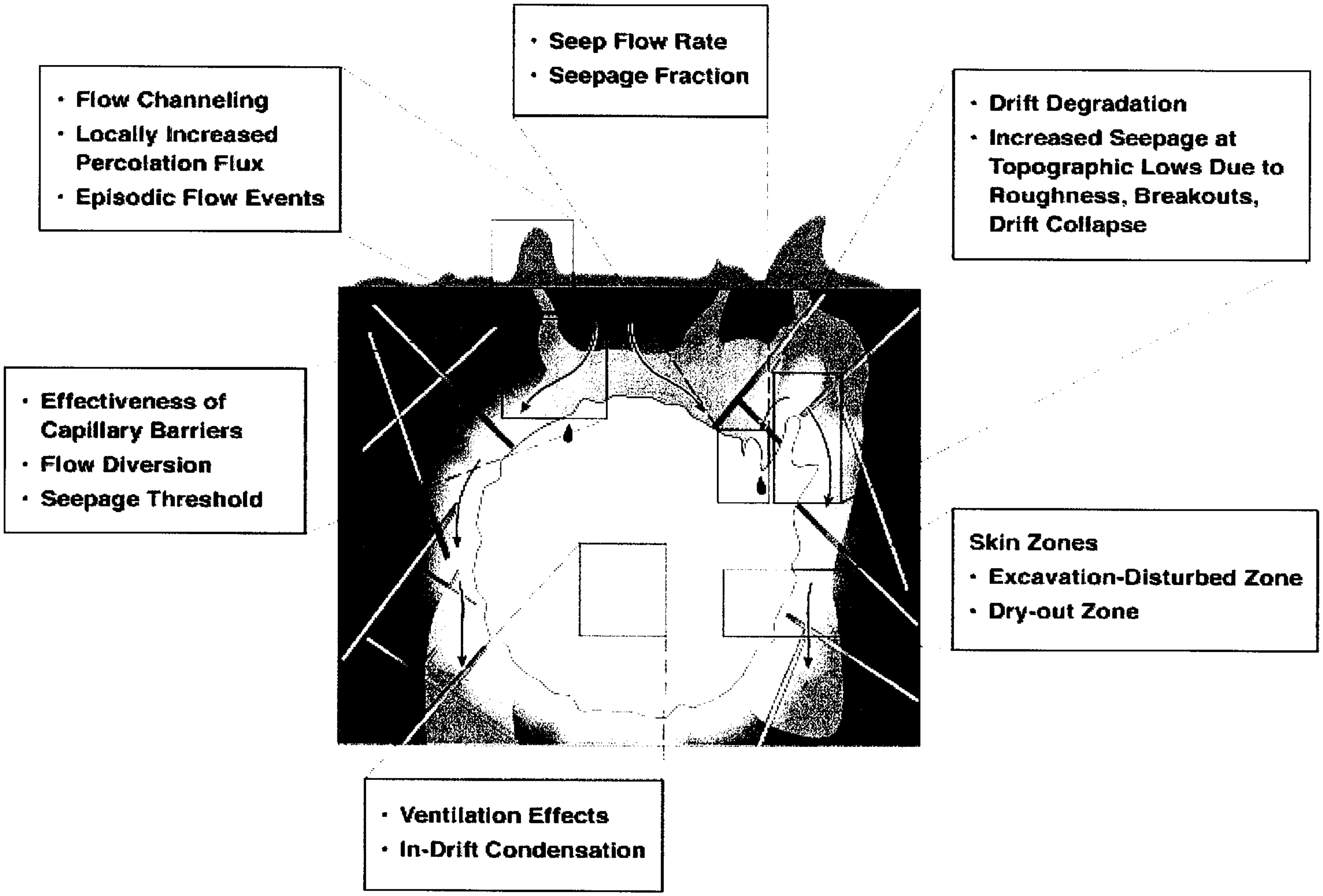
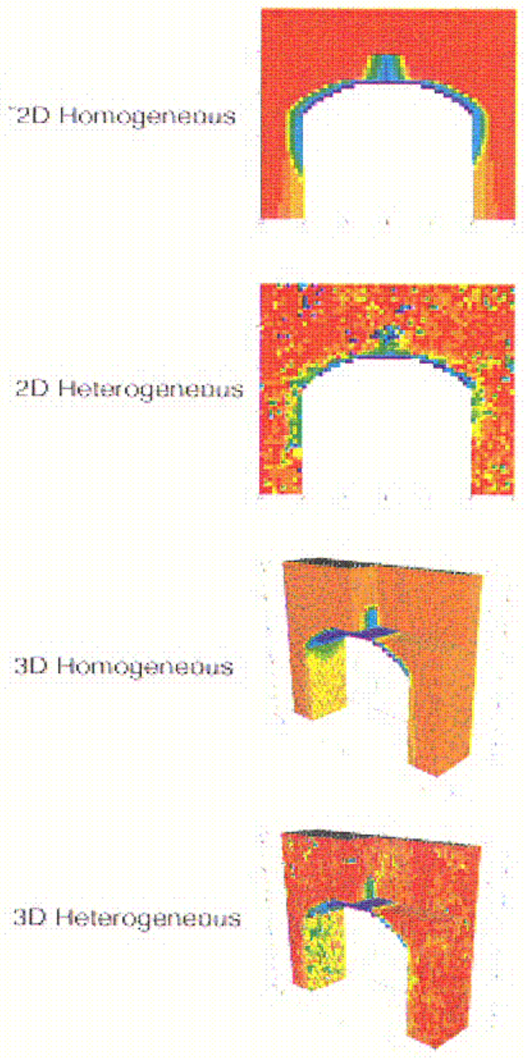


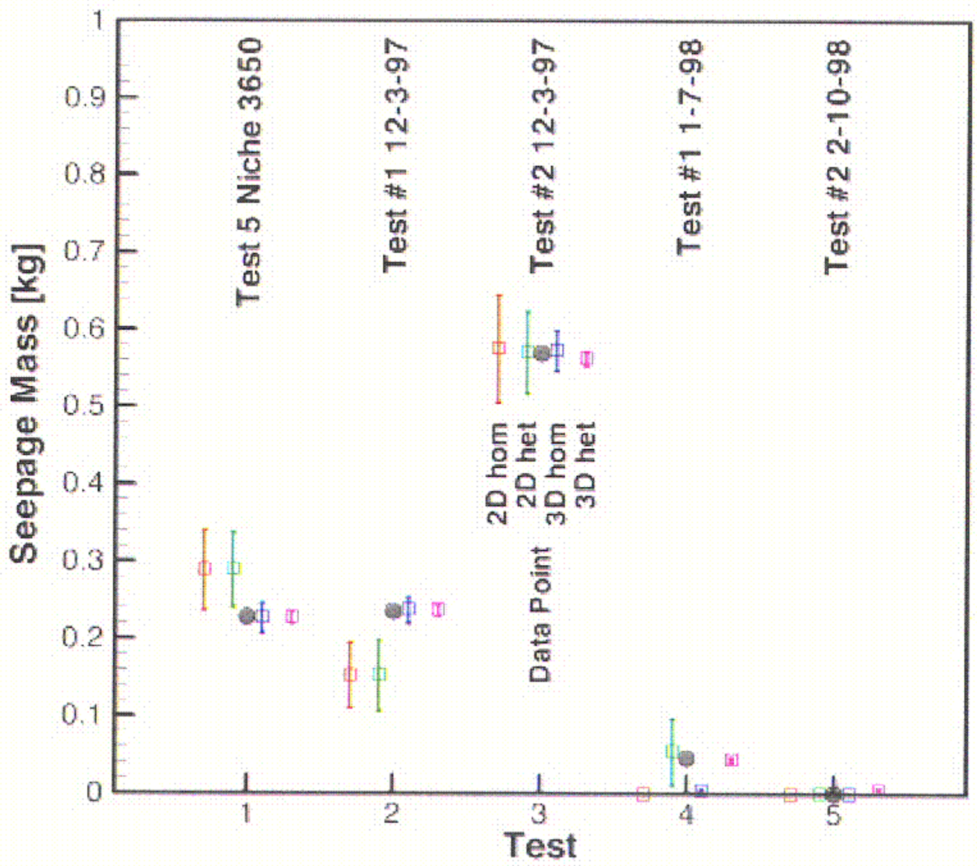
Figure 3.9-3

REV00

Comparison between the Measured Seepage Mass (Circles) and that Calculated with Two- and Three-Dimensional , Homogeneous and Heterogeneous Models (Squares)

(UZ Flow and Transport PMR Figure 3.9-6)





C3

Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution, Criterion 2

- Uncertainty in the location of the contact between volcanic units and the alluvium bounded in model stochastically by varying amount of alluvium along the flow path
  - SZ flow directions based on hydraulic gradient from mapping the potentiometric surface and validated by hydrochemistry data
  - Uncertainty in the northern boundary of alluvium represented as an "uncertainty zone" that has properties of the valley fill aquifer hydrogeologic unit
  - Dimensions of the uncertainty zone are stochastically varied for transport simulations for performance assessment

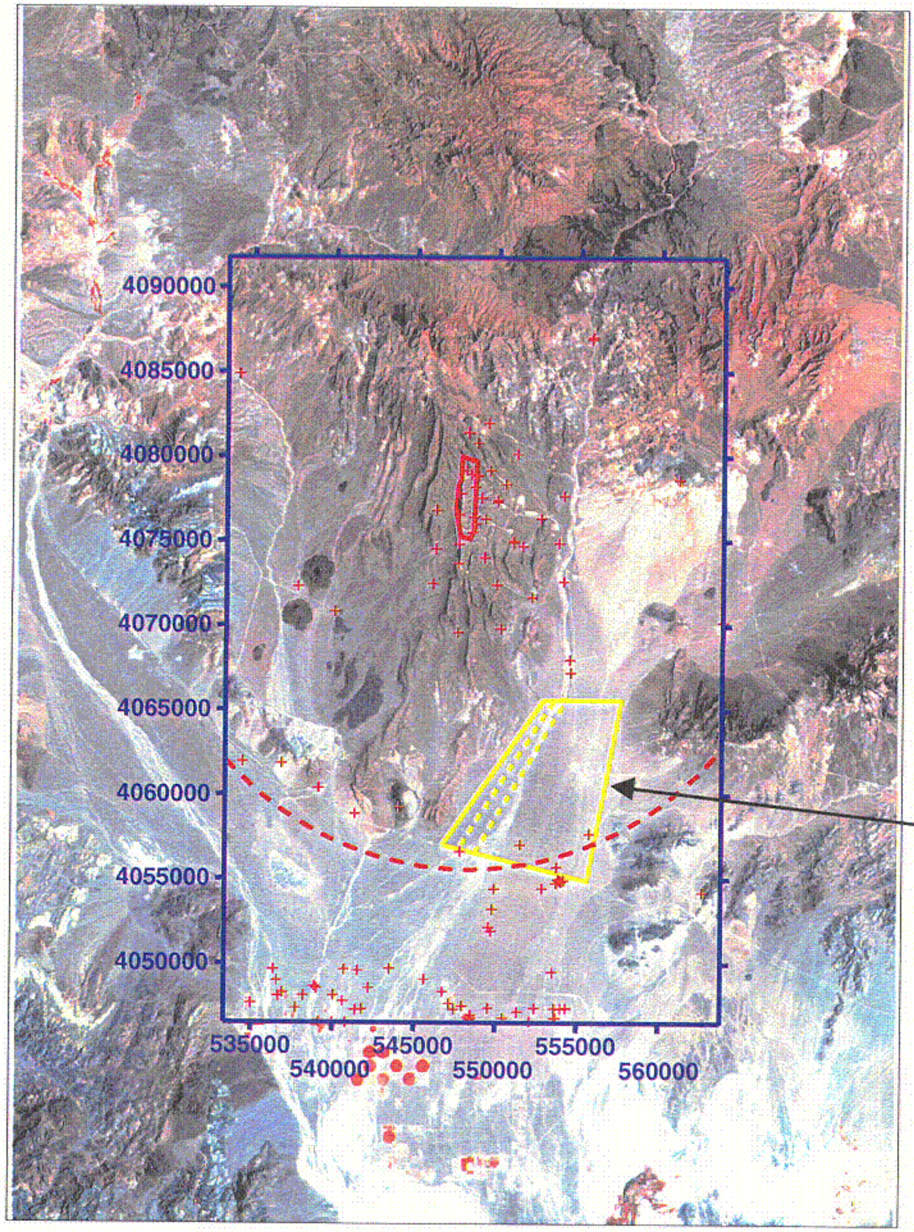
Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution, Criterion 2

(Continued)

- The northern boundary of the uncertainty zone is varied from north to south
- The western boundary is varied from the most westerly yellow line to the eastern most dashed line (slide 26)
- Uncertainty zone includes alluvium at the southern boundary, based on data from Nye County wells
- Additional data from the Nye County wells will further reduce uncertainty in hydraulic and transport properties of units downgradient from the potential repository and the volcanic tuff/alluvium contact

Alluvial Uncertainty Zone

(Outlined in yellow lines) in the SZ site-scale model area (blue axes)



C4

Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution, Criterion 2

(Continued)

- Dual porosity approach is incorporated explicitly into the transport methodology for volcanic units to simulate matrix diffusion
- Potential effects of horizontal anisotropy are bounded by setting the anisotropy ratio stochastically to either 1 (isotropic) or 5 (based on the C-well data) by making permeability values for the volcanic units 5 times greater in the north-south direction than in the east-west direction

Subissue 5 - Saturated Zone Ambient Flow Conditions and Dilution, Criterion 2

(Continued)

- Uncertainty in groundwater flux is incorporated by considering three discrete cases of low, mean, and high flux by scaling the values of permeability and the boundary fluxes of the mean-flux case downward or upward by a constant factor of 10. Proportional scaling preserves the calibration of the model to head measurements among the three cases
- Potentiometric levels in the carbonate aquifer at UE-25p#1 are about 21 m higher than levels in the overlying rocks. This indicates a potential for upward flow and suggests that water will not flow from the tuffs into the carbonates

Subissue 6 - Matrix Diffusion, Criterion 1

- Matrix diffusion is now included in the radionuclide transport model for TSPA
- Matrix diffusion model is summarized in the PMR for UZ flow and transport
  - Based on a dual-porosity approximation (no flow in the matrix); conservatively ignores the effects of fracture-to-matrix imbibition flow that occurs for most of the fracture/matrix interaction area

Subissue 6 - Matrix Diffusion, Criterion 1

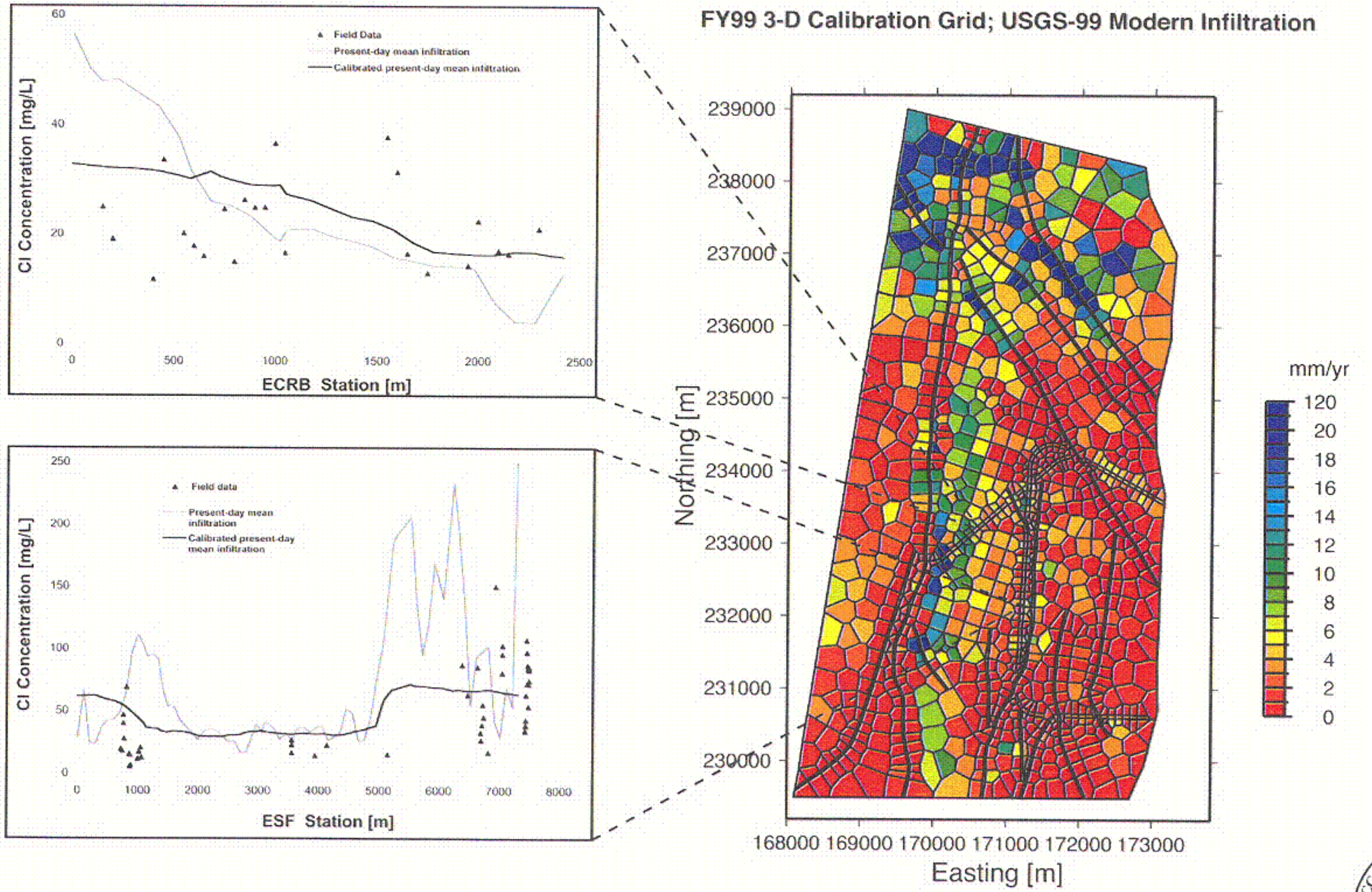
(Continued)

- Accounts for the effects of finite fracture spacing
- Reduces diffusive flux in proportion to the fracture/matrix contact area reduction as defined by the active fracture model

- Matrix diffusion model was found to be consistent with geochemical data for Chloride from the ESF

Infiltration Rates Plotted on 3-D UZ Calibration Grid. Simulated (using base-case infiltration rates), calibrated, and measured Cl concentrations in the ESF and the ECRB

(UZ Flow and Transport PMR Figure 3.8-3)



C5

Summary

- **Current Understanding:**
  - Preliminary analyses of climate change, and hydrologic effects of climate change, and present-day shallow infiltration suggest these factors do not strongly contribute to postclosure performance (Subissues 1, 2 and 3)
  - UZ flow models provide a reasonable basis for representing retardation in the UZ and seepage into drifts (Subissue 4)
  - SZ model provides a reasonable basis for representing retardation in the SZ (Subissue 5)
  - Matrix diffusion model is consistent with geochemical data (Subissue 6)
  - These results are summarized in the PMRs for UZ flow and transport and SZ flow and transport

Summary
(Continued)

- **Areas of Agreement**
  - Subissues for climate change, hydrologic effects of climate change, and present-day shallow infiltration are resolved; minor improvements completed to address remaining questions
  - Subissues on deep percolation, SZ flow conditions and dilution processes are partially resolved; additional analyses are ongoing to address remaining concerns
  - Additional analyses have been completed to address Subissue 6 (Matrix Diffusion)

Summary
(Continued)

- **Areas of Disagreement (Brocoum letter to Reamer, 3/00)**
  - Specific technical acceptance criteria are not closely linked to the postclosure safety case and/or are too prescriptive
    - Analyses (e.g., cause of the moderate and large hydraulic gradients)
    - Data needs (e.g., use of specific logging tools)

Backup

Key Technical Issue : Unsaturated and Saturated Zone Flow under Isothermal Conditions		
Acceptance Criterion	**USFIC IRSR Rev 2 Status**	**DOE Comment**
Subissue 1- Climate Change		
1 - Climate projections used in performance assessments of the YM region are based on paleoclimate data, considering, at a minimum, information contained in Forester, et al. (1996}. Winograd, et. Al. (1992); Szabo, et al. (1994)	Closed at this time.	Agree
2 - DOE has evaluated long-term climate change based on known patterns of climatic cycles during the Quaternary, especially the last 500 k.y.	Closed at this time.	Agree
3 - If used, numerical climate models are calibrated with paleoclimate data and their use suitably simulates the historical record, before being used for projection of future climate.	Closed at this time.	Agree
4 - Climate-affected parameters (e.g., onset times for climate change, MAP, and MAT) used in YM performance assessment models include, as bounding condition, a return to full pluvial climate (higher precipitation and lower temperatures) for at least a part of the first 10-k.yperiod, using parameter values that are supported by scientific data and analyses.	Closed at this time.	Agree
5 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches	Closed at this time.	Agree
6 - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document.
Subissue 2 – Hydrologic Effects of Climate Change		
1 - If bounding analysis are used to predict climate-induced effects (water table rise, for example), the analysis are based on a reasonably complete search of paleoclimate data pertinent to water-table rise and other effects (for example, changes in precipitation and geochemistry), including, at a minimum, information contained in Paces, et al. (1996), Szabo, et al. (1994), Forester, et al. (1996)	Closed at this time.	Agree
2 - Regional and sub-regional models for the SZ that are used to predict climate-induced consequences are calibrated with the paleohydrology data, and are consistent with evidence that the water-table rise during the late Pleistocene was up to 120 m.	Closed at this time.	Agree
3 - DOE has incorporated future climate changes and associated effects in its performance assessments. For example, available information does not support an assumption that present-day climate will persist unchanged for 10 k.y. or more	Closed at this time.	Agree
4 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches.	Closed at this time.	Agree

Key Technical Issue : Unsaturated and Saturated Zone Flow under Isothermal Conditions		
Acceptance Criterion	**USFIC IRSR Rev 2 Status**	**DOE Comment**
Subissue 2 – Hydrologic Effects of Climate Change, continued		
5 - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the QARD document.
Subissue 3 – Present-day Shallow Infiltration		
1 - DOE has estimated present-day shallow infiltration at YM for use in TSPA using mathematical models that are reasonably verified with site-specific climatic, surface, and subsurface information, and the fundamental effects of heterogeneities, time-varying boundary conditions, evapotranspiration, depth of soil cover, and surface-water runoff have been considered in ways that do not underestimate infiltration.	Closed at this time.	Agree
2 - DOE has analyzed infiltration at appropriate time and space scales for performance assessment, and has tested the abstracted model against more detailed models to assure that if produces reasonable results	Closed at this time.	Agree
3 - DOE has characterized shallow infiltration in the form of either probability distributions or deterministic upper-bound values for performance assessment, and provided sufficient data and analyses to justify the chosen probability distribution or bounding value.	Open-bias in upper bound Mean Annual Infiltration multipliers.	The methodology for assigning probabilities to the mean annual infiltration multipliers has been changed to address the apparent bias.
4 - DOE can show through TSPA and associated sensitivity analyses that refinements of shallow infiltration estimates will not significantly alter performance predictions, no further refinement will be necessary.	Closed at this time.	Agree
5 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches	Closed at this time.	Agree
6- The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the QARD document.
Subissue 4 – Deep Percolation		
1 - Estimates of deep percolation flux rates and the fraction of flux that occurs in fractures will be acceptable provided that they are: (i) shown to constitute a conservative upper bound, or (ii) based on a technically defensible UZ flow model that reasonably represents the physical system, including flow in fracture systems and matrix-fracture interaction. The flow model has been calibrated using site-specific hydrologic, geologic, and geochemical data.	Open, pending review of data reports from the ESF, the cross drift, the busted butte Facility, and future performance assessments. Conservatively assume the fraction of flow in the matrix is negligible or for units with a significant portion of flow in the matrix, demonstrate that parameter values for fracture and matrix hydrologic properties are consistent with *in situ* observations. Seal off a section of the cross drift.	Dual permeability model represents fractures and matrix as overlapping, interacting continua. Modeling, using an active fracture model leads to a high percentage of flow in fractures in the TCw, TSw, and CHnz but a low percentage of fracture flow in the PTn andCHnv. A section of the cross drift has been sealed off for observation.

Key Technical Issue : Unsaturated and Saturated Zone Flow under Isothermal Conditions		
Acceptance Criterion	**USFIC IRSR Rev 2 Status**	**DOE Comment**
Subissue 4 – Deep Percolation, continued		
2 - To estimate deep-percolation flux, spatial and temporal variability of model parameters and boundary conditions must be considered. Model parameters must be averaged over appropriate time and space scales. DOE must also consider climate-induced change in soil depth and vegetation.	Open, pending review of future performance assessments. Consider alternative models to volume averaging or confirm parameters used to run the site-scale model. The UZ flow model should account for heterogeneity or discrete features that lead to fast flow through the PTn. Examine the effects of transient flow on seepage.	Current modeling results indicate a low percentage of fracture flow in the PTn unit. The PTn is expected to dampen pulses of infiltration so that water flow below the PTn is assumed to be steady rather than episodic.
3 - For estimates of the amount of water that may contact waste packages DOE must (i) demonstrate that coupled thermal-mechanical-chemical changes in rock mass properties will not focus deep percolation into the drifts; and (ii) rigorously justify estimated diversion of deep percolation away from the waste package footprints. This must include direct observations of dripping in test drifts or tunnels under ambient (unventilated) conditions in the repository horizon, or in an analog horizon with similar characteristics. Also needed are model calculations that account for the effects of backfill (if used), drift collapse, and coupled thermal-mechanical-chemical changes to rock properties. The models have been calibrated to niche studies and tracer tests in the ESF, or using an analog with characteristics similar to the repository horizon.	Open, pending review of future performance assessments. Improve models of capillary diversion and seepage, using conservative assumptions and accounting for heterogeneity and uncertainty. Include models of drift collapse and alteration of hydraulic properties.	Model calculations now account for effects of drift collapse. The seepage calibration model developed and calibrated with seepage test data from a niche in the ESF. Tracer tests in the ESF were used to directly estimate fracture porosity of the Topopah Spring middle nonlithophysal unit.
4 - In predicting likely flow and transport pathways beneath the proposed repository horizon, DOE must either i) conservatively assume that all deep percolation below the repository level bypasses the bulk of the non-welded units, either by lateral movement above the units or through vertical flow through fractures and faults; or (ii) demonstrate that the estimated fraction of deep percolation that flows vertically through the matrix of the non-welded units is supported by (a) characterization data and (b) two-dimensional or three-dimensional modeling that accounts for spatial and temporal variability that may result in lateral diversion of flow, and uses model parameter values appropriate for the scale of model discretization.	Open, pending review of future performance assessments. If (ii) is implemented, continue to replace parameter sets obtained from 1-D model calibrations with those from 3-D model calibrations. Complete additional work on flow paths at Busted Butte in the highly zeolitized tuffs. Develop better estimates of fracture/matrix flow at various percolation rates in vitric anddevitrified units to evaluated the appropriate values for F/M reduction factors. Characterize variations in hydrologic and sorption properties with variations in alteration and welding in the Calico Hills, Prow Pass, and Bullfrog tuffs.	Perched water model primarily defines pathways through nonwelded units. Two perched water models have been evaluated-both results in significant change in spatial distribution of flux at the water table compared to the repository level. Transport predictions from the two models are similar. Flux through the CHnv, primarily in the southern part of the potential repository, is dominated by matrix flow.
5 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches	Closed at this time.	Agree
6 – The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the QARD document.

Key Technical Issue : Unsaturated and Saturated Zone Flow under Isothermal Conditions		
Acceptance Criterion	**USFIC IRSR Rev 2 Status**	**DOE Comment**
Subissue 5 – Saturated Zone Ambient Flow Conditions and Dilution Processes		
1 - DOE has considered conceptual flow and data uncertainties. Uncertainties due to sparse data or low confidence in the data interpretations have been considered by analyzing reasonable conceptual flow models that are supported by site data, or by demonstrating through sensitivity studies that the uncertainties have little impact on repository performance.	Open pending review of published peer-reviewed reports to document the results of testing at the C-Holes complex.	Updated results of C-wells testing published in Reimus et al., 1999.
2 - DOE has reasonably delineated possible flow paths from beneath the repository to potential receptor locations based on data that is sufficient to elucidate (I) the relative travel distances through aquifers of differing hydrologic and geochemical properties; (ii) in fractured-rock aquifers, the portions of flow through rock matrix and fractures; (iii) flow directions with respect to the hydraulic gradient, considering the potential effects of horizontal anisotropy; (iv) approximate volume fluxes and pore velocities; and (v) vertical hydraulic gradients, including the potential for flow between the Paleozoic carbonate aquifer and the volcanic tuff aquifer. A sufficient number of wells and exploratory holes should be drilled, and an adequate number of tests conducted, to reasonably bound the hydraulic and transport properties of the units downgradient from the proposed repository.	Partially resolved. Continue to fill data gaps. Complete hydraulic and tracer testing on a scale large enough to include a statistically representative elementary volume in the tuff fracture network and in the valley fill. Complete drilling and logging to delineate the transition between tuff aquifer and the valley fill aquifer 2 km northwest of well 2D and the data gap between the Washburn 1-X well and JF-3. Need to develop a reasonable set of conceptual flow models.	Data gaps being filled. Conceptual flow models have been improved. Uncertainty in travel distances through aquifers of differing properties is bounded in the model by varying the amount of alluvium along flow paths. Dual porosity approach incorporated into transport methodology. Effects of horizontal anisotropy have been bounded. Uncertainty in groundwater flux has been incorporated.
3 - DOE has provided a hydrologic assessment to describe likely causes of the "moderate hydraulic gradient" and the "large hydraulic gradients."	Open, pending review of reports on WT-24 and SD-6.	Reports not yet available.
4 - DOE has provided maps of approximate potentiometric contours of the regional uppermost aquifer for an area that, at a minimum, includes wells J-11 on the east, VH-1, VH-2, and the GEXA Well on the west, UE-29z #2 to the north, and domestic and irrigation wells south of Amargosa Valley aka Lathrop Wells). Maps of regional and site-scale recharge and discharge should be provided, along with site-scale flow-net analysis of the SZ.	Open, pending review of new reports. Include additional wells in the regional potentiometric map. Provide maps of regional and site-scale recharge and discharge and site-scale hydrostratigraphic cross sections along flow paths and site-scale flow-net analysis of the saturated zone.	Analysis and modeling report on water levels is in review.
5 - DOE estimates of key hydrologic parameters are described in the form of either probability distributions or deterministic bounding values that are reasonably consistent with site data. These parameters should include transmissivity, hydraulic gradient, effective porosity, effective immobile porosity, and effective aquifer thickness.	Open, pending review of new data from Nye County. Recommend additional geophysical logging. Continue interpretation of data from hydraulic head and tracer tests. Drill new wells to fill data gaps in Nye County wells.	The site-scale model is calibrated and testing is calibrated against relevant data, including water level, permeability, temperature, and ambient hydrochemistry data and validated with natural analog data.
6 - DOE has used mathematical groundwater model(s) that incorporate site-specific climatic and subsurface information. The models were reasonably calibrated and reasonably represent the physical system. Fitted aquifer parameters compare reasonably well with observed site data. Implicitly- or explicitly-simulated fracturing and faulting are consistent with the data in the 3D geologic model. Abstractions are based on initial and boundary conditions consistent with site-scale modeling and the regional models of the Death Valley groundwater flow system. Abstractions of the groundwater models for use in PA simulations should use appropriate spatial- and temporal- averaging techniques	Open, pending review of future performance assessments. Update of the hydrologic framework model to include data gaps south of YM. Incorporate horizontal anisotropy, complete additional calibration. Account for water table rise in the top model layer or show that neglecting the water table rise is conservative.	Disregarding rises in groundwater that would be redirected into lower permeability units, is conservative with regard to radionuclide transport.

Key Technical Issue : Unsaturated and Saturated Zone Flow under Isothermal Conditions		
Acceptance Criterion	**USFIC IRSR Rev 2 Status**	**DOE Comment**
Subissue 5 – Saturated Zone Ambient Flow Conditions and Dilution Processes, continued		
7 - If credit for wellbore dilution is taken, a demonstration has been provided that reasonable assumptions have been made about well design, aquifer characteristics, plume geometry, withdrawal rates, and capture zone analysis for the receptor location.	Resolved at this time.	Agree
8 - If credit is taken for dilution due to either dispersion, groundwater mixing below the repository footprint, or mixing of the YM water with water from the north in Fortymile Wash, reasonable assumptions have been made about spatial and temporal variations of aquifer properties and groundwater volumetric fluxes.	Open, pending review of the random walk particle tracking in future performance assessment.	Random walk particle tracker is described in the process model report for Saturated Zone Flow and Transport, and the analysis and modeling report, Saturated Zone Transport Methodology and Transport Component Integration.
9 - DOE has incorporated key conclusions regarding potential geothermal and seismic effects on the ambient SZ flow system (e.g., National Research Council, 1992; NWTRB, 1998; memorandum from R. Craig to S. Brocoum, October 8, 1997)	Open, pending review of future performance assessments and review of data on fluid inclusions.	Fluid inclusion studies are ongoing; results not yet available.
10 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches.	Resolved at this time.	Agree
11 - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the QARD document.
Subissue 6 – Matrix Diffusion		
1 - If credit for matrix diffusion criteria for matrix diffusion in the unsaturated zone, then transport predictions must be consistent with site geochemical and isotopic data	Open, pending review of future performance assessments. Include detailed small-scale feature models to verify the RTTF approach, appropriate scaling of assumed value of the diffusion coefficient.	Partially resolved. A discrete fracture model has been implemented; the matrix diffusion model is consistent with geochemical data.
2 - If credit for matrix diffusion in the SZ is take, rock matrix and solute diffusion parameters must be (I) based on a SZ transport model that reasonably matches the results of the field tracer tests that are conducted over different distance scales and flow rates with multiple tracers of different diffusive properties, and (ii) consistent with laboratory data.	Open, pending review of future performance assessments, including new approach to including matrix diffusion in transport models that explicitly considers physical properties of aquifers.	An analytical solution has been implemented that requires parameter values, such as fracture aperture, mean fracture spacing, linear groundwater velocity in the fractures, matrix porosity, retardation factors in matrix and fractures, and the effective diffusion coefficient.
3 - If used, expert elicitations are conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation (NRC, 1996), or other acceptable approaches	Closed at this time.	Agree
4 - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable Quality Assurance Procedures (QAP). If they were not subject to an acceptable QAP, they have been appropriately qualified.	TBD	Activities associated with this work were determined to be subject to the quality assurance program as described in the QARD document.

KEY TECHNICAL ISSUE (KTI)

CONTAINER LIFE AND SOURCE TERM (CLST)

CLST TEAM:

Tae Ahn[1,3]
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NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION STATUS
APRIL 25 - 26, 2000, LAS VEGAS, NV

CLST KTI SUBISSUES AND STATUS OF RESOLUTION

Subissue 1: The effects of corrosion processes on the lifetime of the containers
OPEN

Subissue 2: The effects of phase instability and initial defects on the mechanical failure and lifetime of the containers
CLOSED PENDING CONFIRMATORY INFORMATION

Subissue 3: The rate at which radionuclides in spent nuclear fuel are released from the engineered barrier subsystem through the oxidation and dissolution of spent nuclear fuel
CLOSED PENDING CONFIRMATORY INFORMATION

Subissue 4: The rate at which radionuclides in high-level waste glass are released from the engineered barrier subsystem
CLOSED PENDING CONFIRMATORY INFORMATION

Subissue 5: The effects of in-package criticality on waste package and engineered barrier subsystem performance
OPEN

Subissue 6: The effects of alternate engineered barrier subsystem design features on container lifetime and radionuclide release from the engineered barrier subsystem

CLOSED PENDING CONFIRMATORY INFORMATION

Subissue 1: The effects of corrosion processes on the lifetime of the containers

- DOE Repository Safety Strategy (RSS) Principal Factors: Performance of the Waste Package

- NRC Abstractions: Engineered Barrier Degradation

STATUS: OPEN

A-Need for additional analysis

Likelihood of localized corrosion, microbially influenced corrosion, and (internal or inter-granular) dry-air oxidation

- Provide data and justification for inclusion or exclusion taking into consideration uncertainties in the definition of in-drift environmental conditions

Long-term behavior of Alloy 22 considering ASTM Standard C-1174-97 and relevant analogue data

- Provide justification on selection of analogues considered

B-Need for additional data and analysis

Long-term uniform corrosion rates of Alloy 22

- Apply technically acceptable methods to determine rates eliminating uncertainties related to the deposition of silica and corrosion products as well as other experimental factors affecting test results
- Provide qualified range of values and distributions derived from experimental measurements

Susceptibility of Alloy 22 to stress corrosion cracking (SCC)

- Determine with technically acceptable and sensitive SCC test methods applicable to the range of in-drift environmental conditions
- Provide qualified range of values and distributions for crack growth rates and SCC stress intensity thresholds derived from experimental measurements

Corrosion environment in contact with containers

- Include effects of gamma radiolysis, maximum estimated concentration of anions, and acceptable determination of temperature and redox conditions considering temporal and spatial variations

Effects of fabrication, welding (with and without post-weld heat treatment), compositional variations, and thermal aging on corrosion of Alloy 22

- Provide adequate evaluation of the effect on localized corrosion, corrosion rates and SCC considering the variability associated with fabrication processes

Subissue 2: The effects of phase instability and initial defects on the mechanical failure and lifetime of the containers (partially covered by Repository Design and Thermal-Mechanical Effects KTI)

- DOE RSS Principal Factors: Performance of the Waste Package

- NRC Abstractions: Mechanical Disruption of Engineered Barriers

STATUS: CLOSED PENDING CONFIRMATORY INFORMATION

Confirmatory information needed

- Provide information on ultimate tensile strength or linear-elastic (or elastic-plastic) fracture toughness parameters to estimate mechanical failure of Alloy 22

- Provide acceptable database, and estimates of initial failure probabilities for Alloy 22 and 316 stainless steel welded containers

- Provide information on the effect of post-weld heat treatment and thermal aging on the parameters governing mechanical failure of Alloy 22 and 316 stainless steel welded containers

Subissue 3: The rate at which radionuclides in spent nuclear fuel are released from the engineered barrier subsystem through the oxidation and dissolution of spent nuclear fuel

- DOE RSS Principal Factors: Solubility Limits of Dissolved Radionuclides in Yucca Mountain Water
- NRC Abstractions: Radionuclide Release Rates and Solubility Limits

STATUS: CLOSED PENDING CONFIRMATORY INFORMATION

Confirmatory information needed

- Provide information on radionuclide release from partially failed waste package including parameter values, assumed ranges, probability distributions and bounding assumptions
- Provide updated information and justification for using dissolution rate of spent nuclear fuel from accelerated flow-through tests including appropriate consideration of drip scenarios

- Provide information on radionuclide solubility limit including parameters values,assumed ranges, probability distributions and bounding assumptions, in particular for Np species

- Provide information on failure rate of cladding (including hydride embrittlement, and localized corrosion and SCC caused by in-package environment) considering both PWR and BWR fuel cladding materials and conditions

- Provide information on in-package chemistry including effects of gamma radiolysis and internal waste package materials, interaction of spent nuclear fuel and high-level waste glass and redox conditions considering temporal and spatial variations

Subissue 4: The rate at which radionuclides in high-level waste glass are released from the engineered barrier subsystem

- DOE RSS Principal Factors: Solubility Limits of Dissolved Radionuclides in Yucca Mountain Water

- NRC Abstractions: Radionuclide Release Rates and Solubility Limits

STATUS: CLOSED PENDING CONFIRMATORY INFORMATION

Confirmatory Information needed

- Provide information on radionuclide release from partially failed waste package including parameters values, assumed ranges, probability distributions and bounding assumptions

- Provide information on the effect of in-package corrosion products such as ferrous and ferric ions on glass dissolution rates and the significance of the radionuclide release rates in dose calculations

Subissue 5: The effects of in-package criticality on waste package and engineered barrier subsystem performance

- DOE RSS Principal Factors: not included
- NRC Abstractions: Engineered Barrier Degradation, Mechanical Disruption of Engineered Barriers

STATUS: OPEN

A-Need for additional analysis

- Multi-parameter trending analysis for developing code biases and uncertainties
- Verification of k_{eff} regression equation or look-up tables

B-Need for additional data and analysis

Methodology and modeling

- Provide the analysis methodology and modeling for initial and post-closure radionuclide inventory (e.g., SAS2H adequacy, bias on depletion code) and other types of moderators

- Provide the modeling validation approach for steady-state criticality consequence and isotopic depletion
- Measure spent nuclear fuel burnup on each assembly
- Develop criticality margin

C-Aspect of the subissue that has not been addressed

- Effects of radionuclide migration through pinholes and cracks in cladding
- Potential of igneous-induced criticalities
- Transient criticality consequences
- Criticality input to Total System Performance Assessment
- Methodology, modeling, and validation for the criticality assessment of Navy and DOE-owned spent nuclear fuel, and Plutonium-bearing high-level waste glass

Subissue 6: The effects of alternate engineered barrier subsystem design features on container lifetime and radionuclide release from the engineered barrier subsystem

- DOE RSS Principal Factors: Performance of the Drip Shield
- NRC Abstractions: Engineered Barrier Degradation, Mechanical Disruption of Engineered Barriers, Radionuclide Release Rates and Solubility Limits

STATUS: CLOSED PENDING CONFIRMATORY INFORMATION

Confirmatory information needed

- Provide information on temperature and the chemical environment in contact with drip shields, including the effects of gamma radiolysis and in-drift materials, and the maximum estimated concentration of anions
- Provide information on long-term uniform corrosion rates of Ti Grade 7, including range of values and distributions derived from experimental measurements
- Provide information on source and database used to estimate initial failure probability of Ti Grade 7 drip shield

- Provide information on ultimate tensile strength or linear-elastic (or elastic-plastic) fracture toughness parameters to estimate mechanical failure of Ti Grade 7
- Provide information on the effect of post-weld heat treatment and thermal aging on the parameters governing mechanical failure of Ti Grade 7 drip shield

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

Container Life and Source Term

Presented to:
NRC/DOE Technical Exchange
on Yucca Mountain Pre-Licensing Issues

Presented by:
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U. S. Department of Energy

April 25, 2000

YUCCA
MOUNTAIN
PROJECT

Current Status

(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Effects of Corrosion Processes on Lifetime of the Containers**
  - All technical acceptance criteria open
  - Some components related to corrosion of carbon steel closed
  - Concerns with corrosion of Alloy 22 remain open
- **Subissue 2 - Effects of Phase Stability of Materials and Initial Defects on the Mechanical Failure and Lifetime of the Containers**
  - All technical acceptance criteria open
  - Some components related to corrosion of carbon steel closed

Current Status

(Continued)

- **Subissue 3 - The Rate at Which Radionuclides in Spent Nuclear Fuel (SNF) Are Released from the Engineered Barrier System (EBS) Through the Oxidation and Dissolution of Spent Fuel**
  - All acceptance criteria are open

Current Status

(Continued)

- **Subissue 4 - The Rate at Which Radionuclides in High-Level Radioactive Waste (HLW) Glass are Leached and Released from the EBS**
  - All technical acceptance criteria open
  - Issue Resolution Status Report notes that effect of colloids on release and transport, for SNF and for HLW glass, is considered closed
  - DOE's recent work indicates that colloids may affect transport of some radionuclides

Current Status
(Continued)

- Subissue 5 - The Effect of In-Package Criticality on Waste Package (WP) and EBS Performance
  - All technical acceptance criteria open
- Subissue 6 - The Effects of Alternate EBS Design Features on Container Lifetime and Radionuclide Release from EBS
  - All technical acceptance criteria open
  - Backfill no longer part of the repository design

Key Activities

- Fiscal Year (FY) 1998
  - Completed waste package materials selection for the Viability Assessment (VA) design. The corrosion-resistant material was changed from Alloy 625 to more corrosion-resistant Alloy 22
  - Developed new waste package barrier degradation models for input to Total System Performance Assessment (TSPA)- VA
  - Developed Disposal Criticality Analysis Methodology Topical Report
  - Continued waste package and waste form material testing

Key Activities
(continued)

- FY 1999
  - Continued testing of waste package and waste form materials
  - Revised materials selection for the waste package culminating in Enhanced Design Alternative (EDA) II design. EDA II uses Alloy 22 as the outer barrier with stainless steel structural support and Titanium grade 7 for the drip shield
  - Submitted Disposal Criticality Analysis Methodology Topical Report to NRC

Key Activities
(continued)

- **FY 2000**
  - Updated waste package and waste form degradation models for TSPA - Site Recommendation (SR)
  - Completed documentation of the models in Analysis and Model Reports (AMRs) and Process Model Reports (PMRs) for waste package and waste form
  - Responded to NRC request for additional information on the Disposal Criticality Analysis Methodology Topical Report

Key Activities
(continued)

- **FY 2001**
  - Plan to complete revisions of the AMRs and PMRs, as needed
  - Plan to submit revised Disposal Criticality Analysis Methodology Topical Report to NRC
  - Plan to continue waste package and waste form materials testing, as needed
  - Plan to update waste package design, as needed

Key Technical Issue: Container Life and Source Term

KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1. Effects of Corrosion Processes on Lifetime of the Containers	Waste package degradation and performance Drip shield degradation and performance	Waste package and drip shield degradation and performance are Principal Factors.
2. Effects of Phase Stability of Materials and Initial Defects on the Mechanical Failure and Lifetime of the Containers	Waste package degradation and performance Drip shield degradation and performance	
3. The Rate at Which Radionuclides in SNF are Released from the EBS Through the Oxidation and Dissolution of Spent Fuel	Dissolved radionuclide concentrations Colloid-associated radionuclide concentrations	Dissolved radionuclide concentrations and colloid-associated radionuclide concentrations are Principal Factors
4. The Rate at Which Radionuclides in HLW Glass are Leached and Released from the EBS	Dissolved radionuclide concentrations Colloid-associated radionuclide concentrations	
5. The Effect of In-Package Criticality on WP and EBS Performance	None	The FEPs associated with this subissue are not included in the process model. Data and analyses supporting this exclusion will be provided.
6. The Effects of Alternate EBS Design Features on Container Lifetime and Radionuclide Release from EBS	Waste package degradation and performance Drip shield degradation and performance	Waste package and drip shield degradation and performance are Principal Factors.

