Attachment 5

Presenter's Slides

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

Repository Design and Thermal-Mechanical Effects

Presented to:
DOE/NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

Presented by:
Kirk Lachman
Yucca Mountain Site Characterization Office
Department of Energy

February 6-8, 2001
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Purpose of the Technical Exchange
- Identification of Subissues
- Background
- Status of Subissues and Subissue 3 Acceptance Criteria from the Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3

Purpose of Technical Exchange

- Discuss status of Subissues 1, 2, and 4 for the Repository Design and Thermal-Mechanical Effects Key Technical Issue
- Present and agree on approach to close Subissue 3, Components 1, 2, and 3 for the Repository Design and Thermal-Mechanical Effects Key Technical Issue
- Provide update on DOE's progress made in identifying and screening of features, events, and processes related to the Repository Design and Thermal-Mechanical Effects Key Technical Issue

Current Subissues

- **Subissue 1: Implementation of an Effective Design Control Process Within the Overall Quality Assurance Program**
- **Subissue 2: Design of the Geologic Repository Operations Area for the Effects of Seismic Events and Direct Fault Disruption**
- **Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance**
- **Subissue 4: Design and Long-Term Contribution of Seals to Performance**

Background

- Acceptance criteria in the Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3 have changed significantly relative to acceptance criteria listed in Rev. 2
- Lacking a specific cross-walk between the acceptance criteria in Rev. 3 and those in Rev. 2, DOE assumes that criteria in Rev. 3 include any open items from Rev. 2

Background
(Continued)

- DOE presentations address both the acceptance criteria (summary level) and the specific comments that have been provided by the NRC
- DOE understands that by addressing the items identified by the NRC as concerns, the acceptance criteria have been addressed sufficiently to discuss closure of the associated subissues
- Issues related to thermal-hydrological-chemical processes were discussed at length during the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchange, January 2001 and are not considered the focus of this technical exchange

Subissue Status

Subissue	NRC IRSR Rev. 3 Status	DOE Proposed Status
1) Implementation of an Effective Design Control Process Within the Overall Quality Assurance Program	Closed	Closed
2) Design of the Geologic Repository Operations Area for the Effects of Seismic Events and Direct Fault Disruption	Closed-Pending	Closed-Pending
3) Thermal-Mechanical Effects on Underground Facility Design and Performance	Open	Closed-Pending
4) Design and Long-Term Contribution of Seals to Performance	Closed	Closed

Subissue 3, Component 1 Acceptance Criteria Status

Acceptance Criteria	NRC IRSR Rev. 3 Status	DOE Proposed Status
1) Surface Facility Design, Codes and Standards	Open	Closed
3) Surface Facility Materials and Material Properties	Open	Closed-Pending
4) Design Analysis Load Combinations	Open	Closed-Pending
5) Design Analyses Uncertainties	Open	Closed-Pending
6) Ground Support Design Methodologies	Open	Closed
7) Subsurface Ventilation Design	Open	Closed-Pending

Subissue 3, Component 2 Acceptance Criteria Status

Acceptance Criteria	NRC IRSR Rev. 3 Status	DOE Proposed Status
1) Evaluation and Abstraction of Design Features and Processes	Open	Closed-Pending
2) Sufficiency of Data	Open	Closed-Pending
3) Data Uncertainty	Open	Closed-Pending
4) Alternative Conceptual Models	Open	Closed-Pending
5) Model Abstractions	Open	Closed-Pending

Subissue 3, Component 3 Acceptance Criteria Status

Acceptance Criteria	NRC IRSR Rev. 3 Status	DOE Proposed Status
Degradation of Engineered Barriers		
1) Evaluation and Abstraction of Design Features and Processes	Open	Closed-Pending
Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms		
1) Evaluation and Abstraction of Design Features and Processes	Open	Closed-Pending
2) Sufficiency of Data	Open	Closed-Pending
3) Data Uncertainty	Open	Closed-Pending
4) Alternative Conceptual Models	Open	Closed-Pending
5) Model Abstractions	Open	Closed-Pending
Spatial and Temporal Distribution of Flow		
1) Evaluation and Abstraction of Design Features and Processes	Open	Closed-Pending
3) Data Uncertainty	Open	Closed-Pending

Conclusion

- **Based on the material provided in the presentations for this Technical Exchange, DOE will demonstrate that the status of the currently open Subissue 3 can be considered Closed-Pending**

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

Subissue 1: Design Control Processes
Subissue 2: Seismic Design Methodology
Subissue 4: Repository Seals

Presented to:
DOE/NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

Presented by:
Dan McKenzie, Richard Quittmeyer
Civilian Radioactive Waste Management System Management and Operating Contractor

February 6-8, 2001
Las Vegas, NV

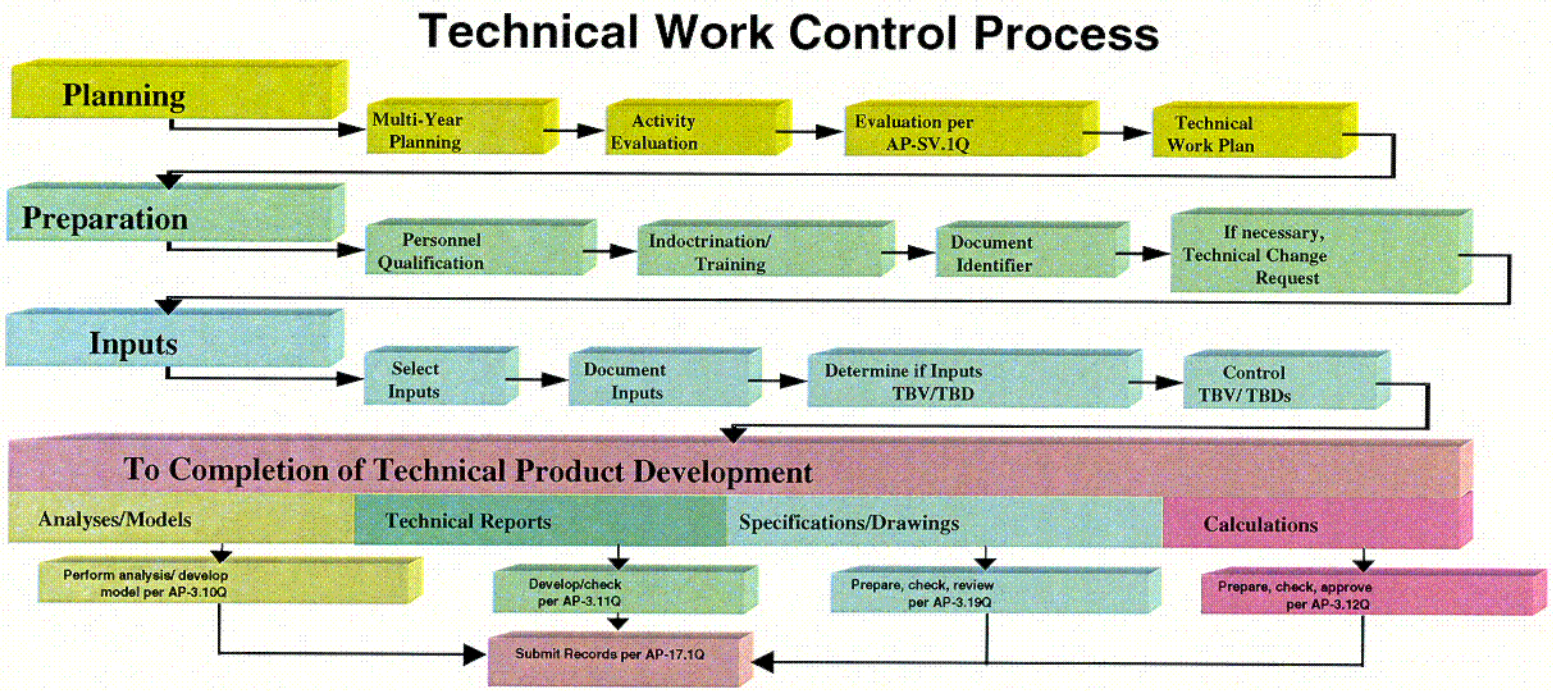
YUCCA MOUNTAIN PROJECT

Outline

- Status of Subissue 1, Design Control Processes
- Status of Subissue 2, Seismic Design Methodology
- Status of Subissue 4, Repository Seals
- Conclusions

Subissue 1, Design Control Processes

- DOE has developed a technical work control process consistent with the quality assurance program
- Design controls are implemented within this process as shown below



Reference: AP 3.13Q

Subissue 1, Design Control Processes
(Continued)

- NRC has identified this subissue as Closed in the Repository Design and Thermal Mechanical Effects Issue Resolution Status Report, Rev. 3
- DOE considers that this subissue remains Closed. No additional work is required for this subissue

Subissue 2, Seismic Design Methodology

- **The seismic design methodology is described in a series of three topical reports:**
  - Topical Report YMP/TR-002-NP, Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain, Revision 1, August 1997
    - Identifies the methodology utilized by DOE to assess vibratory ground motion and fault displacement hazards for the potential repository
  - Topical Report YMP/TR-003-NP, Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain, Revision 2, August 1997
    - Describes the DOE preclosure seismic design methodology and design acceptance criteria and establishes the seismic hazard levels appropriate for design
  - Topical Report 3, Preclosure Seismic Design Inputs for a Geologic Repository at Yucca Mountain (in development)
    - Summarizes the seismic hazard at the potential repository and presents the seismic design inputs

Subissue 2, Seismic Design Methodology
(Continued)

- The NRC has reviewed the first two topical reports and has no further questions
- This subissue is identified as Closed-Pending completion and review of Seismic Topical Report 3 in the Repository Design and Thermal Mechanical Effects Issue Resolution Status Report, Rev. 3
- DOE considers this subissue to be Closed-Pending completion of Seismic Topical Report 3 in FY 2002

Subissue 4, Repository Seals

- DOE does not take credit for the use of repository seals in the performance assessment
- NRC has identified this Subissue as Closed in the Repository Design and Thermal Mechanical Effects Issue Resolution Status Report, Rev. 3
- DOE considers that this subissue remains Closed. No additional work is required for this subissue

Conclusions

- **DOE considers Subissues 1 and 4 remain Closed and Subissue 3 remains Closed-Pending completion of Seismic Topical Report 3**

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

Overview of Postclosure Features, Events, and Processes Relevant to Repository Design and Thermal-Mechanical Effects

Presented to:
DOE/NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

Presented by:
Peter Swift
Civilian Radioactive Waste Management System Management and Operating Contractor

February 6-8, 2001
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Overview of Total System Performance Assessment-Site Recommendation Process
- Features, Events, and Processes Process and Screening Criteria
- Features, Events, and Processes Implementation
- Features, Events, and Processes Analysis and Model Reports
- Discussion of Specific Features, Events, and Processes that map to Repository Design and Thermal-Mechanical Effects Subissues

Total System Performance Assessment

- **Total System Performance Assessment is the approach prescribed by proposed regulations to evaluating postclosure performance**
- **Relevant performance measures apply at the system level**
  - 10,000-year probability-weighted dose at 20 km from all pathways except human intrusion ("expected annual dose"; proposed 10 CFR Part 63 and proposed 40 CFR Part 197)
  - 10,000-year radioactivity in groundwater (proposed 40 CFR Part 197)
  - Conditional dose following human intrusion (proposed 10 CFR Part 63 and proposed 40 CFR Part 197)
  - Peak dose regardless of time (Environmental Impact Statement, proposed 40 CFR Part 197)
- **Proposed regulations do not include postclosure subsystem requirements**

Total System Performance Assessment and Repository Design

- **Total System Performance Assessment does not establish postclosure design requirements for individual components**
- **Total System Performance Assessment analyzes system-level postclosure performance of proposed design**
  - Analyses extend beyond the preclosure lifetime of design components (e.g., waste package and drip shield degradation are expected processes in Total System Performance Assessment)
  - Individual components are evaluated in Total System Performance Assessment in terms of their impact on dose
  - Subsystem and intermediate results from Total System Performance Assessment provide insight into component performance
- **Alternative designs analyzed to assess impact on postclosure performance**

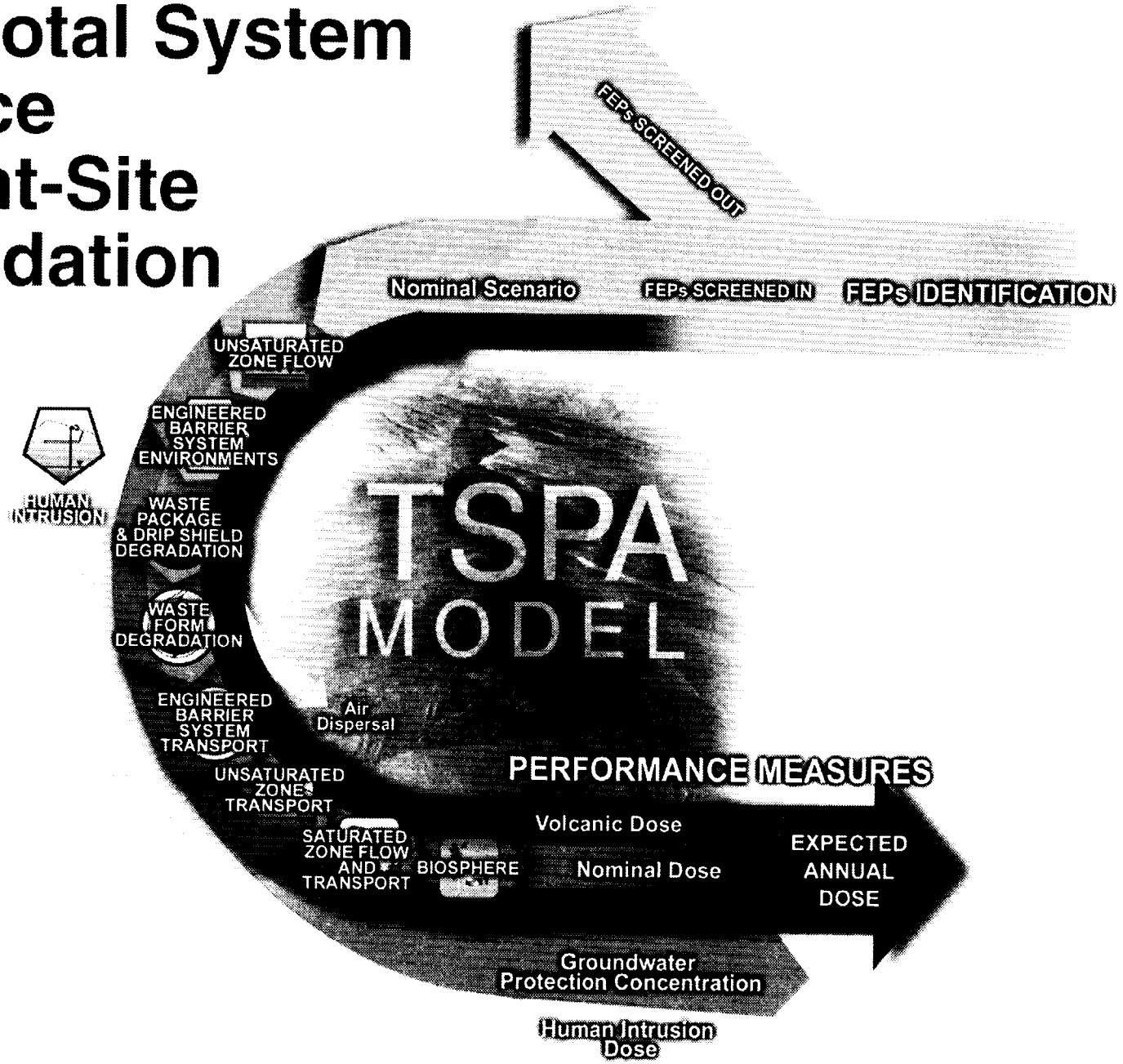
Total System Performance Assessment Process

- **Identify and screen features, events and processes to determine those that must be retained in performance assessment**
  - DOE's Features, Events, and Processes process is consistent with that described by NRC in the Total System Performance Assessment and Integration Issue Resolution Status Report Rev. 3, Sec. 4.2
- **Develop models, along with their scientific basis, for each process included in Total System Performance Assessment**
- **Identify uncertainty in models and parameters**

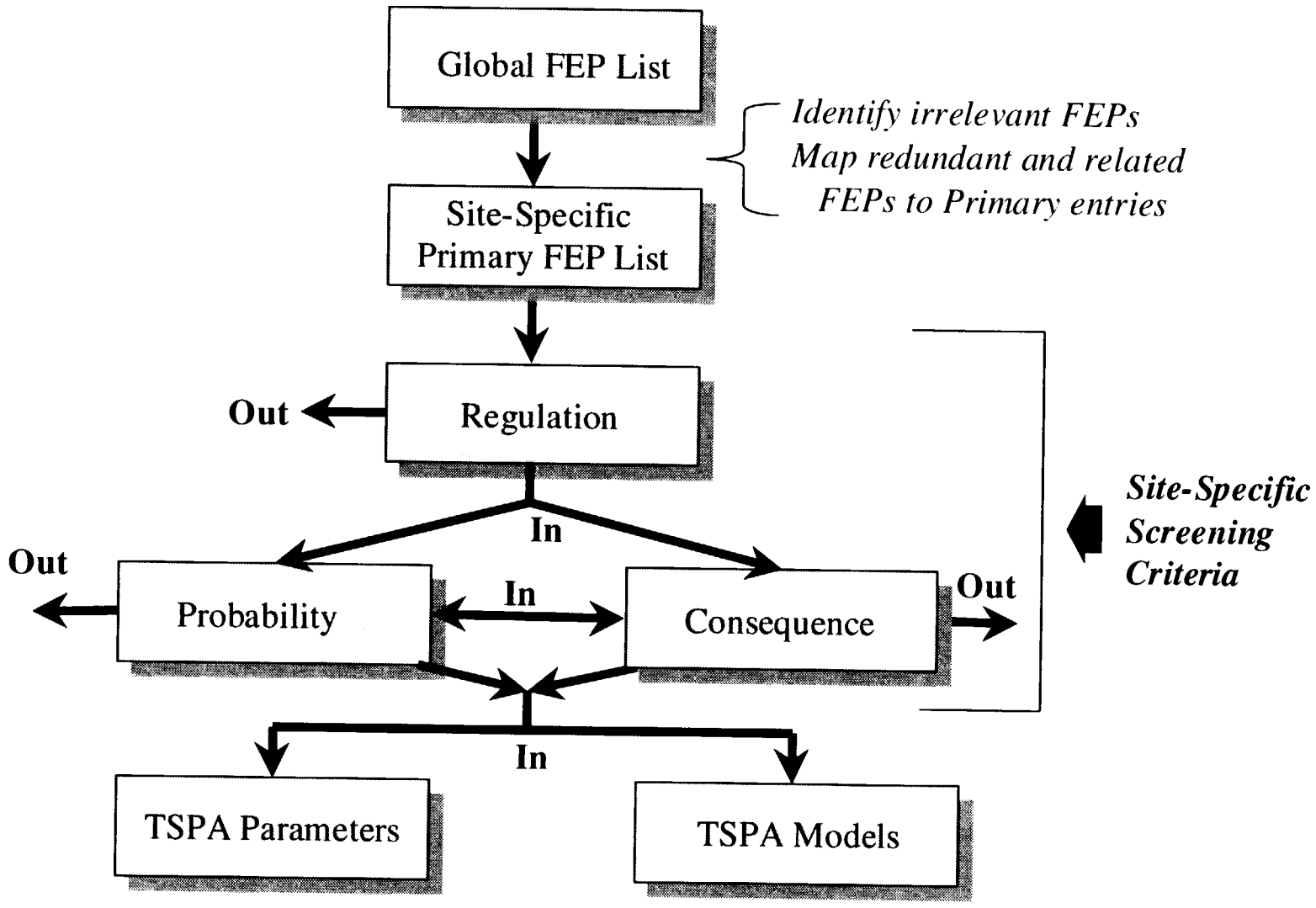
Total System Performance Assessment Process (Continued)

- **Construct integrated Total System Performance Assessment model using all retained features, events, and processes**
  - "Nominal" performance model contains all features, events and processes likely to occur
  - "Disruptive event" performance model contains low-probability events (e.g., volcanism)
  - Stylized human intrusion model, as specified by regulation
- **Evaluate total-system performance (individual dose and groundwater protection) considering uncertainty**

Overview Total System Performance Assessment-Site Recommendation



Screening Features, Events, and Processes (FEPs)



Features, Events, and Processes Screening Criteria

- **From proposed 10 CFR 63.114 d, e, f**
  - "Any performance assessment used to demonstrate compliance with §63.113(b) shall:
    - ...Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.
    - ...Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.
    - ...Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission."

