Agenda
DOE-NRC Technical Exchange
STRUCTURAL DEFORMATION AND SEISMICITY KTI
October 11-12, 2000 Las Vegas, Nevada

Objective: Provide the basis to resolve open issues related to the Seismicity and Structural Deformation Key Technical Issue and determine path forward for items that remain open.

NOTE: Time allotted for each presentation includes time for presentation and additional time for discussion.

Wednesday October 11, 2000

8:00 – 8:15 AM	Introduction/Objectives/Logistics – Opening Remarks (DOE/NRC)
8:15 – 8:30 AM	Key Technical Issue for Structural Deformation and Seismicity (SDS) – Summary of Status from DOE Perspective (DOE - Sullivan)
8:30 – 9:30 AM	SDS Subissues in TSPA-SR (DOE/NRC)
9:30 – 9:45 AM	BREAK
	FAULTING SUBISSUE
9:45 – 10:45 AM	Status of SDS Faulting Subissue (DOE/NRC)
	TECTONIC FRAMEWORK SUBISSUE
10:45 – 11:15 AM	Status of SDS Tectonic Framework Subissue (DOE/NRC)
11:15 – 12:15 PM	Caucus on Faulting and Tectonic Framework Subissues
12:15 – 1:15 PM	LUNCH
1:15 – 1:45 PM	DOE/NRC Discussion of Resolution Status
	SEISMICITY SUBISSUE
1:45 – 3:45 PM	Status of SDS Seismicity Subissue (DOE/NRC)
3:45 – 5:00 PM	Caucus on Seismicity Subissue
5:00 – 5:30 PM	DOE/NRC Discussion of Resolution Status

Attachment 2

5:30 – 5:45 PM	Closing remarks for Day 1
5:45 PM	ADJOURN DAY 1

Thursday October 12, 2000

FRACTURING SUBISSUE

8:00 – 10:15 AM	Status of SDS Fracturing Subissue (DOE/NRC)
10:15 – 10:30 AM	BREAK
10:30 – 11:45 AM	Status of SDS Fracturing Subissue – continued (DOE/NRC)
11:45 – 12:45 PM	LUNCH
12:45 –2:15 PM	Caucus on Fracturing Subissue
2:15 – 2:45 PM	DOE/NRC Discussion of Resolution Status
2:45 – 3:45 PM	Caucus on KTI Agreements
3:45 – 4:15 PM	Discussion of Agreements
4:15 – 4:30 PM	Closing Remarks
4:30 PM	ADJOURN MEETING

STRUCTURAL DEFORMATION AND SEISMICITY
KEY TECHNICAL ISSUE
TECHNICAL EXCHANGE/MANAGEMENT MEETING
OCTOBER 11 AND 12, 2000

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STRUCTURAL DEFORMATION AND SEISMICITY
KEY TECHNICAL ISSUE
TECHNICAL EXCHANGE/MANAGEMENT MEETING
OCTOBER 11 AND 12, 2000

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STRUCTURAL DEFORMATION AND SEISMICITY
KEY TECHNICAL ISSUE
TECHNICAL EXCHANGE/MANAGEMENT MEETING
OCTOBER 11 AND 12, 2000

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Presenter's Slides

Attachment 4

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

Overview
Structural Deformation and Seismicity: Key Technical Issue

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
Tim Sullivan
Regulatory Products Team Lead
Office of Licensing and Regulatory Compliance
Department of Energy
Yucca Mountain Site Characterization Office

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- **KTI Subissue Status**
  - Faulting
  - Seismicity
  - Fracturing and Structural Framework
  - Tectonic Framework

KTI Subissue Status

Subissue	Status*	
	NRC	DOE Proposed
Faulting	Closed - Pending	Closed - Pending
Seismicity	Closed - Pending	Closed - Pending
Fracturing and Structural Framework	Open	Closed
Tectonic Framework	Open	Closed - Pending

*NRC status based on presentation at the NRC-DOE Technical Exchange on Status of Key Technical Issues, April 2000

Delta Analysis provides additional details about how IRSR acceptance criteria and NRC requests for additional information have been addressed and provides references to relevant information

KTI Subissue Status
Faulting

Acceptance Criteria	NRC Status (IRSR Rev. 2)	DOE Proposed Status
Data and Model Justification	Resolved	Closed
Data Uncertainty and Verification	Resolved	Closed - Pending
Model Uncertainty	Resolved	Closed - Pending
Model Verification	Resolved	Closed - Pending
Integration	Resolved	Closed - Pending
Quality Assurance	Open	N/A
Expert Elicitation	Resolved	Closed

KTI Subissue Status
Seismicity

Acceptance Criteria	NRC Status (IRSR Rev. 2)	DOE Proposed Status
Data and Model Justification	Resolved	Closed - Pending
Data Uncertainty and Verification	Open	Closed - Pending
Model Uncertainty	Open	Closed - Pending
Model Verification	Open	Closed - Pending
Integration	Open	Closed - Pending
Quality Assurance	Open	N/A
Expert Elicitation	Resolved	Closed

KTI Subissue Status
Fracturing and Structural Framework

Acceptance Criteria	NRC Status (IRSR Rev. 2)	DOE Proposed Status
Data and Model Justification	Open	Closed
Data Uncertainty and Verification	Open	Closed
Model Uncertainty	Open	Closed
Model Verification	Open	Closed
Integration	Open	Closed
Quality Assurance	Open	N/A
Expert Elicitation	Resolved	Closed

KTI Subissue Status
Tectonic Framework

Acceptance Criteria	NRC Status (IRSR Rev. 2)	DOE Proposed Status
Data and Model Justification	Resolved	Closed
Data Uncertainty and Verification	Resolved	Closed
Model Uncertainty	Resolved	Closed - Pending
Model Verification	Resolved	Closed
Integration	Resolved	Closed - Pending
Quality Assurance	Open	N/A
Expert Elicitation	Resolved	Closed

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

Structural Deformation and Seismicity Subissues in the Total System Performance Assessment-Site Recommendation

Presented to:
DOE/NRC Technical Exchange Meeting

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

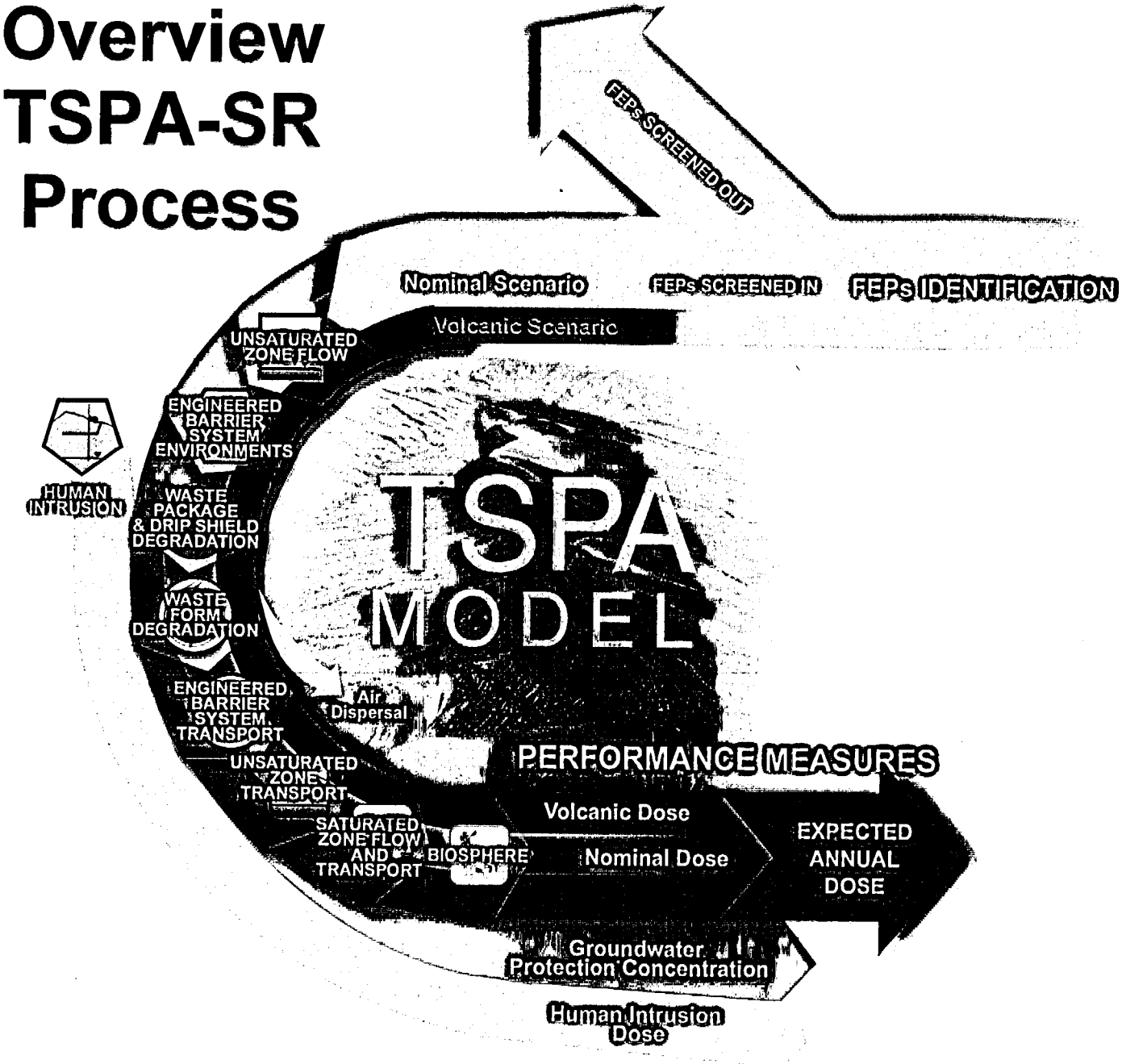
October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Overview of Total System Performance Assessment (TSPA) - Site Recommendation (SR) Process
- Features, Events, and Processes (FEPs) Screening Criteria
- FEPs Implementation
- FEPs Analysis and Model Reports (AMRs)
- Updated FEPs AMRs
- Structural Deformation and Seismicity (SDS) Subissues
  - Faulting
  - Seismicity
  - Fracture Framework
  - Tectonic Framework

Overview TSPA-SR Process



FEPs 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."

FEPs Implementation

- Initial FEPs identified by review of Yucca Mountain Project (YMP) and international literature
- FEPs evaluated outside TSPA by appropriate YMP subject-matter experts
- FEPs evaluations documented in analysis and model reports (AMRs) that draw on multiple sources
  - e.g., Disruptive Events FEPs AMR relies on contributions from geologists, seismic hazard analysts, waste package engineers
- TSPA-SR models the FEPs identified as included by the FEPs AMRs

FEPs AMRs

- What is in the FEPs AMRs?
  - FEPs identification and classification description
  - FEPs screening process discussion
  - Detailed screening arguments for excluded FEPs
    - 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
  - Pointers to TSPA-SR for included FEPs/FEPs database
  - FEPs AMRs are quality assurance documents

Updated FEPs AMRs

- Biosphere — Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes
- Disruptive Events — Disruptive Event FEPs
- Engineered Barrier System (EBS) — EBS FEPs/Degradation Modes Abstraction
- Near Field Environment (NFE) — Features, Events, and Processes in Thermal Hydrology and Coupled Processes
- System — Analyses to Support Screening of System-Level Features, Events, and Processes (including Criticality FEPs) for the Yucca Mountain TSPA-SR

Updated FEPs AMRs

(Continued)

- Saturated Zone (SZ) — Features, Events, and Processes in SZ Flow and Transport
- Unsaturated Zone (UZ) — Features, Events, and Processes in UZ Flow and Transport
- Waste Form (WF)
  - Miscellaneous Waste Form FEPs
  - Clad Degradation FEPs Screening Arguments
  - Waste Form Colloid-Associated Concentration Limits — Abstraction and Summary
- Waste Package (WP) — FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation

Updated FEPs AMRs

(Continued)

- Update Objectives
  - Each FEP must be traceable to its final resolution within the AMR
  - All screening arguments and discussions will be linked to supporting documentation
    - Excluded FEPs — technical bases strengthened and clarified; full argument may be contained in the FEP AMR or may reference other AMRs, including the TSPA
    - Included FEPs — disposition statements updated to include discussion of inclusion in the completed TSPA-SR and references
  - All FEPs AMR updates are expected to be completed in December 2000
  - Key screening arguments and discussions from FEPs AMRs are expected to be input into FEPs Database in December 2000

SDS Subissues Faulting

- TSPA-SR does not contain a separate scenario for faulting, consistent with FEPs screening decisions
- Included
  - Effects of existing faults on UZ and SZ flow for the nominal scenario
    - Issues addressed in UZ and SZ Technical Exchanges
- Excluded
  - Effects of new faults and new displacement on existing faults

SDS Subissues Seismicity

- **Included**
  - **Evaluation of cladding failure due to seismic ground motion**
    - ***Breakage of Commercial Spent Fuel Cladding by Mechanical Loading*** **(CAL-EBS-MD-000001 Rev. 00)**
      - » **Evaluates commercial spent nuclear fuel (CSNF) cladding fragility only**
      - » **TSPA-SR does not have a performance model for DOE spent nuclear fuel cladding**
    - **Convolution of seismic hazard and cladding fragility yields overall seismic risk for fuel rod breakage of 1.1 x 10^{-6}/yr**

SDS Subissues Seismicity

(Continued)

- **Included** (Continued)
  - Implementation of seismic cladding failure
    - Included in nominal scenario
      - » Note: For igneous disruption scenario, cladding failure is assumed in all damaged packages, regardless of seismicity
    - Treated as a Poisson process (random) with a rate constant of 1.1×10^{-6}/yr
    - Times of seismic cladding failure sampled
    - Failure implemented as simultaneous perforation of all cladding in all packages; unzipping then proceeds by nominal processes

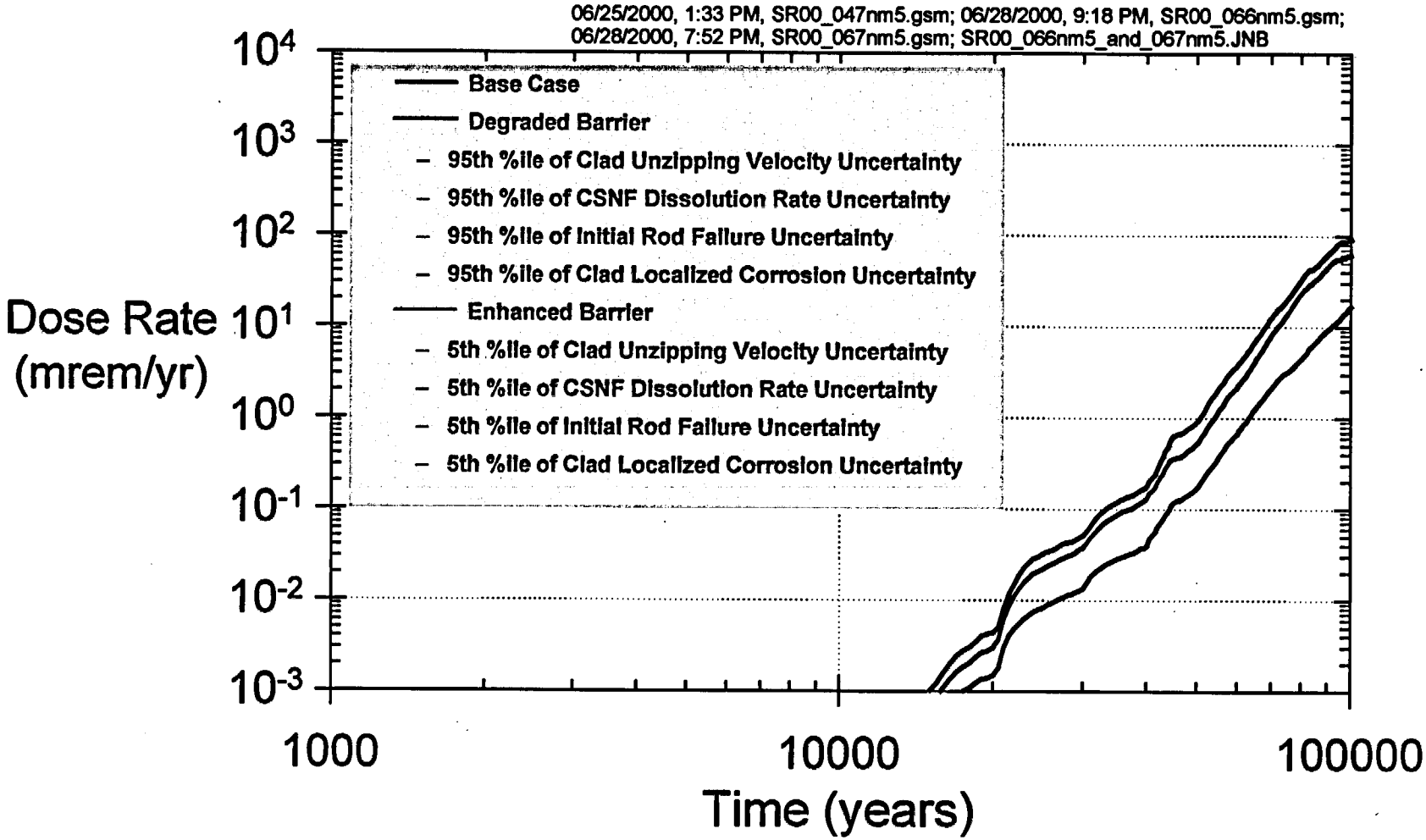
SDS Subissues Seismicity
(Continued)

- **Included** (Continued)
  - Seismic cladding failure as part of the nominal scenario
    - TSPA results are insensitive to cladding performance as long as waste packages function and moderately sensitive thereafter
    - Approach taken allows evaluating importance of failure after the performance period
- **Excluded**
  - Most effects of seismicity
    - e.g., vibratory ground motion damage to waste package and drip shield, rockfall, effects on UZ and SZ flow

SDS Subissues Seismicity

(Continued)

Degraded Cladding Condition Increases Dose by Factor of 2

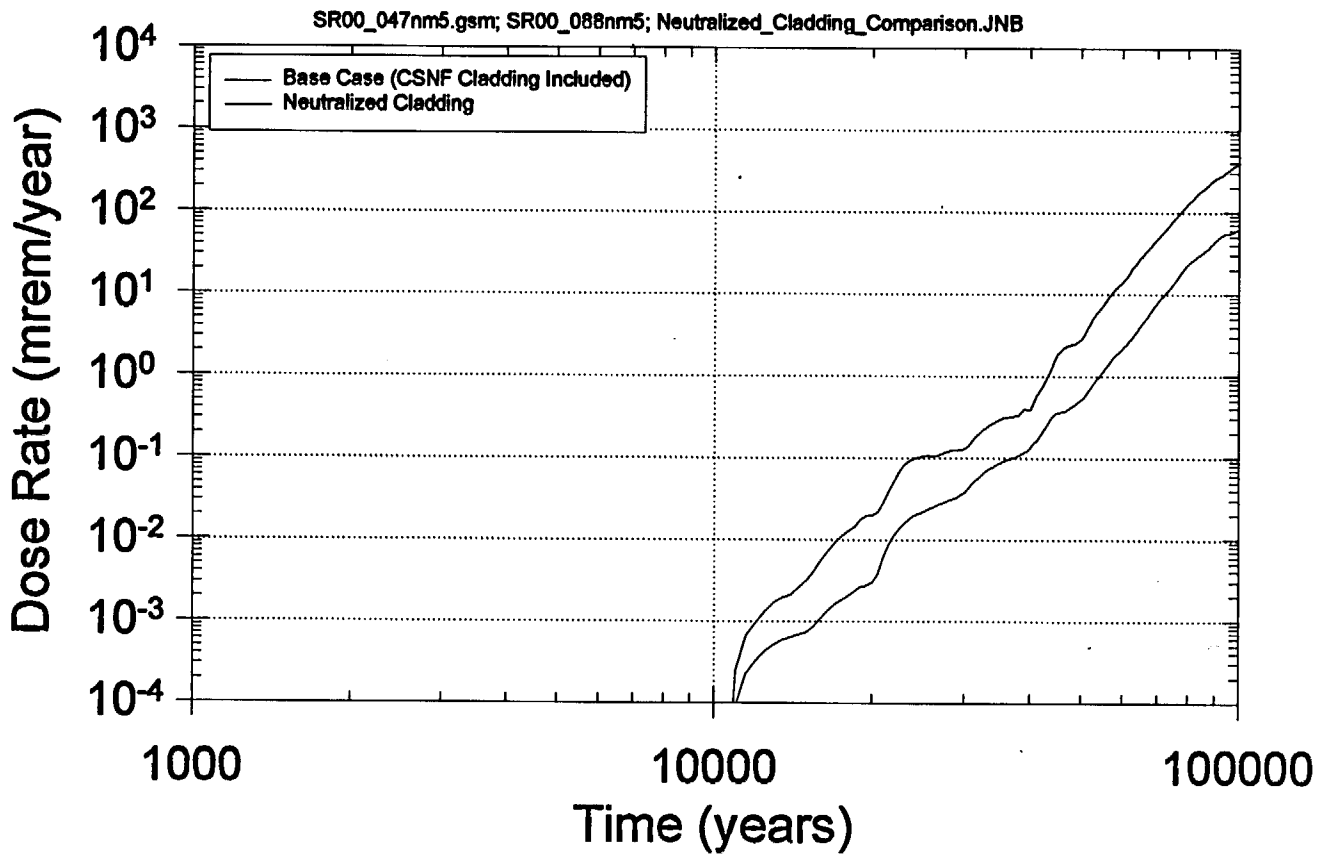


This information was prepared for illustrative purposes only and is subject to revision; not appropriate for assessing regulatory compliance.

SDS Subissues Seismicity

(Continued)

Neutralizing Cladding Increases Dose by Factor of 10



This information was prepared for illustrative purposes only and is subject to revision; not appropriate for assessing regulatory compliance.

SDS Subissues Fracture Framework

- Included
  - Effects of existing fractures on UZ and SZ flow models for nominal scenario
    - Addressed later in this meeting
    - Also addressed in UZ and SZ Technical Exchanges
- Excluded
  - Effects of new fractures and changes in properties of existing fractures

SDS Subissues Tectonic Framework

- **Included**
  - Tectonic models considered by the probabilistic volcanic hazards analysis (PVHA) and probabilistic seismic hazards analysis (PSHA) through the use of expert elicitation
    - i.e., seismic risk in the clad failure model, igneous event probability
  - The tectonic framework enters the TSPA indirectly through the geologic model
    - i.e., stratigraphy, rock properties, etc.
- **Excluded**
  - FEPs related to regional tectonic processes that might change properties of the geologic setting

Conclusion

- Treatment of SDS issues is consistent with FEPs evaluations
  - Included — Ground motion damage to cladding
  - Excluded — Other SDS issues

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

Subissue #1: Structural Deformation and Seismicity — Faulting

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
Kathy N. Gaither
Civilian Radioactive Waste Management System
Management and Operating Contractor

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Current Subissue Status
- For items identified in Issue Resolution Status Report (IRSR), Rev. 2 and subsequent interactions for each closed-pending acceptance criterion, presentation will
  - Summarize technical basis for resolution of items
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- Conclusions

Note: Additional summary information is provided in the delta analysis

Presentation Objectives

- Describe the basis for resolving Acceptance Criteria (AC) associated with the Faulting Subissue
  - AC 1: Data and Model Justification — DOE has adequately evaluated the nature and amount of faulting, ranges of faulting hazard, and fault geometry
  - AC 2: Data Uncertainty and Verification — Faulting FEPs evaluations have appropriately considered fault displacements
  - AC 3: Model Uncertainty — Existing fault and fracture characteristics are included in UZ and SZ flow and transport modeling
  - AC 4: Model Verification — Postclosure analyses take no credit for potential preclosure design measures to mitigate fault displacement effects

Presentation Objectives
(Continued)

- AC 5: Integration — Existing fault/fracture characteristics are included in postclosure analyses
- AC 6: Quality Assurance — Not addressed in this presentation
- AC 7: Expert Elicitation — NRC Issue Resolution Status Report Rev. 2 indicates this AC is resolved

Current Subissue Status

- IRSR, Rev. 2 indicates all technical acceptance criteria in this subissue are resolved (except QA)
- April 2000 KTI Status Technical Exchange identified this subissue as closed-pending
  - Analyses are needed to show rationales for faults/faulting that are included and excluded from consideration in performance assessments
  - Analyses are needed to show how DOE abstracted and used faulting hazard estimates in performance assessments

Acceptance Criterion 1

AC 1: Data and Model Justification — Sufficiency of geological and geophysical data to support conceptual models

- Action or information needs
  - None were identified in IRSR, Rev. 2 nor at the April 2000 Technical Exchange related to this AC
- Basis for closure
  - IRSR, Rev. 2 indicates that DOE has adequately evaluated the nature and amount of faulting, ranges of faulting hazard, and fault geometry
- No additional work required. This AC is closed

Acceptance Criterion 2

AC 2: Data Uncertainty and Verification — Inputs are technically defendable and account for uncertainties

- **Action or information needs**
  - None were identified in IRSR, Rev. 2 nor at the April 2000 Technical Exchange related to this AC
  - Additional information needs identified by NRC
    - Need analyses including current repository designs (no backfill)
    - Basis for using 10^{-4} and 10^{-5} reference probabilities for fault displacement
- **Updated analyses address information needs identified. This AC is closed-pending**

Acceptance Criterion 2

(Continued)

Analyses showing current repository designs (no backfill)

- Basis for closure
  - *Effects of Fault Displacement on Emplacement Drifts* (ANL-EBS-GE-000004) and the AMR, *Features, Events, and Processes: Disruptive Events* (ANL-WIS-MD-000005) ICN 1 (in preparation) address the backfill and no backfill cases of repository design
- References
  - *Effects of Fault Displacement on Emplacement Drifts* (ANL-EBS-GE-000004)
  - *Features, Events, and Processes: Disruptive Events* (ANL-WIS-MD-000005), ICN 1 (in preparation)
- The AMRs address the current repository design information requested. No additional work is required

Acceptance Criterion 2

(Continued)

Fault displacement probability values

- Basis for closure
  - Fault displacement values for preclosure (10^{-5}) and postclosure (10^{-6} to 10^{-8}) exceedance probabilities are taken from the Probabilistic Fault Displacement Hazard Analysis (PFDHA)
  - For postclosure, median fault displacement is used as the appropriate measure for analysis and evaluation
    - Mean values are often greater than 85th percentile values at 10^{-8} exceedance probabilities, reflecting major contribution from the extreme tails of uncertainty distributions
    - The median better represents the central tendency of the experts interpretations
  - The updated Disruptive Events FEPs AMR evaluates faulting FEPs with appropriate consideration of likelihood of occurrence (median displacement with 10^{-8} annual exceedance probability)

Acceptance Criterion 2
(Continued)

Fault displacement probability values (Continued)

- **Basis for closure** (Continued)
  - Faulting FEP
    - PFDHA results indicate a low probability of significant faulting in intact rock (new faults)
      - » Median displacements are less than 0.1 cm for an annual frequency of exceedance of 10^{-8}: Condition "d" at Sites 7 and 8
    - Potential effects of faulting along existing faults have low consequence to UZ flow (addressed in Fracturing Subissue)
    - PFDHA results also indicate potential for secondary displacement on existing intrablock faults. (Addressed by "Fault movement shears waste container" FEP)

Acceptance Criterion 2
(Continued)

Fault displacement probability values (Continued)

- **Basis for closure** (Continued)
  - Fault Movement Shears Waste Container FEP
    - PSHA for median displacement and 10^{-8} annual exceedance probability indicate
      - » < 0.1 cm for intact rock (Condition "d", Site 7 and 8)
      - » < 100 cm for intrablock faults (Sites 3 through 6 and conditions a, b, and c at Sites 7 and 8)
      - » < 300 cm for Solitario Canyon fault (Site 2)
    - AMR, *Effects of Fault Displacement on Emplacement Drifts* examined displacement from 0.1cm to 1m
      - » For a = 400m, set-back = 60m, and 1 m displacement; induced displacement = 0.4 m
      - » Extrapolation of results to 3 m suggests 1.2 m induced displacement, without adjusting for "a" value

Acceptance Criterion 2
(Continued)

Fault displacement probability values (Continued)

- **Basis for closure** (Continued)
  - **Fault Movement Shears Waste Container FEP** (Continued)
    - **Excluded based on low probability (not credible) because:**
      - » Distance from waste package/drip shield to drift wall is approximately 2 m (an Engineered Barrier System (EBS) design feature)
      - » Movement along intrablock faults (< 1 m) is insufficient to shear waste package because of EBS design
      - » Set-backs from block-bounding faults will be adequate to avoid direct fault postclosure fault displacement