Subissue 1, Corrosion Process

- **Corrosion Modes**
  - Variety of corrosion modes have been considered. Corrosion modes evaluated include general corrosion, localized corrosion, microbiologically influenced corrosion, stress corrosion cracking, and hydrogen-induced cracking
  - A range of environments has been evaluated, and bounding environments based on the evaporative concentration of J-13 water have been selected
  - Uncertainties are accounted for in the corrosion models
  - Materials selection process for waste package and drip shield include evaluation of material compatibility, expected exposure conditions, and ease of fabrication
  - Extensive corrosion testing program has been established, and the process model development includes the use of published data outside of the Project

Subissue 2, Effects of Phase Stability and Initial Defects

- **Phase Stability Effects**
  - Materials testing to evaluate phase stability effects is ongoing, and test program has been expanded to include welded and cold worked materials
  - Current data indicates that phase stability will not be an issue from the corrosion standpoint for the waste package outer barrier

Subissue 2, Effects of Phase Stability and Initial Defects
(Continued)

- **Mechanical Failure Processes**
  - Current waste package and drip shield degradation modeling include stress corrosion cracking and hydrogen-induced cracking. Stress corrosion cracking model incorporates fabrication-related flaws
  - Structural analysis of the waste package shows that the failures (through-wall penetrations) due to rockfall are precluded
  - Nondestructive examination (NDE) protocol is under development to evaluate detection of fabrication defects

Subissue 2, Effects of Phase Stability and Initial Defects

(Continued)

- **Early Failures**
  - Analysis of mechanism for early waste package failures was documented in an AMR
  - Weld flaws associated with the closure weld were determined to be the most likely condition that could lead to early failures
  - Surface-breaking weld flaw sizes and distributions were determined based on limited NDE
  - Flaw size and distributions are used as input to the stress corrosion cracking model
  - Approach to early failures is different from that of NRC

Subissues 3 and 4

- Subissue 3: The Rate at Which Radionuclides in SNF are Released from the EBS Through the Oxidation and Dissolution of Spent Fuel
- Subissue 4: The Rate at Which Radionuclides in HLW Glass are Leached and Released from the EBS
- These are related to the Principal Factor: Radionuclide Concentrations at the Source

Subissues 3 and 4

(Continued)

- **Consider all categories of SNF/HLW**
  - DOE has tested a range of wastes and considered all categories of wastes in the uncertainty assessments documented in the AMRs
- **Justify isotope selection**
  - DOE reevaluated and documented isotope selection in an AMR (Inventory Abstraction)
- **Identify range of in-waste package environment**
  - DOE has performed reaction path calculations for a wide range of reaction rates and flows for both commercial SNF and several co-disposal waste packages

Subissues 3 and 4

(Continued)

- **Identified and considered all likely processes for SNF and HLW degradation and radionuclide release from EBS**
  - SNF matrix dissolution
  - Prompt release
  - Dry oxidation
  - Degradation and failure of fuel cladding
  - Preferential release from defense SNF
  - Glass dissolution
  - Secondary phases & colloids
  - Microbial action
  - Radionuclide release from waste package

Subissue 5, Effect of In-Package Criticality

- **DOE is addressing criticality using Disposal Criticality Analysis Methodology Topical Report and its supporting documents**
- **Expect to show criticality risk is not a significant contributor to TSPA**

Subissue 6, Alternate EBS Design Features

- **Effects of Drip Shield**
  - Current models conservatively assume that the environment on the surface of the waste package is same as that on the drip shield
  - The degradation model for the waste package accounts for potential crevice development under the drip shield
  - No condensation of water on the underside of the drip shield is expected based on the temperature distribution within the drift
- **Drip Shield Performance**
  - General and localized corrosion and hydrogen-induced cracking of the drip shield are addressed in two separate AMRs

Subissue 6, Alternate EBS Design Features

(Continued)

- **Effects of Design changes**
  - Current waste package design is relatively thinner than the VA design, so the surface radiation levels are expected to be higher
  - Potential for radiolysis-enhanced corrosion of the outer barrier has been evaluated using hydrogen peroxide additions to the test media. The threshold for localized corrosion was not exceeded
  - Backfill has been removed from the repository design. This reduces temperature of spent nuclear fuel cladding

Summary

- DOE is in general agreement with the subissues
- DOE is conducting materials testing and modeling program to address the Container Life and Source Term subissues, and this effort will continue through the Performance Confirmation period
- Differences exist between NRC and DOE in the area of waste package early failure levels. These differences need to be resolved in future meetings on Container Life and Source Term

Backup

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
Subissue 1: Corrosion Process		
1 - DOE has identified and considered likely modes of corrosion for container materials, including dry-air oxidation, humid-air corrosion, and aqueous corrosion processes, such as general corrosion, localized corrosion, MIC, SCC, and hydrogen embrittlement, as well as the effect of galvanic coupling.	The following components of this subissue are considered closed at the staff level: 1. dry oxidation of carbon steel 2. aqueous corrosion of carbon steel 3. microbial influenced corrosion (MIC) of carbon steel 4. stress corrosion cracking of carbon steel 5. galvanic coupling Issues still to be addressed for Alloy-22	All likely modes of corrosion have been considered and modeled in the WP PMR. The constituent models of this PMR include process models for dry-air oxidation, humid-air corrosion, stress corrosion cracking, hydrogen induced cracking, and aqueous corrosion processes, such as general corrosion, localized corrosion, and microbial influenced corrosion. Galvanic coupling effects have been minimized.
2 - DOE has identified the broad range of environmental conditions within the WP emplacement drifts that may promote the corrosion processes listed previously, taking into account the possibility of irregular wet and dry cycles that may enhance the rate of container degradation.	Open	The corrosion models in the WP PMR include environmental thresholds that can be used to switch between dominant modes of corrosion.
3 - DOE has demonstrated that the numerical corrosion models used are adequate representations, taking into consideration associated uncertainties, of the expected long-term behaviors and are not likely to underestimate the actual degradation of the containers as a result of corrosion in the repository environment.	Open	Uncertainties are accounted for in corrosion rates reported in the WP PMR.

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
4 - DOE has considered the compatibility of container materials, the range of material conditions, and the variability in container fabrication processes, including welding, in assessing the performance expected in the container's intended waste isolation function.	Open	The effects of welding and thermal aging on the corrosion resistance of the waste package materials have been accounted for in the WP PMR.
5 - DOE has justified the use of data collected in corrosion tests not specifically designed or performed for the YM repository program for the environmental conditions expected to prevail at the YM site.	Open	Models in the WP PMR are based on bounding environmental conditions (temperature, humidity, chemistry, etc.) expected in the proposed repository. In addition to the data generated from long-term and short-term corrosion tests, the process model development also includes data generated outside the Yucca Mountain. These data in general include testing in environments not directly applicable to Yucca Mountain and therefore are used as corroborative information.

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
6 - DOE has conducted a consistent, sufficient, and suitable corrosion testing program at the time of the LA submittal. In addition, DOE has identified specific plans for further testing to reduce any significant area(s) of uncertainty as part of the performance confirmation program.	Open	The DOE has established a corrosion test program that addresses all anticipated modes of corrosive attack of the waste package. In addition, the Project will continue testing of materials both in the laboratory and in the field. This part of the testing program is covered in the Performance Confirmation Plan.
7 - DOE has established a defensible program of corrosion monitoring and testing of the engineered subsystem components during the performance confirmation period to assure they are functioning as intended and anticipated.	Open	This acceptance criterion will be addressed as part of the Performance Confirmation Program currently under development.
Subissue 2: Material failure		
1 - DOE has identified and considered the relevant mechanical failure processes that may affect the performance of the proposed container materials.	Open	All relevant mechanical degradation modes, including HIC and SCC as two possible mechanical failure modes have been considered in the WP PMR.
2 - DOE has identified and considered the effect of material stability on mechanical failure processes for the various container materials as a result of prolonged exposure to the expected range of temperatures and stresses, including the effects of chemical composition, microstructure, thermal treatments, and fabrication processes.	Open	The WP PMR presents data showing that Alloy 22 has adequate phase stability to serve as a waste package material, provided that the temperature is not allowed to exceed 260°C. Expected range of temperature and stresses, chemical composition, microstructure, thermal treatments,

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
		and fabrication processes are all related to the material stability and have been considered in modeling in the PMR.
3 - DOE has demonstrated that the numerical models used for container materials stability and mechanical failures are effective representations, taking into consideration associated uncertainties, of the expected materials behavior and are not likely to underestimate the actual rate of failure in the repository environment.	Open	Uncertainties, assumptions, and limitations of the specific models are addressed in WP PMR and the related AMRs. The analysis also takes into account quantifiable uncertainties and variability of the degradation model for the possible ranges of corrosion parameters and exposure conditions.
4 - DOE has considered the compatibility of container materials and the variability in container manufacturing processes, including welding, in its WP failure analyses and in the evaluation of radionuclide release.	Open	The design now accounts for material compatibility. Variabilities in processes used for weld stress mitigation are also accounted for in the SCC models for both laser peening and induction annealing techniques.
5 - DOE has identified the most appropriate methods for nondestructive examination of fabricated containers to detect and evaluate fabrication defects in general and, particularly, in seam and closure welds.	Open	An NDE protocol is under development and will be used for DS and waste package inspection. Such inspection will limit the size of manufacturing defects as a means of helping prevent SCC and HIC. Materials used in waste package construction will be tested electrochemically, to assure that materials used are not unexpectedly susceptible to localized corrosion.

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
6 - DOE has justified the use of material test results not specifically designed or performed for the YM repository program for environmental conditions (i.e., temperature, stress, and time) expected to prevail at the proposed YM repository.	Open	Various AMRs supporting the WP PMR, such as the AMR on degradation of stainless steel, provide discussion for the use of material test results from published data not specifically designed or performed for the Yucca Mountain repository program for environmental conditions expected to prevail at the proposed Yucca Mountain repository.
7 - DOE has conducted a consistent, sufficient, and suitable material testing program at the time of the LA submittal. In addition, DOE has identified specific plans for further testing to reduce any significant area(s) of uncertainty as part of the performance confirmation program.	Open	This acceptance criterion will be addressed as part of the Performance Confirmation Program currently under development.
8 - DOE has established a defensible program of monitoring and mechanical testing of the engineered subsystems components, during the performance confirmation period, to assure they are functioning as intended and anticipated, in the presence of thermal and stress perturbations.	Open	This acceptance criterion will be addressed as part of the Performance Confirmation Program currently under development.
Subissue 3: Radionuclide Release from Spent Fuel		
1 - DOE has considered all categories of SNF planned for disposal at the proposed YM repository.	Open	Many types of SNF to be emplaced have been considered and are discussed in Section 3.3 and 3.5 of the Waste Form (WF) Degradation PMR.

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
2 - DOE has adequately justified the selection of radionuclides tracked in the release models from SNF and their related release parameters.	Open	With the issuance of draft regulations 10 CFR 63 and 40 CFR 197 (64 FR 46976), the selection of radioisotopes was reevaluated and is discussed in Section 3.1 of WF PMR.
3 - DOE has identified the range of environmental conditions to be expected inside breached WPs.	Open	The range of environmental conditions expected inside the WPs are addressed in the WF PMR.
4 - DOE has identified and considered likely processes for SNF degradation and the release of radionuclides from the EBS, as follows: dissolution of the irradiated UO_2 matrix, with the consequent formation of secondary minerals and colloids; prompt release of radionuclides; degradation in the dry air environment; degradation and failure of fuel cladding; preferential dissolution of intermetallics in DOE SNF; and release of radionuclides from the WP emplacement drifts.	Open	Several sections of the WF PMR, address dissolution of the irradiated UO_2 matrix; modeling of the degradation and failure of fuel cladding including topics of prompt release of radioisotopes and degradation of UO_2 and cladding in the dry air environment (this topic was also a FEP); dissolution of DOE SNF; and formation of colloids. The part of this criterion that deals with release of radioisotopes from the WP emplacement drifts is addressed in the EBS PMR.
5 - DOE has demonstrated that the numerical models used for SNF degradation and radionuclide release from the EBS are adequate representations, including consideration of uncertainties, of the expected SNF performance and are not likely to overestimate the actual performance in the repository environment.	Open	The models in the WF PMR were designed to avoid over estimation of performance. In general, the models are regression analyses of experimental data at repository conditions, bounding representations

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
		of experimental data, or assume very aggressive degradation to bound uncertainty. Bounding representations of numerical simulations explicitly include a function to represent uncertainty, define an uncertain distribution, or use bounding values for radioisotope solubility.
6 - DOE has considered the compatibility of SNF and the internal components of the WP, such as the basket materials, in the evaluation of radionuclide releases. Specifically, the SNF should not compromise the performance of the WP.	Open	Compatibility of internal components, the SNF, and the waste package has been considered in selection of materials for the waste package and internals.
7 - DOE has justified the use of SNF test results not specifically collected for the YM site for the environmental conditions expected to prevail after breaching of the containers at the YM site.	Open	In several cases, the WF degradation PMR uses test results of the degradation of SNF not specifically collected for the Yucca Mountain site to corroborate the YMP data (e.g., CSNF Matrix Degradation Component). In the case of the CSNF Cladding Degradation Component, the extensive data collected over the past 30 years on cladding failure mechanisms are used. This use, however, is evaluated under specific QA procedures that address qualification of unqualified data and appropriateness of data for its intended use.

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
8 - DOE has conducted a consistent, sufficient, and suitable SNF corrosion and radionuclide release testing program at the time of the LA submittal. In addition, DOE has identified specific plans for further testing to reduce any significant area(s) of uncertainty as part of the performance confirmation program.	Open	As explained in Sections 3.3 and 3.5, of the WF PMR, the foundation of the commercial SNF and DOE SNF degradation rates for the TSPA-SR is the testing program conducted. A Performance Confirmation Plan has been developed that establishes the test and analysis requirements to confirm, with reasonable assurance, that the performance objective for the period after permanent repository closure is met.
9 - DOE has established an adequate program of monitoring radionuclide release from the WP during the performance confirmation period, to assure that assumptions and calculations of SNF dissolution and radionuclide release from the WP are appropriately substantiated.	Open	A Performance Confirmation Plan has been developed that establishes the test and analysis requirements to confirm, with reasonable assurance, that the performance objective for the period after permanent repository closure is met.
Subissue 4: Degradation of High Level Waste Glass		
1 - DOE has taken into account all types of HLW glass planned for YM disposal.	Open	Consideration of the several types of HLW to be placed into the potential Yucca Mountain is discussed in Section 3.6 of the WF PMR.
2 - DOE has adequately justified the selection of radionuclides tracked in the release models from HLW glass and their related	Open	After issuance of draft regulations 10 CFR 63 and 40 CFR 197

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
release parameters.		(64 FR 46976), the selection of radionuclides was reevaluated. Section 3.1 of WF PMR and associated AMR provide justification for the radionuclides and parameters to be tracked in release models
3 - DOE has identified the range of environmental conditions to be expected inside breached WPs containing HLW glass and eventually certain types of SNF as in the co-disposal WPs.	Open	The Waste Form Degradation Model discusses and captures the range of environmental conditions expected inside the waste packages.
4 - DOE has identified and considered likely processes for the degradation of HLW glass and the release of radionuclides from the EBS, i.e., dissolution of the primary phase; formation of secondary minerals and colloids; microbial action; and radionuclide releases and transport from the WP emplacement drifts.	Open. However, the IRSR notes effect of colloids on release and transport, for SNF and for high-level radioactive waste (HLW) glass is considered closed at the staff level.	WF PMR addresses dissolution of the HLW glass and uses of experimental data on the formation of colloids from HLW. Microbial action is the topic of a FEP that applies both to SNF and HLW degradation. Release and transport of radionuclides from the emplacement drifts is discussed in the EBS PMR.
5 - DOE has demonstrated that the numerical models used for determining the rate of dissolution of HLW glass and the rate of radionuclide release from the EBS are adequate representations, taking into consideration the associated uncertainties, of the expected HLW glass performance, and are not likely to underestimate the actual rate of degradation of the HLW glass and the subsequent rate of release in the repository environment.	Open	The degradation model in WF PMR is a bounding representation of experimental results at different pH values. Furthermore, representations of numerical simulations explicitly include a function to represent uncertainty of the pH. The HLW model was designed to avoid under-

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
		estimation of rate of degradation and release. In the discussion of this criterion in Section 5.4.5 of the IRSR, NRC expressed a concern that, "DOE has not considered field data on naturally occurring glasses, combined with experimental data and models on dissolution of HLW glasses, to demonstrate that long-term dissolution behavior under repository conditions can be represented by extrapolation of results from short-term laboratory tests." The DOE has considered data on naturally occurring glasses and successfully compared the paragenetic sequence observed to that found for HLW glass. DOE has used a bounding value for a variety of experimental data on dissolution of HLW glass to bolster confidence in the prediction of long-term behavior. Therefore, DOE has not been overly optimistic in its use of short-term data for modeling of long-term HLW glass dissolution.
6 - DOE has assessed the compatibility of HLW glass with internal components of the WP in the evaluation of radionuclide release,	Open	The compatibility of internal components, the HLW, and the WP

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
taking into consideration co-disposal with DOE-owned SNF in the same WP. Specifically, HLW glass should not compromise the performance of the WP.		components has been considered in and corrosion of the internal selection of materials for the waste package and its internal parts.
7 - DOE has justified the use of test results for HLW glass not specifically collected for the YM site for environmental conditions expected to prevail after breaching of the containers at the YM site.	Open	In several cases, the WF Degradation PMR uses test results of the degradation of HLW not specifically collected for the Yucca Mountain site to expand the range of applicability and corroborate the YMP data. This use is evaluated under specific QA procedures that address qualification of unqualified data and appropriateness of data for its intended use.
8 - DOE has conducted a consistent, sufficient, and suitable HLW glass and radionuclide release corrosion testing program at the time of the LA submittal. In addition, DOE has identified specific plans for further testing to reduce any significant area(s) of uncertainty as part of the performance confirmation program.	Open	The foundation of the HLW degradation rates for the TSPA related to the site recommendation is the testing program conducted. A Performance Confirmation Plan has been developed that establishes the test and analysis requirements to confirm, with reasonable assurance, that the performance objective for the period after permanent repository closure is met.
9 - DOE has established an adequate program of monitoring radionuclide release from the WP during the performance	Open	A Performance Confirmation Plan has been developed that establishes the

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
confirmation period to assure that assumptions and calculations regarding HLW glass dissolution and radionuclide release are appropriately substantiated.		test and analysis requirements to confirm, with reasonable assurance, that the performance objective for the period after permanent repository closure is met.
Subissue 5: Effects of In-package Criticality on Waste Package		
1 - DOE has used sound technical bases for selecting the design criteria for components to mitigate any potential effects of in-package criticality on the repository performance. These design criteria may include development of subcritical limit, probability and consequence of criticality, and any other design criteria considered being necessary by DOE.	Open	Note: In-package criticality and related acceptance criteria are addressed in DOE's *Disposal Criticality Analysis Methodology Topical Report* and its supporting references.
2 - DOE has identified all the features, events, and processes that may increase the reactivity of the system inside the WP. The acceptance criteria provided for the Scenario Analysis subissue in the Total System Performance Assessment and Integration (TSPAI) IRSR must also be considered.	Open	
3 - DOE has identified the configuration classes and configurations that have potential for nuclear criticality. If models are used to develop the configurations, approach and accuracy in modeling verification and validation will be evaluated.	Open	
4 - DOE has developed a technically defensible, transparent, and traceable method in assigning probability values to each of the scenario classes, scenarios, configuration classes, and configurations.	Open	

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
5 - DOE has developed appropriate computer models, input parameters, and determined quantitative values for calculating the effective neutron multiplication factor (k_{eff}), including appropriate biases and uncertainties in the model.	Open	
6 - DOE has developed appropriate computer models, evaluated input parameters, and determined quantitative values for calculating the radionuclide inventory, heat, kinetic energy, and other parameters that would change as a result of k_{eff} exceeding the subcritical limit developed under Criterion (1).	Open	
7 - DOE has determined the risk contribution from the in-package criticality to the total repository system performance appropriately.	Open	
Subissue 6: Alternate EBS Design Features		
1 - DOE has identified and considered the effects of backfill, and the timing of its emplacement, on the thermal loading of the repository, WP lifetime (including container corrosion and mechanical failure), and the release of radionuclides from the EBS.	Open	The current design does not include backfill. The effects of the backfill are not considered in determining the environment on the surface of drip shield and waste package.
2 - DOE has identified and considered the effects of ceramic coating on WP lifetime, including negative consequences as a result of breakdown of the ceramic coating (cracking, spalling, or delamination) in response to the action of environment, manufacturing defects, mechanical impacts and stresses arising from a multiplicity of sources, and the potential for enhanced localized corrosion of the containers that might occur at cracks or perforations in the ceramic coating layers.	Open	This criterion is no longer applicable, as the current design for the repository does not include ceramic coatings.

Key Technical Issue: Container Life and Source Term

Acceptance Criteria	CLST IRSR Rev. 2 Status	DOE Comment
3 - DOE has evaluated the compatibility of ceramic coating materials with outer overpack materials and the combined effect of ceramic coating with backfill on container lifetime.	Open	See comment on Criterion 2.
4 - DOE has identified and considered the effects of drip shields (with backfill) on WP lifetime, including extension of the humid-air corrosion regime, environmental effects, breakdown of drip shields and resulting mechanical impacts on WP, the potential for crevice corrosion at the junction between the WP and the drip shield, and the potential for condensate formation and dripping on the underside of the shield.	Open	The effects of the drip shield have been considered and evaluated in the analysis of waste package performance. This aspect is discussed in Section 3.2.3 of Waste Package PMR. The analysis conservatively assumes that the environment on the surface of the waste package is not affected by the presence of the drip shield. Degradation model for the waste package takes into account potential for crevice corrosion and degradation due to mechanical failure and assumes exposure to drift environment with no protection by drip shield against water dripping. The effects of the backfill with respect to changes in water chemistry are also not assumed since the current design does not include backfill.
5 - DOE has evaluated the effect of design changes in container wall thickness that may increase (-radiolysis of the water contacting WPs and, therefore, enhance the possible occurrence of localized corrosion processes.	Open	Experiments have been performed with Alloy 22 to accurately mimic the effects of gamma radiolysis. It is known that gamma radiolysis of aqueous electrolytes produces hydrogen peroxide, and that

Key Technical Issue: Container Life and Source Term		
Acceptance Criteria	**CLST IRSR Rev. 2 Status**	**DOE Comment**
		hydrogen peroxide increases the open circuit corrosion potential of stainless steels. There has been concern that such effects could push the corrosion potential close to the threshold potential for the initiation of LC. Laboratory experiments have shown that the maximum increase in corrosion potential due to hydrogen peroxide in concentrated repository ground waters is approximately 200 mV, and insufficient to exceed the threshold for initiation of localized corrosion.
6 - DOE has identified the chemical composition of the water in the environment surrounding the WPs and its evolution with time.	Open	This has been done through both evaporative concentration and thermodynamic calculation.
7 - DOE has justified the use of test results for drip shields, ceramic coatings, and backfill materials not specifically collected for the YM site for the environmental conditions expected to prevail at the proposed YM repository.	Open	At the present time, the ceramic coating is not part of the drip shield or waste package design.
8 - DOE has conducted a consistent, sufficient, and suitable corrosion testing program at the time of the LA submittal. In addition, DOE has identified specific plans for further testing to reduce any significant area(s) of uncertainty as part of the performance confirmation program.	Open	This acceptance criterion will be addressed as part of the Performance Confirmation Program currently under development.

KEY TECHNICAL ISSUE
EVOLUTION OF THE NEAR FIELD ENVIRONMENT (ENFE)

ENFE TEAM

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NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION STATUS
APRIL 25-26, 2000

Status of ENFE Subissues

Subissue 1: **OPEN**	Effects of Coupled Thermal-Hydrologic-Chemical (THC) Processes on Drift Seepage and Flow in the Unsaturated Zone (UZ)
Subissue 2: **OPEN**	Effects of Coupled THC Processes on the Waste Package Chemical Environment
Subissue 3: **OPEN**	Effects of Coupled THC Processes on Chemical Environment for Radionuclide Release
Subissue 4: **OPEN**	Effects of Coupled THC Processes on Radionuclide Transport Through Engineered and Natural Barriers
Subissue 5: **Closed Pending Confirmation**	Effects of Coupled THC Processes on Potential Nuclear Criticality in the Near-Field

Subissue 1: Effects of Coupled THC Processes on Drift Seepage and Flow in the UZ
OPEN

DOE Repository Safety Strategy

Principal Factors: Seepage into Drifts

Other Factors: Coupled Processes - Effects on UZ Flow
Coupled Processes - Effects on Seepage
Advective Paths in the UZ

NRC Abstractions:
- Quantity and chemistry of water contacting waste packages and waste forms
- Spatial and temporal distribution of flow
- Flow paths in the unsaturated zone

- Need for additional analysis
  - Analyses of Features, Events, and Processes (FEPs) in each abstraction
    - Provide technical bases for excluded FEPs (20% still require additional basis)
    - Link included FEPs to abstractions and their technical bases
  - Analyses of THC effects on drift seepage
    - Complete analyses which demonstrate that neglect of THC processes will not likely underestimate dose or provide models for changes in hydrological properties near drift
    - If latter approach is used, incorporate resulting effects on drift seepage

Subissue 1: OPEN — Effects of Coupled THC Processes on Drift Seepage and Flow in the UZ (continued)

- Need for additional analysis (continued)
  - Analyses of THC effects on unsaturated zone flow fields
    - Complete analyses which demonstrate that neglect of THC processes will not likely underestimate dose or provide models for changes in hydrological properties in zeolitic zones
    - Complete analyses which demonstrate that neglect of THC processes will not likely underestimate dose or provide models for changes in fracture/matrix interaction below repository
    - If models for changes in hydrological properties and fracture/matrix interaction are developed, incorporate resulting effects on unsaturated zone flow

- Need for additional data and analysis
  - Coupled THC model results are inconsistent with laboratory measurements of coupled THC effects on flow
    - Document column THC test results, in particular changes in permeability
    - Incorporate laboratory results [e.g., Lin and Daily (1990)] into modeling analysis
  - Coupled THC model results are inconsistent with field observations
    - Chemistry of Drift Scale Heater Test (DST) fluids ($pH < 4.0$) different from predictions ($pH > 7$)
    - Provide justification why predicted ranges in pH are not likely to underestimate repository performance or incorporate the range of field observations results into THC modeling analysis
  - To be verified assumptions are used as a technical basis for exclusion of FEPs in Unsaturated Zone Flow and Transport Process Model Report
  - Technical basis needs to be provided for why temperatures predicted for zeolite bearing units will not cause alteration in UZ flow (changes in hydrologic properties)

Subissue 2: OPEN — Effects of Coupled THC Processes on the Waste Package Chemical Environment

DOE Repository Safety Strategy

Principal Factors: Performance of the drip shield
Performance of the waste package barriers

Other Factors: Environments on the drip shield
Environments on the waste package

NRC Abstractions:
- Quantity and chemistry of water contacting waste packages and waste forms
- Degradation of engineered barriers

- Need for Additional Analysis
  - Analyses of Features, Events, and Processes (FEPs) in each abstraction
    - Provide technical bases for excluded FEPs (10% still require additional basis)
    - Link included FEPs to abstractions and their technical bases
    - Explain how Analysis Model Report models are intended to address specific FEPs
  - Likelihood of microbially influenced corrosion
    - Provide data and justification for inclusion or exclusion taking into consideration uncertainties in the definition of in-drift environmental conditions

Subissue 2: Effects of Coupled THC Processes on the OPEN Waste Package Chemical Environment (cont)

- Need for additional data and analysis
  - Determine and assess effects of gamma radiolysis on drip shield and waste package
  - Consider temporal and spatial variations in determination of maximum estimated concentration of anions, temperature, and redox conditions
  - Coupled THC model results for waste package chemical environment are inconsistent with field observations
    - Chemistry of DST fluids (pH < 4.0) different from predictions (pH >7)
    - Provide justification why predicted ranges in fluid chemistry are not likely to underestimate repository performance or incorporate the range of field observations results into THC modeling analysis
  - Provide justification that DOE's major assumptions are not likely to underestimate repository performance
    - Neglect of kinetics in THC modeling
    - THC processes can be decoupled, evaluated separately, then re-linked
  - Evaluation of coupled THC interactions between the DOE's in-drift geochemical abstractions
  - DOE's design changes require additional data, modeling, and FEP analysis

Subissue 3: Effects of Coupled THC Processes on Chemical Environment for Radionuclide Release
OPEN

DOE Repository Safety Strategy

Principal Factors: Solubility limits of dissolved radionuclides

Other Factors:
Environments within waste package
CSNF waste form performance
DSNF, Navy fuel, and Pu disposition waste form performance
DHLW waste form performance
Colloid associated radionuclide concentrations

NRC Abstractions:
- Quantity and chemistry of water contacting waste packages and waste forms
- Radionuclide release rates and solubility limits

- Need for Additional Analysis
  - Analyses of Features, Events, and Processes (FEPs) in each abstraction
    - Provide technical bases for excluded FEPs (15% still require additional basis)
    - Link included FEPs to abstractions and their technical bases (interaction with corrosion products is relevant to multiple abstractions, yet no technical basis provided for several abstractions)
    - Engineered Barrier System FEPs and Degradation Modes Analysis Analysis Model Report is a good example

Subissue 3: Effects of Coupled THC Processes on Chemical Environment for Radionuclide Release (cont)
OPEN

- Need for additional data and analysis
  - Determine and assess effects of gamma radiolysis on in-package chemistry
  - Apply chemical environment to analysis of waste form degradation
  - Provide basis for maximum estimated concentration of Np, U, and Pu determination given the uncertainty of in-package chemistry (addressed in Waste Form Process Model Report, but not all FEPs considered in determination of solubility)
  - Coupled THC model results for in-package chemical environment are inconsistent with field observations
    - Chemistry of DST fluids (pH < 4.0) different from predictions (pH >7)
    - Provide justification why predicted ranges in fluid chemistry are not likely to underestimate repository performance or incorporate the range of field observations results into THC modeling analysis
  - Provide justification that DOE's major assumptions are not likely to underestimate repository performance
    - Neglect of kinetics in THC modeling
    - THC processes can be decoupled, evaluated separately, then re-linked
  - Evaluation of coupled THC interactions between the DOE's in-drift geochemical abstractions

Subissue 4: OPEN — Effects of Coupled THC Processes on Radionuclide Transport

DOE Repository Safety Strategy

Principal Factors: Retardation of radionuclide migration in the UZ

Other Factors: In-package radionuclide transport
Transport through the drift invert
Coupled processes -effects on UZ transport

NRC Abstractions:
- Radionuclide release rates and solubility limits
- Radionuclide transport in the UZ

- Need for Additional Analysis
  - Analyses of Features, Events, and Processes (FEPs) in each abstraction
    - Provide technical bases for excluded FEPs (15% still require additional basis)
    - Link included FEPs to abstractions and their technical bases
  - Provide transparent link between waste package and unsaturated zone parameters
    - Demonstrate approach is consistent between engineered barrier abstractions and natural systems
  - Demonstrate that neglect of zeolite alteration is not likely to underestimate repository performance

Subissue 4: OPEN — Effects of Coupled THC Processes on Radionuclide Transport (continued)

- Need for additional data and analysis
  - Because DOE is taking credit for retardation during in-package transport and transport through the invert
    - Demonstrate transport parameters are not likely to underestimate repository performance
    - Complete abstraction and analysis of FEPs consistent with design
    - Abstracted models should be supported by lab, field and analog data
  - Coupled THC model results for radionuclide transport through natural barriers are inconsistent with laboratory and field observations
    - Provide justification why predicted ranges in fluid chemistry and mineralogy are not likely to underestimate repository performance or incorporate the range of field (e.g., DST and Busted Butte) and laboratory observations (e.g, THC column tests) into the assessment of THC effects on transport modeling
  - Determine effects of coupled THC processes on colloidal transport
  - Technical basis needs to be provided for why temperatures predicted for zeolite bearing units will not reduce radionuclide retardation
  - Provide justification that DOE's major assumptions are not likely to underestimate repository performance
    - Neglect of kinetics in THC modeling
    - THC processes can be decoupled, evaluated separately, then re-linked

Subissue 5: Effects of Coupled THC Processes on Potential Nuclear Criticality in the Near-Field

Closed Pending Confirmation

- Need for additional analysis
  - Provide technical basis for exclusion of the FEPs associated with criticality in the near-field environment

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

Evolution of the Near-Field Environment

Presented to:
NRC/DOE Technical Exchange
on Yucca Mountain Pre-Licensing Issues

Presented by:
Debbie Barr
Yucca Mountain Site Characterization Office
U. S. Department of Energy

April 25, 2000

YUCCA MOUNTAIN PROJECT

Current Status

(Issue Resolution Status Report Revision 2)

- Subissue 1 - Effects of Coupled Thermal-Hydrological-Chemical (THC) Processes on Seepage and Flow
  - Unresolved
- Subissue 2 - Effects of Coupled THC Processes on the Waste Package Chemical Environment
  - Unresolved
- Subissue 3 - Effects of Coupled THC Processes on the Chemical Environment for Radionuclide Release
  - Unresolved

Current Status
(Continued)

- Subissue 4 - Effects of Coupled THC Processes on Radionuclide Transport through Engineered and Natural Barriers
  - Unresolved
- Subissue 5: Coupled THC Processes Affecting Potential Nuclear Criticality in the Near Field
  - Resolved, Pending Confirmation

Key Activities

- Fiscal Year (FY) 1998
  - Established Near-Field/Altered Zone Coupled Effects Expert Elicitation to help quantify the large uncertainties associated with coupled processes
  - Performed preliminary thermal-hydrological-mechanical modeling
    - Based on this modeling, thermal-hydrological-mechanical alteration of the flow field was considered negligible
- FY 1999
  - Held Thermal Hydrology and Coupled Processes Workshop in March 1999

Key Activities
(Continued)

- **FY 2000**
  - **Completed Analysis and Model Reports (AMRs) and other documents supporting the Near-Field Environment Process Model Report (PMR)**
    - **AMR *Thermal Tests Thermal-Hydrological***
    - **AMR *Features, Events and Processes in Thermal Hydrology and Coupled Processes***
    - **AMR *Drift-Scale Coupled Processes (Drift Scale Test and THC Seepage) Models***
    - **AMR *Abstraction of Drift-Scale Coupled Process Model***
  - **Issued thermal-hydrological-mechanical (THM) calculation to discuss the mechanical responses to the thermal pulse and the effects of the consequent fracture opening on the hydrologic properties of the rock mass**

Key Activities
(Continued)

- FY 2001
  - Plan to issue PMR Revision 1 to address fully coupled thermal-hydrological-mechanical-chemical (THMC) coupling
  - Plan to continue current thermal testing
  - Plan to initiate cross drift thermal test to better understand THMC processes in the lower lithophysal unit

KTI Subissues and Associated Factors of the Safety Case

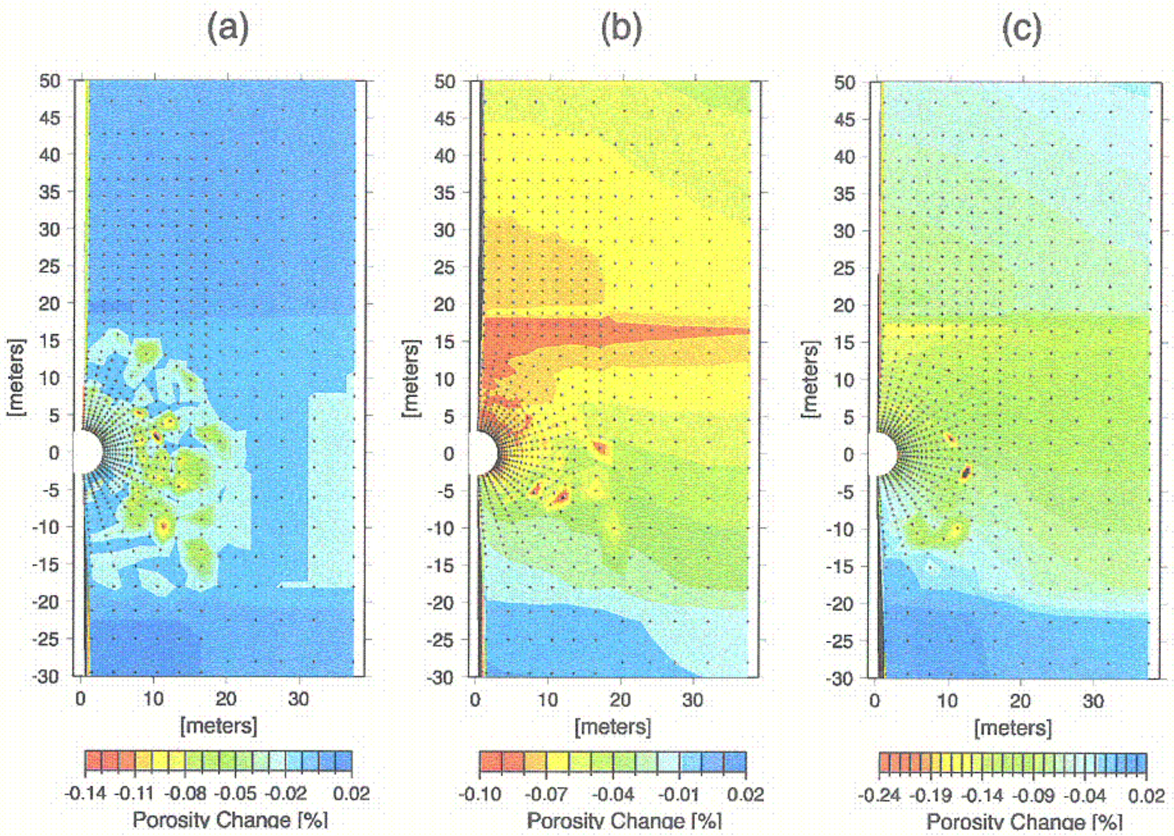
KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1 Effects on Seepage and Flow 2 Effects on Waste Package Chemical Environment 3 Effects on Chemical Environment for Radionuclide Release 4 Effects on Radionuclide Transport 5 Coupled THC Processes Affecting Potential Nuclear Criticality in the Near-field	Environment on Drip Shield Environment of Waste Package	Analyses are currently being conducted to evaluate the importance of these factors to repository performance. Completed analyses will be provided for the Site Recommendation Consideration Report.