Features, Events, and Processes Screening Criteria (Continued)

- **Features, Events, and Processes screened for 10,000-year performance**
  - Re-examined on a case-by-case basis for peak dose

Features, Events, and Processes Implementation

- **Initial Features, Events, and Processes identified by review of Yucca Mountain Project and international literature**
- **Features, Events, and Processes evaluations documented in analysis and model reports that correspond to the Process Model Reports**
  - There is no Repository Design and Thermal-Mechanical Effects process model report or Features, Events, and Processes analysis and model report - relevant Features, Events, and Processes appear in several analysis and model reports
  - Features, Events, and Processes work is interdisciplinary, and draws on multiple sources: e.g., Disruptive Events Features, Events, and Processes analysis and model report relies on contributions from geologists, seismic hazard analysts, waste package engineers

Features, Events, and Processes Implementation (Continued)

- **Total System Performance Assessment-Site Recommendation models the Features, Events, and Processes identified as included by the Features, Events, and Processes analysis and model reports**

Features, Events, and Processes Analysis and Model Reports

- **What is in the Features, Events, and Processes Analysis and Model Reports?**
  - Features, Events, and Processes identification and classification description
  - Features, Events, and Processes screening process discussion
  - Detailed screening arguments for excluded Features, Events, and Processes
    - Low annual probability of occurrence
    - Low consequence to dose
  - Compilation of work from multiple subject areas
  - Summary of the work of subject-matter experts
  - Supporting references and citations

Features, Events, and Processes Analysis and Model Reports (Continued)

- **What is in the Features, Events, and Processes Analysis and Model Reports? (Continued)**
  - Pointers to Total System Performance Assessment-Site Recommendation for included Features, Events, and Processes and Features, Events, and Processes database
  - Features, Events, and Processes analysis and model reports prepared under AP-3.10Q

Features, Events, and Processes Analysis and Model Reports (Continued)

- **Biosphere:**
  - *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes,* ANL-MGR-MD-000011 REV01 ICN01
- **Disruptive Events:**
  - *Features, Events, and Processes: Disruptive Events,* ANL-WIS-MD-000005 REV 00 ICN 1
- **Engineered Barrier System:**
  - *Engineered Barrier System Features, Events, and Processes,* ANL-WIS-PA-000002 REV 01
- **Near Field Environment:**
  - *Features, Events, and Processes in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 REV 00 ICN 01

Features, Events, and Processes Analysis and Model Reports (Continued)

- **System-Level and Criticality:**
  - *Features, Events and Processes: System-Level and Criticality*, ANL-WIS-MD-000019 REV 00
- **Saturated Zone:**
  - *Features, Events, and Processes in SZ Flow and Transport*, ANL-NBS-MD-000002 REV 01
- **Unsaturated Zone:**
  - *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 REV 01

Features, Events, and Processes Analysis and Model Reports (Continued)

- **Waste Form:**
  - *Miscellaneous Waste Form FEPs*, ANL-WIS-MD-000009 REV 00 ICN 01
  - *Clad Degradation FEPs Screening Arguments*, ANL-WIS-MD-000008 REV 00 ICN 01
  - *Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary*, ANL-WIS-MD-000012 REV 00 ICN 01
- **Waste Package:**
  - *Features, Events, and Processes Screening of Processes and Issues in Drip Shield and Waste Package Degradation*, ANL-EBS-PA-000002 REV 01

Features, Events, and Processes Relevant to Repository Design and Thermal Mechanical Effects

- **No specific Repository Design and Thermal-Mechanical Effects category in Features, Events, and Processes list**
- **89 Primary Features, Events, and Processes currently map to Repository Design and Thermal-Mechanical Effects subissues**
  - Addressed in five analysis and model reports
    - *Engineered Barrier System Features, Events, and Processes*
    - *Features, Events, and Processes in Thermal Hydrology and Coupled Processes*
    - *Features, Events, and Processes Screening of Processes and Issues in Drip Shield and Waste Package Degradation*
    - *Features, Events, and Processes in Unsaturated Zone Flow and Transport*
    - *Features, Events and Processes: System-Level and Criticality*

Features, Events, and Processes Relevant to Repository Design and Thermal Mechanical Effects (Continued)

- Aspects of 67 of these Features, Events, and Processes are included in the Total System Performance Assessment, remainder are excluded on the basis of screening analyses

Repository Design and Thermal-Mechanical Effects Cross-mapping to Features, Events, and Processes

- **NRC identification inferred from mappings in the Total System Performance Assessment and Integration Issue Resolution Status Report Rev. 3, Tables 3 and 5**
  - Table 3 maps Key Technical Issue Subissues to Integrated Subissues
  - Table 5 maps DOE Primary Features, Events, and Processes to NRC Integrated Subissues
- **Primary Features, Events, and Processes map well to Key Technical Issues and Integrated Subissues**

Repository Design and Thermal-Mechanical Effects Cross-mapping to Features, Events, and Processes (Continued)

- Because of interrelationships, Features, Events, and Processes may map to one or more Integrated Subissues: Results of cross-mapping are, therefore, non-unique
- Repository Design and Thermal-Mechanical Effects Features, Events, and Processes list provided in backup information

Summary

- Postclosure aspects of Repository Design and Thermal-Mechanical Effects evaluated through Features, Events, and Processes process
- Technical basis for Features, Events, and Processes screening decisions documented in Features, Events, and Processes analysis and model reports
- Features, Events, and Processes that are screened in by Features, Events, and Processes analysis and model reports are included in Total System Performance Assessment modeling

Summary
(Continued)

- Inclusion or exclusion of specific Features, Events, and Processes from the Total System Performance Assessment will be discussed in the context of relevant subissues and components
- Additional backup information provides summary of Primary Features, Events, and Processes relevant to Repository Design and Thermal-Mechanical Effects, with references to appropriate analysis and model reports

Backup Information

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes

RDTME IRSR Rev 3

* Based on: *Total System Performance Assessment and Integration Issue Resolution Status Report* REV 3, Table 3

RDTME 1: Design Control within the QA Program
- (no ISIs listed)

RDTME 2: Design for Seismic Effects and Direct Fault Disruption
- ENG2 Mechanical Disruption of Engineered Barriers
- UZ2 Flow Paths in the UZ

RDTME 3: TM Effects on Underground Facility Design and Performance
- ENG1 Degradation of Engineered Barriers
- ENG2 Mechanical Disruption of Engineered Barriers
- ENG3 Quantity and Chemistry of Water Contacting WP and WF
- UZ2 Flow Paths in the UZ

RDTME 4: Design and Contribution of Seals
- ENG1 Degradation of Engineered Barriers
- UZ2 Flow Paths in the UZ

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
0.1.09.00.00	Regulatory requirements and exclusions	SYS	X								
0.1.10.00.00	Model and data issues	SYS	X			X	X	X	X		
1.1.01.02.00	Loss of integrity of borehole seals	UZ								X	X
1.1.02.00.00	Excavation/construction	NFE, UZ, EBS	X				X		X		
1.1.02.02.00	Effects of pre-closure ventilation	NFE, EBS	X			X	X			X	
1.1.03.01.00	Error in waste or backfill emplacement	WP, EBS	X			X	X	X			
1.1.04.01.00	Incomplete closure	UZ	X							X	
1.1.07.00.00	Repository design	SYS, EBS	X	X		X	X			X	
1.1.08.00.00	Quality control	SYS, EBS	X	X		X	X			X	
1.1.09.00.00	Schedule and planning	SYS	X			X	X			X	
1.1.13.00.00	Retrievability	SYS, EBS	X							X	
1.2.02.01.00	Fractures	NFE, UZ, SZ, DE		X	X		X	X	X		
1.2.02.02.00	Faulting	UZ, SZ, DE		X	X		X	X	X		
1.2.03.01.00	Seismic activity	UZ, SZ, DE		X	X		X	X	X		
2.1.01.01.00	Waste inventory	WFMisc	X								
2.1.01.02.00	Co-disposal/co-location of waste	WFMisc	X								

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
2.1.01.03.00	Heterogeneity of waste forms	WFMisc	X								
2.1.01.04.00	Spatial Heterogeneity of Emplaced Waste	WFMisc	X								
2.1.02.13.00	General corrosion of cladding	WFClad				X					
2.1.02.16.00	Localized corrosion (pitting) of cladding	WFClad				X					
2.1.02.17.00	Localized corrosion (crevice corrosion) of cladding	WFClad				X					
2.1.02.19.00	Creep rupture of cladding	WFClad				X	X				
2.1.02.21.00	Stress corrosion cracking (SCC) of cladding	WFClad				X					
2.1.02.24.00	Mechanical failure of cladding	WFClad					X				
2.1.03.01.00	Corrosion of waste containers	WP, EBS				X					
2.1.03.02.00	Stress corrosion cracking of waste containers and drip shields	WP				X					
2.1.03.03.00	Pitting of waste containers and drip shields	WP				X					
2.1.03.05.00	Microbially-mediated corrosion of waste container and drip shield	WP				X					
2.1.03.07.00	Mechanical impact on waste container and drip shield	WP					X				
2.1.03.11.00	Container form	WP	X	X		X	X				
2.1.03.12.00	Container failure (long-term)	WP, EBS		X		X	X	X			
2.1.04.02.00	Physical and chemical properties of backfill	EBS				X	X	X			
2.1.04.04.00	Mechanical effects of backfill	EBS		X			X				
2.1.04.05.00	Backfill evolution	EBS					X				

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
2.1.05.01.00	Seal physical properties	UZ								X	X
2.1.05.02.00	Groundwater flow and radionuclide transport in seals	UZ								X	X
2.1.05.03.00	Seal degradation	UZ								X	X
2.1.06.02.00	Effects of rock reinforcement materials	EBS	X	X			X				
2.1.06.05.00	Degradation of invert and pedestal	EBS	X	X			X				
2.1.06.06.00	Effects and degradation of drip shield	WP, EBS		X		X	X	X			
2.1.07.01.00	Rockfall (large block) WFClad—Rockfall	WP, WFClad, DE, WFMisc, EBS		X			X				
2.1.07.02.00	Mechanical degradation or collapse of drift	DE, EBS					X				
2.1.07.05.00	Creeping of metallic materials in the EBS	WP, EBS				X	X				
2.1.07.06.00	Floor buckling	EBS					X				
2.1.08.01.00	Increased unsaturated water flux at the repository	NFE, UZ, EBS						X	X		
2.1.08.02.00	Enhanced influx (Philip's drip)	NFE, UZ, EBS						X	X		
2.1.08.03.00	Repository dry-out due to waste heat	NFE						X			
2.1.08.04.00	Condensation forms on backs of drifts	EBS						X			
2.1.08.05.00	Flow through invert	EBS						X			
2.1.08.07.00	Pathways for unsaturated flow and transport in the waste and EBS	WFMisc, EBS						X			
2.1.08.08.00	Induced hydrological changes in the waste and EBS	WFMisc, EBS						X			

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
2.1.08.10.00	Desaturation/dewatering of the repository	NFE, WFMisc						X			
2.1.08.11.00	Resaturation of repository	NFE, EBS						X			
2.1.08.15.00	Waste-form and backfill consolidation	WFMisc				X		X			
2.1.09.07.00	Reaction kinetics in waste and EBS	WFMisc, EBS				X		X			
2.1.09.11.00	Waste-rock contact	WFMisc, EBS					X				
2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock	NFE, WFMisc, EBS				X	X	X			
2.1.11.01.00	Heat output / temperature in waste and EBS	NFE, WFMisc, EBS				X	X	X			
2.1.11.02.00	Nonuniform heat distribution / edge effects in repository	NFE					X	X			
2.1.11.04.00	Temperature effects / coupled processes in waste and EBS	WFMisc, EBS				X	X	X			
2.1.11.05.00	Differing thermal expansion of repository components	WP, WFMisc, EBS					X	X			
2.1.11.06.00	Thermal sensitization of waste containers and drip shields increases their fragility	WP				X	X				
2.1.11.07.00	Thermally-induced stress changes in waste and EBS	WFMisc, EBS					X				
2.1.11.08.00	Thermal effects: chemical and microbiological changes in the waste and EBS	WFMisc, EBS						X			
2.1.11.09.00	Thermal effects on liquid or two-phase fluid flow in the waste and EBS	WFMisc, EBS						X			
2.1.11.10.00	Thermal effects on diffusion (Soret effect) in waste and EBS	WFMisc, EBS						X			

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	NFE, UZ					X		X		
2.2.01.02.00	Thermal and other waste and EBS-related changes in the adjacent host rock	NFE					X				
2.2.01.03.00	Changes in fluid saturations in the excavation disturbed zone	NFE						X			
2.2.03.02.00	Rock properties of host rock and other units	UZ, SZ		X					X		
2.2.06.01.00	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	NFE, DE			X			X			
2.2.06.02.00	Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults	UZ, SZ, DE			X				X		
2.2.06.03.00	Changes in stress (due to seismic or tectonic effects) alter perched water zones	UZ, SZ, DE			X				X		
2.2.07.02.00	Unsaturated groundwater flow in geosphere	UZ							X		
2.2.07.03.00	Capillary rise	UZ, Bio							X		
2.2.07.04.00	Focusing of unsaturated flow (fingers, weeps)	UZ							X		
2.2.07.08.00	Fracture flow in the unsaturated zone	UZ							X		
2.2.07.09.00	Matrix imbibition in the unsaturated zone	UZ							X		
2.2.07.10.00	Condensation zone forms around drifts	NFE, UZ						X	X		
2.2.07.11.00	Return flow from condensation cap / resaturation of dry-out zone	NFE, UZ						X	X		

Cross-mapping of Repository Design and Thermal-Mechanical Effects Key Technical Issues, Integrated Subissues, and Features, Events, and Processes (Continued)

FEP Database Number	FEP Title	FEP AMR	RDTME1 (Design Control / QA)	RDTME 2 (Design for Seismic Effects/Fault		RDTME3 (Thermal Mechanical Effects)				RDTME 4 (Repository Seals)	
			-- (none listed)	ENG2 *Disruption*	UZ2 *Flow Paths*	ENG 1 *Degradation*	ENG 2 *Disruption*	ENG 3 *Water Contacting WP and WF*	UZ2 *Flow Paths*	ENG 1 *Degradation*	UZ2 *Flow Paths*
2.2.08.01.00	Groundwater chemistry / composition in UZ and SZ SZ—Groundwater Chemistry FEPs	UZ, SZ							X		
2.2.08.03.00	Geochemical interactions in geosphere (dissolution, precipitation, weathering) and effects on radionuclide transport SZ—Groundwater Chemistry FEPs	NFE, UZ, SZ						X	X		
2.2.08.04.00	Redissolution of precipitates directs more corrosive fluids to containers	NFE, UZ, EBS						X	X		
2.2.10.01.00	Repository-induced thermal effects in geosphere	UZ, SZ							X		
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	NFE, UZ					X	X	X		
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	NFE, UZ					X	X	X		
2.2.10.10.00	Two-phase bouyant flow / heat pipes	NFE, UZ	X			X	X				
2.2.10.11.00	Natural air flow in unsaturated zone	UZ	X						X	X	
2.2.10.12.00	Geosphere dry-out due to waste heat	NFE						X			

Note:
- FEPs numbers, names, status, and assignments was originally taken from REV 00 of the FEPs Database, available as Appendix D of *The Development of Information Catalogued in REV 00 of the YMP FEP Database*.
- The FEP information has been checked and modified to reflect more recent revisions of the respective FEPs AMRs, but the information in this table should be considered preliminary.
- The relationship of the FEPs, KTI Subissues, and Subissues is based on Tables 3 and 5 of the TSPAI REV 3, on the discussions provided in the RDTME IRSR REV 3, on subjective judgement of the analyst

DE - Disruptive Events	UZ - Unsaturated Zone
EBS - Engineered Barrier Systems	WFMisc - Miscellaneous Waste Form
NFE - Near Field Environment	WFCladding- Waste Form Cladding
SYS - System-Level and Criticality	WP - Waste Package
SZ - Saturated Zone	