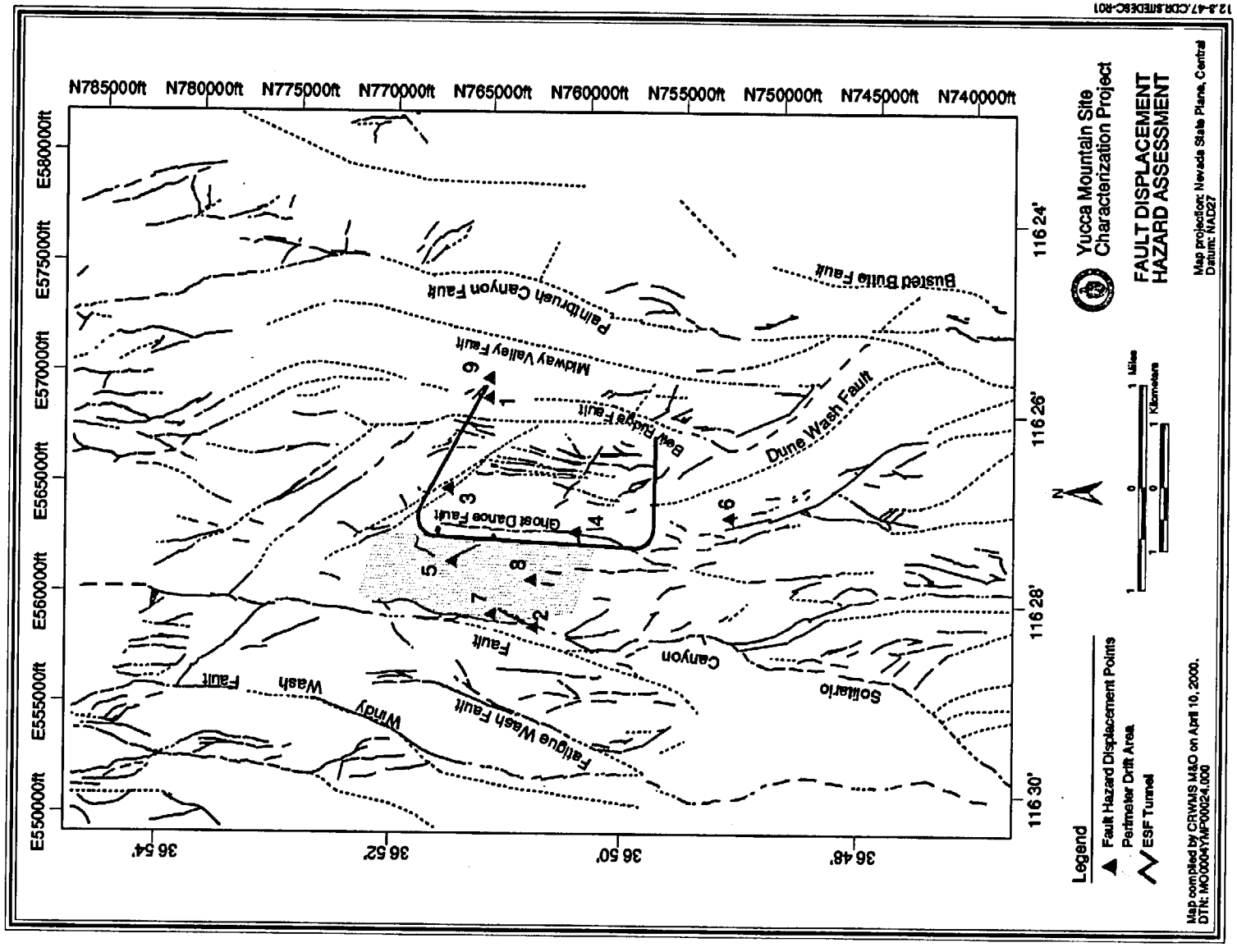
Acceptance Criterion 2
(Continued)

Fault displacement probability values (Continued)

- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
  - *Effects of Fault Displacement on Emplacement Drifts* (ANL-EBS-GE-000004)
  - Probabilistic Seismic Hazards Analyses (Wong and Stepp 1998)
  - *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP/TR-003-NP)
- Updated faulting FEPs evaluations appropriately consider fault displacements with 10^{-4}/10,000 year probabilities of occurrence

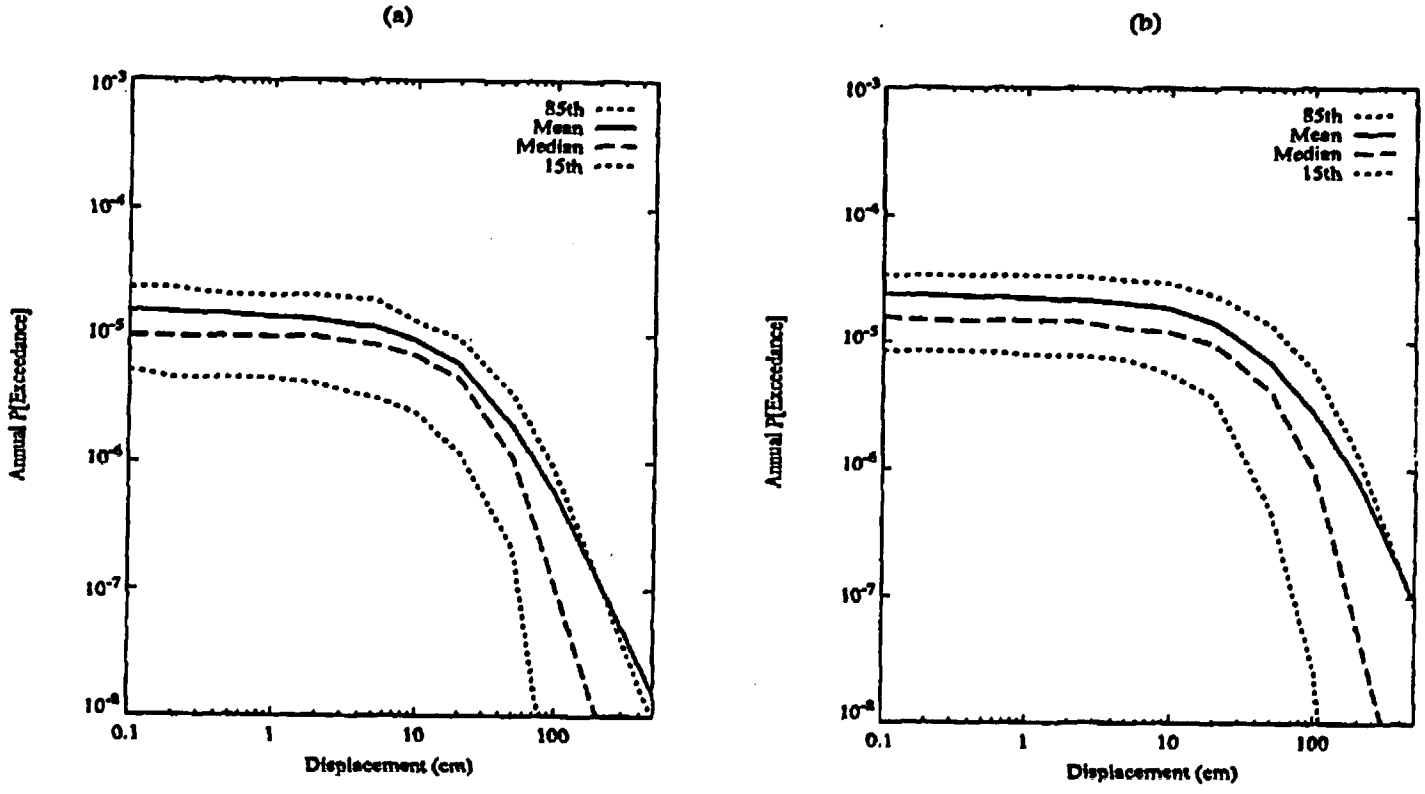
Fault Displacement Probability Values

(Continued)



Fault Displacement Probability Values

(Continued)

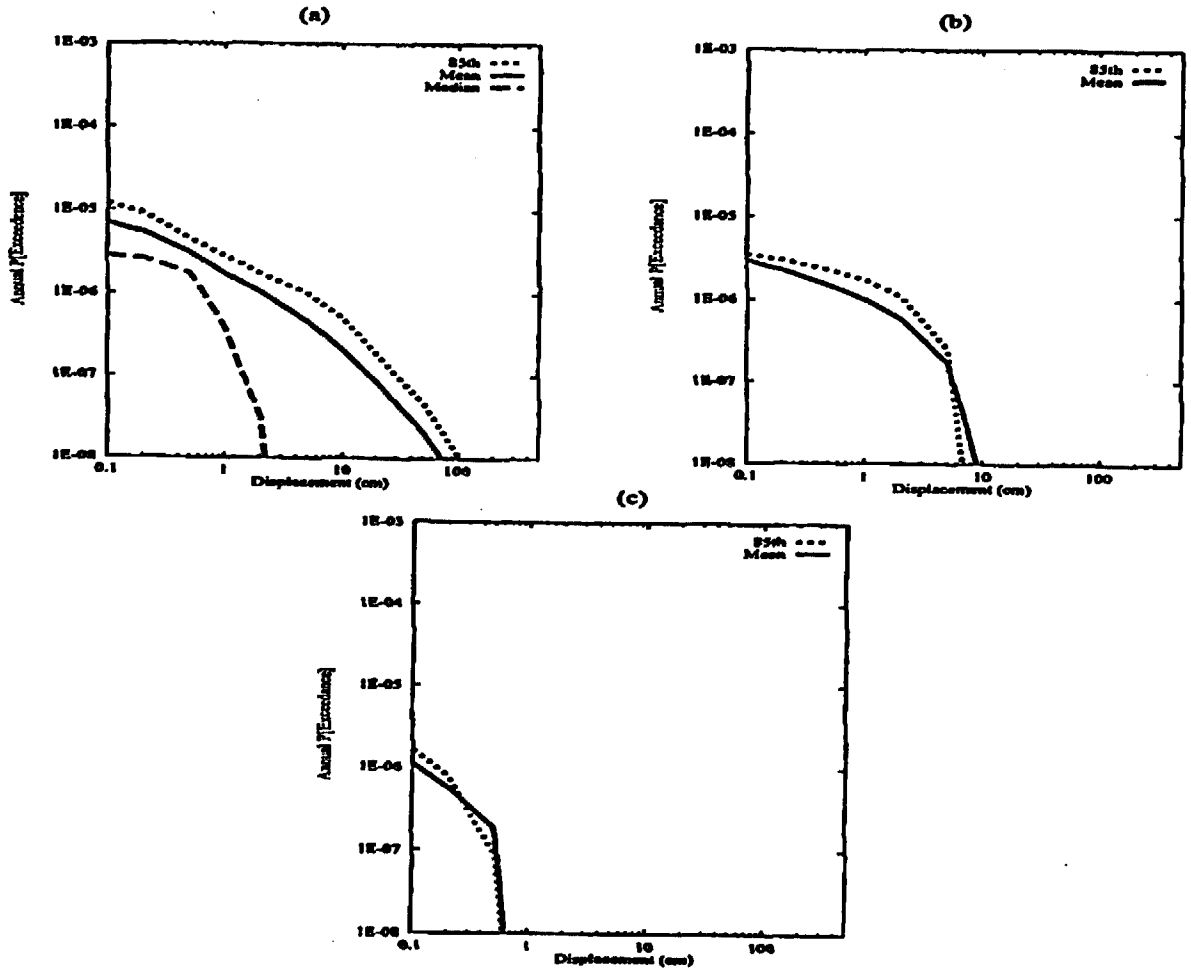


Source: CRWMS M&O 1998a, Section 8
Note: See Figure 3 for site locations.

Summary Fault Displacement Hazard Curves for (a) Site 1, Bow Ridge Fault and (b) Site 2, Solitario Canyon Fault

Fault Displacement Probability Values

(Continued)



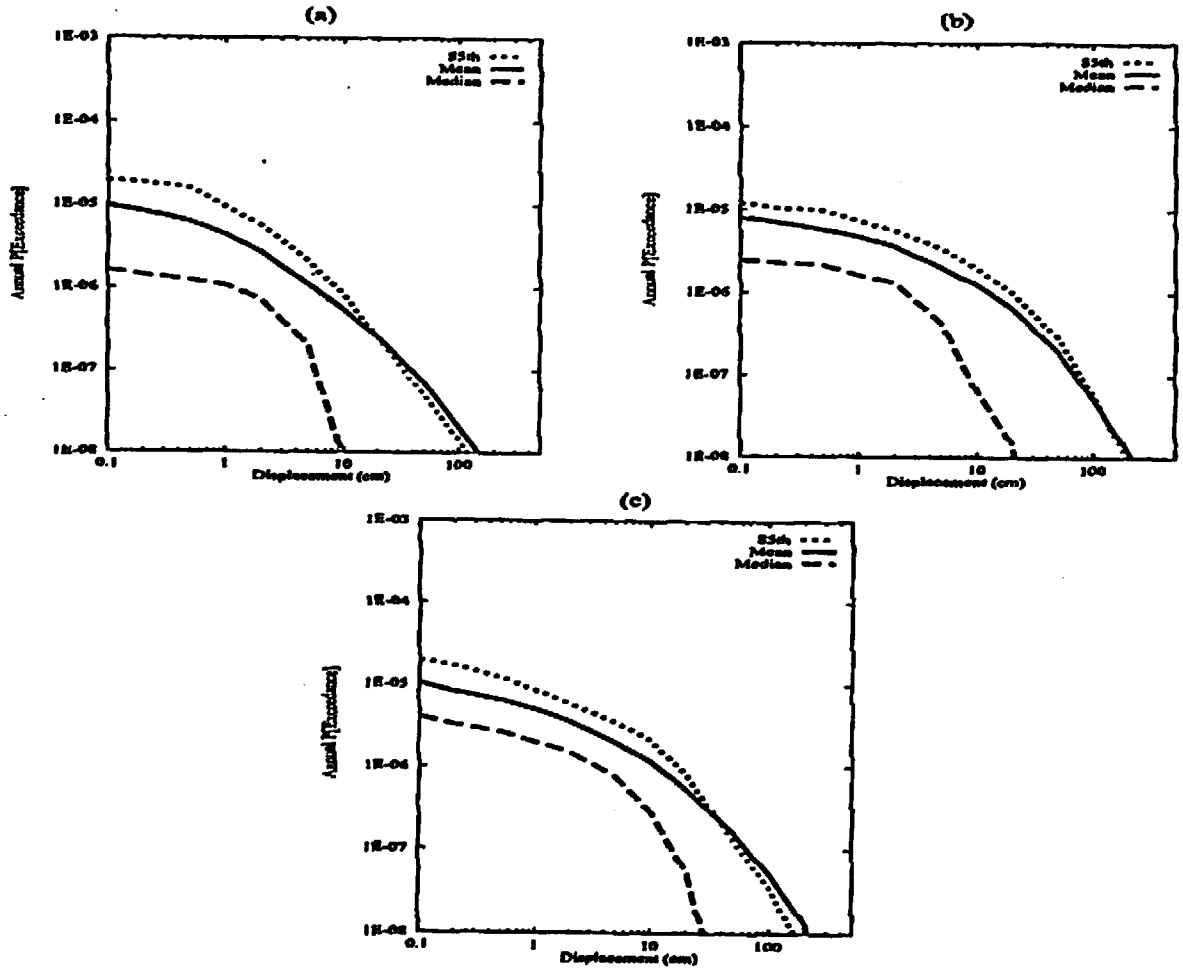
Source: CRWMS M&O 1998a, Section 8

Note: The 15th percentile curve lies below the range shown for all conditions and the median lies below the range shown for Plots b and c. See Figure 3 for site location.

Summary Fault Displacement Hazard Curves for Site 7, Considering Three Hypothetical Conditions: (a) 2 m of Cumulative Displacement, (b) 10 cm of Cumulative Displacement, and (c) No Measurable Cumulative Displacement

Fault Displacement Probability Values

(Continued)



Source: CRWMS M&O 1998a, Section 5

Note: The 15th percentile curve lies below the range of displacements plotted for both sites.

Summary Fault Displacement Hazard Curves for (a) Site 5, Sundance Fault (b) Site 6, Unnamed Fault West of Dune Wash, and (c) Site 9, Midway Valley

Acceptance Criterion 3

AC 3: Model Uncertainty — Alternative models are considered and appropriately incorporated in analyses

- Action or information needs
  - From IRSR, Rev. 2 and restated at April 2000 Technical Exchange, the following were identified
    - Analyses are needed to show rationales for faults/faulting that are included and excluded from consideration in performance assessments
    - Analyses are needed to show how DOE abstracted and used faulting hazard estimates in performance assessments

Acceptance Criterion 3
(Continued)

- **Action or information needs** (Continued)
  - Additional information needs identified by NRC
    - Zero fault width assumption in AMR
    - Sufficiency of technical justification for excluded FEPs
- **Updated analyses address information needs identified. This AC is closed**

Acceptance Criterion 3

(Continued)

Rationale for inclusion/exclusion of faults/faulting in TSPA

- **Basis for closure**
  - The basis for inclusion or exclusion of fault displacement is established in the *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN1 (in preparation). Refer to discussion in AC 2

Acceptance Criterion 3
(Continued)

Rationale for inclusion/exclusion of faults/faulting in TSPA
(Continued)

- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
  - *Fault Displacement Effects on Transport in the Unsaturated Zone* (ANL-NBS-HS-000020)
  - Probabilistic Seismic Hazards Analyses (Wong and Stepp 1998)
  - Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain (YMP/TR-003-NP)
- Updated faulting FEPs evaluations appropriately consider fault displacements with 10^{-4}/10,000 year probabilities of occurrence based on the PSHA results

Acceptance Criterion 3
(Continued)

Abstraction of faulting hazard estimates in performance assessment (Continued)

- Basis for closure
  - TSPA-SR includes effects of existing faults and fractures on UZ and SZ flow and transport (discussed in Fracturing Subissue)
  - TSPA-SR does not include faulting shearing effects on waste packages based on FEPs exclusion (see discussion of AC 2)

Acceptance Criterion 3

(Continued)

Abstraction of faulting hazard estimates in performance assessment (Continued)

- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
  - Probabilistic Seismic Hazards Analyses (Wong and Stepp 1998)
- Based on FEPs evaluation, changes in characteristics and shearing effects of faulting are excluded

Acceptance Criterion 3

(Continued)

Fault width assumption

- **Basis for closure**
  - The AMR, *Effects of Fault Displacement on Emplacement Drifts*, assumes that the fault width for calculations is zero:
    - Concentrates all displacement on a knife edge fault
    - Maximizes rock movement and stress/strain values
    - Zero width provides no zone over which to distribute fault displacement effects
- **References**
  - *Effects of Fault Displacement on Emplacement Drifts* (ANL-EBS-GE-000004)
- **This assumption is considered bounding for analysis of fault displacement effects**

Acceptance Criterion 3

(Continued)

FEPs screening justification

- **Basis for closure**
  - The Disruptive Events FEPs AMR is currently in change process. ICN 1 to this AMR includes the following changes
    - Results of AMRs and calculations completed since Rev. 0
    - Description of potential consequences for primary FEPs
    - Citations to related PMRs and AMRs
- **References**
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
- **Changes included in the ICN to the FEPs AMR will significantly improve justifications**

Acceptance Criterion 4

AC 4: Model Verification — Results are verified

- Action or information needs
  - Same as AC 3 were identified in IRSR, Rev. 2 and restated at the April 2000 Technical Exchange
  - Additional information needs identified by NRC
    - Justification for 0-100 cm range was used to bound mean values of fault displacement. Address fault displacements for the Solitario Canyon fault for 10^{-8} probability
    - Provide technical basis for setback distance
    - Use of design measures to mitigate hazards
- Updated analyses address information needs identified. This AC is closed-pending

Acceptance Criterion 4

(Continued)

Fault displacement ranges for Solitario Canyon fault

- Basis for closure
  - The AMR, *Effects of Fault Displacement on Emplacement Drifts*
    - Considered displacements of 0.1 to 100 cm
    - The AMR examines fault displacement effects on EBS as a function of distance from the fault
    - Results also provide information useful in postclosure analyses
  - FEPs evaluation of fault displacement uses this AMR along with other information
    - See discussion in AC 2
    - The range of displacements in the AMR addresses postclosure intrablock displacements
    - The results of the AMR have been extrapolated to address 10^{-4}/10,000 year displacements on block-bounding faults

Acceptance Criterion 4

(Continued)

Fault displacement ranges for Solitario Canyon fault

(Continued)

- **References**
  - *Effects of Fault Displacement on Emplacement Drifts* (ANL-EBS-GE-000004)
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
  - *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP/TR-003-NP)
- **Evaluation of fault displacement effects on Solitario Canyon fault are addressed through fault avoidance (setbacks)**
- **Set-backs are sufficient to address postclosure displacements**

Acceptance Criterion 4

(Continued)

Technical basis for fault setback

- Basis for closure
  - The current setback distance (a preclosure design requirement) is based on engineering judgement and is denoted as to be verified (TBV) in the design documents
- References
  - *Subsurface Facility System Description Document* (SDD-SFS-SE-000001, Rev. 1)
- Fault avoidance, as a design requirement, is an acceptable approach to address preclosure displacement effects
- The existence of the requirement is also sufficient to address postclosure technical concerns

Acceptance Criterion 4

(Continued)

Consistency of application of preclosure and postclosure issues

- Basis for closure
  - Postclosure FEPs faulting evaluations and TSPA-SR do not take credit for ground support. Any ground support designs to mitigate fault displacement during the preclosure period are not included in postclosure analyses
- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
  - TSPA-SR
- Postclosure analyses take no credit for ground support to mitigate fault displacement effects

Acceptance Criterion 5

AC 5: Integration — Appropriately incorporate results in performance assessment

- Action or information needs
  - Same as AC 3 were identified in IRSR, Rev. 2 and restated at the April 2000 Technical Exchange
- Basis for closure
  - Previously discussed for AC 3
  - PSHA (Wong and Stepp 1998) identifies faulting models and parameters

Acceptance Criterion 5
(Continued)

- **Basis for closure** (Continued)
  - Fault displacement has been excluded from the TSPA-SR by FEPs screening on the basis of:
    - Low probability of displacement on new faults
    - Low probability of shearing of waste containers from existing faults
    - Low consequence to dose from displacement on existing faults
  - Existing fault/fracture characteristics are included in TSPA-SR
- **No additional work required**

Acceptance Criterion 7

AC 7: Expert Elicitation — Appropriate implementation

- Action or information needs
  - None were identified in IRSR, Rev. 2 nor at the April 2000 Technical Exchange related to this AC
- Basis for closure
  - Expert elicitation supporting the PFDHA was carried out in accordance with the QARD
  - Process carried out following guidance in NRC NUREG 1563
  - NRC Issue Resolution Status Report Rev. 2 indicates this AC is resolved
- No additional work required. This AC is closed

Conclusions

- The status of the acceptance criteria for this subissue is as follows:
  - AC 1: Closed
  - AC 2: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 3: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 4: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 5: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 7: Closed

Backup

FEPs Statements

- **Faulting (1.2.02.02.00)**
  - Faulting may occur due to sudden major changes in the stress situation (e.g., seismic activity) or due to slow motions in the rock mass (e.g., tectonic activity). Movement along existing fractures and faults is more likely than the formation of new faults. Faulting may alter the rock permeability in the rock mass and alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository.New faults or the [reactivation] of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides
- **Fault Movement Shears Waste Container (1.2.02.03.00)**
  - A fault intersects the repository and a line of waste containers. That intersection shears containers by virtue of the relative offset across the containers

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

Subissue #4: Structural Deformation and Seismicity — Tectonic Framework

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
Carl Stepp, Ph.D.
Civilian Radioactive Waste Management System Management and Operating Contractor

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Current Subissue Status
- For items identified in Issue Resolution Status Report (IRSR), Rev. 2 and subsequent interactions for each closed-pending acceptance criterion, presentation will
  - Summarize technical basis for resolution
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- Conclusions

Note: Additional summary information is provided in the delta analysis

Presentation Objectives

- Describe the basis for resolving the Acceptance Criteria (AC) associated with the Tectonic Framework subissue
  - AC 1: Data and Model Justification — Sufficient geologic and geophysical data considered in evaluating tectonic models
  - AC 2: Data Uncertainty and Verification — Viable tectonic models evaluated in Probabilistic Seismic Hazards Analysis (PSHA) include appropriate assessment of uncertainty
  - AC 3: Model Uncertainty — Alternative models considered and appropriately incorporated
  - AC 4: Model Verification — Models verified through expert elicitation
  - AC 5: Integration — Tectonic models appropriately incorporated
  - AC 6: Quality Assurance — Not addressed in this presentation
  - AC 7: Expert Elicitation — NRC Issue Resolution Status Report Rev. 2 indicates this AC is resolved

Current Subissue Status

- IRSR, Rev. 2 indicates technical acceptance criteria in this subissue are resolved (except QA)
- April 2000 Key Technical Issue (KTI) Status Technical Exchange identified this subissue as open
  - Analyses are needed to show rationales for tectonic models included and excluded
  - Analyses are needed to show consistent and appropriate use of tectonic models used in Probabilistic Volcanic Hazard Analysis (PVHA) and PSHA

Acceptance Criterion 1

AC 1: Data and Model Justification — Sufficiency of geological and geophysical data

- Action or information needs
  - None identified
- Basis for closure
  - IRSR acknowledges sufficient geologic and geophysical data considered in evaluating tectonic framework and tectonic models relevant to faulting and ground motion hazard analyses
- No additional work required. This AC is closed

Acceptance Criterion 2

AC 2: Data Uncertainty and Verification — Inputs technically defensible and account for uncertainties

- Action or information needs
  - None
- Basis for closure
  - IRSR acknowledges evaluations of viable tectonic models include appropriate assessment of uncertainty
  - Expert elicitation process ensures defensibility
  - PSHA results incorporate uncertainty in applicability of data supporting tectonic models as well as uncertainty due to limited data
  - Development of seismic design inputs, engineering analyses, and features, events, and processes (FEPs) evaluations use PSHA results and incorporate underlying data uncertainties
- No additional work required. This AC is closed

Acceptance Criterion 3

AC 3: Model Uncertainty — Alternative models are considered and appropriately incorporated in analyses

- Action or information needs
  - None identified in IRSR, Rev. 2
  - April 2000 KTI status Technical Exchange identified
    - Analyses are needed to show rationales for tectonic models included and excluded from consideration
    - Analyses are needed to show tectonic models used in PVHA and PSHA are consistent and appropriate
- Updated analyses address information needs identified. This AC is closed-pending

Acceptance Criterion 3

(Continued)

Rationale for inclusion/exclusion of tectonic models

- Basis for closure
  - Tectonic models were evaluated in PSHA and PVHA
  - Engineering analyses and FEPs evaluations use PSHA results and incorporate underlying model uncertainties
  - TSPA-SR includes tectonic models through its use of PSHA and PVHA results
  - Rationale for inclusion/exclusion of specific tectonic features and processes in TSPA-SR is contained in the report *Features, Events, and Processes: Disruptive Events*
    - Tectonic activities (e.g., large-scale uplift, subsidence, folding) are excluded based on low consequence

Acceptance Criterion 3
(Continued)

Rationale for inclusion/exclusion of tectonic models
(Continued)

- References
  - PVHA (CRWMS M&O 1996)
  - PSHA (Wong and Stepp 1998)
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005)
- Tectonic model uncertainty is considered in hazard analyses
- Large-scale tectonic activity processes excluded from TSPA-SR based on low consequence

Acceptance Criterion 3

(Continued)

Consistency of treatment of tectonic models in PSHA and PVHA

- Basis for closure
  - Multiple tectonic models considered in developing the PVHA
    - Volcanic experts gave low weight to tectonic models in development of volcanic source zones
    - Hinge line is not a structural barrier between Crater Flat and Yucca Mountain was assumed or identified
  - Multiple tectonic models considered in developing seismic source and fault displacement models in the PSHA

Acceptance Criterion 3

(Continued)

Consistency of treatment of tectonic models in PSHA and PVHA (Continued)

- **References**
  - PVHA (CRWMS M&O 1996)
  - PSHA (Wong and Stepp 1998)
  - *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (ANL-NBS-GS-00001)
  - *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (ANL-CRW-GS-000003)
  - Summary Highlights of NRC/DOE Technical Exchange on Igneous Activity, August 29-31, 2000, Las Vegas, NV

Acceptance Criterion 3
(Continued)

Consistency of treatment of tectonic models in PSHA and PVHA (Continued)

- The technical basis to resolve this issue was described at the Igneous Activity Technical Exchange, August 2000
  - Hinge line is not a structural barrier that delimits volcanic source zone
  - Volcanic source zones do not represent seismogenic sources used in PSHA

Acceptance Criterion 4

AC 4: Model Verification — Viable tectonic models verified

- Action or information needs
  - None
- Basis for closure
  - IRSR, Rev. 2 acknowledges adequate verification of alternative models
  - Expert elicitation used for conceptual model verification (referred to as validation in QARD)
  - PSHA experts based interpretations on available data; thus models are consistent with data
- No additional work required. This AC is closed

Acceptance Criterion 5

AC 5: Integration — Appropriately incorporate results

- Action or information needs
  - None identified in IRSR, Rev. 2
  - Same as AC 3 identified at the April 2000 Technical Exchange
- Basis for closure
  - Previously discussed for AC 3
  - Tectonic models appropriately incorporated in performance assessment using probabilistic fault displacement and seismic hazard analysis results
- No additional work required. This AC is closed-pending

Acceptance Criterion 7

AC 7: Expert Elicitation — Appropriate implementation

- Action or information needs
  - None
- Basis for closure
  - IRSR, Rev. 2 describes this AC as resolved
  - Expert elicitation carried out in accordance with the QARD
  - Process carried out following guidance in NUREG 1563
- No additional work required. This AC is closed

Conclusions

- Status of acceptance criteria for this subissue
  - AC 1: Closed
  - AC 2: Closed
  - AC 3: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 4: Closed
  - AC 5: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 7: Closed

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

Subissue #2: Structural Deformation and Seismicity — Seismicity

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
Richard Quittmeyer, Ph.D.
Civilian Radioactive Waste Management System
Management and Operating Contractor

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Current Subissue Status
- For items identified in Issue Resolution Status Report (IRSR), Rev. 2 and subsequent interactions for each open or closed-pending acceptance criterion, presentation will
  - Summarize technical basis for resolution
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- Conclusions