Subissue 1: Effects of Coupled THC Processes on Seepage and Flow

- A drift-scale coupled processes model is being developed to evaluate the effects of coupled THC processes on seepage and flow
- Simulation results indicate that, for current range of ambient hydrologic properties, THC-driven alteration to those properties will have a negligible permanent effect on seepage during and after thermal pulse

Subissue 1: Effects of Coupled THC Processes on Seepage and Flow

(Continued)



Contour plot of Calculated Total Fracture Porosity Change at 10,000 Years for Three Climate Change Scenarios (Calcite-Silica-Gypsum System): (a) Lower Bound, (b) Mean, and (c) Upper Bound. Red areas indicate the maximum decrease in porosity as a result of mineral precipitation

Subissue 1: Effects of Coupled THC Processes on Seepage and Flow
(Continued)

- Seepage composition results from the THC model are abstracted and explicitly included in the Total System Performance Assessment-Site Recommendation (TSPA-SR)
- Expert elicitation recommendations not used because recommendations were already bounded by the near-field seepage abstraction

Subissue 2: Effects of Coupled THC Processes on the Waste Package Chemical Environment

- An in-drift physical and chemical environment model was developed for the TSPA-SR to explicitly account for the effects of coupled THC processes on the waste package chemical environment
- The model accounts for processes that govern salt precipitation and dissolution and resulting water composition on drip shields and waste packages
- The model has been validated using the results of laboratory evaporation experiments

Subissue 2: Effects of Coupled THC Processes on the Waste Package Chemical Environment

(Continued)

- Results of simulations show that evaporation causes dissolved solids to concentrate and precipitate. It also causes solution ionic strength and pH to increase. As evaporation rates decrease, ionic strength, pH, and salt concentrations decrease towards incoming values
- Simulations are abstracted into TSPA-SR and are coupled to temperature and relative humidity conditions across the repository

Subissue 3: Effects of Coupled THC Processes on the Chemical Environment for Radionuclide Release

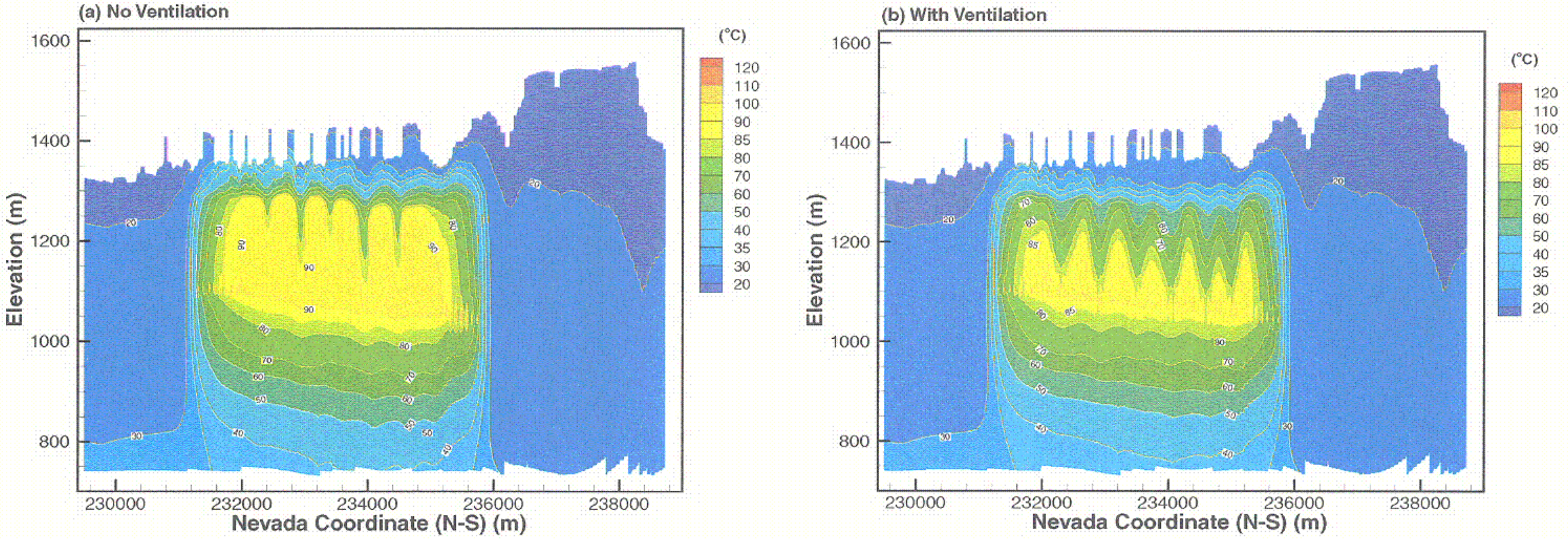
- An in-package chemistry model was developed for the TSPA-SR to explicitly account for the effects of coupled THC processes on radionuclide release
- The model provides time-varying pH and ionic strength of in-package seepage for radionuclide solubilities and colloid concentrations, respectively

Subissue 4: Effects of Coupled THC Processes on Radionuclide Transport through Engineered and Natural Barriers

- The in-drift physical and chemical environment model is used in the TSPA-SR to explicitly account for the effects of coupled THC processes on transport through the invert underneath the waste package
- Mountain-scale thermal-hydrologic modeling indicates that the Calico Hills Nonwelded Unit (CHn) will remain below zeolite alteration temperatures

Subissue 4: Effects of Coupled THC Processes on Radionuclide Transport through Engineered and Natural Barriers

(Continued)



Temperature distribution along NS#2 Cross-Section Grid at 1,000 Years (a) No Ventilation, (b) with Ventilation

C7

Subissue 4: Effects of Coupled THC Processes on Radionuclide Transport through Engineered and Natural Barriers

(Continued)

- The effects of THC processes on changes in the geochemical environment for radionuclide transport are still uncertain
  - The model provides time-varying pH and ionic strength for determining radionuclide solubilities and colloid concentrations, respectively, in the invert
  - Reduction of cementitious materials in current design of the emplacement drifts greatly reduces potential for alkaline plumes from emplacement drifts

Subissue 5: Coupled THC Processes Affecting Potential Nuclear Criticality in the Near Field

- Criticality is addressed in DOE's Disposal Criticality Analysis Methodology Topical Report and its supporting documents
- NRC has no further questions concerning potential nuclear criticality in the near field, and this issue is resolved at the staff level, pending confirmation of the bases

Summary

- **Areas of Agreement**
  - DOE agrees in large part with the subissues
  - Agree Subissue 5 is resolved, pending confirmation
  - Agree with the need to incorporate models of THC effects
  - A formal features, events and processes analysis has been performed

Summary

(Continued)

- **Areas of Disagreement (Brocoum letter to Reamer, 3/00)**
  - A number of requirements remove the flexibility contained in the proposed regulations
  - Acceptance criteria are phrased in terms that imply a detailed analysis of THC phenomena is needed, regardless of the effects of these phenomena on performance
  - ~~Data collection and model development will continue to improve models and enhance modeling performance~~

Issue Resolution Status Report: Evolution of the Near-Field Environment		
Acceptance Criteria	**ENFE IRSR Rev 2 Status**	**DOE Comment**
Subissue 1 - Coupled THC Effects on Seepage Flow		
Data and Model Justification Acceptance Criteria		
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on seepage and flow were considered.	Open pending review of DOE's use of available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on seepage and flow in their abstractions.	The NFE Drift-Scale Coupled Processes AMR describes how available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects was considered. In addition, Section 3.10 of the Unsaturated Zone Flow and Transport (UZ F&T) PMR documents the abstraction of coupled THC effects for TSPA, based on the process modeling results presented in the same section. In-drift processes are also addressed in the EBS PMR.
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of coupled processes that may affect seepage and flow.	Open pending review of DOE's use of results from their thermal testing program to establish initial and boundary conditions for their conceptual models in their abstractions.	The Drift-Scale Coupled Processes AMR describes how available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects were considered. In addition, the UZ F&T PMR summarizes data on the site characteristics that were used to establish initial and boundary conditions for the evaluation of THC effects on seepage and flow in the near field.
3 - Sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect seepage and flow.	Open pending review of DOE's use of data on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes.	The Water Distribution and Removal Model, the Physical and Chemical Environment (P&CE) Model, and the Multiscale TH Model provide predictions of seepage and flow that are based upon the selection of a consistent set of thermal properties, and hydrologic properties for the active fracture model. The active fracture model and the drift scale properties sets for these models are consistent with properties sets used in the UZ model which were determined by inverse modeling methods. The UZ F&T PMR summarizes available data. The THC model incorporates site data to establish initial and boundary conditions and incorporates specific aspects of the design, including in-drift geometry, drift spacing, and the TH properties of the components of the EBS, such as waste packages and invert.
4 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional new data are needed to better define ranges of input parameters.	Open pending review of DOE's abstraction of the effects of coupled THC on seepage and flow.	Sensitivity and uncertainty analyses will be included in TSPA-SR. The DOE is developing a plan that will define the performance confirmation program.

Issue Resolution Status Report: Evolution of the Near-Field Environment		
Acceptance Criteria	**ENFE IRSR Rev 2 Status**	**DOE Comment**
5 - If the testing program for coupled THC processes on seepage and flow is not complete at the time of license application, or if sensitivity and uncertainty analyses indicate additional data are needed, DOE has identified specific plans to acquire the necessary information as part of the performance confirmation program.	Open pending review of DOE's identification of specific plans to acquire the necessary information as part of the performance confirmation program.	The DOE is developing a plan that will define the performance confirmation program.
Data Uncertainty and Verification Acceptance Criteria		
(1) Reasonable or conservative ranges of parameters or functional relations were used to determine effects of coupled THC processes on seepage and flow. Parameter values, assumed ranges, probability distributions, and bounding assumptions are technically defensible and reasonably account for uncertainties.	Open pending review of DOE's usage of reasonable or conservative ranges of parameters to determine effects of coupled THC processes on seepage and flow in their abstracted models.	The UZ F&T PMR discusses ranges in the characteristics of the natural system that were used to evaluate the effects of THC processes on seepage and flow and the rationale for these ranges. The UZFT PMR discusses the uncertainty in data affecting THC coupled processes on seepage and flow. The parameter values used in the NFE PMR were the values either provided by the UZ F&T AMRs or used in their evaluations.
(2) Uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on seepage and flow were considered.	Open pending review of DOE's implementation of contributions to uncertainty in their abstracted models of the effects of coupled THC processes on seepage and flow.	The UZFT PMR discusses the uncertainty in data affecting THC coupled processes on seepage and flow.
(3) DOE's evaluation of coupled THC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect seepage and flow.	Open pending review of DOE's consider uncertainties in the characteristics of the natural and engineered materials in their abstraction of the effects of coupled THC processes on seepage and flow.	The UZ F&T PMR discusses the uncertainty in data affecting THC coupled processes on seepage and flow.
(4) The initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on seepage and flow were consistent with available data.	Open pending review of DOE's use of initial conditions, boundary conditions, and computational domains in their sensitivity analyses involving coupled THC effects on seepage and flow.	Sensitivity analyses will be addressed in TSPA-SR.
(5) DOE's performance confirmation program should assess whether the natural system and engineered materials are functioning as intended and anticipated with regard to coupled THC effects on seepage and flow.	Open pending review of how DOE addresses this objective in their performance confirmation plan.	The DOE is developing a plan that will define the performance confirmation program.

Issue Resolution Status Report: Evolution of the Near-Field Environment

Acceptance Criteria	ENFE IRSR Rev 2 Status	DOE Comment
Model Uncertainty Acceptance Criteria		
(1) Appropriate models, tests, and analyses were used that are sensitive to the THC couplings under consideration for both natural and engineering systems, as described in the following examples. The natural-setting data indicate processes that should be evaluated include: (i) zeolitization of volcanic glass, which could affect flow pathways; (ii) precipitation of calcite and opal on the footwall of fracture surfaces and the bottoms of lithophysal cavities, which indicates gravity-driven flow in open fractures that could affect permeability and porosity; and (iii) potential dehydration of zeolites and vitrophyre glass, which could release water affecting heat and fluid flow. The effects of THC coupled processes that may occur due to interactions with engineered materials or their alteration products include: (i) changes in water chemistry that may result from interactions between cementitious materials and groundwater, which, in turn, may affect seepage and flow; (ii) dissolution of the geologic barrier (e.g.	Open pending review of DOE's use of appropriate models, tests, and analyses that are sensitive to the THC couplings under consideration for both natural and engineering systems.	The THC couplings under consideration for the engineered systems are covered in the EBS PMR , the Waste Package (WP) Degradation PMR, and the Waste Form (WF) Degradation PMR. THC couplings for the natural system are covered in both the UZ F&T PMR and the NFE PMR. However, much of this issue has been mitigated by design changes, which no longer incorporate use of concrete liners and invert materials. Thus, the major potential source of hyperalkaline fluids no longer exists.
(2) Given the current design of the repository, it will be acceptable to ignore the potential effects of microbial processes on seepage and flow.	The DOE approach is acceptable and we have no current concerns regarding the potential effects of microbial processes on seepage and flow.	The DOE agrees that the potential effects of microbial processes on seepage and flow are not significant, given the current design.
(3) Alternative modeling approaches consistent with available data and current scientific understanding were investigated, and their results and limitations were appropriately considered.	Open pending review of DOE's examination and resolution of mineral precipitation issues using multiphase coupled models, which can handle the effects of boiling.	Model approaches and alternative model approaches for THC impacts on flow and transport are discussed in the UZ F&T PMR. This acceptance criterion is also addressed in the EBS PMR. The UZ F&T PMR also addresses the alternative conceptual model.
(4) DOE provided a reasonable description of the mathematical models included in its analyses of coupled THC effects on seepage and flow. The description should include a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.	Open pending review of DOE's discussion of the limitations and uncertainties of their process-level model including alternative modeling approaches not considered in its final analysis.	The UZ F&T PMR summarizes the mathematical models used; an alternative conceptual model is discussed that document.

Issue Resolution Status Report: Evolution of the Near-Field Environment		
Acceptance Criteria	**ENFE IRSR Rev 2 Status**	**DOE Comment**
Model Verification Acceptance Criteria		
(1) The mathematical models for coupled THC effects on seepage and flow are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.	Open pending review of DOE's use of the results, from both their laboratory and field heater test program, to test their abstracted models for consistency with observations.	The UZ F&T PMR summarizes the mathematical models used to evaluate coupled THC effects on seepage and flow. Rev. 0 of this PMR addresses the effects of THC on property sets. However, backcoupling with EBS PMR to consider expected engineered materials impacts on NFE properties was not included. Therefore, the effects of flow out of the drifts were not addressed in Rev. 0 of the NFE PMR.
(2) DOE appropriately adopted accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THC effects on seepage and flow.	Open pending review of DOE's application of accepted testing procedures in the development of TOUGH-REACT and other numerical codes that will be used to generate models providing the basis for abstraction of the effects of coupled THC processes on seepage and flow.	The NFE PMR describes the abstraction of the models used to evaluate the potential effects of coupled THC processes on NFE properties, which were considered in the unsaturated zone flow and transport PMR. The Abstraction of Drift-Scale Coupled Processes AMR provides detailed descriptions of the inputs and assumptions used in the model abstraction. Abstractions in Section 3.10 of the UZ F&T PMR were derived from the underlying process models described in the UZ F&T PMR. This acceptance criterion is also addressed by the EBS PMR. Procedures were followed, consistent with the governing quality assurance requirements (see the UZ F&T PMR).
(3) Abstracted models for coupled THC effects on seepage and flow were based on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems. Abstracted model results were verified through comparison to outputs of detailed process models and empirical observations. Abstracted model results are compared with different mathematical models to judge robustness of results.	Open pending review of DOE's use of the results, from both their laboratory and field heater test program, to test their abstracted models for consistency with observations	The NFE PMR describes the abstraction of the models used to evaluate the potential effects of coupled THC processes on NFE properties, which were considered in the unsaturated zone flow and transport PMR. The Abstraction of Drift-Scale Coupled Processes AMR provides detailed descriptions of the inputs and assumptions used in the model abstraction. It also provides a comparison of thermal hydrologic variables obtained from a drift-scale THC model that implemented two different geochemical systems. A comparison across process-level models (TH-only and THC) is also described in the AMR. In addition, a 2-D, drift-scale, TH-only model is compared to the TH results of the 2-D drift-scale THC model described in the Drift-Scale Coupled Processes AMR (CRWMS M&O 2000b). Finally, the drift-scale THC model TH results were compared to the multiscale TH model in order to determine the extent of edge effects.
Integration Acceptance Criteria		
(1) DOE has considered all the relevant features, events, and processes. The abstracted models adequately incorporated important design features, physical	Open pending review of DOE's inclusion of a formal screening process for features, events, and processes	The NFE PMR describes the treatment and documentation of primary features, events, and processes affecting thermal hydrology and coupled process phenomena that impact the NFE. Section 3.3 describes the abstraction of the

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phenomena, and couplings, and used consistent and appropriate assumptions throughout.	(FEP).	models used to evaluate the potential effects of coupled THC processes on unsaturated zone flow and transport. The UZ F&T PMR contains a discussion of FEPs impacting seepage and flow. UZ F&T PMR Section 1.2.3 discusses the relevant features, processes and events. Included FEPS are directly represented in the process models and abstractions that support TSPA and discussed in other sections of the PMR corresponding to the specific models.
(2) Models reasonably accounted for known temporal and spatial variations in conditions affecting coupled THC effects on seepage and flow.	Open pending review of DOE inclusion of important design features, physical phenomena, and couplings that cause temporal and spatial variations in conditions.	The UZ F&T PMR and Integrated Site Model (ISM) PMR discuss the spatial variations in properties and conditions that occur within the natural system that have impact on the near field. Temporal and spatial variations in thermal output are assessed in the EBS PMR.
(3) Not all THC couplings may be determined to be important to performance, and DOE may adopt assumptions to simplify PA analyses. If potentially important couplings are neglected, DOE should provide a technical basis for doing so. The technical basis can include activities such as independent modeling, laboratory or field data, or sensitivity studies.	Open pending DOE provision of a technical basis for omitting listed processes or inclusion of these effects in the performance analyses via abstracted models or bounding assumptions.	Section 2 of the NFE PMR describes the process of analysis used to determine which couplings need to be considered in performance assessment and which were excluded, and the technical justification for that determination. Section 3 describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption.
(4) Where simplifications for modeling coupled THC effects on seepage and flow were used for PA analyses instead of detailed process models, the bases used for modeling assumptions and approximations were documented and justified.	Open pending review of DOE documentation of the bases for simplifications used in modeling coupled THC effects on seepage and flow.	Section 3 of the NFE PMR describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption. In addition, the Abstraction of Drift-Scale Coupled Processes AMR provides explanations, documentation and justification for simplifications used in the abstractions described in that AMR. Modeling of seepage and flow, as well as abstractions of those models, is discussed in the UZ F&T PMR. The UZ F&T PMR documents the basis for the abstraction of coupled THC effects on seepage and flow.

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Programmatic Acceptance Criteria		
(1) Data and models were collected, developed, and documented under acceptable quality assurance (QA) procedures.	Open pending review of DOE's qualification of the data and models that could be used.	Activities associated with development of this PMR and its related AMRs were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
(2) Deficiency reports concerning data quality on issues related to coupled THC effects on seepage and flow were closed.	Open pending closure of three QA deficiency reports concerning issues related to coupled THC effects on seepage and flow.	The NFE PMR has been prepared according to AP-3.10Q and AP-3.15Q to address quality assurance deficiency issues.
(3) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Kotra, et al., 1996) or other acceptable approaches.	Open pending review of DOE's demonstration of its understanding of the expected use of elicited expert judgements, prior to convening expert panels.	Expert elicitations were determined to be subject to the quality assurance program as described in the QARD document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563.
Subissue 2 - WP Chemical Environment		
Data and Model Justification Acceptance Criteria		
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on WP chemical environment were considered	Open pending review of DOE's use of available data, relevant to both temporal and spatial variations, in conditions affecting coupled THC effects on the WP chemical environment.	The WP and EBS PMRs determine the chemistry of fluids that result from THC couplings between the drift and waste package materials. In particular, the precipitates/salts process model provides predictions of the chemical environment on the drip shield/waste package. This model accounts for variations in gas composition, relative humidity, and evaporation rates and has been validated using available laboratory evaporation data. They also provide the water chemistry information for analysis of its effect on flow and transport. The Physical and Chemical Environment (P&CE) Model is based upon a two-dimensional thermal hydrologic analysis that accounts for temporal waste heat loading and variations in percolation rates.
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of coupled processes that may affect the WP chemical environment.	Open pending review of DOE's use of results from their thermal testing program to establish initial and boundary conditions for their conceptual models in their abstractions.	The UZ THC and Multiscale TH models incorporate site data to establish initial and boundary conditions for determining WP environment. The WP environment is predicted using drift seepage boundary conditions provided by the UZ THC process model, the UZ Abstraction model and NFE THC Abstraction model. These boundary conditions in combination with the in-drift TH condition provided by the Multiscale TH model are used by the Precipitates/Salts model to predict WP environment.

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3 - Sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect the WP chemical environment.	Open pending review of DOE's collection and use of data on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes.	The EBS PMR and the WP PMR report the efforts to evaluate waste package chemical environment. The UZ F&T PMR provides the descriptions of models used in establishing seepage water chemistry and reports seepage water chemistry that is used as input to the EBS/Waste Package models. The NFE PMR provides an assessment of the changes in mineralogy and deposition of salts etc. that would effect seepage water chemistry.
4 - A nutrient and energy inventory calculation (e.g., McKinley, West, and Grogan, 1985; Grogan and McKinley, 1990; Noy, et al., 1996) should be used to determine the potential for microbial activity that could impact the WP chemical environment.	We have no further concerns regarding the nutrient and energy inventory calculations approach used by DOE to determine the potential for microbial activity that could impact the WP chemical environment.	The EBS PMR discusses the EBS P&CE model environments which consider the effects on the growth of microbial communities. The microbial communities model considers steel alloys, and organic substances on the microbial growth rate. Further the model is implemented with the MING V 1.0 code that combines the nutrient and thermodynamic approaches. The model assumes that all energy from microorganisms is derived from oxidation reduction (redox) reactions.
5 - Should microbial activity be sufficient to allow microbial influenced corrosion (MIC) of the WP, then the time-history of temperature, humidity, and dripping should be used to constrain the probability for MIC (CRWMS M&O, 1997b).	Open pending completion and documentation of NRC's analysis of MIC in the next revision of the Container Life and Source Term IRSR.	The EBS P&CE Environment Model provides an analysis of the effects of temperature, humidity, and dripping on the growth of microbial communities. The Microbial Communities Model considers the relative humidity, which depends on the temperature and dripping environment. The model considers how humidity, dripping, high temperatures, and dryout constrain microbial growth during the thermal period.
6 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional new data are needed to better define ranges of input parameters.	Open pending review of DOE's use of sensitivity and uncertainty analyses of their abstracted model to determine whether additional new data are needed to support the abstracted model.	In general, where assumptions have been used and documented in individual AMRs (Table 1-1), in the absence of data, sensitivity and uncertainty analyses have been performed to assess their impact and the need to collect additional data. Where parameters for stated assumptions are uncertain, and performance is sensitive to the parameter, laboratory scale testing has been identified to provide confirmation of stated assumptions, e.g., EBS PMR Section 3.1.2.
7 - If the testing program for coupled THC processes on WP Chemical Environment is not complete at the time of license application, or if sensitivity and uncertainty analyses indicate additional data are needed, DOE has identified specific plans to acquire the necessary information as part of the performance confirmation program.	Open pending review of additional data for a repository system that contains large quantities of cementitious materials. These data would address the potential for enhanced pitting at alkaline pH.	The DOE is developing a plan that will define the performance confirmation program.

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Data Uncertainty and Verification Acceptance Criteria		
(1) Reasonable or conservative ranges of parameters or functional relations were used to determine effects of coupled THC processes on the WP chemical environment. Parameter values, assumed ranges, probability distributions, and bounding assumptions are technically defensible and reasonably account for uncertainties.	Open pending review of DOE use of reasonable or conservative ranges of parameters to determine effects of coupled THC processes on WP chemical environment in their abstracted models.	In the preparation of the respective AMRs (Table 1-1 for the EBS PMR) assumptions are documented through the AP 3.10Q procedure. The basis for each assumption is stated and the need for confirmation is identified.
(2) Uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on WP chemical environment were considered.	Open pending review of DOE consideration of uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on the WP chemical environment.	The EBS PMR Section 3.2.1 documents model uncertainties as they relate to the performance of the natural barrier system (NBS) and EBS. While data have been developed in the NBS, model uncertainties associated with the EBS are also stated. EBS process models provide the basis for selecting robust designs for EBS performance and waste isolation in the face of model uncertainty.
(3) DOE's evaluation of coupled THC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect the WP chemical environment.	Open pending review of DOE consideration of uncertainties in the characteristics of the natural and engineered materials in their abstraction of the effects of coupled THC processes on the WP chemical environment.	The EBS PMR discusses bounding calculations that have been performed to estimate physical effects such as flow through the drip shields and chemical effects such as the alteration of groundwater chemistry.
(4) The initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on WP chemical environment were consistent with available data.	Open pending review of DOE's use of initial conditions, boundary conditions, and computational domains in their sensitivity analyses involving coupled THC effects on WP chemical environment that are consistent with available data.	The EBS TH submodels are based on initial conditions, and computational domains consistent with site characteristics. The thermal hydrology models used in the EBS PMR are based on the selection of NBS hydrologic and thermal properties used in the UZ Process Model. The initial conditions and boundary conditions for the models for specific locations use the same infiltration rates, and temperature and boundary conditions consistent with the UZ Process Model.
(5) DOE's performance confirmation program should assess whether the natural system and engineered materials are functioning as intended and anticipated with regard to coupled THC effects on WP chemical environment.	Open pending DOE's inclusion of this objective in their performance confirmation plan.	The DOE is developing a plan that will define the performance confirmation program.

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Model Uncertainty Acceptance Criteria		
(1) Appropriate models, tests, and analyses were used that are sensitive to the THC couplings under consideration for both natural and engineering systems as described in the following examples. The effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products include: (i) TH effects on gas and water chemistry; (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect water chemistry and WP environmental conditions; (iii) dehydration of hydrous phases liberating moisture that may affect the WP environment; (iv) effects of microbial process on the WP environment; and (v) changes in water chemistry that may result from the release of corrosion products from the WP and interactions between cementitious materials and groundwater, which, in turn, may affect the WP chemical environment.	Open pending DOE's use of appropriate models, tests, and analyses that are sensitive to the THC couplings under consideration for both natural and engineering systems.	The EBS P&CE model analyzes these effects. The Gas Flux and Fugacity submodel analyzes TH effects for CO2 and O2 gas fugacity (Section 3.1.2.5). These results are then used in the Chemical Summary submodel (Section 3.1.2.7) to estimate changes in groundwater chemistry during various stages of the thermal cycle. The Chemical Summary submodel inputs information from the TH 2D submodel, and evaluates water composition in the surround rock such as in the drift above the repository. The Chemical Summary Submodel uses the composition for Time Period 2, and calculates an assemblage of evaporative minerals using the normative approach. The microbial growth submodel evaluates the potential for microbial growth, and concludes that no microbial growth will occur for temperatures greater than 120 degrees C. The cementitious materials submodel evaluates interactions between the cementitious grout, and groundwater.
(2) Alternative modeling approaches consistent with available data and current scientific understanding were investigated, and their results and limitations were appropriately considered.	Open pending review of DOE's provision of adequate models.	The EBS P&CE Model considers alternative modeling approaches. The P&CE model is consistent with the available data regarding introduced materials, CO2 fugacity, TH effects, and groundwater chemistry. Alternative models for cementitious materials, steel corrosion, and gas phase mass fluxes of O2 and CO2 were investigated as summarized in Section 3.1.2. The alternative approach for modeling the EBS physical and chemical environment involves fully coupled reactive transport simulations. These were investigated, but found to be restricted to a chemical species and precipitates with limited flexibility to handle ionic strength limitations.

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(3) DOE provided a reasonable description of the mathematical models included in its analyses of coupled THC effects on WP chemical environment. The description should include a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.	Open pending review of how DOE clearly distinguishes between the different approaches used.	For the WP environment, the DOE provides a reasonable description of the mathematical models. The thermal hydrological model based upon NUFT is described in the EBS PMR. Certain specialized models were developed as part of the EBS PMR. For example, these include the conservative solute analysis in Section 3.1.2.1. The system of differential equations is described. Further, in Section 3.1.2.2, steady state methods for CO2 transport in the UZ and through the EBS were described. Modeling limitations and uncertainties as they relate to the PC&E environment are described throughout Section 3.1.2. Note that the EBS PMR is a summary document. As part of the AP-3.10Q process for documentation, each of the respective AMRs presented in Table 1-1 is documented in detail. As described above, and discussed in the EBS PMR, alternative models are presented for fully coupled THC modeling.
Model Verification Acceptance Criteria		
(1) The mathematical models for WP chemical environment are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.	Open pending review of how DOE uses the results from both their laboratory and field heater test program to test their abstracted models for consistency with observations.	The P&CE Model thermal hydrology submodel provides a prediction of seepage and flow that are based upon the same conceptual active fracture model. The active fracture model for the NBS is consistent with the active fracture model for the UZ.
(2) DOE appropriately adopted accepted and well-documented procedures to construct and test the numerical models used to simulate the WP chemical environment.	Open pending review of DOE' s effort to verify their abstracted model of the effects of coupled THC effects on the waste package chemical environment, using well-documented procedures to construct and test the numerical models.	Each AMR was prepared according to AP-3.10Q with discussion of quality assurance, computer software, model inputs, and model assumptions. For analyses involving the use of software routines, the routines were verified by separate hand calculations. In other cases, the more complex models are compared with experimental test data. For example, two evaporation tests using synthetic J-13 water were simulated using the Salts model. The comparison of the model predictions for measured pH and ionic strength compare with measured data.

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(3) Abstracted models for coupled THC effects on WP chemical environment were based on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems. Abstracted model results were verified through comparison to outputs of detailed process models and empirical observations. Abstracted model results are compared with different mathematical models to judge robustness of results.	Open pending review of DOE's exercises using experimental, site, and natural analog data to aid verification of their models. And, that models used produce results reasonably representative of the systems modeled.	The EBS and WP PMRs report the waste package chemical environment and report on the associated abstractions. The EBS and WP PMRs provide the descriptions of assumptions, approximations, simplifications and abstractions used in those assessments. The UZ F&T PMR reports similar information for models used to determine seepage water chemistry. The NFE PMR provides the description of assumptions and approximations used in models to assess the changes in mineralogy and deposition of salts etc. that would effect the seepage water chemistry.
Integration Acceptance Criteria		
(1) DOE has considered all the relevant features, events, and processes. The abstracted models adequately incorporated important design features, physical phenomena, and couplings, and used consistent and appropriate assumptions throughout.	Open pending review of DOE's approach to confirm it includes a formal screening process for FEPs and evaluates important design features, physical phenomena, and couplings, in a performance assessment framework.	The determination of features, events and processes important to an assessment of the waste package chemical environment is described in the EBS and WP PMRs.
(2) Models reasonably accounted for known temporal and spatial variations in conditions affecting coupled THC effects on WP chemical environment.	Open pending review of DOE's inclusion of important design features, physical phenomena, and couplings that cause temporal and spatial variations in conditions, such as in the thermal reflux.	The P&CE Model is based upon a two dimensional thermal hydrologic analysis that accounts for temporal waste heat loading and variations in percolation rates.
(3) Not all THC couplings may be determined to be important to performance, and DOE may adopt assumptions to simplify performance assessment analyses. If potentially important couplings are neglected, DOE should provide a technical basis for doing so. The technical basis can include activities such as independent modeling,	Open pending review of DOE's FEP analysis and integration between the major abstraction efforts.	Section 2 of the NFE PMR describes the process of analysis used to determine which couplings need to be considered in performance assessment and which were excluded, and the technical justification for that determination. Section 3 describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions

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laboratory or field data, or sensitivity studies.		that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption.
(4) Where simplifications for modeling coupled THC effects on WP chemical environment were used for performance assessment analyses instead of detailed process models, the bases used for modeling assumptions and approximations were documented and justified.	Open pending review of DOE's continued documentation of the bases for simplifications used in modeling coupled THC effects on the waste package chemical environment.	Section 3 of the NFE PMR describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption. In addition, the Abstraction of Drift-Scale Coupled Processes AMR provides explanations, documentation and justification for simplifications used in the abstractions described in that AMR. Modeling of seepage and flow, as well as abstractions of those models, is discussed in the UZ F&T PMR. The UZ F&T PMR documents the basis for the abstraction of coupled THC effects on seepage and flow.
Programmatic Acceptance Criteria		
(1) Data and models were collected, developed, and documented under acceptable QA procedures.	Open pending review of DOE's qualification of the data and models that could be used.	Activities associated with development of PMRs and AMRs were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
(2) Deficiency reports concerning data quality on issues related to coupled THC effects on WP chemical environment were closed.	Open pending closure of three QA deficiency reports concerning issues related to coupled THC effects on seepage and flow.	PMRs have been prepared according to AP-3.10Q and AP-3.15Q to address quality assurance deficiency issues.
(3) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Kotra, et al., 1996) or other acceptable approaches.	Open pending review of DOE's demonstration of its understanding of the expected use of elicited expert judgements, prior to convening expert panels.	Expert elicitations were determined to be subject to the quality assurance program as described in the QARD document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563.

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Subissue 3 - Effects of THC Processes on the Chemical Environment for Radionuclide Release		
Data and Model Justification Acceptance Criteria		
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release were considered.	Open pending review of DOE's use of available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on WP chemical environment in their abstractions.	The Waste Form Degradation PMR summarizes the technical bases of models. This includes consideration of the coupled effects on the chemical environment. A conservative range of bounding chemistries has been considered as discussed in Section 3.2 and the supporting AMRs In-Package Chemistry Abstraction for TSPA-LA and Summary of In-Package Chemistry for Waste. Where adequate THC coupled data and models are not available, conservative representations are used, such as using the minimum pH for CSNF dissolution and the maximum pH for DHLW dissolution, each of which is the more conservative bound.
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of coupled processes that may affect the chemical environment for radionuclide release.	Open pending review of DOE's use of results from their thermal testing program to establish initial and boundary conditions for their conceptual models in their abstractions.	The Waste Form Degradation PMR summarizes the technical bases of models, which includes the evaluation of coupled processes. As more specifically explained in Section 3.2, the In-Package Chemistry Component justified use of several initial conditions (e.g., use of J-13 water chemistry in a FEP argument) in modeling in-package chemistry. However, the Waste Form Degradation PMR is not the sole source for initial and boundary conditions. Initial and boundary conditions for hydrologic effects and temperature effects are found in the EBS PMR.
3 - Sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect the chemical environment for radionuclide release.	Open pending review of studies of environmental conditions affecting the stability of oxidized engineered and waste form materials, such as secondary uranyl phases.	An important purpose of the Waste Form Degradation PMR is to summarize the technical bases of models. As explained throughout the Waste Form Degradation PMR, sufficient data were collected by the project or were available in the literature to develop defensible bounding models of the chemical environment. The PMR and its supporting AMRs summarize the basis of EBS chemistry, although ongoing EBS testing may allow further refinement of these bounded representations.
4 - A nutrient and energy inventory calculation (e.g., McKinley, West, and Grogan, 1985; Grogan and McKinley, 1990; Noy, et al., 1996) should be used to determine the potential for microbial activity that could impact radionuclide release.	NRC has no further concerns regarding the nutrient and energy inventory calculations approach used by DOE to determine the potential for microbial activity that could impact the chemical environment for radionuclide release.	A nutrient and energy balance was estimated for the repository. However, based on arguments for FEPs related to microbial activity, the influence of microbial activity on radionuclide release was screened out and, thus, not considered further as a process within the repository.

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5 - Should microbial activity be sufficient to potentially affect the chemical environment for radionuclide release, then the time-history of temperature, humidity, and dripping (CRWMS M&O, 1997b) should be used to constrain the probability for microbial effects, such as production of organic by-products that act as complexing ligands for actinides (McKinley, West, and Grogan, 1985) and microbial- enhanced dissolution of the HLW glass form (Staudigel, et al., 1995)	Open pending review of DOE's justification for neglecting the potential impact of microbial processes on radionuclide release.	Based on arguments for FEPs related to microbial activity, microbial activity was screened out and, thus, not further considered as a process within the repository. The screening (WP PMR Section 2.3), as summarized in FEPs 2.1.10.01.00 and 2.1.09.18.00 and 2.1.09.13.00 is based on limited nutrient availability limiting biological activity and the offsetting beneficial effect of microbial activity increasing colloid size and increasing filtration.
6 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional new data are needed to better define ranges of input parameters.	Open pending review of studies of environmental conditions affecting the stability of oxidized engineered and waste form materials, such as secondary uranyl phases.	Sensitivity and uncertainty analyses on the simplified components of the Waste Form Degradation Model to determine whether additional data are needed are part of the general sensitivity and uncertainty analyses of the TSPA related to the site recommendation and discussed in its accompanying documentation.
7 - If the testing program for coupled THC processes on the chemical environment for radionuclide release from the engineered barrier system is not complete at the time of license application, or if sensitivity and uncertainty analyses indicate additional data are needed, DOE has identified specific plans to acquire the necessary information as part of the performance confirmation program.	Open pending review of DOE's identification of specific plans to acquire the necessary information as part of the performance confirmation program, if sensitivity studies indicate additional data are needed.	The DOE is developing a plan that will define the performance confirmation program.
Data Uncertainty and Verification Acceptance Criteria		
(1) Reasonable or conservative ranges of parameters or functional relations were used to determine effects of coupled THC processes on the chemical environment for radionuclide release. Parameter values, assumed ranges, probability distributions, and bounding assumptions are technically defensible and reasonably account for uncertainties.	Open pending review of DOE's use of reasonable or conservative ranges of parameters to determine effects of coupled THC processes on WP chemical environment in their abstracted models.	Models in the Waste Form Degradation PMR are regression analyses of experimental data at repository conditions, bounding representations of experimental data, or very aggressive assumptions of degradation to bound uncertainty. Bounding representations of numerical simulations explicitly include a function to represent uncertainty, define an uncertain distribution, or use bounding values for radioisotope solubility. The bounded, or most aggressive conditions are determined from coupled THC calculations.

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(2) Uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release were considered.	Open pending review of DOE's consideration of contributions to data uncertainty from both temporal and spatial variability, and their implementation in abstracted models.	The In-Package Chemistry Component uses the available data to couple temporal thermal effects (waste temperature), temporal hydrologic effects (seepage into the package), and temporal chemical effects (degradation rates of steel, aluminum, HLW, SNF) to evaluate the chemical environment inside the WP. Although the conceptual model of a fully saturated WP did not assume spatial variations within one package, spatial variations in temperature were considered. Spatial discretization across the repository and temporal discretization of the simulation is not the topic of the Waste Form Degradation PMR; rather, justification of the temporal and spatial discretization is discussed in the TSPA-SR analysis report (under development).
(3) DOE's evaluation of coupled THC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect the chemical environment for radionuclide release.	Open pending review of DOE's consideration of contributions to data uncertainty from both temporal and spatial variability, and implementation, in their abstracted Models, of the effects of coupled THC processes on the chemical environment for radionuclide release.	The In-Package Chemistry Component justified use of several initial conditions (e.g., use of J-13 water chemistry in a FEP argument) in modeling in-package chemistry. However, the Waste Form Degradation PMR is not the sole source for initial and boundary conditions. Initial and boundary conditions for hydrologic effects and temperature effects are found in the EBS PMR.
(4) The initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on the chemical environment for radionuclide release were consistent with available data.	Open pending review of DOE's use of initial conditions, boundary conditions, and computational domains in their sensitivity analyses involving coupled THC effects on the chemical environment for radionuclide release that are consistent with available data.	The Waste Form Degradation PMR In-Package Chemistry Component (Section 3.2) justified use of several initial conditions (e.g., use of J-13 water chemistry in a FEP argument) in modeling in-package chemistry. However, the Waste Form Degradation PMR is not the sole source for initial and boundary conditions. Initial and boundary conditions for hydrologic effects and temperature effects are found in the EBS PMR.
(5) DOE's performance confirmation program should assess whether the natural system and engineered materials are functioning as intended and anticipated with regard to coupled THC effects on the chemical environment for radionuclide release form the EBS.	Open pending review of DOE's inclusion of this objective in their performance confirmation plan.	The DOE is developing a plan that will define the performance confirmation program.
Model Uncertainty Acceptance Criteria		
(1) Appropriate models, tests, and analyses were used that are sensitive to the THC couplings under consideration for both natural and engineering systems as described in the following examples. The effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products include: (i) TH effects on gas and water chemistry; (ii) hydrothermally driven geochemical reactions, such as zeolitization of volcanic glass; (iii) dehydration of hydrous phases liberating moisture; (iv) effects of microbial	Open pending review of DOE's use of appropriate models, tests, and analyses that are sensitive to the THC couplings under consideration for both natural and engineering systems.	The Waste Package PMR In-Package Chemistry Component uses the available data to couple temporal thermal effects (waste temperature), temporal hydrologic effects (seepage into the package), and temporal chemical effects (degradation rates of steel, aluminum, HLW, SNF) to evaluate the chemical environment inside the WP. Hydrothermally driven geochemical processes and zeolitization of volcanic class (item ii) and dehydration of tuff (item iii) occur in the near-field environment. Based on arguments found in the FEPs discussion, microbial activity (item iv) was screened out (see Section 2.3). Interactions of waters exiting the WP with invert and structural material (item v) are found in the EBS PMR.