Subissue 1, Design in QA Program

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
0.1.09.00.00	Regulatory requirements and exclusions	SYS—Include for Primary FEP / Exclude for Secondary FEPs	SYS
0.1.10.00.00	Model and data issues	SYS—Include / Exclude for unmodeled design features	SYS
1.1.02.00.00	Excavation/construction	NFE—Include fracture effects/exclude chemistry related effects. UZ—Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry EBS—Exclude	NFE, UZ, EBS
1.1.02.02.00	Effects of pre-closure ventilation	NFE—Include for Primary / Exclude for non-YMP site specific secondaries EBS—Include	NFE, EBS

Subissue 1, Design in QA Program (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.1.03.01.00	Error in waste or backfill emplacement	WP—Exclude EBS—Exclude (see Section 5.1.22 [of EBS FEP AMR Rev 00: Assumptions, Repository Closure] for discussion)	WP, EBS
1.1.04.01.00	Incomplete closure	UZ—Exclude effects of deep boreholes. Include effects of ground-support boreholes on drift seepage.	UZ
1.1.07.00.00	Repository design	SYS—Include for licensed design and for design modifications/ Exclude for undetected deviations from design / Exclude for inadequacy or lack of safety and non-YMP design elements EBS—Include (exclude deviations from design)	SYS, EBS
1.1.08.00.00	Quality control	SYS—Include for "Quality Control" (primary FEP and secondary FEPs (1.1.08.00.05 and .06)/ Exclude for material defects and faulty construction / Exclude for installation of panels, silos, and drains. EBS—Include / Exclude defects and deviations from design)	SYS, EBS
1.1.09.00.00	Schedule and planning	SYS—Exclude	SYS
1.1.13.00.00	Retrievability	SYS—Include for design elements related to retrievability and emplacement/ Exclude for operational and administrative considerations. EBS—Include	SYS, EBS

Subissue 1, Design in QA Program
(Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.01.01.00	Waste inventory	WFMisc—Included. However, only a limited number of radionuclides are shown to be important to repository performance.	WFMisc
2.1.01.02.00	Co-disposal/co-location of waste	WFMisc—Include co-location and codisposal.	WFMisc
2.1.01.03.00	Heterogeneity of waste forms	WFMisc—Include	WFMisc
2.1.01.04.00	Spatial Heterogeneity of Emplaced Waste	WFMisc: Exclude	WFMisc
2.1.03.11.00	Container form	WP—Exclude	WP

Subissue 1, Design in QA Program
(Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.06.02.00	Effects of rock reinforcement materials	EBS—Include	EBS
2.1.06.05.00	Degradation of invert and pedestal	EBS—Include	EBS
2.2.10.10.00	Two-phase bouyant flow / heat pipes	NFE—Include TH effects / THC effects partially included UZ—Include	NFE, UZ
2.2.10.11.00	Natural air flow in unsaturated zone	UZ—Exclude	UZ

Subissue 2, Design for Seismic Effects and Fault Displacement

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
0.1.09.00.00	Regulatory requirements and exclusions	SYS—Include for Primary FEP / Exclude for Secondary FEPs	SYS
0.1.10.00.00	Model and data issues	SYS—Include / Exclude for unmodeled design features	SYS
1.1.07.00.00	Repository design	SYS—Include for licensed design and for design modifications/ Exclude for undetected deviations from design / Exclude for inadequacy or lack of safety EBS—Include (exclude deviations from design)	SYS, EBS
1.1.08.00.00	Quality control	SYS—Include for "Quality Control" (primary FEP and secondary FEPs (1.1.08.00.05 and .06)/ Exclude for material defects and faulty construction / Exclude for installation of panels, silos, and drains EBS—Include (exclude defects and deviations)	SYS, EBS

Subissue 2, Design for Seismic Effects and Fault Displacement (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.2.02.01.00	Fractures	NFE—Include in seepage / Exclude permanent effects. UZ—Include effects of present-day fracture system / Exclude the effects of changes to the fracture system . SZ—Exclude DE—Include for existing characteristics / Exclude for changes to characteristics	NFE, UZ, SZ, DE
1.2.02.02.00	Faulting	UZ—Include effects of present-day faults. Exclude the effects of changes to the faults SZ—Exclude DE—Include for existing fault characteristics, Exclude for changes of fault characteristics and new faults	UZ, SZ, DE
1.2.03.01.00	Seismic activity	UZ—Exclude SZ—Exclude DE—Exclude (Preliminary) for indirect effects / Exclude (Preliminary) for drip shield, waste package, and emplacement drift / Include for fuel rod cladding damage	UZ, SZ, DE
2.1.03.11.00	Container form	WP—Exclude	WP
2.1.03.12.00	Container failure (long-term)	WP—Include EBS—Include	WP, EBS

Subissue 2, Design for Seismic Effects and Fault Displacement (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.04.04.00	Mechanical effects of backfill	EBS—Include / Exclude (dependent on inclusion in repository design)	EBS
2.1.06.02.00	Effects of rock reinforcement materials	EBS—Include	EBS
2.1.06.05.00	Degradation of invert and pedestal	EBS—Include	EBS
2.1.06.06.00	Effects and degradation of drip shield	WP—Exclude damage to drip shield by rock fall. Exclude damage to drip shield by ground motion during seismic events and oxygen embrittlement) / Include chemical degradation processes. EBS—Include	WP, EBS

Subissue 2, Design for Seismic Effects and Fault Displacement (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.2.03.02.00	Rock properties of host rock and other units	UZ—Include SZ—Include	UZ, SZ
2.2.06.01.00	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	NFE—Exclude DE—Exclude	NFE, DE
2.2.06.02.00	Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults	UZ—Exclude SZ—Exclude DE—Exclude	UZ, SZ, DE
2.2.06.03.00	Changes in stress (due to seismic or tectonic effects) alter perched water zones	UZ—Exclude effects of perched water changes below the potential repository. Include effects of perched water changes above potential repository on drift seepage. SZ—Exclude DE—Exclude	UZ, SZ, DE

Subissue 3, Component 1- Thermal-Mechanical Effects on Design and Performance

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
0.1.10.00.00	Model and data issues	SYS—Include / Exclude for unmodeled design features.	SYS
1.1.02.00.00	Excavation /construction	NFE—Include fracture effects / Exclude chemistry related effects. UZ—Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry. EBS—Exclude	NFE, UZ, EBS
1.1.02.02.00	Effects of pre-closure ventilation	NFE—Include for Primary / Exclude for non-YMP specific secondaries EBS—Include	NFE, EBS
1.1.03.01.00	Error in waste or backfill emplacement	WP—Exclude EBS—Exclude (see Section 5.1.22 [of EBS FEP AMR Rev 00: Assumptions, Repository Closure] for discussion)	WP, EBS
1.1.07.00.00	Repository design	SYS—Include for licensed design and for design modifications/ Exclude for significant undetected deviations / Exclude for inadequacy or lack of safety EBS—Include (exclude deviations from design)	SYS, EBS

Subissue 3, Component 1- Thermal-Mechanical Effects on Design and Performance (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.1.08.00.00	Quality control	SYS—Include for "Quality Control" (primary FEP and secondary FEPs (1.1.08.00.05 and .06)/ Exclude for material defects and faulty fabrication / Exclude for installation of panels, silos, and drains EBS—Include / Exclude defects and deviations from design	SYS, EBS
1.1.09.00.00	Schedule and planning	SYS—Exclude	SYS
2.1.03.11.00	Container form	WP—Exclude	WP
2.1.03.12.00	Container failure (long-term)	WP—Include EBS—Include	WP, EBS
2.1.04.02.00	Physical and chemical properties of backfill	EBS—Include/ Exclude (dependent on inclusion of backfill in design)	EBS
2.1.04.04.00	Mechanical effects of backfill	EBS—Include / Exclude (dependent on inclusion of backfill in design)	EBS
2.1.04.05.00	Backfill evolution	EBS—Include / Exclude (dependent on inclusion of backfill in design)	EBS
2.1.06.02.00	Effects of rock reinforcement materials	EBS—Include	EBS
2.1.07.05.00	Creeping of metallic materials in the EBS	WP—Exclude EBS—Exclude	WP, EBS

Subissue 3, Component 1- Thermal-Mechanical Effects on Design and Performance (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock	NFE—Include in THC model/ Excluded from TH model and EBS transport WFMisc—Included in radionuclide mobilization. Excluded in adjacent rock. EBS—Include	NFE, WFMisc, EBS
2.1.11.01.00	Heat output / temperature in waste and EBS	NFE—Include / Exclude for non-YMP secondaries WFMisc—Include EBS—Include	NFE, WFMisc, EBS
2.1.11.02.00	Nonuniform heat distribution / edge effects in repository	NFE—Include for TH and THC / Exclude TH effects	NFE
2.1.11.05.00	Differing thermal expansion of repository components	WP—Exclude WFMisc—Include EBS—Exclude	WP, WFMisc, EBS
2.1.11.06.00	Thermal sensitization of waste containers and drip shields increases their fragility	WP—Include	WP

Subissue 3, Component 1- Thermal-Mechanical Effects on Design and Performance (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.11.07.00	Thermally-induced stress changes in waste and EBS	WFMisc—Include thermally induced stress changes in near-field environment. Exclude thermally induced stress changes in the waste and packaging. EBS—Include	WFMisc, EBS
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	NFE—Include for initial conditions / Exclude permanent changes UZ—Include the effects of stress relief and ground support on drift seepage / Exclude changes in water chemistry	NFE, UZ
2.2.01.02.00	Thermal and other waste and EBS-related changes in the adjacent host rock	NFE—Exclude	NFE
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	NFE—Exclude UZ—Exclude	NFE, UZ
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	NFE—Exclude UZ—Exclude	NFE, UZ
2.2.10.10.00	Two-phase bouyant flow / heat pipes	NFE—Include TH effects / THC effects partially included UZ—Include	NFE, UZ
2.2.10.11.00	Natural air flow in unsaturated zone	UZ—Exclude	UZ

Subissue 3, Component 2 - Effects of Seismically Induced Rockfall

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
0.1.10.00.00	Model and data issues	SYS—Include / Exclude for unmodeled design features.	SYS
1.1.07.00.00	Repository design	SYS—Include for licensed design and for design modifications/ Exclude for significant undetected deviations / Exclude for inadequacy or lack of safety EBS—Include (exclude deviations from design)	SYS, EBS
1.2.02.01.00	Fractures	NFE—Include in seepage / Exclude permanent effects. UZ—Include effects of present-day fracture system. Exclude the effects of changes to the fracture system . SZ—Exclude DE—Include for existing fractures / Exclude for changes in fracture properties	NFE, UZ, SZ, DE
1.2.02.02.00	Faulting	UZ—Include effects of present-day faults. Exclude the effects of changes to the faults SZ—Exclude DE—Include for existing fault characteristics / Exclude for changes of fault characteristics.	UZ, SZ, DE

Subissue 3, Component 2 - Effects of Seismically Induced Rockfall (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.2.03.01.00	Seismic activity	UZ—Exclude SZ—Exclude DE—Exclude (Preliminary) for indirect effects / Exclude (Preliminary) for breaching of the drip shield, waste package, and emplacement package. Include for fuel rod cladding damage	UZ, SZ, DE
2.1.02.19.00	Creep rupture of cladding	WFClad—Include	WFClad
2.1.02.24.00	Mechanical failure of cladding	WFClad—Include	WFClad
2.1.03.07.00	Mechanical impact on waste container and drip shield	WP—Exclude	WP
2.1.03.11.00	Container form	WP—Exclude	WP
2.1.03.12.00	Container failure (long-term)	WP—Include EBS—Include	WP, EBS
2.1.04.04.00	Mechanical effects of backfill	EBS—Include / Exclude (dependent on inclusion of backfill in design)	EBS

Subissue 3, Component 2 - Effects of Seismically Induced Rockfall (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.06.06.00	Effects and degradation of drip shield	WP—Exclude rock fall/ Exclude seismic and oxygen embrittlement / Include chemical degradation EBS - Include	WP, EBS
2.1.07.01.00	Rockfall (large block) WFClad—Rockfall	WP—Exclude WFClad—Exclude DE—Exclude WFMisc—Exclude EBS—Exclude	WP, WFClad, DE, WFMisc, EBS
2.1.07.02.00	Mechanical degradation or collapse of drift	DE—Exclude EBS—Exclude	DE, EBS
2.1.07.06.00	Floor buckling	EBS—Exclude	EBS
2.1.09.11.00	Waste-rock contact	WFMisc—Exclude EBS—Exclude	WFMisc, EBS

Subissue 3, Component 2 - Effects of Seismically Induced Rockfall (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.11.04.00	Temperature effects / coupled processes in waste and EBS	WFMisc—Include EBS—Include	WFMisc, EBS
2.1.11.06.00	Thermal sensitization of waste containers and drip shields increases their fragility	WP—Include	WP
2.1.11.07.00	Thermally-induced stress changes in waste and EBS	WFMisc—Include thermally induced stress changes in near-field environment. Exclude thermally induced stress changes in the waste and packaging EBS—Include	WFMisc, EBS
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	NFE—Exclude (initial condition) / Exclude (permanent changes). UZ—Include the effects of stress relief and ground support on drift seepage / Exclude changes in water chemistry	NFE, UZ
2.2.01.02.00	Thermal and other waste and EBS-related changes in the adjacent host rock	NFE—Exclude	NFE

Subissue 3, Component 2 - Effects of Seismically Induced Rockfall (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	NFE—Exclude UZ—Excluded	NFE, UZ
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	NFE—Exclude UZ—Exclude	NFE, UZ

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
0.1.10.00.00	Model and data issues	SYS—Include / Exclude for unmodeled design features	SYS
1.1.02.00.00	Excavation/construction	NFE—Include fracture effects / Exclude chemistry related effects / Exclude non-YMP specific secondary FEPs UZ—Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry EBS—Exclude	NFE, UZ, EBS
1.1.03.01.00	Error in waste or backfill emplacement	WP—Exclude EBS—Exclude (see Section 5.1.22 [of EBS FEP AMR Rev 00: Assumptions, Repository Closure] for discussion)	WP, EBS
1.2.02.01.00	Fractures	NFE—Include seepage / Exclude permanent effects. UZ—Include effects of present-day fracture system. Exclude the effects of changes to the fracture system . SZ—Exclude. Low consequence. DE—Include for existing characteristics / Exclude for changes to characteristics	NFE, UZ, SZ, DE
1.2.02.02.00	Faulting	UZ—Include effects of present-day faults. Exclude the effects of changes to the faults SZ—Exclude DE—Include for existing fault characteristics / Exclude for changes of fault characteristics	UZ, SZ, DE

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.2.03.01.00	Seismic activity	UZ—Exclude SZ—Exclude DE—Exclude (Preliminary) for indirect effects / Exclude (Preliminary) for drip shield, waste package, and emplacement pallet / Include for fuel rod cladding damage	UZ, SZ, DE
2.1.03.12.00	Container failure (long-term)	WP—Include EBS—Include	WP, EBS
2.1.04.02.00	Physical and chemical properties of backfill	EBS—Include / Exclude (dependent on inclusion of backfill in design)	EBS
2.1.06.06.00	Effects and degradation of drip shield	WP—Exclude rock fall / Exclude seismic and oxygen embrittlement) / Include chemical degradation EBS - Include	WP, EBS

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.08.01.00	Increased unsaturated water flux at the repository	NFE—Include climate change / Exclude water quenching waste package UZ—Include EBS—Include	NFE, UZ, EBS
2.1.08.02.00	Enhanced influx (Philip's drip)	NFE—Include UZ—Include EBS—Exclude	NFE, UZ, EBS
2.1.08.03.00	Repository dry-out due to waste heat	NFE—Include	NFE
2.1.08.04.00	Condensation forms on backs of drifts	EBS—Include	EBS
2.1.08.05.00	Flow through invert	EBS—Include	EBS
2.1.08.07.00	Pathways for unsaturated flow and transport in the waste and EBS	WFMisc—Include through the use of a series of linked one dimensional flowpaths and mixing cells through the EBS, drip shield, waste package and into the invert / Exclude preferential pathways within the EBS, waste form and invert EBS – Include	WFMisc, EBS

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.08.08.00	Induced hydrological changes in the waste and EBS	WFMisc—Include induced hydrological changes (flow areas) from corrosion for the waste package and drip shield. Include induced hydrological changes (exposed fuel area) for the waste form / Exclude changes to hydrological properties for the waste form EBS—	WFMisc, EBS
2.1.08.10.00	Desaturation/dewatering of the repository	NFE—Include / Exclude non-YMP specific secondary FEPs WFMisc—Include	NFE, WFMisc
2.1.08.11.00	Resaturation of repository	NFE—Include / Exclude non-YMP specific FEPs EBS—Include	NFE, EBS
2.1.08.15.00	Waste-form and backfill consolidation	WFMisc—Excluded	WFMisc
2.1.09.07.00	Reaction kinetics in waste and EBS	WFMisc—Include reaction kinetics in the equilibrium model / Exclude - reaction transients EBS—Exclude	WFMisc, EBS

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock	NFE—Included in THC model / Excluded from TH models WFMisc—Include for radionuclide mobilization./ Exclude for adjacent rock. EBS—Include	NFE, WFMisc, EBS
2.1.11.01.00	Heat output / temperature in waste and EBS	NFE—Include primary and some secondaries / Exclude non-YMP specific secondaries WFMisc—Include EBS—Include	NFE, WFMisc, EBS
2.1.11.02.00	Nonuniform heat distribution / edge effects in repository	NFE—Include TH and THC / Exclude TM effects	NFE
2.1.11.04.00	Temperature effects / coupled processes in waste and EBS	WFMisc—Include EBS—Include	WFMisc, EBS
2.1.11.05.00	Differing thermal expansion of repository components	WP—Exclude WFMisc—Include EBS— Exclude	WP, WFMisc, EBS

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.11.08.00	Thermal effects: chemical and microbiological changes in the waste and EBS	WFMisc—Include EBS—Include	WFMisc, EBS
2.1.11.09.00	Thermal effects on liquid or two-phase fluid flow in the waste and EBS	WFMisc—Include / Exclude two-phase flow within the waste / Exclude thermall driven single-phase flow EBS—Include	WFMisc, EBS
2.1.11.10.00	Thermal effects on diffusion (Soret effect) in waste and EBS	WFMisc—Exclude EBS—Exclude	WFMisc, EBS
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	NFE—Include (initial condition) / Exclude (permanent change) UZ—Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry	NFE, UZ
2.2.01.03.00	Changes in fluid saturations in the excavation disturbed zone	NFE—Exclude	NFE
2.2.03.02.00	Rock properties of host rock and other units	UZ—Include SZ—Include	UZ, SZ