Note: Additional summary information is provided in the delta analysis

Presentation Objectives

- Describe the basis for resolving the Acceptance Criteria (AC) associated with the Seismicity Subissue
  - AC 1: Data and Model Justification — Identify documentation that will provide final values of kappa and shallow shear wave velocity and describe technical basis for the values
  - AC 2: Data Uncertainty and Verification — Describe the basis of using 1E-4 and 1E-5 reference probabilities and representation of ground motion uncertainties
  - AC 3: Model Uncertainty — Discuss seismic design inputs and basis for FEPs evaluations
  - AC 4: Model Verification — Discuss seismic design inputs

Presentation Objectives
(Continued)

- AC 5: Integration — Demonstrate that predicted levels of ground shaking from PSHA are adequately integrated into TSPA subsystem models and other TSPA calculations
- AC 6: Quality Assurance — Not addressed in this presentation
- AC 7: Expert Elicitation — Clarify treatment of uncertainty in ground motion component of PSHA

Current Subissue Status

- IRSR, Rev. 2 indicates technical acceptance criteria 2 through 6 in this subissue are open (data characterization and expert elicitation are resolved)
- April 2000 Key Technical Issue (KTI) Status Technical Exchange identified this subissue as closed-pending:
  - Analyses are needed to show how DOE abstracted and used seismic hazard estimates in performance assessments
  - Providing data used in Probabilistic Seismic Hazard Analysis (PSHA) for NRC analyses
  - Final seismic design values (Topical Report 3), damping factor (kappa), and crustal shear wave velocities

Acceptance Criterion 1

AC 1: Data and Model Justification — Sufficiency of geological and geophysical data

- Action or information needs
  - None related to this AC were identified in IRSR, Rev. 2 nor at the April 2000 Technical Exchange
  - Additional needs identified by NRC
    - Kappa and shallow shear wave velocity
    - Treatment of epistemic uncertainty associated with kappa
- Seismic Topical Report 3 addresses the information needs identified. This AC is closed-pending

Acceptance Criterion 1

(Continued)

Kappa and shallow shear wave velocities

- **Basis for Closure**
  - PSHA hazard was determined for reference rock outcrop to decouple uncertainties related to kappa and shallow shear wave velocity from the analysis
  - If future work indicates kappa used in PSHA is not a reasonable bound, difference will be addressed in developing seismic design inputs
  - Development of seismic design inputs will be based on results of geotechnical investigations now in progress to characterize shallow conditions at the site
  - Technical basis for kappa and for shallow soil and rock properties will be discussed in the Seismic Design Inputs report and Seismic Topical Report 3

Acceptance Criterion 1
(Continued)

Kappa and shallow shear wave velocities (Continued)

- References
  - Probabilistic Seismic Hazards Analyses *(Wong and Stepp 1998)*
  - Seismic Framework *(ANL-CRW-GS-000003)*
  - Seismic Design Inputs report *(To be developed)*
  - Seismic Topical Report 3 *(To be developed)*
- Values for kappa and shallow shear-wave velocity will be discussed in the Seismic Design Inputs report and in Seismic Topical Report 3

Acceptance Criterion 1

(Continued)

Epistemic uncertainty associated with kappa

- **Basis for closure**
  - If needed, epistemic uncertainty in kappa will be addressed in developing seismic design inputs based on the PSHA results
  - Preliminary assessment is that kappa used in PSHA reasonably bounds the epistemic uncertainty in kappa
- **References**
  - *Seismic Design Inputs report (to be developed)*
- **Use of bounding value for kappa is an acceptable approach**

Acceptance Criterion 2

AC 2: Data Uncertainty and Verification — Inputs are technically defendable and account for uncertainties

- Action or information needs
  - IRSR, Rev. 2 specified need for DOE PSHA data to carry out independent assessment of uncertainty
  - Additional needs identified by NRC
    - Analyses for current repository designs (no backfill)
    - Basis for using 1E-4 and 1E-5 reference probabilities for component response analyses
    - Representation of ground motion uncertainties in the PSHA
- Updated and existing analyses address information needs identified. This AC is closed-pending

Acceptance Criterion 2
(Continued)

PSHA Data

- Basis for closure
  - PSHA data provided to NRC
- References
  - *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (ANL-CRW-GS-000003)
- No additional work is needed

Acceptance Criterion 2

(Continued)

Analyses for current repository designs (no backfill)

- **Basis for closure**
  - The AMR, *Drift Degradation Analysis* (ANL-EBS-MD-000027), has been supplemented by a calculation to address the current design alternative with no backfill
- **References**
  - *Supporting Rockfall Calculation for Drift Degradation: Drift Reorientation with No Backfill* (CAL-EBS-MD-000010)
- **Calculation addresses no backfill case**

Acceptance Criterion 2

(Continued)

Basis for ground motion probabilities

- Basis for closure
  - Preclosure component design analyses evaluate ground motions at probabilities up to 10^{-4} annual probability of exceedance
  - Seismic analysis have been performed for the drip shield, waste package and emplacement pallets for up to 10^{-5}/year ground motions (preliminary)
    - No instances of drip shield separation
  - Seismic-fragility analysis has been performed for the fuel-rod cladding for preclosure and postclosure ground motions
    - Combined risk is approximately 10^{-6}/year
    - Included in TSPA-SR nominal case
    - Ground motion induced cladding failure is included in TSPA-SR

Acceptance Criterion 2
(Continued)

Basis for ground motion probabilities (Continued)

- **Basis for closure** (Continued)
  - Postclosure probabilities of exceedance (10^{-5} to 10^{-8}) is excluded from TSPA-SR on the basis of low consequence to dose
  - Preliminary evaluations address up to 10^{-5}/year ground motions and show no or minimal damage
  - Additional damage from 10^{-5}/year to 10^{-8}/year ground motions would result in failure mechanisms that are addressed by preclosure design requirements
    - Drops - Applicable drop height is TBD. Preliminary calculations used drop height of 0.775 m based on lift travel of the emplacement gantry

Acceptance Criterion 2

(Continued)

Basis for ground motion probabilities (Continued)

- **Basis for closure** (Continued)
  - Impacts — drip shield and waste package design requirement is to withstand 6 metric ton rock fall event
  - Stress Cracking — Low consequence to dose unless located under a drip through the drip shield. Corrosion degradation already considered through WAPDEG analysis
- **References**
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), ICN 1 (in preparation)
- **The current approach examining the effects of beyond design basis ground motions (i.e., those with 10^{-5} to 10^{-8} probability of exceedance) provides reasonable assurance**

Acceptance Criterion 2

(Continued)

Representation of ground motion uncertainty in PSHA

- **Basis for closure**
  - Two components of uncertainty considered
    - Aleatory (randomness)
    - Epistemic (resulting from imperfect knowledge)
  - Epistemic uncertainty in the median ground motion and in ground motion scatter is represented in the PSHA by 10 discrete values of associated "epistemic" variables ε_μ and ε_σ
  - Representation preserves a sufficiently large number of probabilistic moments

Acceptance Criterion 2
(Continued)

Representation of ground motion uncertainty in PSHA
(Continued)

- **Basis for closure** (Continued)
  - Discrete epistemic distribution of hazard associated with one ground-motion expert is combined with those associated with other ground-motion experts and with the effects of discrete distributions for other uncertain quantities
  - PSHA used 70 attenuation equations (7 experts times 10-point uncertainty distribution)
- **References**
  - Probabilistic Seismic Hazards Assessment (Wong and Stepp 1998)
- **Representation of ground motion uncertainty is adequate**

Acceptance Criterion 3

AC 3: Model Uncertainty — Alternative models are considered and appropriately incorporated in analyses

- Action or information needs
  - IRSR, Rev. 2 and April 2000 KTI Status Technical Exchange specified the following information needs
    - DOE PSHA data to carry out independent assessment of uncertainty
    - Seismic Topical Report 3 will document treatment of uncertainty in development of seismic design inputs

Acceptance Criterion 3

(Continued)

- **Action or information needs** (Continued)
  - Additional needs identified by the NRC
    - Sufficient technical basis for FEPs evaluations
    - Clarification of use of "low consequence" and "low probability" in FEPs evaluations
    - Clarification of use of "consequence" in FEPs evaluations
- **Updated analyses and completion of Seismic Topical Report 3 address the information needs identified. This AC is closed-pending**

Acceptance Criterion 3

(Continued)

PSHA Data

- Basis for closure
  - Refer to discussion included in AC 2

Acceptance Criterion 3

(Continued)

Seismic design inputs

- Basis for closure
  - Development of seismic design inputs and treatment of uncertainties will be documented in an analysis report and in Seismic Topical Report 3
- References
  - Seismic Design Inputs report (to be developed)
  - Seismic Topical Report 3 (to be developed)
- This item can be closed pending completion of Seismic Topical Report 3

Acceptance Criterion 3

(Continued)

Exclusion of seismicity-related FEPs from TSPA

- Basis for closure
  - AMR that evaluates disruptive events FEPs is being updated
    - Clarifies technical basis for screening
    - Clarifies use of term "consequences"
    - Clarifies use of "low consequence" and "low probability"
- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005)
- ICN 1 to Disruptive Events FEPs AMR addresses NRC items. Refer to additional discussion in AC 2

Acceptance Criterion 4

AC 4: Model Verification — Results are verified

- Action or information needs
  - IRSR, Rev. 2 and April 2000 KTI Status Technical Exchange specified the following needs
    - DOE PSHA data to carry out independent assessment of uncertainty
    - Seismic Topical Report 3 documenting treatment of uncertainty in development of seismic design inputs
- See previous discussion for AC 3
- This AC is closed-pending

Acceptance Criterion 5

AC 5: Integration — Appropriately incorporate results in performance assessment

- Action or information needs
  - IRSR, Rev. 2 specified the following information need:
    - Demonstrate that predicted levels of ground shaking from PSHA are adequately integrated into TSPA subsystem models and other TSPA calculations
  - Additional needs identified by NRC
    - Definition of event and event sequence
- Updated analyses address the information needs identified. This AC is closed-pending

Acceptance Criterion 5

(Continued)

Ground shaking values from PSHA are adequately integrated

- Basis for closure
  - Cladding damage from ground shaking is included in TSPA-SR
  - FEPs screening analyses support exclusion of other vibratory ground motion effects
    - See additional discussion for AC 2
  - Ground motion effects on rockfall are discussed in the *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)

Acceptance Criterion 5
(Continued)

Ground shaking values from PSHA are adequately integrated (Continued)

- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), Rev 0, ICN 1 (in preparation)
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
- Seismicity FEPs are appropriately screened
- If evaluation is "include," FEP is incorporated in TSPA-SR

Acceptance Criterion 5

(Continued)

Definition of event and event sequence

- Basis for closure
  - Events are defined by FEPs descriptions
  - Seismic fragility analyses can be used to evaluate component responses
  - Based on results, a determination is made as to whether a low consequence or low probability screening decision is applicable
- References
  - *Features, Events, and Processes: Disruptive Events* AMR (ANL-WIS-MD-000005), Rev 0, ICN 1 (in preparation)
- Seismicity FEPs are appropriately screened
- If evaluation is "include," FEP is incorporated in TSPA-SR

Acceptance Criterion 7

AC 7: Expert Elicitation

- Action or information needs
  - IRSR, Rev. 2 identified this acceptance criterion as resolved
  - Additional needs identified by NRC
    - Treatment of uncertainties associated with median ground motions (e.g., Anderson versus Silva)
    - Feedback to experts and expert satisfaction with elicitation results
- The following slides provide the information requested. This AC is closed

Acceptance Criterion 7

(Continued)

Uncertainties associated with median ground motions

- Basis for closure
  - Treatment of uncertainties was extensively discussed during PSHA process
    - Presentation of uncertainty model
    - Feedback during expert elicitation interviews
    - Feedback workshops and working meetings
  - Documented in PSHA Report, Workshop Summaries, and Ground Motion Data Packages provided to experts
- References
  - Probabilistic Seismic Hazard Analyses (Wong and Stepp 1998)
  - Probabilistic Seismic Hazard Analyses Workshop Summary Reports

Acceptance Criterion 7
(Continued)

Uncertainties associated with median ground motions
(Continued)

- Experts understood treatment of uncertainties
- Experts' interpretations, based on the available data, accurately reflect their judgments

Acceptance Criterion 7

(Continued)

Feedback to experts and expert satisfaction

- Basis for closure
  - Feedback to experts took place during elicitation interviews, during workshops, and in working meetings
  - One working meeting included an exercise to focus experts on the point values that resulted from their interpretations
  - Treatment of uncertainty extensively discussed at all stages of process
- References
  - Probabilistic Seismic Hazard Analyses (Wong and Stepp 1998)
  - Probabilistic Seismic Hazard Analyses Workshop Summary Reports
- Experts understood their results and were satisfied that they reflected their judgments

Conclusions

- The status of the acceptance criteria for this subissue is as follows
  - AC 1: Closed-pending Seismic Topical Report 3
  - AC 2: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 3: Closed-pending ICN 1 of Disruptive Events FEPs AMR, Seismic Topical Report 3
  - AC 4: Closed-pending Seismic Topical Report 3
  - AC 5: Closed-pending ICN 1 of Disruptive Events FEPs AMR
  - AC 7: Closed

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

Subissue #3: Structural Deformation and Seismicity — Fracturing and Structural Framework

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
Steve Beason
U.S. Bureau of Reclamation
Jennifer Hinds
Dwayne Kicker
Civilian Radioactive Waste Management System
Management and Operating Contractor

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Current Subissue Status
- For items identified in Issue Resolution Status Report (IRSR), Rev. 2 and subsequent interactions for each open or closed-pending acceptance criterion (AC), presentation will:
  - Summarize technical basis for resolution of items
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- Conclusions

NOTE: Additional summary information is provided in the delta analysis

Presentation Objectives

- Demonstrate how open acceptance criteria (AC) are addressed and provide the basis to resolve the AC associated with Fracturing and Structural Framework Subissue
  - AC 1: Data and Model Justification — Demonstrate adequacy of characterizations of fracture characteristics and distributions abstracted in process level and total system performance assessment (TSPA) models
  - AC 2: Data Uncertainty and Verification — Demonstrate adequacy of constrained ranges of fracture parameter values or distributions of fractures characteristics and bounding assumptions
  - AC 3: Model Uncertainty — Demonstrate adequacy of consideration of alternative modeling approaches for fracture distributions and ranges of fracture properties and appropriate abstraction through process model and PA models of ambient and perturbed conditions

Presentation Objectives

(Continued)

- AC 4: Model Verification — Demonstrate incorporated abstractions of fracture data and models are reasonably consistent with expected sensitivity to range of fracture distributions, properties, and field observations
- AC 5: Integration — Demonstrate adequate integration of incorporated abstractions of fracture data and models
- AC 6: Quality Assurance — Not included in this presentation
- AC 7: Expert Elicitation — Not applicable to this subissue

Current Subissue Status

- IRSR, Rev. 2 indicates all technical acceptance criteria applicable to this subissue are OPEN
- April 2000 Technical Exchange also identified this subissue as OPEN with the following summary
  - Analyses are needed to show rationales for fracture/structural framework characteristics included and excluded from consideration of performance
  - Analyses are needed to show included fracture/structural framework characteristics (Features, Events, and Processes (FEPs)) are abstracted and used in process models and TSPA

Acceptance Criterion 1

AC 1: Data and Model Justification

- Action or information needs
  - Demonstrate adequacy of characterizations of fracture characteristics and distributions abstracted in process level and TSPA models:
    - Fracture aperture distribution
    - Fracture connectivity across stratal boundaries
    - Fracture characterization in key stratigraphic units in the unsaturated zone (UZ)
    - Fracture orientation and length
    - Role of fracture dynamics
- Information needs are addressed on the following slides. This AC is closed

Acceptance Criterion 1

(Continued)

Fracture aperture distribution

- Basis for closure
  - Fracture aperture distribution data from field observations are not critical to flow modeling and are not used directly in UZ models
    - Fracture apertures important to flow modeling < 200 microns
    - Observable field measurements are > 200 microns
  - Hydraulic apertures important to flow modeling
    - Derived from pneumatic fracture permeability measurements and fracture frequency information from fracture mapping data
    - These data, plus the cubic law for fracture permeability, define an average hydraulic aperture
      - » Average apertures are defined for each model unit
      - » Aperture variability within model units is treated through the relative permeability and capillary pressure functions

Acceptance Criterion 1
(Continued)

Fracture aperture distribution (Continued)

- **Basis for closure** (Continued)
  - Fracture aperture data are not critical for rockfall analysis and were not included in the drift degradation analysis
  - Joint parameters of importance to rockfall models include fracture geometry and fracture frictional properties
- **References**
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
- Fracture aperture is not a critical parameter for flow models. A more critical parameter is fracture porosity, measured through gas tracer tests
- Rockfall analyses use joint set orientation and trace lengths

Acceptance Criterion 1

(Continued)

Treatment of fracture connectivity across stratal boundaries

- Basis for closure
  - Flow models consider 100% connectivity by assuming all fracture flow paths are fully connected, i.e., no dead ends
    - Supported by observations of construction water in Niche 3, originating from Alcove 8 construction directly overlying Niche 3. The TSw1/TSw2 stratal boundary lies between these excavations
    - Features that could indicate reduced connectivity, such as increased saturations at unit boundaries in the Repository Host Horizon consistent with ponding, have not been observed in excavations or boreholes
    - Fracture continuity within the TCw and TSw units also supported by lack of significant attenuation of pneumatic signals

Acceptance Criterion 1
(Continued)

Treatment of fracture connectivity across stratal boundaries (Continued)

- **Basis for closure** (Continued)
  - Geologic cross sections do not generally depict locations or connectivity of fractures
    - Scale necessary to portray the cross section does not allow sufficient resolution to show individual fractures
    - Cross-sections accompanying full-periphery maps show individual fractures and accurately depict fracture abutting relationships
  - Rockfall analyses in the Drift Degradation Analysis AMR consider the joint trace length from field mapping data to model extent of fracture planes
    - Multiple planes may contribute to formation of one rock block

Acceptance Criterion 1
(Continued)

Treatment of fracture connectivity across stratal boundaries (Continued)

- References
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)
  - *Conceptual and Numerical Models for UZ Flow and Transport AMR* (MDL-NBS-HS-000005)
- Rockfall analysis accurately characterizes potential rock block development within each stratigraphic unit
  - Unnecessary to consider fracture connectivity across stratal boundaries in rockfall analyses
- Fracture connectivity database is unnecessary to confirm the UZ model. Connectivity information is augmented by other data

Acceptance Criterion 1

(Continued)

Sufficiency of fracture characterization in key stratigraphic units in the UZ

- Basis for closure
  - The UZ model considers fracture data from the entire ESF, the ECRB, boreholes, and surveys of surface exposures and outcrops
    - ECRB fracture frequency data were not directly used because data between 30 cm and 1m were not available
      - » Model considered conservative because it assumes a lower fracture frequency in the lower lithophysal zone compared to the middle nonlithophysal zone; higher fracture frequency leads to better performance with respect to radionuclide transport, therefore, lower frequency is conservative

Acceptance Criterion 1
(Continued)

Sufficiency of fracture characterization in key stratigraphic units in the UZ (Continued)

- **Basis for closure** (Continued)
  - Limited data available for the Calico Hills Formation
    - Where possible, fracture data from similar units in SZ (Prow Pass Tuff) are used in the UZ flow model
    - UZ model conservatively assumes significant lateral flow in perched water bodies into faults leading to poorer-than-expected performance
  - Pneumatic data from sensors in instrumented boreholes show that the attenuation of the pneumatic signals within the Topopah Spring welded unit are directly related to the thickness of the overlying Paintbrush Tuff non-welded unit (PTn)

Acceptance Criterion 1
(Continued)

Sufficiency of fracture characterization in key stratigraphic units in the UZ (Continued)

- References
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Particle Tracking Model and Abstraction of Transport Processes AMR* (ANL-NBS-HS-000026)
  - *Characterization and Prediction of Subsurface Pneumatic Response at Yucca Mountain, Nevada.* Journal of Contaminant Hydrology
  - Unsaturated Zone Process Model Report
  - *In Situ Field Testing of Processes* AMR (ANL-NBS-HS-000005)
- Sufficient data have been collected to address uncertainty in the UZ flow and transport models

Acceptance Criterion 1
(Continued)

Fracture orientation and length bias

- Basis for closure
  - Fracture length is not a critical measurement for UZ flow models
    - Fracture length data used to establish the geometric fracture/matrix contact area for UZ flow model
    - Model calibrated by matrix saturation and capillary pressure data that adjusts amount of fracture/matrix flow exchange
      - » Calibration employs active fracture model parameter
      - » Effectively adjusts fracture/matrix interface area to give appropriate amount of fracture/matrix flow exchange
      - » Model matches known saturation/capillary pressure data
    - Therefore, model ultimately not very sensitive to fracture length
  - Fracture orientation not used in UZ flow or transport models because flow assumed dominantly vertical

Acceptance Criterion 1
(Continued)

Fracture orientation and length bias (Continued)

- **Basis for closure** (Continued)
  - Fracture database is appropriately represented
    - Truncation bias at the tunnel diameter occurs only when fractures are normal and fracture length is greater than the tunnel diameter
    - Fractures may only be partially sampled at any given tunnel location, but sample size is sufficient to represent the diameters of fracture population adequately
  - Fracture orientation and length bias addressed for rock fall analyses by development of fracture orientation database
    - Derived from fracture strike and dip measurements mapped on full periphery geotechnical maps (FPGMs)
    - Includes FPGM data from cross-drift
    - Uses stereographic projection techniques to determine orientation of major joint sets within lithostratigraphic units of repository host horizon

Acceptance Criterion 1
(Continued)

Fracture orientation and length bias (Continued)

- References
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* AMR (ANL-EBS-GE-000006)
- FPGMs and the derived database represent sampling of a three-dimensional volume, the directional bias associated with 2-dimensional detail line survey is not applicable

Acceptance Criterion 1

(Continued)

Derivation of fracture dynamics

- **Basis for closure**
  - Process models and PA abstractions need only information about present and reasonably likely future characteristics
    - Information about how those characteristics developed is not necessary
  - TSPA models do not consider orientation of regional stress field at time of fracturing
  - Development of new fractures will not significantly effect UZ hydrologic model
    - Current 3-D UZ model uses uniform properties for a given layer calibrated to borehole data
    - Model parameters sufficiently flexible to account for variations in fracture characteristics

Acceptance Criterion 1
(Continued)

Derivation of fracture dynamics (Continued)

- References
  - *Disruptive Events FEPs* AMR (ANL-WIS-MD-000005)
- Explanations of the development history of fracture characteristics unnecessary to include fracture characteristics in process models or TSPA abstractions
- Information about the development history would address only how the fractures developed and is not needed by process models

Acceptance Criterion 2

AC 2: Data Uncertainty and Verification

- Action or information needs
  - From IRSR, Rev. 2
    - Demonstrate adequacy of constrained ranges of fracture parameter values or distributions of fractures characteristics and bounding assumptions
      - » Downward-convergent connected fracture networks (flow paths)
      - » Excavation-induced fractures
      - » Fault - and fracture-zone properties
      - » Assessment of fracture origins
      - » Boundary conditions of numerical abstractions of fracture data, models, and modifications under ambient and thermally perturbed conditions
- Information needs are addressed on the following slides. This AC is closed

Acceptance Criterion 2

(Continued)

Downward convergent connected fracture networks

- Basis for closure
  - Spatially heterogeneous flow in the UZ is addressed by
    - Hydrogeologic parameter sets that describe each of 32 model units
    - Dual permeability description of fracture and matrix flow within each model unit
    - Explicit incorporation of fault features
  - Bomb pulse ^{36}Cl has generally been found near faults in the ESF and is believed to be a result of fast pathways along the faults
    - Explicit inclusion of faults in the model captures this aspect

Acceptance Criterion 2

(Continued)

Downward convergent connected fracture networks

(Continued)

- **References**
  - *Conceptual and Numerical Models for UZ Flow and Transport* AMR (MDL-NBS-HS-000005)
- **Spatially heterogeneous flow and fast pathways have been addressed within the UZ flow and transport models by the inclusion of fault features and hydrogeologic parameter sets**

Acceptance Criterion 2

(Continued)

Excavation-induced fractures

- Basis for closure
  - Observations in the ESF and ECRB have not found the randomly-oriented fractures expected as excavation-induced effects
  - Some excavation-induced fracturing has been observed in the upper lithophysal zone of the Topopah Spring Tuff (Tptpul) in both the ESF and the ECRB
    - This rock is not expected to host the proposed repository

Acceptance Criterion 2
(Continued)

Excavation-induced fractures (Continued)

- **Basis for closure** (Continued)
  - Underground observations indicate that there has been no significant amount of stress-induced fracturing in the underground in the repository host rocks
  - Pre- and post-excavation permeability from testing in niches indicate that excavation enhances local permeability in the surrounding rock
  - The ambient seepage model relies on data from the excavation disturbed zone
    - Seepage relevant effective parameters include potential excavation effects

Acceptance Criterion 2

(Continued)

Excavation-induced fractures (Continued)

- References
  - Observations of mapping team
  - Unsaturated Zone Process Model Report
  - *In Situ Field Testing and Processes* AMR (ANL-NBS-HS-000005)
- Mapping of the ESF and ECRB have not revealed significant amounts of excavation-induced fracturing from the tunneling machines in the rock expected to host the proposed repository (Tptpmn, Tptpll, and Tptpln)
- Excavation may enhance permeability in existing fractures
- The ambient seepage model includes potential excavation effects

Acceptance Criterion 2

(Continued)

Fault and fracture zone properties

- Basis for closure
  - Explaining development history of fracture characteristics is unnecessary in process models or TSPA abstractions
    - Process models and TSPA abstractions use only present characteristics and do not consider the past modifications to fractures
  - Presence of fracture coatings noted
    - Effect on flow cannot be quantified, however
      - » Fault and fracture properties (e.g., permeability and fracture-matrix interaction) are obtained through measurements and calibration
      - » The proportion of observed fractures mineralized are consistent with active fracture model
  - Sensitivity studies, based on simple estimates to bound changes, are adequate to analyze potential changes in fracture properties on UZ flow and transport

Acceptance Criterion 2
(Continued)

Fault and fracture zone properties (Continued)

- References
  - *An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks.* Water Resources Research
  - *Fault Displacement Effects on Transport in the Unsaturated Zone* AMR (ANL-NBS-HS-000020)
- Sufficient work has been done to characterize fractures adequately to support process model and abstraction development
- Additional studies cannot be clearly linked to repository performance

Acceptance Criterion 2

(Continued)

Assessment of origin of fractures

- Basis for closure
  - Definition of fracture origins is not needed
    - Hydraulic properties of fractures that may affect performance are unrelated to fracture origin
  - Information derived from existing measured properties or analog information based on rock units having known similar hydrogeologic characteristics
  - Correlations for hydrogeologic properties based on fracture origin and subsequent evolution are unlikely to be successful due to complex relationships
    - Because of the complex history of both cooling and tectonic fractures including reactivation of previous existing cooling fractures, specific hydrologic characteristics for modeling cannot be assigned to a particular set of fractures based on their origin

Acceptance Criterion 2

(Continued)

Assessment of origin of fractures (Continued)

- References
  - Yucca Mountain Site Description AMR (TDR-CRW-GS-000001)
  - *Particle Tracking Model and Abstraction of Transport Processes* AMR (ANL-NBS-HS-000026)
- Sufficient information about fracture characteristics has been collected and documented
- TSPA does not require linking fracture hydraulic properties to fracture origin because fracture hydraulic properties used in process models are derived by calculation and calibration
- Hydraulic properties are unrelated to fracture origin

Acceptance Criterion 2

(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions

- Basis for closure
  - Drift degradation analysis considered behavior of fractures under the effects of seismic and thermal loading
    - Approach considered a significant reduction in joint cohesion in response to thermal loading and the subsequent effect on rockfall
    - Seismic loading in the drift degradation analysis was examined using a quasi-static approach involving a significant reduction in the joint friction angle to simulate the effect of increased force along rock block sliding surfaces in response to a seismic event
    - Both seismic and thermal loading were shown to have minimal effects on rockfall development

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- Basis for closure (Continued)
  - Analysis results indicate the mechanical behavior of fractures under seismic and thermal loads need not be completely understood
    - » Relatively large reduction of fracture strength parameters provides reasonable bounds on these parameters
  - Sensitivity analyses concerning the effects of changes in fracture aperture in the UZ on potential radionuclide transport have been conducted

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- **Basis for closure** (Continued)
  - Large changes (x10 increases in fracture aperture) over the entire UZ domain are required to influence transport results
  - Large and spatially extensive changes in fracture properties are considered conservative
    - » Based on observations of existing fractures in relation to previous fault displacements along nearby faults such as Solitario Canyon fault and the Ghost Dance fault

Acceptance Criterion 2

(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- **Basis for closure** (Continued)
  - The effects of fault displacement on fracture properties near emplacement drifts is addressed
    - Anisotropic changes are expected to result in less seepage because the capillary barrier for seepage from vertical fractures would be increased while the permeability for lateral drainage (around drifts) would also increase
  - Air permeability measurements taken during the drift scale testing indicated modest changes in air permeability that can be attributed to changes in water saturation in fractures
    - Thermal mechanical effects on permeability are evidently not significant over this time period

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- **Basis for closure** (Continued)
  - Potential changes in fracture network characteristics (i.e., fracture aperture) which could potentially result from differential thermal expansion and contraction or other tectonic perturbations have been addressed in SZ models
    - The range of uncertainty in SZ groundwater flux is relatively large for TSPA-SR simulations
      - » Given the range of uncertainty in horizontal anisotropy, the potential effects were modeled by setting the bounding anisotropy ratio values to 1 (isotropic) or 5 (anisotropic)
    - Range of uncertainty encompasses the potential changes in fracture network characteristics

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- References
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
  - *Fault Displacement Effects on Transport in the Unsaturated Zone* AMR (ANL-NBS-HS-000020)
  - *Impact of Thermal Loading on Repository Performance at Yucca Mountain.* High Level Radioactive Waste Management, Proceedings of the Third International Conference, Las Vegas, Nevada, April 12-16, 1992

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- **References** (Continued)
  - *Thermal Tests Thermal-Hydrological* AMR (ANL-NBS-TH-000001)
  - *Saturated Zone Flow and Transport Process Model Report* (TDR-NBS-HS-000001)
  - *Uncertainty Distribution for Stochastic Parameters* AMR (ANL-NBS-MD-000011)

Acceptance Criterion 2
(Continued)

Adequacy of boundary conditions of numerical abstractions under ambient and thermally perturbed conditions (Continued)

- Fracture behavior under expected seismic and thermally perturbed conditions considered in rockfall analyses and flow and transport models

Acceptance Criterion 3

AC 3: Model Uncertainty

- **Action or information needs**
  - From IRSR, Rev. 2
    - Demonstrate adequacy of consideration of alternative modeling approaches for fracture distributions and ranges of fracture properties and appropriate abstraction through process model and PA models of ambient and perturbed conditions
      - » Nonrepresentative data sets
      - » Assumption of spatial homogeneity in fracture distribution in the UZ
      - » Assumption of isotropic fracture permeability in the saturated zone (SZ)
      - » Continuity of consideration of fracture data and alternative fracture models abstracted in the DOE process-level and PA models
- **Information needs identified are addressed on the following slides. This AC is considered closed**

Acceptance Criterion 3
(Continued)

Nonrepresentative data sets

- Basis for closure
  - The UZ model now considers fracture data from the entire ESF, the ECRB, boreholes, and surveys of surface exposures and outcrops
    - For the SR models, fracture characteristics have been developed from pneumatic permeability measurements and fracture mapping information on fracture frequency and fracture length
  - Synthetic fracture networks have not been used in the UZ model
    - Inputs from Anna, 1997, were not used in the UZ model

Acceptance Criterion 3
(Continued)

Nonrepresentative data sets (Continued)

- **Basis for closure** (Continued)
  - Fracture data used in Mountain-Scale UZ Model for SR
    - DLS data from ESF (fracture frequency, length)
    - Borehole fracture frequency
    - Estimates of fracture permeability and porosity (based on air injection test data from surface boreholes and air-injection and gas tracer data from test alcoves)

Acceptance Criterion 3
(Continued)

Nonrepresentative data sets (Continued)

- **Basis for closure** (Continued)
  - Fracture data not used in Mountain-Scale UZ Model for SR
    - Measured apertures from DLS
    - Fracture orientations from DLS
    - Niche fracture data
    - DLS fracture data from ECRB*
    - Data from small scale fracture mapping
    - Air-injection data from Tptpll in ECRB, Niche 5
    - Surface fracture data

*ECRB DLS sub-1-meter length fracture data was not available from TDMS when UZ models for SR were developed. These data will be included in models for LA.