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processes; and (v) changes in water chemistry that may result from interactions between cementitious, or WP, materials and groundwater, which, in turn, may affect the chemical environment for radionuclide release.		
(2) Alternative modeling approaches consistent with available data and current scientific understanding were investigated, and their results and limitations were appropriately considered.	Open pending review of DOE's additional modeling work on the AREST-CT alternative approach.	Each of the sections describing the components of the Waste Form Degradation Model of the Waste Form Degradation PMR describes alternative modeling approaches that were considered.
(3) DOE provided a reasonable description of the mathematical models included in its analyses of coupled THC effects on the chemical environment for radionuclide release. The description should include a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.	Open pending review establishing that DOE distinguished between the different approaches that they used.	Thorough descriptions of models are included in the Waste Form Degradation PMR and related AMRs. Additionally, the quality assurance program and implementing procedures require that analyses, models, and calculations provide adequate documentation of assumptions. Analysis procedures address discussion, as applicable, of any alternate methods or models that were not used and the rationale for not selecting them.
Model Verification Acceptance Criteria		
(1) The mathematical models for coupled THC effects on the chemical environment for radionuclide release are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.	Open pending review of DOE's use of the results, from both their laboratory and field heater test program, to test their abstracted models for consistency with observations.	Model validation requirements are established in the quality assurance program. The Waste Form Degradation PMR summarizes the current technical basis of the CSNF Matrix Degradation Component , the CSNF Cladding Degradation Component, the HLW Degradation Component, and the Dissolved Radioisotope Concentration Component, which all are a function of temperature and the chemical effects evaluated in the In-Package Chemistry Component. Furthermore, the In-Package Chemistry Component is a function of the influx of water (hydrology) into the WP. The justification and confidence in the component are discussed in a section titled "Justification/ Limitations/Validation."
(2) DOE appropriately adopted accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THC effects on the chemical environment for radionuclide release.	Open pending review of DOEs use of well-documented procedures to construct and test the numerical models.	The Waste Form Degradation PMR summarizes the current technical basis of the CSNF Matrix Degradation Component , the CSNF Cladding Degradation Component, the HLW Degradation Component, and the Dissolved Radioisotope Concentration Component, which all are a function of temperature and the chemical effects evaluated in the In-Package Chemistry Component. The validation of the component is discussed in a section titled "Justification/Limitations/Validation."

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(3) Abstracted models for coupled THC effects on the chemical environment for radionuclide release were based on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems. Abstracted model results were verified through comparison to outputs of detailed process models and empirical observations. Abstracted model results are compared with different mathematical models to judge robustness of results.	Open pending review of DOE's use of experimental, site, and natural analog data to aid verification of their models, and that models used produce results reasonably representative of the systems modeled.	For most modeling components within the Waste Form Degradation PMR, a detailed process component model of the phenomena was not developed. Rather a simplified (abstraction) component was directly developed from the experimental observations and information. For the In-Package Chemistry Component , a detailed process model was developed and then the numerical results used directly through regression to develop a simple empirical relationship, as summarized in the PMR and justified in the corresponding AMRs, In-Package Chemistry Abstraction for TSPA-LA and Summary of In-Package Chemistry for Waste Forms. Other views and alternative models are discussed in each section of the PMR as appropriate.
Integration Acceptance Criteria		
(1) DOE has considered the relevant features, events, and processes. The abstracted models adequately incorporated important design features; physical phenomena and couplings; and used consistent and appropriate assumptions throughout.	Open pending review and confirmation that DOE includes a formal screening process for features, events, and processes (FEP). And, that important design features, physical phenomena, and couplings are evaluated in a performance assessment framework.	The PMRs describes the treatment and documentation of primary features, events, and processes.
(2) Models reasonably accounted for known temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release.	Open pending review confirming that DOE models account for known temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release.	The UZ F&T PMR and Integrated Site Model (ISM) PMR discuss the spatial variations in properties and conditions that occur within the natural system that have impact on the near field. Temporal and spatial variations in thermal output are assessed in the EBS PMR.
(3) Not all THC couplings may be determined to be important to performance, and DOE may adopt assumptions to simplify PA analyses. If potentially important couplings are neglected, DOE should provide a technical basis for doing so. The technical basis can include activities, such as independent modeling, laboratory or field data, or sensitivity studies.	Open pending review confirming the FEP analysis meets the acceptance criteria in the TSPAI IRSR (U.S. Nuclear Regulatory Commission, 1998c) for scenario analysis.	Section 2 of the NFE PMR describes the process of analysis used to determine which couplings need to be considered in performance assessment and which were excluded, and the technical justification for that determination. Section 3 describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption.
(4) Where simplifications for modeling coupled THC effects on the chemical environment for radionuclide release were used for PA analyses instead of detailed process models, the bases used for modeling assumptions and approximations were documented and justified.	Open pending review confirming DOE continues to document the bases for simplifications used in modeling coupled THC effects on the chemical environment for radionuclide release.	The NFE PMR describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption. In addition, the Abstraction of Drift-Scale Coupled Processes AMR provides explanations, documentation and justification for simplifications used in the abstractions described in that AMR.

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		Modeling of seepage and flow, as well as abstractions of those models, is discussed in the UZ F&T PMR . Section 3.10.11 of the UZ F&T PMR documents the basis for the abstraction of coupled THC effects on seepage and flow.
Programmatic Acceptance Criteria		
(1) Data and models were collected, developed, and documented under acceptable QA procedures.	Open pending review of DOE's qualification of the data and models that could be used.	Activities associated with development of PMRs and AMRs were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
(2) Deficiency reports concerning data quality on issues related to coupled THC effects on the chemical environment for radionuclide release were closed.	Open pending closure of three QA deficiency reports concerning issues related to coupled THC effects on seepage and flow.	PMRs have been prepared according to AP-3.10Q and AP-3.15Q to address quality assurance deficiency issues.
(3) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Kotra, et al., 1996) or other acceptable approaches.	Open pending review of DOE's demonstration of its understanding of the expected use of elicited expert judgements, prior to convening expert panels.	Expert elicitations were determined to be subject to the quality assurance program as described in the QARD document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563.
Subissue 4 - Effects of Coupled THC Processes on the Radionuclide Transport through Engineered and Natural Barriers		
Data and Model Justification Acceptance Criteria		
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on transport of radionuclides in the near field were considered.	Open pending review of DOE's use of available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on WP chemical environment in their abstractions.	Radionuclide transport issues are reported in the UZ F&T PMR. Section 3.10 of the UZ F&T PMR describes how relevant data were incorporated into the modeling. The EBS, WF, and WP PMRs provided input to unsaturated zone analyses relative to the chemistry of water and the amount and form of radionuclides released from the drifts.
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of coupled processes that may affect radionuclide transport in the near field.	Open pending review of DOE's use of results from their thermal testing program to establish initial and boundary conditions for their conceptual models in their abstractions.	The evaluation of coupled THC processes in the UZ F&T PMR considered site characteristics in establishing initial and boundary conditions for conceptual models and simulation of coupled processes. Therefore, the near-field effects were appropriate only for seepage, not subsequent flow and transport.

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3 Sufficient data were collected on the characteristics of natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect transport of radionuclides in the near field.	Open pending review of DOE consideration of uncertainties in the characteristics of the natural and engineered materials such as type, quantity and reactivity of material to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes.	Data on EBS processes are being collected at the current time for the Water Distribution and Removal Model and the Physical and Chemical Environment Model. Where appropriate, bounding calculations have been performed to not take credit for chemical retardation in the invert.
4 - A nutrient and energy inventory calculation (e.g. McKinley, West, and Grogan, 1985; Grogan and McKinley, 1990; Noy, et al., 1996) should be used to determine the potential for microbial activity that could adversely affect radionuclide transport through engineered and natural barriers.	NRC has no further concerns regarding the nutrient and energy inventory calculations approach used by DOE to determine the potential for microbial activity that could impact the chemical environment for radionuclide release.	The EBS P&CE Model provides a bounding analysis for a nutrient and energy inventory.
5 - Should microbial activity be sufficient to allow microbial effects on transport of radionuclides through engineered and natural barriers, then the time-history of temperature, humidity, and water saturation in engineered and natural materials should be used to constrain the probability for these effects.	Open pending review of DOE's justification for neglecting the potential impact of microbial processes on radionuclide release.	The EBS P&CE Model provides a bounding analysis for a nutrient and energy inventory.
6 - Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were used to determine whether additional new data are needed to better define ranges of input parameters.	Open pending review of DOE's use of sensitivity and uncertainty analyses of their abstracted model to determine whether additional new data are needed to support the abstracted model.	The EBS PMR provides a discussion of alternative conceptual models for the EBS Radionuclide Transport Model. In the EBS Radionuclide Transport model, assumptions have been used and documented. In the absence of data, sensitivity and uncertainty analyses have been performed to assess their impact and the need to collect additional data.
7 - If the testing program for the effects of coupled THC processes on radionuclide transport is not complete at the time of license application, or if sensitivity and uncertainty analyses indicate additional data are needed, DOE has identified specific plans to acquire the necessary information as part of the performance confirmation program.	Open pending review of DOE's identification of specific plans to acquire the necessary information as part of the performance confirmation program, if sensitivity studies indicate additional data are needed.	The DOE is developing a plan that will define the performance confirmation program.
Data Uncertainty and Verification Acceptance Criteria		
(1) Reasonable or conservative ranges of parameters or functional relations were used to determine effects of coupled THC processes on transport of radionuclides in the	Open pending review of DOE's use of reasonable or conservative ranges of parameters to determine effects of	The EBS Radionuclide Transport Model (EBS PMR Section 3.1.3) provides a bounding analysis (EBS PMR Section 3.1.3) based upon the thermal hydrology from the water distribution and removal (WD&R) Model (EBS PMR Sections 3.1.1 through 3.1.2). For the base case analysis, the conservative assumption to neglect chemical retardation

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near field. Parameter values, assumed ranges, probability distributions, and bounding assumptions are technically defensible and reasonably account for uncertainties.	coupled THC processes on WP chemical environment in their abstracted models.	effects is made. A sensitivity analysis is presented in Section 3.1.3 for the assumed range of parameters that is technically defensible, and that reasonably accounts for uncertainties.
(2) Uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on radionuclide transport in the near field were considered.	Open pending review of DOE's consideration of contributions to data uncertainty from both temporal and spatial variability, and their implementation in abstracted models.	The EBS radionuclide transport model (EBS PMR Section 3.1.3) provides an analysis of release based upon the thermal hydrological calculations in the WD&R model. The EBS radionuclide transport model (EBS PMR Section 3.1.3) is an advection/dispersion/diffusion model. The WD&R model considers the temporal variations in conditions affecting the TH effects, and provides a bounding calculation for chemical effects due to fracture plugging that would alter saturation levels and porewater velocities. The EBS radionuclide transport (Section 3.1.3) model provides a sensitivity analysis for the chemical retardation that bounds temporal and spatial variations in the chemical retardation factor that reflects the chemical environment. For the base case, the EBS radionuclide transport takes no credit for chemical retardation, which is a bounding assumption for radionuclide transport.
(3) DOE's evaluation of coupled THC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect transport of radionuclides in the near field.	Open pending review of DOE's consideration of contributions to data uncertainty from both temporal and spatial variability, and implementation, in their abstracted Models, of the effects of coupled THC processes on the chemical environment for radionuclide release.	The EBS Radionuclide Transport Model provides a bounding calculation. For the base case, the effects of chemical retardation are neglected, which is a conservative assumption. The effects of Ca, Si, and Mg precipitation that would result in possible reduction in porosity are discussed in the PMR, and are found to be negligible. It is unlikely that pore water velocities would be altered by a reduction in porosity.
(4) The initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on radionuclide transport in the near field were consistent with available data.	Open pending review of DOE's use of initial conditions, boundary conditions, and computational domains in their sensitivity analyses involving coupled THC effects on the chemical environment for radionuclide release that are consistent with available data.	The Water Distribution and Removal TH Model used to provide pore water velocities and saturation levels in the Radionuclide Transport model is based upon initial conditions, boundary conditions, and computational domains consistent with site characteristics. In general, the thermal hydrology models used are based upon the selection of NBS hydrologic and thermal properties used in the UZ process model. The initial conditions and boundary conditions for the models for specific locations use the same infiltration rates, and temperature and pressure boundary conditions consistent with the unsaturated zone process model.

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(5) DOE's performance confirmation program should assess whether the natural system and engineered materials are functioning as intended and anticipated with regard to coupled THC effects on transport of radionuclides in the near field.	Open pending review of DOE's inclusion of this objective in their performance confirmation plan.	The DOE is developing a plan that will define the performance confirmation program.
Model Uncertainty Acceptance Criteria		
(1) Appropriate models, tests, and analyses were used that are sensitive to the THC couplings under consideration for both natural and engineering systems as described in the following examples. The effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products include: (i) TH effects on gas and water chemistry in the unsaturated zone and saturated zone; (ii) precipitation of calcite and opal on the footwall of fracture surfaces and the bottoms of lithophysal cavities, which indicates gravity-driven flow in open fractures, and isolation of transport pathways from sorption sites in the rock matrix; (iii) zeolitization of volcanic glass, that could affect transport pathways; (iv) precipitation and dissolution of oxides and hydroxides on fracture surfaces, illitization of smectite, and recrystallization of zeolites to analcime, which could affect sorption characteristics; (v) effects of microbial processes; (vi) effects of corr	Open pending review of DOE's use of appropriate models, tests, and analyses that are sensitive to the THC couplings under consideration for both natural and engineering systems.	The UZ F&T PMR reports the issues related to zeolites and other minerals related to sorption characteristics. The NFE PMR discusses issues of precipitation and dissolution of minerals within the fracture system of the near-field.
(2) Alternative modeling approaches consistent with available data and current scientific understanding were investigated, and their results and limitations were appropriately considered.	Open pending review of DOE's more detailed simulation of colloidal transport in the saturated zone.	The EBS PMR provides a discussion of alternative conceptual models for the EBS Radionuclide Transport Model (Section 3.1.3). The EBS Radionuclide Transport Model is consistent with available data regarding the properties of the invert. An alternative view regarding the effects of storage capacity was presented. It was found that this alternative view is not likely to be important because increased EBS flow rates will cause increased dilution.

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(3) DOE provided a reasonable description of the mathematical models included in its analyses of coupled THC effects on radionuclide transport in the near field. The description should include a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.	Open pending review establishing that DOE distinguished between the different approaches that they used.	For the Radionuclide Transport Model, the DOE provides a reasonable description of the mathematical models. The thermal hydrological model based upon NUFT is described in Section 3.1.1. The basic contaminant transport equation is presented in Section 3.1.3. Alternative models were discussed in Section 3.1.3 with regards to reduction in drainage capacity, and storage capacity in the invert.
Model Verification Acceptance Criteria		
(1) The mathematical models for coupled THC effects on radionculide transport in the near field are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.	Open pending review of DOE's use of the results, from both their laboratory and field heater test program, to test their abstracted models for consistency with observations.	The Water Distribution Model which was used for the Radionuclide Transport Model provides predictions of seepage and flow that are based on the active fracture model. The conceptual model for the prediction of advection or pore water velocities and radionuclide transport due to advection/dispersion/diffusion through the EBS is consistent with conceptual models for the UZ.
(2) DOE appropriately adopted accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THC effects on transport of radionuclides in the near field.	Open pending review of DOEs use of well-documented procedures to construct and test the numerical models.	The EBS Radionuclide Transport Process and Abstraction Models are based upon a well documented and accepted procedure for evaluating contaminant transport as stated in the previous comment. The radionuclide transport model was prepared according to AP-3.10Q with discussion of quality assurance, computer software, model inputs, and model assumptions. For analyses involving the use of software routines, the routines were verified by separate hand calculations.
(3) Abstracted models for coupled THC effects on seepage and flow were based on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems. Abstracted model results were verified through comparison to outputs of detailed process models and empirical observations. Abstracted model results are compared with different mathematical models to judge robustness of results.	Open pending review of DOE's use of experimental, site, and natural analog data to aid verification of their models, and that models used produce results reasonably representative of the systems modeled.	The EBS Radionuclide Transport Model provides a bounding calculation. For the base case, the effects of chemical retardation are neglected (Section 3.1.3) which is a conservative assumption. The effects of Ca, Si, and Mg, precipitation that would result in possible reduction in porosity are investigated in Section 3.1.2.5, and are found to be negligible. It is unlikely that pore water velocities would be altered by a reduction in porosity.
Integration Acceptance Criteria		
(1) DOE has considered all the relevant features, events, and processes. The abstracted models adequately incorporated important design features, physical phenomena, and couplings, and used consistent and appropriate assumptions throughout.	Open pending review and confirmation that DOE includes a formal screening process for features, events, and processes (FEP). And, that important design features, physical phenomena,	The PMRs describe the treatment and documentation of primary features, events, and processes.

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	and couplings are evaluated in a performance assessment framework.	
(2) Models reasonably accounted for known temporal and spatial variations in conditions affecting coupled THC effects on transport of radionuclides in the near field.	Open pending review confirming that DOE models account for known temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release.	The EBS Radionuclide Transport Model discussed in the EBS PMR is based on the thermal hydrology from the WD&R Model.
(3) Not all THC couplings may be determined to be important to performance, and DOE may adopt assumptions to simplify performance assessment analyses. If potentially important couplings are neglected, DOE should provide a technical basis for doing so. The technical basis could include activities, such as independent modeling, laboratory or field data, or sensitivity studies.	Open pending review confirming the FEP analysis meets the acceptance criteria in the TSPAI IRSR (U.S. Nuclear Regulatory Commission, 1998c) for scenario analysis.	The NFE PMR describes the process of analysis used to determine which couplings need to be considered in performance assessment and which were excluded, and the technical justification for that determination. Section 3 describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption.
(4) Where simplifications for modeling coupled THC effects on radionuclide transport in the near field were used for performance assessment analyses instead of detailed process models, the bases used for modeling assumptions and approximations were documented and justified.	Open pending review confirming DOE continues to document the bases for simplifications used in modeling coupled THC effects on the chemical environment for radionuclide release.	The NFE PMR describes the process level models, model abstractions and supporting analyses that address the near-field environment process. The AMRs that support the development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption. In addition, the Abstraction of Drift-Scale Coupled Processes AMR provides explanations, documentation and justification for simplifications used in the abstractions described in that AMR.
Programmatic Acceptance Criteria		
(1) Data and models were collected, developed, and documented under acceptable QA procedures.	Open pending review of DOE's qualification of the data and models that could be used.	Activities associated with development of PMRs and AMRs were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
(2) Deficiency reports concerning data quality on issues related to coupled THC effects on the chemical environment for radionuclide release were closed.	Open pending closure of three QA deficiency reports concerning issues related to coupled THC effects on seepage and flow.	PMRs have been prepared according to AP-3.10Q and AP-3.15Q to address quality assurance deficiency issues.
(3) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Kotra, et al., 1996) or other acceptable approaches.	Open pending review of DOE's demonstration of its understanding of the expected use of elicited expert judgements, prior to convening expert panels.	Expert elicitations were determined to be subject to the quality assurance program as described in the QARD document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563.

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Subissue 5 - Coupled THC Processes Affecting Potential Nuclear Criticality in the Near Field		
Scenario Screening Acceptance Criteria		
(1) Sensitivity and uncertainty analyses (including consideration of alternative conceptual models) were completed to determine whether criticality will impact repository performance, and whether additional new data are needed to better define ranges of input parameters.	Open pending the results of the staff review of DOE's Disposal Criticality Analysis Methodology Topical Report.	Agree
Data and Model Justification Acceptance Criteria		
1 - Available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on the potential for nuclear criticality in the near-field environment were considered	Open pending review of DOE's abstraction of near field criticality in a future performance assessment.	Agree
2 - DOE's evaluation of coupled THC processes properly considered site characteristics in establishing initial and boundary conditions for conceptual models and simulations of couple processes that may affect nuclear criticality in the near-field environment.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment.	Agree
3 - Sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that may affect nuclear criticality in the near-field environment.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment.	Agree
Data Uncertainty Verification Acceptance Criteria		
(1) Reasonable or conservative ranges of parameters or functional relations were used to determine effects of coupled THC processes on potential nuclear criticality in the near-field environment. Parameter values, assumed ranges, probability distributions, and bounding assumptions are technically defensible and reasonably account for uncertainties.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(2) Uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on potential nuclear criticality were considered.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree

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(3) DOE's evaluation of coupled THC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect potential nuclear criticality.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(4) The initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on potential nuclear criticality in the near-field environment were consistent with available data.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
Model Uncertainty Acceptance Criteria		
(1) Alternative modeling approaches consistent with available data and current scientific understanding were investigated, and their results and limitations were appropriately considered.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(2) DOE provided a reasonable description of the mathematical models included in its analyses of coupled THC effects on potential nuclear criticality. The description should include a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
Model Verification Acceptance Criteria		
(1) The mathematical models for coupled THC effects on potential nuclear criticality are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(2) DOE appropriately adopted accepted, and well-documented, procedures to construct and test the numerical models used to simulate coupled THC effects on potential nuclear criticality.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(3) Abstracted models for coupled THC effects on potential nuclear criticality were based on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems. Abstracted model results were verified through comparison to outputs of detailed process models and empirical observations. Abstracted model results are compared with different mathematical models to judge robustness of results.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree

Issue Resolution Status Report: Evolution of the Near-Field Environment		
Acceptance Criteria	**ENFE IRSR Rev 2 Status**	**DOE Comment**
Integration Acceptance Criteria		
(1) DOE has considered all the relevant features, events, and processes. The abstracted models adequately incorporated important design features, including criticality safety features; physical phenomena and couplings, including neutron absorbers; and used consistent and appropriate assumptions throughout.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(2) Important mass transfer and mass transport processes and mechanisms considered for formation of both a critical mass and configuration are plausible for the YM near-field environment.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(3) Models reasonably accounted for known temporal and spatial variations in conditions affecting coupled THC effects on potential nuclear criticality.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(4) Criticality in the near field, and not all THC couplings, may be determined to be important to performance, and DOE may adopt assumptions to simplify PA analyses. If potentially important couplings and criticality in the near field are neglected, DOE should provide a technical basis for doing so. The technical basis could include activities, such as independent modeling, laboratory or field data, or sensitivity studies.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
(5) Where simplifications for modeling coupled THC effects on potential nuclear criticality were used for PA analyses instead of detailed process models, the bases used for modeling assumptions and approximations were documented and justified.	Open pending review of DOE's abstraction of near field criticality in a future performance assessment	Agree
Programmatic Acceptance Criteria		
(1) Data and models were collected, developed, and documented under acceptable QA procedures.	Open pending review of DOE's qualification of the data and models that could be used	Agree
(2) Deficiency reports concerning data quality on issues related to coupled THC effects on the potential for nuclear criticality were closed.	Closed.	Agree
(3) If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Kotra, et al., 1996) or other acceptable approaches.	Open pending review of DOE's demonstration of its understanding of the expected use of elicited expert judgements, prior to convening expert panels.	Agree

KEY TECHNICAL ISSUE (KTI)

REPOSITORY DESIGN AND THERMAL MECHANICAL EFFECTS (RDTME)

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NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION STATUS
APRIL 25-26, LAS VEGAS, NV

RDTME KTI SUBISSUES AND RESOLUTION STATUS

Subissue 1: Implementation of an effective design control process within the overall quality assurance program: CLOSED

Subissue 2: Design of the geologic repository operations area for the effects of seismic events and direct fault disruption: CLOSED PENDING CONFIRMATORY INFORMATION

Subissue 3: Thermal-mechanical effects on underground facility design and performance: OPEN

Subissue 4: Design and long-term contribution of seals to performance: CLOSED PENDING CONFIRMATORY INFORMATION

PATH TO RESOLUTION (SUBISSUE 1)

Component 1: Design Control Process for the ESF: (CLOSED)

Component 2: Design control process for the GROA: (CLOSED)

Need for Continued Evaluation

- NRC staff to evaluate DOE implementation of design control process through audit observations

- DOE to inform NRC of any changes to its Design Control Process

Progress in Implementation:

- Document Hierarchy Simplified and In Place
- Design Control Process Appears to be Transparent and Traceable
- Effectiveness of Implementation Monitored Through Periodic Audit Observations and design reviews

PATH TO RESOLUTION (SUBISSUE 2)

Component 1: Seismic Hazard Assessment Methodology: (CLOSED -- SEE SDS IRSR)
Component 2: Seismic Design Methodology: (CLOSED -- SEE RDTME IRSR)

Component 3: Seismic and Fault Displacement Inputs for Design and Performance Assessment: (CLOSED PCI i.e., TR-3 OR OTHER ALTERNATIVE)

- DOE Repository Safety Strategy (RSS) Principal Factors:
  — Seepage Into Drifts
  — Performance of Drip Shield
  — Performance of Waste Package

- NRC Abstractions:
  — Mechanical Disruption of Engineered Barriers
  — Spatial and Temporal Distribution of Flow
  — Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms
  — Degradation of Engineered Barriers

Need for Additional Data/Rationale

- Seismic and Fault Displacement input data that are consistent with the seismic design methodology and Performance Assessment Methodology along with technical bases.

PATH TO RESOLUTION (SUBISSUE 3)

Thermal-mechanical (TM) effects on underground facility design and performance

- DOE RSS Principal Factors:
  — Seepage Into Drifts
  — Performance of Drip Shield
  — Performance of Waste Package
  — Coupled Processes-Effects on Seepage
  — Environments on the Drip Shield and on/within Waste Package

- NRC Abstractions:
  — Mechanical Disruption of Engineered Barriers
  — Spatial and Temporal Distribution of Flow
  — Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms
  — Degradation of Engineered Barriers
  — Radionuclide Release Rates and Solubility Limits

PATH TO RESOLUTION (SUBISSUE 3)

Component 1: Consideration of TM effects on Underground Facility Design/Performance (OPEN)

Need for Additional Data

- Intact-rock thermal and mechanical properties for TSw2 lithophysal unit
- Rock-mass properties for TSw2 lithophysal unit

Need for Additional Analysis

- Applicability of available empirical equations
- Degradation of rock properties under repository environment
- Design analysis of emplacement drift stability needs to:
  - Consider appropriate combination of models
  - Consider site-specific fracture patterns in discontinuum analysis
  - Use site-specific frequency content and duration of ground motion data
  - Consider effects of lithophysae on rock bolt performance/effectiveness

PATH TO RESOLUTION (SUBISSUE 3)

Component 2: Consideration of TM effects and Resulting Rock-fall on the Design and Performance of Engineered Barriers (OPEN)

Need for Additional Analysis (SEE CLST KTI PRESENTATION)

- Rock-fall impact analysis needs to consider the following:
  - Appropriate mechanical properties for the EB component materials (consistent with emplacement drift conditions, e.g., temperature effects)
  - Effects of flaws and cracks that are created during the fabrication process when assessing the capability of the EB component to withstand rock block impact(s)
  - Integrity of waste package pedestal support
  - Thermal load and ground motion on predicting rock-fall
  - Design and fabrication details for the Individual EB components
  - Appropriate failure criteria for the different EB components
  - Effects of seismic ground motion on the relative velocity between the EB component and rock block during impact
  - Effects of residual stresses and potential loss of material ductility in the region of the closure welds
  - Effect of multiple rock blocks falling in unison
  - Potential creep rupture of the Titanium (Grade 7) drip shield due to the sustained load of supporting a seismically dislodged rock block after impact

PATH TO RESOLUTION (SUBISSUE 3)

Component 3: Consideration of TM effects in Estimating Quantities of Seepage and Dripping Characteristics into Emplacement Drifts (OPEN)

Need for Additional Analysis

- Evaluation of long-term TM effects should consider:

  — Changes in geometry of emplacement drifts

  — Changes in permeability around emplacement drifts

PATH TO RESOLUTION (SUBISSUE 4)

Design and contribution of seals to long-term performance (CLOSED PCI)

- No specific design/performance requirements for Borehole/Shaft/Ramp Seals in Part 63
- DOE to establish criteria for Seal Design to meet long-term performance needs
- DOE to establish material/construction specifications to meet its design goals
- DOE to evaluate contribution of Seals to overall repository performance
- NRC to review Seal Design in the context of repository long-term performance

SUMMARY

SUBISSUE 1

DESIGN CONTROL PROCESS FOR THE GROA TO BE MONITORED BY NRC THROUGH PERIODIC OBSERVATIONS OF DOE AUDITS AND DESIGN REVIEWS

SUBISSUE 2

DOE SUBMITS TR-3, NRC REVIEWS TR-3 AND CONSIDERS TR-1, TR-2 AND TR-3 IN PREPARING SER, TR's WILL BECOME AN ACCEPTED REFERENCE TO DOE'S LA.

SUBISSUE 3

DOE TO RESPOND TO NRC QUESTIONS ON DATA AND ANALYSES, NRC TO REVIEW AND CONSIDER NEW INFORMATION IN SUBSEQUENT REVISIONS TO RDTME KTI IRSR.

SUBISSUE 4

RISK-INFORMED PERFORMANCE-BASED PART 63 APPROACH RESULTS IN RETHINKING OF SEALS SUBISSUE. DOE TO PROVIDE AN EVALUATION OF SEAL DESIGN AND ITS CONTRIBUTION TO LONG-TERM PERFORMANCE. NRC TO REVIEW SEAL DESIGN IN THE CONTEXT OF LONG-TERM PERFORMANCE

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

Repository Design and Thermal-Mechanical Effects

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Paul Harrington
Yucca Mountain Site Characterization Office
U. S. Department of Energy

April 26, 2000

YUCCA MOUNTAIN PROJECT

Current Status
(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Design Control (Quality Assurance Program)**
  - **Most of acceptance criteria have been evaluated satisfactorily**
  - **DOE has taken action related to the one concern expressed**
- **Subissue 2 - Effects of Seismic Events and Direct Fault Disruption**
  - **Seismic Topical Report-1 and -2 (Components 1 and 2) have been provisionally accepted pending review of Seismic Topical Report-3**
  - **DOE agrees with criteria of Component 3 (Seismic Topical Report-3)**

Current Status

(Issue Resolution Status Report Revision 2)
(Continued)

- **Subissue 3 - Thermal-Mechanical Effects on Underground Facility Design and Performance**
  - No criteria are closed. NRC has reviewed many of the criteria and deferred others
  - A valuable Appendix 7 meeting was held in November 1999
  - Additional interactions probable after NRC reviews DOE's letter of 3/00
- **Subissue 4 - Design and Long-Term Contribution of Seals to Performance**
  - NRC has not yet developed related acceptance criteria
  - DOE classifies seals as non-Q and does not relate the seals to postclosure performance

Key Activities

- **Fiscal Year (FY) 1998**
  - Appendix 7 meeting June 1998 to evaluate design control acceptance criteria
  - NRC found Seismic Topical Report-2 acceptable (pending review of Seismic Topical Report-3)
  - Completed analyses that identified three options for ground support for emplacement drifts (pre-cast concrete, cast-in-place concrete, and steel sets and lagging)
  - Completed preliminary block size calculation

Key Activities
(Continued)

- **FY 1999**
  - Issued Viability Assessment (VA), which reflected three options for ground support for emplacement drifts
  - Disqualified use of concrete for emplacement drifts ground support (uncertainties regarding the potential effects of concrete on migration of contaminants released from waste packages)
  - Decided to use carbon steel for ground support (steel sets and wire mesh, supplemented by grouted rockbolts where necessary)
  - Completed analyses of rockfall on different waste package design concepts. Selected design using corrosion-resistant material

Key Activities
(Continued)

- **FY 1999** (Continued)
  - Completed analysis for the rockfall on corrugated drip shield design
  - Performed preliminary key block analysis for the static case. Completed a design basis block size assessment based on preliminary fracture data

Key Activities
(Continued)

- **FY 2000**
  - **Held Appendix 7 meeting November 1999 on thermal-mechanical analyses of emplacement drifts, data, model development, and application of results**
  - **Completed analysis of emplacement drifts ground support (steel sets and wire mesh supplemented by grouted rockbolts) in support of the Site Recommendation Consideration Report**
  - **Modified rockfall analysis methodology based on more detailed rock geometry input**
  - **Completed drift degradation analysis that included a modified approach for assessing seismic and time-dependent joint degradation effects on block size**

Key Activities
(Continued)

- **FY 2001**
  - Plan to perform analyses to develop preliminary designs for steel sets, wire mesh, and grouted rockbolts for License Application
  - Plan to analyze results of in situ (heated) tests for confirmation or adjustment of design parameters and analysis procedures
  - Plan to examine multiple rockfall scenario if determined to be a credible event

KTI Subissues and Associated Factors of the Safety Case

	KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1	Implementation of an Effective Design Control Process within the Overall Quality Assurance Program	All	Quality assurance program will be applied.
2	Design of the Geologic Repository Operations Area for the Effects of Seismic Events and Direct Fault Disruption	Waste package degradation/performance and drip shield degradation/performance	These elements will be designed to withstand design seismic events.
3	Thermal-Mechanical Effects on Underground Facility Design and Performance	Waste package degradation/performance and drip shield degradation/performance	These elements will be designed to withstand the design-basis rockfall.
4	Design and Long-Term Contribution of Repository Seals in Meeting Postclosure Performance Objectives	None	Not considered important to repository performance.

Subissue 1: Implementation of an Effective Design Control Process within the Overall Quality Assurance Program

- Acceptance criteria are included as elements of the quality assurance (QA) program
- QA program is implemented by the *Quality Assurance Requirements and Description* Document, accepted by NRC
- NRC satisfied with implementation of most criteria during review of June 1998
- Individual QA program concerns being addressed separately

Subissue 1: Implementation of an Effective Design Control Process within the Overall Quality Assurance Program

(Continued)

- **The single concern expressed in the Issue Resolution Status Report (IRSR) has been addressed by DOE**
  - **Investigated extent of problem, issued Lessons Learned**
  - **Performed self-assessment, issued deficiency report**
  - **Status provided to NRC in DOE comment letters on IRSR**
  - **Deficiency report closed 3/00**

Subissue 2: Design of the Geologic Repository Operations Area for the Effects of Seismic Events and Direct Fault Disruption

- Approach to subissue resolution is through a series of three seismic topical reports
- Seismic Topical Report-1 and Seismic Topical Report-2 have been provisionally accepted pending review of Seismic Topical Report-3
- Seismic Topical Report-3 is expected to be delivered for review in November 2001

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance

- **Three Major Components**
  1. **Thermal-Mechanical Effects on Design of Underground Facility**
  2. **Effects of Seismically Induced Rockfall on Waste Package Performance**
  3. **Thermal-Mechanical Effects on Flow into Emplacement Drifts**

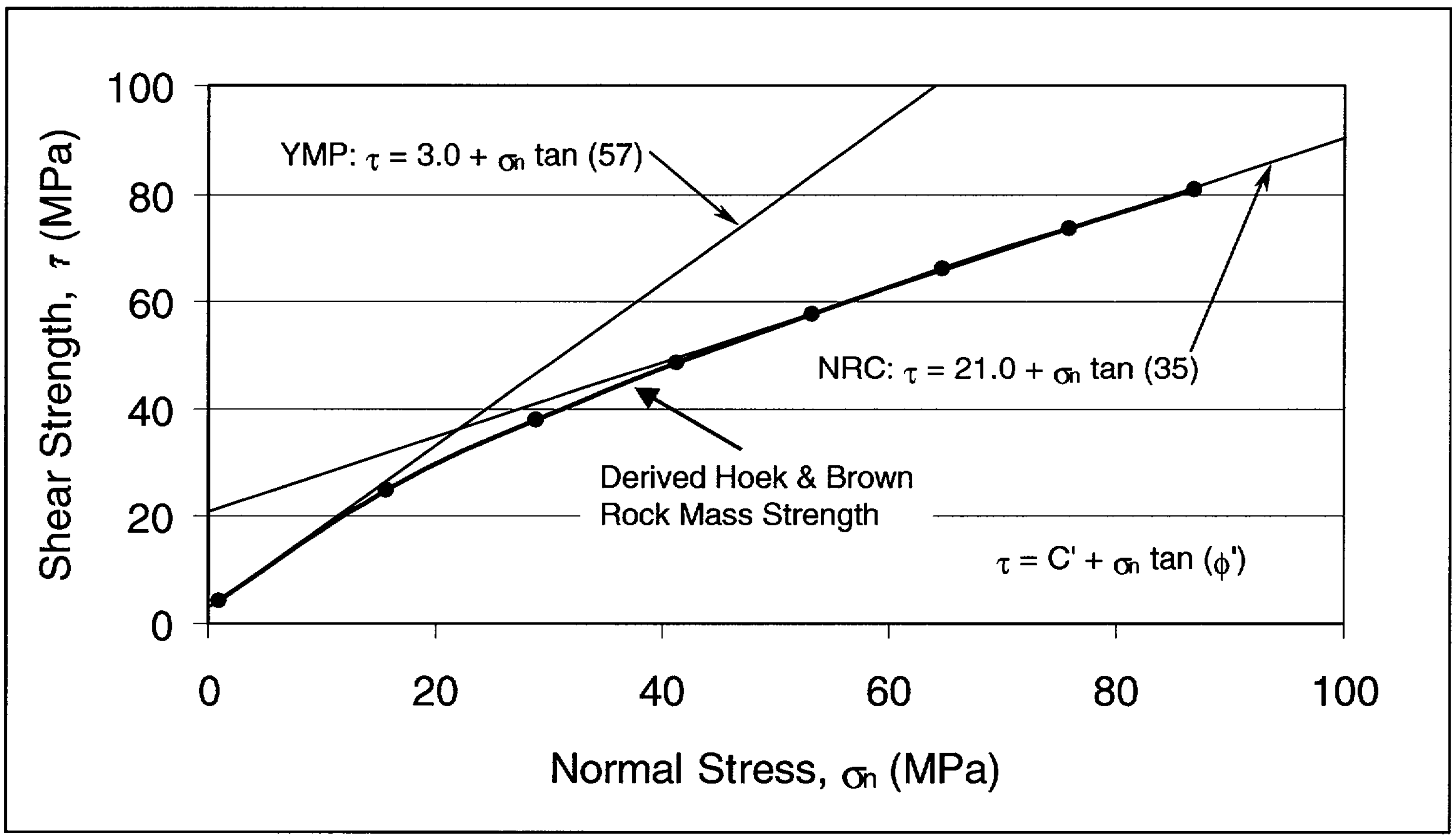
Thermal-Mechanical Effects on Design of Underground Facility

- **Divergence of opinion related to predicted rock mass friction angles (IRSR, Section 4.3.3.2)**
- **DOE estimated rock mass properties based on geotechnical mapping of the rock mass following guidelines described by Hoek and Brown**
- **IRSR reports discrepancy in rock mass friction angles**
  - **DOE values: 57° to 58°**
  - **NRC values: 28° to 35°**

Thermal-Mechanical Effects on Design of Underground Facility
(Continued)

- **DOE/NRC basic approach to assessing rock mass friction angle is the same. The difference is in the stress range over which the friction angles were calculated**
- **DOE letter to NRC of 3/00 addresses in detail**

Shear Strength Curve Based on the Hoek and Brown Approach (GSI=62, σ_{ci} =167.9 MPa, m_i=19.68)



GSI – Geological Strength Index σ_{ci} – intact rock unconfined compressive strength
m_i – Hoek and Brown rock mass strength parameter

Determination of Seismically Induced Rockfall on Waste Package Performance

- **At Appendix 7 meeting in November 1999, NRC staff expressed concern related to a need for additional dynamic analyses to validate the existing approach**
- **Current drift degradation analysis**
  - **Based on VA emplacement drift alignment**
  - **Includes backfill**
- **New calculation (March 2000 - in review) includes revised block sizes based on new emplacement drift alignment and excludes backfill**

Determination of Seismically Induced Rockfall on Waste Package Performance
(Continued)