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.2.06.01.00	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	NFE—Exclude DE—Exclude	NFE, DE
2.2.06.02.00	Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults	UZ—Exclude SZ—Exclude DE—Exclude	UZ, SZ, DE
2.2.06.03.00	Changes in stress (due to seismic or tectonic effects) alter perched water zones	UZ—Exclude effects of perched water changes below the potential repository / Include effects of perched water changes above potential repository on drift seepage. SZ—Exclude DE—Exclude	UZ, SZ, DE
2.2.07.02.00	Unsaturated groundwater flow in geosphere	UZ—Include	UZ
2.2.07.03.00	Capillary rise	UZ—Include Bio—Exclude	UZ, Bio
2.2.07.04.00	Focusing of unsaturated flow (fingers, weeps)	UZ—Include	UZ
2.2.07.08.00	Fracture flow in the unsaturated zone	UZ—Include	UZ

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.2.07.09.00	Matrix imbibition in the unsaturated zone	UZ—Include	UZ
2.2.07.10.00	Condensation zone forms around drifts	NFE—Include UZ—Exclude mountain-scale effects / Include effects on drift seepage.	NFE, UZ
2.2.07.11.00	Return flow from condensation cap / resaturation of dry-out zone	NFE—Include primary and most secondaries / Exclude one non-YMP specific secondary UZ—Exclude mountain-scale effects on the basis of low consequence. Include effects on drift seepage.	NFE, UZ
2.2.08.01.00	Groundwater chemistry / composition in UZ and SZ SZ—Groundwater Chemistry FEPs	UZ—Include the effects of ambient-condition geochemistry / Exclude changes in geochemical conditions SZ—Include	UZ, SZ
2.2.08.03.00	Geochemical interactions in geosphere (dissolution, precipitation, weathering) and effects on radionuclide transport SZ—Groundwater Chemistry FEPs	NFE—Include changes in fracture porosity in THC model / Exclude dissolution and precipitation effects UZ—Exclude SZ—Include	NFE, UZ, SZ
2.2.08.04.00	Redissolution of precipitates directs more corrosive fluids to containers	NFE—Include in THC model / Exclude in TH model UZ—Include EBS—Include	NFE, UZ, EBS

Subissue 3, Component 3 - Quantity and Chemistry of Water Contacting Waste Packages/Waste Forms (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.2.10.01.00	Repository-induced thermal effects in geosphere	UZ—Exclude mountain-scale thermo-chemical effects / Include thermo-chemical effects on drift seepage. SZ—Exclude	UZ, SZ
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	NFE—Exclude UZ—Exclude	NFE, UZ
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	NFE—Exclude UZ—Exclude	NFE, UZ
2.2.10.11.00	Natural air flow in unsaturated zone	UZ—Exclude	UZ
2.2.10.12.00	Geosphere dry-out due to waste heat	NFE—Include	NFE

Subissue 4 - Repository Seals

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
1.1.01.02.00	Loss of integrity of borehole seals	UZ—Exclude effects of deep boreholes / Include effects of ground-support boreholes on drift seepage.	UZ
1.1.02.02.00	Effects of pre-closure ventilation	NFE—Include / Exclude non-specific YMP secondaries EBS—Include	NFE, EBS
1.1.04.01.00	Incomplete closure	UZ—Exclude effects of deep boreholes on the basis of low consequence. Include effects of ground-support boreholes on drift seepage.	UZ
1.1.07.00.00	Repository design	SYS—Include for licensed design and for design modifications/ Exclude for significant undetected deviations / Exclude for inadequacy or lack of safety EBS—Include (exclude deviations from design)	SYS, EBS
1.1.08.00.00	Quality control	SYS—Include for "Quality Control" (primary FEP and secondary FEPs (1.1.08.00.05 and .06)/ Exclude for secondary fEPs addressing material defects and faulty fabrication, Exclude for installation of panels, silos, and drains EBS—Include (exclude defects and deviations)	SYS, EBS
1.1.09.00.00	Schedule and planning	SYS—Exclude	SYS
1.1.13.00.00	Retrievability	SYS—Include for design elements related to retrievability and emplacement/ Exclude for operational and administrative considerations. EBS—Include	SYS, EBS

Subissue 4 - Repository Seals (Continued)

FEP Number	FEP Title	Screening Decision(s)	FEP AMR(s)
2.1.05.01.00	Seal physical properties	UZ—Exclude	UZ
2.1.05.02.00	Groundwater flow and radionuclide transport in seals	UZ—Exclude	UZ
2.1.05.03.00	Seal degradation	UZ—Exclude	UZ
2.2.10.11.00	Natural air flow in unsaturated zone	UZ—Exclude	UZ

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

Subissue 3, Thermal-Mechanical Effects on Underground Facility Design and Performance - Component 1, Thermal-Mechanical Effects on Design of Underground Facility

Presented to:
DOE-NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

Presented by:
Dan McKenzie, Barry Thom, Richard Quittmeyer, and Fei Duan
Civilian Radioactive Waste Management System Management and Operating Contractor

February 6-8, 2001
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 3, Component 1 in the Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3, this presentation will**
  - Summarize technical basis for item resolution
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- **Conclusions**

Current Subissue Status

- **Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3 indicates Component 1 of Subissue 3 is Open**

Presentation Objectives

- **Describe the basis for resolving Subissue 3, Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3**
- **Component 1- Thermal-Mechanical Effects on Design of Underground Facility**
  - Acceptance Criterion 1 - *Subsurface Facility Design Codes and Standards*: DOE has established appropriate controls for engineering design inputs which are implemented in controlled documents and specify the applicable design codes, standards, and criteria. DOE considers this criterion to be Closed as discussed in the presentation for Subissue 1
  - Acceptance Criterion 3 - *Subsurface Facility Materials and Material Properties*: DOE has specified material requirements in design documents. DOE considers this criterion to be Closed-Pending any potential integrated license application design that will include an evaluation of materials for acceptability and impact on long-term performance

Presentation Objectives
(Continued)

- **Component 1- Thermal-Mechanical Effects on Design of Underground Facility (Continued)**
  - Acceptance Criterion 4 - *Design Analysis Load Combinations*: DOE is evaluating seismic, thermal and in-situ stresses. DOE considers this criterion to be Closed-Pending completion of Seismic Topical Report 3
  - Acceptance Criterion 5 - *Design Analysis Uncertainties*: Rock properties have been incorporated into design analyses. DOE considers this criterion to be Closed-Pending completion of design parameters analysis and rock mass classification analysis
  - Acceptance Criterion 6 - *Ground Support Design Methodology*: DOE has focused on the development of a ground support system that is robust enough to accommodate the range of rock mass quality at the repository host horizon. DOE considers this criterion to be Closed
  - Acceptance Criterion 7 - *Subsurface Ventilation Design*: DOE considers this criterion to be Closed-Pending. DOE is in the process of acquiring corroborating modeling for ventilation design as well as testing data to increase confidence in its thermal modeling methods

Acceptance Criterion 1

- **Design assumptions, codes, and standards used for the design of subsurface facility structures, systems and components important to safety are acceptable**
- **Action or Information Needs**
  - Design codes, standards, and criteria need to be made available for review
- **Basis for Closure**
  - Overview
    - Design control is described in AP-3.13Q
    - AP-3.13Q requires the design to be developed in accordance with system description documents
    - Design control documents are available to the NRC

Acceptance Criterion 1
(Continued)

- **Basis for Closure (Continued)**
  - The following system description documents were used for Site Recommendation design of the underground facility:
    - » Subsurface Facility
    - » Emplacement Drift
    - » Waste Emplacement/Retrieval
    - » Subsurface Ventilation
    - » Ground Control
  - Applicable design codes, standards, detailed criteria for subsurface design are specified
  - Specified in Section 1 of the system description documents
  - Codes and standards are similar to those accepted by the NRC for design of nuclear facilities
    - NRC regulation and guidance has been reviewed and incorporated as applicable

Acceptance Criterion 1
(Continued)

- **Basis for Closure (Continued)**
  - Non-standard approaches are justified
    - Appendix A of the system description documents provides the rationale or references the rationale for the design codes, standards, and detailed criteria identified
  - Assumptions made for the design of the subsurface facility are technically defensible
    - All assumptions used in any design analysis are evaluated by a technical checker in accordance with AP-3.10Q and evaluated again by reviewing organizations via the AP-2.14Q review process
  - Designs for all subsurface structures, systems and components for Site Recommendation use applicable standards
    - System description documents specify applicable standards and are used as input into all design analyses
    - Confirmation that system description documents are incorporated into the design process occurs during the technical checking and review of design documents as required by AP-3.10Q and AP-2.14Q
  - System description documents have been provided to NRC
  - Any potential license application will identify applicable codes and standards utilized for design

Acceptance Criterion 1
(Continued)

- **References**
  - *Design Control*, AP-3.13Q
  - *Analyses and Models*, AP-3.10Q
  - *Review of Technical Products and Data*, AP-2.14Q
  - *Subsurface Facility System Description Document,* SDD-SFS-SE-000001 REV 01
  - *Emplacement Drift System Description Document,* SDD-EDS-SE-000001 REV 01
  - *Waste Emplacement/Retrieval System Description Document,* SDD-WES-SE-000001 REV 01
  - *Subsurface Ventilation System Description Document,* SDD-SVS-SE-000001 REV 01
  - *Ground Control System Description Document,* SDD-GCS-SE-000001 REV 01

Acceptance Criterion 1
(Continued)

- **Appropriate controls for engineering design inputs are utilized and implemented in controlled documents. These controls ensure that the appropriate design codes, standards and criteria are used. DOE considers this criterion to be Closed**

Acceptance Criterion 3

- **Materials and material properties used for the subsurface facility design are appropriate**
- **Action or Information Needs**
  - None identified
- **Basis for Closure**
  - DOE agrees the use of appropriate materials is potentially important to the repository's performance and has already performed significant work in this area
    - For example: The removal of the pre-cast segmental concrete liner from the emplacement drift design was in response to concerns over its potential to adversely affect long-term performance
  - Material standards are specified in the system description documents
  - The ultimate selection of committed materials (left underground after closure) is an iterative process involving the subsurface designers and Performance Assessment team

Acceptance Criterion 3
(Continued)

- **Basis for Closure (Continued)**
  - Materials planned to be committed will be quantified and cataloged for use in the Total System Performance Assessment for any potential License Application
  - This information will be provided in the *Emplacement Drift System Description Document,* SDD-EDS-SE-000001
- **References**
  - *Emplacement Drift Invert Structural Design Analysis.* BBDC00000-01717-0200-00001 REV 00
  - *Materials for Emplacement Drift Ground Support.* BCAA00000-01717-0200-00003 REV 00
  - *Emplacement Drift Invert Structural Design Analysis.* BBDC00000-01717-0200-00001 REV 01
  - *Evaluation of Alternative Materials for Emplacement Drift Ground Control.* BCAA00000-01717-0200-00013 REV 00

Acceptance Criterion 3
(Continued)

- **References (Continued)**
  - *Longevity of Emplacement Drift Ground Support Materials.* ANL-EBS-GE-000003 REV 00
  - *Longevity of Emplacement Drift Ground Support Materials.* ANL-EBS-GE-000003 REV 01
  - *Invert Configuration and Drip Shield Interface.* TDR-EDS-ST-000001 REV 00
  - *Emplacement Drift Invert-Low Steel Evaluation.* TDR-EDS-ST-000002 REV 00
- **DOE is implementing appropriate controls on materials and material properties. DOE considers this acceptance criterion to be Closed-Pending completion of any potential license application design and its associated system description documents, design documentation, and Total System Performance Assessment for License Application**

Acceptance Criterion 4

- **Design analyses use appropriate load combinations for normal and Category 1 and 2 event sequence conditions**
- **Action or Information Needs**
  - Appropriateness of in-situ stress ratio
  - Incorporation of thermal load in ground support design
  - Appropriateness of seismic design inputs for design analysis
- **Basis for Closure**
  - In-situ stresses based on field measurements show lower and upper bounds of the horizontal to vertical stress ratio (K_o) to be 0.3 and 1.0
    - The use of 0.3 is conservative under in-situ and seismic loads; 1.0 is conservative under thermal loads
  - Thermal loads are adequately applied to ground control analyses
  - Seismic loads are based on documented preliminary results
    - Loads will be updated based on completion of seismic design inputs (Seismic Topical Report 3)

Acceptance Criterion 4
(Continued)

- **References**
  - RIB 00077, *In Situ Rock Conditions*, DTN: MO0007RIB00077.000
  - *ANSYS Thermal Calculations in Support of Waste Quantity, Mix and Throughout Study* CAL-EBS-MG-000001 REV 00
  - *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
  - DTN MO0004MWDRIFM3.002 and DTN MO0004MWDRIFM3.002, Preliminary Seismic Inputs
    - Work in support of Seismic Topical Report 3, which will provide final seismic design inputs, is in progress

Acceptance Criterion 4
(Continued)

- Data on in-situ stresses and seismic loads are adequate. Thermal loads for ground control analyses are properly implemented based on thermal management parameters provided as input
- DOE considers this acceptance criterion to be Closed-Pending completion of Seismic Topical Report 3

Appropriateness of In-Situ Stress Ratio

- **Basis for Resolution**
  - Thermally induced stresses are dominant in the horizontal direction
  - Both hydraulic fracturing data and Goodman Jack measurements show that K_o values of 0.3 and 1.0 are lower and upper bounds for the horizontal to vertical stress ratio at the repository host horizon
    - A lower K_o value of 0.2 could be inferred from USW G-4 borehole measurements up to 250 m depth. However, this is above the repository host horizon
  - Use of K_o=1.0 leads to highest resultant horizontal stress under combined in-situ and thermal loads. Such a stress state is least favorable to drift stability and, therefore, considered to be conservative
- **References**
  - RIB 00077, *In Situ Rock Conditions*, DTN: MO0007RIB00077.000
- **DOE considers questions on the appropriateness of stress ratio values to be resolved. No additional work is required**

Incorporation of Thermal Load in Ground Support Design

- **Basis for Resolution**
  - Thermal loads for thermal-mechanical models take the heat output and ventilation rate from thermal management analyses and are adequately applied to ground control analyses
  - Any changes to thermal loads would be evaluated for impact on ground control analysis results
- **References**
  - *ANSYS Thermal Calculations in Support of Waste Quantity, Mix and Throughout Study,* CAL-EBS-MG-000001 REV 00
  - *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
- **DOE considers this comment to be resolved. Thermal load for ground control is adequately represented, and peak thermally induced loads on ground support are obtained. No additional work is required**

Appropriateness of Seismic Design Inputs for Design Analysis

- **Basis for Resolution**
  - A full suite of seismic design inputs is being developed including
    - Horizontal and vertical response spectra
    - Horizontal and vertical time histories
    - Horizontal and vertical peak ground acceleration and velocity
    - Variation in peak values, strains, and curvatures as a function of depth to 300 m
  - Ground motion response spectra will cover the structural frequency range from 0.3 to 100 Hz
  - Use of seismic inputs for design analyses will be discussed later in this presentation (Acceptance Criterion 5)
  - The Seismic Design Inputs analysis and model report (in progress) will contain the inputs to be used for design

Appropriateness of Seismic Design Inputs for Design Analysis (Continued)

- **References**
  - *Seismic Design Inputs Analysis and Model Report* (to be developed)
  - *Preclosure Seismic Design Inputs for a Geologic Repository at Yucca Mountain, Seismic Topical Report 3* (to be developed)
- **Appropriate seismic loads will be used in design analyses. Seismic Topical Report 3 will document the seismic design inputs and their technical basis**

Acceptance Criterion 5

- **Design analyses use appropriate models and site-specific properties of the host rock and consider spatial and temporal variation and uncertainties in such properties**
- **Action or Information Needs**
  - Justify mechanical properties for continuum rock mass modeling
  - Justify mechanical properties for discontinuum rock mass modeling
  - Provide basis for mechanical degradation of rock support materials
  - Justify thermal-mechanical modeling
- **Basis for Closure**
  - Ground support analyses have considered the site conditions, postulated loadings, and available modeling approaches
  - Ground support analyses have considered combinations of continuum and discontinuum modeling methods

Acceptance Criterion 5
(Continued)

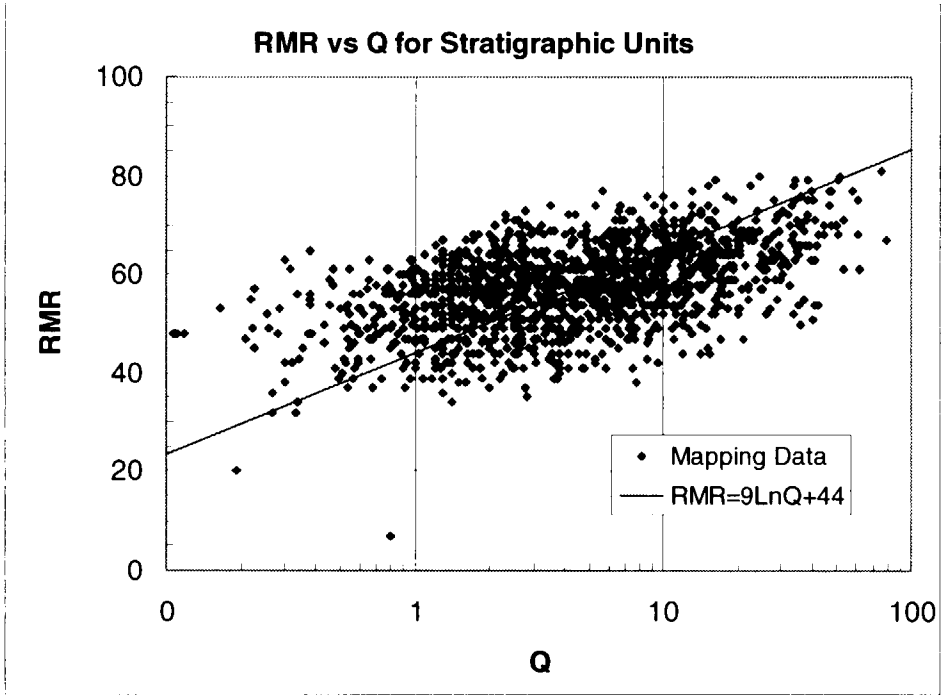
- **Basis for Closure (Continued)**
  - Two-dimensional modeling has been used for general evaluation of emplacement drifts and is considered to be conservative in general. Three-dimensional modeling has been used in local areas such as emplacement drift turnouts and intersections among emplacement drifts and non-emplacement openings
  - Selection of representative fracture patterns has been based on the extensive mapping of the Exploratory Studies Facility tunnels and Enhanced Characterization of the Repository Block Cross Drift (DTN: MO0002SPAFRA06.002). Variations in discontinuum modeling are covered by using bounding properties in the models. For example, rock mass mechanical properties are considered for the intact rock blocks between joints
  - Ground support analyses have assessed the behavior of a jointed rock mass under prolonged heated conditions and assumed Category 1 and 2 seismic events