Acceptance Criterion 3
(Continued)

Nonrepresentative data sets (Continued)

- **References**
  - *Unsaturated Zone Flow and Transport Process Model Report* (TDR-NBS-HS-000002)
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Development of Numerical Grids for Unsaturated Zone Flow and Transport Modeling* AMR (ANL-NBS-HS-000015)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)

Acceptance Criterion 3
(Continued)

Nonrepresentative data sets (Continued)

- Effective hydrologic properties of fractures are more important to UZ process models than measured geometric characteristics
- Measured characteristics (aperture, orientation, spacing/frequency, length) and genetic information are not sufficient to describe parameters controlling flow
- Available information indicates the fracture data needed for the model is adequately representative

Acceptance Criterion 3

(Continued)

Assumption of spatial homogeneity in fracture distribution in the UZ

- Basis for closure
  - Fracture data used and not used in the development of the UZ process models have been identified
  - Homogeneity and heterogeneity captured in UZ models
    - Fracture characteristics used are modeled as homogeneous within each model unit
    - Heterogeneity is addressed by defining 32 model units corresponding to various rock types based on variations in hydrologic properties
  - Testing results and geochemical data from the Tiva Canyon Tuff indicate permeability is sufficiently large that detailed heterogeneities characterization would not impact Tiva Canyon flow model

Acceptance Criterion 3
(Continued)

Assumption of spatial homogeneity in fracture distribution in the UZ (Continued)

- **Basis for closure** (Continued)
  - Faults are discretized and assigned specific hydrologic properties
    - Model fault zone thickness is 30 m and is characterized by enhanced permeability
    - Model fault zone thickness is greater than any intra-block faults in the repository block; so model depiction is conservative
  - Long fractures (100m) observed in Tpcpul have not been observed in Tpcpmn. Observations indicate long fractures are not underrecognized

Acceptance Criterion 3
(Continued)

Assumption of spatial homogeneity in fracture distribution in the UZ (Continued)

- References
  - *Analysis of Hydrologic Properties* AMR (ANL-NBS-HS-000002)
  - *UZ Flow Models and Submodels* AMR (MDL-NBS-HS-000006)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)
- Even though fractures are assumed to be spatially homogeneous in each model units, current process models adequately depict spatial variations because of differences in hydrologic properties between model units and discrete modeling of faults

Acceptance Criterion 3

(Continued)

Assumption of isotropic fracture permeability in the SZ

- Basis for closure
  - Uncertainty in horizontal anisotropy of permeability in fractured tuff units of the SZ is included in simulations of groundwater flow and radionuclide transport for TSPA-SR
  - Two equiprobable discrete cases of SZ flow are simulated
    - Anisotropic case accounts for effects of preferentially-oriented faults
    - Isotropic case is retained as viable alternative
  - Anisotroic case results in more rapid transport and is therefore conservative relative to isotropic case

Acceptance Criterion 3
(Continued)

Assumption of isotropic fracture permeability in the SZ
(Continued)

- References
  - *Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA* AMR (ANL-NBS-HS-000030)
- SZ flow and transport models cases based on anisotropic fracture permeability and isotropic fracture permeability
- The anisotropic case produces more rapid transport than the isotropic case and is therefore conservative

Acceptance Criterion 3

(Continued)

Continuity of consideration of fracture data and alternative fracture models

- Basis for closure
  - Fracture data are traceable from acquisition to end use
    - Fracture data are maintained in the technical data management system (TDMS)
  - Data users interpret fracture data consistent with their needs and document the uses of the data in technical products
    - Drift Degradation Analysis uses a continuous and traceable approach to incorporate all ESF fracture data
    - Analysis of the mapped fracture data is summarized in the AMR, Fracture Geometry in Key Stratigraphic Units in the Repository Host Horizon (ANL-EBS-GE-000006), which provides identification of fracture sets, fracture spacing, and trace length data

Acceptance Criterion 3
(Continued)

Continuity of consideration of fracture data and alternative fracture models (Continued)

- **Basis for closure** (Continued)
  - Abstractions of fracture data for use in process models (e.g. flow and rockfall modeling) do not necessarily need to be the same
    - For example, in rock units where fracture/matrix interaction is weak, it is acceptable to ignore spatial variability in fracture spacing for UZ flow and transport modeling
  - For UZ flow process modeling and abstraction
    - Effective hydrologic properties of fractures are more important to UZ process models than measured geometric characteristics
    - Measured characteristics (aperture, orientation, spacing/frequency, length) and genetic information are not sufficient to describe parameters controlling flow

Acceptance Criterion 3
(Continued)

Continuity of consideration of fracture data and alternative fracture models (Continued)

- **References**
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* AMR (ANL-EBS-GE-000006)
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Fault Displacement Effects on Transport in the Unsaturated Zone* AMR (ANL-NBS-HS-000020)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)

Acceptance Criterion 3
(Continued)

Continuity of consideration of fracture data and alternative fracture models (Continued)

- Data users interpret fracture data consistent with their needs and document the uses of the data in technical products
- The level of detail used is consistent with the process being modeled

Acceptance Criterion 4

AC 4: Model Verification

- Action or information needs
  - From IRSR, Rev. 2
    - Demonstrate incorporated abstractions of fracture data and models are reasonably consistent with expected sensitivity to range of fracture distributions, properties, and field observations:
      - » Joint set orientation for rockfall analysis
- Information needs identified are addressed on the following slides. This AC is considered closed

Acceptance Criterion 4

(Continued)

Joint set orientation for rockfall analysis

- Basis for closure
  - Drift degradation analysis has considered variability in joint set orientation, spacing, and trace length using numerical code DRKBA (Discrete Region Key Block Analysis)
    - Statistical distributions of fracture data are inputs to DRKBA
    - Beta distributions are used to represent fracture spacing and trace lengths
    - Watson bi-polar distributions are used to model joint set orientations

Acceptance Criterion 4
(Continued)

Joint set orientation for rockfall analysis (Continued)

- References
  - *Drift Degradation Analysis* AMR (ANL-EBS-MD-000027)
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* AMR (ANL-EBS-GE-000006)
- DRKBA examines effects on key blocks of variations in fracture geometry using Monte Carlo simulations of the fractured rock mass
- Fracture patterns are generated based on the statistical distribution of fracture data

Acceptance Criterion 5

AC 5: Integration

- Action or information needs
  - From IRSR, Rev. 2
    - Demonstrate consistent use of
      - » Representative and bias-adjusted data and models
      - » Assumptions about fracture behavior under expected ambient and thermally perturbed conditions
      - » Scaling factors and geological correlations where fracture data are extrapolated or interpolated from limited databases
- Information needs identified are addressed on the following slides. This AC is considered closed

Acceptance Criterion 5

Representative and bias-adjusted data and models

- **Basis for closure**
  - Fracture orientation database registered to 3-D Nevada State Plane Coordinates has been completed
  - Database represents sampling of 3-D volume and question of bias associated with 2-D DLS is not applicable
  - AMR describes joint set orientations based on database and identifies major joint sets in lithostratigraphic units of the Repository Host Horizon for use in rockfall analysis
- **References**
  - *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* AMR (ANL-EBS-GE-000006)

Acceptance Criterion 5
(Continued)

Representative and bias-adjusted data and models
(Continued)

- Volume-based fracture data are, by definition, unbiased
- Discussions of directional and length censorship biases, and corrections for these biases, in fracture data are no longer relevant
- Additional discussion in AC 1 for fracture orientation and length bias

Acceptance Criterion 5

(Continued)

Fracture behavior under expected ambient and thermally perturbed conditions

- Basis for closure
  - DOE has examined rockfall under static and dynamic conditions and has specifically considered effects of seismic and thermal loading on rockfall
    - Seismic effects result from differential accelerations which require much higher frequencies than the principal frequencies typically associated with earthquakes. Seismic effects are therefore expected to be negligible
    - Thermal effects tend to be directed horizontally and tend to lock steep fractures, thereby decreasing rockfall potential

Acceptance Criterion 5

(Continued)

Fracture behavior under expected ambient and thermally perturbed conditions (Continued)

- **Basis for closure** (Continued)
  - DOE has examined the effects of changes in fracture aperture in the UZ on potential radionuclide transport
    - Results indicate that large increases in fracture aperture (on the order of 10X) over the entire UZ domain are needed to affect transport results
    - Such changes are unlikely and the analysis is considered conservative
  - DOE has also examined the range of uncertainty for SZ flow using simulations
    - Results indicate that the range of uncertainty encompasses the potential changes in fracture network characteristics that could result from differential thermal expansion and contraction or from tectonic perturbations

Acceptance Criterion 5

(Continued)

Fracture behavior under expected ambient and thermally perturbed conditions (Continued)

- References
  - Drift Degradation Analysis AMR (ANL-EBS-MD-000027)
  - Fault Displacement Effects on Transport in the Unsaturated Zone AMR (ANL-NBS-HS-000020)
  - Uncertainty Distributions for Stochastic Parameters AMR (ANL-NBS-MD-000011)
  - Saturated Zone Flow and Transport Model Process Model Report (TDR-NBS-HS-000001)
- Effects of seismic and thermal perturbations on rockfall are expected to be negligible
- An increase in fracture aperture of 10X or more over the entire UZ domain is necessary to affect transport results in the UZ

Acceptance Criterion 5

(Continued)

Fracture behavior under expected ambient and thermally perturbed conditions (Continued)

- In the SZ the range of uncertainty in groundwater flux encompasses the potential changes in fracture network properties that could result from thermal perturbation or tectonic processes

Acceptance Criterion 5

(Continued)

Scaling factors and geological correlations

- Basis for closure
  - Rockfall analyses incorporate appropriate scaling factors and geological correlations
  - For UZ flow and transport modeling, fracture properties are correlated with model units
  - UZ flow and transport modeling shows that:
    - Effective hydrologic properties of fractures are more important to UZ process models than measured geometric characteristics
    - Measured characteristics (aperture, orientation, spacing/frequency, length) and genetic information are not sufficient to describe parameters controlling flow

Acceptance Criterion 5
(Continued)

Scaling factors and geological correlations (Continued)

- **Basis for closure** (Continued)
  - SZ modeling of fracture permeability anisotropy uses 2 cases
    - Isotropic permeability with anisotropy ratio value of 1
    - Anisotropic permeability with anisotropy ratio value of 5
  - Anisotropic case shows more rapid transport than isotropic case and is therefore considered conservative

Acceptance Criterion 5
(Continued)

Scaling factors and geological correlations (Continued)

- **References**
  - *Analysis of Hydrologic Properties Data* AMR (ANL-NBS-HS-000002)
  - *Calibrated Properties Model* AMR (MDL-NBS-HS-000003)
  - *Fault Displacement Effects on Transport in the Unsaturated Zone* AMR (ANL-NBS-HS-000020)
  - *Uncertainty Distributions for Stochastic Parameters* AMR (ANL-NBS-MD-000011)
  - *Saturated Zone Flow and Transport Process Model Report* (TDR-WIS-MD-000002)

Acceptance Criterion 5
(Continued)

Scaling factors and geological correlations (Continued)

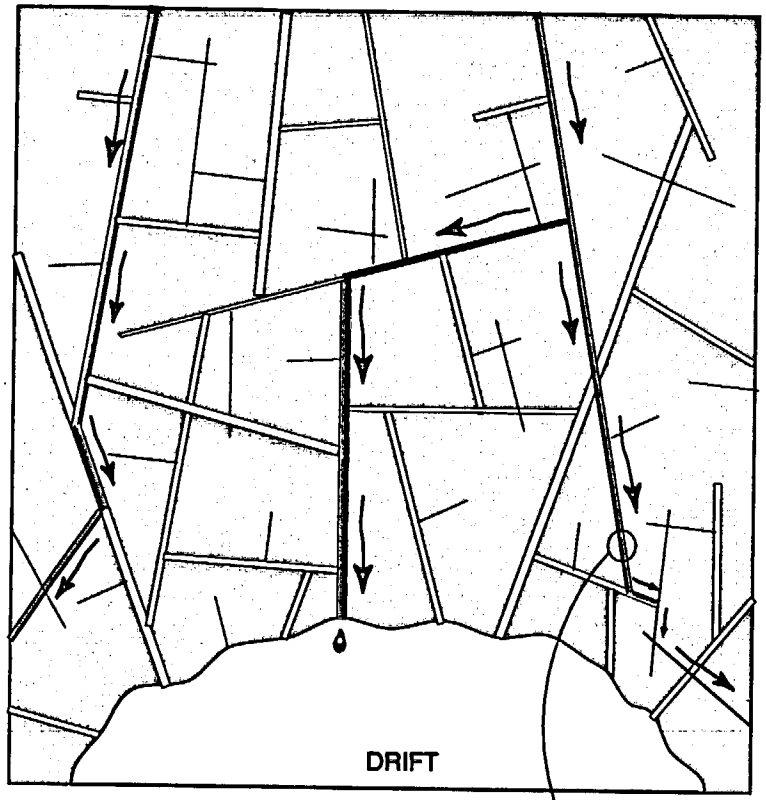
- Rockfall analyses and UZ flow and transport models incorporate appropriate scaling factors for relevant fracture parameters
- Rockfall analyses correlate fracture properties with lithostratigraphic units of the repository host horizon
- UZ flow and transport analyses correlate variations in fracture permeability with model units
- SZ flow and transport modeling contains significant uncertainty. Two cases are modeled to bound variations in horizontal anisotropy

Conclusions

- DOE believes the status of the acceptance criteria for this subissue is as follows
  - AC 1: closed
  - AC 2: closed
  - AC 3: closed
  - AC 4: closed
  - AC 5: closed

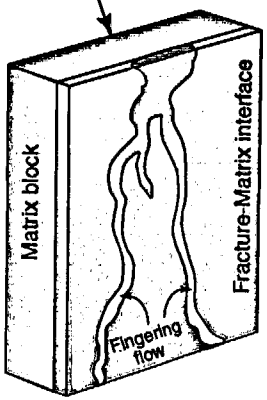
Backup

Mtn-Scale & Drift-Scale Flow under Ambient Conditions

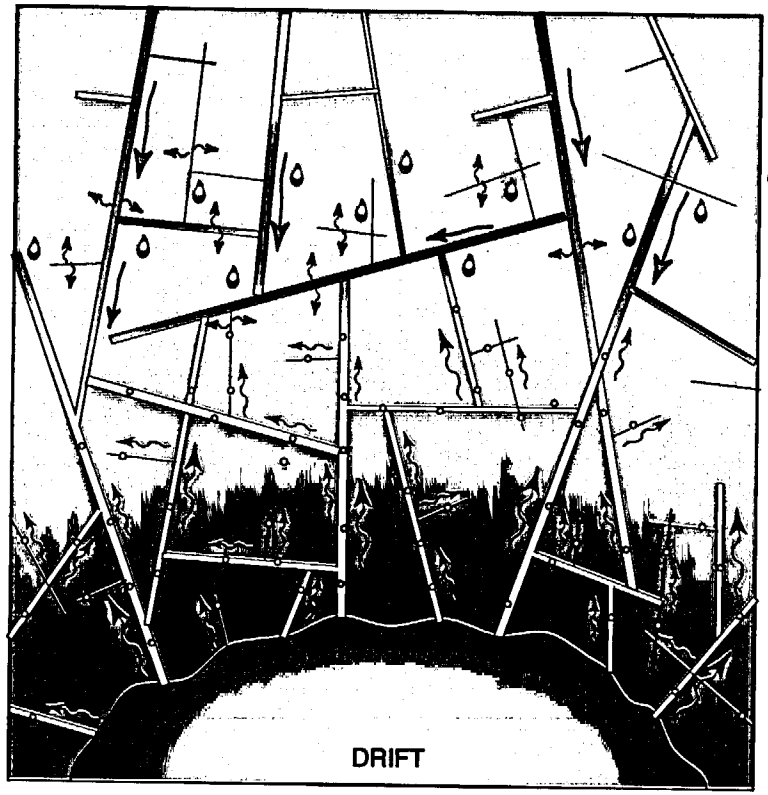


LEGEND:

- fracture flow path with direction of fracture flow
- inactive fracture
- seepage



Drift-Scale Flow under Thermal Conditions



Ambient conditions

Cooling and condensation

Flow and imbibition

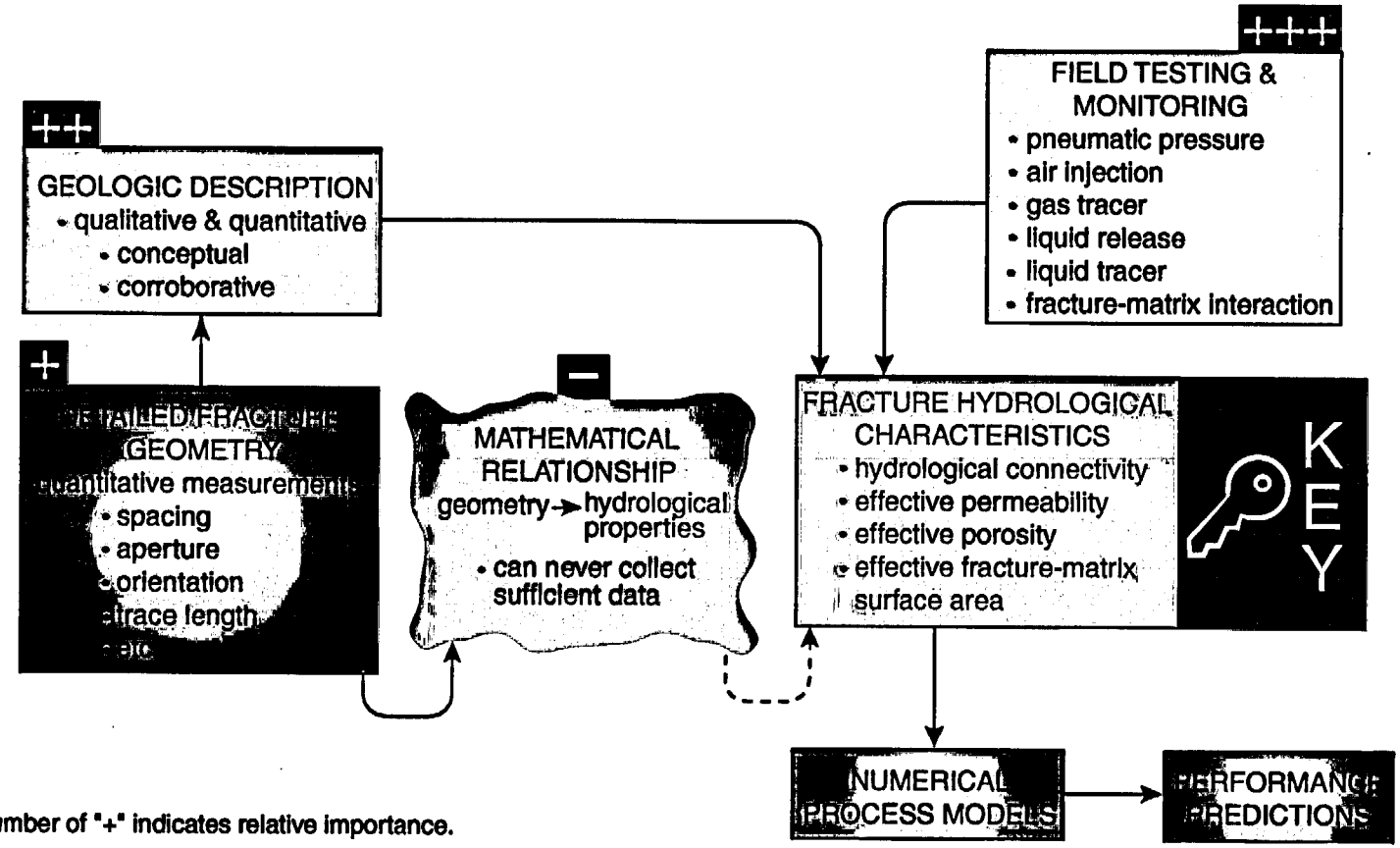
Vapor movement

LEGEND:

- fracture flow path with direction of fracture flow
- vapor flow in fractures
- inactive fracture in ambient zone
- water imbibition into rock matrix
- condensation

Use of Fracture Data in UZ Models

Fracture Data Needed for Performance Predictions



Number of "+" indicates relative importance.

Use of Fracture Data in UZ Models

(Continued)

- **Mountain-scale UZ model (for SR)**
  - Fracture data used
    - DLS data from the ESF (which provide fracture frequency, length, etc.)
    - Borehole fracture frequency
    - Air-injection testing data from surface-based boreholes (which provided estimates of fracture permeability)
    - Air-injection and gas-tracer data from the Upper Tiva Canyon, Bow Ridge fault, and Upper Paintbrush Contact Alcoves, the Single Heater Test (SHT) area, and the Drift-Scale Test (DST) area (which provide estimates of fracture permeability and porosity)

Use of Fracture Data in UZ Models

(Continued)

- **Mountain-scale UZ model (for SR)**
  - Fracture data not used:
    - Measured apertures from DLS
    - Fracture orientation data from DLS
    - Niche fracture data
    - DLS fracture data from ECRB*
    - Data from small-scale fracture mapping studies
    - Air-injection data from Tptpll in ECRB in Niche 5
    - Surface outcrop mapping

* DLS sub-1-meter length fracture data from the ECRB were not available from the TDMS during development of the UZ models for Site Recommendation. These data have since become available and will be included in the models for License Application.

Use of Fracture Data in UZ Models

(Continued)

- Mountain-scale UZ model (for SR)
  - Dual-permeability numerical grid formulation requires
    - Fracture frequency
    - Effective fracture porosity
    - Fracture-matrix interface area

Use of Fracture Data in UZ Models

(Continued)

- Mountain-scale UZ model (for SR)
  - Calibration of rock hydrological properties requires
    - Initial estimates of fracture permeability
    - Estimated fracture "hydraulic" aperture
    - Initial estimates of van Genuchten parameters (a, m)

Use of Fracture Data in UZ Models

(Continued)

- **Drift-scale models**
  - Ambient Seepage Model [AMR U0080]
  - Drift-Scale THC Model [AMR N0120/U0110]

The calibrated fracture permeability produced using mountain-scale data are not appropriate for simulation of processes at the drift scale (fracture permeability at the mountain scale is a few orders of magnitude higher than at the drift scale because of the effect of faults at a larger scale). To provide drift-scale properties, the fracture permeabilities are determined using air-injection data from boreholes (UZ PMR, Section 3.6.1.1.2; AMR U0035, Section 6.2).