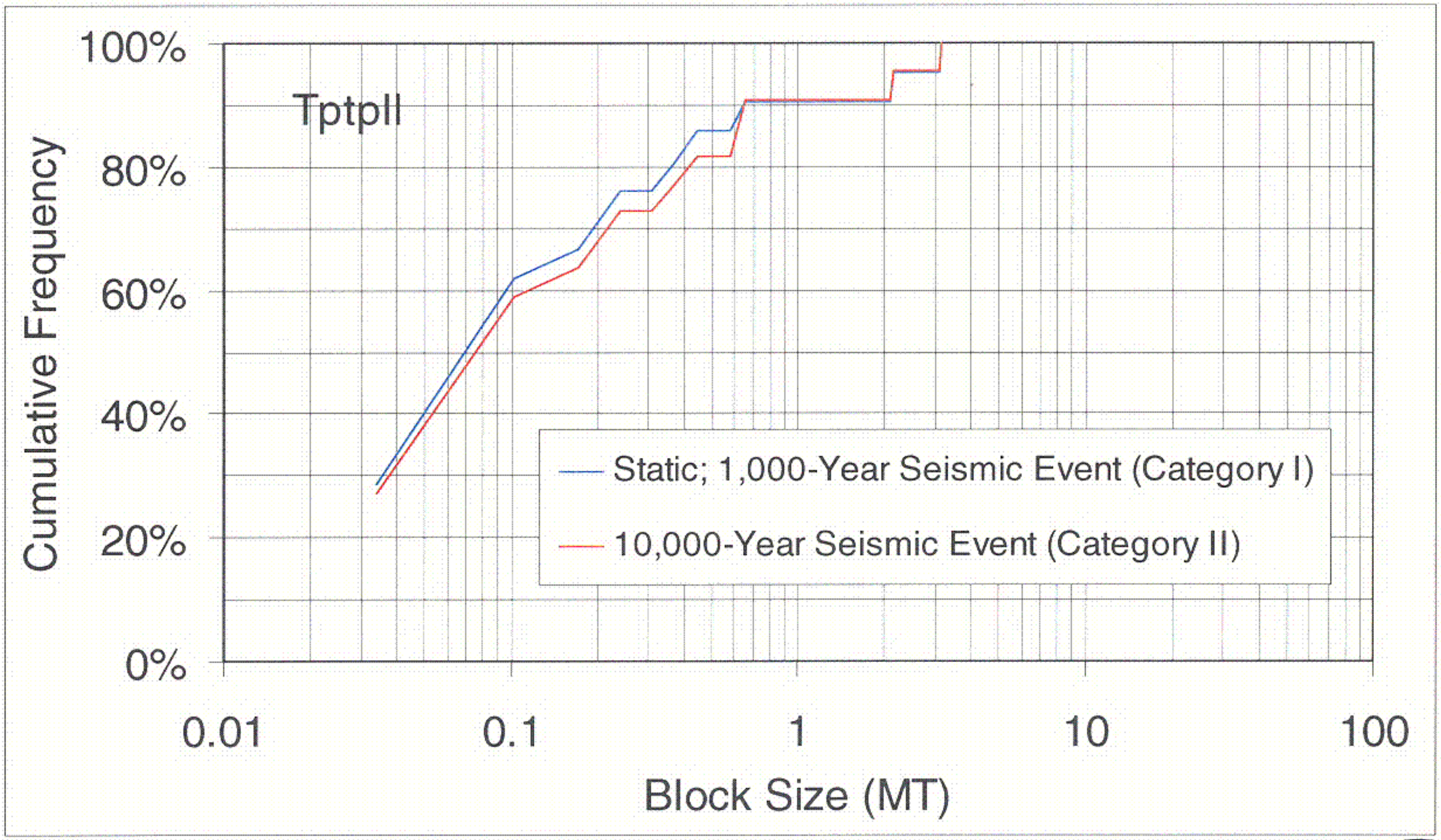
- **Planning under development for revised drift degradation analysis**
  - **Will include current emplacement drift alignment and exclude backfill**
  - **Will consider additional dynamic analyses for seismic effects on rockfall**

Determination of Seismically Induced Rockfall on Waste Package Performance

(Continued)

- **Quasi-static approach to drift degradation analysis**
  - Assemble related site data (joint geometrical data, joint frictional properties, fallen blocks, rock properties from laboratory tests of borehole samples)
  - Analyze the joint data to assess the potential formation of key blocks and the seismic and thermal effects on joint and block movement
  - Determine the number and average mass of rockfall per unit length of drift for various levels of seismic hazard and the distribution data for each lithologic unit
  - Analyze the drift profile showing the progressive movement of joints and blocks with time and establish basis for block size criteria for subsurface facilities and waste package design

Cumulative Size Key Block Distributions for TptpII Unit (Seismic Case, Current Emplacement Drift Alignment)



Predicted Number of Key Blocks per Unit Length (km) along Emplacement Drift (Seismic Consideration, Current Emplacement Drift Alignment)

Lithologic Unit	Emplacement Drift Length (%)	Static	Static Plus Seismic 1,000 year (Category I)	Static Plus Seismic 10,000 year (Category II)
Tptpmn	7	28	29	32
Tptpll	78	2	2	2
Tptpln	15	6	7	7

- **Drift degradation analysis revision will include additional dynamic analyses to confirm results of the current methodology**

Subissue 4: Design and Long-Term Contribution of Repository Seals in Meeting Postclosure Performance Objectives

- **Acceptance criteria are not yet developed for this subissue in the IRSR**
- **Based on work done to date:**
  - This subissue includes no factors demonstrated to be important to waste isolation in the Repository Safety Strategy
  - Seals are classified as CQ (Conventional Quality), not subject to QA program
  - Work continues to evaluate other aspects of seal performance

Summary

- **Areas of agreement**
  - Subissues 1 and 2 criteria
  - Subissue 4 – NRC acknowledges DOE work to identify importance of seals
- **Areas of potential disagreement**
  - Aspects of Subissue 3 addressed in Brocoum letter to Reamer of 3/00. For example:
    - Need for repository-scale modeling (IRSR, Section 4.3.3.1, Criteria 8, and Section 5.3.1.8)
    - Magnitude of predicted rock mass friction angles
  - Specific approach to individual analyses (possible topics for Appendix 7 meetings)

Summary
(Continued)

- **Subissue 1, Design Control, will be applied as established by the QA program**
- **Subissue 2, Design for the Effects of Seismic Events and Direct Fault Disruption, is being addressed mostly through a series of topical reports**
- **Subissue 3, Thermal-Mechanical Effects on Underground Facility Design and Performance, is being addressed by DOE, with specific areas of divergence to be discussed in Appendix 7 meetings**

Summary
(Continued)

- Subissue 4, Design and Long-Term Contribution of Repository Seals in Meeting Postclosure Performance Objectives, is addressed, although evaluation of certain aspects continues

Backup

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
Subissue 1 - Effective Design Control Process within Quality Assurance		
1) The applicable regulatory requirements are identified.	Evaluated - Generally satisfactory	Implemented
2) The design bases associated with the regulatory requirements are defined.	Evaluated - Generally satisfactory	Implemented
3) The regulatory requirements of Acceptance Criteria 1 and the design bases of Acceptance Criteria 2 are appropriately translated into specifications, drawings, procedures, and instructions.	Evaluated - Generally satisfactory	Implemented
4) Appropriate quality standards are specified in the design documents.	Evaluated - Generally satisfactory	Implemented
5) Any deviations from the standards specified under Acceptance Criteria 4 are properly controlled, documented, and justified.	Evaluated - Generally satisfactory	Implemented
6) Measures are established for selection of materials, parts, equipment, and processes that are essential to functions of structures, systems, and components that are important to safety and waste containment and isolation.	Evaluated - Generally satisfactory	Implemented
7) Design interfaces are identified, controlled, and appropriately coordinated among participating design organizations.	Evaluated - Generally satisfactory	Implemented
8) Procedures are established for review, approval, release, distribution, and revision of documents involving design interfaces.	Evaluated - Generally satisfactory	Implemented
9) Measures are established for verifying or checking the accuracy of design calculations (e.g., performing design reviews using alternate or simplified calculational methods).	Evaluated - Generally satisfactory	Implemented
10) If testing is employed for verification of design adequacy for its intended service life, the testing is conducted under the most adverse conditions.	Limited evaluation. No concerns expressed.	Implemented

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
11) The design verification is conducted by independent and qualified professionals who did not participate in the original design efforts.	Evaluated - Generally satisfactory	Implemented
12) In addition to being applied to the original design, the design control process is also applied to design changes and to field changes, and these changes are properly documented.	Evaluated - Concern identified	Implemented. Concern identified was investigated by DOE, corrective action initiated, and related corrective action taken.
Subissue 2 Seismic Design Methodology (Part 1)		
1) The topical report addresses all important-to-safety (or important-to-waste-isolation) topics pertaining to the scope of the topical report.	NRC agreed that the issue of seismicity and fault displacement is an appropriate one to be dealt through the topical report process. Seismic Topical Report (STR) -1 and STR-2 have been provisionally accepted pending review of STR-3.	Agree
2) The subject of the topical report is currently undergoing pre-licensing evaluation.		
3) NRC's acceptance of the topical report would result in increased efficiencies in the staff review of DOE's license application.		
4) The topical report contains complete and detailed information on each element of the scope of the report.		
Subissue 2 Seismic Design Methodology (Part 2)		
1) Sufficient technical reasoning is provided for the proposed methodology.	No further questions at this time related to STR-1 and STR-2. These have been found acceptable to the staff pending review of STR-3. Final resolution after review of STR-3. Implementation of the design methodology will be monitored during the LA review.	Agree
2) If available, documented case histories of the performance of structures, systems, and components important to safety designed using the proposed methodology are presented in the topical report. In the absence of documented case histories, no serious problems have been identified that would impede applying the methodology.		

Key Technical Issue: Repository Design and Thermal-Mechanical Effects

ACCEPTANCE CRITERIA	RDTME IRSR Rev 2 Status	DOE Comment
3) The proposed methodology does not contradict established methodologies and principles tested and documented in the license applications for nuclear power plants and independent spent fuel storage installations.	No further questions at this time related to STR-1 and STR-2. These have been found acceptable to the staff pending review of STR-3. Final resolution after review of STR-3. Implementation of the design methodology will be monitored during the LA review.	Agree
4) Uncertainties associated with the proposed methodology that would significantly affect or impede the repository design process and development of inputs to performance assessments have been considered adequately.		
5) The various steps involved in the proposed methodology are transparent.		
6) To the extent that the proposed design methodology depends on site-specific test data, such data are available now, are being gathered now, or there are plans for gathering such data during site characterization and before submittal of the license application.		
7) To the extent that the proposed methodology depends on analytical/computer models, such models have been verified, calibrated, and validated to the extent practical, or there are plans for such activities prior to license application submittal or during the performance confirmation period, as appropriate.		
8) Any major assumptions or limitations to the proposed methodology are identified, and the implications regarding design and performance are discussed in the topical report.		
9) The contents of TR-2 are consistent with the contents of TR-1 and, taken together, the two topical reports support the development of inputs for design and performance assessments, as described in TR-3.		

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
Subissue 3: Thermal-Mechanical Effects		
Component 1: Thermal-Mechanical Effects on Design of the Underground Facility		
1) Approved quality assurance and control procedures and standards are applied to collection, development, and documentation of data, methods, models, and codes.	Review methods are under development. NRC will continue to participate as observers in DOE audits and surveillance to ensure implementation.	This criterion is met. Collection of data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement quality assurance program requirements.
2) If used, expert elicitations are conducted and documented in accordance with the guidance in NUREG-1563 or other acceptable guidelines.	Review methods are under development. NRC will continue to participate as observers in DOE audits and surveillance to ensure implementation.	This criterion is met. Expert elicitations are conducted in accordance with the requirements of the QA program which incorporates, in part, the guidance of NUREG-1563.
3) Thermal-mechanical analyses of the repository design are based on site-specific thermal and mechanical properties, spatial variation of such properties, and temporal variations caused by post-emplacement thermal-mechanical-hydrological-chemical processes, as appropriate, including consideration of seismic effects relevant to the Yucca Mountain site within the rock-mass.	Review methods are under development. NRC will continue to participate as observers in DOE audits and surveillance to ensure implementation. This was indicated as an area for discussion at an Appendix 7 meeting.	DOE includes site-specific information in its analyses, when applicable. An Appendix 7 meeting was held in November 1999 that included discussions of this criterion. Agreement was not reached related to DOE's use of lower stress values.
4) The process to develop inputs to thermal-mechanical design includes consideration of associated uncertainties and documents the potential impacts on design.	IRSR expressed need for an Appendix 7 meeting to discuss validation of empirical equations	Uncertainties are fully considered and documented. An Appendix 7 meeting was held in November 1999 that included discussions of this criterion.

Key Technical Issue: Repository Design and Thermal-Mechanical Effects

ACCEPTANCE CRITERIA	RDTME IRSR Rev 2 Status	DOE Comment
5) The seismic and fault-displacement data inputs for design are consistent with those established in seismic design TR-3.	Will be addressed when STR-3 is reviewed and data is used in the design.	STR-3 is currently planned for submission to NRC in November 2001. Agree
6) The methodologies used for the thermal-mechanical design and analyses are consistent with those established in DOE Seismic TR-2.	Awaits design details that will be provided in the SR and LA.	Methodologies are and will be consistent with those identified in STR-2. Agree
7) The thermal-mechanical design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. These models are tested as appropriate (verified, validated, and calibrated) to the extent practicable before the submittal of the license application. (For those aspects of the models for which long-term experimental data are needed, continued verification and validation during performance confirmation are considered acceptable as long as detailed plans and procedures for such continued activities are found in the license application.)	Anticipates further review in FY 2000. This was indicated as an area for discussion at an Appendix 7 meeting.	This criterion is met. The Performance Confirmation Plan describes the currently-identified confirmation activities that will be conducted. An Appendix 7 meeting was held in November 1999 that included discussions of this criterion.
8) Both drift- and repository-scale models of the underground facility are used in thermal-mechanical analyses to establish the intensity and distribution of ground movement (rock deformations, collapse, and other changes that may affect the integrity or geometrical configuration of openings within the underground facility). The number and variety of models permit the examination of conditions along drift-parallel and drift-normal directions.	NRC will continue to follow DOE's progress in this area. This was indicated as an area for discussion at an Appendix 7 meeting.	DOE has suggested a revision to the wording of the criterion to remove the mandate to develop repository-scale models. To date, DOE has not identified problems that require a full-scale repository model. Drift-scale models have been developed that represent the range of expected repository conditions, and modeling has been developed to examine limiting or bounding conditions. An Appendix 7 meeting was held in November 1999 that included discussions of this criterion.

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
9) The principles formulating the thermal-mechanical analytical methodology, underlying assumptions, resulting limitations, and various steps involved in the design procedures are clearly explained and justified.	Anticipates further review in FY 2000.	This criterion is met. Agree
10) Time sequences of thermal loading used in thermal-mechanical design and analyses are clearly defined.	Will follow developments based on changes to designs	This criterion is met. Agree
11) The thermal-mechanical design and analyses consider the presence of roof supports (bolts, shotcrete, concrete, and steel liners, as applicable), consider the interaction between rock and roof supports, and address the degradation of supports with time under high temperature and moisture conditions as they affect the maintainability of stable openings during the extended preclosure period.	This was indicated as an area for discussion at an Appendix 7 meeting.	This criterion is met. An Appendix 7 meeting was held in November 1999 that included discussions of this criterion.
12) The results of the thermal-mechanical analyses, including the consideration of ground support (e.g., liners), are accounted for in the determination of maintenance requirements for the underground facility.	This is a topic for future review when DOE develops related requirements.	Agree
13) The design discusses maintenance plans for keeping the underground openings stable, with particular attention to maintaining the option for retrieval. (If the details of retrieval operations/plans are found in other sections of the license application, a reference to such sections would be acceptable.)	Review will be done when pertinent sections of the LA are reviewed.	Agree

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
Component 2: Effects of Seismically Induced Rockfall on Waste Package Performance		
1) Approved quality assurance and control procedures and standards are applied to collection, development, and documentation of data, methods, models, and codes.	Evaluation is deferred until the relevant DOE audit is conducted.	This criterion is met. Collection of data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
2) If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG-1563 or other acceptable approaches.	Will review in conjunction in FY 2000 with the related criterion in the KTI on Structural Deformation and Seismicity.	This criterion is met. Expert elicitations are conducted in accordance with the requirements of the QA program, which incorporates, in part, the guidance of NUREG-1563.
3) The seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the design and performance assessments as established in DOE's TR-3 reviewed and accepted by NRC.	The effect on waste package damage of the revisions to the exceedence curve for horizontal PGV needs to be evaluated.	Inputs are based on preliminary design basis seismic ground motion parameters. Updates addressing the postclosure earthquake will be performed as needed using guidance presented in the STRs.
4) Size distribution of rocks that may potentially fall on the waste packages is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions) with adequate consideration of associated uncertainties.	Evaluation will continue when additional work is done by DOE.	This criterion is met. Drift degradation analysis is based upon a probabilistic key block analysis. The key block analysis is based upon the collection of data for joint patterns, spacing, and orientation from underground detailed line surveys conducted in the ESF main loop and the ECRB cross drift. The joint data is analyzed statistically to account for uncertainties in joint properties.

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
5) The analytical model used in the estimation of impact load due to rockfall on the waste package is: (i) based on reasonable assumptions and site data; (ii) consistent with the underground facility (emplacement drift geometry and backfill) and waste package designs; and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses.	The approach is acceptable, with a few concerns to be addressed.	This criterion is met. For information, based on current design, rockfall will not result in rock hitting the waste package. The drip shield is substantial enough to absorb or deflect rockfall to prevent it from contacting the waste package.
6) The thermal-mechanical analyses that provide the background conditions on which seismic loads are superimposed consider time-dependent jointed rock behavior.	The TSPA-VA rockfall models do not consider the potential effect of time-dependent jointed rock behavior. Review will occur as new documents are produced.	This criterion is met. Drift degradation analysis considers the change in rock mass properties due to thermal loading. The analysis accounts for time-dependent and thermal effects with joint cohesion degradation.
7) Rockfall analyses consider, in a rational and realistic way through dynamic analyses, the possibility of multiple blocks falling onto a waste package simultaneously, and the extent of potential rockfall area around an individual emplacement drift as well as over the entire repository as functions of ground motions.	Since larger rock blocks cause more damage to waste packages, mechanisms that may increase the "effective rock size" should be considered in the model (e.g., potential for rock blocks located one above the other to fall in unison).	DOE has considered multiple blocks falling at one location. Current position is that the largest single block represents the most conservative impact load. More work is needed to assess the possibility of multiple rock impact and waste package responses.
Component 3: Thermal-Mechanical Effects on Flow into Emplacement Drifts		
1) Approved quality assurance, control procedures, and standards, were applied to collection, development, and documentation of data, methods, models, and codes.	Evaluation is deferred until the relevant DOE audit is conducted.	This criterion is met. Collection of data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement quality assurance program requirements.

Key Technical Issue: Repository Design and Thermal-Mechanical Effects		
ACCEPTANCE CRITERIA	**RDTME IRSR Rev 2 Status**	**DOE Comment**
2) If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG-1563 or other acceptable approaches.	To date no questions or comments regarding the use of expert elicitation related to this component have been raised. The expert elicitation process for the near-field/altered zone will be reviewed under the ENFE KTI.	This criterion is met. Expert elicitations are conducted in accordance with the requirements of the QA program which incorporates, in part, the guidance of NUREG-1563.
3) Time-dependent changes in size and shape of the emplacement drifts due to thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) are estimated taking into account uncertainties in the context of their impacts on the performance.	Change in geometry' potential effect on dripping characteristics into emplacement drifts was not considered in TSPA-VA.	This criterion is met. Drift degradation analysis estimate time-dependent changes and take uncertainties into account.
4) Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are estimated taking into account the uncertainties in the context of their impacts on performance.	Thermally and seismically induced ground movements will alter the hydraulic properties of the environment immediately next to the waste package. The RDTME KTI staff is working with the TEF KTI staff to evaluate the importance of such changes to the performance assessment.	This criterion is met. Calculations have been performed to estimate bounds on changes in fracture permeability in rock surrounding emplacement drifts.
Subissue 4: Design and Long-Term Contribution of Repository Seals in Meeting Postclosure Performance Objectives		
Criteria for this subissue have not yet been developed.	Initial limited analysis of unsealed open borehole scenario suggest that the contributions of seals to overall performance is small.	Based on work done to date, seals relate to no factors considered to be important in the Repository Safety Strategy. Seals are classified as CQ (Conventional Quality), not subject to QA program. Work continues to evaluate other aspects of seal performance.

THERMAL EFFECTS ON FLOW (TEF)
KEY TECHNICAL ISSUE (KTI)

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NRC/DOE TECHNICAL EXCHANGE

PRE-LICENSING ISSUE RESOLUTION STATUS

APRIL 25-26, 2000, LAS VEGAS, NV

TEF KTI SUBISSUES

SUBISSUE 1: IS THE U.S. DEPARTMENT OF ENERGY THERMOHYDROLOGIC TESTING PROGRAM, INCLUDING PERFORMANCE CONFIRMATION TESTING, SUFFICIENT TO EVALUATE THE POTENTIAL FOR THERMAL REFLUX TO OCCUR IN THE NEAR FIELD?

Status: Open

SUBISSUE 2: IS THE U.S. DEPARTMENT OF ENERGY THERMOHYDROLOGIC MODELING APPROACH SUFFICIENT TO PREDICT THE NATURE AND BOUNDS OF THERMAL EFFECTS ON FLOW IN THE NEAR FIELD?

Status: Open

SUBISSUE 3: DOES THE U.S. DEPARTMENT OF ENERGY TOTAL SYSTEM PERFORMANCE ASSESSMENT ADEQUATELY ACCOUNT FOR THERMAL EFFECTS ON FLOW?

Status: Open

TEF KTI SUBISSUE's 1, 2, and 3

Relationships between DOE Key Attributes and NRC Abstractions

- **DOE RSS Key Attributes of Repository System:**
  - **Limited Water Contacting Waste Package**
    3. UZ flow above repository (Ranking 1, Confidence B)
    4. Seepage into drifts (Ranking 2, Confidence C)
    5. Coupled processes-effects on UZ flow and seepage (Ranking 1, Confidence C)
    6. Water distribution and removal-moisture on drip shield (Ranking 1, Confidence C)
    7. Physical and chemical environment-environment on drip shield (Ranking 1, Confidence C)
    8. EBS degradation-degradation of drip shield (Ranking 2, Confidence C)
  - **Long Waste Package Lifetime**
    9. Water distribution and removal-moisture on waste package (Ranking 2, Confidence C)
    10. Physical and chemical environment-environments on waste package (Ranking 2, Confidence C)

- NRC Abstractions
  - Near-Field Heat Transfer and Temperature Calculation
  - Near-Field Groundwater Infiltration
  - EBS Failure, Humid Air and Aqueous Corrosion.
  - EBS Release, Water Dripping Abstraction.

Summary -- TEF KTI SUBISSUE 3

- Assess the effect of water contacting waste packages during the thermal period **or** provide technical bases that this will not occur **or** will not adversely effect repository performance. (a)

- Assess the effects of all relevant repository design features such as: thermal loading, ventilation, and drip shield in evaluating waste package conditions (Temperature, Pressure, Relative Humidity). (a)

- Assess the effect on water flow (i.e permeability changes) of coupled thermal-hydrological-mechanical-chemical processes **or** provide technical bases that these effects are bounded **or** can be safely excluded. (a)

- Demonstrate that results of performance assessments related to TEF are consistent with process-level models. (a)

a	Additional analyses
b	Additional data and analyses

Summary -- TEF KTI SUBISSUE 2

- Process-level conceptual and mathematical models should include: (a)
    - evaporation, condensation, and the effects of discrete features,
    - lateral movement of condensate, cold-trap effect, repository edge effects, and condensate drainage through fractures,
    - all significant repository design features (e.g. ventilation)
    - spatially variable infiltration,
    - adequate heterogeneity in media properties,
    - adequate representation of drift-wall geometry.

- Demonstrate that models are: (b)
    - consistent with physical observations from tests,
    - appropriate to the expected temperature regime.

- Assess the effect of permeability changes due to coupled thermal-hydrological-mechanical-chemical processes on water flow **or** show that these changes are not significant (a).

a	Additional analyses
b	Additional data and analyses

Summary -- TEF KTI SUBISSUE 1

- Account for the effects of mass and energy losses, from the heated drift to the connecting drift via the thermal bulkhead (and other boundary conditions), on condensate buildup above the heated drift, refluxing during heating, and condensate drainage back to the heated drift during heating and cooling. (b)

a	Additional analyses
b	Additional data and analyses

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

Thermal Effects on Flow

Presented to:
NRC/DOE Technical Exchange
on Yucca Mountain Pre-Licensing Issues

Presented by:

Debbie Barr
Yucca Mountain Site Characterization Office
U. S. Department of Energy

April 26, 2000

YUCCA
MOUNTAIN
PROJECT

Current Status

(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Is the DOE Thermohydrologic Testing Program, Including Performance Confirmation Testing, Sufficient to Evaluate the Potential for Thermal Reflux to Occur in the Near Field?**
  - Most acceptance criteria satisfactorily resolved
  - Remaining issues address expert elicitation and mass/energy losses
- **Subissue 2 - Is the DOE Thermohydrologic Modeling Approach Sufficient to Predict the Nature and Bounds of Thermal Effects on Flow in the Near Field?**
  - Many acceptance criteria remain open

Current Status
(Continued)

- **Subissue 3 - Does the DOE Total System Performance Assessment (TSPA) Adequately Account for Thermal Effects on Flow?**
  - **Many acceptance criteria remain open**

Key Activities

- **Fiscal Year (FY) 1999**
  - Held Thermal Hydrology and Coupled Processes Workshop in March 1999
  - Major areas of workshop included
    - Thermal-hydrological-mechanical (THM)
    - Thermal-hydrological-chemical (THC)
    - Thermal effects of drift seepage
    - Thermal effects on flow

Key Activities
(Continued)

- FY 2000
  - Completed Analysis and Model Reports (AMRs) supporting the Near-Field Environment and Engineered Barrier System Process Model Reports (PMRs)
    - AMR *Thermal Tests Thermal-Hydrological*
    - AMR *Features, Events and Processes in Thermal Hydrology and Coupled Processes*
    - AMR *Drift-Scale Coupled Processes (Drift Scale Test and THC Seepage) Models*
    - AMR *Abstraction of Drift-Scale Coupled Process Model*
    - AMR *Multi-scale Thermohydrologic Model*

Key Activities
(Continued)

- **FY 2001**
  - Plan to address fully coupled thermal-hydrological-mechanical-chemical (THMC) coupling in PMR Revision 1
  - Plan to continue current thermal testing
  - Plan to initiate cross drift thermal test to better understand THMC processes in the lower lithophysal unit

KTI Subissues and Associated Factors of the Safety Case

KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1 - Is the DOE Thermohydrologic Testing Program, including performance Confirmation Testing, Sufficient to Evaluate the Potential for Thermal Reflux to Occur in the Near Field? 2 - Thermohydrologic Modeling Approach 3 - Adequacy of DOE's TSPA with Respect to Thermal Effects on Flow	Coupled Processes – Effects on Unsaturated Zone Flow Coupled Processes – Effects on Seepage	Analyses are currently being conducted to evaluate importance of these factors to repository performance. Completed analyses will be provided for the Site Recommendation Consideration Report.

Subissue 1: Is the DOE Thermohydrologic Testing Program, Including Performance Confirmation Testing, Sufficient to Evaluate the Potential for Thermal Reflux to Occur in the Near Field?

- NRC concerned that excessive uncertainty in analyses may result from unmonitored heat and mass losses in the Drift Scale Test
- Analyses indicate that including an assumed convective boundary condition at the Drift Scale Test bulkhead results in good comparative agreement between measured and simulated temperatures

Subissue 1: Is the DOE Thermohydrologic Testing Program, Including Performance Confirmation Testing, Sufficient to Evaluate the Potential for Thermal Reflux to Occur in the Near Field?

(Continued)

- The lack of accurate measurements of heat loss can be offset by proper numerical modeling
- With proper numerical modeling, DOE considers extensive and more accurate characterization of the heat and mass loss through the Drift Scale Test bulkhead unnecessary

- **Additional measurements of heat and mass loss through the Drift Scale Test bulkhead are planned**

Subissue 2: Is the DOE thermohydrologic Modeling Approach Sufficient to Predict the Nature and Bounds of Thermal Effects on Flow in the Near Field?

- A drift-scale coupled processes model is being developed to evaluate the effects of coupled THC processes on seepage and flow
- Simulation results indicate that thermal loading will produce negligible changes in rock hydrologic properties surrounding the drifts

Subissue 2: Is the DOE Thermohydrologic Modeling Approach Sufficient to Predict the Nature and Bounds of Thermal Effects on Flow in the Near Field?

(Continued)

- **Mountain-scale Thermohydrologic (TH) modeling shows that**
  - Thermal effects on flux are small outside the potential repository
  - Thermal effects on flux near the emplacement drifts cause large changes to the unperturbed fracture flow for more than 1,000 years
- **To account for thermal effects on seepage in the TSPA-SR, the drift seepage model is coupled to the percolation flux provided by the multi-scale TH model**

Subissue 3: Does the DOE TSPA Adequately Account for Thermal Effects on Flow?

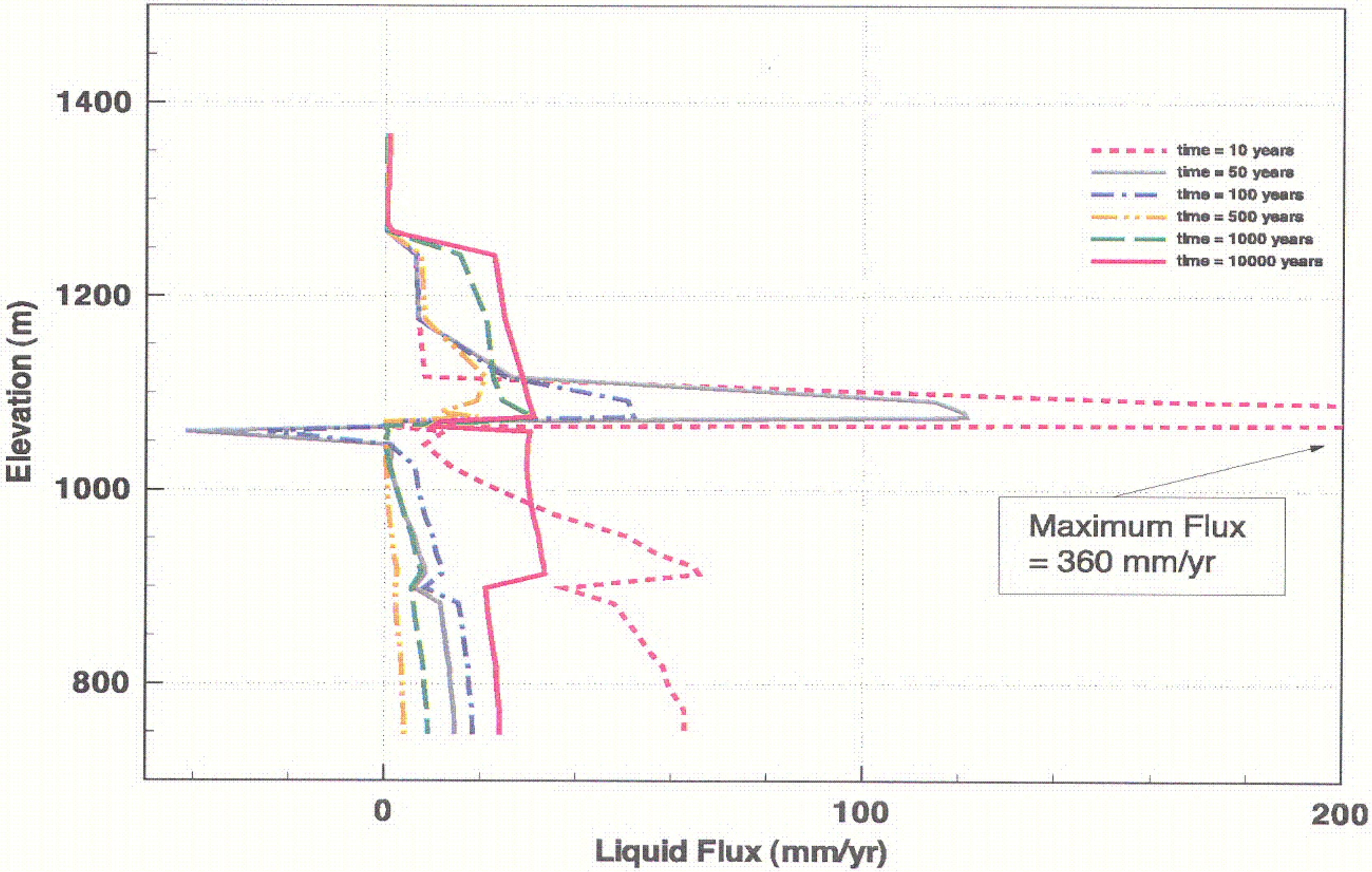
- NRC considers issues open as a result of the heat and mass transfer issue in the Drift Scale Test
- Issue Resolution Status Report (IRSR) states that DOE has not yet demonstrated that the abstracted models used to bound process-level models, which predict water influx into an emplacement drift, are conservative
- IRSR states that process-level models do not yet incorporate all potentially important heat and mass transfer mechanisms

Summary

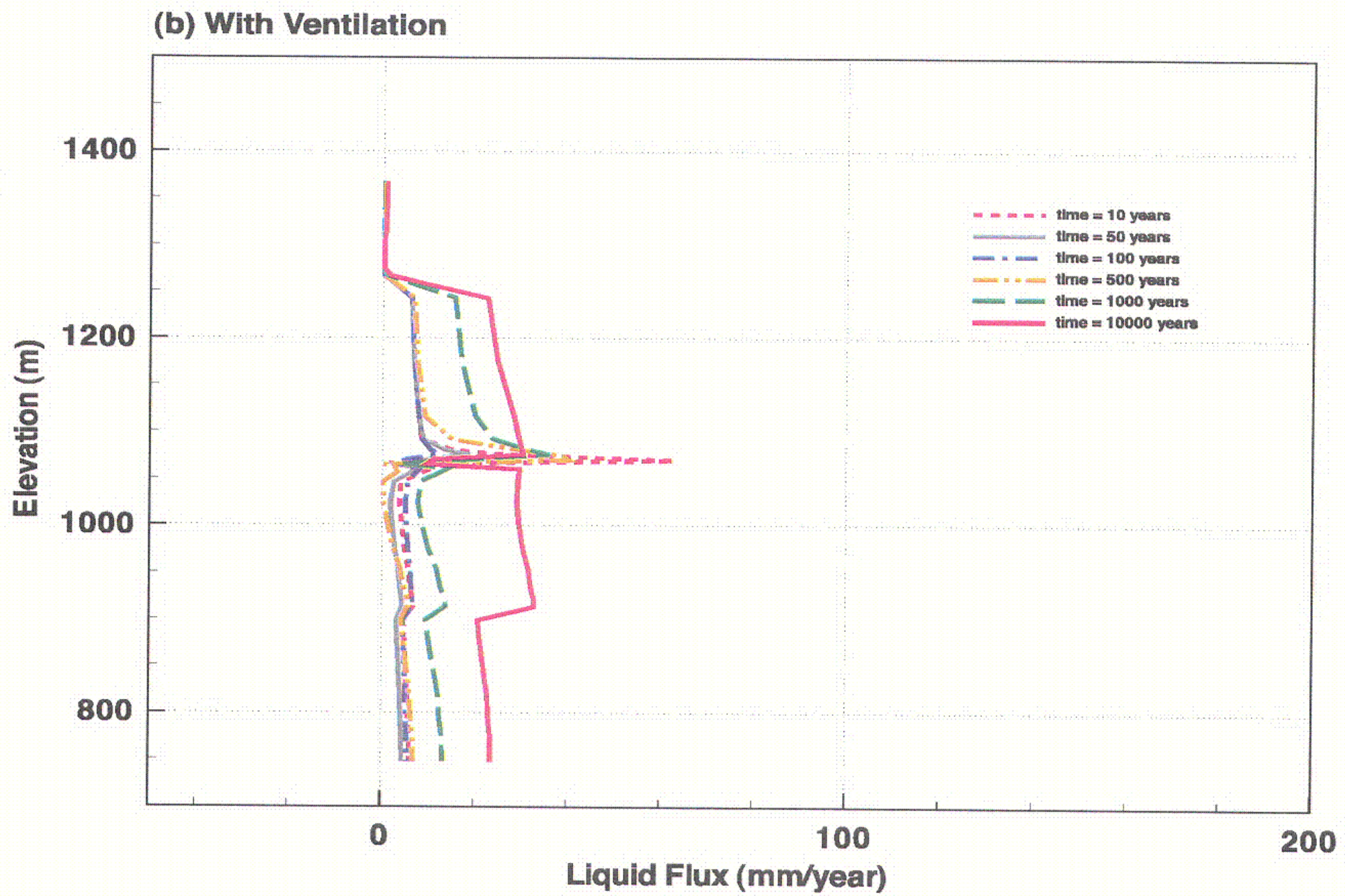
- **Areas of Agreement**
  - Conceptual and mathematical models need to include mechanisms that could lead to water refluxing into the drift
- **Areas of Disagreement (Brocoum letter to Reamer, 3/00)**
  - A number of requirements appear to be more prescriptive than is the intent of the performance-based, proposed 10 CFR Part 63
  - Some of the acceptance criteria inappropriately call for conservatism
  - DOE does not believe it necessary to directly measure all heat and mass losses through the bulkhead for the Drift Scale Test. Extensive and more accurate characterization of the heat and mass loss through the bulkhead is considered difficult and unnecessary

Backup

(a) No Ventilation



Fracture Liquid Flux at Location 31, NS#2 Cross-Section Grid (a) Ventilation



Fracture Liquid Flux at Location 31, NS#2 Cross-Section Grid (b) with Ventilation

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
SUBISSUE 1 - Is the U.S. Department of Energy Thermohydrologic testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?		
Programmatic		
1 - DOE's thermohydrologic testing program was developed under acceptable quality assurance procedures (QAP). Data were collected and documented under purview of these procedures	Open pending continued review of DOE's Quality Assurance (QA) program implementation.	Activities associated with development of Process Model Reports (PMRs) and associated Analysis Model Reports (AMRs) were determined to be subject to the quality assurance program as described in the QARD document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
2 - Expert elicitation may be used for, but not necessarily limited to, assessing if conceptual models bound the range of thermally driven refluxing expected at YM, in addition to thermohydrologic testing to provide conservative bounds to estimates. All expert elicitation are conducted and documented in accordance with NUREG -1563 (Kotra, et al., 1996) or other acceptable approaches	Closed at this time	Agree
Technical Acceptance Criterion (AC) 1		
1.1 - Thermohydrologic tests are designed and conducted with the explicit objective of testing conceptual and numerical models so that critical thermohydrologic processes can be observed and measured	Closed at this time	Agree
1.2 - Thermohydrologic tests are designed and conducted with explicit consideration of TH, thermal-chemical, and hydrologic-chemical couplings	Closed at this time	Agree
1.3 - Thermohydrologic tests are designed and conducted at different scales to discern scale effects on observed phenomena	Closed at this time	Agree
1.4 - Thermohydrologic tests are designed and conducted for temperature ranges expected under repository operating conditions	Closed at this time	Agree
1.5 - Thermohydrologic tests are designed and conducted to determine if water refluxes back to the heaters during either the heating or cool-down phases of the tests	Closed at this time	Agree
1.6 - Thermohydrologic tests are designed and conducted to evaluate the possibility for occurrence of cyclic wetting/drying on WP surfaces	Closed at this time	Agree

Issue Resolution Status Report: Thermal Effects on Flow

Acceptance Criterion	TEF IRSR Rev 2 Status	DOE Comment
1.7 - Thermohydrologic tests are designed and conducted to account for all mass and energy losses/gains in the model system	Open pending resolution of concerns regarding the effect additional uncertainty caused by unmonitored water mass loss through the thermal bulkhead may have on interpretation of DST data.	The Large Block Test had controlled or monitored side boundaries to account for all mass and energy losses/gains. These boundaries consisted of impermeable membrane glued to the side rock surface to prevent loss of water mass through the sides with insulation and heat flux monitoring outside of the membrane to account for the energy losses/gains. Further, there was a temperature control system installed at the top of the block to maintain constant surface temperature. The power input from this system was monitored. There were no controls on water mass movement through the top and bottom of the block, although measurements were made below the block. The Drift Scale Test (DST) was heavily monitored to account for mass and energy losses within the measurement sections. There was only partial control or accounting for energy losses from the ends. Evaluations of impacts of heat/moisture losses in the DST conclude the test is acceptable and heat losses do not invalidate the test. The Quarter Scale Tests measure the amount of water injected into the test cell, the amount of water stored in EBS components, and the amount of water ejected by weighing of the test cell.
1.8 - Thermohydrologic tests are designed and conducted such that the model environment is sufficiently characterized so that the level of uncertainty in property values does not result in unacceptable uncertainty in thermal test interpretation	Closed at this time	Agree
1.9 - Thermohydrologic tests are designed and conducted such that accuracy in the measurement of the test environment saturation is sufficient to discern the relative ability of different conceptual models to represent the TH processes in heated partially saturated, fractured porous media	Closed at this time	Agree
Technical AC 2		
Thermohydrologic test results from other sites and programs have been analyzed and applied, as appropriate, to the YM site	Closed at this time	Agree
Technical AC 3		
If the thermohydrologic testing program is not complete at the time of LA submittal, DOE has explained why the testing program does not need to be completed for the LA and identified specific plans for completion of the testing program as part of the performance confirmation program	Closed at this time	Agree

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
SUBISSUE 2 - Is the U.S. Department of Energy thermohydrologic modeling approach sufficient to predict the nature and bounds of thermal effects on flow in the near field?		
Programmatic Acceptance Criteria		
1 - DOE's thermohydrologic testing program was developed under acceptable quality assurance procedures (QAP). Data were collected and documented under purview of these procedures	Open pending continued review of DOE's QA program implementation.	Activities associated with development of the PMR and related AMRs were determined to be subject to the quality assurance program as described in the QARD document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.
2 - Expert elicitation may be used for, but not necessarily limited to, assessing if conceptual models bound the range of thermally driven refluxing expected at YM, in addition to thermohydrologic testing to provide conservative bounds to estimates. All expert elicitation are conducted and documented in accordance with NUREG -1563 (Kotra, et al., 1996) or other acceptable approaches	Closed at this time	Agree
Technical AC 1		
1.1 - Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that uncertainties and variabilites in parameter values are accounted for using defensible methods. The technical bases for parameter ranges, probability distributions or bounding values used are provided. Parameter values (single values, ranges, probability distributions, or bounding values) are derived from site-specific data or an analysis is included to show the assumed parameter values lead to a conservative effect on performance	Closed at this time	Agree
1.2 - Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated	Closed at this time	Agree
Technical AC 2		
2.1 - Models are based on well-accepted principles of heat and mass transfer applicable to unsaturated geologic media	Closed at this time	Agree

Issue Resolution Status Report: Thermal Effects on Flow

Acceptance Criterion	TEF IRSR Rev 2 Status	DOE Comment
2-2 - Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features	Open pending review of DOE models to incorporate the effects of discrete geologic features as an influence on seepage into drifts, focusing of flow and influence on refluxing water near drifts.	Current models described in the UZ Flow and Transport (UZFT) PMR include processes of evaporation and condensation. The relationships between TH and geochemical processes in zones of boiling, condensation, and drainage in the rock mass outside of the drift and above the heat source are described. Seepage models include an active fracture conceptual model to evaluate the effects of discrete geologic features. The EBS Process Models are based upon NUFT calculations incorporating phase changes for the fracture model. Currently, they do not simulate evaporation and condensation for an open void space. Data on open void space EBS processes are being collected at the current time for the *Water Distribution and Removal Model*, and the *Physical and Chemical Environment Model.* Where appropriate, bounding calculations have been performed for seepage flow to the drift.
2.3 - Models include, at a minimum, an evaluation of important thermohydrological phenomena, such as: (I) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures	Open pending review of TH modeling results including evaluation of DKM conceptual model based on long-term large-scale heater test; simulation of lateral movement of drainage through fractures; and predictions of cold trap formation containing effects of ventilation and radiate heat transfer.	The current repository design has a lower thermal load than the VA design to eliminate dryout zone coalescence. The UZFT PMR summarizes the evaluation of the extent of the dryout zone and time of rewetting for different calibrated property sets and climate scenarios. It also summarizes TH mountain scale models of the effects of temperature changes over the mountain, including effects on flow around the drift. The EBS Multiscale Thermal Hydrologic Model provides analysis of repository of thermohydrological phenomena at various locations within the repository. The degree of multi-drift dry-out zone coalescence will be a function of the thermal load specified in the final design of the repository. Recent, proposed design modifications by DOE to reduce the repository thermal load to 60 MTU/acre will minimize, if not eliminate, dry-out zone coalescence. Recent DOE models that include the active fracture model appear to adequately predict the extent of dryout surrounding the emplacement drifts.
2.4 - Models include all significant repository design features	Open pending review of TH modeling that incorporates the effects of proposed design features on moisture redistribution.	The UZFT PMR summarizes the design features included in the TH model. For example, the THC model uses in-drift geometry and drift spacing, and the thermal and hydrologic properties of the EBS components, such as waste package and invert, from the current design. The models are based upon the current significant EDA-II repository design features as stated in the PMR.
2.5 - Models are capable of accommodating variation in infiltration	Open pending review of TH modeling for effects of spatially variable infiltration coupled with variable heat load of the repository edge.	The TH model incorporates variation in infiltration as discussed in the UZFT PMR. The models described in the EBS PMR have analyzed thermal-hydrological phenomena for the present day, monsoon, and glacial climates.
2.6 - Conceptual model uncertainties have been defined and documented and effects on conclusions regarding performance assessed	Open pending review of TH models for consistency with physical observations, other appropriate heater test or analog site.	Each of the supporting EBS Process Models addresses specific issues of model uncertainty. For uncertain conditions, bounding assumptions are used throughout where appropriate. The UZFT PMR also summarizes conceptual uncertainties.