Acceptance Criterion 5
(Continued)

- **References**
  - *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
  - *Longevity of Emplacement Drift Ground Support Materials,* ANL-EBS-GE-000003 REV 01
  - DTN:MO0002SPAFRA06.002, *Fracture Geometry for Stratigraphic Units in the Repository Host Horizon*
- **DOE's continuum and discontinuum models are appropriate for their intended use and are adequately justified. DOE considers this acceptance criterion to be Closed-Pending completion of**
  - Design Parameters Analysis (expected to be completed in 2002)
  - Rock Mass Classification Analysis (expected to be completed in 2002)

Justify Mechanical Properties for Continuum Rock Mass Modeling

- **Basis for Resolution**
  - Values of the rock mass rating (RMR) and rock mass quality (Q) for both lithophysal and non-lithophysal rock masses show the empirical correlation by Z. T. Bieniawski is applicable



Reference: *Ground Control for Emplacement Drifts for SR*, ANL-EBS-GE-000002 REV 00

Justify Mechanical Properties for Continuum Rock Mass Modeling (Continued)

- **Basis for Resolution (Continued)**
  - Rock mass mechanical properties derived based on the empirical approach are considered to be appropriate, particularly for the non-lithophysal rock. Further classification analyses are planned, particularly for the lithophysal rock
  - Internal friction angles for the rock mass have been derived using the rock mass quality index approach and field mapping data (DTN: MO0001SEPSRMPC.000). The derived values are very sensitive to the range of confining stress used. Use of a confining stress range of 0 to 3 MPa will lead to a friction angle of 56 to 58 degrees, while a confining stress range of 0 to 42 MPa will result in a friction angle of 37 to 43 degrees. The friction angles based on both confining stress ranges were used and discussed in ground control analyses

Justify Mechanical Properties for Continuum Rock Mass Modeling (Continued)

- **Basis for Resolution (Continued)**
  - In lieu of the coefficients of thermal expansion for the rock mass, the coefficients of thermal expansion values obtained from laboratory tests on small intact specimens have been used in ground control analyses involving the drift-scale rock mass
    - The rationale is that the coefficients of thermal expansion values for the rock mass, if determined by in-situ tests, will be lower than those from small laboratory samples (i.e., the in-situ rock mass may contain all the open discontinuities that will be closed first, making net thermal expansion less than that for the intact rock)
      - » This is confirmed by results from the Single Heater Test
    - In terms of thermally induced stresses in a rock mass, use of higher coefficients of thermal expansion values leads to higher stresses, rendering the thermal-mechanical calculations conservative

Justify Mechanical Properties for Continuum Rock Mass Modeling (Continued)

- **References**
  - *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
  - *Drift Degradation Analysis*, ANL-EBS-MD-000027 REV 01
  - *Single Heater Test Final Report,* BAB000000-01717-5700-00005 REV 00 ICN 01

- **DOE's continuum rock mass models are appropriate and adequately justified. NRC concerns on mechanical properties such as rock mass thermal expansivity, effects of lithophysae, and rock mass mechanical degradation will be examined through sensitivity studies for any potential license application design**

Justify Mechanical Properties for Continuum Rock Mass Modeling (Continued)

- **DOE considers this comment to be resolved pending completion of the *Design Parameters Analysis* and *Rock Mass Classification Analysis* (expected to be completed in 2002)**

Justify Mechanical Properties for Discontinuum Rock Mass Modeling

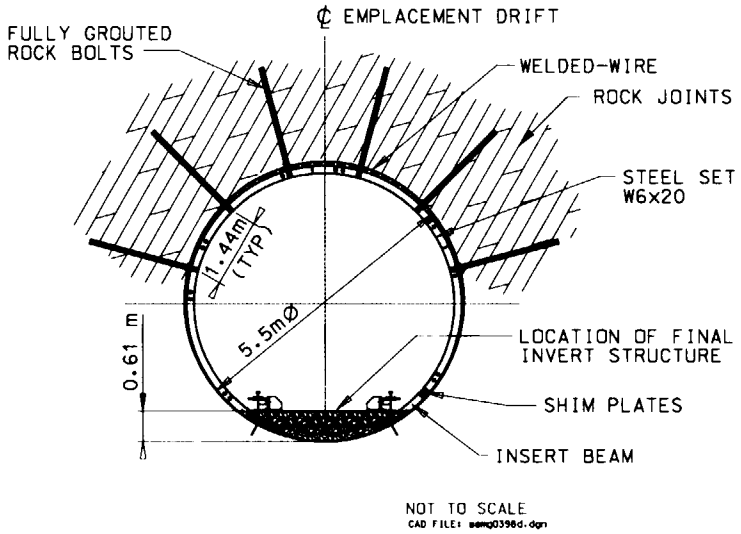
- **Basis for Resolution**
  - Mechanical properties for rock blocks between representative joints (fractures) are size-dependent. Rock mass properties have been used instead of intact rock properties in ground support analyses for Site Recommendation, resulting in conservative approximations of drift behavior in a jointed rock mass
  - Mechanical properties for joints are based on available test data. Values used in ground control analyses are determined such that the mean minus one standard deviation is used as a conservative guide
  - Considering the scattering and stress-dependent nature of mechanical properties for joints, values selected for ground control analyses are considered to be conservatively representative

Justify Mechanical Properties for Discontinuum Rock Mass Modeling
(Continued)

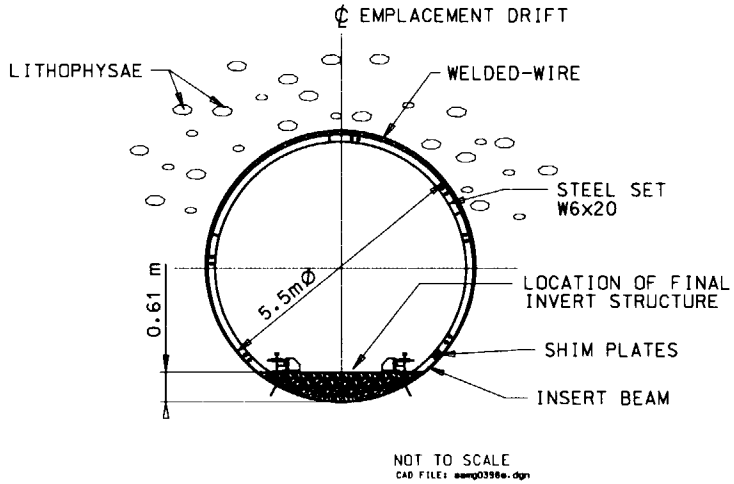
- **References**
  - *Ground Control for Emplacement Drifts for SR*, ANL-EBS-GE-000002 REV 00
  - *Yucca Mountain Site Geotechnical Report*, B00000000-01717-5705-00043 REV 01
- **DOE's discontinuum rock mass models are appropriate and adequately justified. NRC concerns on mechanical properties for interblocks between fractures, fracture patterns, and fracture friction angle will be examined through sensitivity studies for potential license application design**
- **DOE considers this comment resolved pending completion of the *Design Parameters Analysis* and *Rock Mass Classification Analysis* (expected to be completed in 2002)**

Provide Basis for Mechanical Degradation of Rock Support Materials

- **Basis for Resolution**
  - Ground Support Selection for Site Recommendation



Non-lithophysal Rock



Lithophysal Rock

Reference: *Ground Control for Emplacement Drifts for SR*, ANL-EBS-GE-000002 REV 00

Provide Basis for Mechanical Degradation of Rock Support Materials (Continued)

- **Basis for Resolution (Continued)**
  - Ground Support Materials
    - Carbon Steel - for steel sets, wire mesh, and rock bolts
    - Cementitious grout - for grouting rock bolts in boreholes (The amount of grout should be kept to a minimum, while affording satisfactory performance of rock bolts)
  - Degradation Mechanism for Carbon Steel Ground Support
    - Corrosion of carbon steel is considered to be the leading cause
    - Corrosion due to dry oxidation is considered to be applicable, in contrast to humid-air corrosion and aqueous corrosion
    - Due to elevated temperature (up to 125° C) and low relative humidity (1% to < 40%) in emplacement drifts, corrosion depth of carbon steel based on dry oxidation is estimated to be < 0.05 μm (5×10^{-5} mm) for up to 300 years - negligible in terms of its effect on structural integrity and load capacity
    - Due to elevated temperature, a reduction of 2.5% on modulus and 5% on strength is expected - insignificant and inconsequential to steel components

Provide Basis for Mechanical Degradation of Rock Support Materials (Continued)

- **Basis for Resolution (Continued)**
  - Degradation mechanisms for cementitious grout
    - Temperature
    - Sulfate
    - Carbonation
    - Biology
    - Radiation
    - pH of groundwater
  - Temperature is the leading factor for grout degradation. A reduction of up to 30% on modulus and up to 20% on strength is conservatively estimated. Additional degradation caused by other factors listed above is negligible during the preclosure
  - A higher reduction in modulus reduces the thermally induced stress more than strength loss, rendering a favorable safety margin for grout

Provide Basis for Mechanical Degradation of Rock Support Materials (Continued)

- **Basis for Resolution (Continued)**
  - Consideration of mechanical degradation for ground support analyses
    - No mechanical degradation was considered for steel ground support components because such degradation was shown to be negligible
    - No mechanical degradation was considered for cementitious grout because a larger reduction on modulus than strength leads to a more favorable safety margin. Impact of using mechanical properties without degradation is considered to be insignificant
- **References**
  - *Longevity of Emplacement Drift Ground Support Materials,* ANL-EBS-GE-000003 REV 01
- **DOE has adequately documented the basis for mechanical degradation of rock support materials. Completion and documentation of sensitivity studies on ground support material properties will confirm the approaches handling mechanical degradation**

Justify Thermal-Mechanical Modeling

- **Basis for Resolution**
  - Two-dimensional modeling for emplacement drifts is considered to be adequate
  - Combination of both continuum and discontinuum modeling approaches allows for realistically analyzing drift and ground support behaviors
  - Considering the total length of emplacement drifts, fracture patterns have to be idealized or simplified such that least favorable patterns expected from the field are considered. The corresponding results are conservative, and ground support is designed for such scenarios. Proper use of simplified regular joint patterns is believed to be conservative
  - Analyses have shown that thermal load induces higher stress on ground support installed in more competent rock (i.e., Rock Mass Quality - 5) than in weak rock (i.e., Rock Mass Quality - 1), as shown in ground support analysis for the Viability Assessment. Because thermal loads for Site Recommendation are much lower than those for the Viability Assessment, thermally induced stress differences due to different rock mass categories are less pronounced, as shown in *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00A

Justify Thermal-Mechanical Modeling
(Continued)

- **Basis for Resolution (Continued)**
  - Velocity, acceleration, and stress as seismic load input are numerically equivalent, resulting in equivalent response of rock mass and ground supports to seismic load. In the ground control design for Site Recommendation, the velocity time history was used in *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
  - A frequency domain analysis is equivalent to a time domain analysis, if the latter is limited to linear material response. In the ground control analysis for Site Recommendation, *Ground Control for Emplacement Drifts for SR*, ANL-EBS-GE-000002 REV 00, the time domain analysis was performed because nonlinear response of jointed rock mass was expected. The frequency domain analysis does not include a nonlinear analysis
  - Velocity, acceleration, and stress as seismic load input are equivalent in terms of the response of rock mass and ground supports if these three types of inputs are equivalent, meaning that use of either of them will lead to an equivalent result. UDEC is able to handle the three types of seismic inputs

Justify Thermal-Mechanical Modeling
(Continued)

- **References**
  - *Ground Control for Emplacement Drifts for SR,* ANL-EBS-GE-000002 REV 00
- **DOE has adequately justified its thermal-mechanical modeling. To enhance confidence in this conclusion, numerical modeling aspects such as boundary locations, fracture patterns, interaction between ground support and rock, and seismic load representation will be further examined and documented as sensitivity studies in any potential license application ground control reference design**

Acceptance Criterion 6

- **The design of ground support systems is based on appropriate design methodologies and interpretations of modeling results**
- **Action or Information Needs**
  - None identified
- **Basis for Closure**
  - Numerical approaches are the primary means of analyzing ground support design. Selection of ground support systems is compared against the empirical approach
  - Ground support analyses consider in-situ, thermal, seismic loads, and their combinations
  - Interaction between the ground support and ground is considered
  - Ground support analyses are performed with and without ground support to address the need for and adequacy of ground support

Acceptance Criterion 6
(Continued)

- **Basis for Closure (Continued)**
  - Ground support analyses for both Viability Assessment and Site Recommendation have shown that under thermal loads, a rock mass with a greater rock mass quality category (Rock Mass Quality-5) tends to exert greater loads on ground support than a rock mass with a lesser rock mass quality category (Rock Mass Quality-1)
  - These results are consistent with the Center for Nuclear Waste Regulatory Analyses results
    - Ground support design analyses have considered both extreme categories, ensuring an adequate support for the Rock Mass Quality-1 rock mass yet mitigating the potential of overstressing in the Rock Mass Quality-5 rock mass condition by examining construction tolerances and their numerical representations
  - Ground support analyses have treated lithophysal and non-lithophysal rock masses differently

Acceptance Criterion 6
(Continued)

- **References**
  - *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00
  - *Repository Ground Support Analysis for Viability Assessment,* BCAA00000-01717-0200-00004 REV 00
- **DOE has focused on the development of a ground support system robust enough to accommodate the range of rock mass quality at the repository host horizon. Ground support analyses are based on bounding and conservative scenarios**
- **No additional work is required**
- **DOE considers this acceptance criterion to be Closed**

Acceptance Criterion 7

- **The subsurface ventilation systems are adequately designed**
- **Action or Information Needs**
  - Justify assumptions and methodology of ventilation models
- **Basis for Closure**
  - The *Subsurface Ventilation System Description Document* SDD-SVS-SE-000001 contains the criteria and design description for this system
  - The system description documents are continuing to evolve and will be updated throughout any potential license application design period

Acceptance Criterion 7
(Continued)

- **References**
  - *Subsurface Ventilation System Description Document* SDD-SVS-SE-000001
- **DOE has defined design criteria for the ventilation system. DOE considers this acceptance criterion to be Closed-Pending the completion of the subsurface ventilation system description documents for any potential license application design**

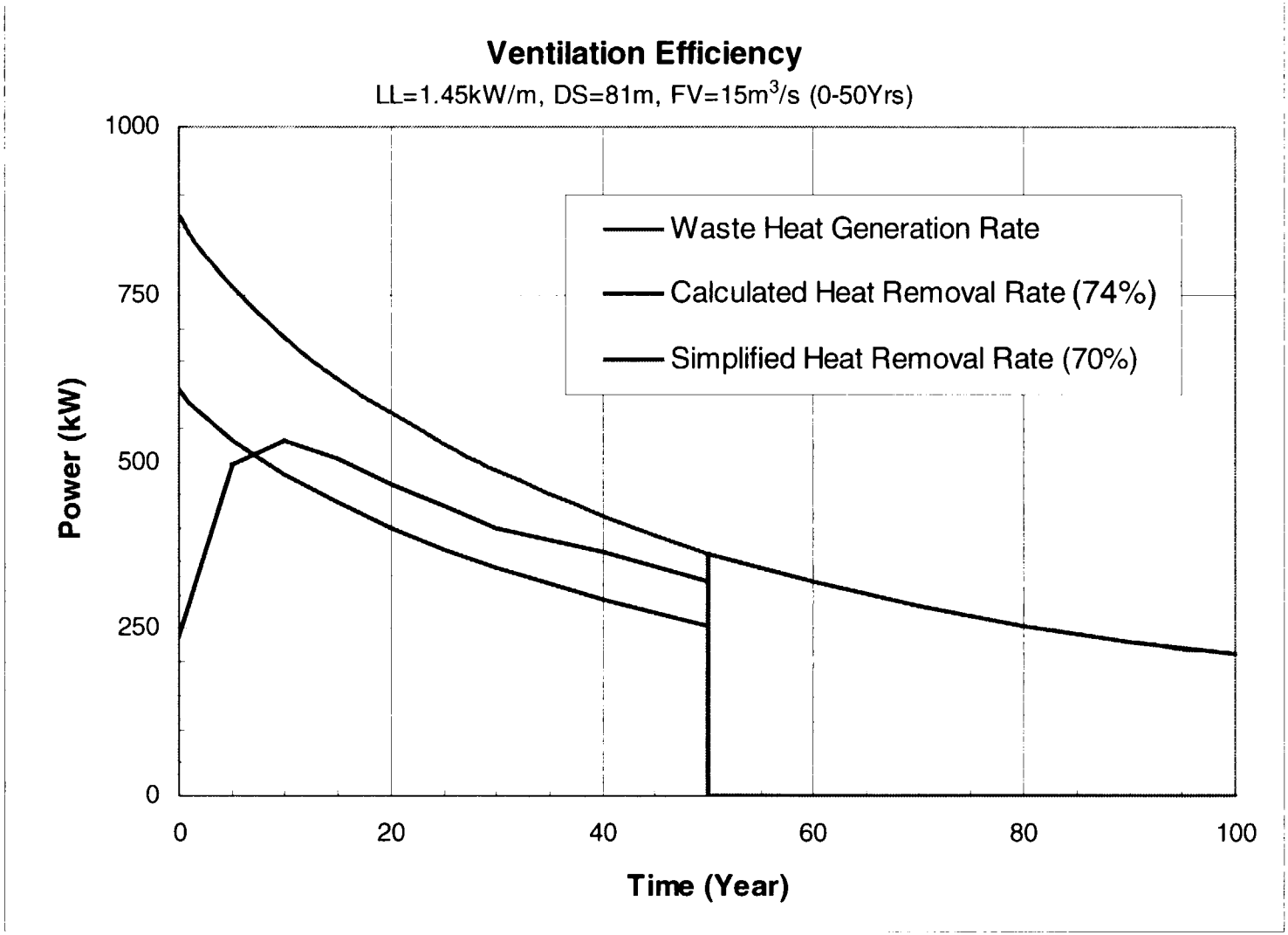
Justify Assumptions and Methodology of Ventilation Models