Use of Fracture Data in UZ Models

(Continued)

- **Drift-scale models**
  - **Ambient Seepage Model**
    - Uses air-injection and liquid-release-test data from experiments performed in ESF niches
    - Uses calibrated drift-scale fracture permeabilities
    - No specific geometric fracture network data are used
      - » Fault-trace maps are likely to be biased because they exclude small fractures and microfractures, which may be crucial for the performance of the capillary barrier but which cannot be measured in the field. Furthermore, it is very difficult to relate the mapped geometric characteristics to the hydrological properties governing unsaturated flow and seepage. The effects of small fractures/microfractures are implicitly accounted for through the calibration against seepage data (UZ PMR, Section 3.9.3.5)

Use of Fracture Data in UZ Models

(Continued)

- **Drift-scale models**
  - **Drift-Scale THC Model**
    - Uses calibrated drift-scale fracture permeabilities
    - Air-injection-test data
    - Calculated fracture frequency, porosity, and interface area for development of dual-permeability numerical grids (same values used in the mtn-scale model)
    - Fracture mapping in the test area is used qualitatively to develop conceptual models of flow behavior and to confirm model results

Use of Fracture Data in UZ Models

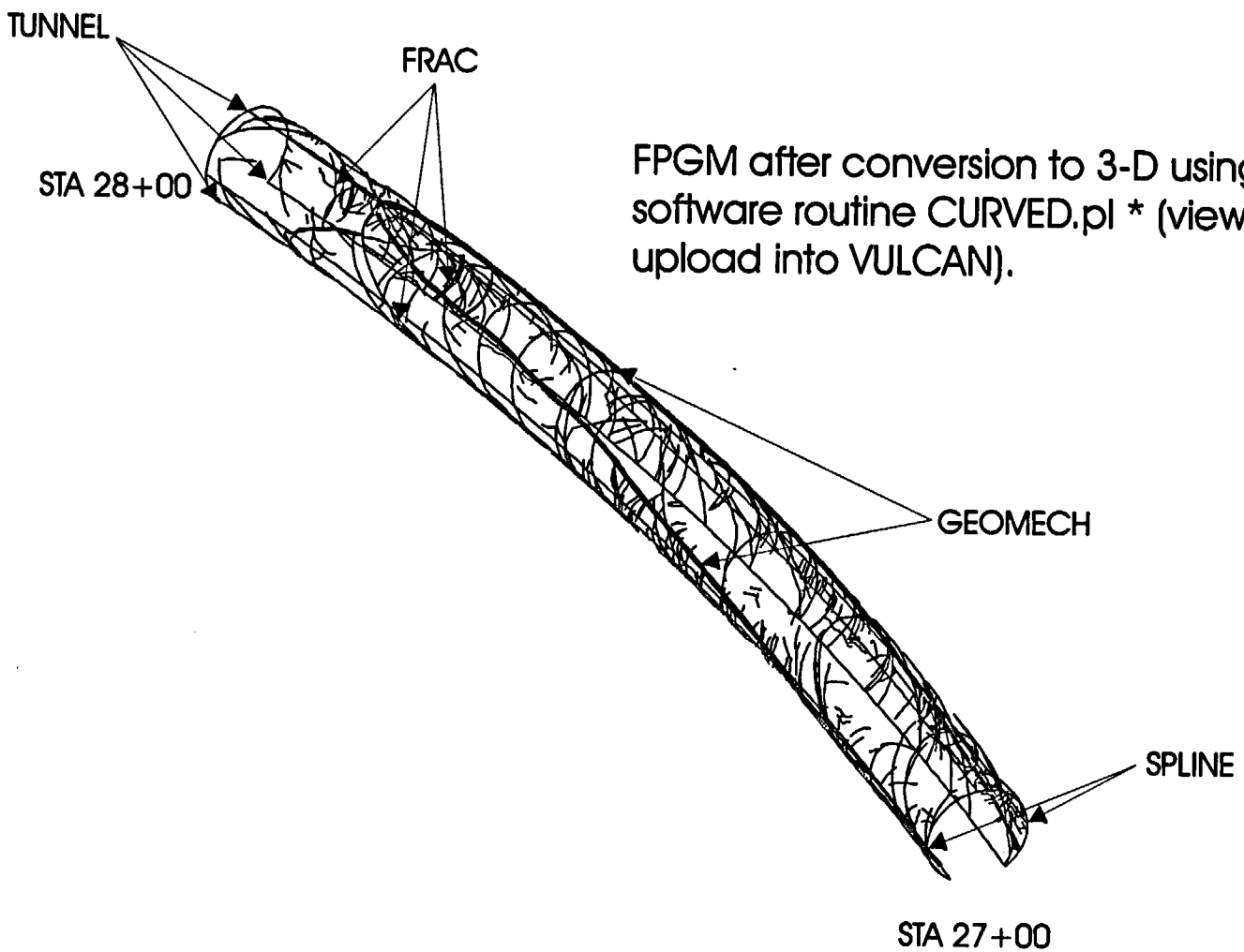
(Continued)

- **Infiltration model**
  - The Infiltration Model uses a water-balance approach to provide estimates of the net infiltration over the Yucca Mountain region for the current and future climate scenarios and is a key input to the flow and transport process models of the unsaturated zone
  - Fracture frequency data from boreholes are used to estimate permeability. Also, three aperture categories are used to obtain alternative estimates of bulk properties. Flint et al. (1996) chose 2.5, 25, and 250 micron apertures with which to calculate fracture permeability. Weighted fracture and matrix (core) permeability led to the "bulk" or equivalent estimates of permeability. Fracture permeability values based on filled, 250-micron fractures, weighted with the matrix values, were chosen because they best matched permeability estimates derived from the neutron probe data

Rockfall Analysis Input Data Sources

- Fracture data from ESF main loop and cross drift tunnel mapping (FPGM and DLS)
  - Joint set, orientation and trace length
- Rock properties from laboratory testing (NRG- 4, 6, 7, 7A, SD-9, 12)
  - Density, joint strength properties, and intact rock elastic properties
- Peak ground acceleration at the repository horizon

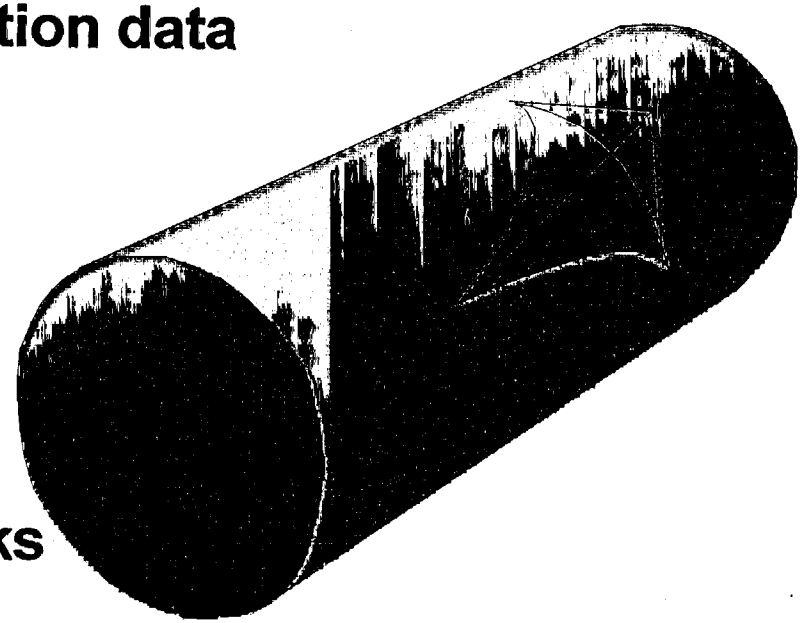
Full-Periphery Geologic Mapping (FPGM) Data from the ESF Main Loop



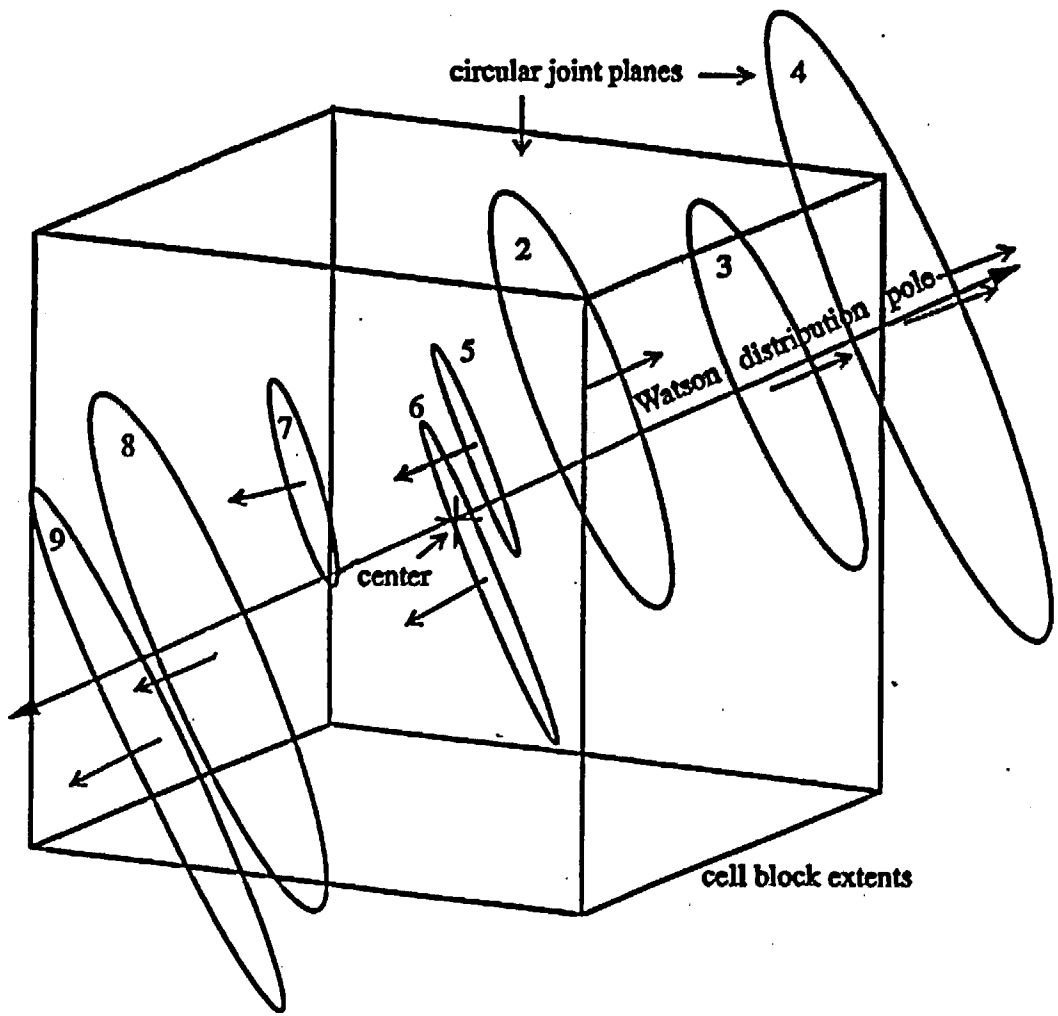
FPGM after conversion to 3-D using the software routine CURVED.pl * (viewed after upload into VULCAN).

Discrete Region Key Block Analysis (DRKBA)

- Input
  - Joint distribution and orientation data
  - Joint properties
  - Tunnel size and orientation
- Output
  - Maximum size key blocks
  - Number of potential key blocks
  - Distribution of block sizes
  - Stability of key blocks
  - Progressive block failure/final drift profile



DRKBA Joint Modeling

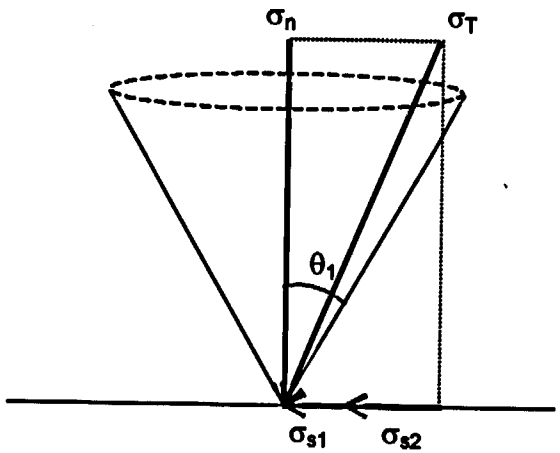


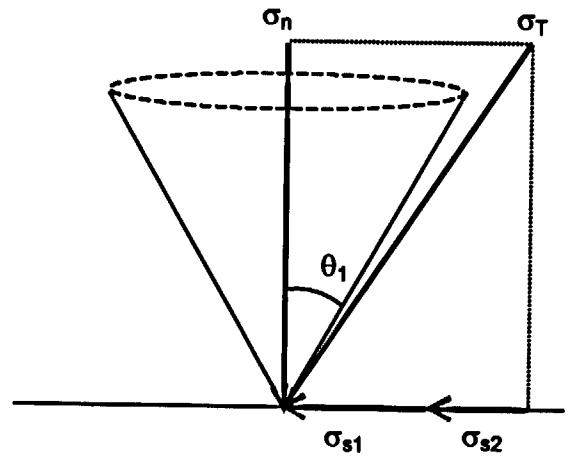
- Joint radii, spacings, and positioning are simulated with Beta distributions
- Joint orientation variability modeled using concentration factor, k
- Joint frictional properties include cohesion and friction angle

Peak Ground Accelerations for Seismic Analysis

Seismic Event	Peak Ground Acceleration (g)
Level 1 (1,000-year event, Category 1)	0.14
Level 2 (5,000-year event)	0.30
Level 3 (10,000-year event, Category 2)	0.43

Method for Simulation of Seismic Effect





σ_n = normal stress

σ_{s1} = shear stress

σ_{s2} = seismic induced shear stress

σ_T = combined stress

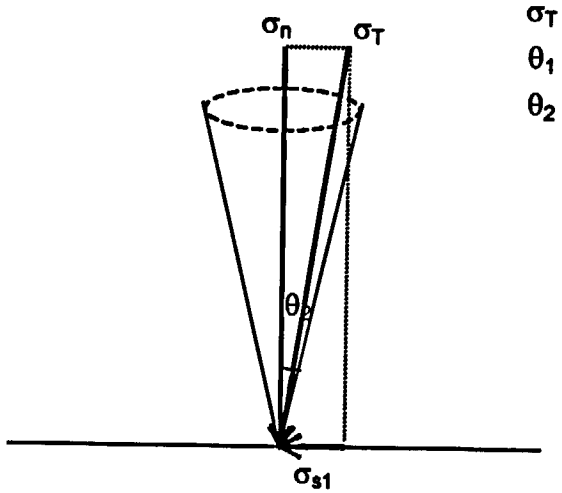
θ_1 = joint friction angle

θ_2 = reduced joint friction angle

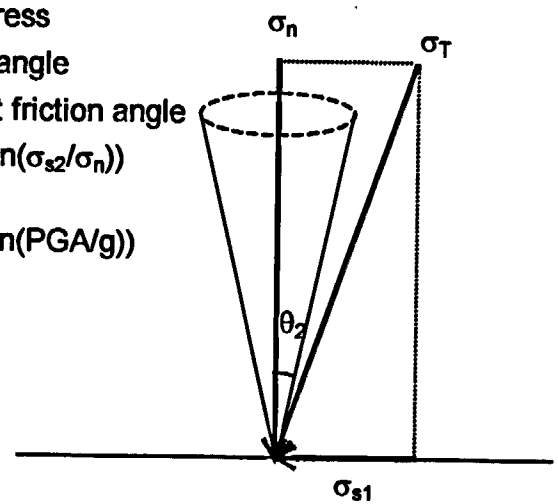
$(\theta_2 = \theta_1 - \mathrm{atan}(\sigma_{s2}/\sigma_n))$

or

$(\theta_2 = \theta_1 - \mathrm{atan}(PGA/g))$



Stable Condition



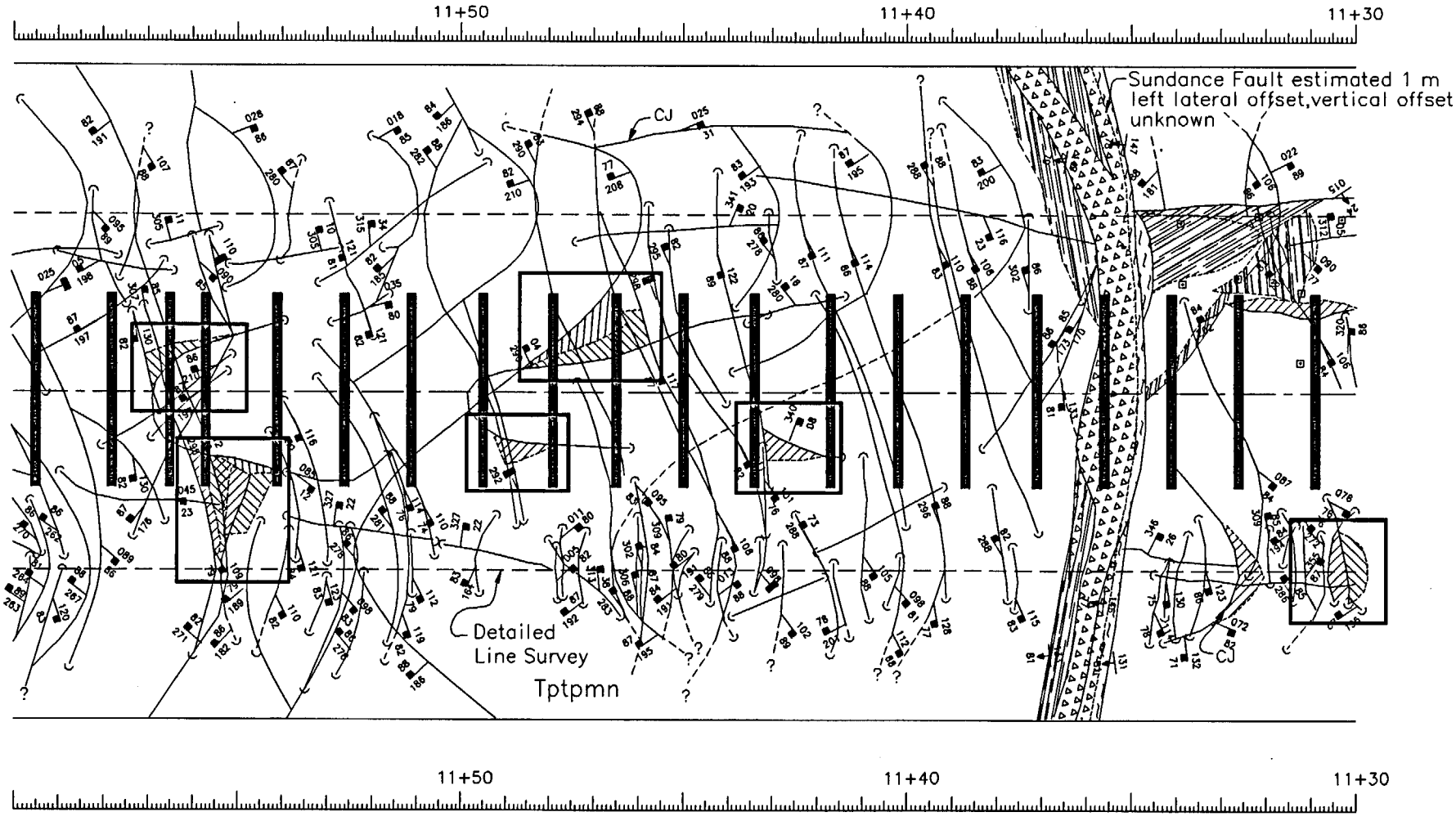
Unstable Condition

Reduced Joint Strength Parameters to Account for Seismic Effect

Loading Case	Joint Cohesion	Joint Friction Angle (degree)
Static	99,873	41
Seismic level 1	21,282	34
Seismic level 2	10,920	24
Seismic level 3	10,776	18

Key Block Location, Tptpmn Unit

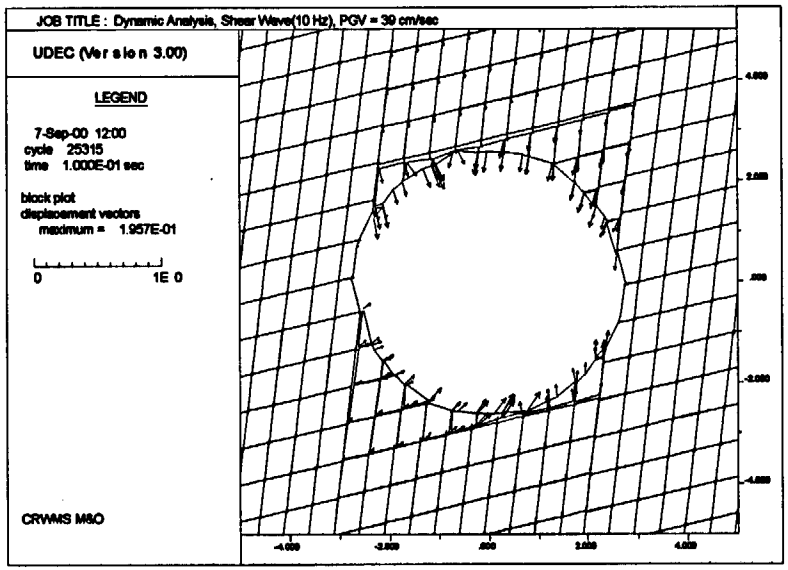
(Cross Drift Stations 11+30 to 11+60)



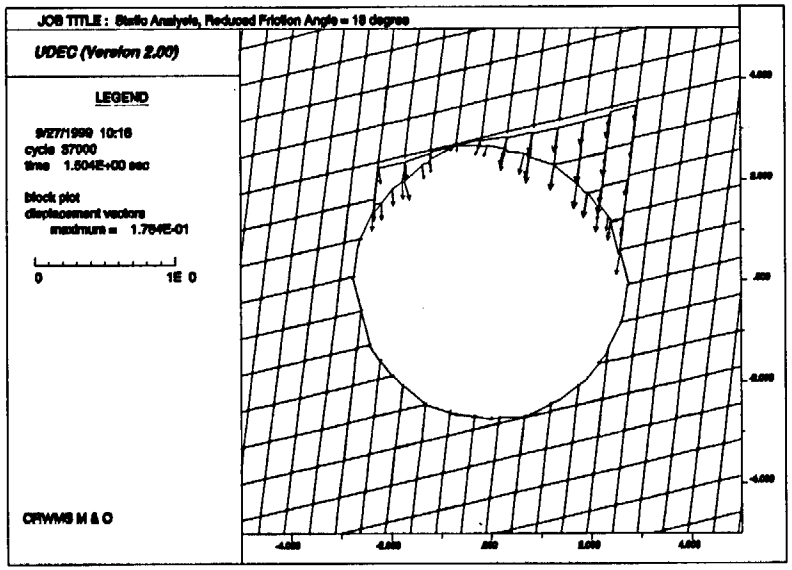
Comparison of DRKBA Rock Fall Model to Field Observations

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

Prediction of Block Movements from UDEC Analysis, Case 1

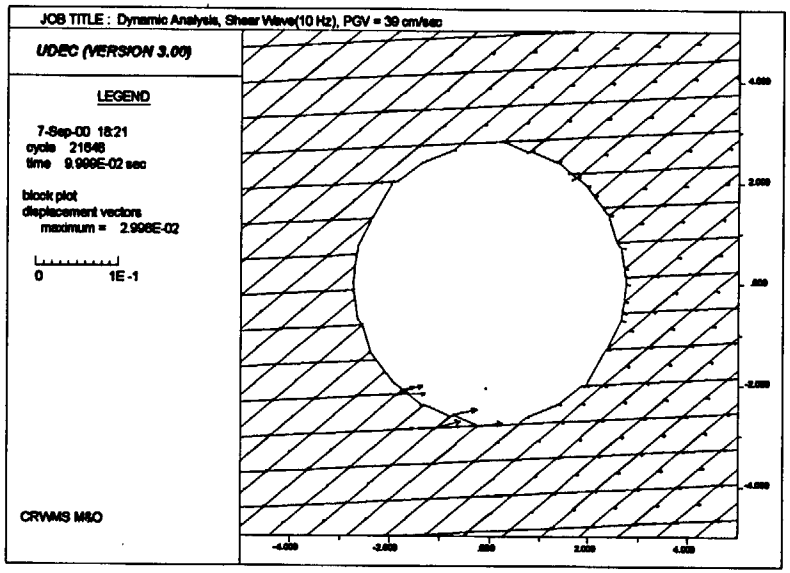


Dynamic Analysis Result

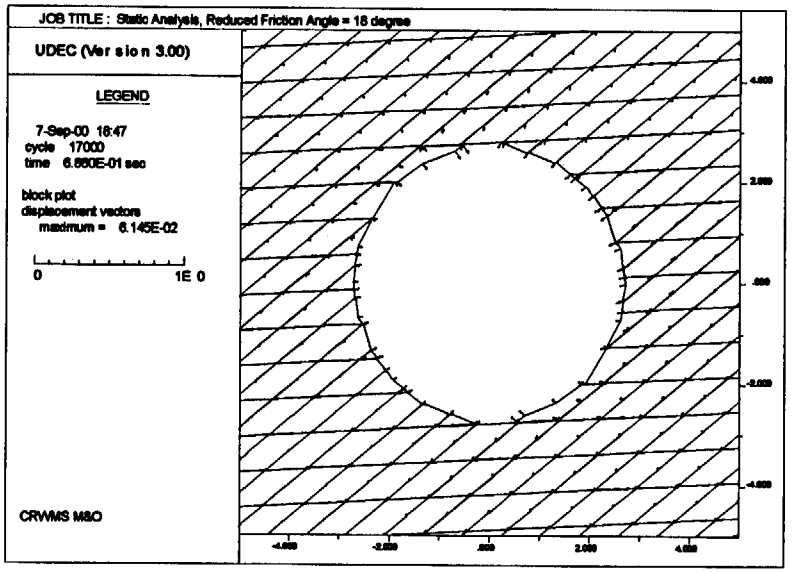


Quasi-Static Analysis Result

Prediction of Block Movements from UDEC Analysis, Case 2



Dynamic Analysis Result



Quasi-Static Analysis Result

DRKBA Rock Fall Model Validation

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

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

Review of Aeromagnetic Data

Presented to:
DOE/NRC Technical Exchange Meeting

Presented by:
John Savino
Civilian Radioactive Waste Management System
Management and Technical Services Contractor

October 11-12, 2000
Las Vegas, NV

YUCCA MOUNTAIN PROJECT

Outline

- Summarize project review of aeromagnetic data in USGS OFR 00-188
  - Summary of review activities
  - Results of review
  - References
- Conclusions

Summary of Review Activities

- Reviewed studies of buried volcanic centers in the Yucca Mountain region
  - USGS OFR 00-188 (Blakely et al 2000) aeromagnetic study of the Amargosa Valley and Crater Flat
  - Connor et al 2000 ground magnetic surveys
  - Igneous Activity IRSR, Rev. 2, July 1999
  - Magsino et al 1998

Results of Review

- Connor et al identifed possible buried centers in the Amargosa Valley and Crater Flat
- Blakely et al identified a possible additional buried center south of Lathrop Wells anomaly and resolved the three anomalies associated with the Amargosa Anomaly A
- Not clear whether the new anomaly is a separate feature or a southern extension of the main Lathrop Wells anomaly

Igneous Activity IRSR Figure 7

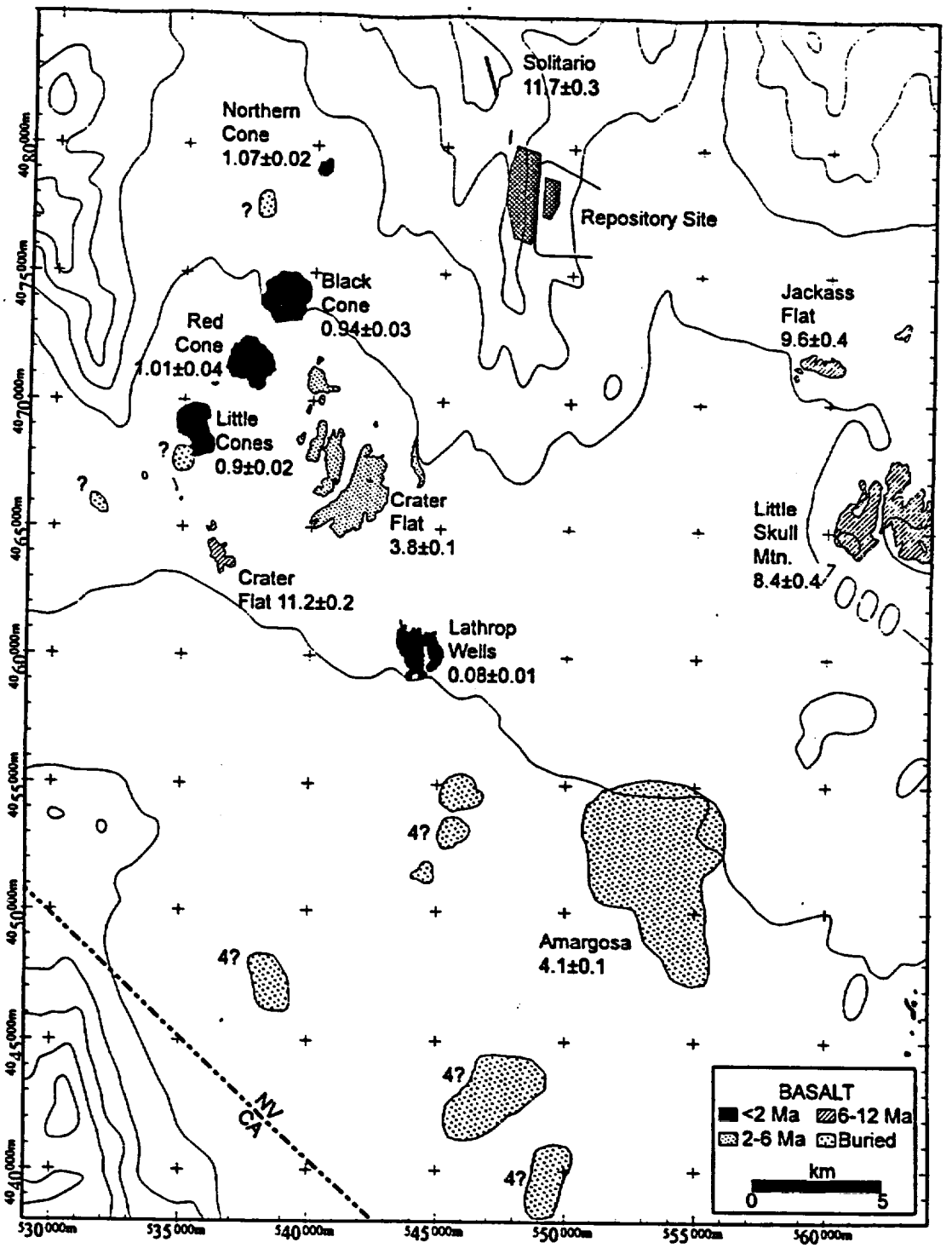
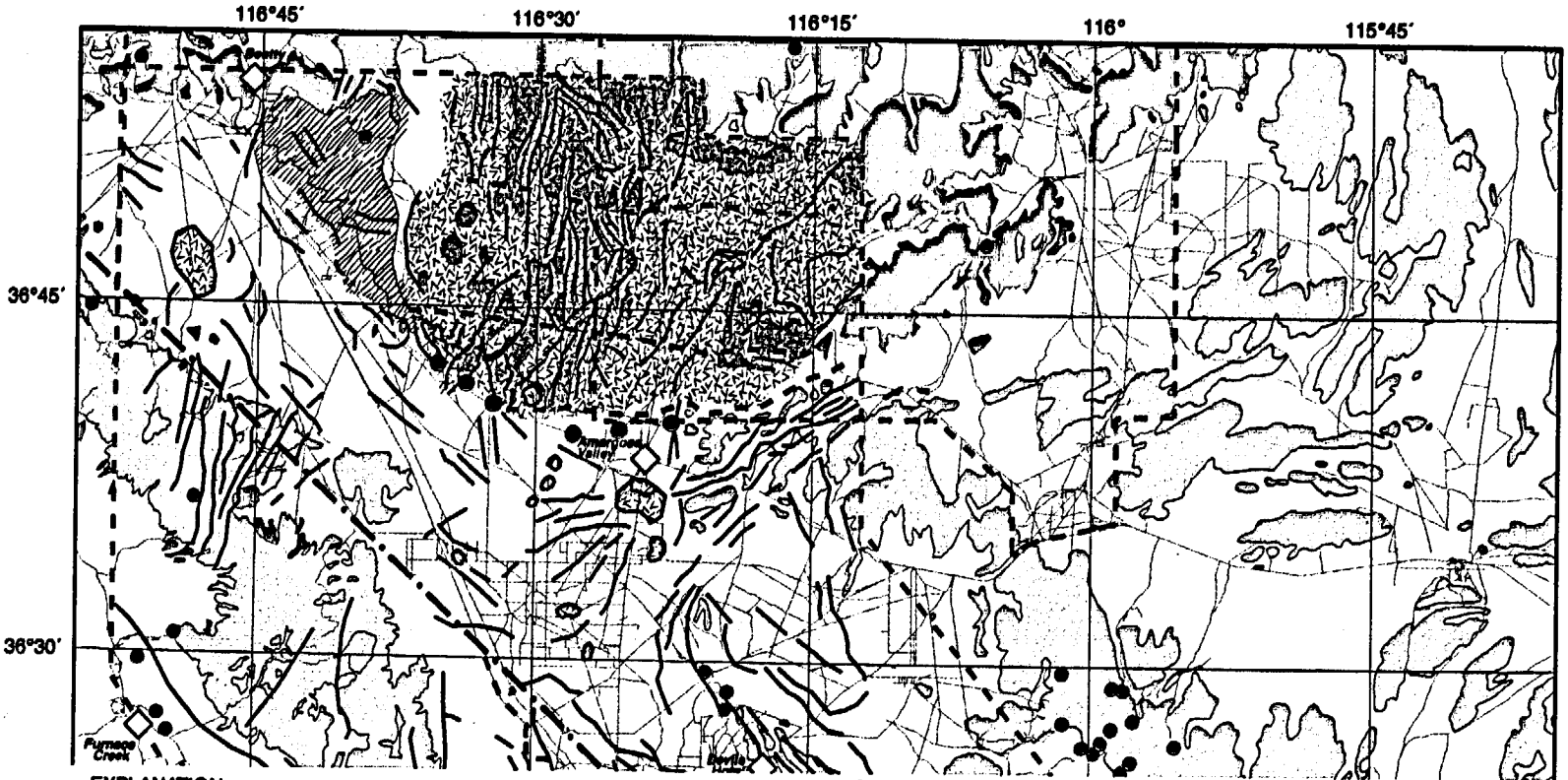


Figure 7. Basaltic volcanic rocks of the Crater Flat area, Nevada. Data sources listed in Appendix A, ages queried when uncertain or unknown. Extent of buried anomalies interpreted from magnetic data in Langenheim, et al. (1993), Connor, et al. (1997), and Magsino, et al. (1998).