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
2.7 - Mathematical models are consistent with conceptual models, based on consideration of site characteristics	Closed at this time	Agree
2.8 - Alternative models and modeling approaches, which are consistent with available data and current scientific understanding, have been investigated, limitations defined, and results appropriately considered	Open pending review of TH models and alternative process-level models for critical process-level heat and mass transfer mechanisms.	The UZFT PMR discusses alternative models. The EBS PMR addresses alternative models involving fully coupled THC processes. Such simulation methods can be applied as they become available, and as the required data, including numerical settings used to operate the simulation codes are qualified. The approach used in the EBS PMR is applied to address conceptual issues and to evaluate bounding conditions for the performance of engineered barriers.
2.9 - Results from different mathematical models have been compared to judge robustness of results	Open pending review of comparison of model results from different mathematical models using field-scale measurements (long duration and large spatial distances)	Numerical approaches that can be used for unsaturated, fractured rock have been reviewed in the AMR on conceptual and numerical models for UZ flow and transport as described in the UZFT PMR. The DOE used appropriate procedures to construct and test numerical models for predicting seepage and flow. For the case of the *Water Distribution and Removal Model*, the results of the NUFT calculations were compared to a closed form analytical solution for the prediction of fluxes in and near the EBS. The software codes used for the models are subject to verification and testing under the procedure AP-SI.1Q.
2.10 - Models used to predict shedding around emplacement drifts are shown to contain an adequate level of heterogeneity in media properties	Open pending review of TH models to adequately represent heat and mass transfer mechanisms in heterogeneous media to adequately predict shedding around emplacement drifts.	The UZFT PMR summarizes the approach to evaluating heterogeneities in TH models. The EBS Multiscale TH Model considers 31 chimney locations within the repository that capture an adequate level of heterogeneity in percolation rates at the repository horizon.
2.11 - TH models have been demonstrated to be appropriate for the temperature regime expected at the repository	Open pending review of TH model predictions for consistency with test results or analog site observations for the appropriate temperature regime.	TH models incorporated the anticipated thermal load for the current design as described in the UZFT PMR. The thermal hydrological calculations are appropriate for the expected regime as discussed in EBS PMR. The current EDA-II design is based upon an 80 m emplacement drift spacing with waste canisters placed together to develop a line thermal loading. The repository is a subboiling repository. The models are based upon the NUFT thermal hydrological code that is appropriate for this temperature regime.
2.12 - Models include radiative heat transport unless it is shown that radiative heat loss by a WP is not significant	Closed at this time	Agree

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
2.13 - Models include the effect of ventilation particularly if ventilation could result in deposition or condensation of moisture on a WP surface	Open pending review of TH models for inclusion of potential negative effects of ventilation on moisture condensation and effects on WP corrosion.	Ventilation effects are included in the EBS multiscale thermal hydrological model. Data on EBS processes for evaporation and condensation are being collected at the current time for the *Water Distribution and Removal Model*, and the *Physical and Chemical Environment Model*. Where appropriate, bounding calculations have been performed to estimate physical effects such as the formation of condensation. Effects of ventilation are also included in the UZFT PMR.
2.14 - The media properties of a model contain an adequate level of heterogeneity so that mechanisms such as dripping are not neglected or misrepresented	Open pending review of TH models for adequate level of heterogeneity so that mechanisms such as dripping from refluxing or seepage are appropriately represented given the appropriate heat and mass transfer mechanisms are included.	The drift seepage model has been enhanced to account for heterogeneities as described in the UZFT PMR.
2.15 - Drift wall representations in models contain sufficient physical detail so that processes predicted using a continuum model, such as capillary diversion, are appropriate for the geologic media at the proposed repository horizon	Open pending review of TH models for sufficient detail for DOE to take credit for capillary diversion.	Models predicting seepage include partial drift collapse and multiple realizations of heterogeneous rock properties as described in the UZFT PMR
2.16 - Physical mechanisms such as penetration of the boiling isotherm by flow down a fracture are not omitted from model predictions due to over-simplification or the physical medium or the conceptual model	Open pending review of TH models for necessary mechanisms to ensure that all processes that could lead to water introduction into the drift and onto WPs are included.	The UZFT PMR summarizes the drift seepage models, including enhancements such as the evaluation of partial drift collapse and episodic percolation flux. The UZFT PMR also describes the seepage THC models.
Technical AC 3		
Coupling of processes has been evaluated using a methodology in accordance with NUREG-1466 (Nataraja and Brandshaug, 1992) or other acceptable methodology. Coupled processes may be uncoupled, if it is shown that the uncoupled model results bound the predictions of the fully-coupled model results	Open - TBD	NUREG-1466 provides logical steps for the development of predictive models and their numerical representation of thermally induced TMHC behavior of the host rock. Models of coupled processes in the UZFT PMR present the current approach to modeling drift scale and mountain scale TH effects. The DOE agrees that coupled processes may be uncoupled if the models bound the effects of fully coupled processes. The NFE PMR discusses the evaluation of coupled process effects on the conditions or parameters (e.g., porosity and permeability) that are input to the TH models.
Technical AC 4		
The dimensionality of models, which include heterogeneity at appropriate scales and significant process couplings, may be reduced, if shown that the reduced dimension model bounds the predictions of the full dimension model.	Open pending review of DOE's multiscale modeling to account for gas-phased advection due to large-scale temperature and pressure gradients.	The EBS multiscale thermal hydrologic model considers the appropriate dimensions for specific problems. The potential repository-scale heterogeneity is represented by the drift scale active properties set which captures the properties for various strata. Lateral variability within the potential repository footprint is represented by the 31 drift-scale-model locations used in the

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
		Multi-Scale Thermohydrologic (MSTH) model. These locations are regularly distributed over the potential repository footprint. This reduces the general three-dimensional problem to a series of two-dimensional problems.
Technical AC 5		
Equivalent continuum models are acceptable for the rock matrix and small discrete features, if it can be demonstrated that water in small discrete features is in continuous hydraulic equilibrium with matrix water. Significant discrete features, such as fault zones, should be represented separately unless it can be shown that inclusion in the equivalent continuum model (ECM) produces a conservative effect on calculated overall performance	Open pending review of models for treatment of discrete feature modeling to conservatively bound heat and mass transfer in TSP calculations	Equivalent continuum models summarized in EBS PMR are used as appropriate where conservative bounding assumptions are made. In the *Water Distribution and Removal Model*, an active fracture concept for a dual continuum model is used for the natural barrier system with properties selected from inverse modeling. This modeling approach simulates matrix-fracture interaction. For evaluating the condensation below the drip shield, the Equivalent Continuum Model (ECM) approach was used, and it is considered a bounding calculation since the treatment of the fractured rock as an equivalent continuum tends to retain water within the EBS. The NFE PMR discusses issues dealing with THC effects on properties or with model confidence building. ECM models are not used in drift-scale THC models. The only models used are dual permeability models.
Technical AC 6		
Accepted and well-documented procedures have been adopted to construct and calibrate numerical models used.	Closed at this time	Agree
Technical AC 7		
Results of process-level models have been verified by demonstrated consistency with results/observations from field-scale, thermohydrologic test. In particular, sufficient physical evidence should exist to support the conceptual models used to predict thermally driven flow in the near field	Closed at this time	Agree
SUBISSUE 3 - Does the U.S. Department of Energy Total System Performance Assessment adequately account for thermal effects on flow?		
Programmatic Acceptance criteria		
1 - DOE's analyses were developed and documented under acceptable QA procedures	Open pending continued review of DOE's QA program implementation.	Activities associated with development of the PMR and related AMRs were determined to be subject to the quality assurance program as described in the QARD document. As such, collection of related data, development of analyses and models, and use and validation of software are subject to the requirements of procedures developed to implement quality assurance program requirements.

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
2 - Expert elicitation may be used for, but not necessarily limited to, justifying the use of abstracted models in DOE's TSPA. All expert elicitation are conducted and documented in accordance with NUREG-1563 (Kotra, et al., 1996) or other acceptable procedures	Closed at this time	Agree
Technical AC 1		
Abstractions of process-level models may be used if predictions from the abstracted model are shown to conservatively bound process-level predictions. In particular, DOE may use an abstracted model to predict water influx into an emplacement drift if the abstracted model is shown to bound process-level model predictions of the influx of water as liquid or vapor into an emplacement drift	Open pending review of abstracted models used to bound process-level models that predict water influx into an emplacement drift for incorporation of all potentially important heat and mass transfer mechanisms	The UZFT PMR summarizes the abstraction of seepage into drifts. Distributions for the amount of seepage as a function of percolation flux are derived directly from process-model results. They are constrained by measurements of permeability around three niches in the Exploratory Studies Facility (ESF) and calibration of seepage tests conducted in one niche in the ESF.
Technical AC 2		
2.1 - Sufficient data are available to adequately define relevant parameter values and conceptual models. Demonstrate that, uncertainties and variabilities in parameter values are accounted for using defensible methods. The technical bases for parameter ranges, probability distributions or bounding values used are provoked. Parameter values (single values, ranges, probability distributions, or bounding values) are derived from site-specific data or an analysis is included to show the assumed parameter values lead to conservative effect on performance	Closed at this time	Agree
2.2 - Sufficient data are available to adequately define relevant parameter values and conceptual models. Demonstrate that, analysis are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated	Closed at this time	Agree

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
Technical AC 3		
3.1 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, performance affecting heat and mass transfer mechanisms, including processes observed in available thermohydrologic tests and experiments, have been identified and incorporated into the TSPA. Specifically, it is necessary to either demonstrate that liquid water will not reflux into the underground facility or incorporate refluxing water into the TSPA and bound the potential adverse effects of: (i) corrosion of the WP; (ii) accelerated transport of radionuclides; and (iii) alteration of hydraulic and transport pathways that result from refluxing water	Open pending review of models for incorporation of heat and mass transport mechanisms hat could lead to water refluxing into the drift, heterogeneity to ensure critical heat and mass transfer mechanisms are not masked and use of "high-seepage" alternative model for conservatism.	The UZFT PMR summarizes the evaluation of flow changes close to drifts and drainage in the pillars. The EBS process models incorporate thermal refluxing in the thermal hydrological calculations. The Water Distribution Model and the Multiscale Thermal-Hydrologic Model consider the waste package heat loading for the EDA-II design. The TH calculations consider the effects of this heat loading on the reduction of liquid moisture content, and the reduction in capillary pressure due to initial heating in EBS components and the surrounding media. After waste package heat decays, the models simulate the increase in liquid moisture content and increase in capillary pressure due to the refluxing of water.
3.2 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, significant Geologic Repository Operations Area underground facility design features, such as the addition of backfill of drip shields, that can result in changes in TSP have been identified and incorporated in to the TSPA	Closed at this time	Agree
3.3 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, conceptual model uncertainties have been defined and documented, and their effects on conclusions regarding TSP have been assessed.	Open pending review of models for incorporation of effects of refluxed water into TSPA.	The UZFT PMR summarizes the evaluation of flux into drifts during and after the thermal period. In addition, each of the major process models is documented in a referenced report that includes a discussion of the model uncertainties.
3.4 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Mathematical models are consistent with conceptual models, based on consideration of site characteristics	Open pending review of models to confirm mass balance in models	Modeling approaches for thermal effects are summarized in the UZFT PMR. The EBS process models for thermal hydrological effects are based upon initial conditions boundary conditions, and computational domains consistent with site characteristics. The thermal hydrology models are based upon the selection of natural barrier system hydrologic and thermal properties used in the UZ Process Model. The initial conditions and boundary conditions for the models for specific locations use the same infiltration rates, and temperature and pressure boundary conditions consistent with the UZ Process Model.
3.5 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, alternative models and modeling approaches, consistent with available data and	Open pending review of models alternative process models for critical heat and mass transfer mechanisms.	Alternative models are presented in the EBS PMR, including models for *Water Distribution and Removal, Bulk Physical and Chemical Environment in the EBS*, and *Radionuclide Transport* respectively. The approach used in the EBS PMR is applied to address conceptual issues and to evaluate bounding

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
current scientific understanding, are investigated; limitations defined; and results appropriately considered		conditions for the performance of engineered barriers. Alternative modeling approaches are also discussed in the UZFT PMR
3.6 - Descriptions of conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further, DOE should demonstrate that, results from different mathematical models have been compared to judge robustness of results	Open pending review sensitivity analyses for robustness of models.	Sensitivity analyses will be included in TSPA-SR. The results of the numerical calculations have been compared to hand calculations where appropriate. The DOE used appropriate procedures to construct and test numerical models for predicting seepage and flow. For the case of the *Water Distribution and Removal Model*, the results of the NUFT calculations were compared to a closed form analytical solution for the prediction of fluxes in and near the EBS. The software codes used for the models are subject to verification and testing under the procedure AP-SI.1Q.
Technical AC 4		
Coupling of thermal processes has been evaluated using a methodology in accordance with NUREG-1466 (Nataraja and Brandshaug, 1992) or other acceptable methodology. Coupled processes may be uncoupled, if it is shown that the uncoupled model results bound the predictions of the fully-coupled model results.	Open - TBD	NUREG-1466 provides logical steps for the development of predictive models and their numerical representation of thermally induced THMC behavior of the host rock. The UZFT PMR summarizes the approach to evaluating coupled processes at the drift-scale and mountain-scale. The DOE agrees that coupled processes may be uncoupled if the models bound the effects of fully coupled processes.
Technical AC 5		
The dimensionality of models used to assess the importance of refluxing water on repository performance may be reduced if it is shown that the reduced dimension model bounds the predictions of the full dimension model in performance	Open pending review of DOE's multiscale modeling to account for gas-phased advection due to large-scale temperature and pressure gradients.	The EBS Process Model uses boundary calculations where appropriate. The potential repository-scale heterogeneity is represented by the drift scale active properties set which captures the properties for various strata. Lateral variability within the potential repository footprint is represented by the 31 drift-scale-model locations used in the MSTH model. These locations are regularly distributed over the potential repository footprint. This reduces the general three dimensional problem to a series of two dimensional problems.
Technical AC 6		
Results of the TSPA related to TEF have been verified by demonstrating consistency with results of process-level models.	Open pending review of process-level models for incorporation of important heat and mass transfer mechanisms.	TSPA analyses related to TEF were based on the process level models. The EBS Process Model uses bounding calculations where appropriate.

Issue Resolution Status Report: Thermal Effects on Flow		
Acceptance Criterion	**TEF IRSR Rev 2 Status**	**DOE Comment**
Technical AC 7		
Sensitivity and importance analyses were conducted to assess the need for additional data or information with respect to TEF	Open pending review of sensitivity analyses for TSPA.	Sensitivity analyses will be included in TSPA-SR. Sensitivity analyses are conducted where appropriate in the EBS Process Models. Data on EBS processes are being collected at the current time for the *Water Distribution and Removal Model*, and the *Physical and Chemical Environment Model*. Where appropriate, sensitivity and importance analyses have been performed as described by the parametric studies

KEY TECHNICAL ISSUE (KTI)
RADIONUCLIDE TRANSPORT (RT)

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NRC/DOE TECHNICAL EXCHANGE
PRE-LICENSING ISSUE RESOLUTION STATUS
APRIL 25-26, 2000

Radionuclide Transport Subissues

Current Status

- Subissue 1: Radionuclide Transport through Porous Rock -Open
- Subissue 2: Radionuclide Transport through Alluvium -Open
- Subissue 3: Radionuclide Transport through Fractured Rock -Open
- Subissue 4: Nuclear Criticality in the Far Field -Closed Pending Confirmation
- All four subissues are related to:
  - RSS Principal Factors: Transport through UZ and SZ
  - NRC Abstractions: Radionuclide Transport in the UZ and SZ

Subissues 1 & 2: Radionuclide Transport through Porous Rock/Alluvium

- Background
  - In developing acceptance criteria, the staff assumed DOE would use one or more of the following model abstractions for retardation in PA:
    - 1) Kd = 0. No interaction
    - 2) Constant Kd approach
    - 3) Process models (i.e., more complex models where sorption is a function of additional parameters)

  Format of Remaining Viewgraphs
- Model Abstraction
  - Information Need
    - Reason for Information Need
      - Example of data gap or status of effort

Subissues 1 & 2: Radionuclide Transport through Porous Rock/Alluvium

Status: Open

- For $K_d = 0$ approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- Provide information on effective porosity
  - Affects travel time to critical group; could affect performance if radionuclides reach critical group before 10,000 years
    - Flowpaths through alluvium have yet to be characterized.
- Demonstrate $K_d = 0$ assumption doesn't underestimate dose
  - Certain special conditions can lead to radionuclide flux that exceeds flux when $K_d = 0$ is assumed.
    - Irreversible sorption of radionuclides on mobile particulates and colloids, e.g., Pu migration from Benham event?

Subissues 1 & 2: Radionuclide Transport through Porous Rock/Alluvium

Status: Open

- For constant K_d approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- Provide information to demonstrate appropriate values of parameters are used in equation, $R_f = 1 + (\rho/n)K_d$
  - Sorption characterization is incomplete
    - Of the 21 Key Radionuclides identified in the RSS (Rev 3), 5 untested using site-specific materials (Pd, Sm, Pb, Ac, & Cm)
    - Ground-water chemistries unbounded for 4 other Key Radionuclides (Se, Pa, Ni, U)
    - Plutonium experiments failed to reach steady state

Subissues 1 & 2: Radionuclide Transport through Porous Rock/Alluvium

Status: Open

- For constant K_d approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- ▸ Provide information to demonstrate appropriate values of parameters are used in equation, $R_f = 1 + (\rho/n)K_d$
  - – Transport characterization is incomplete
    - – Flow-through column tests have been performed involving only 4 radionuclides (Se, Tc, Np, & Pu)
    - – Colloids, evident in batch sorption tests, could affect breakthrough curves in dynamic system (e.g., Th, Sn, & Nb)
    - – Batch sorption tests at initial radionuclide concentrations that exceed solubility limits make K_d's suspect (e.g., U, Np)
    - – Plutonium elution is a function of flowrate, inconsistent with constant K_d approach.

Subissues 1 & 2: Radionuclide Transport through Porous Rock/Alluvium

Status: Open

- For constant K_d approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- Provide information to demonstrate that flowpath acts as a single continuum porous medium.
  - Preferential pathways can bypass potential sorbing material along the flowpath
  - The abstraction that allows the use of Kd's determined in static tests for predicting retardation under dynamic conditions requires the medium be porous.
    - Flowpaths through alluvium have yet to be characterized.
    - Calico Hills nonwelded vitric is being tested in Busted Butte.

Subissue 3: Radionuclide Transport through Fractured Rock

Status: Open

- For $K_d = 0$ approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- Provide information on effective porosity
  - Same as for transport through porous rock/alluvium
- Demonstrate $K_d = 0$ assumption doesn't underestimate dose
  - Same as for transport through porous rock/alluvium
- Justify the length of flowpath to which these fracture transport conditions apply.
  - Affects travel time to critical group; could affect performance if radionuclides reach critical group before 10,000 years
    - The length of flow path in the fractured rock has yet to be established (e.g., the contact between the tuff aquifer and alluvium, valley fill is uncertain).

Subissue 3: Radionuclide Transport through Fractured Rock

Status: Open

- For retardation/attenuation approach (Model Acceptable)

Additional Data and/or Analysis needed by LA

- Demonstrate capability to predict breakthrough curves of reactive, non-reactive, and colloidal tracers.
  - The estimation of transport through fractured rock is relatively untested.
    - C-hole reactive tracer tests are the only field tests demonstrating transport in the SZ at YM, and thus take on added importance.
    - The C-hole breakthrough curves (concentration and travel time) could not be quantitatively predicted using laboratory experiments alone or in concert with hydraulic pump tests.

Subissue 3: Radionuclide Transport through Fractured Rock

Status: Open

- **For retardation/attenuation approach (Model Acceptable)**

Additional Data and/or Analysis needed by LA

- Demonstrate nonradioactive tracers used in field tests are appropriate homologues for radioelements.
  - Processes affecting tracers and radionuclides should be the same.
    - Excavated blocks from Busted Butte to be tested at AECL
- Justify the length of flowpath to which these fracture transport conditions apply.
  - Same as for transport through porous rock/alluvium

Subissue 4: Nuclear Criticality in the Far Field

Status: Closed Pending Confirmation

- Need for additional analysis
  - Provide technical basis for exclusion of criticality in the far-field environment FEP

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

Radionuclide Transport

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Jim Houseworth
Civilian Radioactive Waste Management System Management and Operating Contractor

April 26, 2000

YUCCA MOUNTAIN PROJECT

Current Status

(Issue Resolution Status Report Revision 1)

- **Subissue 1 - Radionuclide Transport through Porous Rock**
  - Subissue closed for neptunium, but other radionuclides (e.g., plutonium and uranium) require further work
  - Subissue closure for each radionuclide of importance does not require closure of all 3 technical acceptance criteria, because the criteria allow alternative approaches to transport modeling

Current Status

(Issue Resolution Status Report Revision 1)
(Continued)

- **Subissue 2 - Radionuclide Transport through Alluvium**
  - Same technical acceptance criteria as for Subissue 1
  - Assumption that alluvium acts as a homogeneous porous medium may be nonconservative; limited data are available to support the assumption
  - Further field and laboratory testing in the Nye County program is expected to supply the needed geologic and hydrologic data

Current Status

(Issue Resolution Status Report Revision 1))
(Continued)

- **Subissue 3 - Radionuclide Transport in Fractured Rock**
  - Two technical acceptance criteria open for lack of geostatistical analysis justifying the flowpath length of fracture transport

Current Status

(Issue Resolution Status Report Revision 1)
(Continued)

- **Current Status**
  - **Subissue 4 - Nuclear Criticality in the Far Field**
    - **Subissue (with 2 acceptance criteria) is resolved at staff level based upon evaluation process presented in Viability Assessment (VA), establishing a path toward resolution**
    - **Review of topical report and Analysis and Model Reports or Process Model Reports describing screening of criticality will be performed in support of safety evaluation report**

Key Activities

- **Fiscal Year (FY) 1998**
  - Conducted C-wells tracer transport field test in the saturated zone. Developed unsaturated zone (UZ) flow and transport modeling methodology
    - C-wells testing provided field data on conservative and reactive tracer transport and colloid transport used to establish matrix diffusion and colloid retardation parameters for fractured rock
    - For the VA, developed methodology for UZ flow and transport based on quasi-steady UZ flow combined with three-dimensional (3D) particle tracking directly coupled with Total System Performance Assessment (TSPA)

Key Activities

(Continued)

- **FY 1999**
  - UZ and Saturated Zone (SZ) workshops for flow and radionuclide transport identified the following areas for additional work, which was performed:
    - Develop more defensible colloid transport model for Performance Assessment
    - Compare particle tracking with alternative calculation methods
    - Improve matrix diffusion model
    - Refine Engineered Barrier System (EBS)/UZ interfaces
    - Validate model from site data and/or analog sites

Key Activities

(Continued)

- **FY 2000**
  - Developed improved flow and transport models for UZ and SZ
    - Developed active fracture model for UZ flow fracture/matrix interaction
    - Included effects of fracture/matrix contact area as developed in the active fracture model on fracture spacing and matrix diffusion in the UZ
    - Developed improved 3D SZ flow model and 3D particle tracking model for transport
    - Continued data collection and analysis for C-wells tracer transport field test and Busted Butte Facility

Key Activities
(Continued)

- **FY 2001**
  - Plan to conduct Busted Butte UZ transport tests, UZ cross-over drift (Exploratory Studies Facility) test, and SZ alluvial testing complex
    - For Busted Butte (CHnv)
      - » Field verification of porous medium flow behavior
      - » Field verification of sorption and improved sorption characterization
      - » Field data for colloid transport behavior
    - For cross-over drift
      - » Field verification of transport processes in fractured rock, including matrix diffusion
      - » Effects of lithologic unit boundaries on transport

Key Activities
(Continued)

- **FY 2001** (Continued)
  - Plan to conduct Busted Butte UZ transport tests, UZ cross-over drift (Exploratory Studies Facility) test, and SZ alluvial testing complex (Continued)
    - For alluvial testing complex
      - » Improved data on the location of contacts for the alluvium
      - » Improved flow and transport characterization in alluvium

KTI Subissues and Associated Factors of the Safety Case

KTI SubIssues	Associated Factors of the Safety Case	Importance to Repository Performance
1 Radionuclide Transport Through Porous Rock	UZ Radionuclide Transport (Advective Pathways, Retardation, Dispersion, Dilution)	Retardation of radionuclide transport in the UZ and SZ are Principal Factors.
2 Radionuclide Transport Through Alluvium	SZ Flow and Transport- (Advective Pathways, Retardation, Dispersion, Dilution)	
3 Radionuclide Transport Through Fractured Rock	UZ Radionuclide Transport and SZ Flow and Radionuclide Transport (Advective Pathways, Retardation, Dispersion, Dilution)	
4 Nuclear Criticality In The Far Field	None	Features, events, and processes associated with this subissue are not included. The basis for this exclusion will be provided.

Subissues 1-3 - Radionuclide Transport through Porous Rock, Alluvium, and Fractured Rock

- **For these subissues the focus is on 1 acceptance criterion. These are examples of criteria that map to the postclosure safety case**
  - Subissue 1-Radionuclide Transport through Porous Rock
    - Criterion 2: Constant sorption coefficient (K_d) approach for estimating radionuclide transport through porous rock
  - Subissue 2-Radionuclide Transport through Alluvium
    - Criterion 2: Constant K_d approach for estimating radionuclide transport through alluvium
  - Subissue 3-Radionuclide Transport through Fractured Rock
    - Criterion 2: Radionuclide attenuation in fractured rock

Subissue 1- Radionuclide Transport through Porous Rock

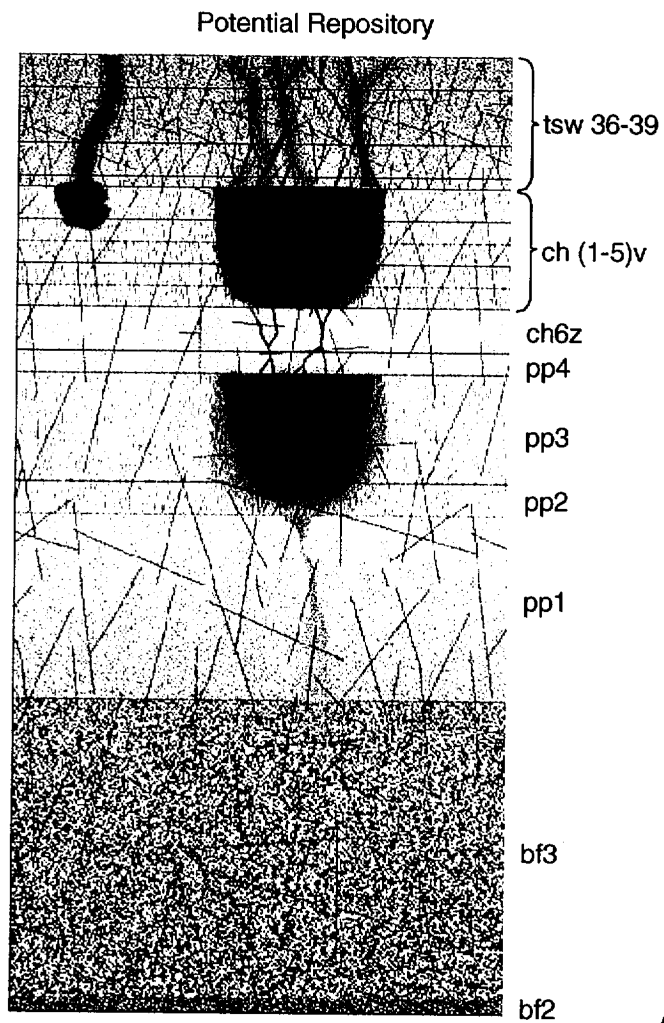
- Porous rock only present in Calico Hills and Prow Pass vitric. No porous rock in SZ
- Using constant K_d approach for estimating radionuclide transport through porous rock
  - Current approach uses constant K_d based on laboratory measurements using site-specific rock and groundwaters
    - Batch sorption
    - Crushed tuff column experiments
    - Expected range of geochemical conditions
  - Sorption isotherms have been shown to be linear or nonlinear with convex-up shape

Subissue 1- Radionuclide Transport through Porous Rock
(Continued)

- Field evidence for porous medium flow behavior, sorption in porous rock, and colloid transport is being developed from the Busted Butte testing program
- The use of the constant K_d approach relative to nonequilibrium effects has been established for neptunium but requires further demonstration for plutonium and uranium

Subissue 1- Radionuclide Transport through Porous Rock
(Continued)

Conceptual Model of Radionuclide Transport in the UZ



Subissue 1- Radionuclide Transport through Porous Rock

(Continued)

- The effects of variations in groundwater chemistry have been partially addressed by calculations of thermal-hydrological-chemical (THC) effects near the emplacement drifts
- Colloid-facilitated radionuclide transport considers radionuclides to be either
  - Irreversibly attached to colloid
  - Reversibly attached in equilibrium with the aqueous phase
- Relative amounts of the differing colloid types based on waste form releases
- Plutonium, americium, thorium, and protactinium are subject to colloid-facilitated transport

Subissue 1- Radionuclide Transport through Porous Rock
(Continued)

- Treatment of colloid-facilitated radionuclide transport in porous rock
  - No matrix diffusion of colloids
  - Accounts for size exclusion to enter matrix from fractures (by advection)
  - Accounts for filtration between matrix units having differing pore size distributions - no other filtration mechanisms are included

Subissue 2- Radionuclide Transport through Alluvium

- **Using constant K_d approach for estimating radionuclide transport through alluvium**
  - **Batch sorption measurements have been conducted for neptunium, technetium, and iodine using rock and water samples obtained from three wells drilled as part of Nye County-Early Warning Drilling Program**
  - **Time-series experiments were conducted to investigate sorption kinetics**

Subissue 2- Radionuclide Transport through Alluvium
(Continued)

Sorption Coefficients in Alluvium (ml/g)

Borehole	Depth (ft)	Np K_d	Tc K_d	I K_d
02D	395-400	44	0.8	0.4
	400-405	77	0.6	
	405-410	5.3	0.4	
	410-415	9.3	0.5	
09SX	145-150	4.7	0.8	0.4
	150-155	5.3	0.7	
	155-160	6.7	0.7	
	160-165	6.2	0.5	
03S	60-65	44.5	0.8	0.7
	65-70	36.5	0.6	
	70-75	18	0.6	
	75-80	15.5	0.6	

Subissue 2 - Radionuclide Transport through Alluvium
(Continued)

- Activities in progress at the alluvium testing complex are investigating:
  - Behavior of the alluvium as a single continuous porous medium
  - Effective porosity
  - Field sorption behavior
  - Colloid transport
- Colloid transport in the alluvium is treated in the same manner as transport through fractured rock

Subissue 3 - Radionuclide Transport through Fractured Rock

- **Radionuclide Attenuation in Fractured Rock**
  - **For the UZ**
    - **Radionuclide attenuation in fractured rock is due to:**
      - » **Advective exchange between fractures and matrix**
      - » **Matrix diffusion**
      - » **Sorption in matrix (no sorption in fractures)**
    - **Advective exchange between fractures and matrix is calibrated to field saturation and capillary pressure data using the active fracture model for fracture/matrix interaction**

Subissue 3 - Radionuclide Transport through Fractured Rock

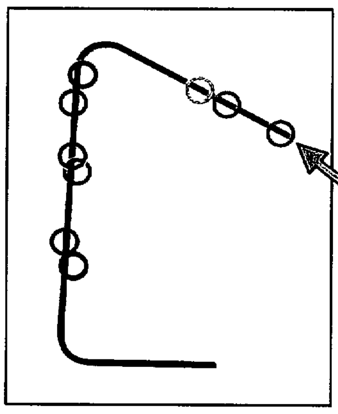
(Continued)

- Range of matrix diffusion values determined by laboratory experiments
  - » Fracture/matrix area reduction (given by the active fracture model) is incorporated into the matrix diffusion calculation
- Transport methodology has been compared to geochemical data (chloride concentrations) observed in the Exploratory Studies Facility (ESF) and ESF tracer transport tests
- The treatment of sorption in the matrix is the same as outlined for porous rock
- Colloid transport occurs in both the matrix and fractures
  - » Matrix interaction the same as outlined for porous rock
  - » Fracture transport is attenuated by retardation based on C-wells data

Subissue 3: Radionuclide Transport through Fractured Rock

(Continued)

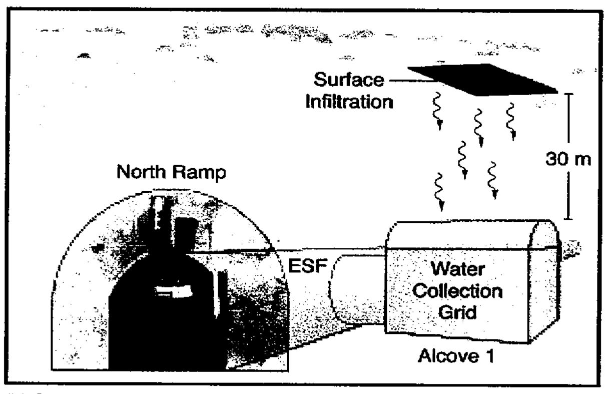
El Niño Infiltration Test at Alcove 1



(a) Photography of ESF North Portal and Infiltration Plot (Blue Cover)

Objectives:
- Quantify large-scale infiltration and seepage processes in the bedrock.
- Evaluate matrix diffusion mechanism in long-term flow and transport tests.

Approaches:
- Water applied on the surface 30 m directly above the alcove.
- Tests conducted in two phases: March - August 1998 and May 1999 - present, with Phase 1 focusing on flow and Phase 2 focusing on tracer transport.



(b) Schematic of Alcove 1 Infiltration Test

UZPMR2.2-8REV00

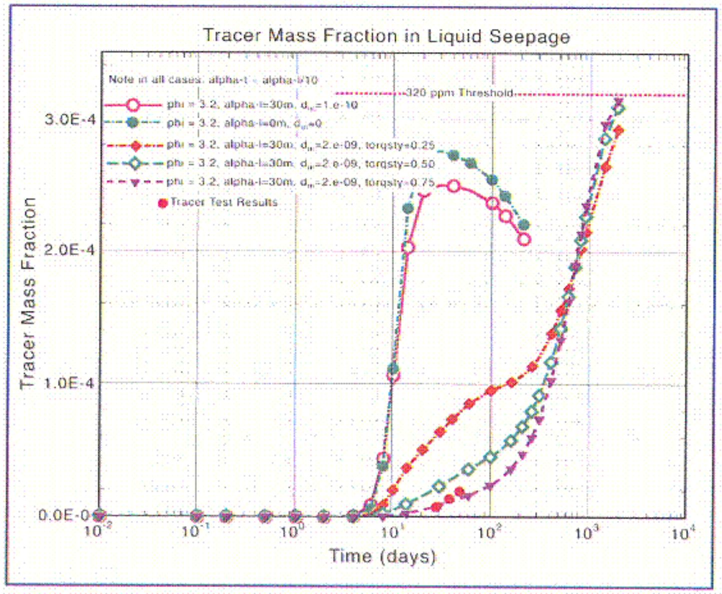
Subissue 3: Radionuclide Transport through Fractured Rock

(Continued)

El Niño Infiltration Test at Alcove 1

Results:

- Over 100,000 liters infiltrated in Phase 1, with observed seepage rates of up to 300 liter/day.
- Pressure/flow response times were on the order of 2 days, with the exception of the first seepage in 58 days.
- High concentrations of LiBr were used in Phase 2 tracer test.
- Tracer recovery data were used to compare with model predictions and to evaluate the importance of matrix diffusion.