- **Basis for Resolution**
  - The DOE has extensively evaluated and checked the ventilation model since its development in 1995. DOE is confident that the model produces valid results
  - To enhance confidence that the model is adequate, the model results are to be compared with results from another model that performs similar calculations and was developed independently at the University of Nevada - Reno
  - The ongoing 1/4-scale testing at the Atlas Facility will provide data that can be used to gauge the accuracy of the model
  - Pre-test predictions were made using the model, and the test results will be compared to these predictions to confirm the model, or allow it to be recalibrated, as necessary
  - The combination of these two confirmatory activities will provide additional confidence in the model's results

Justify Assumptions and Methodology of Ventilation Models (Continued)

- **References**
  - *Ventilation Model*, ANL-EBS-MD-000030 REV 00
- **DOE has checked and evaluated the ventilation model and is confident it produces valid results. Confirmatory analyses are underway to provide additional confidence in the model results**

Justify Assumptions and Methodology of Ventilation Models (Continued)



References: Subsurface ventilation System Description Document, SDD-SVS-SE-000001 REV 01
Ventilation Model ANL-EBS-MD-000030 REV 00

Conclusions

- **DOE considers the status for Subissue 3, Repository Design and Thermal-Mechanical Effects, Component 1 to be Closed-Pending**
  - Acceptance Criterion 1: Closed
  - Acceptance Criterion 3: Closed-Pending completion of any potential license application design and its associated design documents
  - Acceptance Criterion 4: Closed-Pending completion of Seismic Topical Report 3
  - Acceptance Criterion 5: Closed-Pending completion of Design Parameters Analysis and Rock Mass Classification Analysis (expected to be completed in 2002)
  - Acceptance Criterion 6: Closed
  - Acceptance Criterion 7: Closed-Pending the completion of the subsurface ventilation system description documents for any potential license application design

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

Subissue 3, Thermal-Mechanical Effects on Underground Facility Design and Performance - Component 2, Effects of Seismically Induced Rockfall in Engineered Barrier Performance

Presented to:

DOE-NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

Presented by:

Dwayne Kicker
Scott Bennett
Civilian Radioactive Waste Management System Management and Operating Contractor

February 6-8, 2001
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 3, Component 2, identified in the Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3, this presentation will:**
  - Summarize technical basis for item resolution
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- **Conclusions**

Current Subissue Status

- **Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3 indicates Component 2 of Subissue 3 is Open**

Presentation Objectives

- **Describe the basis for resolving Component 2 of Subissue 3, Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3**
- **Component 2- Effects of seismically induced rockfall on Waste Package and drip shield performance**
  - Acceptance Criterion 1 - *Evaluation and Abstraction of Design Features and Processes*: Department of Energy (DOE) has evaluated the important design features, assumptions, and processes for incorporation into performance assessment abstractions. DOE considers this criterion to be Closed-Pending completion of additional rockfall verification analyses
  - Acceptance Criterion 2 - *Sufficiency of Data*: DOE considers that sufficient data and analysis have been conducted. DOE considers this criterion Closed-Pending. DOE considers agreements already established at the Container Life and Source Term and Structural Deformation and Seismicity Technical Exchanges to be sufficient to resolve this criterion

Presentation Objectives
(Continued)

- Acceptance Criterion 3 - *Data Uncertainty*: DOE has determined parameter values, distributions, and assumptions appropriate for performance assessment abstractions consistent with site data. DOE considers this criterion Closed-Pending. DOE considers that agreements already established at the Container Life and Source Term and Structural Deformation and Seismicity Technical Exchanges to be sufficient to resolve this criterion
- Acceptance Criterion 4 - *Alternative Conceptual Models*: DOE has evaluated alternative modeling approaches and applicable features, events, and processes consistent with available data. DOE considers this criterion to be Closed-Pending completion of additional rockfall verification analyses
- Acceptance Criterion 5 - *Model Abstraction*: DOE has evaluated the results of performance assessment abstractions. DOE considers this criterion to be Closed-Pending completion of additional rockfall verification analyses

Acceptance Criterion 1

- **Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of Mechanical Disruption of Engineered Barrier Components and other related abstractions in the Total System Performance Assessment and the technical bases are provided. The Total System Performance Assessment abstraction in the DOE License Application identifies and describes aspects of Mechanical Disruption of Engineered Barrier that are important to waste isolation and includes the technical bases for these descriptions**

Acceptance Criterion 1
(Continued)

- **Action or Information Needs**
  - Basis of assumption regarding modeling of joint plane radius
  - Representativeness of joint mapping data
  - Basis for exclusion of small joint trace lengths
  - Treatment of thermal and long-term degradation of joint strength
  - Joint sampling bias
  - Temperature dependency of titanium material properties
  - Design basis rock size
  - Use of 10^{-4} ground motion values for postclosure seismic ground motion analysis
  - Verification of key block analysis approach

Acceptance Criterion 1
(Continued)

- **Basis for closure**
  - The materials used in the construction of the waste package and other relevant engineered barrier components are identified in waste package design analysis and model reports
  - Material selection criteria and the technical basis are identified in the *Waste Package Degradation Process Model Report* (TDR-WIS-MD-000002) and *Engineered Barrier System Degradation, Flow, and Transport Process Model Report* (TDR-EBS-MD-000006)
  - The environmental conditions are addressed in *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (ANL-EBS-MD-000001)
    - This document is used in the Total System Performance Assessment for the Site Recommendation subsystem model for evaluating degradation of the waste package and drip shield in the *Waste Package Degradation (WAPDEG) Model* (ANL-EBS-PA-000001)

Acceptance Criterion 1
(Continued)

- **Basis for closure (Continued)**
  - Design features and dimensions of the relevant engineered components, as they relate to seismically-induced rockfall, are addressed in the analysis and model report, *Features, Events, and Processes: Disruptive Events* (ANL-WIS-MD-000005). A key design feature is the drip shield, which shields the waste package from rockfall. The drip shield design addresses seismically induced rockfall
  - The mechanically disruptive events are addressed in the *Features, Events, and Processes: Disruptive Events* (ANL-WIS-MD-000005), *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis* (ANL-EBS-MD-000035), and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (ANL-EBS-PA-000002)
  - The effect of internal pressure as a function of temperature is determined and evaluated in the analysis and model reports, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001), *Design Analysis for the Defense High-Level Waste Disposal Container* (ANL-DDC-ME-000001), *Design Analysis for the Naval SNF Waste Package* (ANL-VDC-ME-000001), and their supporting calculation documents

Acceptance Criterion 1
(Continued)

- **Basis for closure (Continued)**
  - The waste package (with emplacement pallet) and the drip shield analyses addressing seismic excitation will be consistent with the seismic hazard analysis discussed at the Structural Deformation and Seismicity Technical Exchange
  - The same seismic evaluations of waste packages and drip shield [revision of analysis and model reports, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001) and *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)] will be used for the agreements made at the Structural Deformation and Seismicity and Container Life and Source Term Technical Exchanges; therefore, consistency is ensured. This was discussed in the Container Life and Source Term Technical Exchange, under Subissue 2, Agreement 9

Acceptance Criterion 1
(Continued)

- **References**
  - *Waste Package Degradation Process Model Report,* TDR-WIS-MD-000002 REV 00 ICN 02
  - *Engineered Barrier System Degradation, Flow, and Transport Process Model Report,* TDR-EBS-MD-000006 REV 00 ICN 01
  - *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier,* ANL-EBS-MD-000001 REV 00 ICN 01
  - *WAPDEG Analysis of Waste Package and Drip Shield Degradation,* ANL-EBS-PA-000001 REV 00 ICN 01
  - *Features, Events, and Processes: Disruptive Events,* ANL-WIS-MD-000005 REV 00 ICN 01
  - *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis,* ANL-EBS-MD-000035 REV 00 ICN 01
  - *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation,* ANL-EBS-PA-000002 REV 01

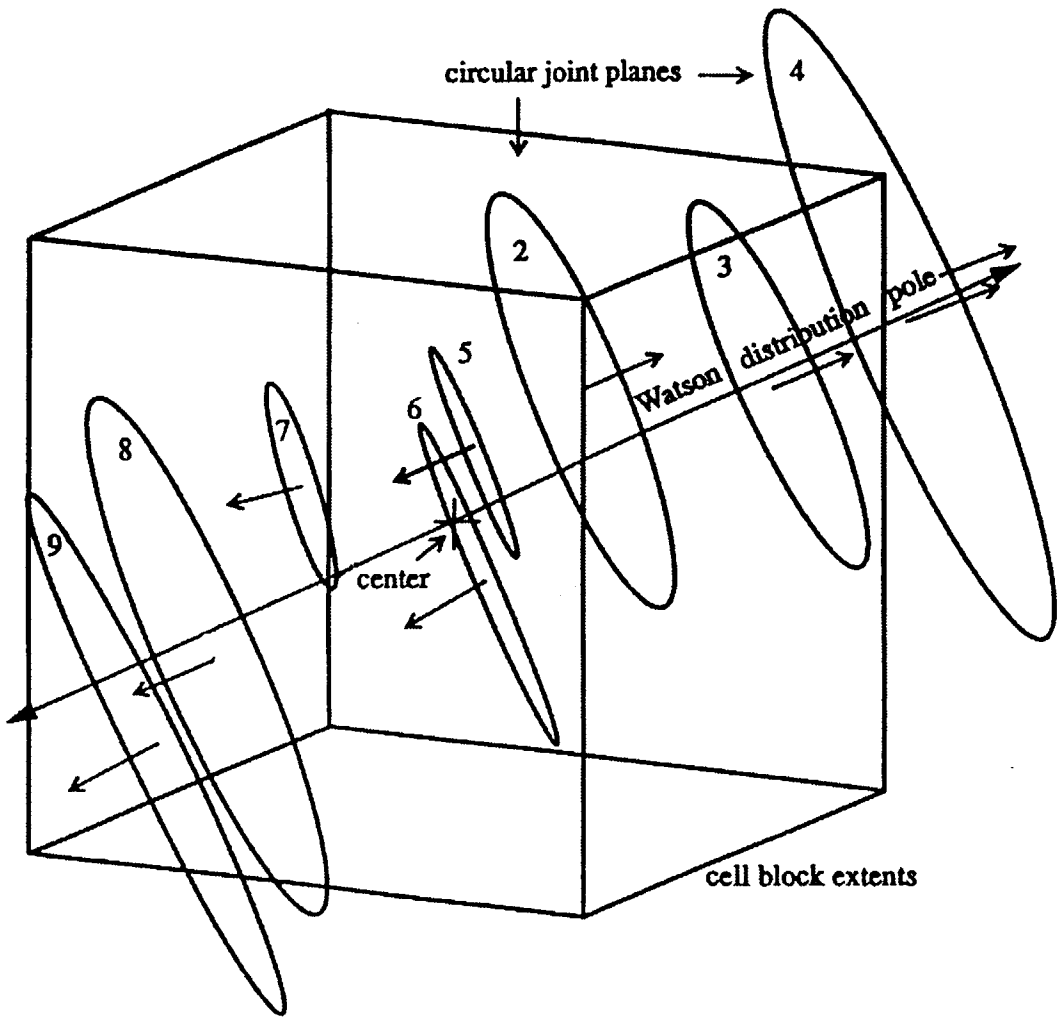
Acceptance Criterion 1
(Continued)

- An adequate definition and description of the aspects of mechanical disruption of engineered barrier components has been provided in the referenced documents
- DOE considers this acceptance criterion to be Closed-Pending completion of additional verification of the rockfall analyses and final seismic design inputs from Seismic Topical Report 3 as described in the following discussions

Modeling of Joint Plane Radius

- **Basis for Resolution**
  - The size and frequency of blocks observed in the Exploratory Studies Facility agrees with the static results from the key block model, thus validating the assumption that the radius of the joint plane in the rockfall model is equal to twice the mapped joint trace length
  - The use of shorter trace lengths would lead to less fracture connectivity and therefore fewer blocks would form
  - The use of shorter trace lengths does not cause the formation of larger blocks since it must be kinematically feasible to move into the opening

Modeling of Joint Plane Radius
(Continued)



- Individual joints within each joint set are represented as circular discs in three-dimensional space. Mean disc radii are typically 4 m or less
- A 26.8 x 26.8 x 26.8 m rock mass volume was modeled represented by a mesh of 680,000 grid points. A 5.5-m diameter, 24.4-m length tunnel was modeled through the center of the rock mass
- The modeled rock mass was sufficiently large to include the full extent of rock failure. Potential "end effects" on block development are diminished with multiple Monte Carlo simulations

Modeling of Joint Plane Radius
(Continued)

Lithologic Unit	Field Observation from ECRB Cross Drift				Results from DRKBA Rock Fall Model			
	Excavation		Key Block Occurrence		Excavation		Key Block Occurrence	
	Diameter (m)	Azimuth (degree)	Number (blocks per km)	Size (m^3)	Diameter (m)	Azimuth (degree)	Number (blocks per km)	Size (m^3)
Tptpul	5	49 to 74	3	< 0.5	5.5	45, 60, 75	14 to 16	0.52 to 0.95
Tptpmn	5	49	40	< 0.5	5.5	45	36	1.15
Tptpll	5	49	0	—	5.5	45	5	1.83
Tptpln	5	49 to 109	8	< 0.5	5.5	45, 60, 75, 90, 105	9 to 14	1.35 to 3.38

Reference: Drift Degradation Analysis (ANL-EBS-MD-000027 REV 01)

Modeling of Joint Plane Radius
(Continued)

- **References**
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon,* ANL-EBS-GE-000006 REV 00
- **DOE considers this comment to be resolved. The joint plane radius assumption is appropriate because the resulting number of blocks simulated for the static case generally agrees with the number of blocks observed in the Tptpul, Tptpmn, Tptpll, and Tptpln units**

Representativeness of Joint Mapping Data

- **Basis for Resolution**
  - The representativeness of the DRKBA rockfall model was addressed in the Structural Deformation and Seismicity Technical Exchange, October 2000
  - The representativeness of the joint mapping data from the Exploratory Studies Facility and Enhanced Characterization of the Repository Block will be compared to joint mapping data collected during construction of the emplacement drifts
  - The uncertainty of fracture geometry (i.e., the orientation, spacing, and trace length of fractures) initially anticipated at the emplacement drift horizon has been diminished with the construction and subsequent detailed fracture mapping of the approximately 10 km of tunnels that comprise the Exploratory Studies Facility
  - The vast amount of fracture data collected from the north-south-trending main drift and the east-west-trending cross drift provide an acceptable representation of the range of fractures anticipated at the emplacement drift horizon

Representativeness of Joint Mapping Data
(Continued)

- **References**
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon,* ANL-EBS-GE-000006 REV 00
  - *Total System Performance Assessment for the Site Recommendation,* TDR-WIS-PA-000001 REV 00 ICN 01
- **DOE considers this comment to be resolved. DOE considers that sufficient fracture mapping data have been obtained and that the data are representative of the potential repository area. Additional field mapping of surface outcrops is being considered in the south end of the repository block to reduce uncertainty associated with the joint set data**

Exclusion of Small Joint Trace Lengths

- **Basis for Resolution**
  - The exclusion of small trace length joints is conservative in terms of block size
    - The inclusion of small trace length joints truncates block formation
    - This truncation results in an increased number of smaller blocks
- **References**
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon,* ANL-EBS-GE-000006 REV 00
- **DOE considers this comment to be resolved. Exclusion of small trace length joints is conservative. An analysis of small trace length data is being considered for inclusion in the next revision of the *Drift Degradation Analysis* to confirm this conclusion**

Treatment of Thermal and Long-Term Degradation of Joint Strength

- **Basis for Resolution**
  - The approach for thermal and long-term degradation of joint strength is based on a fracture mechanics approach in which cohesion was determined to contribute to a crack growth process
  - Because friction was not considered a crack growth process, there was less physical basis for considering long-term degradation of friction angle with time
  - This approach is adequate for Site Recommendation because a conservative reduction in joint strength has been included in the rockfall model resulting in minimal impact on block development and no significant effects on performance
- **References**
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01

Treatment of Thermal and Long-Term Degradation of Joint Strength (Continued)

- DOE considers this comment resolved. To further validate the current approach that considers thermal loading through a reduction in joint cohesion, additional analyses are being considered using an approach that explicitly applies thermal loads
- To account for time-dependent frictional slip, DOE is considering a revision to the *Drift Degradation Analysis* that will incorporate long-term degradation of both friction angle and cohesion

Joint Sampling Bias

- **Basis for Resolution**
  - The issue of joint sampling bias was discussed extensively at the Structural Deformation and Seismicity Technical Exchange, October 2000, and the issues identified were resolved pending a review of the analysis and model report referenced below
  - Discussions are pending with NRC on initial NRC review comments
- **References**
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon,* ANL-EBS-GE-000006 REV 00
- **DOE considers this comment resolved. An adequate joint sample has been mapped in a range of tunnel orientations in the exploratory studies facility. Joint sampling bias has been adequately considered in the reference document. No additional work is planned**

Temperature Dependency of Titanium Material Properties

- **Basis for Resolution**
  - Refer to discussion later in this presentation under Acceptance Criterion 2 for this information need

Design Basis Rock Size for Drip Shield

- **Basis for Resolution**
  - The *Repository Safety Strategy* (Vol III, pp. 7-4, 7-5) identifies the following defense-in-depth roles for the drip shield
    - to divert dripping water away from the waste package, thus mitigating uncertainties in waste-package performance
    - to limit bulk flow through the invert, thereby limiting transport of radionuclides away from the breached waste package
    - to protect the waste package against rockfall
  - Due largely to the presence of ground support, rockfalls in excess of 6 MT are not credible in the preclosure period (*Preclosure Design Basis Events Related to Waste Packages*, p. 64)