Blakely et al 2000 Plate 2



Scale 1:250,000

EXPLANATION

- Quaternary sedimentary deposits
- Tertiary and Quaternary volcanic rocks
- Cenozoic granitic rocks
- Pre-Cenozoic rocks
- Interpreted Tertiary and Quaternary volcanic rocks
- Interpreted deep Precambrian rocks
- Interpreted magnetic lineation
- Spring
- Early Warning Drill Site
- Road
- Political boundary
- Boundary of aeromagnetic survey

Plate 2.—This map describes an interpretation of aeromagnetic data from the Amargosa Desert and surrounding areas. It emphasizes (1) magnetic lineations that in some cases may reflect shallow faults and (2) magnetic lithologies in the shallow subsurface. Refer to text and figures of report for information about individual interpretations. Geologic information generalized from statewide compilations of California (Jennings, 1977) and Nevada (Stewart and Carlson, 1978). Springs are from 1:250,000-scale U.S. Geological Survey topographic maps.

References

- Blakely et al 2000, U. S. Geological Survey Open File Report 00-188, TIC 248767
- Connor et al 2000, Journal of Geophysical Research, V. 105, No. 1, p. 417-432, TIC 247906
- Magsino et al 1998, CNWRA 98-001, TIC 247807

Conclusion

- Expect to confirm observations in late October pending discussions with a principal investigator on the resolution capabilities of the aeromagnetic survey discussed in Blakely et al

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.

Importance to System Performance: Characteristics of existing faults are included in the TSPA. Faulting effects on flow in the UZ are addressed through the use of a dual-permeability flow mode. Faulting effects on flow in the SZ are addressed through the use of flowing intervals and consideration of existing fault zones. The approach for flow in the SZ includes consideration of uncertainties about the flow interval properties and locations. The relocation of flowing intervals in the SZ within each unit does not effect the contaminant flux at the 20 km boundary.

The probability of creation of new faults in intact rock is negligible as demonstrated in the PSHA. Changes in the hydraulic properties of existing faults are expected to be of low consequence as demonstrated by the analysis presented in Fault Displacement Effects on Transport in the Unsaturated Zone. Therefore, the effects of displacements on existing faults or changes in properties of the existing faults will not significantly affect radionuclide transport, and dose will be negligibly impacted. This portion of faulting considerations is therefore excluded from the TSPA based on low consequence to dose.

Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient geological and geophysical data are acquired to adequately support conceptual models of faulting, attendant assumptions, and boundary conditions and to define relevant parameters implemented in process level models and TSPA calculations of the direct disruption of WPs from faulting.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: CLOSED Staff reviewed the data, conceptual models, and assumptions developed by the DOE in the PSHA and find that the DOE has adequately evaluated the nature and amount of faulting and the appropriate range of both principal and secondary faulting hazard sources within the repository block. Staff concludes that the DOE has adequately determined fault geometry applicable to development of the PFDHA. Staff concludes that the DOE's interpretations of faulting from surficial and underground mapping as presented in the DOE PSHA (U.S. Geological Survey, 1998) are geologically consistent and reasonable. Some fault data taken by the DOE from surface outcrops and from the ESF have been confirmed by independent checks by the NRC staff.	DOE believes this criterion is closed. As part of site characterization activities at Yucca Mountain, DOE has studied regional and site faults with known and suspected Quaternary activity. Geologic studies have ranged from reconnaissance surveys to excavation and detailed mapping of multiple trenches across faults (e.g., Whitney 1996). Geophysical studies have ranged from regional seismic and potential field surveys to high-resolution surveys across faults in the immediate vicinity of Yucca Mountain (e.g., Majer et al. 1996). These data, as well as results obtained by non-YMP investigators, were made available to teams of experts who participated in the expert elicitation underlying the Probabilistic Fault Displacement Hazard Analysis (PFDHA) (Wong and Stepp, 1998; summarized in CRWMS M&O 2000a). As part of the PFDHA, the experts evaluated the sufficiency of available data and incorporated appropriate uncertainties into their interpretations of faulting. The expert elicitation process ensured	No additional work required.

(NRC 1999, Section 5.1.1)	that data were considered and that interpretations forming the basis of the PFDHA results (including uncertainties) were developed consistent with the available data. PFDHA results are subsequently used to examine the consequences of faulting on the Engineered Barrier System (EBS) and on transport in the unsaturated zone, and are used in evaluating features, events, and processes for inclusion in Total System Performance Assessment (TSPA).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to develop process, TSPA, or both models of faulting are technically defendable and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 2 is resolved, based on preliminary sensitivity studies documented in Revision 1 [of the IRSR]. Additional sensitivity studies and ancillary detailed analysis of AC2 will be produced in Revision 3. (NRC 1999, Section 5.1.1)	DOE believes this criterion is CLOSED-PENDING. The expert elicitation process underlying the PFDHA provides technically defendable faulting models that incorporate uncertainties and variabilities consistent with the available data. Experts defined and weighted alternative interpretations allowed by the data and documented the technical basis for interpretations in expert elicitation summaries (Wong and Stepp, 1998, Section 4.3.2 and Appendix E). This work is summarized in the seismic framework AMR (CRWMS M&O 2000a). An analysis to examine the consequences of fault displacement on the EBS assumes fault displacement ranges from 0.1 to 100 cm (CRWMS M&O 2000e, Section 5). For locations away from mapped faults, fault displacement of 100 cm is greater than the probabilistic fault displacement hazard with an annual frequency of exceedance of 10^{-8}. An analysis of the effects of fault displacement on transport in the unsaturated zone considered bounding changes in fracture aperture (factors of 0.2 and 10) and examined a case in which the resultant changes in fracture properties were uniformly distributed and one in which they were localized to the vicinity of a fault (CRWMS M&O 2000d, Section 6.2.1.5, Section 6.2.1). Thus uncertainties and variabilities have been accounted for in faulting-related studies.	Complete ICN 1 to Disruptive Events (DE) Features, Events, and Processes (FEPs) analysis and model report (AMR).

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for faulting are investigated, consistent with available data and current scientific understanding. Results and limitations are appropriately considered in the development of the probabilistic fault displacement hazard models and included in abstractions for process level and TSPA subsystem models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING Staff conclude that criterion 3 is resolved, based on preliminary sensitivity studies documented in Revision 1. Additional sensitivity studies and application of the RM and ancillary detailed analysis of acceptance criterion 3 will be produced in Revision 3. The DOE has not developed a PA-level process model for faulting. The DOE contends that faulting in the repository has a probability less than 10^{-8}/yr and therefore any potential consequences do not need to be evaluated. Staff's analysis indicates a probability of recurrence of 5.0×10^{-6}, which warrants consideration in a PA (Revision 1). Staff needs to review the DOE's FEP analysis, PMRs and AMRs when available. (NRC 1999, Section 5.1.1)	DOE believes this criterion is CLOSED-PENDING. Experts involved in the Probabilistic Fault Displacement Hazard Analysis incorporated multiple models of fault displacement into their interpretations consistent with available data and current scientific understanding (Wong and Stepp, 1998, Section 4.3.2 and Appendix E). These interpretations form the basis for the PFDHA results used in subsequent analyses and abstractions (CRWMS M&O 2000b, 2000d, 2000e). The subsequent analyses have, therefore, appropriately considered fault model uncertainty. Analyses addressing effects of faulting on the EBS and on transport in the unsaturated zone (CRWMS M&O 2000d, 2000e) used PFDHA results that incorporated model uncertainty to bound fault displacement and fault-displacement-related parameters that were considered. PFDHA results incorporating model uncertainty were also used to evaluate faulting related features, events, and processes for inclusion in or exclusion from the TSPA (CRWMS M&O 2000b, Sections 6.2.3 and 6.2.4). An analysis to examine the consequences of fault displacement on the EBS assumes fault displacement ranges from 0.1 to 100 cm (CRWMS M&O 2000e, Section 5). For locations away from mapped faults, fault displacement of 100 cm is greater than the probabilistic fault displacement hazard with an annual frequency of exceedance of 10^{-8}. The staff's analysis of faulting recurrence is apparently different than the DOE's PFDHA analysis. The staff's probability value of 5.0×10^{-6} is based on a recurrence interval for faulting of about 200,000 years. However, the PFDHA calculated the probability of exceedance of specified levels of fault displacement rather than a simple recurrence rate. Fault displacement has been considered and excluded from the TSPA-SR calculations of expected annual dose on	Complete ICN 1 to DE FEPs AMR.

	the basis of low probability of displacement on new faults and low consequence of displacement on existing faults (CRWMS M&O 2000b, p. 39-41). DOEs Disruptive Events FEPs AMR and disruptive events PMR have been provided for staff review.	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for faulting are investigated, consistent with available data and current scientific understanding. Results and limitations are appropriately considered in the development of the probabilistic fault displacement hazard models and included in abstractions for process level and TSPA subsystem models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
NRC Expectation: Two new Faulting Subissue items were identified by the NRC for review during the KTI Technical Exchange in April 2000 and identified the status of this subissue as Closed - Pending. 1. Analyses showing rationales for faults/faulting that are included and excluded from consideration in performance assessments (FEPs AMR). 2. Analyses showing how DOE abstracted and used faulting hazard estimates in performance assessments. (NRC Presentation, April 2000)	DOE believes this concern is resolved. Analyses describing the rationales for including/excluding faulting from performance assessment are included in the FEPs AMR (CRWMS M&O 2000b, Section 6.2.3). Fault displacement has been excluded from the TSPA-SR calculations of expected annual dose on the basis of low probability of displacement on new faults and low consequence of displacement on existing faults (CRWMS M&O 2000b, p. 39-41).	Complete ICN 1 to DE FEPs AMR

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 4: Model Verification - Results of PFDHA, TSPA, or both subsystem models are verified by comparison to output from detailed process models, empirical observations, or both.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING Staff conclude that criterion 4 is resolved, based on preliminary sensitivity studies documented in Revision 1. Additional sensitivity studies and application of the RM and ancillary detailed analysis of AC3 will be produced in Revision 3. The DOE has not developed a PA-level process model for faulting. The DOE contends that faulting in the repository has a probability less than 10-8/yr and therefore any potential consequences do not need to be evaluated. Staff's analysis indicates a probability of recurrence of 5.0 x 10-6, which warrants consideration in a PA (Revision 1). Staff needs to review the DOE's FEP analysis, PMRs and AMRs when available. (NRC 1999, Section 5.1.1)	DOE believes this criterion is CLOSED-PENDING. The frequency of future surface faulting for representative features and conditions was determined through a Probabilistic Fault Displacement Hazard Analysis that employed an expert elicitation process to develop interpretations used as the basis for the analysis. Experts considered various fault displacement models, consistent with available data, in preparing their interpretations. These models relied primarily on empirical observations of fault displacement at Yucca Mountain and elsewhere in the Great Basin (Wong and Stepp 1998, Section 4.3.2 and Appendix E; CRWMS M&O 2000a). Since the models are developed and applied as part of an expert elicitation process, the expert elicitation process itself ensures that the experts consider available data and viable models, and document the technical basis for their interpretations. The experts' evaluations and weights on viable models constitute model verification. The sensitivity of fault displacement hazard to various interpretations is described in the seismic framework AMR (CRWMS M&O 2000a, Section 6.2.4). A design approach to avoid Type I faults (CRWMS M&O 1998), along with the small values of fault displacement likely at locations away from principal faults (for annual frequencies of exceedance of 10^{-8}) (CRWMS M&O 2000a) and the low consequences of any such fault displacement on emplacement drifts (CRWMS M&O 2000e) and transport in the unsaturated zone (CRWMS M&O 2000d) form the basis for FEPs evaluations of faulting (CRWMS M&O 2000b). Fault displacement has been excluded from the TSPA-SR calculations of expected annual dose on the basis of low probability of displacement on new faults and low consequence of displacement on existing faults.	Complete ICN 1 to DE FEPs AMR.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 5: Integration - Incorporation of faulting models and parameters into TSPA models adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstraction process..		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING Staff conclude that criterion 5 is resolved, based on preliminary sensitivity studies documented in Revision 1. Additional sensitivity studies and application of the review methods (RM) and ancillary detailed analysis of AC3 will be produced in Revision 3. The DOE has not developed a PA-level process model for faulting. The DOE contends that faulting in the repository has a probability less than 10-8/yr and therefore any potential consequences do not need to be evaluated. Staff's analysis indicates a probability of recurrence of 5.0 x 10-6, which warrants consideration in a PA (Revision 1). Staff needs to review the DOE FEPs analysis, PMRs and AMRs when available. (NRC 1999, Section 5.1.1)	DOE believes this criterion is CLOSED-PENDING. The PSHA (CRMWS M&O 1998) and seismic framework AMR (CRMWS M&O 2000a) discuss faulting models and parameters. Two AMRs, Fault Displacement Effects on Transport in the Unsaturated Zone (CRWMS M&O 2000d) and Fault Displacement Effects on Emplacement Drifts (CRWMS M&O 2000e), describe the effects of fault displacement on specified components of the engineered and natural barriers as discussed in Sections 3.2.2 and 3.2.3 of the Disruptive Events PMR (CRWMS M&O 2000c). Fault displacement has been excluded from the TSPA-SR calculations of expected annual dose on the basis of low probability of displacement on new faults and low consequence of displacement on existing faults (CRWMS M&O 2000b, p. 39-41).	Complete ICN 1 to DE FEPs AMR.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 6: Quality Assurance - The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures, or it the data, models and computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 6 is open. The QA of data, models, and codes is a generic procedure that applies to each of the subissues in this IRSR. The DOE's qualification of data, models, and codes used to support its positions is an ongoing process. The fact that data, models, and codes have not been qualified, but continue to be used as technical bases for design and PAs, has the potential to adversely impact the reliability of design bases and PAs. Therefore, the staff reviews will not be completed until the DOE's qualification program is completed. (NRC 1999, Section 5.1.1)	DOE believes this criterion is CLOSED-PENDING. Requirements for quality-affecting activities associated with collection, documentation, and development of data, models, and computer codes are addressed in DOE's quality assurance program (DOE 2000) and implementing procedures. Since June 30, 1999, such activities have been performed in accordance with these requirements. For activities performed prior to June 1999, DOE has well-documented conditions adverse to quality related to these activities. These conditions adverse to quality have been addressed in accordance with the corrective action process. Action has been taken to assure that pre-June 1999 data, models, and computer codes related to information important to the repository safety case were reviewed and updated to assure their integrity as specified by the related corrective action. More than 90% of the DE PMR/AMRs data and software required to support LA are qualified.	All data, models, and codes important to safety and isolation will be qualified by LA submittal.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 1: Faulting.		
Acceptance Criterion (AC) 7: Expert Elicitation - Formal expert elicitations can be used to support data synthesis and model development for the DOE's process, TSPA, or both models provided that the elicitations are conducted and documented under acceptable procedures (e.g., NUREG-1563, Kotra, et al., 1996).		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 7 is resolved. The results of the DOE's PSHA expert elicitation included information and analyses that contributed to the resolution of three subissues in this IRSR: faulting, seismicity, and tectonic framework of the geologic setting. Staff have no further questions regarding the use of expert elicitation at this point in time. (NRC 1999, Section 5.1.1)	DOE believes this criterion is closed. DOE conducted expert elicitation in compliance with the NRC approved QARD (DOE 2000) and in substantial accordance with the NRC NUREG 1563 (NRC 1996).	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity

Importance to System Performance: Yucca Mountain is located in a seismically activity part of the Basin and Range geographic province. Seismic activity or vibratory ground motion is likely in the Yucca Mountain region, and such activity could affect the postclosure performance of various components of the natural and engineered barrier systems. Potential effects include induced changes in porosity and permeability of rocks at the site, changes in potentiometric levels, increases in size and frequency of rockfalls, and damage to waste packages and contents from ground shaking.

Seismic activity as it relates to fault displacement is more fully addressed under Subissue 1 and, based on the results of the PSHA, has been excluded from the TSPA based on low consequence to dose.

Changes in groundwater flow caused by seismic activity are more fully addressed in the Primary FEP Hydrologic Response to Seismic Activity (1.2.10.01.00), which is excluded from the TSPA based on low consequence to dose (CRWMS M&O 2000b, Table 3). The hydrologic response to seismic activity is either transitory or is of insufficient magnitude to affect repository performance (CRWMS M&O 2000b, Section 6.2.15).

Changes in stress conditions (including those caused by seismicity) are addressed in three Primary FEPs: Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock (2.2.06.01.00), Change in stress (due to thermal, seismic, or tectonic effects) produce changes in permeability of faults (2.2.06.02.00), and Changes in stress (due to seismic or tectonic effects) alter perched water zones (2.2.06.03.00). All are excluded from the TSPA based on low consequence to dose. The analysis justifying the exclusion is provided in the AMR, Fault Displacement Effects on Transport in the Unsaturated Zone. The analysis showed that changes in fracture aperture had minimal impact on UZ flow characteristics.

Seismic effects on drift integrity have been considered as part of the Primary FEPs Rockfall (2.1.07.01.00) and Mechanical degradation or collapse of drift (2.1.07.02.00) and have been excluded based on low consequence to dose. Seismic activity does not significantly increase the frequency or size of rock falls. This analysis is provided in the Drift Degradation Analysis and was analyzed for preclosure requirements for ground motion annual probabilities of 1E-3, 1E-4, and 1E-5.

Seismic activity can also directly affect components of the EBS and waste packages through vibratory motion. This is more fully addressed in the Primary FEP Seismic Vibration Causes Container Failure (1.2.03.02.00), and with the exception of fuel-rod cladding damage had been excluded (TBV) based on low consequence to dose (CRWMS M&O 2000b, Section 6.2.6).

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient geological and geophysical data are acquired to adequately define seismic sources, relevant earthquake and GM parameters, recurrence relationships, and GM attenuation functions, and to support attendant assumptions and conceptual models implemented in the PSHA.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 1 is resolved based on review of the DOE PSHA (U.S. Geological Survey, 1998). The seismic sources identified by the experts in the PSHA adequately characterize the potential sources of seismicity that will contribute to the anticipated peak and spectral ground motions (GMs) at YM resulting from future earthquakes in the YM region. (NRC 1999, Section 5.2.1) At the April 2000 technical exchange, NRC indicated this subissue and criterion is CLOSED – Pending. NRC requires Seismic Topical Report 3.	DOE believes this criterion is CLOSED-PENDING. As part of site characterization activities at Yucca Mountain, DOE has studied regional and local seismicity and the generation and attenuation of ground motion (e.g., CRWMS M&O 2000h, Sections 12.3.3 through 12.3.6 and 12.3.9). These data, as well as results obtained by non-YMP investigators, were made available to teams of experts who participated in the expert elicitation underlying the Probabilistic Seismic Hazard Analysis (PSHA) (Wong and Stepp 1998, summarized in CRWMS M&O 2000a). As part of the PSHA, the experts evaluated the sufficiency of available data and incorporated appropriate uncertainties into their interpretations of seismic sources and ground motion attenuation. The expert elicitation process ensured that data were considered and that interpretations forming the basis of the PSHA results (including uncertainties) were developed consistent with the available data. PSHA results are subsequently used to examine the effects of ground motion on drift stability, on the performance of EBS components, and are used in evaluating features, events, and processes for inclusion in TSPA (CRWMS M&0 2000b). Data collection, analysis, and interpretation of seismic design information is ongoing to support development of the seismic design inputs report. The results of these activities will be reported to the NRC in Seismic Topical Report 3.	DOE will complete data collection, analyses, and interpretations necessary to develop the final preclosure seismic design values. The results will be reported to NRC in Seismic Topical Report 3.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to determine seismicity parameters are technically defensible and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING Although staff preliminary review of the PSHA found that data uncertainty and variability are accounted for and that parameter values, probability distributions, and bounding assumptions are technically defendable, staff still have not performed the detailed analyses to verify the results. For example, staff review, as well as sensitivity studies in the PSHA, note that seismic hazard is sensitive to uncertainties associated with recurrence rates and the attenuation model. Detailed assessment of the uncertainties associated with the PSHA results hinges on acquisition of the seismic data. (NRC 1999, Section 5.2.1) At the April 2000 technical exchange, NRC indicated this subissue and criterion is CLOSED – Pending. NRC requires Seismic Topical Report 3, data used in PSHA for use in performing NRC analyses, and analyses from DOE showing how seismic hazard estimates were abstracted and used in PA.	DOE believes this criterion is CLOSED-PENDING. The expert elicitation process underlying the Probabilistic Seismic Hazard Analysis (PSHA) provides technically defendable seismic source and ground motion evaluations that incorporate uncertainties and variabilities consistent with the available data. Experts defined and weighted alternative interpretations allowed by the data and documented the technical basis for interpretations in expert elicitation summaries (Wong and Stepp, 1998, Sections 4.3.1, 5.6, 5.7, 6 and Appendices E and F). This work is summarized in the seismic framework AMR (CRWMS M&O 2000a). Subsequent analyses using the PSHA results, therefore, also appropriately incorporate uncertainties and variabilities relative to ground motion and seismic sources. Data collection, analysis, and interpretation of seismic design information is ongoing to support development of the seismic design inputs report. The results of these activities will be reported to the NRC in Seismic Topical Report 3. Computer files representing the expert's interpretations and intermediate and final PSHA results have been provided to the NRC to facilitate their review of how uncertainties and variabilities were treated in the PSHA. The experts' evaluations and weights on viable models constitute model verification and uncertainty assessments based on data and knowledge uncertainty. Discussions of how the data were abstracted and used for performance assessment will be provided in the TSPA-SR document. Use of data in TSPA-SR is determined by FEPs screening as described in the DE FEPs AMR (CRWMS M&O	DOE will complete data collection, analyses, and interpretations necessary to develop the final preclosure seismic design values. The results will be reported to NRC in Seismic Topical Report 3. DOE will provide documentation in TSPA-SR describing how DOE abstracted and used seismic hazard estimates in performance assessment analyses of seismically-induced cladding failure. Complete ICN 1 to DE FEPs AMR

	2000b, Sections 6.2.5 to 6.2.7, and Table 3). The TSPA-SR includes assessment of seismically induced cladding failure (CRWMS M&O 1999a). The DE FEPs AMR provides documentation of the basis for excluding other effects of seismicity from the performance assessment (see CRWMS M&O 2000b Table 3 for summary).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for the seismicity model, such as recurrence relationships or GM attenuation relationships, are investigated. Results and limitations are considered in the development of the PSHA and included in the abstractions to TSPA subsystem models, consistent with available data and current scientific understanding of seismicity.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING Although staff preliminary review of the PSHA found that alternative modeling approaches were investigated by the DOE and results of the alternatives were considered by the experts in the PSHA, staff still have not performed the detailed analyses to verity these results. (NRC 1999, Section 5.2.1) At the April 2000 technical exchange, NRC indicated that this subissue and associated criterion is CLOSED-Pending. NRC requires Seismic Topical Report 3, data used in PSHA for use in performing NRC analyses, and analyses from DOE showing how seismic hazard estimates were abstracted and used in performance assessments. (NRC Presentation, April 2000)	DOE believes this criterion is CLOSED-PENDING. Computer files representing the expert's interpretations and intermediate and final PSHA results have been provided to the NRC to facilitate their review of how uncertainties and variabilities were treated in the PSHA. Data collection, analysis, and interpretation of seismic design information is ongoing to support development of the seismic design inputs report. The results of these activities will be reported to the NRC in Seismic Topical Report 3. Discussions of how data are abstracted and used in performance assessment are described in the TSPA-SR document. Use of data in TSPA-SR is determined by FEPs screening as described in the DE FEPs AMR (CRWMS M&O 2000b, Sections 6.2.5 to 6.2.7). The TSPA-SR includes assessment of seismically induced cladding failure (CRWMS M&O 1999a). The DE FEPs AMR provides documentation of the basis for excluding other effects of seismicity from the performance assessment (see CRWMS M&O 2000b Table 3 for summary).	The NRC staff has linked closure of this acceptance criterion to review of Seismic Topical Report 3. DOE will complete data collection, analyses, and interpretations necessary to develop the final preclosure seismic design values. The results will be reported to NRC in Seismic Topical Report 3. DOE will provide documentation in TSPA-SR describing how DOE abstracted and used seismic hazard estimates in performance assessment analyses of seismically-induced cladding failure. Complete ICN 1 to DE FEPs AMR

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 4: Model Verification - Results of PSHA, TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observation, or both.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED-PENDING In the IRSR, Rev 2, Staff conclude that criterion 4 is open. Detailed assessment of the model verification hinges on acquisition of the seismic data. The staff reserve judgment on model verification until the DOE data and reports are available for review and analysis. (NRC 1999, Section 5.2.1) Subsequently, at the April 2000 technical exchange, the staff indicated that this subissue is CLOSED-Pending. NRC requires Seismic Topical Report 3 and data used in PSHA for use in performing NRC analyses.	DOE believes this criterion is CLOSED-PENDING. Alternative seismic source, earthquake recurrence, and ground motion attenuation models considered by the experts during the elicitation process are described in Wong and Stepp 1998, Section 4.0. Since the models are developed and applied as part of an expert elicitation process, the expert elicitation process itself ensures that the experts consider available data and viable models, and document the technical basis for their interpretations. Data collection, analysis, and interpretation of seismic design information is ongoing to support development of the seismic design inputs report. The results of these activities will be reported to the NRC in Seismic Topical Report 3. Computer files representing the experts' interpretations and intermediate and final PSHA results have been provided to the NRC to facilitate their evaluation of how uncertainties and variabilities were treated in the PSHA.	DOE will complete data collection, analyses, and interpretations necessary to develop the final preclosure seismic design values. The results will be reported to NRC in Seismic Topical Report 3.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 5: Integration - Incorporation of seismicity models and parameters into PSHA, TSPA, or both adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstractions process.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN In the DOE's TSPA-VA, rockfall and seismicity were considered as a coupled disruptive event, but not included in the basecase. Moreover, only the probability of earthquakes was extracted from the PSHA, not the associated vibratory ground motion (i.e., rockfall was linked to earthquake size, not anticipated GMs at YM). In planning for its next iteration of TSPA, the DOE indicated that seismicity will be included in the basecase and GMs from the seismic hazard curve will be sampled directly. In a recent Nuclear Waste Technical Review Board meeting, DOE indicated that backfill and a drip shield will be part of the repository design. The DOE suggested that these changes in the design are likely to reduce or eliminate the significance of seismically induced rockfall as a disruptive scenario. The DOE will need to quantitatively document its contention. Also, the direct effect of GM on the stability of intact WPs on pedestals, or on the contents of the WPs such as fuel rods in racks, will need to be addressed quantitatively (CLST IRSR). (NRC 1999, Section 5.2.1)	DOE believes this criterion is CLOSED-PENDING. Potential effects on the engineered and natural barrier systems from vibratory ground motion and rockfall (from all sources, including seismicity) has been examined through the FEPs screening process (CRWMS M&O 2000b, Sections 6.2.5 through 6.2.7), and has been excluded from the TSPA-SR calculation of expected annual dose on the basis of low consequence. Failure of CSNF cladding due to vibratory ground motion is an exception, and has been included in the TSPA-SR based on a calculation of the annual probability of cladding failure due to vibratory ground motion (CRWMS M&O 1999a). The calculation indicates that theprobability of fuel-rod breakage is 1.1×10^{-6}/yr. TSPA-SR therefore includes perforation of all cladding in the repository as a sampled event in the nominal scenario, occurring with an annual probability of 1.1×10^{-6}/yr. Note that the TSPA model does not sample on the seismic hazard curve directly. GM damage to the waste package was screened out of the TSPA as noted above. The seismic rockfall analyses in the Drift Degradation Analysis (CRWMS M&O 2000i) were conducted without backfill. Seismic loading without backfill was shown to have minimal effects on rockfall development (CRWMS M&O 2000i, Section 7.1) (see additional discussion under Subissue 3: Fracturing, Acceptance Criterion 2).	Complete ICN 1 to DE FEPs AMR.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 6: Quality Assurance. The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures, or it the data, models and computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 6 is open. This criterion is being addressed the same way in each subissue. See the discussion above in Faulting subissue. (NRC 1999, Section 5.2.1)	DOE believes this criterion is CLOSED-PENDING. Requirements for quality-affecting activities associated with collection, documentation, and development of data, models, and computer codes are addressed in DOE's quality assurance program (DOE 2000) and implementing procedures. Since June 30, 1999, such activities have been performed in accordance with these requirements. For activities performed prior to June 1999, DOE has well-documented conditions adverse to quality related to these activities. These conditions adverse to quality have been addressed in accordance with the corrective action process. Action has been taken to assure that pre-June 1999 data, models, and computer codes related to information important to the repository safety case were reviewed and updated to assure their integrity as specified by the related corrective action. More than 90% of the DE PMR/AMRs data and software required to support LA are qualified.	All data, models, and codes important to safety and isolation will be qualified by LA submittal.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 2: Seismicity		
Acceptance Criterion (AC) 7: Expert Elicitation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 7 is resolved. This criterion is resolved in the same way for the subissues Faulting and Tectonic Framework of the Geologic Setting. (NRC 1999, Section 5.2.1)	DOE believes this criterion is closed. DOE conducted expert elicitation in compliance with the NRC approved QARD (DOE 2000) and in substantial accordance with the NRC NUREG 1563 (NRC 1996).	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing

Importance to System Performance: Existing fracture characteristics are included in the TSPA for both the UZ and the SZ. The UZ addresses existing fracture characteristics through the use of a dual-permability model. The SZ flow model addresses existing fractures through the use of flowing intervals, which are a subset of water-conducting features within the fracture system. The SZ flow model explicitly models numerous fault and fracture zones to account for major features, while features not explicitly represented in the site scale model are implicitly included through the consideration of horizontal anisotropy in permeability within the fractured volcanic units (CRWMS M&O 2000s, Section 4.2.2.1). Both the UZ and SZ flow models include fractures and uncertainty in the hydraulic and transport properties of the fracture system.