(c) Tracer Breakthoughs Test Results and Model Predictions with Matrix Diffusion

UZPMR2.2-8REV00

C11

Subissue 3 - Radionuclide Transport through Fractured Rock

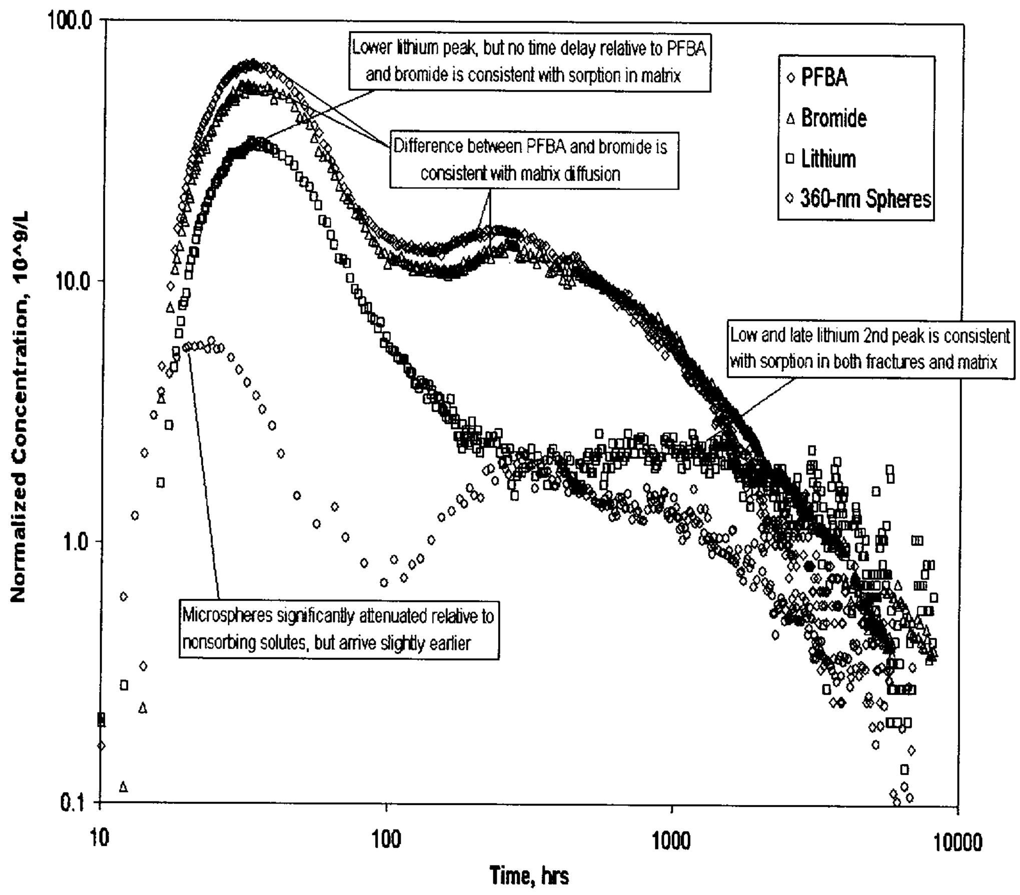
(Continued)

- For the SZ
  - Radionuclide attenuation in fractured rock is due to:
    - » Matrix diffusion
    - » Sorption in matrix (no sorption in fractures)
  - A range of effective matrix diffusion values has been estimated from C-wells testing
  - Transport methodology has been compared to C-wells tracer transport observations
  - The treatment of sorption in the matrix is the same as outlined for porous rock
  - Colloid transport occurs in the fractures only
    - » Fracture transport is attenuated by retardation based on C-wells data

Subissue 3 - Radionuclide Transport through Fractured Rock

(Continued)

C-Well validation of Matrix Diffusion and Sorption Mechanisms



- Model of fracture flow and matrix diffusion consistent with data
  - Model assumes linear isotherm, equilibrium, reversible sorption
  - None of the K_ds are deterministic, all are stochastic in the TSPA analysis
- Sorbing tracer (Li) breakthrough consistent with combined matrix diffusion/sorption model
- Microspheres break through slightly earlier than solutes, but are attenuated

Subissue 4 - Radionuclide Transport through Fractured Rock

- **Nuclear Criticality in the Far Field**
  - DOE is evaluating criticality using methodology from the topical report on criticality and its supporting documents
  - DOE expects to screen out far-field criticality from the TSPA based on low probability

Summary

- **Current Understanding:**
  - UZ flow and transport models provide a reasonable basis for representing retardation in the UZ (Subissue 1)
  - SZ flow and transport model provides a reasonable basis for representing retardation in the SZ (Subissue 2 and 3)
  - Sorption in porous rock and the alluvium is conservatively represented using the constant Kd approach (Subissues 1 and 2)
  - No fracture retardation on fracture surfaces for aqueous radionuclides; colloid retardation based on C-wells data sorption in rock matrix (Subissue 3)

Summary
(Continued)

- **DOE suggests moving subissues under this KTI to the KTI on Unsaturated and Saturated Flow Under Isothermal Conditions**

Summary
(Continued)

- **Areas of Agreement**
  - Subissues on transport through porous rock, alluvium, and fractured rock are partially resolved
  - Subissue on far-field nuclear criticality is resolved based on the proposed evaluation methods

Summary
(Continued)

- **Areas of Potential Disagreement (Letter, Brocoum to Reamer, 03/22/00)**
  - **Homogeneity of porous rock or alluvium does not need to be demonstrated at all scales**
    - **Homogeneity only needs to be addressed at the level of assumed homogeneity in the model, for example, the grid discretization or level of heterogeneity modeled**
  - **Bounding future chemistry of groundwater cannot be proved for this system**
    - **Use of bounding geochemical behavior that can be demonstrated to be reasonable is more appropriate**

Backup

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
Subissue 1- Radionuclide Transport through Porous Rock		
1a For the estimation of radionuclide transport through porous rock, DOE has determined through PA calculations whether radionuclide attenuation processes such as sorption, precipitation, radioactive decay, and colloidal filtration are important to performance	The staff considers that this acceptance criterion has been met for radionuclides important to performance. However, as processes, conditions, and conceptual models are revised based on new site characterization information and repository designs, it is expected that new sensitivity analyses would be needed. The only situation where this criterion would not be met would occur if DOE failed to consider a radionuclide in its PA that the NRC staff considered to be important.	The processes of hydrodynamic dispersion, matrix diffusion, sorption (solutes), filtration (colloids), and radioactive decay are considered important to performance for the UZ and are all explicitly modeled in the UZ transport model abstraction.
1b For the estimation of radionuclide transport through porous rock, DOE has:(i) Assumed K_d is zero and radionuclides travel at the rate of groundwater flow, if it has been found that radionuclide attenuation is unimportant to performance and it can be demonstrated that this assumption is conservative in which case, Acceptance Criteria 2 and 3 do not have to be met or, (ii) demonstrated that Criterion 2 or 3 has been met, if radionuclide attenuation in porous rock is important to performance, or if an assumption that K_d is zero in porous rock is not conservative.	The staff agrees with the selection of C, Tc, I, and Cl as having a K_d of zero, for use in PAs. The staff recognizes, however, that there may be other elements or species that, under certain situations, have a K_d of zero. There are examples where multiple species of a single radionuclide exist in solution at the same time. Therefore, it is important to perform flow-through column tests for identifying mobile species (see status of Methodology 2b below).	Kd is assumed to be zero for C, Tc, I, and Cl.
2a For the valid application of the constant Kd approach, using equation (1) $Rf = 1+\rho Kd/n$, (or $Rf=1+\rho_b Kd/\theta$), DOE has: Demonstrated that the flow path acts as a single continuum porous medium. If the flow can not be shown to be a single continuum porous medium, then the acceptance criteria for radionuclide transport in fractured rock apply.	It remains to be demonstrated that the Calico Hills nonwelded vitric: unit and the alluvium behave as a single continuum porous media. Phase II of the UZ Field Transport Test at Busted Butte involve identifying possible "fast pathways" within the Calico Hills block and performing cross hole tracer tests using conservative and reactive tracers. The effect of variable flow rates on tracer breakthrough will be determined. The NRC staff	The vitric portion of the Calico Hills hydrogeologic units behaves as a porous medium and provides an effective barrier to radionuclide transport. The upper units of the Prow Pass hydrogeologic unit also behave as a porous medium.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
	considers this type of experiment important for demonstrating transport through porous rock.	
2b (methodologies 1-7) For the valid application of the constant K_d approach, using equation (1) $R_f = 1+\rho_b K_d/n$, (or $R_f = 1+\rho_b K_d/\theta$), DOE has: Demonstrated that appropriate values for the parameters, K_d, n or θ, and ρ_b have been adequately considered (e.g., experimentally determined or measured).	The NRC staff considers the sorption coefficients determined from nonsite-specific batch sorption experiments much less certain for application to YM PA calculations than those determined using site specific materials. A general concern of the NRC staff is that although site-specific materials may be used in the batch sorption tests, certain combinations of groundwaters and solids may be unnatural and not expected in the YM environment. Column experiments have been performed to confirm batch sorption K_d values for plutonium, neptunium, and technetium. The criterion has not been met for any other elements. The NRC staff concludes that, although crushed tuff flow-through column experiments have been performed, the criterion to confirm the K_d determined in static tests are appropriate for calculating a retardation in dynamic systems has not been met for plutonium. It was demonstrated that the migration of selenium could be estimated conservatively from batch sorption tests. Similar experiments have not been performed using any of the other radionuclides. Diffusion experiments have been performed for tritium, technetium, neptunium, americium, strontium, cesium, and barium. The discrepancy between the observed and calculated concentrations	Details of the experimental program are provided in the Yucca Mountain Site Description.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
	suggests that one or more of the assumptions are incorrect. The Busted Butte Unsaturated Transport tests are expected to provide additional important information on unsaturated flow and transport in the Topopah Spring and Calico Hills tuffs at the field scale.	
2c (methodologies 1-3) For the valid application of the constant K_d approach, using equation (1) $R_f = 1+\rho_b K_d/n$, (or $R_f = 1+\rho_b K_d/\theta$) DOE has: Demonstrated that the following assumptions (i.e., linear isotherm, fast reversible sorption reaction, and constant bulk chemistry) are valid.	The NRC staff considers that this criterion has not been met for plutonium. Neither has the removal of plutonium from solution been shown to be the result of an ion exchange or adsorption reaction nor has the reaction been shown to be fast. An implicit assumption in using K_d to describe radionuclide sorption is that the chemistry of the groundwater is constant at the scale of discretization used in the transport model. A number of studies, however, have demonstrated that water chemistry in the vicinity of Yucca Mountain can vary significantly with regard to parameters such as pH, ionic strength, and CO_3^{2-} concentration that may affect radionuclide retardation. Both DOE and NRC have made an effort to account for the effects of this changing chemistry in developing the PDFs used in TSPA-VA.	The AMR on radionuclide transport models under ambient conditions provides the supporting rationale for these assumptions.
3a. For the valid application of process models affecting radionuclide transport such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: Demonstrated that the flow path acts as a single continuum porous medium (See USFIC IRSR, deep percolation on subissue describing methods of estimating matrix properties).	See criterion 2a.	The vitric portion of the Calico Hills hydrogeologic units behaves as a porous medium and provides an effective barrier to radionuclide transport. The upper units of the Prow Pass hydrogeologic unit also behave as a porous medium.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
3b For the valid application of process models affecting radionuclide transport such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: Demonstrated that values for the parameters used in process models are appropriate and sufficient.	To provide additional confidence in the model results, the experiments used to calibrate the model should cover a range in critical parameters such as pH, ionic strength, and radionuclide concentration. The experimental variation in these parameters should span the range expected over the time period of interest at the scale of discretization in the PA abstraction.	UZ Transport parameters are summarized in Section 3.11.2 of the UZ F&T PMR.
3c For the valid application of process models affecting radionuclide transport such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: (i) Demonstrated that the three implicit assumptions (see 2c) are valid, if process models are intended to yield a constant K_d for use in the retardation equation (equation 1); or (ii) determined transport in a dynamic reactive transport system model (e.g., PHREEQC, MULTIFLO, HYDROGEOCHEM, etc.) 3c For the valid application of process models affecting radionuclide transport such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: (i) Demonstrated that the three implicit assumptions (see 2c) are valid, if process models are intended to yield a constant K_d for use in the retardation equation (equation 1); or (ii) determined transport in a dynamic reactive transport system model (e.g., PHREEQC, MULTIFLO, HYDROGEOCHEM, etc.).	The variation in groundwater composition in the portion of the pathway that is considered to be an isotropic homogeneous porous medium may be less than that over the whole region, which includes significant fractured rock. The limited availability of groundwater analyses for the porous rock units will likely result in a limited range of calculated K_d values. One additional concern stems from the evidence that in some wells, groundwater compositions have varied over time.	The AMR on radionuclide transport models under ambient conditions provides the supporting rationale for these assumptions.
4 Where data are not reasonably or practicably obtained, expert judgement has been used and expert elicitation procedures have been adequately documented. If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Nuclear Regulatory Commission, 1996) or other acceptable approaches	The NRC staff considers K_d, values from batch sorption tests, confirmed by crushed tuff column or other experiments can be reasonably or practicably obtained. Consequently, expert elicitation would not appear to be appropriate, as a general matter, to use in place of experimentally determined sorption coefficients. This applies only to those radionuclides whose sorption characteristics affect performance.	No expert elicitation was conducted.
5 Data and models have been collected, developed and documented under acceptable QA procedures (e.g., Altman, et al., 1988), or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures.	The TSPA-VA indicates that the K_d values for plutonium, uranium, and neptunium are Q-listed. All other K_ds and K_d distributions have Not Qualified QA status.	Activities associated with this work were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
Subissue 2 – Radionuclide Transport through Alluvium		
1a For the estimation of radionuclide transport through alluvium, DOE has: Determined, through PA calculations, whether radionuclide attenuation processes such as sorption, precipitation, radioactive decay, and colloidal filtration are important to performance.	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	SZ performance assessment calculations indicate these processes are important.
1b For the estimation of radionuclide transport through alluvium, DOE has: (i) Assumed K_d is zero and radionuclides travel at the rate of groundwater flow, if it has been found that radionuclide attenuation is unimportant to performance and it can be demonstrated that this assumption is conservative in which case Criteria 2 and 3 do not have to be met or, (ii) demonstrated that Criterion 2 or 3 has been met, if radionuclide attenuation in alluvium is important to performance or if an assumption that K_d is zero in alluvium is not conservative.	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	K_d is assumed to be zero for C and Cl.
2a For the valid application of the K_d approach, using equation (1) $R_f = 1 + \rho_b K_d/n$, DOE has: Demonstrated that the flow path acts as a single continuum porous medium. If the flow can not be shown to be a single continuum porous medium, then the acceptance criteria for radionuclide transport in fractured rock apply.	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	SZ fluid flow in the alluvium is likely to be well represented using a porous continuum conceptual model. Data to quantify the alluvial portion of the flow path are sparse, and hydrologic parameters used in numerical models should be considered to be bounding.
2b For the valid application of the K_d approach, using equation (1) $R_f = 1 + \rho_b K_d/n$, DOE has: Demonstrated that appropriate values for the parameters, K_d, n or τ, and ρ_b have been adequately considered (e.g., experimentally determined or measured).	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	SZ transport of sorbing solutes in porous media is a subject that has been well studied. Therefore, it is reasonable to assume that the transport velocities of sorbing radionuclides in the alluvium can be conservatively represented using an equilibrium sorption coefficient. Sorption coefficients onto alluvium from the Nye County wells have been measured for a few key radionuclides; for the remaining radionuclides, sorption coefficients have been estimated based on the corresponding values measured for

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
		crushed tuff. Recent evaluations of K_d for Np, Tc, and I have been accomplished for alluvium.
2c For the valid application of the K_d approach, using equation (1) $R_f = 1 + \rho_b K_d / n$, DOE has: Demonstrated that the following assumptions (i.e., linear isotherm, fast reversible sorption reaction, and constant bulk chemistry) are valid.	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	Sorption is incorporated into the site-scale SZ flow and transport model using a linear isotherm model.
3a For the valid application of process models such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: Demonstrated that the flow path acts as a single continuum porous medium [See USFIC IRSR, deep percolation on subissue describing methods of estimating matrix properties as parameters].	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	Saturated zone fluid flow in the alluvium is likely to be well represented using a porous continuum conceptual model. Data to quantify the alluvial portion of the flow path are sparse, and therefore the hydrologic parameters used in numerical models should be considered to be bounding.
3b For the valid application of process models such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: Demonstrated that appropriate values are used in process models.	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	Saturated zone transport of sorbing solutes in porous media is a subject that has been well studied. Therefore, it is reasonable to assume that the transport velocities of sorbing radionuclides in the alluvium can be conservatively represented using an equilibrium sorption coefficient. Sorption coefficients onto alluvium from the Nye County wells have been measured for a few key radionuclides; for the remaining radionuclides, sorption coefficients have been estimated based on the corresponding values measured for crushed tuff. Recent evaluations of sorption coefficient for neptunium, technetium, and iodine have been accomplished for alluvium.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
3c For the valid application of process models such as surface complexation, ion exchange, precipitation/dissolution, and processes involving colloidal material, DOE has: Demonstrated that the three implicit assumptions (as in 2c) are valid, if process models are intended to yield a constant K_d for use in equation (1); otherwise determined transport in a dynamic reactive transport system model (e.g., PHREEQC, MULTIFLO, HYDROGEOCHEM, etc.)	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	Sorption is incorporated into the site-scale SZ flow and transport model using a linear isotherm model.
4 Where data are not reasonably or practicably obtained, expert judgement has been used and expert elicitation procedures have been adequately documented. If used, expert elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Nuclear Regulatory Commission, 1996) or other acceptable approaches	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	No expert elicitation was conducted.
5 Data and models have been collected, developed and documented under acceptable QA procedures (e.g., Altman, et al., 1988), or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures	The status of this subissue is tied closely to subissue 1. However, additional uncertainty is a result of the very limited information collected to date on the mineralogy, groundwater chemistry, and flow systems of the alluvium.	Activities associated with this work were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document.
Subissue 3 - RADIONUCLIDE TRANSPORT THROUGH FRACTURED ROCK		
1a For the estimation of radionuclide transport through fractured rock, DOE has: Determined, through PA calculations, whether radionuclide attenuation processes such as sorption, precipitation, radioactive decay, and colloidal filtration are important to performance.	Closed	Performance assessment calculations have determined that such processes are important. Sorption in the fractures is neglected in the PA transport evaluations because of limited data and the conservative nature of the assumption.
1b For the estimation of radionuclide transport through fractured rock, DOE has: Assumed K_d (or K_A) is zero and radionuclides travel at the rate of groundwater flow through fractures, if it has been found that radionuclide attenuation in fractures is unimportant to performance and it can be demonstrated that this assumption is conservative. In this case Acceptance Criterion 2 does not have to be met.	Closed	K_d is assumed to be zero for C and Cl. Sorption in the fractures is neglected in the PA transport evaluations because of limited data and the conservative nature of the assumption.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
1c For the estimation of radionuclide transport through fractured rock, DOE has: Justified the length of the flowpath to which these fracture transport conditions apply.	Lacking a geostatistical analysis, this criterion has not been met.	Chloride hydrochemical groundwater data, as well as other chemical and isotopic data and the potentiometric surface map have been used to constrain SZ flowpaths. Sorption in the fractures is neglected in the PA transport evaluations because of limited data and the conservative nature of the assumption.
2a If credit is to be taken for radionuclide attenuation in fractured rock, DOE has: Demonstrated the capability to predict breakthrough curves of reactive, nonreactive, and colloidal tracers in field tests.	The estimation of transport through fractured rock is relatively untested. Consequently, this criterion is not met. The NRC staff considers the cross hole reactive tracer tests, like those at the C-hole complex and the Busted Butte facility to be crucial to demonstrate the capability to predict transport.	SZ model of fracture flow and matrix diffusion consistent with data. Sorbing tracer (Li) breakthrough consistent with combined matrix diffusion/sorption model. Microspheres break through slightly earlier than solutes, but are attenuated. Sorption in the fractures is neglected in the performance assessment transport evaluations because of limited data and because of the conservative nature of the assumption.
2b If credit is to be taken for radionuclide attenuation in fractured rock, DOE has: Demonstrated nonradioactive tracers used in field tests are appropriate homologues for radioelements.	The NRC staff considers this criterion is being met with regard to the Busted Butte and C-well complex tests. The NRC staff will continue to track the tests to assure this criterion is met.	The saturated zone model of fracture flow and matrix diffusion is consistent with data. Sorbing tracer (Li) breakthrough is consistent with combined matrix diffusion/sorption model. Microspheres break through slightly earlier than solutes, but are attenuated. Sorption in the fractures is neglected in the PA transport evaluations because of limited data and the conservative nature of the assumption.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
2c If credit is to be taken for radionuclide attenuation in fractured rock, DOE has: Justified the length of the flowpath to which these fracture transport conditions apply.	Lacking a geostatistical analysis, estimation of the fractured pathway length should err on the side of conservatism. This criterion has not been met.	Chloride hydrochemical groundwater data, as well as other chemical and isotopic data and the potentiometric surface map have been used to constrain SZ flowpaths. Sorption in the fractures is neglected in the PA transport evaluations because of limited data and the conservative nature of the assumption.
3 Where data are not reasonably or Practicably Obtained, Expert Judgement has been used and Expert Elicitation procedures have been adequately documented. If used, Expert Elicitations were conducted and documented in accordance with the guidance in NUREG-1563 (Nuclear Regulatory Commission, 1996) or other acceptable approaches. Expert Elicitation and sensitivity analyses should not be used as a replacement for experimental and field data, where such data can be reasonably obtained.	Status of this criterion is not applicable because this process has not been conducted.	No expert elicitation was conducted.
4 Data and models have been collected, developed and documented under acceptable QA procedures (e.g., Altman, et al., 1988), or if data were not collected under an established QA program, they have been qualified under appropriate QA procedures	The NRC has expressed concerns about the DOE's QA program. Status of this criterion is to be determined.	Activities associated with this work were determined to be subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) document.
SUBISSUE 4 - NUCLEAR CRITICALITY IN THE FAR FIELD		
1 DOE has determined the probabilities of scenarios that lead to the accumulation of a critical mass of fissile material into a critical configuration within 10,000 years in the farfield using appropriate site characteristics.	TBD – resolution will be based on topical report	The Disposal Criticality Analysis Methodology Topical Report has been developed and submitted to the NRC. A draft NRC Safety Evaluation Report has been released. FEPs screening considers event of far field occurrence to be low probability Analyses show no significant effect on calculated performance in first 10,000 years, even if waste packages are breached.

Key Technical Issue : Radionuclide Transport		
Acceptance Criterion	**RT IRSR Rev 1 Status**	**DOE Comment**
2 For those scenarios that have probabilities greater than 10^{-7}, the DOE has determined their effects on performance	TBD – resolution will be based on topical report	The Disposal Criticality Analysis Methodology Topical Report has been developed and submitted to the NRC. A draft NRC Safety Evaluation Report has been released. FEPs screening considers event of far field occurrence to be low probability Analyses show no significant effect on calculated performance in first 10,000 years, even if waste packages are breached.

KEY TECHNICAL ISSUE:
IGNEOUS ACTIVITY

NRC/DOE TECHNICAL EXCHANGE ON KEY TECHNICAL ISSUES
APRIL 25-26, 2000

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GENERAL

SUBISSUES AND STATUS OF RESOLUTION

PROBABILITY OF IGNEOUS ACTIVITY - OPEN

CONSEQUENCE OF IGNEOUS ACTIVITY - OPEN

RELATIONSHIP OF SUBISSUES TO NRC ABSTRACTIONS

PROBABILITY SUBISSUE COVERED UNDER SCENARIO ANALYSIS

CONSEQUENCE SUBISSUE IN FOLLOWING INTEGRATED SUBISSUES

- -VOLCANIC DISRUPTION OF WASTE PACKAGE
- -AIRBORNE TRANSPORT OF RADIONUCLIDES
- -MECHANICAL DISRUPTION OF ENGINEERED BARRIERS
- -REDISTRIBUTION OF RADIONUCLIDES IN SOIL
- -LIFESTYLE OF THE CRITICAL GROUP

RELATIONSHIP OF ISSUE TO DOE RSS

AT PRESENT, NOT LISTED AS PRINCIPAL FACTOR

RSS STATES VOLCANISM TO BE CONSIDERED IN FACTORS FOR DISRUPTIVE EVENT SCENARIO

MAY MEETING PLANNED TO DISCUS ISSUE IN DETAIL

BASIS FOR SUBISSUE RESOLUTION AND PATH FORWARD:

PROBABILITY SUBISSUE: OPEN

PROVIDE INFORMATION ON RECURRENCE RATES WHICH CONSIDERS:(AA)[1]

Definition of the Igneous System
Known Events in the Area
Inferred Events in the Area

PROVIDE AN ANALYSIS WHICH DEMONSTRATES THAT DOE MODELS ARE CONSISTENT (OR NOT INCONSISTENT) WITH ACCEPTABLE TECTONIC MODELS AND GEOPHYSICAL DATA (AA)

PROVIDE AN ANALYSIS ADDRESSING THE RELATIONSHIP OF STRAIN AND VOLCANISM WHICH COVERS RECENT STRAIN LITERATURE FOR YMR (E.G., WERNICKIE ET AL., 1998, SAVAGE ET AL., 1999, DIXON ET AL, 2000)(AA)

DEMONSTRATE THAT INFORMATION OBTAINED SINCE PVHA HAS NO SIGNIFICANT EFFECT ON RESULTS, INCLUDING VALIDITY OF BASIC MODELS (AA)

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[1]AA = Need for additional analysis, AD = Need for additional data and analysis, and NA = Aspect of subissue not addressed.

PROBABILITY SUBISSUE (cont):

PROVIDE AN EVALUATION THAT DEMONSTRATES THE ABILITY OF DOE MODELS TO REASONABLY FORECAST THE LOCATION OF NEW VOLCANOES(AA)

PROVIDE AN ANALYSIS WHICH EVALUATES IF MAGMA WOULD LOCALIZE RANDOMLY ALONG A DIKE OR WOULD FLOW INTO AN OPEN DRIFT(AA).

PROVIDE INFORMATION ON THE DIFFERENCES BETWEEN THE DOE PREFERRED PROBABILITY VALUE AND VALUES IN THE OPEN LITERATURE (I.E. RANGE FROM ABOUT 10^{-6} TO 10^{-8} PER YEAR) (AA)

CONSEQUENCE SUBISSUE: OPEN

PROVIDE AN EVALUATION OF THE RESPONSE OF MAGMA TO A DROP IN CONFINING PRESSURE WHEN ENCOUNTERING REPOSITORY DRIFTS (AA)

PROVIDE AN EVALUATION OF WASTE PACKAGE RESPONSE TO PHYSICAL, CHEMICAL AND THERMAL CONDITIONS REPRESENTATIVE OF YMR BASALTIC IGNEOUS ACTIVITY(AA)

PROVIDE AN EVALUATION OF WASTE FORM RESPONSE TO PHYSICAL, CHEMICAL AND THERMAL CONDITIONS REPRESENTATIVE OF YMR BASALTIC IGNEOUS ACTIVITY(AA)

PROVIDE A DEMONSTRATION OF THE UTILITY OF USING ASHPLUME IN PERFORMANCE ASSESSMENT WHICH INCLUDES:(ADA)

- -A Demonstration that the Model Can Reasonably Simulate Tephra-fall Characteristics of Representative Basaltic Volcanoes
- -Accounting For Potential Effects of HLW Entrainment on Dispersal Characteristics in Underlying Conceptual Model (Suzuki, 1983)
- -A Technical Basis to Constrain Past Characteristics of YMR Tephra Eruptions And Basis For Range in Future Eruptions.

CONSEQUENCE SUBISSUE (cont):

PROVIDE AN ANALYSIS RECONCILING HLW ENTRAINMENT MODEL WITH WALL-ROCK ENTRAINMENT STUDIES AT BASALTIC VOLCANOES(NA)

OBTAIN DATA ON WIND SPEED AND DIRECTION AT ALTITUDES OF CONCERN FOR VOLCANIC TEPHRA DISPERSION (GENERAL RANGE OF 2-6 KM),

OR

PROVIDE A REASONABLY CONSERVATIVE METHODOLOGY TO EVALUATE DISPERSAL PATTERNS IN THE ABSENCE OF SUCH DATA. (ADA)

DEMONSTRATE THAT AIRBORNE PARTICLE CONCENTRATIONS ARE REPRESENTATIVE OF TEPHRA-FALL DEPOSITS (NA)

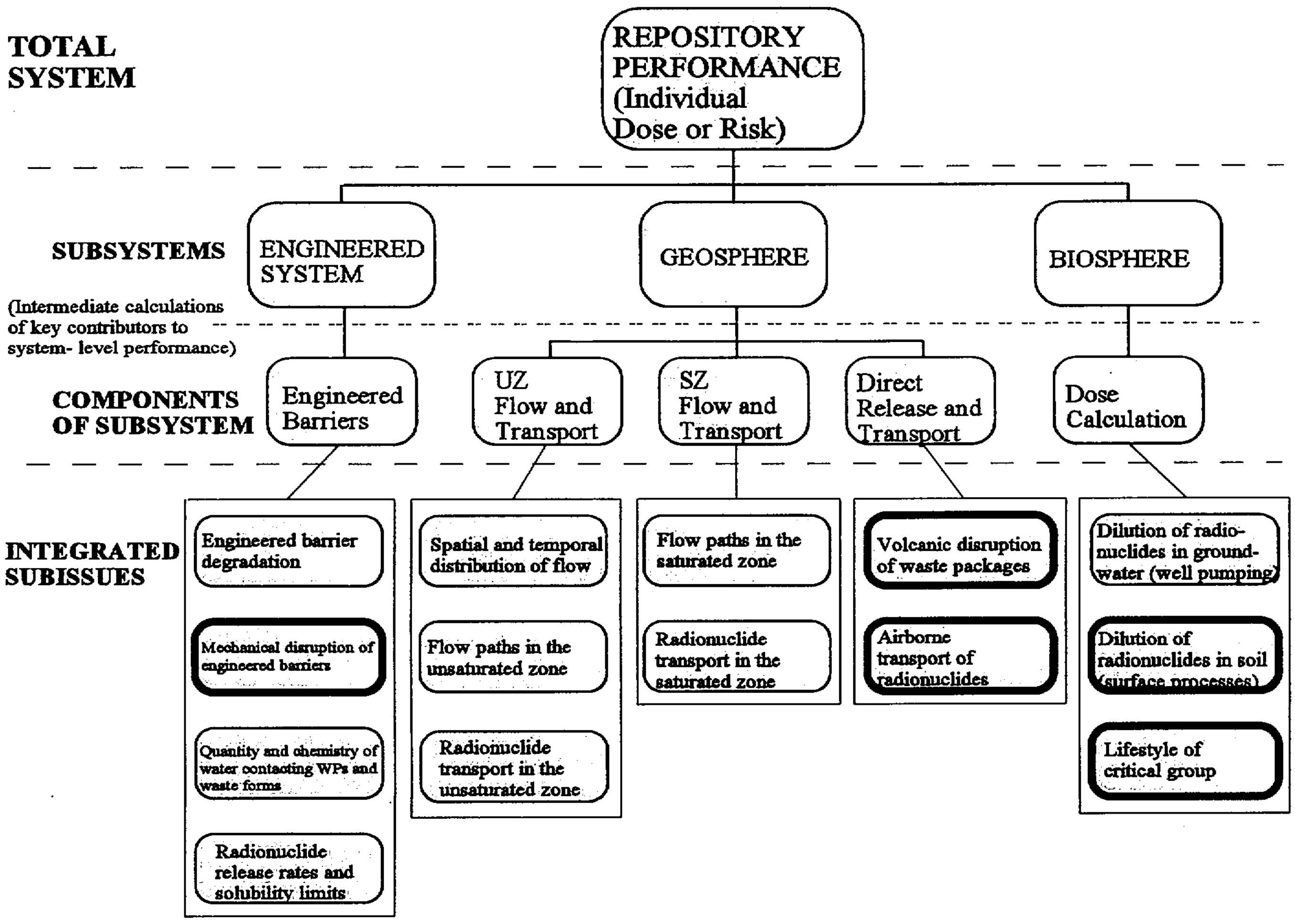
DEMONSTRATE THAT MASS-LOADING PARAMETERS ARE APPROPRIATE FOR LIFESTYLE, LOCATION AND HABITS OF CRITICAL GROUP (DYNAMIC VS STATIC VALUES)(NA)

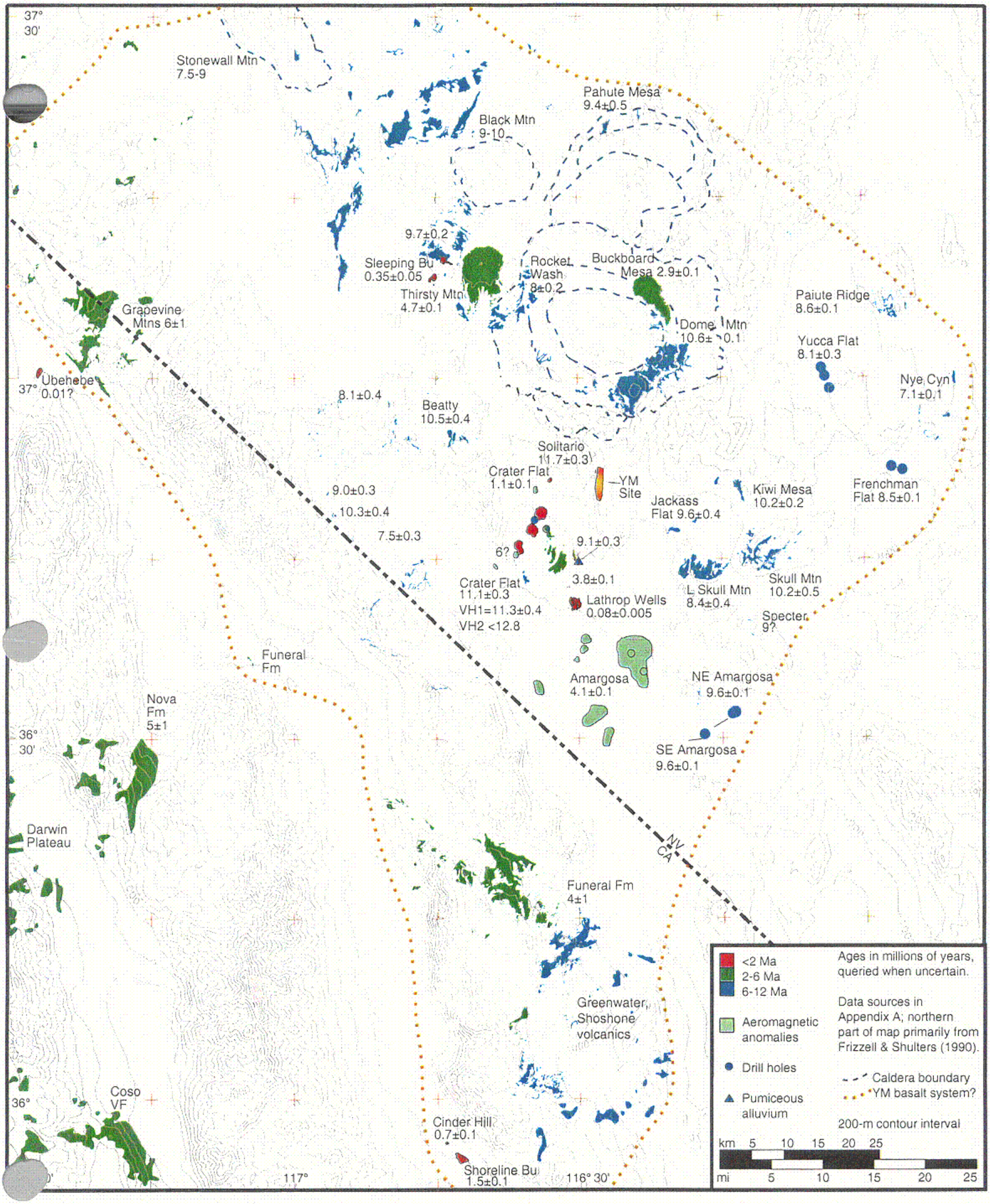
CONSEQUENCE SUBISSUE (cont):

ACCOUNT FOR REMOVAL AND DEPOSITION OF CONTAMINATED TEPHRA ASH AND CHANGE IN PARTICLE CHARACTERISTICS THROUGH TIME BY FLUVIAL AND AEOLIAN PROCESS OCCURRING BETWEEN AREA OF VENT AND LOCATION OF THE CRITICAL GROUP(NA)

ACCOUNT FOR INHALATION DOSE CONTRIBUTIONS FOR PARTICLES UP TO 100 MICRONS IN DIAMETER (AA)

PROVIDE A TECHNICAL BASIS FOR ASSUMPTION THAT THE CRITICAL GROUP WILL SELF-EVACUATE IN RESPONSE TO A YMR TYPE BASALTIC ERUPTION 20 KM AWAY (NA)


TOTAL SYSTEM
REPOSITORY PERFORMANCE (Individual Dose or Risk)
SUBSYSTEMS
ENGINEERED SYSTEM
GEOSPHERE
BIOSPHERE
(Intermediate calculations of key contributors to system- level performance)
COMPONENTS OF SUBSYSTEM
Engineered Barriers
UZ Flow and Transport
SZ Flow and Transport
Direct Release and Transport
Dose Calculation
INTEGRATED SUBISSUES
Engineered barrier degradation
Mechanical disruption of engineered barriers
Quantity and chemistry of water contacting WPs and waste forms
Radionuclide release rates and solubility limits
Spatial and temporal distribution of flow
Flow paths in the unsaturated zone
Radionuclide transport in the unsaturated zone
Flow paths in the saturated zone
Radionuclide transport in the saturated zone
Volcanic disruption of waste packages
Airborne transport of radionuclides
Dilution of radionuclides in ground-water (well pumping)
Dilution of radionuclides in soil (surface processes)
Lifestyle of critical group



37° 30'
Stonewall Mtn 7.5-9
Pahute Mesa 9.4±0.5
Black Mtn 9-10
9.7±0.2
Sleeping Bu 0.35±0.05
Thirsty Mtn 4.7±0.1
Rocket Wash 8±0.2
Buckboard Mesa 2.9±0.1
Paiute Ridge 8.6±0.1
Grapevine Mtns 6±1
Dome Mtn 10.6±0.1
Yucca Flat 8.1±0.3
Ubehebe 0.01?
37°
8.1±0.4
Beatty 10.5±0.4
Nye Cyn 7.1±0.1
Solitario 11.7±0.3
Crater Flat 1.1±0.1
YM Site
Kiwi Mesa 10.2±0.2
Frenchman Flat 8.5±0.1
9.0±0.3
10.3±0.4
Jackass Flat 9.6±0.4
7.5±0.3
9.1±0.3
6?
3.8±0.1
Crater Flat 11.1±0.3
VH1=11.3±0.4
VH2 <12.8
Lathrop Wells 0.08±0.005
L Skull Mtn 8.4±0.4
Skull Mtn 10.2±0.5
Specter 9?
Funeral Fm
Amargosa 4.1±0.1
NE Amargosa 9.6±0.1
Nova Fm 5±1
36° 30'
SE Amargosa 9.6±0.1
Darwin Plateau
NV CA
Funeral Fm 4±1
Greenwater, Shoshone volcanics
Coso VF
36°
Cinder Hill 0.7±0.1
Shoreline Bu 1.5±0.1
117°
116° 30'
<2 Ma
2-6 Ma
6-12 Ma
Aeromagnetic anomalies
Drill holes
Pumiceous alluvium
Ages in millions of years, queried when uncertain.
Data sources in Appendix A; northern part of map primarily from Frizzell & Shulters (1990).
Caldera boundary
YM basalt system?
200-m contour interval
km 5 10 15 20 25
mi 5 10 15 20 25

C12

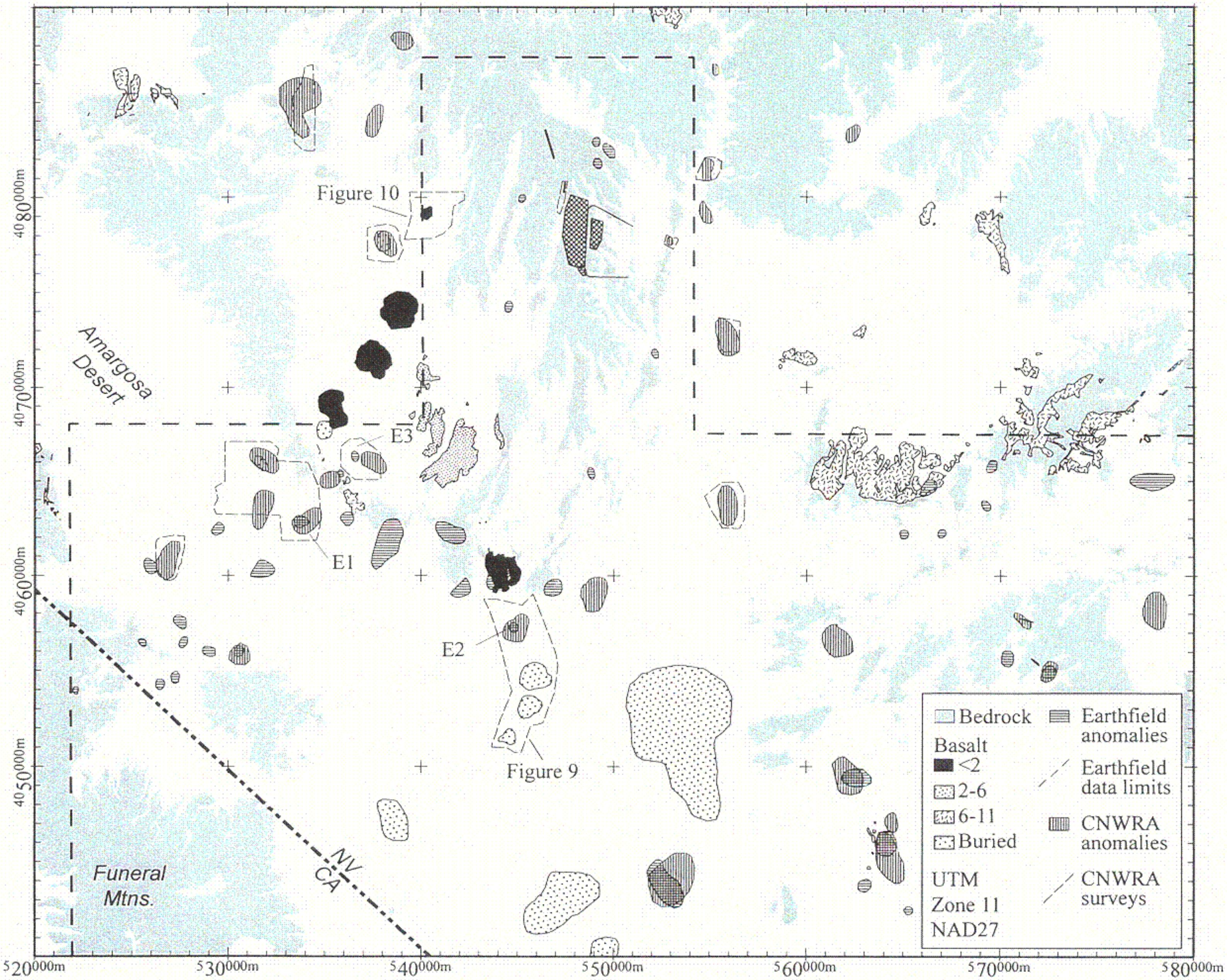
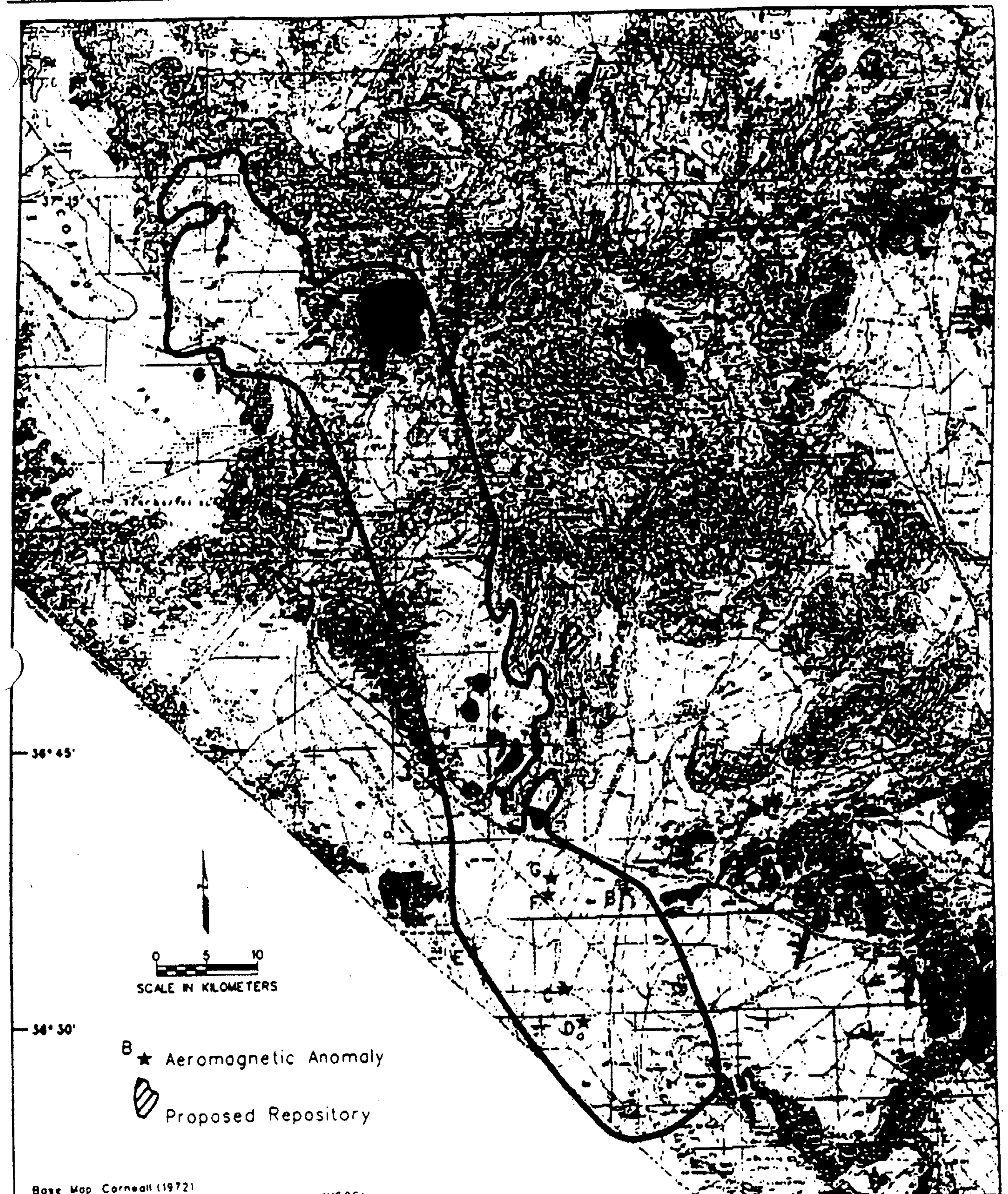