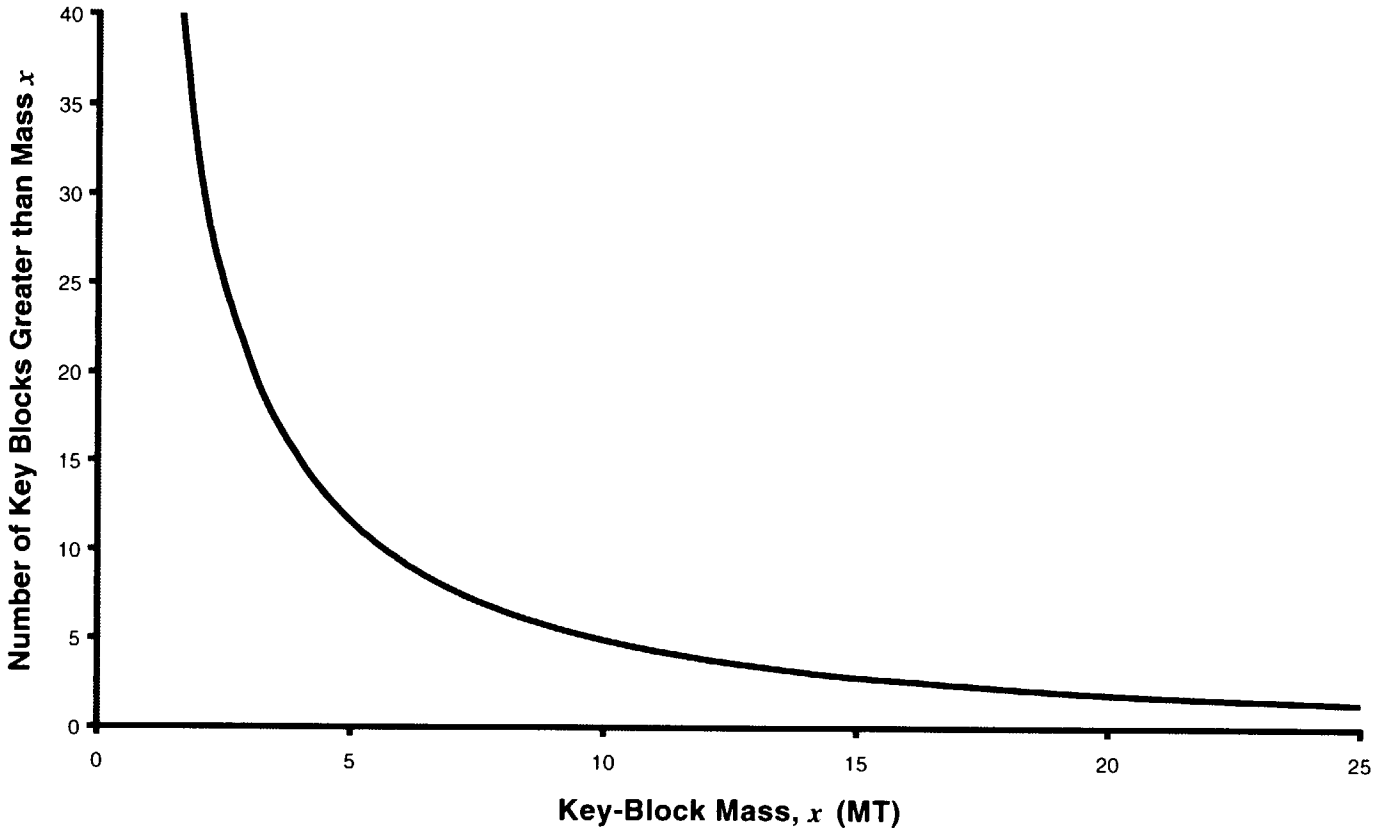
Design Basis Rock Size for Drip Shield
(Continued)

- **Basis for Resolution (Continued)**
  - The drip shield is designed (*Emplacement Drift System Description Document*, p. 10) to withstand the largest credible preclosure rockfall, that is, 6 MT, without
    - rupturing the drip shield or parting drip shield units
    - allowing the drip shield to contact a waste package
  - Because no credit is taken for ground support in the postclosure period, rockfalls in excess of 6 MT are possible during postclosure
    - About ten key blocks in excess of 6 MT could fall on the drip shield for the 70, 000 MT waste inventory (*Expected Number of Key Blocks Throughout the Emplacement Drifts as a Function of Block Size*). This result assumes a 10^{-4} annual probability of exceedance seismic ground motion (See graph)
    - Proportionally more rockfalls would be expected if more waste emplacement drifts are constructed to allow for greater waste inventories or if thermal considerations dictate more waste packages

Design Basis Rock Size for Drip Shield
(Continued)

- **Basis for Resolution (Continued)**
  - The drip shield design that was based on preclosure criteria has been evaluated for postclosure performance (*Rock Fall on Drip Shield*)
  - Rockfall has been screened out of the Total System Performance Assessment for Site Recommendation because calculations show that an effective maximum rock size is about 10 MT and that the current drip shield design would withstand a 10 MT rockfall without allowing water to drip through or allowing the drip shield to contact the waste package (*Rock Fall on Drip Shield*)

Design Basis Rock Size
(Continued)



NOTE: Curve pertains to 60 km of drip shield.

Reference: *Expected Number of Key Blocks throughout the Repository as a Function of Block Size* (CAL-EBS-MD-000012)

Design Basis Rock Size for Drip Shield
(Continued)

- **Basis for Resolution (Continued)**
  - NRC staff expressed concern that the calculations that DOE relied upon for the Total System Performance Assessment for the Site Recommendation screening decision did not account for the effects of thermal load and corrosion on drip shield performance
    - Structural calculations that account for thermal load and corrosion are in progress
    - The rockfall screening decision for any potential Total System Performance Assessments for License Application will consider the effects of thermal load and corrosion on drip shield performance
    - Substantial degradation in repository performance due to rockfalls appears unlikely because only about ten rockfalls greater than 6 MT would be expected and, therefore, only about ten waste packages out of 10,000 (0.1 %) would be subject to possible damage from rockfall

Design Basis Rock Size for Drip Shield
(Continued)

- **References**
  - *Repository Safety Strategy: Plan to Prepare the Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations*, TDR-WIS-RL-000001 REV 04
  - *Emplacement Drift System Description Document*, SDD-EDS-SE-000001 REV 01
  - *Expected Number of Key Blocks Throughout the Emplacement Drifts as a Function of Block Size*, CAL-EBS-MD-000012
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01
  - *Site Recommendation Subsurface Layout,* ANL-SFS-MG-000001 REV 00
  - *Rock Fall on Drip Shield,* CAL-EDS-ME-000001 REV 00
  - *Preclosure Design Basis Events Related to Waste Packages,* ANL-MGR-MD-000012 REV 00

Design Basis Rock Size for Drip Shield
(Continued)

- DOE considers this comment to be resolved pending work that is underway to address the performance of the drip shield when the effects of corrosion and thermal load are considered

Use of 10^{-4} Ground Motion for Post Closure Seismic Ground Motion Analysis

- **Basis for Resolution**
  - Seismic rockfall analyses currently use 10^{-4} peak ground velocity and peak ground acceleration values. The results from the rockfall model are consistent with case history examples, which indicate that rockfall caused by seismic ground motion has no significant effect on performance. Available field data does not suggest a significant development of large blocks within the repository horizon
- **References**
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 REV 01
- **DOE considers this comment to be resolved. The use of increased seismic ground motion values in rockfall analysis is under consideration to confirm the conclusion that rockfall caused by seismic ground motion has no significant effect on performance**

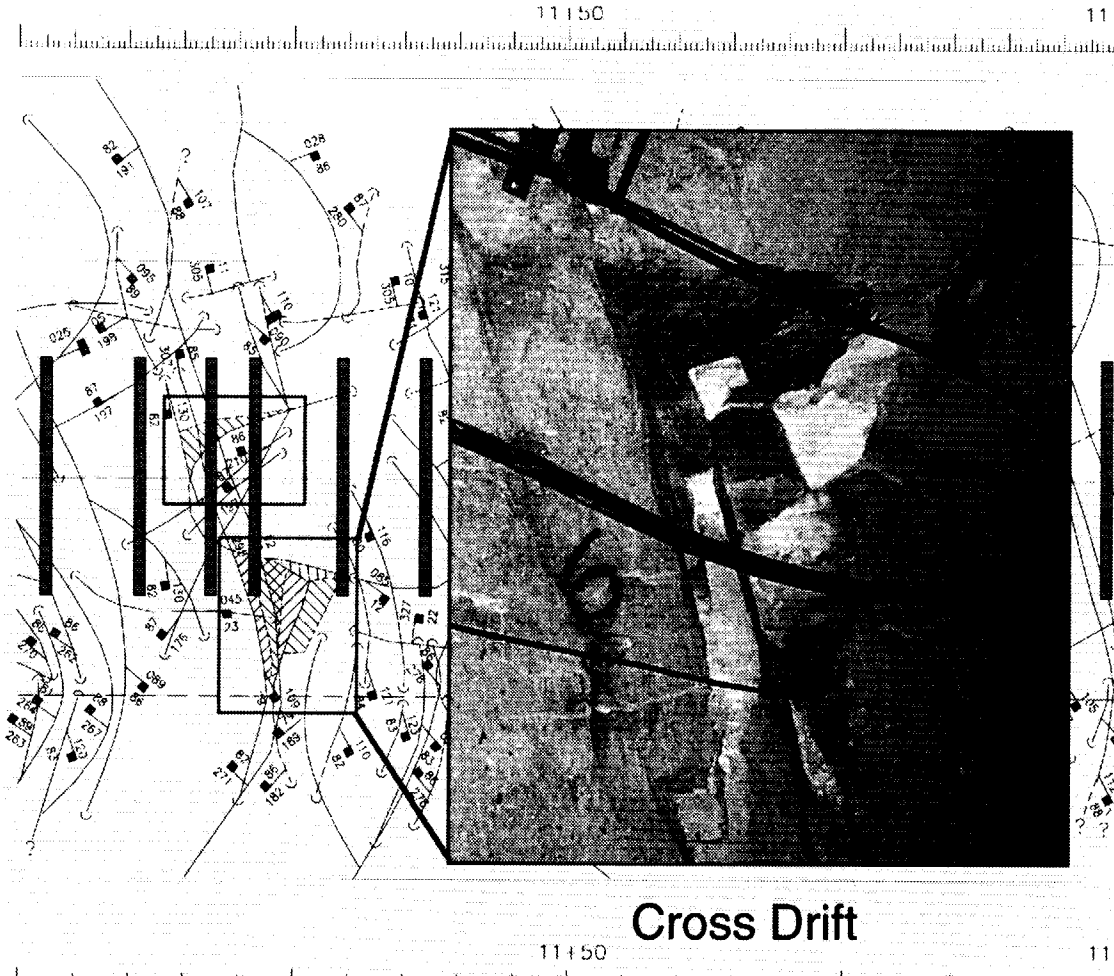
Verification of Key Block Analysis Approach

- **Basis for Resolution**
  - The results from the static rockfall model were verified by comparison to field conditions
    - The simulated static key block results are representative of the observed key block occurrence in the exploratory studies facility
    - The rockfall model is sensitive to the different fracture characteristics within each lithostratigraphic unit

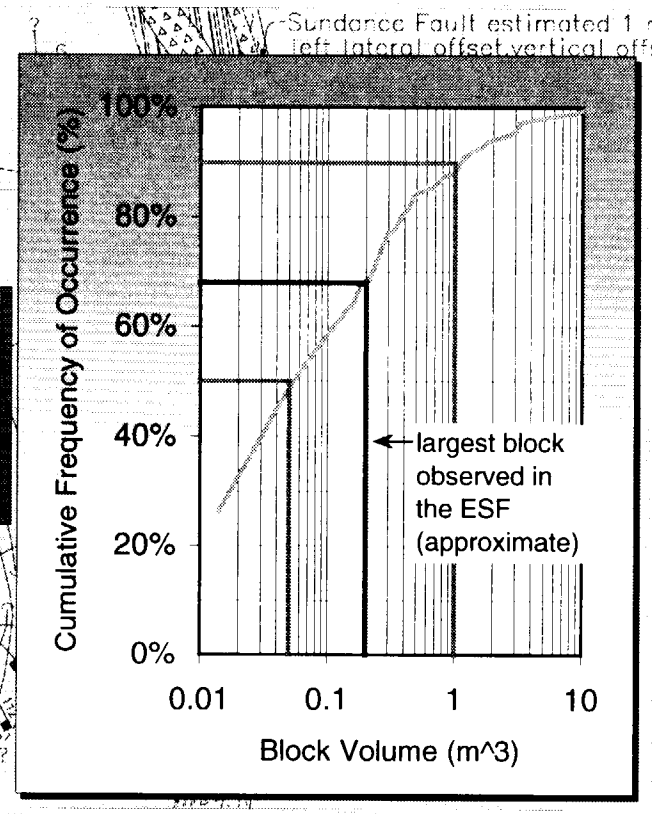
Key Block Frequency (number of blocks per km)		
Lithologic Unit	Cross Drift Observations	DRKBA Rock Fall Model
Tptpul	3	14 to 16
Tptpmn	40	36
Tptpll	0	5
Tptpln	8	9 to 14

Reference: Drift Degradation Analysis (ANL-EBS-MD-000027 REV 01)

Verification of Key Block Analysis Approach (Continued)



Cross Drift



DRKBA Rock Fall Model

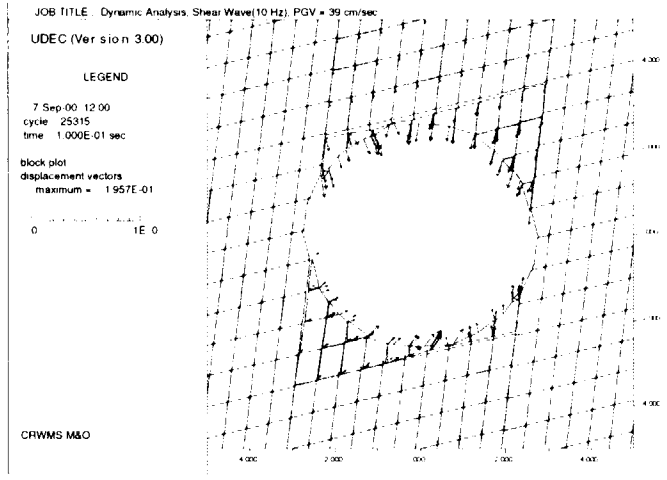
Reference: Drift Degradation Analysis (ANL-EBS-MD-000027 REV 01)

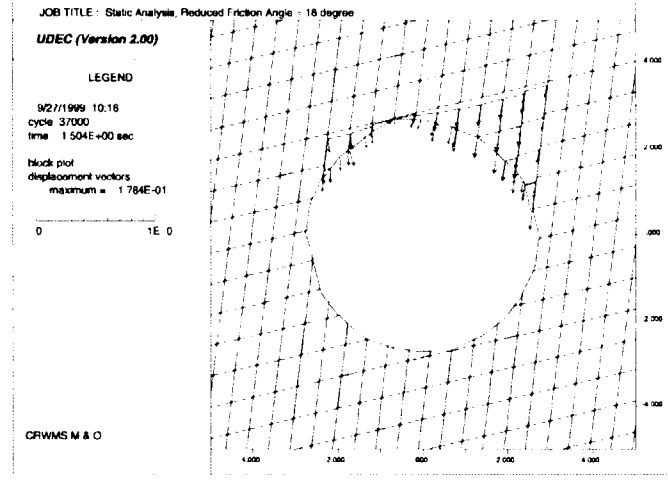
Verification of Key Block Analysis Approach (Continued)

- **Basis for Resolution (Continued)**
  - The results from the seismic component of the rockfall model were verified by
    - comparison to alternative analytical methods involving the dynamic functions of the distinct element code UDEC
    - comparison to case histories of various underground structures subjected to earthquakes

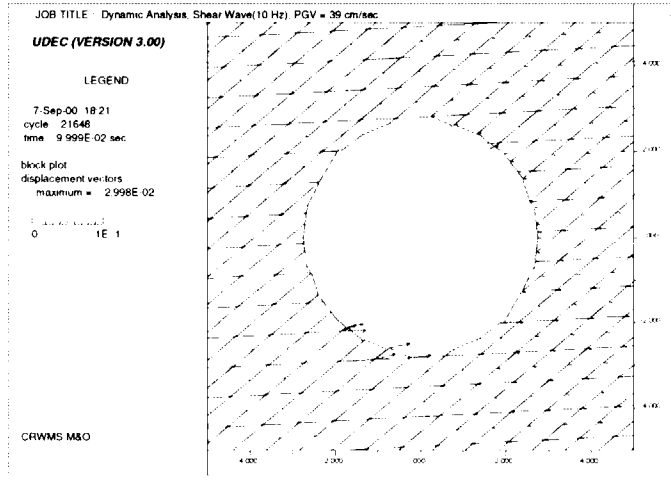
Verification of Key Block Analysis Approach (Continued)

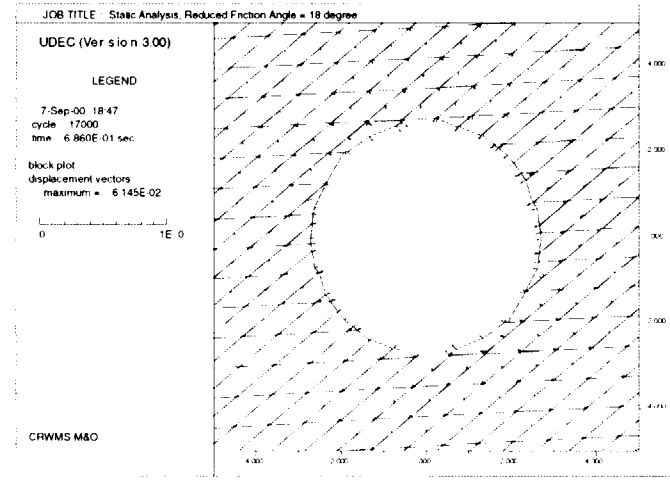
UDEC Analysis Case 1





UDEC Analysis Case 2





Dynamic Analysis Result

Quasi-Static Analysis Result

Reference: Drift Degradation Analysis ANL-EBS-MD-000027 REV 01

Verification of Key Block Analysis Approach (Continued)