The effects of changes to the fracture system due to geologic effects on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach (Fault Displacement Effects on Transport in the Unsaturated Zone ANL-NBS-HS-000020). This analysis includes two bounding assumptions: (1) the change in fracture properties occurs over the entire UZ domain (fault zones and fractured rock), or (2) that the effect of fault displacement is limited to fracture aperture changes in the fault zones. The analysis has been done using a dual-permeability model, and is based on the changing of fracture apertures. Given a change in fracture aperture, other fracture hydraulic properties (permeability, capillary pressure, and porosity) can be estimated through the use of theoretical models. (CRWMS M&O 2000f) indicated that transport times were not sensitive to changes in the fracture aperture. The results of the analysis are currently being reanalyzed using a dual-permeability active fracture flow model, to determine the effect of active fractures on transport time and flux. The results of the analysis are currently being reanalyzed using a dual-permeability active fracture flow model, to determine the effect of active fractures on transport time and flux.

The potential for the formation of new fractures has been considered, and the DE FEPs AMR (CRWMS M&O 2000b, Section 6.2.2) notes that strain is more likely to affect existing features than to create new fractures, as evidenced by field observation of reactivation features and the geologic history of Yucca Mountain.

Because of the existing consideration of uncertainty in fracture properties; the insensitivity of groundwater flow to changes in fracture aperture , and the low probability of the formation of new fractures; changes in fracture properties are not likely to significantly alter the rate of flow, significantly alter the fracture characteristics, or otherwise alter the groundwater flux through the repository. Since flow conditions are not significantly impacted, there is no hydrologic parameter related to the fracture FEP that would significantly impact dose. Changes to fractures are therefore excluded from the TSPA based on low consequence to dose (CRWMS M&O 2000b, Section 6.2.2).

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 1 may not be met. Staff review of fracture data and fracture data summaries indicates that the DOE's characterization of the 3-dimensional (3D) variability of fracture characteristics and distributions abstracted in process level and PA models may not be adequate. The following observations support the conclusion: (1) fracture aperture distribution is underconstrained, (2) fracture connectivity across stratal boundaries is underconstrained, (3) fracture characterization in key stratigraphic units in the UZ is inadequate, (4) fracture orientation (strike and dip) and lengths are not corrected for sampling bias, (5) role of fracture dynamics is underemphasized, and (6) boundary conditions of numerical abstractions of fracture data and fracture models under ambient and thermally perturbed conditions have not been presented. (NRC 1999, Section 5.3.1)	DOE believes this criterion is CLOSED. DOE believes that sufficient fracture data have been acquired to adequately support the models and assumptions used in analyses. See responses below to each of the identified NRC concerns in the IRSR associated with this acceptance criterion. Note: NRC item 6 is actually addressed by the NRC in the IRSR under acceptance criterion 2 for this subissue rather than under acceptance criterion 1.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fracture Aperture Distribution Aperture is a critical factor in numerical models of infiltration, flow, and transport at all scales of interest and in models of rockfall at drift scale under both ambient and thermally perturbed conditions. Single aperture measurements are available for fractures in ESF data sets, but aperture distribution and variability along fractures are generally unconstrained. Aperture largely controls the type flow in fractures (e.g., sheet or rivulet flow on a single fracture, flow induced by local filling of the aperture by capillary forces, or locally saturated flow down the fracture). (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. DOE disagrees that physical aperture data is a critical factor in flow models. As described in the AMR, Analysis of Hydrologic Properties Data (CRWMS M&O 2000f, Section6.1.3), apertures that are important for UZ modeling are hydraulic apertures, which may be very different from geometric apertures. In the UZ flow model apertures information is derived from pneumatic fracture permeability measurements and fracture frequency information from fracture mapping data. This data, plus the cubic law for fracture permeability, have been used to define an average hydraulic aperture. Average apertures are defined for each model unit. Aperture variability within model units is treated through the relative permeability and capillary pressure functions (CRWMS M&O 2000f, p. 38-39). A more critical parameter than fracture aperture is fracture volume (porosity), which has been measured through the use of gas tracer tests (UZ PMR section 2.5.2.3, p. 64 and section 3.6.1.2, p. 129) Preliminary information from Project UZ flow modelers indicates that the fracture apertures that are important for UZ flow modeling are <200 microns. Fracture apertures of this size are too small to be measured in the field, and aperture measurements that can be made in the field are not used in hydrologic modeling. Therefore, fracture aperture data is not used directly in the UZ flow models. Fracture aperture is not a critical factor for rockfall, and was not considered in the rockfall analyses in the Drift Degradation Analysis (CRWMS M&O 2000i). Assumptions about joint parameters used in rockfall analysis, such as fracture geometry and the fracture frictional properties that contribute to rockfall, are identified in the	No additional work required.

	Drift Degradation Analysis AMR (CRWMS M&O 2000i, Section 6.3).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fracture Connectivity Across Stratal Boundaries Steeply-dipping or near-vertical fractures that cut through rock layers and intersect other steeply-dipping fractures are a critical factor in models of infiltration, percolation flux, migration of heated fluids outward from emplacement drifts, refluxing through rock pillars, and rockfall analyses. The connectivity concept has been investigated by air permeability and heater tests and by association of faults and fractures with bomb-induced 36Cl in the ESF. Near-vertical connectivity of fractures across stratal boundaries has been observed in the field, ESF, and ECRB. However, this connectivity has not been investigated systematically and a database of connectivity for purposes of model abstraction is lacking. For example, cross sections of YM at drift or site scale show principal faults clearly and consistently located, but generally no two cross sections depict fracture connections clearly and consistently. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. Development of a fracture connectivity data base is not considered necessary to confirm the UZ model. Fracture connectivity information is augmented by other data that demonstrate effective connectivity. Flow models consider 100% connectivity by assuming that all fracture flow paths are fully connected, i.e., no dead ends. (CRWMS M&O 2000g, Section 6.4). This conclusion is supported by observations of construction water in Niche 3 that originated from the construction of Alcove 8, which directly overlies Niche 3. The TSw1/TSw2 stratal boundary lies between these excavations. Features which could be interpreted to indicate reduced connectivity, such as increased saturations at unit boundaries consistent with ponding, have not been observed in excavations or boreholes (Flint 1998, pg 28, 30). Fracture continuity within the TCw and TSw units is also supported by the lack of significant attenuation of pneumatic signals (CRWMS M&O 2000m, pp. 40-41; also, Rousseau et al 1999, pp. 89-93, 96-97). Geologic cross sections do not generally depict the locations or connections of fractures because the scale necessary to portray the cross section does not allow sufficient resolution to show individual fractures. Cross-sections that accompany full-periphery maps, however, do show individual fractures and accurately depict fracture abutting relationships. The rockfall analyses in the AMR, Drift Degradation Analysis (CRWMS M&O 2000I, Section 4.1), consider the joint trace length from field mapping data to model the extent of the fracture planes (see additional discussion under Subissue 3: Fracturing, Acceptance Criterion 4). Multiple fracture planes may contribute to the	No additional work required.

	formation of one rock block. The connectivity, or intersections of the fracture planes, is considered in the rockfall analyses within stratal boundaries. Since the fracture geometry varies according to lithostratigraphic unit, rockfall data were determined for each lithostratigraphic unit to accurately characterize potential rock block development within each unit. Therefore, it was not necessary to consider fracture connectivity across stratal boundaries in the rockfall analyses.	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fracture Characterization in Key Stratigraphic Units in the Unsaturated Zone About 75 percent of the WPs are planned to be emplaced in the lower lithophysal zone (Tptpll) of the crystal poor Topopah Spring Tuff and the rest in the middle nonlithophysal zone (Tptpmn) and the lower nonlithophysal zone (Tptpln). More than 90 percent of the fracture data available comes from the middle nonlithophysal zone. The heater tests, which include investigation of the behavior of fractures under expected thermal loads, are conducted in the middle nonlithophysal zone. Data available to constrain the fracture network in the non-welded units above (PTtn) and below the repository (Calico Hills Formation) are few (DOE, 1998b), as are similar data for welded tuff s below the repository. This dearth of data imparts uncertainty in infiltration, UZ, and near-field flow and transport modeling. (NRC 1999, Section 5.3.1)	The UZ model now considers fracture data from the entire ESF, the ECRB, boreholes, and surveys of surface exposures and outcrops (CRWMS M&O 2000f, Section 4.0). ECRB fracture frequency data were not directly used because data between 30 cm and 1m was not available. However, the model is considered conservative because it assumes a lower fracture frequency in the lower lithophysal zone compared to the middle nonlithophysal zone (CRWMS M&O 2000f, Table 6). As discussed in the AMR, Particle Tracking Model and Abstraction of Transport Processes (CRWMS M&O 2000t, Section 6.2.1), higher fracture frequency leads to better performance with respect to radionuclide transport, therefore, the lower frequency is conservative. The bulk of the heater testing has been in the middle nonlithophysal zone. However, testing in the lower lithophysal zone has been impeded by access considerations. Flow testing in the lower lithophysal zone has shown behavior significantly different from that in the middle nonlithophysal zone. DOE expects that the thermal performance would also be different. The initial phases of testing flow properties in the lower lithophysal zone is underway. Characteristics from the testing would be used to assess the impact and modify the UZ flow models as appropriate. Limited data are available for the Calico Hills Formation. Where possible, fracture data from similar units in SZ (Prow Pass Tuff) are used in the UZ flow model. Due to limited data below the repository, the UZ model conservatively assumes significant lateral flow in perched water bodies into faults leading to poorer-than-expected performance (CRWMS M&O 2000f). Pneumatic data from sensors in instrumented boreholes show that	No additional work required.

	the attenuation of the pneumatic signals within the Topopah Spring welded unit are directly related to the thickness of the overlying PTn (Ahlers et al 1999, pg 59).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fracture Orientation and Length Biases The abundance of fractures that intersect the ESF DLS at small angles is under-represented in the DLS fracture surveys: this is known as the directional sampling bias. Raw data, uncorrected for this bias, were used to develop permeability tensors for the UZ site scale model (Chapter 7 of Bodvarsson, et al, 1997). Several correction methods exist but were not used. Also, fractures that are long with respect to the sample area (e.g., a pavement) or of greater length than the diameter of the ESF, are under represented in the database. This sampling bias, known as the truncation bias, limits the accuracy of fracture models. Fracture length is important for groundwater flow models because large (long) fractures are often principal conduits for flow. Another sampling bias was introduced in the DOE fracture database- known as the censorship bias, fractures below a prescribed threshold 1 m-length were not sampled through most of the ESF mapping. The numerous fractures thus omitted from investigations have some significance to models of seepage, rockfall, and fracture flow where total fracture permeability or fracture network connectivity is needed. This bias is being corrected by additional fracture mapping of selected DLS intervals, specifically small-length fractures. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. The work to produce a fracture orientation database derived from fracture strike and dip measurements mapped on the USGS/USBR Full Periphery Geotechnical Mapping (FPGMs) of the ESF and registered to the 3-dimensional Nevada State plane coordinate system has been completed. Since the FPGMs, and thus the derived database, represent sampling of a three-dimensional volume, the question of directional bias associated with a 2-dimensional detail line survey is by definition not applicable. The database for this work currently consists of 30,559 individual records (Full Periphery Geologic Map Strike and Dip Correction Analysis, p. 7 and Section 7.5). An AMR (CRWMS M&O 2000p) describes joint set orientations based on an expanded database (includes FPGM data from the ECRB-Cross Drift). This expanded database consists of approximately 35,000 fracture measurements. The fracture AMR uses stereographic projection techniques to determine the orientation of major joint sets within the lithostratigraphic units of the Repository Host Horizon (Tptpul, Tptpmn, Tptpll, and Tptpln). Again the volume-based fracture data are, by definition, unbiased. Hence, the discussions of directional and length censorship biases in, and corrections to, fracture data are no longer relevant topics. DOE disagrees with the statement that fracture length is important for UZ flow models. Fracture length data were used to establish the geometric fracture/matrix contact area for the UZ flow model (CRWMS M&O 2000f, Section 6.1.2.2). However, the model is calibrated by matrix saturation and capillary pressure data that adjusts the amount of fracture/matrix flow exchange. This calibration employs the active fracture model parameter. This parameter effectively adjusts the fracture/matrix interface area to	No additional work required.

	give the appropriate amount of fracture/matrix flow exchange such that the model matches the known saturation and capillary pressure data (CRWMS M&O 2000m, Section 6.1.1). Therefore, the model is ultimately not very sensitive to fracture length. Fracture orientation is not used in the UZ flow or transport models because flow is assumed to be dominantly vertical. DOE disagrees that the fracture database has been significantly misrepresented due to truncation bias. Truncation bias at the tunnel diameter occurs only when fractures are normal to the tunnel, and when the fracture length is greater than the tunnel diameter. DOE recognizes that fractures may only be partially sampled at any given tunnel location, but the sample is of sufficient size to adequately represent the diameters of the fracture population.	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient field, borehole, and underground excavation data are acquired to adequately support conceptual models, assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fracture Dynamics Several aspects of fractures are not observable, but if they were derived, would be useful in assessing, interpolating, or extrapolating such fracture attributes as distribution, spacing, and orientation. These attributes reflect the history of fracture dynamics which is an inherent part of viable tectonic models: (1) the sequence of fracturing of the different sets of fractures; (2) the orientation of the regional stress field at the time of formation of the various fracture sets; and (3) the presence of locally active faults that produce, are producing, or will produce fracture networks not predictable from knowledge of the regional stress field. The first is correlated with the origin of fractures, whereby cooling joints are generally long, and later tectonic joints are shorter. The spacing of joints is associated with the sequence of propagation. The second could explain the orientation of regional joint sets and joint frequency in certain directions. The third could explain or predict anomalous local joint sets and identify fractures subject to displacement that might meet the DOE's criteria for avoidance or setback. Failure to consider these dynamic factors has led to an inability to predict key aspects of the joint network such as abundant NE- and NW-trending cooling joints in the Tiva Canyon Tuff and the unexpected W-NW-trending abundant fractures in the Topopah Spring Tuff along the main drift of the ESF. Given that the repository will be sited in rocks that will not be sampled directly for fracture networks until	DOE believes this concern is resolved. The benefits of implementing the investigation(s) suggested in the NRC position are not clear. Process models and PA abstractions need only information about present and reasonably likely future characteristics; information about how those characteristics developed is not necessary. That is, the models need information about what the characteristics will be. Information about how the characteristics developed is not needed. DOE does not believe that explanations of the development history of fracture characteristics are necessary to include fracture characteristics in process models or TSPA abstractions. Information about the development history would address only how the fractures developed, and as indicated above, this information is not needed by the process models. Further, the basis for the NRC's interest in the orientation of the stress field at the time of fracturing and in fracture patterns in the Tiva Canyon Tuff is not clear. None of the TSPA models considers the orientation of the regional stress field at the time of fracturing. While acknowledging that the intensely fractured zone (IFZ) encountered in the main drift was not expected, DOE doubts that a better understanding of locally active faults would have led to a prediction of the presence of the IFZ. Further, underground work has not revealed the presence of substantial amounts of young appearing fractures, and DOE notes that development of new fractures will not have significant effect on the UZ hydrologic model (CRWMS M&O 2000b, Section 6.2.2). The current 3-D UZ model uses uniform properties for a given layer that have been calibrated to	No additional work required.

repository construction, the capability to predict the most likely fracture trends and abundances may be useful before construction. (NRC 1999, Section 5.3.1)	borehole data. Therefore, the model parameters are sufficiently flexible to account for variations in fracture characteristics. For LA, likely fracture trends can be adequately predicted from the existing 3-D fracture database (CRWMS M&O 2000p). Additionally, subsurface fracture characteristics in the repository host horizon would be assessed during the construction and performance confirmation period.	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilites.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 2 may not be met. Staff review of fracture data and fracture data summaries indicates that the DOE has not adequately constrained ranges of fracture parameter values or distributions of fractures of various characteristics may need to be better constrained, or demonstrated that certain assumptions are bounding assumptions under both ambient and perturbed conditions. The following observations support the conclusion: (1) downward-convergent connected fracture networks (flow paths) are unconstrained, (2) excavation-induced fractures are underconstrained, (3) fault- and fracture-zone properties are underconstrained, (4) assessment of origin of fractures is inadequate, and (5) assessment of future modifications of fractures is inadequate.	DOE believes this criterion is CLOSED. DOE believes that the parameter values, ranges, probability distributions, and assumptions used in analyses and models are technically defensible and reasonably account for uncertainty and variability. See responses below to each of the identified issues.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilites.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Downward-convergent Connected Fracture Networks (flow paths) Bomb-pulse 36Cl in ESF faults and fractures is evidence for spatially heterogeneous groundwater flow in the UZ. However, the fracture network characteristics that cause the heterogeneities remain unexplained. The utility of UZ flow models may be greatly improved when the most-likely-to-flow-fractures or fracture systems can be identified within reason. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. The UZ flow and transport model assumes heterogeneous flow and includes matrix flow and fracture flow components (CRWMS M&O 2000g, Section 6). Heterogeneity is captured in the model through the hydrogeologic parameter sets that describe each of 32 model units, the dual permeability description of fracture and matrix flow within each model unit, and by the explicit incorporation of fault features. Bomb pulse 36Cl has generally been found near faults in the ESF and is believed to be a result of fast pathways along the faults. Explicit inclusion of faults in the model captures this aspect.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Excavation-Induced Fractures Excavation-induced fracturing and skin-effects are observed in the ESF and ECRB. The causes include mechanical stresses induced by the Tunnel Boring Machine disk-cutters, rock-drilling, and blasting, hydrothermochemical stresses induced by changing moisture content, and skin temperatures due to ventilation, and in situ stress relaxation due to creation of the drift-openings. Such increases in fracture intensity and decreases in fracture spacing around underground openings, albeit from small excavation-induced fractures, need to be assessed for their potential influence on flow and rockfall models. This is particularly the case for drift-scale modeling, such as for seepage and stability of underground openings. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. Mapping of the ESF and ECRB have not revealed significant amounts of excavation-induced fracturing from the tunneling machines in the rock expected to host the proposed repository (Tptpmn, Tptpll, and Tptpln). Observations in the ESF and ECRB have not found the randomly-oriented fractures that would be expected as excavation-induced effects. Some excavation-induced fracturing has been observed in the upper lithophysal zone of the Topopah Spring Tuff (Tptpul) in both the ESF and the ECRB, but this rock is not expected to host the proposed repository. Underground observations indicate that there has been no significant amount of stress -induced fracturing in the underground in the repository host rocks.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Fault and Fracture Zone Properties Staff review of descriptions of past modifications of fractures and ongoing field and laboratory analyses of mineral and rock fragment in-filling of fractures and faults indicates that the DOE has not fully used the existing data on fracture modifications to constrain fault and fracture properties that are abstracted into flow and transport models. The staff considers that insights into potential future use of fractures and faults by groundwater, including refluxing water, can be derived from analyses of evidence from analogous past events. Such data may be needed to help constrain the parameters, assumed ranges of values (such as potential fracture and fault zone permeability), probability distributions, and bounding assumptions of perturbed conditions that are abstracted into process and PA models (ENFE, RDTME, USFIC, and RT IRSRs). (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. DOE does not believe that an explanation of the development history of fracture characteristics is necessary to include fracture characteristics in process models or TSPA abstractions. Process models and TSPA abstractions use only the present characteristics and do not consider the past modifications to fractures. DOE believes it has adequately characterized fractures to support the development of process models and abstractions for TSPA and therefore does not view the work described as necessary or clearly linked to repository performance. The presence of fracture coatings has been noted, however, their effect on flow can not be quantified. Fault and fracture properties (e.g., permeability and fracture-matrix interaction) are obtained through measurements and calibration. The proportion of observed fractures mineralized are consistent with the active fracture model (Liu et al 1998, pg 2641). Sensitivity studies based on simple estimates to bound changes to fracture properties have been found to be adequate to analyze the potential effects of changes in fracture properties on UZ flow and transport. (CRWMS M&O 2000d, Section 6.2.1).	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Assessment of Origin of Fractures The DOE identified the occurrence of fractures (joints) of varied origins at YM and documented (1) cooling joints that formed as the volcanic ash was emplaced, cooled at the Earth's surface and contracted (this process ended about 9 ma); (2) tectonic joints representing several episodes of tectonism, including present day; (3) unloading joints formed near the Earth's surface as erosion and atmospheric processes coupled to produce thermal-hydrologic-chemical-mechanical stresses on near-surface rocks, especially the removal (erosion) of hundreds of feet of rock overburden, continuing to the present day; and (4) excavation-induced fractures discussed previously. However, there appear to be attributes correlated to each type of fracture that, if established at YM, could help constrain interpolation between and extrapolation beyond locally exposed fractures and faults used in model abstractions. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. Sufficient information about fracture characteristics has been collected and documented as noted in the Yucca Mountain Site Description (CRWMS M&O 2000h, Section 4.6). Definition of the origins of fractures is not needed for TSPA because hydraulic properties of fractures that may affect performance are not related to the origin of fractures, and TSPA does not require linking fracture hydraulic properties to fracture origin because the hydraulic properties of fractures are used in process models are derived by calculation and calibration of models. These hydraulic properties are not related to the origin of the fractures (e.g. CRWMS M&O 2000t, Section 6.2.1), and hence, the additional work, described in the IRSR, is not necessary to develop process models or demonstrate repository performance. Fracture characterization information is derived from the existing measured properties or analog information based on rock units having known similar hydrogeologic characteristics. Correlations for hydrogeologic properties based on fracture origin and subsequent evolution are not likely to be successful due to the complex relationships involved. Because of the complex history of both cooling and tectonic fractures including the reactivation of previous existing cooling fractures, specific hydrologic characteristics for modeling can not be assigned to a particular set of fractures based on their origin.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties of ambient and perturbed conditions are technically defensible and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Boundary Conditions of Numerical Abstractions of Fracture Data, Models, and Modifications under Ambient and Thermally Perturbed Conditions Most fracture investigations to date have focused on measurements of static properties under current ambient conditions. Data on the behavior of fractures under future expected seismic and thermal loads are necessary for realistic modeling of rockfall and flow through fractures. See the RDTME IRSR for discussion of acceptable rockfall analyses and calculations under seismic and thermal loads. Calculations of aperture changes in fractures under conditions of dilatancy in the SZ are discussed in the USFIC IRSR and in section 4.3. Theoretical calculations of the bulk-rock response to thermal loading have been made (e.g., Buscheck and Nitao, 1992) and steeply-dipping fractures are expected to close under conditions of differential thermal expansion and contraction, while near-horizontal fractures will tend to open and capture refluxing water. This concept needs to be compatible with the assumption that refluxing water will flush through the near-vertical joints of relatively cool pillars between widely spaced warmer drifts and the rocks beneath the drifts. Similarly, the fractures will respond to new and unusual sources of stress from excavation methods, WP-induced thermal loading, subsequent cooling, and the range of potential responses will need to be abstracted for consideration in process level and PA	DOE believes this concern is resolved. DOE believes it has adequately characterized fractures to support the development of process models and abstractions for TSPA and does not view the work described as necessary or clearly linked to repository performance. The Drift Degradation Analysis (CRWMS M&O 2000i) has examined the effects of seismic and thermal loading on rockfall. The approach considered a significant reduction in joint cohesion in response to thermal loading (Section 7.1), and the subsequent effect on rockfall. Seismic loading in the Drift Degradation Analysis was examined using a quasi-static approach (Attachment V) involving a significant reduction in the joint friction angle to simulate the effect of increased force along rock block sliding surfaces in response to a seismic event. Both seismic and thermal loading were shown to have minimal effects on rockfall development (Section 7.1). Analysis results indicate that the mechanical behavior of fractures under seismic and thermal loads need not be completely understood because the relatively large reduction of fracture strength parameters provides reasonable bounds on these parameters (Section 5.4, 6.3.4, 6.3, and Attachment V). Sensitivity analyses concerning the effects of changes in fracture aperture in the UZ on potential radionuclide transport have found that large changes (on the order of x10 increases in fracture aperture) over the entire UZ domain are required to influence transport results (CRWMS M&O 2000d, Section 7.0). Such large and spatially extensive changes in fracture properties are considered conservative based on the observations of existing fractures in relation to previous fault displacements along nearby faults such as Solitario Canyon	No additional work required.

models. The fractures have responded in the past to processes that are expected or at least possible, such as faulting, earthquakes, hydrothermal fluid migration, tectonic strain, in situ stress, and geomorphic unloading. The DOE has not assembled fracture data from these past performances into a database that facilitates abstraction for predictive models. (NRC 1999, Section 5.3.1)	Fault and the Ghost Dance Fault (CRWMS M&O 2000d, Section 5.5). The effects of fault displacement on fracture properties near emplacement drifts is more problematic with respect to drift seepage. However, anisotropic changes such as suggested by the work of Buscheck and Nitao (1992) are expected to result in less seepage because the capillary barrier for seepage from vertical fractures would be increased while the permeability for lateral drainage (around drifts) would also increase. Air permeability measurements taken during the drift scale testing have indicated modest changes in air permeability that can be attributed to changes in water saturation in fractures (CRWMS M&O 2000q, pp 58-59, Figs. 31-32). Therefore, thermal mechanical effects on permeability are evidently not considerable over this time period. The range of uncertainty in SZ groundwater flux is relatively large for TSPA-SR simulations [i.e., given the range of uncertainty in horizontal anisotropy, the potential effects of this anisotropy were modeled by setting the bounding anisotropy ratio values to 1 (isotropic) or 5 (anisotropic) (CRWMS M&O 2000s, Sections 3.5.1 and 3.7.2)]. This range of uncertainty encompasses the potential changes in fracture network characteristics (i.e., fracture aperture) which could potentially result from differential thermal expansion and contraction or other tectonic perturbations (CRWMS M&O 2000r, Section 6.1).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in abstractions for process and PA models of ambient and perturbed repository conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 3 may not be met. Staff review of fracture data and fracture data summaries indicates that the DOE has not adequately considered alternative modeling approaches to develop its understanding of fracture distributions and ranges of fracture properties. The result is that the limitations of fracture distributions and properties may not be appropriately abstracted and propagated through the process level and PA models of ambient and perturbed conditions. The following observations support the conclusion: (1) nonrepresentative data sets are used as the basis for abstractions, (2) assumption of spatial homogeneity in fracture distribution in the UZ is unsupported, (3) assumption of isotropic fracture permeability in the SZ is unsupported and nonconservative, and (4) continuity of consideration of fracture data and alternative models abstracted in the DOE process level and PA models has not been demonstrated.	DOE believes this criterion is CLOSED. DOE believes that the modeling approaches are consistent with available data and current geologic understanding and have been adequately and appropriately abstracted into process and performance assessment models. For example, rockfall analyses (CRWMS M&O 2000i) require fracture orientation and frequency data and utilize as input corrected fracture data provided described in CRWMS M&O 2000i, Tables 1 and 2). To accommodate this data need, DOE evaluated several alternative modeling approaches and developed an unbiased fracture data set (CRWMS M&O 1999b). This information was used in an analysis of the joint set orientations for the lithostratigraphic units associated with the repository host horizon (CRWMS M&O 2000u). See responses below to each of the identified issues.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in abstractions for process and PA models of ambient and perturbed repository conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Nonrepresentative Data Sets DOE needs to demonstrate the representativeness of abstracted fracture data used to build models: (1) The report on the UZ site scale flow model for YM notes that fracture data from the ESF include data taken only to station 40+00 (Bodvarsson, et al 1997). This avoids the intensely fractured zone in the main drift and may be unduly geographically restricted. (2) The report on analysis of spatial variation of shallow infiltration uses fracture data from surface studies (Flint, et al., 1996). Results of Flint, et al. (1996) are input to the UZ site-scale flow model (Bodvarsson, et al., 1997, Chapter 7). However, the surface data have not been gathered in the same systematic continuous manner as the subsurface data from the ESF and ECRB and may not provide an adequate technical basis for assessment of spatial distribution of water infiltration and influx into the subsurface fracture network (see USFIC IRSR). See also section 4.3.1.2. (3) Discrete fracture modeling has been used to simulate flow behavior in the UZ and to identity probable network geometries, persistent flow paths, and permeability anisotropies (Anna, 1997). Inputs from this approach were applied to the UZ site-scale flow model (Bodvarsson, et al., 1997, Chapter 7). However, the use of synthetic fracture networks is not representative of the natural fracture network for at least two reasons. (1) For the Tiva Canyon Tuff models, data were dominantly used from the north	DOE believes this concern is resolved. Items (1) and (2) have been addressed, (CRWMS M&O 2000f, p. 32). The model now considers fracture data from the entire ESF, the ECRB, boreholes, and surveys of surface exposures and outcrops. For the SR models, fracture characteristics have been developed from pneumatic permeability measurements and fracture mapping information on fracture frequency and fracture length (CRWMS M&O 2000f, Section 4.1). For item 3, CRWMS M&O 2000f, Table 2 lists the data used in the analysis of hydrologic properties data. Fracture properties (frequency, permeability, van Genuchten a and m parameters, aperture, porosity, and interface area) were developed for each UZ Model layer (CRWMS M&O 2000f, Section 6.1), but synthetic fracture networks have not been used. Inputs from Anna, 1997, were not used in the UZ model (CRWMS M&O 2000f). With regard to spatial homogeneity, the fracture characteristics are modeled as homogeneous within each model unit. However, there are 32 model units in the UZ corresponding to various rock types based on variations in hydrologic properties (CRWMS M&O 2000f, Table 3). Furthermore, the faults are specifically discretized and assigned specific hydrologic properties (CRWMS M&O 2000f, Section 6.4). This constitutes the level of heterogeneity that is expected to have any consequence on UZ flow and transport behavior because the overall behavior of flow and transport processes in the unsaturated zone is mainly determined by relatively large-scale heterogeneities (RWMS M&O 2000f, Section 5, item 1). Fracture properties that are used in the UZ model are identified in CRWMS M&O 2000f, Section 6.4.2. Fracture orientation is not	No additional work required.

portal of the ESF, which is located in proximity to eight N-S-trending faults, including the Bow Ridge block-bounding fault. In contrast, the Tiva Canyon Tuff above the repository only contains a comparatively minor N-trending fault, the Ghost Dance fault. For the Topopah Spring Tuff models, the region of the main N-S drift of the ESF (along with corroboration of data from the ECRB) where the high-intensity fracture population that trends NW-SE is present, should be modeled separately, in staff's judgment, because this distinct fracture domain is not an artifact of the sampling methodology. (2) Fractures were equally weighted by orientation and not by other attributes such as fracture length and relative age. Fracture data sets were fitted statistically and forced to accommodate all orientations. These data sets have broad orientation ranges unlike those in nature. Also, the basic age attributes of the cooling and tectonic fractures at YM were not used. These attributes are key to any synthetic network construction because cooling joints are older, will tend to be longer, and have tectonic joints abut them. (NRC 1999, Section 5.3.1)	used in the UZ flow and transport models (CRWMS M&O 2000f, Section 6.1.2.1) because flow is assumed to be dominantly vertical.	