Figure 10
E3
E1
E2
Figure 9
Amargosa Desert
Funeral Mtns.
NV
CA
Bedrock
Basalt
<2
2-6
6-11
Buried
Earthfield anomalies
Earthfield data limits
CNWRA anomalies
CNWRA surveys
UTM
Zone 11
NAD27
520000m
530000m
540000m
550000m
560000m
570000m
580000m
4050000m
4060000m
4070000m
4080000m

C13

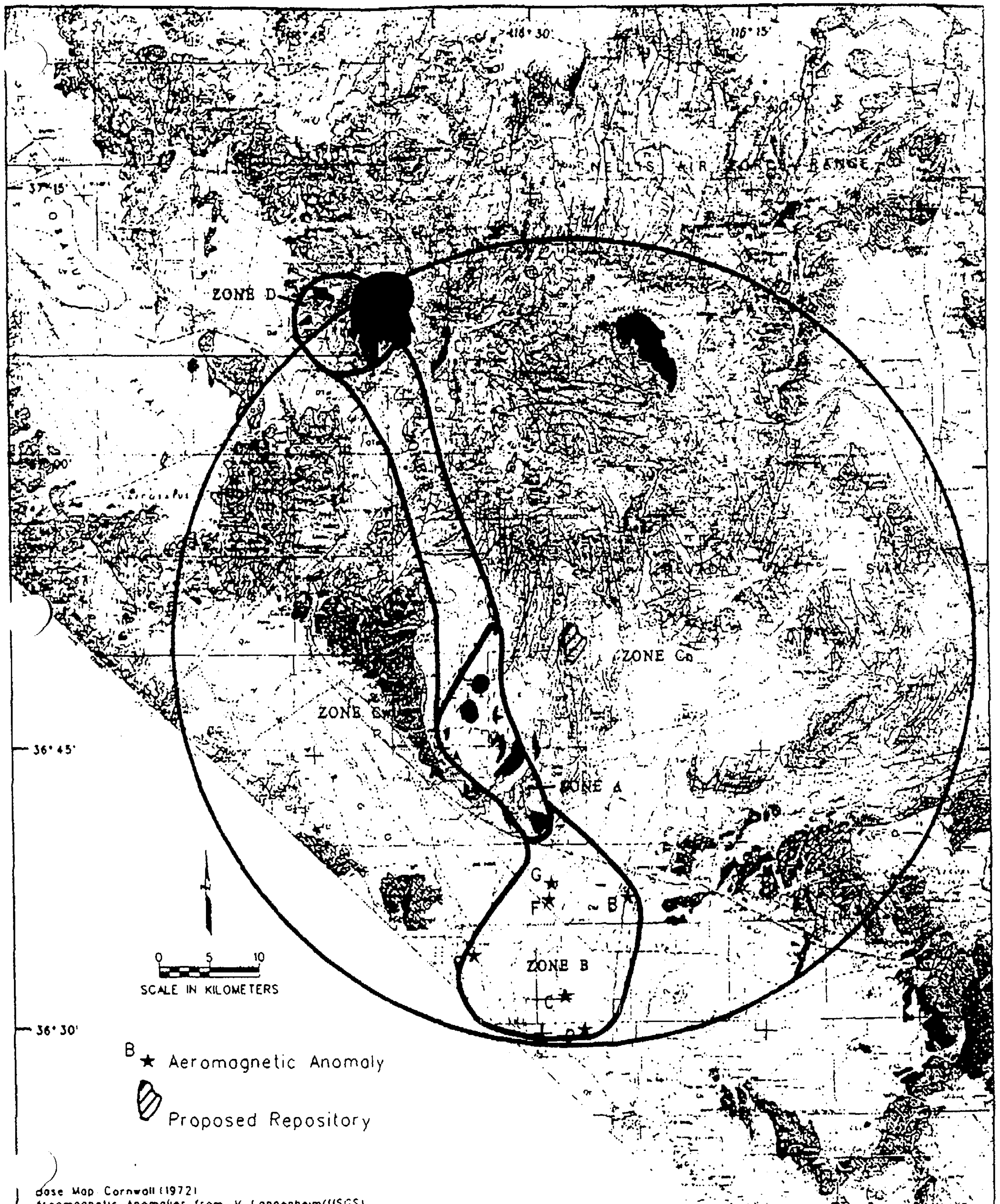


GEOMATRIX

BRUCE M. CROWE
WALKER LANE STRUCTURAL ZONE

Figure BC-11

PVHA Project

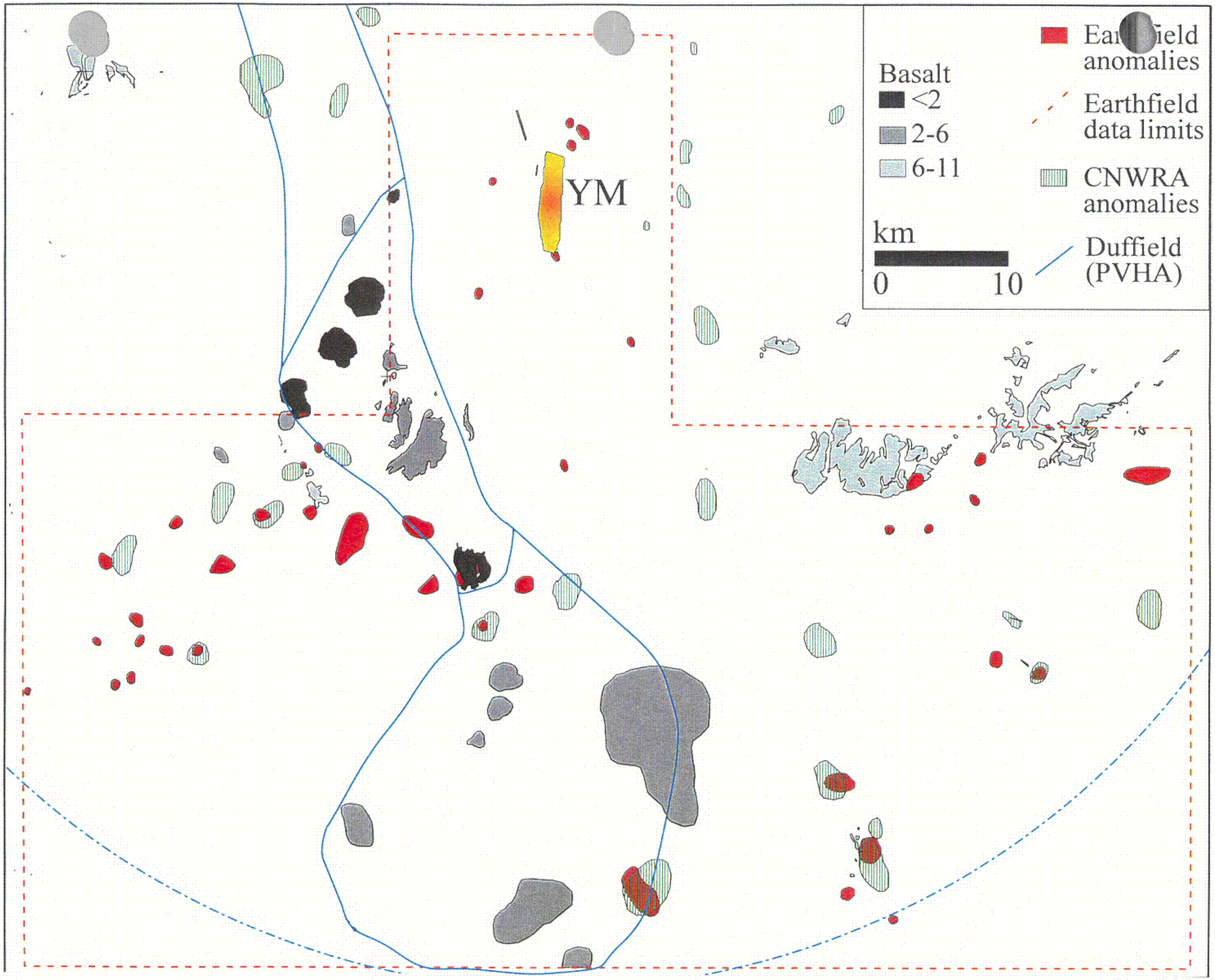


GEOMATRIX

WENDELL A. DUFFIELD
REGIONAL BACKGROUND AND
LOCAL ZONES

Figure WD-2

PVHA Project


YM
Basalt
<2
2-6
6-11
km
0
10
Earthfield anomalies
Earthfield data limits
CNWRA anomalies
Duffield (PVHA)

C14

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

Igneous Activity

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
Eric Smistad
Yucca Mountain Site Characterization Office
U.S. Department of Energy

YUCCA MOUNTAIN PROJECT

April 26, 2000

Current Status

(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Probability**
  - Three technical acceptance criteria are closed; staff have no further questions at this time
  - Five technical acceptance criteria remain open pending additional demonstrations
- **Subissue 2 - Consequences**
  - Two technical acceptance criteria are closed; staff have no further questions at this time
  - Four technical acceptance criteria remain open pending additional demonstrations

Key Activities

- **Fiscal Year (FY) 1996:**
  - **Completed PVHA, culminating more than a decade of volcanic hazard investigations in the Yucca Mountain area**
- **FY 1998:**
  - **Used PVHA results (annual probabilities for intersection of dike with repository) as input to igneous effects scenarios in Total System Performance Assessment - Viability Assessment (TSPA-VA)**
  - **Calculated conditional probabilities of 1 or more eruptive centers through the proposed repository**

Key Activities
(Continued)

- **FY 1998**
  - Completed volcanic synthesis report that provided integrated description of igneous activity site characterization studies
- **FY 2000**
  - Brocoum to Reamer letter (3/00) provided comments on Revision 2 of the Issue Resolution Status Report for this Key Technical Issue (KTI)
  - Developed 6 Analysis and Model Reports (AMRs) to document the igneous characteristics of the site and surrounding region, and provide inputs for TSPA - Site Recommendation (SR) analyses

Key Activities
(Continued)

- **FY 2000**
  - Described conceptual framework for igneous activity consistent with volcanic and tectonic history of the Yucca Mountain Region
  - Recalculated probability of igneous intersection of the repository based on reconfigured repository design
    - Probability distributions for dike lengths and azimuths within repository footprint
    - Number of eruptive centers within repository footprint conditional on dike intersecting repository

Key Activities
(Continued)

- **FY 2000**
  - Features, events, and processes (FEPs) screening used as basis to identify igneous consequences to be included in TSPA-SR. Documentation provided in *Disruptive Events Features, Events, and Processes* AMR
  - Work in progress to
    - Evaluate volcanism effects on postclosure performance
    - Identify safety case factors associated with igneous activity subissues of Probability and Consequences

KTI Subissues and Associated Factors of the Safety Case

KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1 Probability	Not yet identified	Disruptive events will be evaluated as part of the Repository Safety Strategy process.
2 Consequences	Not yet identified	

Subissue 1, Probability

- **Estimates of volcanic hazard were determined based on expert elicitation results as described in PVHA report**
  - **Results expressed as mean annual probability and 5th and 95th percentiles**
  - **Mean annual probability of igneous intrusion is about 1.6×10^{-8}**
  - **Frequency distribution includes NRC's annual probability of 10^{-7} (~0.995)**
- **Probability is specifically included in TSPA-SR**
- **For 3 technical criteria, staff have no further questions**

Subissue 1, Probability

(Continued)

- **Five technical criteria remain open pending results that show**
  - **Sufficient information has been included in DOE analyses**
  - **Consideration of post-PVHA information**
  - **DOE estimates of future volcanic activity are consistent with tectonic models proposed for the Yucca Mountain Region**
- ***Disruptive Events* Process Model Report (PMR) and Supporting AMRs address these open technical criteria**
- **The following slides provide examples of methods DOE has used to address Acceptance Criteria 2 and 6 associated with the Probability subissue**

Subissue 1, Probability, Criterion 2

Estimates of the probability of future igneous activity in the Yucca Mountain Region will be acceptable provided that the definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities separately estimated.

- **DOE's View:**
  - **The definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities estimated separately. Basis for probabilities is documented in *Disruptive Events* PMR**
- **NRC Issues**
  - **Staff consider there is not enough information to rigorously define the probability of igneous activity, or the related probability of intrusive activity affecting repository**

Criterion 2, DOE Approach

- **Intrusive and extrusive events are defined and analyzed separately**
- **Probability of igneous intrusion intersecting the repository derived from PVHA**
  - **Uncertainty included as a distribution of probabilities**
- **Probability of eruption at repository**
  - **Based on PVHA interpretation for dike intersection of repository**
  - **Eruption probability is conditional on dike intrusion probability**
- **Documentation will be presented in the *Disruptive Events* PMR. The documentation and upcoming interactions should resolve open acceptance criteria**

Summary - DOE Position on Probability, Criterion 2

- **DOE meets acceptance criterion**
- **AMR, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada***
  - **Develops separate probabilities for intrusive and eruptive events at repository location**
  - **Documents that probability of intrusion into repository is greater than probability of eruption**

Subissue 1, Probability, Criterion 6

Estimates of the probability of future igneous activity in the Yucca Mountain Region will be acceptable provided that the probability values used by DOE in performance assessments reflect the uncertainty in DOE's probabilistic volcanic hazard estimates

- **DOE's View**
  - **DOE's value is the mean of the probability distribution for annual frequency and is about 1.6 x 10^{-8} for the igneous intrusion**
  - **10^{-7} is high percentile (~0.995) in DOE distribution range for intrusive events and will be included in the range of values used**
- **NRC Issues**
  - **DOE conditional probability of one or more eruptive centers forming within repository footprint is too low**

Summary - DOE Position on Probability, Criterion 6

- **DOE meets acceptance criterion**
- **DOE will continue to use full probability distributions derived from PVHA model as recalculated for current repository footprint**
- **Basis for probability is documented in AMR, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada***

Subissue 1, DOE Position on Probability, Criterion 6
(Continued)

- **DOE will evaluate significance of uncertainty in probability estimates in sensitivity analyses performed for TSPA-SR**
  - **Sensitivity analysis will be run for 10^{-7} value**

Subissue 2, Consequences

- **FEPs screening used to identify consequences included in TSPA**
- **Staff have no further questions for 2 technical criteria**
- **Analyses in AMRs are believed to be responsive to NRC's concerns in remaining open criterion**
- **Additional analyses are in progress**
  - **Analyses of no-backfill case**

Summary

- **Current analyses indicate that:**
  - Mean annual frequency of igneous intrusion is about 1.6×10^{-8}
  - Probability of eruption is conditional and is less than probability of intrusion
  - Uncertainty in probability is included in TSPA
  - FEPs screening used to identify consequences that are included in TSPA
  - Volcanism effects on postclosure performance are being evaluated

Summary
(Continued)

- **Areas of Agreement**
  - NRC and DOE estimates of probability of future igneous activity are based on the same information
  - DOE work will include consideration of the NRC's annual probability and associated uncertainty

Summary
(Continued)

- **Areas of Disagreement (Brocoum letter to Reamer, 3/00)**
  - **DOE will use the full range of annual frequencies of igneous intersection rather than a single value preferred by the NRC**
  - **DOE believes that the NRC approach, emphasizing a single value, is based on overly conservative interpretations and does not represent the appropriate range of interpretations and uncertainties**

Backup

Key Technical Issue: Igneous Activity		
Acceptance Criterion	**IA IRSR Rev 2 Status**	**DOE Comment**
Subissue: Probability		
1 – Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the estimates are based on past patterns of igneous activity in the YMR.	Staff have no questions with material presented in TSPA-VA.	Agree
2 – Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the definitions of igneous events are used consistently. Intrusive and extrusive events should be distinguished and their probabilities estimated separately.	Staff considers that there is not enough information to rigorously define the probability of igneous activity, or the related probability of intrusive activity affecting the repository.	DOE definition of volcanic event allows for calculation of probabilities for both intrusive and extrusive events (see AMR "Characterize Igneous Framework for Igneous Activity at Yucca Mountain, Nevada").
3 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the models are consistent with observed patterns of volcanic vents and related igneous features in the YMR?	Staff have no questions with material presented in TSPA-VA.	Agree
4 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that parameters used in probabilistic volcanic hazard assessments, related to recurrence rate of igneous activity in the YMR, spatial variation in frequency of igneous events, and area affected by igneous	Open; effects of post-PVHA data on PVHA results need to be evaluated.	Disruptive Events PMR and supporting AMRs will provide technical justification and documentation.

Key Technical Issue: Igneous Activity		
Acceptance Criterion	**IA IRSR Rev 2 Status**	**DOE Comment**
events, are technically justified and documented by DOE.		
5 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the models are consistent with tectonic models proposed by NRC and DOE for the YMR.	Open; staff questions ability of DOE to reconcile volcanological models with the tectonic models and geophysical data.	PVHA models are consistent with conceptual model of volcanism in Yucca Mountain Region (AMR "Characterize Igneous Framework for Igneous Activity at Yucca Mountain, Nevada").
6 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the probability values used by DOE in performance assessments reflect the uncertainty in DOE's probabilistic volcanic hazard estimates.	Open; staff analyses indicate that low values (mean 6×10^{-9}) do not accurately account for the long history of recurring basaltic volcanism around Yucca Mountain and better represent the annual probability of a volcano erupting randomly within the western Great Basin.	For TSPA, DOE will continue to use the full probability distribution for a dike intersecting the repository (intrusive) and eruptive center forming in repository (extrusive) based on PVHA and the Disruptive Events PMR. DOE will include 10^{-7} in range of values used.
7 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the values used (single values, distributions, or bounds on probabilities) are technically justified and account for uncertainties in probability estimates.	Staff has no further questions but will monitor implementation of analyses that include 10^{-7} annual probability.	See information for criterion 6.
8 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that if used, expert elicitations were conducted and documented using the	Open; pending reconciliation of post-PVHA information with PVHA results.	Treatment of new information is included in the Disruptive Events PMR and supporting AMRs.

Key Technical Issue: Igneous Activity		
Acceptance Criterion	**IA IRSR Rev 2 Status**	**DOE Comment**
guidance in the Branch Technical Position on Expert Elicitation, or other acceptable approaches.		
9 - Estimates of the probability of future igneous activity in the YMR will be acceptable provided that the collection, documentation, and development of data and models has been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	Open; TBD.	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural QA framework guiding development of DE PMR and the supporting AMRs and calculations
Subissue: Consequences		
1 – Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that the models are consistent with the geologic record of basaltic igneous activity within the YMR.	Open; use of physical conditions representative of violent strombolian activity would resolve NRC questions under this criterion.	The TSPA model is not final at this time.
2 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste	Staff have no questions regarding the implementation of the modified Suzuki model in TSPA-VA.	The TSPA model is not final at this time.

Key Technical Issue: Igneous Activity		
Acceptance Criterion	**IA IRSR Rev 2 Status**	**DOE Comment**
repository will be acceptable provided that the models are verified against igneous processes observed at active or recently-active analog igneous systems and reflect the fundamentals of ash-plume dynamics.		
3 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that the models adequately account for changes in magma ascent characteristics and magma/rock interactions brought about by repository construction.	Open; pending DOE demonstrating adequate consideration of the effects of developing and operating a repository on magma ascent characteristics.	The TSPA model is not final at this time.
4 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that the models account for the interactions of basaltic magma with engineered barriers and waste forms.	Open; pending analyses to support waste package resiliency and waste particle fragmentation.	The TSPA model is not final at this time.
5 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that the	Open; pending DOE developing a reasonably conservative technical basis supporting analyses of radiological dose during and following a volcanic eruption.	The TSPA model is not final at this time.

Key Technical Issue: Igneous Activity		
Acceptance Criterion	**IA IRSR Rev 2 Status**	**DOE Comment**
parameters are constrained by data from YMR igneous features and from appropriate analog systems such that the effects of igneous activity on waste containment and isolation are not underestimated.		
6 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that if used, expert elicitations were conducted and documented using the guidance in the Branch Technical Position on Expert Elicitation, or other acceptable approaches.	Resolved, but also pending demonstration that staff questions associated with Probability criterion 7 have been satisfactorily addressed.	Agree
7 - Estimates of the dose consequences of igneous activity on the proposed Yucca Mountain high-level radioactive waste repository will be acceptable provided that the collection, documentation, and development of data and models has been performed under acceptable QA procedures, or if data was not collected under an established QA program, it has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations

KEY TECHNICAL ISSUE:

STRUCTURAL DEFORMATION AND SEISMICITY (SDS)

SDS TEAM:

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NRC/DOE TECHNICAL EXCHANGE:
YUCCA MOUNTAIN PRE-LICENSING ISSUE RESOLUTION
April 25-26, 2000 Las Vegas, Nevada

[1] Center for Nuclear Waste Regulatory Analyses (CNWRA)
[2] U.S. Nuclear Regulatory Commission (NRC)
[3] Presenter

Key Technical Issue
Structural Deformation and Seismicity
OBJECTIVE:

Ensure that seismotectonics features, events, processes (FEPs) that may significantly affect design or performance of a YM repository are:

(1) identified and characterized	- adequately
(2) understood and considered	- sufficiently
(3) used to assess design and performance	- consistently

SDS SUBISSUES AND STATUS

** (1) TECTONIC FRAMEWORK	OPEN
** (2) SEISMICITY	CLOSED - PENDING
** (3) FAULTING	CLOSED - PENDING
** (4) FRACTURING	OPEN

Subissue(1) **TECTONIC FRAMEWORK: VIABLE TECTONIC MODELS OF YM GEOLOGIC SETTING**

DOE RSS Factors: Not a DOE factor

NRC Abstractions: Mechanical Disruption of EBs/ Volcanic Disruption of Waste Packages

Status: OPEN

What's Needed:

** Analyses showing rationales for tectonic models that are included and excluded from consideration in performance assessments (FEPs AMR)

** Analyses showing that the tectonic model(s) used by DOE for seismic and volcanic hazard assessments are mutually consistent and appropriate for such assessments in that they are not likely to underestimate the hazard

Subissue(2) **SEISMICITY: PROBABILITY OF EARTHQUAKES AND VIBRATORY GROUND MOTION (SEISMIC HAZARD)**

DOE RSS Factors: Disruptive Events Scenarios TBD

NRC Abstractions: Mechanical Disruption of EBs

Status: CLOSED - PENDING

What's Needed:

** Final seismic design values (Topical Report #3), damping factor (Kappa), and crustal shear wave velocities

** Data used in PSHA for NRC/CNWRA analyses

** Analyses showing how DOE abstracted and used seismic hazard estimates in performance assessments

Subissue(3) **FAULTING: PROBABILITY AND CONSEQUENCES OF FAULTING**

DOE RSS Factors: Disruptive Events Scenarios TBD

NRC Abstractions: Mechanical Disruption of EBs

Status: CLOSED - PENDING

What's Needed:

** Analyses showing rationales for faults/faulting that are included and excluded from consideration in performance assessments (FEPs AMR)

** Analyses showing how DOE abstracted and used faulting hazard estimates in performance assessments

Subissue(4) **FRACTURING: FRACTURE/STRUCTURAL FRAMEWORK**

DOE RSS Factors: Infiltration/ Percolation to Depth/ Seepage into Drifts/ Effects of Heat & Excavation on Flow/ Dripping onto Waste Package/ Transport Thru SZ

NRC Abstractions: Mechanical Disruption of EBs/ Quantity-Chemistry of Water Contacting Waste Packages/ Spatial-Temporal Distribution of Flow/ Flow in UZ/ Radionuclide Transp in UZ/ Flow in SZ/ Radionuclide Transp in SZ

Status: OPEN

What's Needed:

** Analyses showing rationales for fracture/structural framework characteristics that are included and excluded from consideration of performance (FEPs AMR); e.g:

Subissue(4) **FRACTURING: FRACTURE/STRUCTURAL FRAMEWORK**

What's Needed: continued

-- fault- and fracture-zone properties, corrected for sampling biases, including orientation, aperture, distribution of sets...

** Analyses showing how included fracture/structural framework characteristics (FEPs) are abstracted and used in process models and total system performance assessments, e.g:

-- AMRs/PMRs for models such as rockfall/ UZ and SZ flow and transport/ seepage under ambient and thermal-loading conditions

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

Structural Deformation and Seismicity

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
J. Timothy Sullivan
Yucca Mountain Site Characterization Office
U. S. Department of Energy

April 26, 2000

YUCCA
MOUNTAIN
PROJECT

Key Technical Issue - Structural Deformation and Seismicity

- **The scope of this Key Technical Issue (KTI) includes:**
  - **Elements that may affect the evaluation of faulting and earthquake effects on long-term performance and postclosure waste containment and isolation**
  - **Elements that affect development of the preclosure seismic design inputs**

Outline of Presentation on Earthquake-Related Analysis

- Overall subissue status
- Key activities related to structural deformation and seismicity
- Subissue discussion
- Summary
- Backup

Current Status
(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Faulting**
  - All technical acceptance criteria are resolved
- **Subissue 2 - Seismicity**
  - Two technical acceptance criteria are resolved
  - Four technical acceptance criteria are open
- **Subissue 3 - Fracturing and Structural Framework of the Geologic Setting**
  - All technical acceptance criteria are open
- **Subissue 4 - Tectonic Framework of the Geologic Setting**
  - All technical acceptance criteria are resolved

Key Activities

- **Fiscal Year (FY) 1998**
  - Completed Probabilistic Seismic Hazard Analysis (PSHA) culminating more than a decade of seismic hazard investigations in the Yucca Mountain area
  - Used PSHA results (hazard curves) as input to seismic effects scenarios in Total System Performance Assessment - Viability Assessment (TSPA-VA)
  - Developed methodology for determining seismic response spectra and time histories for design

Key Activities
(Continued)

- **FY 1999**
  - Developed preliminary ground motion site response information based on limited site data
  - Developed preliminary seismic design inputs for Site Recommendation (SR)
  - Received NRC request for PSHA data input files

Key Activities
(Continued)

- **FY 2000**
  - Updated design input analyses for use in SR design analysis, including motions for a soil site with assumed engineered fill as the top layer
  - Completing dynamic analysis of Waste Handling Building to identify seismic vulnerabilities
  - Established the basis for analysis of postclosure seismic effects
  - Provided NRC PSHA data input files
  - Initiated Waste Handling Building geotechnical investigations for the License Application (LA)
  - Plan to provide seismic effects analyses results and Analysis and Model Reports (AMRs), Disruptive Events Process Model Report (PMR), and TSPA-SR

Key Activities
(Continued)

- **FY 2001**
  - Plan to complete geotechnical investigations at Waste Handling Building
  - Plan to develop final design inputs
  - Plan to provide Seismic Topical Report-3 to NRC (11/01)

KTI Subissues and Associated Factors of the Safety Case

	KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1	Faulting	To be determined (TBD)	Disruptive events will be evaluated as part of Repository Safety Strategy process.
2	Seismicity	TBD	
3	Fracturing and Structural Framework of the Geologic Setting	TBD	
4	Tectonic Framework of the Geologic Setting	TBD	

Subissue 1, Faulting

- All acceptance criteria, except those related to quality assurance (QA), are resolved
- All features, events, and processes (FEPs) associated with faulting effects on unsaturated zone flow (UZ), saturated zone flow (SZ), waste package, and engineered barrier system (EBS) have been excluded from the TSPA
- Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)
- Preclosure design criteria, including fault avoidance, ensure that fault displacement is not a significant factor for preclosure

Subissue 2, Seismicity

- **Two Criteria resolved; 4 Criteria open**
- **All FEPs associated with seismic effects on UZ flow, SZ flow, waste package, and EBS have been excluded from TSPA**
- **Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)**
- **Preliminary analyses indicate that vibratory ground motion is an issue for preclosure surface design, but analyses will have to demonstrate design requirements have been met**

Subissue 2, Seismicity
(Continued)

- **Work is in progress to collect information needed to finalize seismic design motions for specific facilities, such as the Waste Handling Building**
- **DOE anticipates that NRC review of Seismic Topical Report-3 will lead to resolving open items**

Subissue 3, Fracturing and Structural Framework of the Geologic Setting

- **All acceptance criteria are open**
- **Features Events and Processes screening results are reported in the AMR *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)**
- **NRC has concerns over completeness of fracture information**
  - **Origin of fractures**
  - **Sampling bias**

Subissue 3: Fracturing and Structural Framework of the Geologic Setting
(Continued)

- DOE believes an adequate basis exists for representing fracture effects in TSPA
- These acceptance criteria are addressed by DOE in UZ Flow and Transport and SZ Flow and Transport PMRs (UZ Flow and Transport PMR, Sections 3.3, 3.4, 3.6.3.2, 3.7, 3.9; SZ Flow and Transport PMR, Sections 3.2.2.4, 3.2.2.5, 3.2.3.4, 3.6.3.3.1)

Subissue 4 - Tectonic Framework of the Geologic Setting

- **All acceptance criteria, except those related to QA, are resolved**
- **All FEPs associated with non-igneous, tectonic effects on UZ flow, SZ flow, waste package, and EBS have been excluded from TSPA**
- **Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)**

Subissue 4 - Tectonic Framework of the Geologic Setting
(Continued)

- **DOE recognizes that NRC still has concerns related to "inconsistent" treatment of tectonic models in Probabilistic Volcanic Hazards Analysis and PSHA**
  - **This will be addressed in the Disruptive Events PMR and subsequent interactions**

Summary

- **All technical criteria related to Subissue 1, Faulting, and Subissue 4, Tectonic Framework, are resolved**
- **For TSPA-SR (11/00), DOE will have completed a full seismic effects analysis for the nominal scenario**
- **For the Site Recommendation Consideration Report (11/00), DOE will have developed**
  - Preliminary preclosure seismic design basis information based on limited site ground motion response data
  - Dynamic analysis of the Waste Handling Building using preliminary preclosure seismic design basis information
- **Further interactions should lead to resolution of remaining issues with fracture information and tectonic models**

Summary

- DOE's planned investigations and analyses will lead to completion of Seismic Topical Report-3 in 11/01
- NRC review of Seismic Topical Report-3 should lead to resolution of open criteria for the seismicity subissue related to preclosure seismic design methodology

Backup

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
Subissue 1: Faulting (Fault Displacement Hazard)		
1 – Sufficient geological and geophysical data are acquired to adequately support conceptual models of faulting, attendant assumptions, and boundary conditions and to define relevant parameters implemented in process level models and TSPA calculations of the direct disruption of WPs from faulting.	Resolved	Agree
2 – Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to develop process, TSPA, or both models of faulting are technically defendable and reasonably account for uncertainties and variabilities.	Resolved	Agree
3 – Alternative modeling approaches for faulting are investigated, consistent with available scientific understanding. Results and limitations are appropriately considered in the development of the probabilistic fault displacement hazard models and included in abstractions for process level and TSPA subsystem models.	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
4 - Results of PFDHA [Probabilistic Fault Displacement Hazard Analysis], TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observation, or both.	Resolved	Agree
5 - Incorporation of faulting models and parameters into TSPA models adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstraction process.	Resolved	Agree
6 - Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Resolved	Agree
Subissue: Seismicity (Vibratory Ground Motion Hazard)		
1- Sufficient geological and geophysical data are acquired to adequately define seismic	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
sources, relevant earthquake and GM parameters, recurrence relationships, GM attenuation functions, and boundary conditions, and to support attendant assumptions and conceptual models implemented in TSPA.		
2 - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to determine seismicity parameters are technically defensible and reasonably account for uncertainties and variabilities.	Open; pending detailed analyses. Seismic hazard is sensitive to uncertainties associated with recurrence rates and the attenuation model.	Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level, and the surface of the emplacement block.
3 - Alternative modeling approaches for seismicity model, such as recurrence relationships of GM attenuation relationships, are investigated. Results and limitations are considered in the development of the PSHA and included in the abstractions to TSPA subsystem models, consistent with available data and current scientific understanding.	Open; pending detailed analyses.	Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level , and the surface of the emplacement block.
4 - Results of PSHA, TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observation, or both.	Open; pending acquisition of seismic data.	1. Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level, and the surface of the

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
		emplacement block. 2. Complete evaluations of the response of the repository system to ground motion hazard for input to postclosure TSPA.
5 - Incorporation of seismicity models and parameters into PSHA, TSPA, or both adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstractions process.	Open	1.Complete evaluations of the response of the repository system to ground motion hazard for input to postclosure TSPA. 2. Complete analysis of response of the repository system to fault displacement hazard for input to the TSPA.
6 - Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Resolved	Agree
Subissue 3: Fracturing and Structural Framework of the Geologic Setting		
1 - Adequate field, borehole, and underground excavation data are acquired to sufficiently support conceptual models,	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties reasonably account for uncertainties and variabilities.	Criterion may not be met. Results of NRC evaluation to be reported in Rev 3 of SD&S IRSR.	Not addressed by DE PMR.
3 - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in process, TSPA, or both models of ambient and perturbed repository conditions.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.
4 - Results of fracture data analyses and fracture models are verified by comparison with output of sensitivity studies, detailed process level models, natural analogs, and empirical observations, as appropriate.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
5 - Results of abstractions of fracture data are consistent [with] physical and geological phenomena and coupled processes.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.
6- Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Criterion does not apply. No expert elicitations were conducted to characterize fractures.	Agree.
Subissue 4: Tectonic Framework of the Geologic Setting		
1 - Sufficient geological information and geophysical data are available to adequately support conceptual models of tectonics, attendant assumptions, and boundary conditions and to define relevant parameters of tectonic models implemented in process, subsystem, or PA models and calculations.	Resolved	Agree
2 - Parameter values, assumed ranges, probabilistic distributions, and/or bounding assumptions used to develop viable tectonic	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
models are technically defendable and reasonably account for uncertainties and variabilities.		
3 - Alternative modeling approaches for tectonics are investigated, consistent with available data and current scientific understanding. Results and limitations of tectonic models are sufficiently considered in the development of process, subsystem and TSPA models.	Resolved	Agree
4 - Viable tectonic models are verified within the context of all geological and geophysical data [and] the tectonic framework of the geologic setting.	Resolved	Agree
5 - Incorporation of tectonic models into PSHA, Probabilistic Volcanic Hazards Assessment (PVHA) and TSPA adequately includes major structural features, physical phenomena, and coupling important to design and performance and relies on consistent and appropriate assumptions throughout the abstraction process.	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
6 – Quality Assurance	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 – Expert Elicitation	Resolved	Agree

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.01.01.00	Tectonic activity—large scale	*Exclude*	Low Consequence
1.2.01.01.01	Folding, uplift or subsidence lowers facility with regard to current water table	*Exclude*	Low Consequence
1.2.01.01.02	Tectonic changes to local geothermal flux causes convective flow in SZ and elevates water table	*Exclude*	Low Probability
1.2.01.01.03	Tectonic folding alters dip of tuff beds, changing percolation flux	*Exclude*	Low Consequence
1.2.01.01.04	Uplift or subsidence changes drainage at the site, increasing infiltration	Exclude	Low Consequence
1.2.01.01.08	Uplift and subsidence	*Exclude*	Low Consequence
91.2.02.01.00	Fractures	*Include*: existing characteristics / *Exclude*: changes to characteristics.	Low Consequence
1.2.02.02.00	Faulting	*Include*: existing characteristics/ *Exclude*: changes in fault properties.	*Excluded* based on low consequence, and low probability
1.2.02.02.05	Faulting/Fracturing	*Include*	
1.2.02.02.08	Normal faulting occurs or exists at Yucca Mountain	*Include*	
1.2.02.02.09	Strike/slip faulting occurs or exists at Yucca Mountain	*Include*	

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.02.02.10	Detachment faulting occurs or exists at Yucca Mountain	*Exclude*	Low Consequence
1.2.02.02.11	Dip/slip faulting occurs at Yucca Mountain	*Include*	
1.2.02.02.12	New fault occurs at Yucca Mountain	*Exclude*	Low Consequence
1.2.04.02.03	Volcanic activity in the vicinity produces an impoundment	*Exclude*	Low Consequence
1.2.02.02.13	Old fault strand is reactivated at Yucca Mountain	*Exclude*	Low Consequence
1.2.02.02.14	New fault strand is activated at Yucca Mountain	*Exclude*	Low Probability
1.2.02.03.00	Fault movement shears waste container	*Exclude*	Low Probability
1.2.03.01.00	Seismic activity (Note: Includes faulting, hydraulic heads, recharge-discharge zones, rock stresses, drift integrity)	*Exclude* for indirect effects / *Include* for drip shield and fuel-rod cladding damage	Low Consequence
1.2.03.02.00	Seismic vibration causes container failure	*Exclude* TBV for waste package / *Include* for drip shield and fuel-rod cladding.	Low Consequence
1.2.03.02.01	Container failure induced by microseisms associated with dike emplacement	*Exclude* TBV	Low Consequence
1.2.03.03.00	Seismicity associated with igneous activity	*Exclude* for indirect effects / *Include* for drip shield and fuel-rod cladding damage	Low Consequence

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.01.00	Igneous activity (Note: Also effects on faults, topography, rock stresses, groundwater temperatures & drift integrity)	*Include*: for direct effects / *Exclude*: for indirect effects	Low Consequence of Indirect Effects
1.2.04.02.00 *	Igneous activity causes changes to rock properties	*Exclude*	Low Consequence
1.2.04.02.01	Dike provides a permeable flow path	*Exclude*	Low Consequence
1.2.04.02.02	Dike provides a barrier to flow	*Exclude*	Low Consequence
1.2.04.02.06	Dike related fractures alter flow	*Exclude*	Low Consequence
1.2.04.03.00	Igneous intrusion into repository	*Include*	
1.2.04.03.03	Sill intrudes repository openings	*Include*	
1.2.04.04.00	Magma interacts with waste	*Include*	
1.2.04.04.01	Magmatic volatiles attack waste	*Include*	
1.2.04.04.02	Dissolution of spent fuel in magma	*Include*	
1.2.04.04.03	Dissolution of other waste in magma	*Include*	
1.2.04.04.04	Heating of waste container by magma (without contact)	*Include*	
1.2.04.04.05	Failure of waste container by direct contact with magma	*Include*	
1.2.04.04.06	Fragmentation (Note: with subsequent damage to waste package)	*Include*	

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.05.00	Magmatic transport of waste	*Exclude* for transport in liquid magma and other types of transport. / *Include* for transport through eruptive events	Low Consequence
1.2.04.05.01	Direct exposure of waste in dike apron	*Exclude*	Low Consequence
1.2.04.05.02	Volatile radionuclides plate out in the surrounding rock	*Exclude*	Low Consequence
1.2.04.05.03	Entrainment of SNF in a flowing dike	*Exclude*	Low Consequence
1.2.04.06.00	Basaltic cinder cone erupts through the repository (Note: Also entraining waste)	*Include*	
1.2.04.06.01	Vent jump (formerly called "wander")	*Include*	
1.2.04.06.02	Vent erosion	*Include*	
1.2.04.07.00	Ashfall	*Include*	
1.2.10.01.00	Hydrologic response to seismic activity	*Exclude*	Low Consequence
1.2.10.02.00	Hydrologic response to igneous activity (Note: Includes groundwater flow directions; water level, chemistry, temperature; change in rock properties)	*Exclude*	Low Consequence
1.2.10.02.01	Interaction of WT (water table) with magma	*Exclude*	Low Consequence
1.2.10.02.02	Interaction of UZ pore water with magma	*Exclude*	Low Consequence
2.1.07.01.00	Rockfall (large block)	*Exclude*	Low Consequence

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
2.1.07.01.01	Rockbursts in container holes	*Exclude*	Low Consequence
2.1.07.02.00	Mechanical degradation or collapse of drift	*Exclude*	Low Consequence
2.1.07.02.03	Rockfall stopes up fault	*Exclude*	Low Consequence
2.1.07.02.04	Rockfall (rubble)(in waste and EBS)	*Exclude*	Low Consequence
2.2.06.01.00 *	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	*Exclude*	Low Consequence
2.2.06.02.00 *	Changes in stress (due to thermal, seismic, or tectonic effects) produces change in permeability of faults	*Exclude*	Low Consequence
2.2.06.03.00 *	Changes in stress (due to seismic or tectonic effects) alter perched water zones)	*Exclude*	Low Consequence

NOTES: Shaded Items are Primary FEPs; others are Secondary FEPs.
* These FEPs are addressed by multiple FEP AMRs , see the YMP FEP Database (CRWMS M&O 1999d)
SNF = spent nuclear fuel; EBS = engineered barrier system.