- **Basis for Resolution (Continued)**
  - Natural and man-made analogues of the effect of seismic events on rockfall
    - » Major Earthquakes
      - — Tang-Shan, China earthquake on July 28, 1976 (magnitude 7.8)
      - — Alaskan earthquake on March 28, 1964 (magnitude 8.5)
    - » Recent Earthquake
      - — Kobe, Japan earthquake on January 16, 1995 (magnitude 6.9)
    - » Site-Specific Earthquake
      - — Little Skull Mountain earthquake on June 29, 1992 (magnitude 5.6)
    - » Case studies where underground facilities were subjected to an earthquake and received significant damage are in general characterized by either shallower overburden than Yucca Mountain (Sharma and Judd 1991), poor ground condition (Rowe 1992), or fault intersection (Rowe 1992 and Raney 1988)

Verification of Key Block Analysis Approach (Continued)

- **Basis for Resolution (Continued)**
  - Other sources of uncertainty in the rockfall model are thermal and time-dependent effects. These uncertainties are accounted for as follows
    - The potential "locking effect" on blocks has been ignored in the rockfall model. The "locking effect" is caused by the application of horizontal thermal stress on blocks formed by steeply dipping fracture planes, and could potentially increase block stability
    - A significant reduction in joint cohesive strength has been included in the model, as previously described
- **References**
  - *Drift Degradation Analysis*, ANL-EBS-MD-000027 REV 01

Verification of Key Block Analysis Approach (Continued)

- **An adequate level of confidence is provided for use of the model based on**
  - Field observation of key block occurrence in the exploratory studies facility
  - Consistent prediction of blocks based on alternative numerical solutions
  - Comparison to natural analogues of seismic motion
  - Conservative reduction of joint cohesion to account for uncertainties associated with thermal and time-dependent effects on rockfall

Verification of Key Block Analysis Approach (Continued)

- **Additional rockfall model validation is being considered, potentially using the three-dimensional distinct element code, 3DEC. 3DEC is capable of modeling a complex fracture pattern, and can explicitly apply thermal and seismic loading**
  - 3DEC approach
    - Select a 24.4-m length simulation for both the Tptpmn and Tptpll units from existing DRKBA analyses
    - Model DRKBA fracture pattern in 3DEC
    - Set up 3DEC model using DRKBA static joint strength properties
    - Run 3DEC models for static, seismic, and thermal loading
    - Compare 3DEC rockfall frequency and volume to DRKBA
    - Compare 3DEC drift profile to DRKBA

Verification of Key Block Analysis Approach (Continued)

- **Additional rockfall model validation is being considered, potentially using the three-dimensional distinct element code, 3DEC. 3DEC is capable of modeling a complex fracture pattern, and can explicitly apply thermal and seismic loading (Continued)**
  - 3DEC seismic loading
    - Generate sinusoidal velocity waves and velocity time history of design earthquake
    - Apply appropriate seismic duration
  - 3DEC thermal loading
    - Use thermal properties consistent with project data
    - Use heat generation rates that are compatible with the waste package layout configuration

Acceptance Criterion 2

- **Sufficient data (e.g., field, laboratory, and natural analog data) pertaining to the Engineered Barrier materials, mechanical failure processes, and the characterization of potential disruptive events are available to adequately define relevant parameters and conceptual models necessary for developing the Mechanical Disruption of Engineered Barrier abstraction in the total system performance assessment. The data are also sufficient to assess the degree to which Features, Events, and Processes related to Mechanical Disruption of Engineered Barrier and which affect compliance with 10 CFR 63.113(b) have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these Features, Events, and Processes are adequate**

Acceptance Criterion 2
(Continued)

- **Action or Information Needs**
  - Temperature dependency of titanium material properties
  - Adequacy of drip shield stress analysis
  - Adequacy of stress corrosion cracking analysis
- **Basis for closure**
  - Sufficient data have been obtained to address engineered barrier component failure processes and to support the models
    - All material properties used in the waste package and drip shield design are obtained from the following sources
      - Approved QA testing programs
      - American Society of Mechanical Engineers Boiler and Pressure Vessel Code
      - American Standards for Testing and Materials specifications
      - ASM International Metals Handbook
      - Manufacturers' catalogues
    - Data are qualified and appropriate for use in determining the engineered barrier response to mechanical disturbances. No additional work is required

Acceptance Criterion 2
(Continued)

- **Basis for closure (Continued)**
  - Temperature, corrosion, embrittlement, and other effects have been evaluated for engineered barrier components
    - Effects of temperature in the waste package material properties are included in the the analysis and model report, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001)
    - The drip shield response to temperature effects and hydrogen embrittlement was addressed by an NRC/DOE agreement made at the Container Life and Source Term Technical Exchange, under Subissue 2, Agreement 8
      - » The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001), will include the effects of temperature
    - The effects of prolonged exposure to the drift environment are contained in the *Waste Package Degradation Process Model Report* (TDR-WIS-MD-000002) and its supporting documents
    - No additional work is required

Acceptance Criterion 2
(Continued)

- **Basis for closure (Continued)**
  - Sufficient data to support features, events, and processes screening evaluations have been identified
    - Screening evaluations are documented in the analysis and model report, *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (ANL-EBS-PA-000002)
    - The supporting documents in regard to the waste package and the drip shield are
      - *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001)
      - *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)
      - *Waste Package Degradation Process Model Report* (TDR-WIS-MD-000002)
    - No additional work is required

Acceptance Criterion 2
(Continued)

- **Basis for closure (Continued)**
  - The effects of fabrication methods have been addressed
    - The supporting analysis and model reports in regard to the waste package and the drip shield are
      - *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001),
      - *Design Analysis for the Defense High-Level Waste Disposal Container* (ANL-DDC-ME-000001)
      - *Design Analysis for the Naval SNF Waste Package* (ANL-VDC-ME-000001)
      - *Waste Package Design Methodology Report* (ANL-EBS-MD-000053)
      - *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)
      - *Waste Package Degradation Process Model Report* (TDR-WIS-MD-000002)
    - The supporting documentation for the fabrication process includes
      - *Waste Package Operations Fabrication Process Report* (TDR-EBS-ND-000003)
      - *Waste Package Operations Closure Weld Technical Guidelines Document* (TDP-EBS-ND-000005)
    - No additional work is required

Acceptance Criterion 2
(Continued)

- **Basis for closure (Continued)**
  - Rockfall effects on the engineered barrier components have been addressed
    - The drip shield response to rockfall effects was addressed by an NRC/DOE agreement made at the Container Life and Source Term Technical Exchange under Subissue 2, Agreement 8
      - » The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001), will revise the effects of rockfall
    - No additional work is required
  - Static loading for representing the effects of drift collapse on drip shields has been addressed
    - The drip shield response to rockfall effects were addressed by an NRC/DOE agreement made at the Container Life and Source Term Technical Exchange under Subissue 2, Agreement 8
      - » Seismic calculations addressing the load of fallen rock on the drip shield will be included in the next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)
    - No additional work is required

Acceptance Criterion 2
(Continued)

- **References**
  - *Design Analysis for UCF Waste Packages*, ANL-UDC-MD-000001
  - *Design Analysis for the Ex-Container Components*, ANL-XCS-ME-000001
  - *Waste Package Degradation Process Model Report*, TDR-WIS-MD-000002
  - *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation*, ANL-EBS-PA-000002
  - *Design Analysis for the Defense High-Level Waste Disposal Container*, ANL-DDC-ME-000001
  - *Design Analysis for the Naval SNF Waste Package*, ANL-VDC-ME-000001
  - *Waste Package Design Methodology Report*, ANL-EBS-MD-000053

Acceptance Criterion 2
(Continued)

- **References (Continued)**
  - *Waste Package Operations Fabrication Process Report,* TDR-EBS-ND-000003
  - *Waste Package Operations Closure Weld Technical Guidelines Document*, TDP-EBS-ND-000005
- **DOE considers this criterion to be Closed-Pending. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC will support closure of this criterion**

Temperature Dependency of Titanium Material Properties

- **Basis for Resolution**
  - The drip shield response to temperature effects was addressed by an NRC/DOE agreement made at the Container Life and Source Term Technical Exchange, under Subissue 2, Agreement 3
    - The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001) and its supporting calculation document, will include the effects of temperature
- **References**
  - *Design Analysis for the Ex-Container Components*, ANL-XCS-ME-000001
- **DOE considers this comment to be resolved. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC will support closure of the associated acceptance criterion**

Adequacy of Drip Shield Stress Analysis

- **Basis for Resolution**
  - The drip shield stress analysis and appropriate failure criteria (shear stress theory, in accordance with the ASME Boiler and Pressure Vessel Code) were addressed by an NRC/DOE agreement made at the Container Life and Source Term Technical Exchange under Subissue 2, Agreement 3
    - The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001) and its supporting calculation, will include the use of shear stress theory as the failure criterion
- **References**
  - *Design Analysis for the Ex-Container Components,* ANL-XCS-ME-000001
- **DOE considers this comment to be resolved. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC will support closure of the associated acceptance criterion**

Adequacy of Stress Corrosion Cracking Analysis

- **Basis for Resolution**
  - In order for a crack to propagate, the tensile stress would have to be perpendicular to the surface. Therefore, the hoop and axial components of stress need to be used to compare against the failure criterion
  - The stress corrosion failure criterion is provided in the analysis and model report, *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (ANL-EBS-MD-000005 REV 00 ICN 01)
  - The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001) and its supporting calculation, will include the discussion of the stress components and the failure criterion used to determine the structural performance of the drip shield under stress corrosion cracking

Adequacy of Stress Corrosion Cracking Analysis (Continued)

- **References**
  - *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material,* ANL-EBS-MD-000005 REV 00 ICN 01
  - *Design Analysis for the Ex-Container Components,* ANL-XCS-ME-000001
- **DOE considers this comment to be resolved. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC will support closure of the associated acceptance criterion**

Acceptance Criterion 3

- **Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the Total System Performance Assessment abstraction of mechanical disruption of engineered barrier are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the Total System Performance Assessment abstraction are provided**
- **Action or Information Needs**
  - None identified

Acceptance Criterion 3
(Continued)

- **Basis for closure**
  - Corrosion-dependent material properties related to stress corrosion cracking, hydrogen embrittlement, fracture toughness, and ultimate strength are appropriate for the engineered barrier components
    - The drip shield response to rockfall effects were addressed by NRC/DOE agreements made at the Container Life and Source Term Technical Exchange under Subissue 2, Agreement 8
      - The next revision of the analysis and model report, *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001), will revise the effects of rockfall considering the effects of stress corrosion cracking, hydrogen embrittlement, wall thinning due to corrosion, multiple rockfalls, and change in strength as a function of temperature
    - Furthermore, the effects of potential embrittlement of the waste package closure weld material after stress annealing due to aging and multiple rockfalls on the waste package will be included in the next revision of the analysis and model report, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001)

Acceptance Criterion 3
(Continued)

- **Basis for closure (Continued)**
  - Fabrication defects that may lead to early failure have been evaluated and will be considered for rockfall
    - Waste package fabrication defects are analyzed in the analysis and model report, *Analysis of Mechanisms for Early Waste Package Failure* (ANL-EBS-MD-000023)
    - The fabrication defects when evaluating rockfall will be addressed in the future revisions of the analysis and model report, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001)
  - Uncertainty in engineered barrier component corrosion models will be addressed through appropriate sensitivity analyses
    - Conservatively selected bounding values of corrosion rates are currently being used for the waste package and the drip shield; these will be included in the next revisions of the analysis and model reports, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001) and *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001), respectively

Acceptance Criterion 3
(Continued)

- **References**
  - *Design Analysis for the Ex-Container Components,* ANL-XCS-ME-000001
  - *Design Analysis for UCF Waste Packages,* ANL-UDC-MD-000001
  - *Analysis of Mechanisms for Early Waste Package Failure,* ANL-EBS-MD-000023
- **DOE considers this criterion to be Closed-Pending. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC will support closure of this criterion**

Acceptance Criterion 4

- **Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of Mechanical Disruption of Engineered Barrier. DOE has provided sufficient evidence that Alternative Conceptual Models of Features, Events, and Processes have been considered, that the models are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effect of these Alternative Conceptual Models on Total System Performance Assessment has been evaluated**
- **Action or Information Needs**
  - None identified other than the issues related to rockfall analysis discussed under Acceptance Criterion 1

Acceptance Criterion 4
(Continued)

- **Basis for closure**
  - Alternative rockfall models were considered, including those using deterministic methods such as UNWEDGE, UDEC, and 3DEC
    - These methods were not used as the primary method for determining block size distributions because they are limited in their ability to analyze the full range of fracture geometry within the potential repository horizon
    - The primary rockfall model (i.e., DRKBA) was selected because
      - » the model is capable of analyzing the full range of fractures as mapped in the Exploratory Studies Facility
      - » the model is capable of analyzing progressive rock failure, and the block size distributions developed include multiple blocks at one location
      - » the seismic and thermal loading limitations can be adequately included through joint property reduction

Acceptance Criterion 4
(Continued)

- **Basis for closure (Continued)**
  - Temporal and spatial variations of parameters relevant to the response of engineered barriers to mechanical disturbances have been evaluated, and DOE plans to update the evaluations (fracture toughness, dimensional changes, residual stresses, and stress corrosion cracking)
    - The corrosion behavior and material property changes of the waste package and the drip shield are addressed in the analysis and model reports
      - *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (ANL-EBS-MD-000003)
      - *General Corrosion and Localized Corrosion of Drip Shield* (ANL-EBS-MD-000004)
    - The response of the waste package and the drip shield to changes in material properties are included in analysis and model reports
      - *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001)
      - *Design Analysis for the Defense High-Level Waste Disposal Container* (ANL-DDC-ME-000001)
      - *Design Analysis for the Naval SNF Waste Package* (ANL-VDC-ME-000001)
      - *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)

Acceptance Criterion 4
(Continued)

- **Basis for closure (Continued)**
  - Credible alternative models have been considered. Appropriate analytical models are used in the estimation of impact load due to rockfall on the waste package and other engineered barrier components. In addition, DOE plans to evaluate multiple rockfalls
    - The waste package and the drip shield rockfall evaluations are performed using a commercially available finite element analysis code (ANSYS). This method effectively incorporates the material and geometrical nonlinearities of the problem. Closed-form solution methods are inappropriate to use since these nonlinearities cannot be incorporated into the solution
    - The question of multiple rockfalls onto the drip shield and waste package was addressed by NRC/DOE agreements made at the Container Life and Source Term Technical Exchange, January 2001
      - The next revisions to the analysis and model reports, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001), and *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001) will include consideration of multiple rockfalls onto the waste package and the drip shield

Acceptance Criterion 4
(Continued)

- **References**
  - *Drift Degradation Analysis*, ANL-EBS-MD-000027 REV 01
  - *Design Analysis for UCF Waste Packages*, ANL-UDC-MD-000001
  - *Design Analysis for the Ex-Container Components*, ANL-XCS-ME-000001
  - *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*, ANL-EBS-MD-000003
  - *General Corrosion and Localized Corrosion of Drip Shield*, ANL-EBS-MD-000004
  - *Design Analysis for the Defense High-Level Waste Disposal Container*, ANL-DDC-ME-000001
  - *Design Analysis for the Naval SNF Waste Package*, ANL-VDC-ME-000001

Acceptance Criterion 4
(Continued)

- DOE has considered alternative conceptual models, and has documented this consideration in the reference documents
- DOE considers this acceptance criterion to be Closed-Pending completion of additional rockfall verification and completion of additional waste package and drip shield analyses as agreed at the Container Life and Source Term Technical Exchange

Acceptance Criterion 5

- **Output from the Total System Performance Assessment abstraction of the degradation of Engineered Barrier is justified through comparison with output from detailed process-level models and empirical observations arising from laboratory tests and field measurements**
- **Action or Information Needs**
  - None identified
- **Basis for closure**
  - The effects of rockfall have been excluded from total system performance assessment as documented in the analysis and model report *Features, Events, and Processes: Disruptive Events* (ANL-WIS-MD-000005). Therefore, there is no applicable abstraction to be compared with process models

Acceptance Criterion 5
(Continued)

- **Basis for closure (Continued)**
  - The waste package and the drip shield rockfall evaluations [*Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001), *Design Analysis for the Defense High-Level Waste Disposal Container* (ANL-DDC-ME-000001), *Design Analysis for the Naval SNF Waste Package* (ANL-VDC-ME-000001), and *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001)] include the effects of corrosion degradation and rock block size and shape
  - As agreed at the Container Life and Source Term Technical Exchange (Subissue 2, Agreement 3), the relative impact velocities and temperature-dependent material properties for the waste package and the drip shield will be included in the future revisions to the analysis and model reports, *Design Analysis for UCF Waste Packages* (ANL-UDC-MD-000001), and *Design Analysis for the Ex-Container Components* (ANL-XCS-ME-000001), respectively

Acceptance Criterion 5
(Continued)

- **References**
  - *Design Analysis for the Ex-Container Components*, ANL-XCS-ME-000001
  - *Design Analysis for UCF Waste Packages*, ANL-UDC-MD-000001
  - *Features, Events, and Processes: Disruptive Events*, ANL-WIS-MD-000005 REV 00 ICN 01
  - *Design Analysis for the Defense High-Level Waste Disposal Container*, ANL-DDC-ME-000001
  - *Design Analysis for the Naval SNF Waste Package*, ANL-VDC-ME-000001

Acceptance Criterion 5
(Continued)

- Because rockfall has been excluded from Total System Performance Assessment, this criterion is not applicable. However, based on the information presented under Acceptance Criterion 1, additional rockfall verification analyses are being considered
- DOE considers this acceptance criterion to be Closed-Pending completion of additional rockfall verification analyses

Conclusions

- **DOE believes the status of the Acceptance Criterion for Subissue 3, Repository Design and Thermal - Mechanical Effects, Component 2 are**
  - Acceptance Criterion 1: Closed-Pending completion of additional verification of the rockfall analyses and final seismic design inputs from Seismic Topical Report 3
  - Acceptance Criterion 2: Closed-Pending data collected, analyses performed, and agreements established at the Container Life and Source Term Technical Exchange
  - Acceptance Criterion 3: Closed-Pending data collected, analyses performed, and agreements established at the Container Life and Source Term Technical Exchange
  - Acceptance Criterion 4: Closed-Pending completion of additional analyses to extend the validation of the DRKBA rockfall model
  - Acceptance Criterion 5: Closed-Pending resolution of the need for additional rockfall verification