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NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
<u>Assumption of Spatial Homogeneity in Fracture Distribution in the Unsaturated Zone</u> Much of the fracture network characterization and abstraction of the network into flow, transport, and rockfall models tends to amalgamate large data sets from large areas and assume spatial homogeneity. These simplifications appear to be used in UZ and SZ flow models. However, existing work indicates that the fracture network has significant spatial heterogeneities (Barton, et al., 1993; Sweetkind and Williams-Stroud, 1996). Two prominent examples are increased joint intensities near normal faults and swarms of cooling joints. Cooling joint swarms were identified by earlier workers in the Tiva Canyon Tuff (Barton. et al. -1993), but the DOE's current conceptual model of the fracture network in this rock unit does not incorporate the strongly anisotropic and heterogeneous aspects of the network (DOE, 1998b). In particular, the actual dimensions, greater than 100 m long, cutting the entire thickness of the thermomechanical unit, have been underrecognized. Concentrations of fractures near faults or in swarms are likely to be loci of increased infiltration where exposed at the surface and zones of focused flow that may be fast pathways for groundwater (USFIC IRSR). (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. With regard to spatial homogeneity, the fracture characteristics are modeled as homogeneous within each model unit. However, there are 32 model units in the UZ corresponding to various rock types based on variations in hydrologic properties (CRWMS M&O 2000f, Table 3). Furthermore, the faults are specifically discretized and assigned specific hydrologic properties (CRWMS M&O 2000f, Section 6.4). This constitutes the level of heterogeneity that is expected to have significant consequence on UZ flow and transport behavior (CRWMS M&O 2000f). Testing results and geochemical data indicate that the permeability of the entire Tiva Canyon Tuff is sufficiently large that a detailed characterization of the heterogeneities referenced would not impact the current Tiva Canyon flow model (CRWMS M&O 2000k). The current model fault zone thickness (30m) is characterized by enhanced permeability based on pneumatic data (CRWMS M&O 2000m). This zone is considerably wider than any of the intra-block fault zones in the potential repository block as observed in the surface and underground and is conservative in terms of flow. The 100m long fractures observed apply only to the Tpcpul and have not been observed even in the Tpcpmn. Cooling joints of that length have not been observed throughout the rest of the ash flow units and may be unique to the Tpcpul. Hence, the observations indicate that the long fractures in question have not been underrecognized.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in abstractions for process and PA models of ambient and perturbed repository conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Assumption of Isotropic Fracture Permeability in the Saturated Zone The TSPA 3D, SZ model assumes material properties in the hydrogeologic layers are homogeneous and isotropic (DOE, 1998a). This approach is implemented because of limited data. Also, it lacks a technical basis and is not conservative. Faults, which may act as conduits or barriers to flow, are only accounted for in the model by hydrogeologic unit offsets. Although not accounted for in the base case analyses, the potential impacts of high permeability faults on SZ flow have been considered in the sensitivity analyses. These features were found to influence groundwater flow paths and affect performance (Ferrill, et al., 1999b). In areas where the maximum fracture and fault anisotropy axes are not parallel to the potentiometric gradient, groundwater flow directions could be oblique to the hydraulic gradient. Incorporation of fracture anisotropy in flow models could warrant changing the configuration of flow tubes currently used to model flow in the TSPA code. The assumption of homogeneous and isotropic aquifer properties leads to flow paths controlled by the potentiometric gradient. At YM, the potentiometric gradient suggests a relatively short groundwater flow path to the unconsolidated valley fill aquifer in Jackass Flat and a relatively long travel distance in the valley fill material that has higher retardation potential than tuff. The presence of faults and fractures that act as flow conduits may modify these groundwater flow	DOE believes this concern is resolved. Uncertainty in the horizontal anisotropy of permeability in fractured tuff units of the SZ is included in the groundwater flow and radionuclide transport simulations for TSPA-SR as described in SZ flow and transport AMR for TSPA (CRWMS M&O 2000j; Section 5.4 and 6.2.5). Two equiprobable discrete cases of SZ groundwater flow (isotropic and anisotropic) are simulated with the 3-D SZ site-scale flow and transport model and are used in the Monte Carlo realizations for TSPA. The anisotropic case implicitly accounts for the effects of preferentially oriented faults and fracture zones. Relative to the isotropic case, the anisotropic case results in more rapid (and thus, more conservative) radionuclide transport as simulated with the SZ site-scale flow and transport model. Radionuclide transport pathways simulated for the anisotropic case are somewhat more directly south from the repository than pathways for the isotropic case, resulting in potentially shorter travel distances in the alluvium. TSPA analyses included both the anisotropic and isotropic cases. Inclusion of the anisotropic case in TSPA analyses of SZ flow and transport is based on the technical analysis presented by Ferrill et al. (1999). Because the analysis of Ferrill et al. (1999) was based on pump test results from a single site and because of uncertainties in the analysis, the isotropic case was retained as a viable alternative conceptual model in the TSPA-SR.	No additional work required.

paths resulting in alternative flow paths, possibly with increased travel distances in the unconfined welded tuff aquifer. At YM, hydraulic conductivities within the Miocene tuff layers appear to be strongly anisotropic at both the local and regional scales (USFIC IRSR, Revision 2; Geldon, et al., 1997; Bredehoft, 1997; Ferrill, et al., 1999b). (NRC 1999, Section 5.3.1)		

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in abstractions for process and PA models of ambient and perturbed repository conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Continuity of Consideration of Fracture Data and Alternative Fracture Models Abstracted in the US DOE Process Level and Performance Assessment Models The DOE has not demonstrated the continuity or traceability of fracture data, fracture models, and potential future modifications to fractures abstracted in its process level and PA models of fracture flow at the various scales of interest, under both ambient and perturbed conditions, or for rock-failure models that may affect repository design or performance during operations and post-closure. (NRC 1999, Section 5.3.1)	DOE believes this concern is resolved. Fracture data are contained in the technical data management system (TDMS) for controlled use and dissemination to modelers and analysts. Different technical products may have unique objectives and sensitivities. Data users interpret fracture data consistent with the intended use. The use and application of the data are described in the technical product. The Drift Degradation Analysis (CRWMS M&O 2000i, Section 4.1 and Table 1) uses a continuous and traceable approach incorporating all of the ESF-mapped fracture data. Analysis of the mapped fracture data is summarized in ANL-EBS-GE-000006. Predominant fracture sets were identified, and fracture spacing and trace length data were provided in this fracture report. Abstractions of fracture data for flow and rockfall modeling do not necessarily need to be the same. For example, in rock units where fracture/matrix interaction is weak, it is acceptable to ignore spatial variability in fracture spacing for UZ flow and transport modeling. Use of fracture data in UZ models is addressed in the hydrologic properties AMR (CRWMS M&O 2000f, Section 6.4). Fracture models for UZ are discussed in the calibrated properties AMR (CRWMS M&O 2000m, e.g., Section 1 and Table 3). The effects of changes in fracture aperture on UZ transport are given in the fault displacement effects AMR (CRWMS M&O 2000d, Section 7).	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 4: Model Verification - Results of abstractions of fracture data and fracture models incorporated in process models and TSPA models are verified by comparison with output of sensitivity studies, natural analogs, and empirical observations, as appropriate.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff review of the UZ site-scale flow model, the SZ flow model, TSPA-VA and rockfall models and associated sensitivity studies indicates that incorporated abstractions of fracture data and models may not be reasonably consistent with expected sensitivity to the range of fracture distributions, properties, and field observations. Sensitivity studies associated with analyses of rockfall in drifts show that rockfall processes are sensitive to variation in fracture orientation within joint sets (RDTME IRSR). When all joints in a set are modeled as perfectly parallel, drifts tend to be more stable than when some are modeled as nonparallel. Slight natural variation in orientation, which is typical within natural joint sets, leads to increased drift instability. Current DOE abstractions assume single orientations for fractures in a set (e.g.; DOE, 1998b). For example (DOE, 1998b. Table 4-12), multiple sets are represented by a single orientation; an abstraction apparently based on a previous abstraction (DOE, 1997b). Simplifications need to be technically justified and transparent with regard to representativeness and linked directly to fracture characterization and models. (NRC 1999, Section 5.3.1)	DOE believes this criterion is CLOSED. The Drift Degradation Analysis (CRWMS M&O 2000i) has considered the variability in joint set orientation, spacing, and trace length through the use of the numerical code, DRKBA (Discrete Region Key Block Analysis). Statistical distributions of fracture data were input into DRKBA. Beta distributions were used to represent the fracture spacing and trace lengths, whereas Watson bi-polar distributions were used to model the joint set orientations. The concentration factor, k, in the Watson bi-polar distribution, determined from the mapped fracture data, represents the degree to which the orientation data are clustered about the mean orientation. DRKBA examines the variation of fracture geometry through multiple Monte Carlo simulations of the fractured rock mass, where fracture patterns are generated based on the statistical distributions of the fracture data.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 5: Integration - Results of abstractions of fracture data are consistent with physical and geological phenomena and coupled processes.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff review of the UZ site-scale flow model, the SZ flow model, TSPA-VA and rockfall models and ancillary sensitivity studies indicates that incorporated abstractions of fracture data and models may not be adequately integrated in those models. For example, a continuity check (review for consistency in abstraction of same fracture data across all models) indicated that fracture data and fracture models for the middle nonlithophysal unit are not similarly abstracted in flow and rockfall models (heater-test models were not reviewed). In general, fracture abstractions input among the various process and PA models do not account for, or appear to propagate, uncertainties associated with fracture parameters, alternative models of fractures within and across units under investigation for flow, and transport and rockfall stability. Fracture abstractions also may not project ranges of values of relevant parameters due to expected variations in behavior of fractures that result from, for example, radiogenic thermal pulse and refluxation. (IRSR, Rev. 2, Section 5.3.1)	DOE believes this criterion is CLOSED. Abstractions of fracture data for flow and rockfall modeling do not necessarily need to be the same. For example, in rock units where fracture/matrix interaction is weak, it is acceptable to ignore spatial variability in fracture spacing for UZ flow and transport modeling. Use of fracture data in UZ models is addressed in the hydrologic properties AMR (CRWMS M&O 2000f, Section 6.4). Fracture models for UZ are discussed in the calibrated properties AMR (CRWMS M&O 2000m, e.g., Section 1 and Table 3). The effects of changes in fracture aperture on UZ transportare described in the fault displacement effects AMR (CRWMS M&O 2000d, Section 7). For rockfall modeling, the Drift Degradation Analysis (CRWMS M&O 2000I, e.g., Section 4.1) has considered variations in fracture properties in the assessment of rockfall (see additional discussion under FRACTURING: Criteria 2 and 4). Fracture network data are not directly used in the SZ flow and transport model. A continuum representation of groundwater flow in the fracture network of the SZ is supported by hydraulic testing indicating a generally well interconnected fracture network. The impacts of coupled processes on fracture network hydrologic characteristics in the SZ due to the presence of the repository are expected be minor relative to such effects in the near field and UZ (CRWMS M&O 2000o).	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 6: Quality Assurance. The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures, or it the data, models and computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 6 is open. This criterion is being addressed the same way in each subissue. See the discussion in Faulting subissue. (NRC 1999, Section 5.3.1)	DOE believes this criterion is CLOSED Pending. Requirements for quality-affecting activities associated with collection, documentation, and development of data, models, and computer codes are addressed in DOE's quality assurance program (DOE 2000) and implementing procedures. Since June 30, 1999, such activities have been performed in accordance with these requirements. For activities performed prior to June 1999, DOE has well-documented conditions adverse to quality related to these activities. These conditions adverse to quality have been addressed in accordance with the corrective action process. Action has been taken to assure that pre-June 1999 data, models, and computer codes related to information important to the repository safety case were reviewed and updated to assure their integrity as specified by the related corrective action. More than 90% of the DE PMR/AMRs data and software required to support LA are qualified.	All data, models, and codes important to safety and isolation will be qualified by LA submittal.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 3: Fracturing		
Acceptance Criterion (AC) 7: Expert Elicitation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Resolved This criterion does not apply to the fracturing subissue, because no relevant expert elicitation was conducted. (NRC 1999, Section 5.3.1)	DOE believes this criterion is CLOSED. DOE does not intend to convene an expert elicitation to evaluate fracturing and structural framework items.	No further work is needed.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting

Importance to System Performance: The TSPA, through the PSHA includes evaluations of the tectonic framework and geologic setting and all viable tectonic models. The viable models (tectonic models determined to have any support in the available literature) were appropriately evaluated by expert elicitation teams for the Probabilistic Seismic Hazard Assessment (PSHA) and to the Probabilistic Volcanic Hazard Assessment (PVHA). The viable models were assessed using available data and weighted by the expert elicitation teams to express their uncertainties in the viability of each. The results of the expert elicitations are used as the basis for hazard calculation and are incorporated into the hazard results which are used in various TSPA activities (such as volcanism), for the features, events, and processes screening, and for formulating bounding assumptions for tectonically-related events and processes (such as ground motions, fault displacement).

As processes considered separate from volcanism, seismicity, and faulting, the geologic processes related to large-scale tectonic activity (uplift, subsidence, folding) occur on a geologic time scale. Consequently, physical and thermo-hydrologic properties of the repository will not experience significant alterations within the period of regulatory concern (CRWMS M&O 2000b, Section 6.2.1). Since only insignificant changes will occur, dose is unlikely to be affected, and tectonic activity is therefore excluded from TSPA calculations based on low consequence to dose (CRWMS M&O 2000b, Section 6.2.1).

Acceptance Criterion (AC) 1: Data and Model Justification - Sufficient geological and geophysical data are available to adequately support conceptual models of tectonics, attendant assumptions, and boundary conditions and to define relevant parameters of tectonic models implemented in process, subsystem, or TSPA models and calculations.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: CLOSED Staff conclude that criterion 1 is resolved. Staff reviewed, as detailed in RM in section 4.5.1.1 the treatment of tectonic models and current crustal conditions in the DOE PSHA (U.S. Geological Survey, 1998). The DOE examined and incorporated a comprehensive range of viable tectonic models. The DOE is encouraged to maintain this level of adherence to existing data and reasonable explanations for inconsistencies in the treatment of tectonic models and crustal conditions in all related subissues. The DOE's current assessment of crustal conditions is adequate. (NRC 1999, Section 5.4.1)	DOE believes this criterion is closed. Based on available geologic and geophysical data, several tectonic models for the Yucca Mountain region have been proposed by a number of investigators. Available data include numerous geologic studies by YMP scientists and others and regional gravity, magnetic, and seismic geophysical information. Evaluation of proposed models by YMP, CNWRA, NRC, and State of Nevada scientists identified five that should be considered in seismic analyses (NRC 1999, Section 4.4.1.2, p. 86). Information pertaining to these and other tectonic models was presented to experts participating in the Probabilistic Seismic Hazard Analyses at workshops associated with the expert elicitation process (Wong and Stepp 1998, Appendix C, pp. C-39 to C-40.)	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting		
Acceptance Criterion (AC) 2: Data Uncertainty and Verification - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to develop viable tectonic models are technically defendable and reasonably account for uncertainties and variabilities.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 2 is resolved. Staff reviewed, as detailed in RM2 in section 4.4.1.1, the DOE PSHA (U.S. Geological Survey, 1998). Although the abstraction of tectonic models and crustal conditions is not complete for all affected subissues, Staff conclude that the DOE's characterization of the viable tectonic models as presented in the DOE PSHA (U.S. Geological Survey, 1998) is adequate. Tectonic, structural and seismic elements, and associated uncertainties are adequately described, abstracted, and implemented for the purpose of seismic hazard assessment. The DOE PSHA expert elicitation considered the full range of viable tectonic models as supported by existing data to bound the seismic hazard at YM. (NRC 1999, Section 5.4.1)	DOE believes this criterion is closed. In the Probabilistic Seismic Hazard Analyses (PSHA), tectonic models supported by the available data were considered by the seismic source and fault displacement experts in developing their interpretations for the hazard calculation. Data uncertainty and variability resulted in multiple tectonic models being considered viable by the PSHA experts.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting		
Acceptance Criterion (AC) 3: Model Uncertainty - Alternative modeling approaches for tectonics are investigated, consistent with available data and current scientific understanding. Results and limitations of tectonic models are sufficiently considered in the development of process, subsystem and TSPA models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff concluded in IRSR, Rev. 2, that criterion 3 is resolved. Staff reviewed, as detailed in RM3 in section 4.4.1.1, the DOE PSHA (U.S. Geological Survey, 1998). Given the present state of knowledge, Staff conclude that the DOE's determination of viable tectonic models as presented in the DOE PSHA is adequate. Based on a DOE letter, (Brocoum to Reamer, 1999) the staff are no longer concerned that a DOE preferred tectonic model such as described in the Seismotectonic Synthesis Report (U.S. Geological Survey, 1996) [Whitney 1996] and the TSPA-VA (U.S. Department of Energy, 1998b) was intended as the primary tectonic model to be considered in seismotectonic hazard analyses. At present, staff consider 5 of the 11 models discussed at the May 7-8, 1996, Appendix 7 Meeting on Conceptual Tectonic Models as viable. The DOE PSHA expert elicitation considered the full range of viable tectonic models, and staff have no further questions at this time as to the DOE's use of the full range of variable tectonic models. Staff will continue to monitor the DOE's program to ensure that this full range of tectonic models is applied uniformly and with continuity across the entire DOE analysis of YM, as appropriate. (IRSR, Rev. 2, Section 5.4.1) NOTE: In the April 2000 KTI Technical Exchange presentation on SDS, the staff indicated that this	DOE believes this criterion is CLOSED-PENDING. The Disruptive Events FEPs AMRs have been made available for staff review and provide the justifications for inclusion and exclusion in the performance assessment. DOE assessed volcanic and seismic hazards probabilistically, using expert elicitation to develop inputs to the hazard calculations. The experts were presented information related to the tectonic setting and tectonic models at workshops associated with the expert elicitation process (CRWMS M&O 1996, pp. C-12, C-15; USGS 1998, Appendix C, pp. C-39 to C-40). The experts incorporated information on the tectonic setting and tectonic models into their interpretations and used the information appropriately in defining and characterizing volcanic or seismic sources. Different experts assessed different weights for the viable models. Thus, for purposes of hazard assessment, there is no single tectonic model for Yucca Mountain, but rather evaluations of all viable models with weights assigned by the experts reflecting their assessments of the degree that a given model is supported by available data. Given that both the PVHA and PSHA incorporate viable tectonic models in the experts' evaluations and the experts' assessments of uncertainty determine the weights models have in the experts' input interpretations, the models have been evaluated and used consistently in the PVHA and PSHA. Therefore, DOE considers this subissue closed for the SDS KTI. TSPA-SR does not explicitly include tectonic models. However, certain tectonic processes, such as volcanism, faulting, and seismicity were considered in the FEPs screening process. Disposition of the processes considered is documented in the	Complete ICN 1 to DE FEPs AMR.

issue was OPEN and indicated a need to review the following: 1. Analyses showing rationales for tectonic models that are included and excluded from consideration in performance assessment (FEPs AMRs) 2. Analyses showing that the tectonic models used by DOE for seismic and volcanic hazard assessments are mutually consistent and appropriate for such assessments in that they are not likely to underestimate the hazard. (NRC Presentation, April 2000)	Disruptive Events FEPs AMR (CRWMS M&O 2000b, Table 4). In addition, tectonic models were considered in the expert elicitations used to estimate the volcanic hazard (CRWMS M&O 1996), and the fault displacement and vibratory ground motion hazards (Wong and Stepp 1998). For the PVHA (CRWMS M&O 1996), tectonic models were given low weight in the development of experts' volcanic source zones. The nature of the hinge line in central Crater Flat is discussed in (CRWMS M&O 2000v, Section 6.4.1.1). Basically the hinge line marks the location of about 20° of clockwise rotation in the strike of faults. DOE has neither identified nor described the hinge line as a tectonic barrier between Crater Flat and Yucca Mountain, and the hinge line was not described as a structural barrier that delimits volcanic source zone. In addition, the volcanic source zones defined for the PVHA do not represent seismogenic source zones used in the PSHA; so DOE believes that NRC concerns related to potentially inconsistent use of tectonic models in PVHA and PSHA have been adequately addressed. Finally, the issue of consistent use of tectonic models in PVHA and PSHA was discussed during the Igneous Activity KTI Technical Exchange in Las Vegas, August 29 – 31. Tthe NRC and DOE agreed that the issue could be resolved by a simple statement that there is no geologic structural barrier to volcanic activity along the eastern boundary (see IA Technical Exchange Meeting Summary).	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting		
Acceptance Criterion (AC) 4: Model Verification - Viable tectonic models are verified within the context of all geological and geophysical data the tectonic framework of the geologic setting.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED In the IRSR (NRC 1999), staff conclude that criterion 4 is resolved. Staff reviewed the application of tectonic models to development of the DOE PSHA, including the fault displacement hazard, and have no further questions at this time, as detailed in RM4 in section 4.4.1.1 and discussed in Sections 5.1 and 5.2. Implementation of tectonic model development of the site scale GFM3.1 model is also adequate and staff have no further questions about the GFM3.1 model. (NRC 1999, Section 5.4.1)	DOE believes this criterion is CLOSED In considering tectonic models to develop interpretations of seismic sources and fault displacement, the Probabilistic Seismic Hazard Analyses experts evaluated the models with respect to available geologic and geophysical data. Models were incorporated into interpretations and weighted in accordance with their support in the data.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting

Acceptance Criterion (AC) 5: Integration - Incorporation of tectonic models into PSHA and TSPA adequately includes major structural features, physical phenomena, and coupling important to design and performance and relies on consistent and appropriate assumptions throughout the abstraction process.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: CLOSED In the IRSR (NRC 1999), staff reviewed the incorporation of the full range of viable tectonic models in PSHA and the TSPA-VA. The PSHA adequately incorporated the viable models and additional variations on the themes of the viable models. Uncertainties in tectonic models considered in the PSHA are adequately incorporated in the seismic hazard curves. DOE indicated that tectonic effects on performance not directly related to hazard parameters, such as potential changes to permeability related to an earthquake, may need to be evaluated in light of different tectonic models," and staff generally agree. However, the TSPA-VA included only one tectonic model, a preferred model, that did not meet criteria for an acceptable tectonic model (see section 4.4.1.2). DOE suggested two approaches it could take to address the sensitivity of certain hydrologic parameters to tectonic model information evaluate the consequences of different viable tectonic models and demonstrate that consequences are not sensitive to any tectonic model. Staff plans to review the applicability and continuity of tectonic models across subissues in all other relevant KTIs that rely on information from tectonic models, such as USFIC, - including the link, of future fracturing to tectonic activity - and IA. (NRC 1999, Section 5.4.1) NOTE: In the April 2000 KTI Technical Exchange	DOE believes this criterion is CLOSED-PENDING A sensitivity analysis of sub-system performance in the unsaturated zone (CRWMS M&O 2000d) to changes in the hydrogeologic properties of fractures and faults was conducted. This analysis addresses any type of seismic event that may cause these changes in properties. The changes in fracture and fault properties were not coupled to any particular tectonic model. The sensitivity analysis is based on the idea that changes to existing fracture and fault properties, due to seismic activity of any kind, will be primarily due to changes in the fracture apertures of existing fractures rather than the generation of new fractures. The idea is supported by the fact that the rocks at Yucca Mountain are highly fractured and that changes in mechanical stress are much more likely to result in changes in strain along the existing fractures rather than generating new fractures. A wide range of changes in fracture apertures were considered, both for cases where changes in apertures were limited to fault zones and for cases where changes in aperture affected the entire unsaturated zone domain. The effects of changes in fracture aperture were incorporated in the UZ flow and transport models as changes in permeability, porosity, and capillary pressure. Tectonic activity could alter the groundwater flow and radionuclide transport characteristics of the SZ by changing the permeability of the fractured media and by changing the fracture porosity. Relatively wide ranges of uncertainty in the groundwater specific discharge parameter and the flowing interval porosity were included in the abstraction of the SZ site-scale flow and transport model for TSPA-SR (CRWMS M&O. 2000j). The TSPA-SR analyses therefore implicitly include the potential impacts of alternative tectonic models as they would affect the hydrology of the SZ.	Complete ICN 1 to DE FEPs AMR.

presentation on SDS, the staff indicated that this issue was OPEN and indicated a need to review the following: 3. Analyses showing rationales for tectonic models that are included and excluded from consideration in performance assessment (FEPs AMRs) Analyses showing that the tectonic models used by DOE for seismic and volcanic hazard assessments are mutually consistent and appropriate for such assessments in that they are not likely to underestimate the hazard. (NRC Presentation, April 2000)	The items identified at the April 2000 Technical Exchange are discussed in AC 3.	

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting		
Acceptance Criterion (AC) 6: Quality Assurance. The collection, documentation, and development of data, models, and computer codes have been performed under acceptable QA procedures, or it the data, models and computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: OPEN Staff conclude that criterion 6 is open. This criterion is being addressed the same way in each subissue. See the discussion in Faulting subissue. (NRC 1999, Section 5.4.1)	DOE believes this criterion is CLOSED Pending. Requirements for quality-affecting activities associated with collection, documentation, and development of data, models, and computer codes are addressed in DOE's quality assurance program (DOE 2000) and implementing procedures. Since June 30, 1999, such activities have been performed in accordance with these requirements. For activities performed prior to June 1999, DOE has well-documented conditions adverse to quality related to these activities. These conditions adverse to quality have been addressed in accordance with the corrective action process. Action has been taken to assure that pre-June 1999 data, models, and computer codes related to information important to the repository safety case were reviewed and updated to assure their integrity as specified by the related corrective action. More than 90% of the DE PMR/AMRs data and software required to support LA are qualified.	All data, models, and codes important to safety and isolation will be qualified by LA submittal.

Analysis of the Resolution Status for the Key Technical Issue on Structural Deformation and Seismicity

Subissue 4: Tectonic Framework of the Geologic Setting		
Acceptance Criterion (AC) 7: Expert Elicitation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: CLOSED Staff conclude that criterion 7 is resolved. This criterion is resolved in the same way for the Faulting and Seismicity Subissues. See the detailed discussion in sections 4.1.1.1 and 5.1.1. (NRC 1999, Section 5.4.1)	DOE believes this criterion is CLOSED. DOE does not intend to convene an expert elicitation to evaluate the tectonic framework of the geologic setting.	No additional work required.

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